

# **Spatial management of southern rock lobster fisheries to improve yield, value and sustainability**

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**Project No. 2006/220**



**AUSTRALIAN  
SEAFOOD  
COOPERATIVE  
RESEARCH CENTRE**



**Australian Government**  
**Fisheries Research and  
Development Corporation**



Department of  
**Primary Industries**



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**ISBN:** 978-0-646-58073-9

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*The Australian Seafood CRC is established and supported under the Australian Government's Cooperative Research Centres Program. Other investors in the CRC are the Fisheries Research and Development Corporation, Seafood CRC company members, and supporting participants.*

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## 1 NON-TECHNICAL SUMMARY

**2006/220 Spatial management of southern rock lobster fisheries to improve yield, value and sustainability**

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**PROJECT OBJECTIVES:**

To meet these needs of the fishery for improved management of a spatially diverse stock, we have nine objectives:

- (1) To enable assessment reporting of trends in biomass and egg production by depth.
- (2) To evaluate separate deep-water quota to increase yield and egg production.
- (3) To evaluate regional size limits in Tasmania for increase in yield and egg production.
- (4) To conduct field experiments and sampling to provide additional data required for alternative harvest strategy evaluation:
  - i. fisher catch sampling,
  - ii. translocation release survival,
  - iii. release movement,
  - iv. translocation growth transition,
  - v. effects of translocation on maturity and egg production parameters,
  - vi. density-dependent growth.
- (5) To conduct field experiments on translocation to provide additional data required for economic evaluations:
  - i. change in colour,
  - ii. tail width,
  - iii. condition,
  - iv. survival in live transport.
- (6) To evaluate translocation options that increase yield and egg production.
- (7) To evaluate and compare spatial management options by economic analysis.
- (8) To determine the extent of ecological community change in deep water reef habitats in response to increased harvest rates of lobsters.
- (9) To develop functional management and monitoring recommendations to apply outcomes.

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## **OUTCOMES ACHIEVED**

The project outputs have contributed to or will lead to the following outcomes:

- a) A commercial scale translocation of southern rock lobster in Tasmania;
- b) Development of the capability to model geographic variation in southern rock lobster stocks in each of Tasmania, South Australia and Victoria;
- c) An evaluation of deep water quota as a management tool to encourage fishing of under-exploited deep water stocks;
- d) Economic modelling of potential yields from a range of spatial management methods;
- e) Bio-economic modelling with an application to TACC setting;

## **ACKNOWLEDGEMENTS**

The project was supported by the Australian Seafood CRC and the Fisheries Research and Development Corporation. It involved collaboration between the Institute of Marine and Antarctic Science-IMAS University of Tasmania, Department of Primary Industries, Parks, Water and Environment, Tasmania (DPIPWE), South Australian Research and Development Institute (SARDI), Tasmanian Rock Lobster Fishermen's Association (TRFLA), Andre Punt, University of Washington, USA, and the Department of Primary Industry Victoria.

**KEYWORDS:** southern rock lobster, stock enhancement, spatial management, sustainable fisheries, translocation.

## 2 INTRODUCTION AND BACKGROUND

### 2.1 Need

This project investigated alternatives to the existing management rules. These rules have a history of providing for sustainable harvests but do not optimize economic yield from the available stock of southern rock lobster (*Jasus edwardsii*). One of the causes is that there is a mismatch between the scale of management of southern rock lobster across its Australian distribution and the scale of variation in biological traits of lobsters. Each of the three main states (Victoria, South Australia and Tasmania) involved in the Australian southern rock lobster fishery, manage their harvests across variable and somewhat arbitrary ‘zones’ of the population. As a result, management rules that are applied across broad areas are often sub-optimal for smaller locations within these zones. One extreme is in the deep water regions off SW Tasmania where rules are badly suited to the biology of the stock with the consequence that yield is lost and other regions are depleted.

Various forms of spatial management were considered within the project including regional size limits, incentives to draw effort into deeper water and translocating lobsters between regions. This idea of translocating lobsters between areas arose because lobsters could be caught in abundance in deep water and it was anticipated that their growth and quality would improve if they were shifted to shallow water. In effect, this was a form of sea-ranching where stock was shifted to better quality habitat.

Quota management of rock lobster fisheries in southern States combined with higher prices for shallow-water lobsters has driven effort inshore as fishers now manage their businesses to optimise the value of each kilogram, rather than maximizing total catch. Deeper water lobsters are often uneconomical to fish under current management as beach price can be as little as \$4/kg above lease price, as lease price responds to beach price of shallow water product. This has produced an unusual situation in fisheries management where fishers are shifting effort away from high catch rate areas and into more depleted areas. There is now a management need for improved capability to follow trends in stocks at different depths and to evaluate novel harvest strategies suited to these spatial issues.

Adjusting harvest strategies to take account of geographic variation in the biology of lobsters and patterns in the fleet has the potential to substantially increase yield, value and sustainability of the fishery. For example, preliminary modelling of the Tasmanian fishery indicated that regional size limits might double egg production in northern regions where levels are currently of concern, while simultaneously increasing yield by around 25%. Shifting effort into deeper water by means such as specific deep-water quota was expected to increase yield given that these stocks are currently under-exploited. Translocating lobsters from slow to high growth areas leads to increased productivity and also higher beach price per lobster due to improved colour. Bio-economic modelling has indicated that gains in nett economic yield could be more than doubled in many cases through translocation (FRDC 2005/217 Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield). These opportunities also existed to varying degrees in SA and Victoria.

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## 2.2 Objectives

To meet these needs of the fishery for improved management of a spatially diverse stock, we have nine objectives:

- (1) To enable assessment reporting of trends in biomass and egg production by depth.
- (2) To evaluate separate deep-water quota to increase yield and egg production.
- (3) To evaluate regional size limits in Tasmania for increase in yield and egg production.
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  - vi. density-dependent growth.
- (5) To conduct field experiments on translocation to provide additional data required for economic evaluations:
  - i. change in colour,
  - ii. tail width,
  - iii. condition,
  - iv. survival in live transport.
- (6) To evaluate translocation options that increase yield and egg production.
- (7) To evaluate and compare spatial management options by economic analysis.
- (8) To determine the extent of ecological community change in deep water reef habitats in response to increased harvest rates of lobsters.
- (9) To develop functional management and monitoring recommendations to apply outcomes.

## 2.3 Discussion of Results

Three approaches to managing a fishery with large-scale geographic variation were evaluated with all appearing to provide opportunity for sustainable increase in the value of harvests. Regional size limits (Section 5.4) better suited to local growth rates could increase yield, especially in areas that are growth-underfished. The use of additional catch as an incentive to drag a portion of the catch into deep water was implemented with some success although record low recruitment into the fishery led to a hiatus in this initiative after two years (Section 5.3). Of the options examined, greatest gains appear possible through the translocation of lower yield and value lobsters from deep water to shallow water to increase yield and value as evaluated through a large-scale pilot experiment (Section 5.5).

*Summary*

Pilot scale translocation of 30,000 slow-growing pale lobster from deep-water to shallow water showed that pale, low value lobsters from deep water could be captured rapidly and at low cost. Translocations led to a range of positive outcomes which were: (i) improved colour from pale to higher-value red within 6-12 months (Section 5.6.1); (ii) improved morphology to wider-bodied more desirable shape over 1 moult, or 12 months (Section 5.6.1); (iii) increased omega-3 lipids (Section 5.6.2); (iv) better survival in live transport (Section 5.6.3); (v) and faster growth (Section 5.5.4). Translocated lobsters remained at the release site (Section 5.5.2), had equal survival to residents (Section 7.5.1), and increased egg production (Section 5.5.3). Habitat was monitored at the capture and release sites with no change detected as a consequence of the change in lobster density (Section 5.5.1, 5.5.2, 5.5.3). Translocation appears to have opportunity to greatly improve the value of the southern rock lobster fishing industry (Section 5.6.6). Large scale translocations appear feasible in Tasmania with movements of 500,000 animals per year feasible in the far SW region (area 8) alone. This is clearly a large scale operation but a step towards this level of production occurred with industry deciding to extend results by contributing funds for small scale commercial operations with 100,000 lobsters to be moved per year. Even at this scale, translocations are estimated to result in an increase in net present value of \$47.6 million.

Modelling of the lobster stock in combination with a fleet dynamics model showed that any translocation scenarios led to benefits for the wider stock and fishery. This is because translocation increases the productivity of the stock in a similar manner to a regional pulse in recruitment. This draws effort and catch from the wider fishery. Under TACC management, this leads to broad-scale stock rebuilding and associated improvements in egg production, catch rate, ecology and fishery profitability.

## **2.4 Conclusions**

Spatial management systems offer scope for improvement in stock and industry profitability in SRL fisheries. Of the systems examined, the most promising is the translocation of lobsters off western Tasmania. This was a novel management approach to the geographic differences in demographic traits of southern rock lobster. It appeared to be economically feasible and without adverse impacts on genetics or ecosystem unlike many forms of stock enhancement. The policy and governance of translocation also appears feasible as the translocated undersize stock remains the property of the state and thus accessible to harvest under normal recreational and commercial ITQ management rules.

## **2.5 Further Work**

The present pilot scale study demonstrated that yield, value and sustainability in the southern rock lobster fishery could be improved by spatial management with largest gains through the option of translocation of lobsters from deepwater areas to inshore areas. The next stage is to roll-out commercial scale translocation in fishery. This commercial roll-out will involve facilitating the governance arrangements, monitoring

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the translocation operations and tracking performance under large scale operations. A need for the larger scale commercialisation is the development of harvest rules for the deep water removal sites. These are required to balance the costs of capture of lobster against the gains from translocation. Costs of capture will rise as deepwater stocks are reduced through translocation and optimising this operation will require active management.

### **3 BACKGROUND**

The application was developed over several years in response to ongoing issues with the level of geographic variation in southern rock lobster fisheries: (a) regional mismatch between biology and management; (b) the concentration of commercial effort in shallow water; (c) increasing stocks with low harvest rates in deep water; (d) increased competition with the recreational sector in sheltered and shallow water regions; (e) the market discounting of lobsters from some locations; (f) concerns for sustainability with geographically variable egg production and possible ecological effects of fishing. Improvements in management of this resource are expected to lead to increased production and value. The situation applies across Southern Australia and is compounded in Tasmania where the fishery has especially large geographic variation in growth rate.

Managers and fishers are aware that opportunities exist to increase the value of their industries but are lacking in information to make informed choices on alternative management strategies. This project was compiled and submitted in response to repeated calls for changes to management to increase the value of the industry.

#### **3.1 Unfished stock**

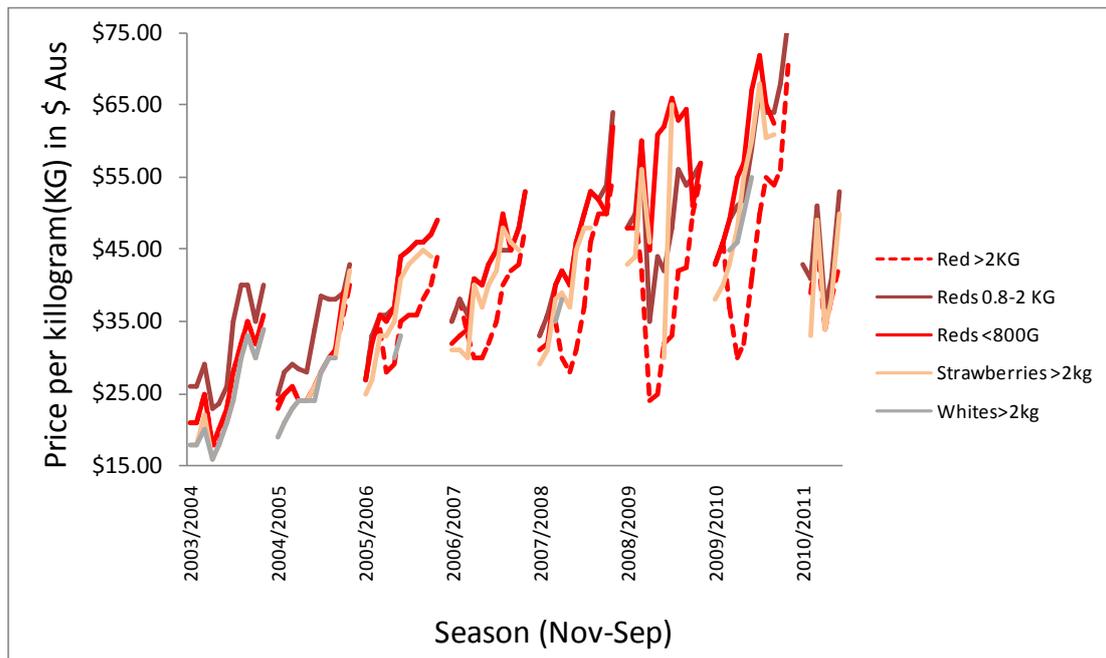
In deep water regions off the SW of Tasmania, female lobsters rarely reach legal size. Research sampling in this region over the last 13 years has involved measurement of 76,411 female lobsters, only eight of which were legal size. This is a massive unfished stock of one of the world's premium seafoods. Broad regions of the fishery have size limits that are too large so that although some individual lobsters reach legal size, harvesting is sub-optimal and substantial yield is lost.

#### **3.2 Decreased effort in deep water**

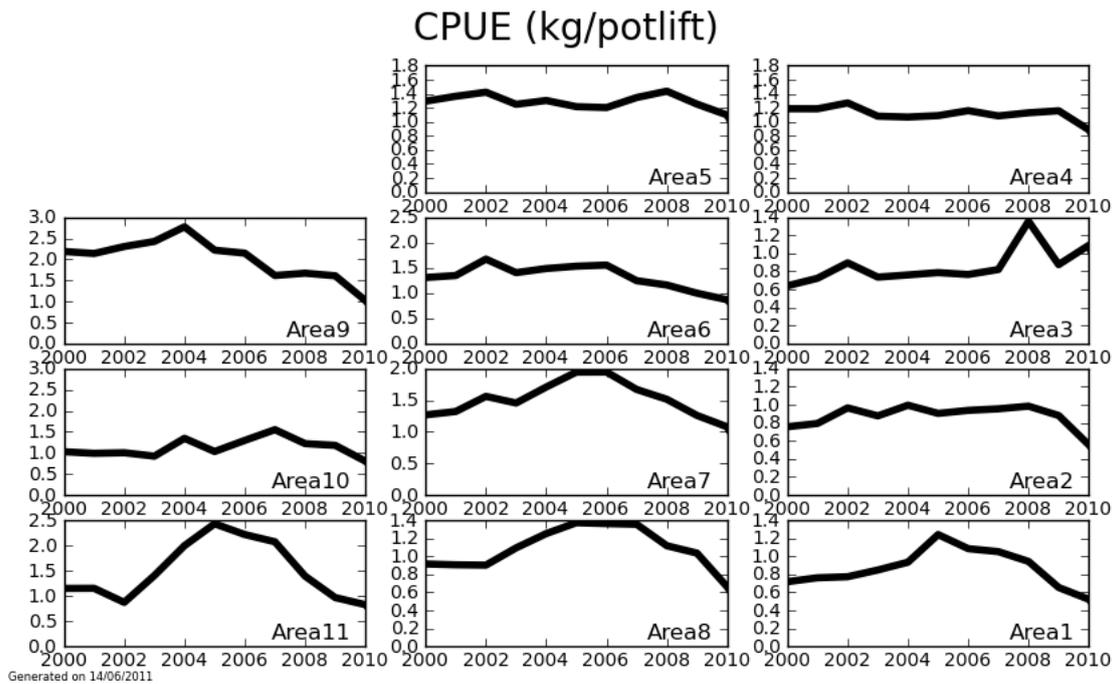
At the inception of this project in 2005/2006, effort in deep-water areas (>70m) off NW Tasmania/ SW Victoria was around 1/3 of that a decade ago because lobsters from these depths are pale in colour and receive a lower price (Figure 3-1, Figure 3-4). Over the same period, catch rate in these deep water areas had almost trebled to extremely high average levels of almost 3 kg per potlift (Figure 3-2). Remarkably, at the same time, catch rates on shallow reef were comparatively stable at less than 1.4 kg potlift. This shows that the current management promotes sub-optimal concentration of effort into shallow water, while other regions are left under-exploited and could contribute more to the yield of the fishery.

### 3.3 Discarding or upgrading

At the commencement of this project, it was reported that lobster fishers in some deep water were discarding a large portion of their catch because of lower prices. Personal logs from one of the largest fishers in Tasmania and Victoria show that 46% of his legal- sized catch in 2004 was discarded because these were large males (>2kgs) that receive a lower price. Smaller females between 105 mm and 110 mm CL (<800g) were also discarded for the same reason. Aside from economical inefficiency, this practice reduces yield and shifts effort onto egg producing females. The problem of discarding of extra large males was mainly a concern in SA.



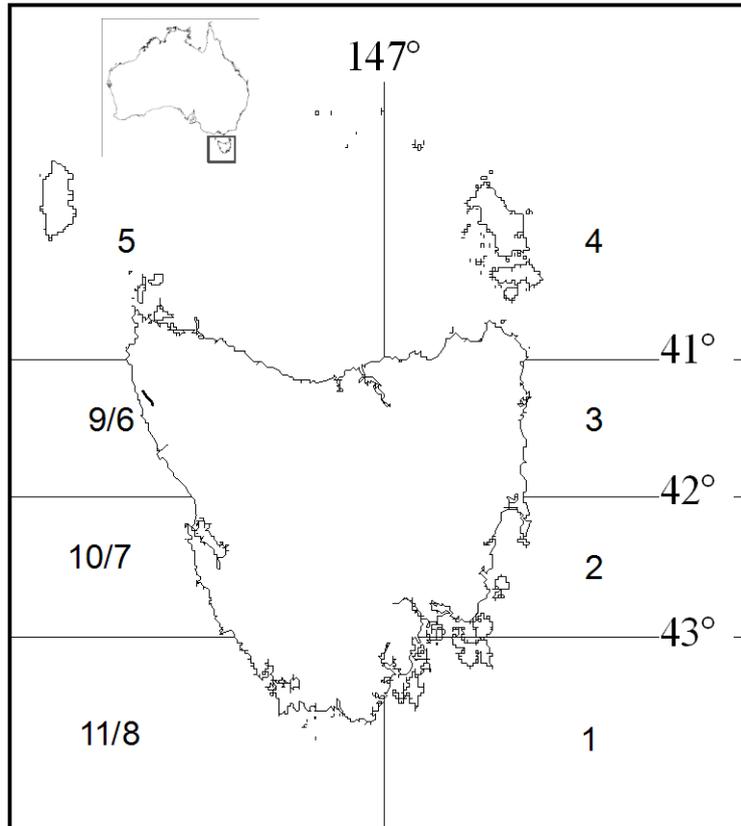
**Figure 3-1** Average monthly beach prices of southern rock lobster in Tasmania based on prices from two processors. This graph reflects landed product only, not the discards reported above.



**Figure 3-2** CPUE of Tasmanian southern rock lobster fishery in shallow and deep water. Deep water areas are 9, 10 and 11 on the west coast and 5-8 are the adjacent shallow water sites on the west coast. There is no divide between shallow and deep on the East coast (areas 1-4). This reflects landed catch only.

### 3.4 Growth overfishing

Growth over-fishing is a risk region of the fishery where growth is above average and thus management rules are not well aligned. For example, the average legal-sized female lobster from Area 5 Tasmania (Figure 3-3) landed in 2004 was valued at \$19 based on average beach price for that size for that year. In 1968, the average size was greater so that the average lobster landed had a net present value (NPV) of \$71. Productivity gains from better management of size at harvest appear to have potential to increase yield.



**Figure 3-3** Map of Tasmania and boundaries of the 11 Stock Assessment Areas. Areas 9-11 are offshore from Areas 6-8, delineated by the 62.18m depth contour.

In order to respond to this need and opportunity, managers and industry need information and advice. These stock issues are difficult to manage because fishing effort isn't responding in the manner of typical fisheries – for example, effort is moving away from areas with high catch rates and into areas with low catch rates. While this unusual situation can be explained economically, it is clearly difficult to manage by standard management methods.

The first step was to provide stakeholders with information on what changes are happening in deep and shallow regions of the resource. Assessments were unable to provide information on this beyond simple breakdown of fisher catch per unit effort (CPUE) data by depth. Stakeholders needed information on how the resource is likely to trend under current management (including impact of inshore recreational fishing).

The next step was to develop management options that increase yield, value and sustainability. Three management options have been proposed that appear to have promise in delivering substantial gains in yield. These are:

- a. **Deep-water quota:** provision of additional quota allowance for fishers operating in deep water to offset lower price per kg. This will shift effort from shallow to deep water.

- 
- b. **Regional size limits:** to move size at harvest toward more optimal levels for economic yield (including consideration of effects of CPUE on harvest costs and price differentials for different sizes).
  - c. **Translocation:** shifting lobsters from slow growth, low value areas to more productive regions to increase yield and value per recruited lobster.

In 2005, FRDC funded a project to examine the economic feasibility of the last of these, translocation (FRDC 2005/217 Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield). That project indicated considerable opportunity from translocation. For example, cost of charter operations to increase yield was estimated at less than \$3/kg of gain in catch (i.e. per kg quota increase). This compares favourably with other options for increasing yield on the level of an individual lobster fisher (e.g., ~\$16 / kg to lease additional quota) or for seafood production generally (e.g., ~\$4/kg Atlantic salmon production). Given these results, translocation was included in this project as one of the possible management options and further investigation through field trials is planned.



**Figure 3-4** Photo of fast growing, red, shallow water lobster and slow-growing, pale deep-water lobster.

## **4 GENERAL METHODS**

The project was composed of four broad methods to achieve the above objectives, designed to produce alternative harvest strategies for the fishery. These steps were:

- (1) development of the capability to model geographic variation in lobster stocks;
- (2) field-based data collection;
- (3) biological and economic modelling of alternative harvest strategies; and
- (4) the development of an approach to apply outcomes of the project.

This included implementing the stock assessment model for each state, the subsequent development of a discussion paper of policy options, and development of ongoing monitoring tools/techniques.

### **4.1 Development of the Capability to Model Geographic Variation in Lobster Stocks**

#### ***4.1.1 Enabling assessment reporting of trends in biomass and egg production by depth***

##### **Rationale**

Development of the capability to model spatial changes in abundance by depth is a requirement for the subsequent evaluation of alternative management options (i.e. deep water quota - objective 2; regional size limits – objective 3; translocation – objective 6).

##### **Experimental design**

Stock assessment modelling in each State already takes geographic variation into account to some extent, e.g., the evaluation of separate zones in South Australia, and the division of the Tasmanian and Victorian regions into several assessment blocks (Figure 3-3, Figure 5-1, Figure 5-43). This project increased the resolution by dividing areas into shallow and deep water, defined by the marketability of lobsters. The shallow-water category equates to premium grade in terms of colour, morphology and vitality, based on processor grading and research within this proposal. Analyses were conducted to determine the extent to which the data currently available were able to support additional spatial structure. Additional sampling was subsequently undertaken through this project (Section 4.2.1 for methods of increased coverage of length frequency data).

Increasing the resolution of the stock assessment model required modification of the length-based assessment models developed during the late 1990s for Tasmania (eg

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Punt et al. 1997) and more recently for Victoria (Hobday and Punt 2001) and implement a generalised model using the AD Model Builder framework. The resultant model was sex- and size-structured, with the capability to have multiple time-steps during the year and user-specified length bins. The use of a single generalised model increased consistency across all states. The size-structured dynamics processes underlying the current Tasmanian and Victorian models, which include growth, natural and fishing mortality, and recruitment, remained broadly unchanged. However, some of the parameters of the model (e.g., those that govern the size-specific probability of capture and maturation) were re-estimated as these differed between shallow- and deep-water.

Other parameters were introduced or altered to allow the evaluation of alternative management options. All existing southern rock lobster assessment models assumed that natural mortality was independent of size and density and that growth is independent of density. These assumptions were reviewed because a change in density in deepwater stocks was a focus of the project, and density may potentially reach levels not seen through years for which existing data are available (e.g., post 1970 for Tasmania). Density-dependent mortality (and growth) has the potential to influence the management recommendations resulting from this project. We examined these processes through the course of the project from translocation experiments. In particular, the growth and survival of unfished stocks of sub-legal females from translocation harvest sites in southern Tasmania was informative.

The model was fitted to several data sources. Yearly catch (in number) and catch rate of commercial fishers were available through logbooks. Data on length-frequency was available through research catch sampling and from commercial fishers. We increase data collection by fishers through the course of this project (Objective 4). Estimated recreational catch and effort was attributed to shallow water regions rather than across all depths, as was implicitly the case in the original models.

Data assimilation for model fitting involved researchers in each State. The different spatial cells of the model were linked by movement of lobsters and by movement of fishers within a management jurisdiction. The original model for Tasmania included a fleet dynamics component where the future distribution of fishing effort was a function of block, season and catch rate. The values for the parameters that determined the fleet dynamics for Tasmania were re-estimated to take account of the additional spatial strata introduced by adding depth categories (see objective 3). Movement of (trappable) lobsters was assumed to be nil in original models, but this was re-examined using existing tag-recapture data and included in the model.

A Bayesian approach was used to quantify the uncertainty of the estimates of fishing mortality and annual recruitment. The outputs from the model were designed to have direct relevance to the provision of management advice (i.e. time-trajectories of available biomass and egg production) and the evaluation of alternative management

options (i.e. future biomass, egg production, catch length-frequency and catch-rate). The latter two quantities are required for economic analysis of management options (length-frequency to determine market grade and thus beach price, and catch rate to determine the effort required to maintain TACC).

## **Products**

We produced a stock assessment model for use in each state for assessing trends in stock and evaluating alternative harvest strategies. There has been complete adoption of these models in each state, with the new stock assessment models used in the management process.

### **4.2 Field based data collection**

#### **4.2.1 *Fisher catch sampling***

##### **Rationale**

The length-based model developed at Step 1 produced estimates of population abundance in different regions. This model was fitted to catch and effort as well as size frequency data. Improved size-frequency data was required for this process and also benefited routine stock assessments for each State. Deep-water areas were especially under-represented in existing data and were targeted in this component. Data were used for evaluating all three of the spatial management options.

##### **Experimental design**

Waterproof data-loggers that record length measurements from electronic callipers were developed for sampling giant crabs (FRDC 2001/042 Development of the tools for long term management of the giant crab resource - data collection methodology, stock assessment and harvest strategy evaluation: tools for giant crab assessment). These were deployed with commercial fishers in each State to increase data coverage of rock lobster populations. Fishers were asked to record measurements from a portion of their catch, at a minimum one pot per shot.

Data was downloaded from the units and then cleaned and analysed by automated routines developed for (FRDC 2001/042 Development of the tools for long term management of the giant crab resource - data collection methodology, stock assessment and harvest strategy evaluation: tools for giant crab assessment). Plots generated by this process are used to provide feedback to participating fishers. Data were stored in an Oracle databases in each state.

#### **4.2.2 *General methods for translocation field experiments***

##### **Rationale**

These experiments provided additional data for the analysis of translocation as a management option. Sites covered a range of locations to provide spatial contrast – clearly required given the spatial diversity of biological parameters in southern rock lobsters.

### Experimental design

Translocations were conducted in each state with the assistance of commercial fishers. In Victoria and South Australia, translocations from deep water to shallow water were conducted at 1 and 2 release sites respectively. In Tasmania, deep to shallow water translocations were conducted at 10 release sites. At each site we translocated up to 2000 lobsters per year over 3 years (Table 4-1). All lobsters released were tagged (Figure 4-1) and carapace length (CL), sex, damage, setose state and shell grade were recorded.

In Tasmania, where the majority of translocations occurred, the same site of origin was targeted to reduce density and to test density dependent changes in biology. Maatsuyker Island (43°40'30S 146°12'56"E) is a southern, deep -water (60-100 m) rocky reef 12 nm offshore. The sampling area was approximately 800m<sup>2</sup>. The average depth was 60 m, and the maximum depth was 100 m. Ten percent of all the animals captured at Maatsuyker Island were tagged and released back to the capture site (undersized and legal size). All remaining undersized lobsters captured were translocated to new shallow water sites along the east coast of Tasmania.

**Table 4.1.** Number of lobsters moved to each shallow water site in Tasmania as part of the translocation experiment.

|                             | 2004 | 2005 | 2006  | 2007 |
|-----------------------------|------|------|-------|------|
| Stanley                     | 1200 |      |       |      |
| King Island                 |      | 1200 |       |      |
| Crayfish Point (Taroona)    |      | 1800 | 2000  | 2000 |
| Ketchum Island              |      | 1800 |       |      |
| Reidle Bay (Maria Island)   |      | 1800 | 2000  |      |
| Ansons Bay                  |      | 1800 |       |      |
| Georges Rocks               |      |      | 2000  | 1400 |
| Gull Island                 |      |      | 2000  | 1525 |
| Whale Head                  |      |      | 2000  | 1500 |
| Emerald Bay (Maria Island)* |      |      |       | 2000 |
| Total                       | 1200 | 8400 | 10000 | 8425 |

Release sites were resurveyed twice per annum initially and then once per year to collect data on: tag recapture for survival and growth; change in colour and condition;

change in maturity. Resurveys were extended to the 5th year of the project to attempt to collect information on density related changes to growth, survival and habitat.

#### 4.2.1 Translocation release survival and movement

##### Rationale

The feasibility of translocation is affected by the survival and movement of lobsters after release. Based on releases of juveniles for FRDC 2000/185 (Rock lobster Enhancement and aquaculture subprogram: evaluating the release and survival of juvenile rock lobsters released for enhancement purposes), the period 48 hours after release is most critical (Mills et al. 2006). Sensitivity testing of the translocation model developed for FRDC2005/217 (Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield) indicated that fieldwork addressed to this issue was warranted (Gardner and Putten 2008a; Gardner and Putten 2008b).



**Figure 4-1** T-bar tags used to tag all translocated lobster (left) and tag inserted into the ventral surface of a lobsters abdomen (right).

Movement of animals away from the survey site in the first 24 hours after release introduced biases in survival estimates of juveniles (so that survival appeared low due to emigration, rather than mortality). This bias was eliminated by releasing the



juveniles onto reef within a temporary (24 h) pen formed by a “fence” of fine mesh weighted with chain. That procedure was repeated at release sites in this experiment using 80 m pens constructed from discarded salmon-pen base nets. These “fences” were weighted at the lower edge by lead-core rope and were also used successfully in large-scale

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(>2000 lobsters) releases conducted in 2005. These pens are cheap (free) and can be deployed easily and quickly from vessels so could be used in commercial scale translocation operations – thus they did not introduce a structural bias in our experiment. The “fences” did not have a roof and so were not predator proof. Their main purpose was to slow the immediate escape response of lobsters released onto the reef. Releases occurred at night to reduce predation.

Survival was also evaluated over longer periods from data collected through sampling of release sites for growth, colour, and egg production. We estimated survival using Cormack-Jolly-Seber. Estimates obtained from longer releases were biased lower by movement. This is of limited concern as we compared survival relative to local lobsters tagged during recapture surveys, rather than utilise absolute survival values estimated through CJS modelling. Of greater concern was the risk of extremely broad confidence limits from these longer period surveys, hence the need for short intensive experiments.

Movement was of concern with releases of juvenile lobsters as some lobsters were found to undergo a flight response immediately after release and disperse onto inappropriate habitat, presumably increasing risk of mortality. We examined this initial flight response during the same experiment as for short-term survival by acoustically tagging 15 of the animals released. Movements were tracked with an array of moored Vemco VR2 recording beacons. See section 5.5.2 for full methods and results.

#### ***4.2.2 Translocation growth transition***

##### **Rationale**

Although we expected growth of lobsters to adapt to the new location, the time it took was unknown. The transition of growth rates from the old to the new location was complicated by maturity of animals being moved and the number and timing of moults each year. Model sensitivity testing conducted for FRDC 2005/217 (Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield) showed that outcomes were sensitive to this parameter.

#### ***4.2.3 Maturity and egg production***

##### **Rationale**

The way that the maturity of females responded to the new site affects egg production. There was some evidence that a mature female can become immature again so this change was explored. Maturity scenarios were tested in FRDC 2005/217 (Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield) and found to result in vastly different

levels of estimated egg production – up to 2-fold difference (Gardner and Putten 2008a).

### **Experimental design**

The maturity status of females was monitored in tagged lobsters that are translocated in the operations described at 4.2.2 above. The sites selected for capture and release were adjacent to existing research sites where maturity information is available to provide baseline comparison. Maturity was assessed by both presence/absence of ovigerous setae and presence/absence of eggs during winter months. See section 5.5.3 for full methods and results

#### ***4.2.4 Density-dependent growth and mortality***

### **Rationale**

Density dependent changes in growth rate and mortality provided a negative feedback on populations that result in stability. In fished populations, this includes processes such as reduced competition for food and shelter when density is lowered so that growth increases and mortality decreases. This information was required for each of the management options being examined.

In long term modelling of populations of lobsters (as proposed in Step 3), simulations tended to become unstable unless these processes are included.

### **Experimental design**

Density dependent processes were examined in four ways:

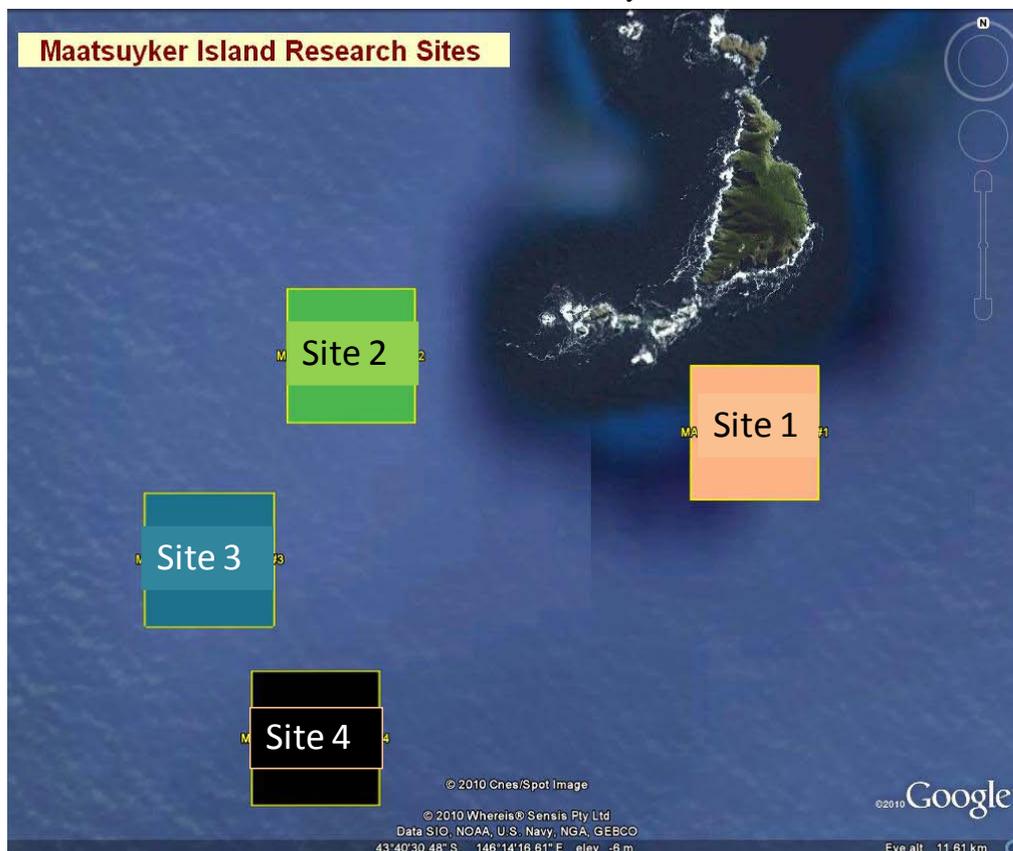
Firstly, McGarvey et al. (1999) obtained estimates of density dependent suppression of growth through spatial comparison between sites in South Australia. While these observations were potentially confounded by spatial differences aside from density, they ensured that modelling could proceed and allowed comparison between methods.

Secondly, existing tagging data of lobsters inside and outside MPAs were examined. This was also examined in Tasmania through FRDC 1999/162 (Evaluating the Effectiveness of Marine Protected Areas as a Fisheries Management Tool) but fewer data were available at that time. We note that these analyses are potentially confounded by spatial differences aside from density.

Thirdly, historical patterns in growth rate data were contrasted with changes in density. These analyses are included in Step 1. We note that these analyses are potentially confounded by temporal differences aside from density.

Fourthly, the translocation of lobsters between sites offered a unique opportunity to experimentally manipulate density and observe the effects on lobster biology. We reduced density in deep-water sites while concurrently increasing density at shallow water sites. Lobsters were tagged at all sites (a subsample of lobsters were tagged and released back to the origin site). Sites were selected to allow comparison in tag recapture data with adjacent non-manipulated sites. For example, in Tasmania we depleted lobsters at 1 of 4 adjacent deep-water research sites near Maatsuyker Island (Figure 4-2). Density at these sites were extremely high (catch rates average around 30 lobsters per potlift) and growth extremely low (8 out of 76,411 females sampled were legal sized). We removed females from one site and were able to track changes in growth rate and mortality at that site using the remaining 3 sites as controls (Figure 4-2). This design allowed testing and elimination of spatial and temporal confounding.

The tag and release of a proportion of lobsters at depletion sites also enabled us to obtain estimates of lobster abundance and density.



**Figure 4-2** Maatsuyker island sampling sites. Maatsuyker island is south of Tasmania.

#### 4.2.5 *Changes in marketability through translocation*

##### **Rationale**

The higher price paid for shallow water is related to several factors including their darker red colour, their vitality and survival during transport, and their broader tails

with associated higher meat yields. These characteristics are not linked so that it is possible to capture pale coloured lobsters in some regions that have broad tails and good meat yields. As these characters are not linked, we did not expect them to be adopted by lobsters at their new site at the same rate. For example, lobsters can adopt the red colour of their new site only a few months after transit, but this is inadequate for processors if they remain weak and survive poorly in transport. Economic model sensitivity testing conducted for 2005/217 (Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield) showed that outcomes were moderately sensitive to this parameter.

### **Experimental design**

Changes in colour, condition, morphology and meat yield were monitored in tagged lobsters that were translocated. Methods were developed for this component through preliminary studies on changes in marketability of lobsters through translocation. That research examined spatial and depth variation in the parameters examined here by sampling around Tasmania as part of stock assessment catch sampling. Additional spatial data on shell colour has been obtained from SA and Victoria.

Colour was quantified from macro photographs of the carapace surface. The colour composition of these digital images was then quantified through image software. Condition was evaluated through blood chemistry including blood protein (FRDC 1996/160 Condition and its assessment in the Southern rock lobster field application of the techniques for condition assessment). In addition, a leg was removed from a sub-sample of lobsters to allow analysis of lipid, protein and moisture content of muscle tissue. Meat yield was evaluated from both biochemical analyses of leg samples and also tail width measurements (for full methods and results see section 5.6.1).

#### ***4.2.6 Response of deep water ecological communities to translocation***

##### **Rationale**

Current quota management has led to a concentration of effort on inshore reefs where lobsters have characteristics that place them in the premium price category. This has led to concerns about the ecological impacts, in particular the development of urchin barrens. Conversely, concern has been expressed that removal of lobsters from high-density deep-water stocks may also have impacts on the benthic community. This component examined if ecological change occurred with increased harvest rates in deep water (potentially an outcome of deep water quota, translocation and regional size limits), plus if there was potential to reverse incipient barrens through translocation.

##### **Experimental design**

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This component of the project used translocation sites (both depletion and release sites) described above.

Habitat information was collected by video as sites were typically unsuitable for diving, either because they were remote and thus pose OH&S risk due to distances to decompression chambers, or because the depths were too great. Digital video transect data was scored for community type, percent cover of macroalgae, sponge or other benthic organisms, and density scores taken of key taxa. Analytical techniques were modified from those developed for divers to quantify change in MPAs for FRDC 1999/162 (Evaluating the Effectiveness of Marine Protected Areas as a Fisheries Management Tool). This experimental design was reviewed and described in detail at a workshop in 2002 “examining underwater visual census techniques for the assessment of population structure and biodiversity in temperate coastal marine protected areas”.

Briefly, a “beyond BACI” survey design was employed with multiple transects conducted in control and impact sites, with several surveys before and after. Transects were not fixed, because our equipment did not allow precise geo-positioning of the video transect in relation to the vessel.

We examined change through time at both experimental translocation sites where density was altered, and also at nearby control sites.

### **4.3 Biological and economic modelling of alternative harvest strategies**

#### ***4.3.1 Model evaluation of separate deep-water quota***

##### **Rationale**

This component used the model developed at Step 1 to conduct projections for scenarios in which there were separate deep- and shallow-water quotas. The aim of this component was to provide advice on sustainable TACCs for separate deep and shallow water zones.

##### **Experimental design**

The projections were intended to determine the total allowable catches that appeared sustainable for both the shallow- and deep-water zones, specifically to develop management options that increased yield and egg production. Given that the number of quota units is fixed, this process also identified the possible increase in quota that could be accommodated to provide an incentive for fishers to shift effort to deeper water. Future catch rates under different scenarios were predicted to enable an economic evaluation of this management approach. The scenarios examined involved

sequences for the commercial catch (in weight) in the future, and the future distribution of fishing effort among assessment blocks and depths.

#### ***4.3.2 Model evaluation of regional size limits***

##### **Rationale**

This component related to Tasmania only due to the greater variation in growth rates than the other states. The model developed at Step 1 was used to evaluate the consequences of alternative size limits in different assessment blocks and hence determine the change in economic yield with different size limits. Also of interest to stakeholders was the potential for meeting regional targets for egg production simultaneously with an increase in yield.

##### **Experimental design**

This section only dealt with Tasmania because growth varies substantially among assessment blocks so that there are some areas in Tasmania that currently experience growth over-fishing while others appear under-utilised.

In model scenarios, the fleet was allowed to move among the different assessment blocks, which clearly creates enforcement issues, although solutions are available with modern technology such as VMS. A key issue for managers and industry was whether the magnitude of gains in terms of increased yield were sufficient to warrant the adoption of regional size limits and the associated increase in enforcement costs.

Projections involved change in both regional size limits and the TACC. The projections were based on the same method as for objective 2, and assessed the effect of regional size limits on biomass, egg production and catch rates. Economic evaluation of size limit options (Objective 8) was possible because the model predicts the catch rate, catch, and catch size structure (to determine market category). The number of regional size limits was limited to two or three (i.e. north and south; or southern, middle and northern regions) so that enforcement was feasible.

Regional size limits were only considered for broad regions, and not split by depth category due to difficulty in enforcement. However, the issue of depth of fishing effort was relevant and important to these scenarios because: (a) the shallow- and deep-water categories in the model allowed the effect of alternative size limits on stocks at different depths to be examined; (b) regional size limits could be combined with deep- and shallow-water quota; (c) regional size limits could be combined with translocations.

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### **4.3.3 *Model evaluation of translocation***

#### **Rationale**

Translocation was the third spatial management tool to be evaluated. Previous modelling of translocation was cohort-based, and established the feasibility of translocation, but was unable to address the probable impacts on catch rate or the magnitude of gains in yield. These aspects were addressed in this objective.

#### **Experimental design**

This component was conducted for all three states. Simulations of translocations in Victoria and South Australia were between deep- and shallow-water, while in Tasmania the movement among assessment blocks was also explored.

The concept of the projections was the same as that applied in FRDC 2005/217 (Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield). That is, biomass of a known length- and sex-structure were shifted from one region to another and projected through time. The catch and stock benefits of the exercise was measured by simulating both the translocation of the lobsters and the status quo situation of no translocation – the difference between the two was then the net benefit. A key difference between the analysis conducted here and that conducted previously is that the projections were based on the stock assessment models developed during step 1 and the magnitude of possible translocation exercises was examined (e.g., previous analyses showed that translocations by charter vessels with 5 tonne well capacity between Port Davey and King Island were economically beneficial – but how many such trips could be done sustainably and what would be the impact on residual biomass and catch rates at both locations?) Basing the projections on the assessment model allowed the impact of the translocations on the regional level to be assessed in relation to the biomass already in the region within a self-consistent framework, in terms of biomass and catch.

Modelling of the fate of lobsters after translocation was assisted by data collected through Step 2. The factors considered and quantified were: a) losses from translocation through mortality at release plus movement away from the release site, b) the time to transit to the growth rate applicable to the region in which the lobster was translocated, c) the impact of translocation on maturity, and d) density-dependent processes.

### **4.3.4 *Compare spatial management options by economic analyses***

#### **Rationale**

The population model analyses of management options (objectives 2, 3 and 6) provided information on gains in biomass, egg production, catch rates and yield

(TAC). While this was valuable, it was insufficient for industry and management to choose between options because costs and economic gains vary. Economic analyses were extended here from the economic model developed for FRDC 2005/217 (Rock Lobster Enhancement and Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield) although the process was similar with different options contrasted by the net present value approach.

### **Experimental design**

The economic model interacted with the population model through effort factors affecting costs (catch rates) and yield factors affecting benefits (yield predictions of scenarios with new management vs. current management). As the biological model was length based, it was possible to attribute value to catch on the basis of individual lobster size and discount lobsters outside the premium size category (0.8 to 2.0 kg). This was especially important for scenarios of deep-water quota and regional size limits because although there appeared to be opportunity for substantially increased yield, this yield consisted of lower grade lobsters that fishers find difficult to sell during some periods.

Biological and economic model scenarios were conducted over a 20-year period with a discount rate of 7.5% to allow depreciation of fishing business assets to near zero.

## **4.4 Extending results with functional management and monitoring**

### **4.4.1 Development of Monitoring Tools**

#### **Rationale**

Although the options for spatial management examined in this project were intended to increase revenue in the fishery, they also entailed additional complexity and cost. Managers and industry were involved throughout the project to provide information specifically about the feasibility of the altered management regime.

#### **Experimental design**

The division of the assessment model into deep and shallow blocks enabled ongoing monitoring of change on a level of greater spatial detail than was available before this project. Estimates of recruitment obtained through this model were used to simulate the stock under different strategies. Alternative scenarios with different recruitment periods were run. This process provided insight into the effects of normal variation in recruitment.

The second approach was relevant to translocation only and utilised tag recapture data, which were obtained through normal translocation operations (costing for translocation operations in FRDC 2005/217 (Rock Lobster Enhancement and

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Aquaculture Subprogram: the feasibility of translocating rock lobsters in Tasmania for increasing yield) included the cost of tags and observer labour for marking all translocated lobster before release).

#### ***4.4.2 Development of Policy Options and Discussion Paper***

##### **Rationale**

Outputs from the modelling process provided guidance on options for management, but these need to be underpinned by sound operational system and policy. The management systems proposed in this project are novel and operational systems were developed from scratch with assistance from industry and government policy experts.

##### **Experimental design**

Examples of the need for a project component to extend results included; (a) how could feasible enforcement protocols be implemented for regional size limits; (b) what allocation process could be applied for deep water quota?; and (c) the policy to regulate and govern translocation.

Model outputs from Step 3 indicated probable outcomes of management changes in terms of biological and economic benefits, however, these need to be feasible on an operational level – for this we required further input from commercial and recreational sectors as well as government.

Workshops were held to enable discussion amongst stakeholders of policy issues. Outcomes of pilot scales translocations and the modelling of alternative harvest options guided discussions so communication of these results through reports was important to ensure an informed discussion.

An especially important step for the commercial sector in Tasmania was the formation of an industry sub-committee, termed the Sustainability and Profitability Options Committee (the SPOC). This committee took the research results and developed options for industry to consider. This ultimately led to industry voting on many of the management changes developed through this project.

## 5 RESULTS/DISCUSSION

### 5.1 Better Spatial Stock Information

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The majority of the southern rock lobster (*Jasus edwardsii*) fishery in Australia occurs within the 3nm state water boundaries of 3 States, Victoria, Tasmania and South Australia. Each state manages the fishery in the waters of its 3 nm boundary independently, with assessments involving the use of a length-based stock assessment model which includes demographic traits, fleet movements and catch rates from that region. Each model was separately parameterised to enable more detailed reporting of trends in biomass and egg productions by depth.

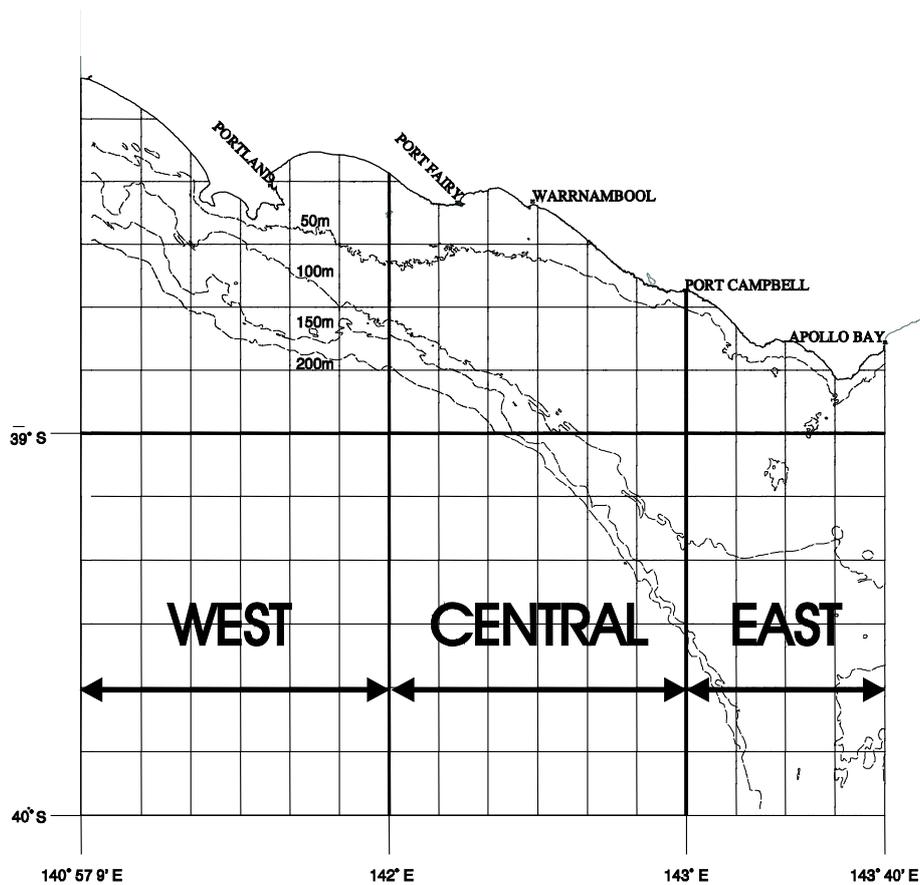
#### 5.1.1 Victoria

Victoria's focus in this study was directed to the development of the new spatial model as translocation of lobsters was not an industry priority and not practical because of the small offshore fishery in the Western Zone which would be the source for any translocations. The main aim was to improve fishery and biological information from the deep water sector in the western zone to aid in the development of the depth stratified spatial model. We describe the development of a western zone model which includes inshore/offshore components and regional separation. The eastern zone model only incorporates regional components.

The Victorian fishery is divided into two zones east and west of Apollo Bay. The western zone includes lobster habitat extending to around 140 metres and supports an inshore fishery for red and an offshore fishery for speckled/brindled lobsters. The eastern zone fishery is confined to inshore reefs and as such comprises predominantly red lobsters. FRDC project 2004/037 Spatial modelling and assessment of the Victorian Southern Rock Lobster (*Jasus edwardsii*) fishery (Hobday and Punt 2006) developed a spatial model for Victoria which divided each of the two fishing zones into three sub-zones (e.g. Figure 5-1) This study further developed the spatial model to incorporate the biological differences associated with depth.

#### *Data collection*

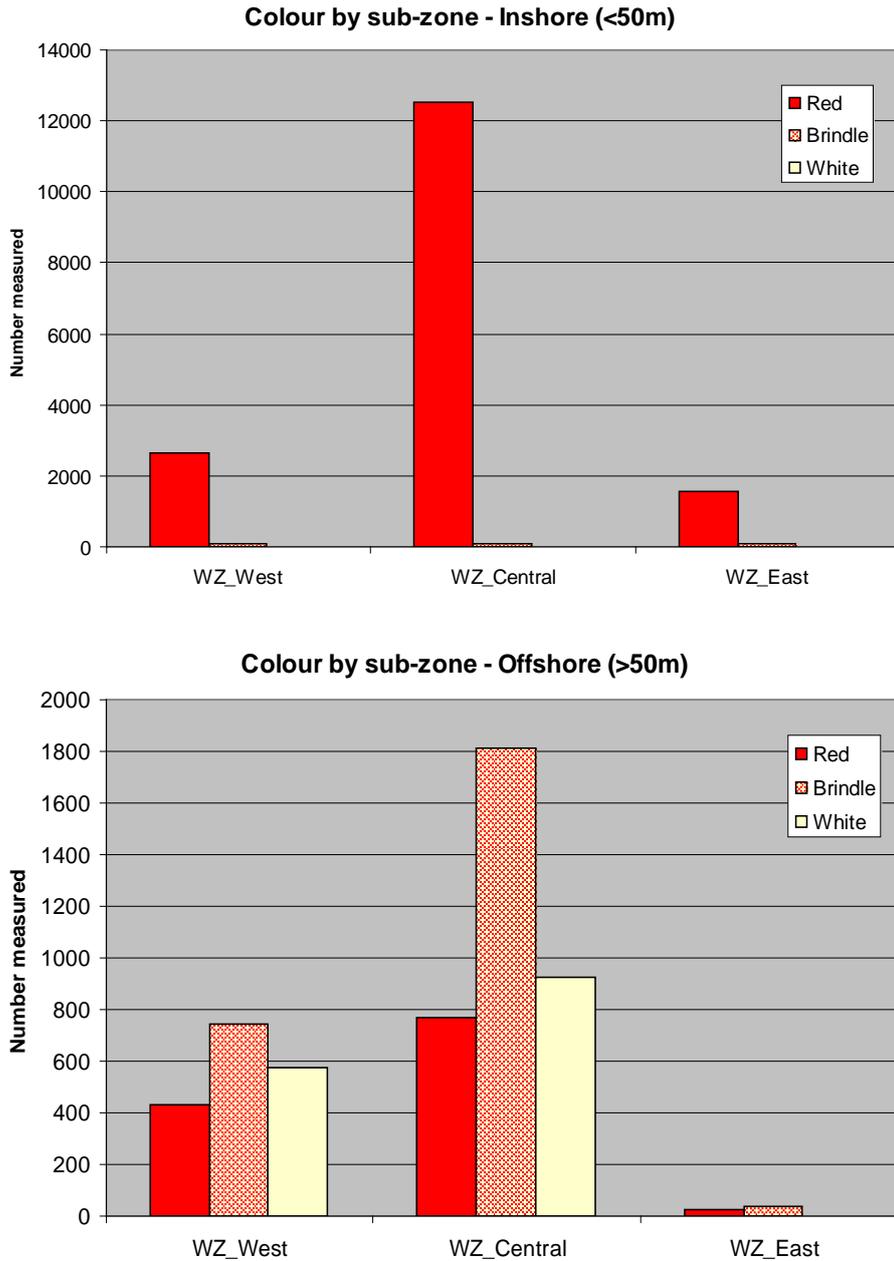
As part of this study, a total of 52 days sampling was conducted by onboard observers in waters greater than 50 metres during the 2006-07 fishing season (Table 5.1). As these deeper waters are fished by a small number of fishers, data collection was difficult. This work directed observer sampling to the offshore areas of the western zone to improve the data required for modelling. Over six thousand lobsters were measured and two thousand tagged from the offshore waters. A further 250 days sampling was conducted as part of an ongoing monitoring program funded by Fisheries Victoria in the main area of the fishery in waters less than 50 metres. The inshore areas were dominated by red lobsters while the offshore contained a mixture with the brindled most abundant (Figure 5-2).



**Figure 5-1** The three sub-zones of Victoria's western zone rock lobster fishery.

**Table 5.1** Summary of data acquisition to September 2007.

| Sub-zone   | Depth range | No. days sampled | No. measured | No. tagged | No. of undersize females | No. of legal size females | No. of undersize males | No. of legal size males |
|------------|-------------|------------------|--------------|------------|--------------------------|---------------------------|------------------------|-------------------------|
| WZ_West    | 0-50m       | 33               | 2,841        | 1,657      | 1,063                    | 339                       | 893                    | 529                     |
| WZ_Central | 0-50m       | 201              | 13,954       | 1,799      | 4,136                    | 3,087                     | 3,170                  | 3,248                   |
| WZ_East    | 0-50m       | 20               | 1,952        | 893        | 632                      | 391                       | 539                    | 375                     |
| WZ_West    | > 50m       | 19               | 2,516        | 1,095      | 1,051                    | 310                       | 669                    | 470                     |
| WZ_Central | > 50m       | 24               | 3,519        | 1,054      | 979                      | 886                       | 532                    | 1,112                   |
| WZ_East    | > 50m       | 9                | 66           | 32         | 20                       | 15                        | 13                     | 18                      |



**Figure 5-2** Colour of lobsters from the western zone inshore (top) and offshore (bottom) waters by sub-zone.

*Translocation*

The translocation operation was conducted during May 2007. Over several days, a number of undersize lobsters were captured by participating fishers south of Warrnambool from waters greater than 50 metres and returned to shore-based holding facilities. When sufficient numbers were available, the lobsters were measured and tagged and one hundred and thirty five were released south of Portland at depths between 15 and 20 metres. Only one recapture was reported from this translocation with a growth increment of 10 mm and no change from the release colour of white.

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### *Fishery independent sites*

In 2007, two new ‘deep water’ sites were added to the ten existing fishery independent, monitoring sites (Figure 5-3). These sites are monitored annually and provided additional opportunities to measure and tag lobsters in offshore waters. Data was recorded from 200 potlifts at each site.

### *Model History*

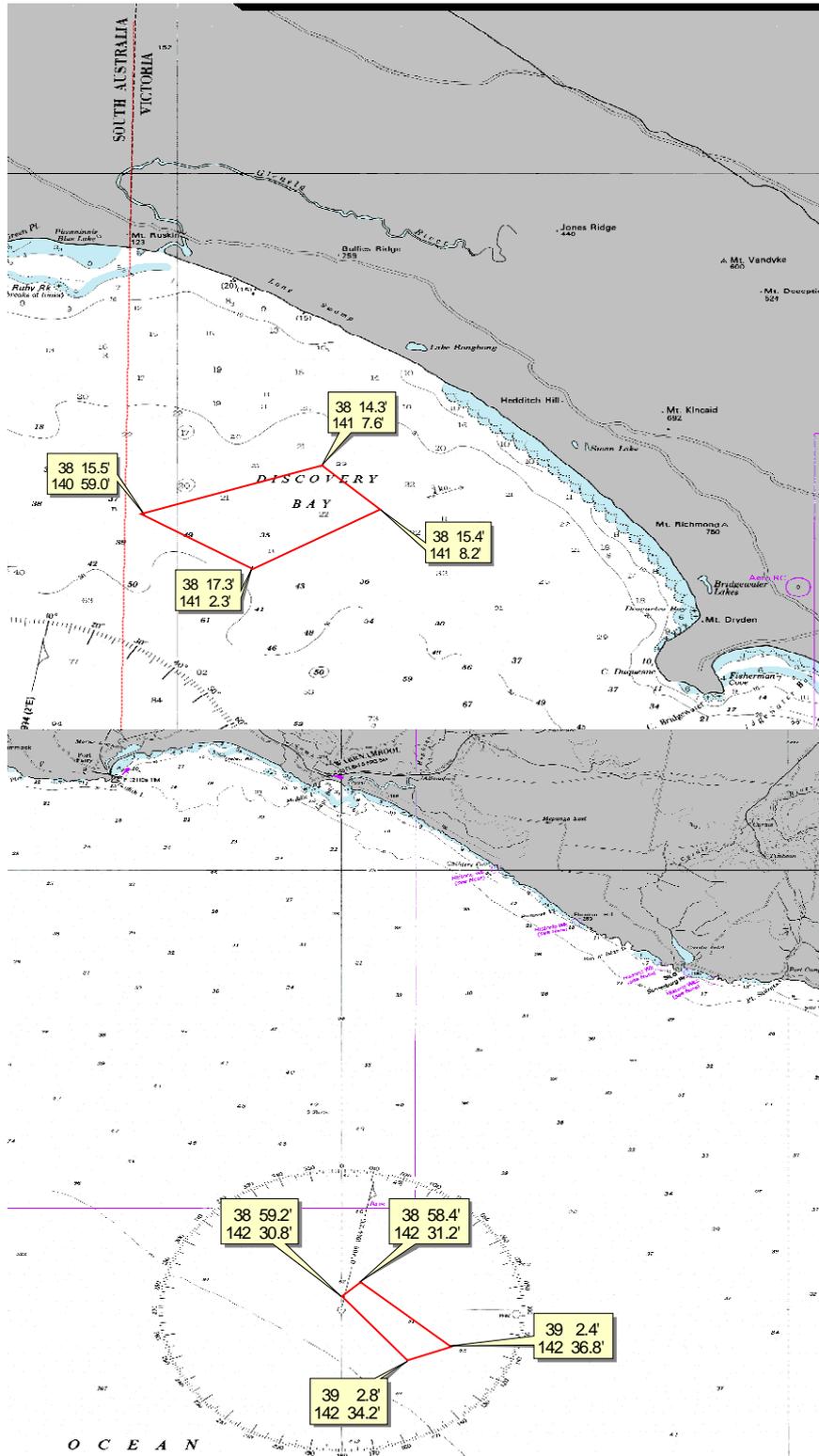
The current model had its origins with the length-structured model (Punt et al. 1997) for the Tasmanian rock lobster fishery. A simplified version of this model was developed by Hobday and Punt (2001) to assess the Victorian fishery with considerably less data than used with the Tasmanian model. The model had an annual time cycle commencing in 1951 and was run at the whole zone level. A second version (Hobday et al. 2005a) refined the whole-zone model by incorporating Marine Protected Areas (MPAs). The third Victorian model (Hobday and Punt 2009) introduced more spatial definition with each Zone divided into three regions with the time series commencing in 1951. This model formed the basis of the model being developed in this project and was continually modified and developed until the end of the project. Significant improvements to date include model derived estimates of growth, selectivity, recruitment and female vulnerability and utilisation of undersize length frequency data.

## **Detailed Methods**

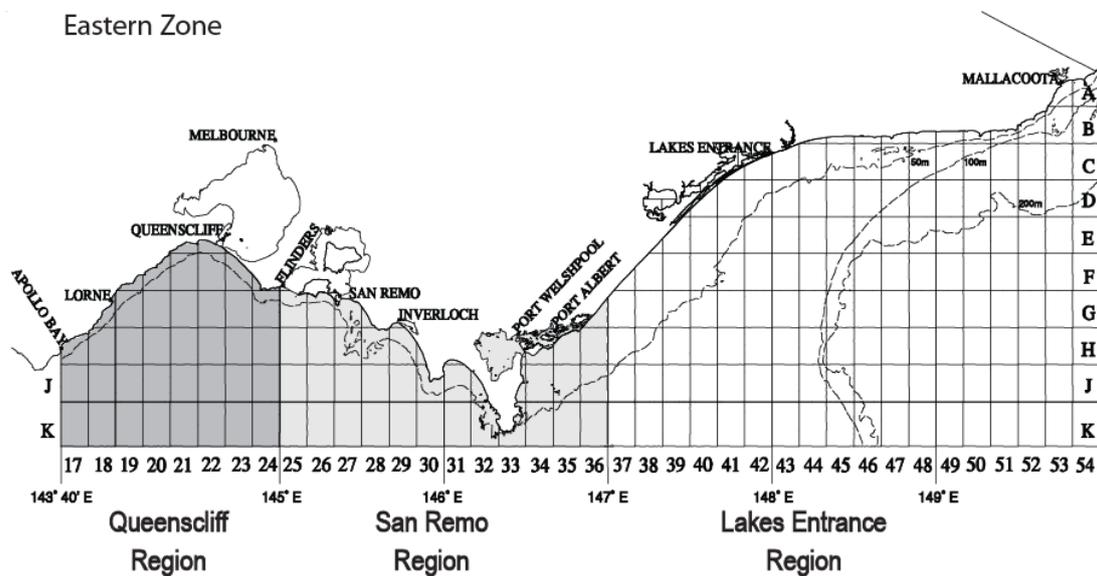
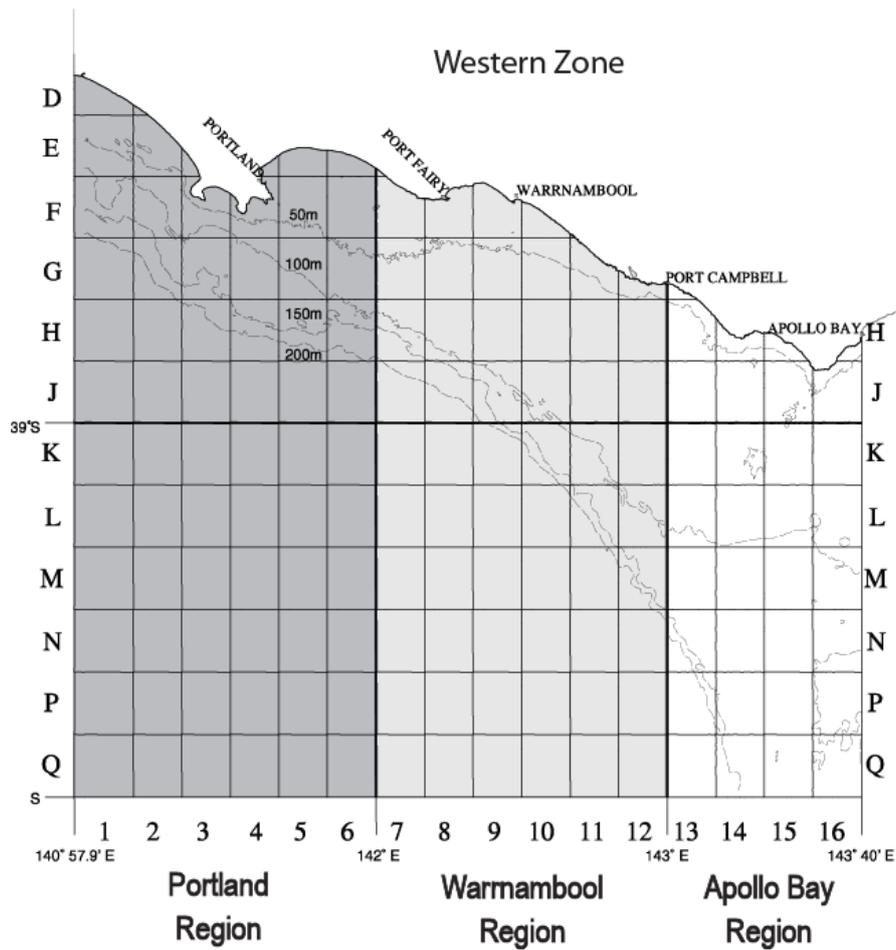
### *Commercial fishery data*

Commercial catch in both weight and numbers and effort data (potlifts) from fisher logbooks was extracted from the Rock Lobster Assessment Project’s mirror of Fisheries Victoria’s Catch and Effort System. The sub-zonal divisions introduced by Hobday and Punt (2009) were used for each Zone however they were renamed as regions with more relevant names representing the major port in each (Figure 5-4).

Each Western Zone region was further divided into inshore and offshore along the 50m depth contour. Initially, the Eastern Zone data was also divided into inshore and offshore but the model gave poor results because of the lack of growth and size structure data in the offshore areas. Therefore the Eastern Zone was only assessed using three regions without depth stratification. The time series of all data used in the model commenced in 1978 as this was the first year that depth was recorded in commercial logbooks. The time step used in the model was the “Assessment year” from April to March corresponding to the pre-2009 Quota and licensing year. Each year in the analysis is represented by the first calendar year of the assessment year i.e. 1978 is the assessment year April 1978 – March 1979. The CPUE time series for both zones were not standardized.



**Figure 5-3** Deep water, fishery independent monitoring sites in the western zone of the Victorian rock lobster fishery. Left, Discovery Bay (40-80m) adjacent to SA border; right, South of Warrnambool (100-110m).



**Figure 5-4** Regional divisions of the Western (top) and Eastern Zones with the Catch and effort grid. The 50m contour of the Western Zone is the boundary used to differentiate the inshore and offshore fisheries.

Port sampling of landed catches at processing plants has been carried out mainly in the Western Zone for a number of years. These data include lobster sex and carapace length but generally do not contain detailed capture position data and were allocated to the region containing the port of landing. The commercial length frequency data was allocated to the inshore depth range. The data is included along with historic length frequency data from port measuring and CSIRO data in the length frequency input to the model.

**Table 5.2** Sample sizes by year and region for Western Zone commercial length frequency.

| Commercial Region | Year | Inshore |        | Total  |
|-------------------|------|---------|--------|--------|
|                   |      | Female  | Male   |        |
| Apollo Bay        | 1995 | 415     | 262    | 677    |
|                   | 2002 | 84      | 68     | 152    |
|                   | 2006 | 222     | 1018   | 1240   |
|                   | 2007 | 122     | 1189   | 1311   |
| Portland          | 1978 | 1457    | 1799   | 3256   |
|                   | 1979 | 1785    | 1821   | 3606   |
|                   | 1980 | 3253    | 4808   | 8061   |
|                   | 1981 | 5489    | 10076  | 15565  |
|                   | 1982 | 3038    | 9204   | 12242  |
|                   | 1983 | 3581    | 7764   | 11345  |
|                   | 1984 | 1050    | 1000   | 2050   |
|                   | 1985 | 2447    | 2106   | 4553   |
|                   | 1986 | 79      | 96     | 175    |
|                   | 1993 | 377     | 406    | 783    |
|                   | 1994 | 2099    | 2644   | 4743   |
|                   | 1995 | 2344    | 2368   | 4712   |
|                   | 1996 | 699     | 593    | 1292   |
|                   | 1997 | 708     | 860    | 1568   |
|                   | 1998 | 504     | 1269   | 1773   |
|                   | 1999 | 1136    | 3002   | 4138   |
|                   | 2000 | 1826    | 3918   | 5744   |
|                   | 2001 | 1963    | 3492   | 5455   |
|                   | 2002 | 1326    | 2382   | 3708   |
|                   | 2003 | 1693    | 2966   | 4659   |
| 2004              | 75   | 951     | 1026   |        |
| 2005              | 1063 | 2477    | 3540   |        |
| 2006              | 2070 | 6248    | 8318   |        |
| 2007              | 7608 | 16066   | 23674  |        |
| 2008              | 3451 | 6598    | 10049  |        |
| Warrnambool       | 1995 | 642     | 380    | 1022   |
|                   | 1997 | 447     | 285    | 732    |
|                   | 1998 | 71      | 1419   | 1490   |
|                   | 1999 | 594     | 1371   | 1965   |
|                   | 2000 | 910     | 2195   | 3105   |
|                   | 2002 | 588     | 1165   | 1753   |
|                   | 2003 | 88      | 314    | 402    |
|                   | 2006 | 31      | 40     | 71     |
|                   | 2007 | 735     | 1267   | 2002   |
| 2008              | 1162 | 1977    | 3139   |        |
| Total             |      | 57232   | 107864 | 165096 |

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## Research data

Detailed position and biological data were recorded by research staff and on-board observers whilst on commercial fishing vessels. In recent years, most data came from on-board observers and the annual fixed site surveys conducted in February in the Western zone (Table 5.2) and August/September in the East.

The research data inputs to the model were length frequency, growth, movement, weight at length and egg production by length.

The following length weight conversions were used:

$$\begin{aligned}\text{Male weight} &= 7\text{e-}07 \times \text{carapace length}^{2.9221} \\ \text{Female weight} &= 2\text{e-}06 \times \text{carapace length}^{2.7535}\end{aligned}$$

Egg production was related to female carapace length by the following:

$$\text{Fecundity} = 0.0316 \times \text{carapace length}^{3.359} \quad (\text{Hobday and Ryan 1997})$$

Movement is only considered in the Western zone within a region i.e. between the inshore and offshore areas of a region. Only the first recapture of an individual lobster was used for growth estimation.

### *Model data*

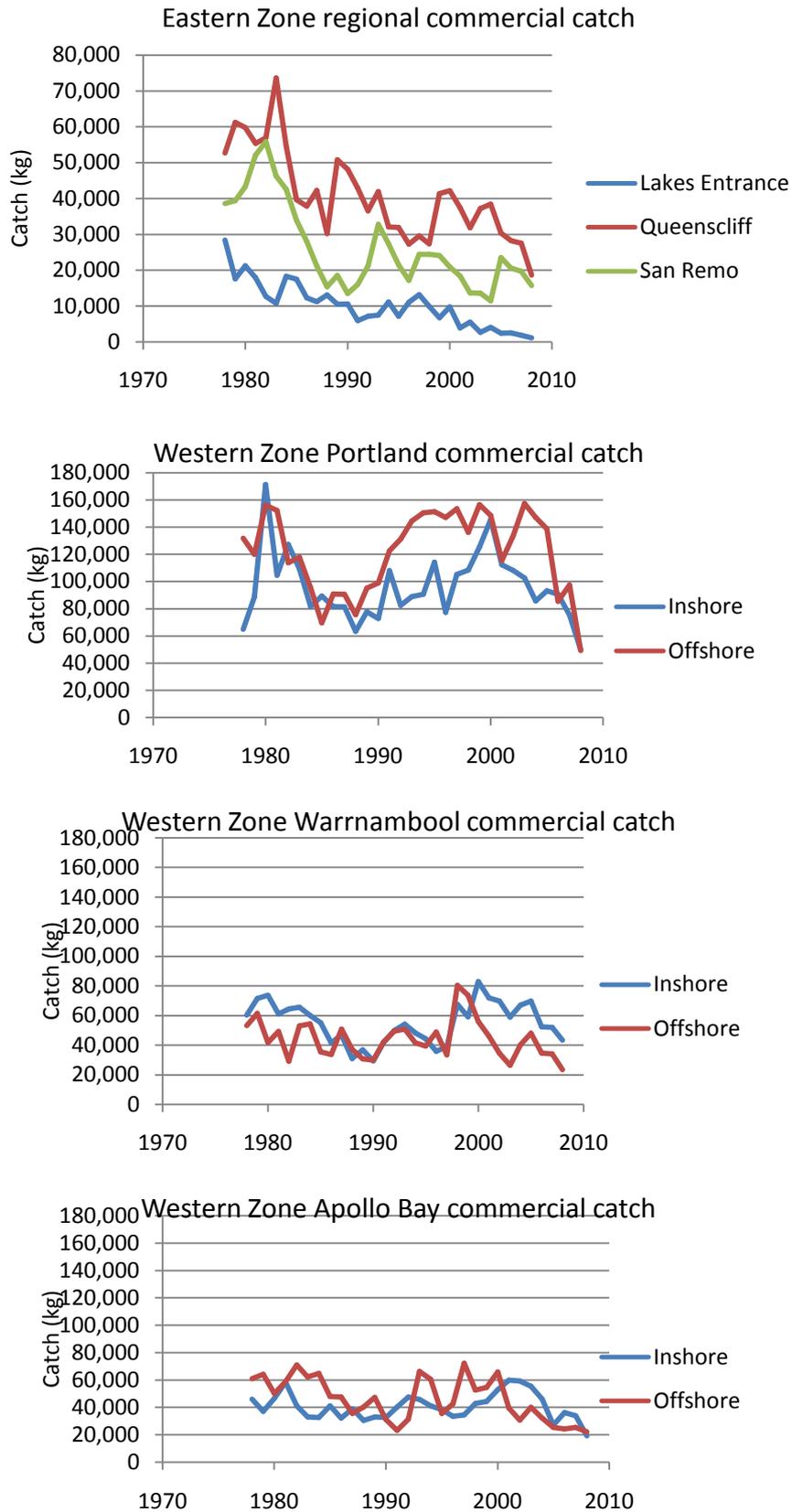
The number of size-classes and the width of each size-class differ between males and females because of differences in growth and minimum size limits. For males, each size-class is 10 mm and the model considers carapace lengths from 80 to 200 mm, with all animals of 190 mm and larger being pooled in the 190–200 mm size-class. For females, each size-class is 5 mm and the model considers carapace lengths from 80 to 160 mm, with all animals of 160 mm and larger being pooled into the 160–180 mm size-class. Size-specific selectivity was determined by Treble et al. (1998) and is proportionally reduced for females to allow for the winter closed season for females. The legal minimum lengths are set to 105 mm for females and 110 mm for males. Inshore recruitment at 80 mm is estimated by the model as part of the fitting procedure. Offshore recruitment at 80 mm is set to zero with recruitment thereafter determined from inshore/offshore movements defined by tagging data.

## Results

### *Catch and Effort by Region*

#### *Landed catch*

All Eastern Zone regions have shown a declining catch over time. Most of the catch comes from the Queenscliff region and decreases to the east to the Lakes Entrance region which has landed less than 5 tonnes in each of the past five years (Figure 5-5). Portland has the highest regional catch in the Western region, and the offshore fishery has been the most important since the early 1990's due to the proximity of the >50m depth to the coast close to Portland (Figure 5-5). Warrnambool's offshore catch has



**Figure 5-5** Regional commercial catches for the Eastern Zone (top) and Western Zone (lower three).

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been higher than the inshore since the early 1990's and both have decreased significantly since 2003. The importance of the inshore and offshore fisheries in the Apollo Bay region has fluctuated but since 2000 both have declined and the inshore catches have been higher (Figure 5-5).

## **Catch rate**

Eastern Zone catch rates are highest in the Lakes Entrance region as most of the catch comes from the high catch rate summer months (Figure 5-6). The Queenscliff and San Remo regions have similar catch rate trends and have seen some increase since the mid 1990's. With the exception of the Apollo Bay region in the last few years, offshore catch rates in all the Western Zone regions have been higher than inshore (Figure 5-6). All have seen a decrease since 2003.

### *Model Fits*

#### **Western Zone**

##### *Fits to catch rate and catch in numbers*

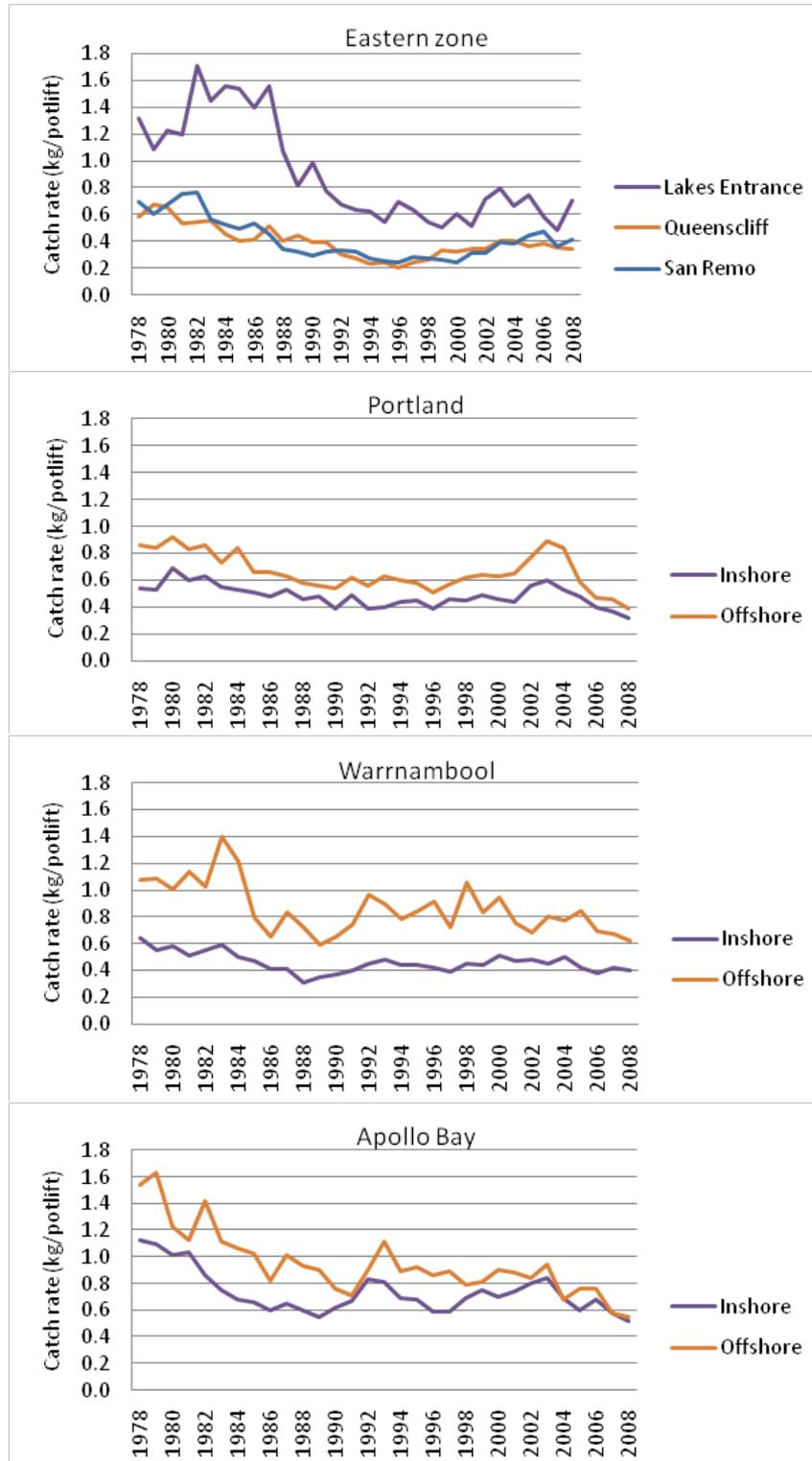
The fit to inshore (Fleet 1) catch rates was relatively good with the offshore (Fleet 2) failing to fit some years (Figure 5-7). The model's fit to the catch in numbers data is not as good, but still acceptable.

##### *Fits to length frequency*

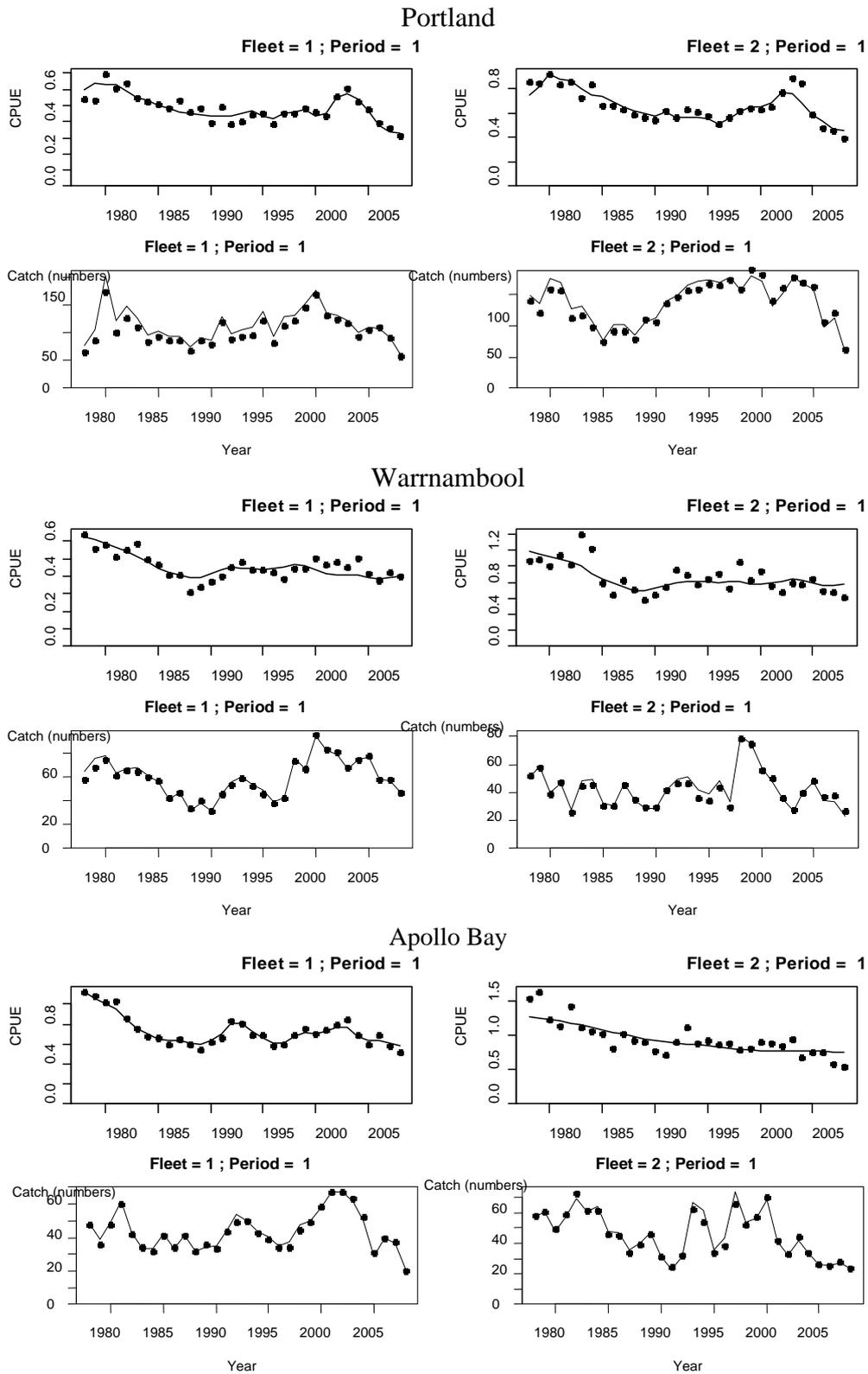
The fits to commercial length frequency were good for the Portland region except for males in 2004 but this is probably due to the small sample size for that year. There were fewer years with commercial length frequency data in the Warrnambool region but the model fits were generally good with years of low sample size having more outliers. Research sampling for the Warrnambool region was more comprehensive and fits were good except for 2001-2002 and 2007.

##### *Model estimates*

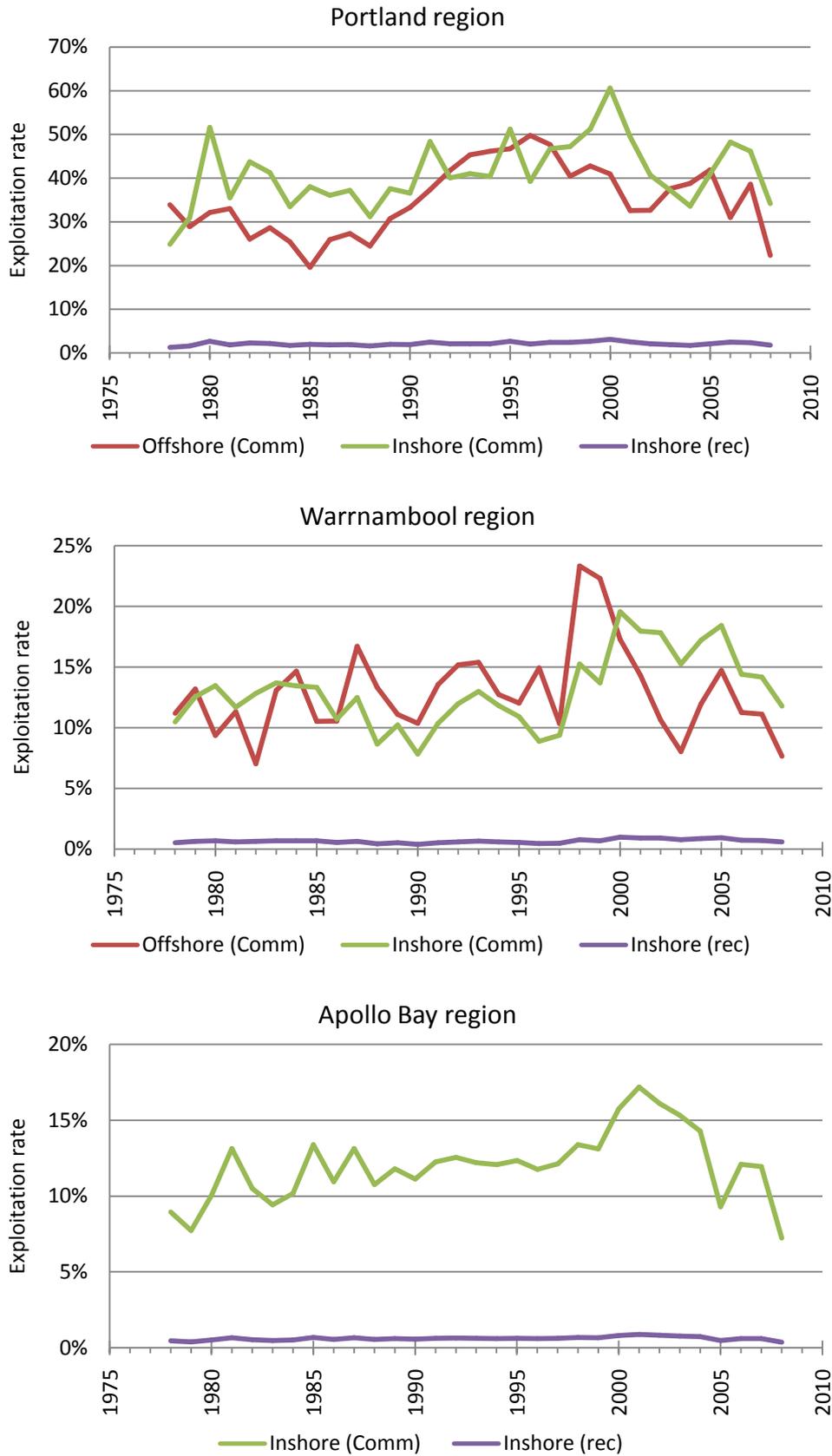
Results for the offshore Apollo Bay did not make sense, or fit with our current understanding of the stock in that area. Available biomass estimates were extremely high and are probably due to a paucity of data for this area to keep the model pinned down properly. Apollo Bay offshore has therefore been left out of the following results.



**Figure 5-6** Regional commercial catch rates for the Eastern Zone (top) and Western Zone (lower three).



**Figure 5-7** Western Zone regional model fits to catch rate (CPUE, kg/potlift) and catch in numbers. Points are actual data and lines are the model fits. Plots on the left are inshore and on the right offshore.



**Figure 5-8** Model estimated exploitation rates for commercial inshore and offshore and recreational inshore for the Western Zone regions.

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### *Available biomass*

The available biomass in the Warrnambool and Apollo Bay regions is much higher than the Portland region which has the highest landed catch and exploitation rates (Figure 5-9). Portland's offshore biomass is higher than the inshore and both have followed a similar trend of decline since 1980, an increase to a peak in 2003 followed by a steep decline to 2008. The Warrnambool region inshore biomass is higher than the offshore biomass with both showing a gradual decline to 1988 followed by a relatively stable period to 2008 without the decline observed post-2003 in Portland. Apollo Bay available biomass showed a similar trend to Warrnambool with some increases around 1992 and 1998-2003 and a decline post 2003. Inshore biomass summed across the Western zone regions was around 40% higher than inshore biomass. Both showed a gradual decline through the 1980's to 1990 (Figure 5-10). Zonal available biomass had three peaks between 1990 and 2003 coming from increased inshore available biomass. The highest peak in 2003 was boosted by an increased offshore biomass. Zonal biomass in 2008 was 59% the biomass in 1978.

### *Spawning biomass*

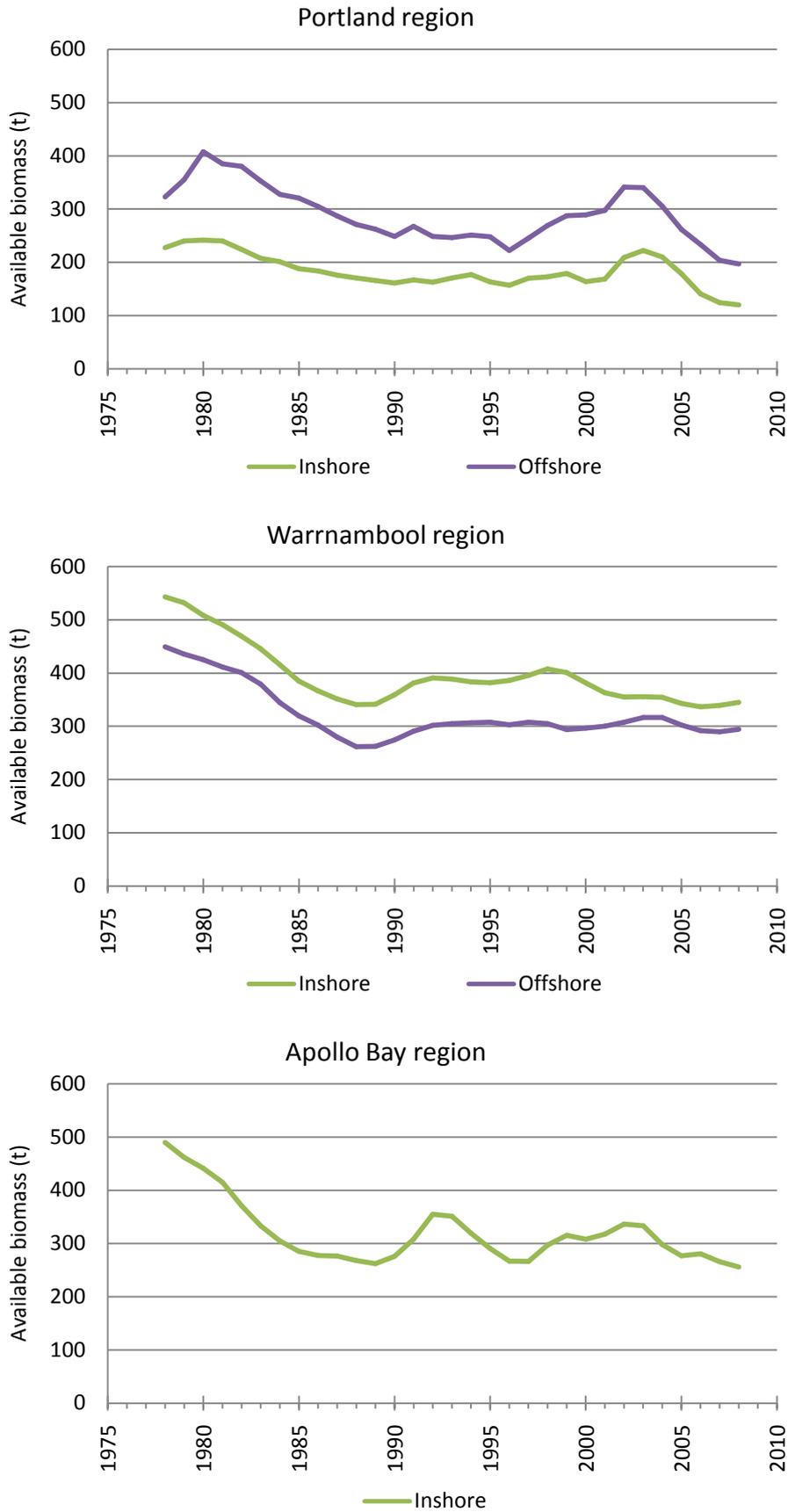
Spawning biomass showed similar regional trends to the available biomass estimates (Figure 5-11).

### *Recruitment*

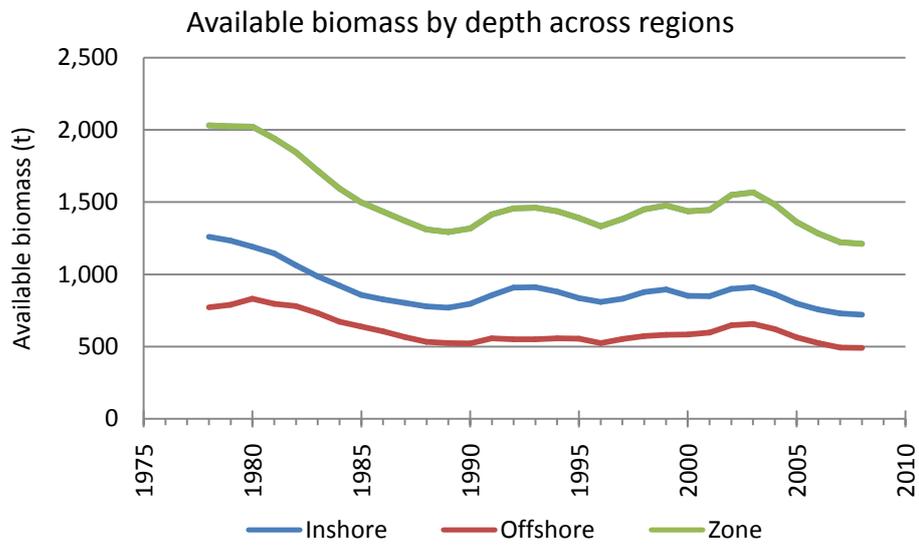
Model estimated recruitment to the lowest model size class (80 mm) in the Portland and Apollo Bay regions showed the most variation and both had peaks in 1996/97 and 2001 (Figure 5-12). With a 1-2 year lag to reach the model recruitment length of 80 mm these two peaks correspond to high puerulus settlements recorded in 1995 and 1999 (settlement monitoring commenced in 1994). A third high settlement period across the regions was between 1989 and 1991.

### *Comparison with whole-zone model*

Available biomass estimates from the spatial model were consistently higher than the whole-zone model (Hobday et al. 2005b) currently used in stock assessments (Figure 5-13). With available biomass expressed as a percentage of the 1978 biomass, estimates were similar through the 1980's decline and from the early 1990's available biomass from the spatial model were slightly higher. This may be due to incorporation of regional growth. The spatial model could be more productive because the higher growth rates in the Warrnambool and Apollo Bay regions which would have been reduced by an average zonal growth rate. The initial reduction of biomass from the whole-zone model in 2004 was due to the introduction of Marine Protected Areas (MPAs) which reduced the available biomass by 8%. MPA's were not included in this spatial model run but would have made the post 2004 estimates from both models more comparable. Spawning biomass estimates from the two models were similar with the slightly higher biomass post 2004 from the whole-zone model due to the additional egg production from MPA's. The Spatial model picks up the 1995 and 1999 settlement peaks with lag whereas the whole-zone model's main peak in 1995 didn't include a lag (Figure 5-13).



**Figure 5-9** Inshore and offshore model estimated exploitable biomass for the Western Zone regions.



**Figure 5-10** Available biomass estimates by depth and for regions combined (Zone).

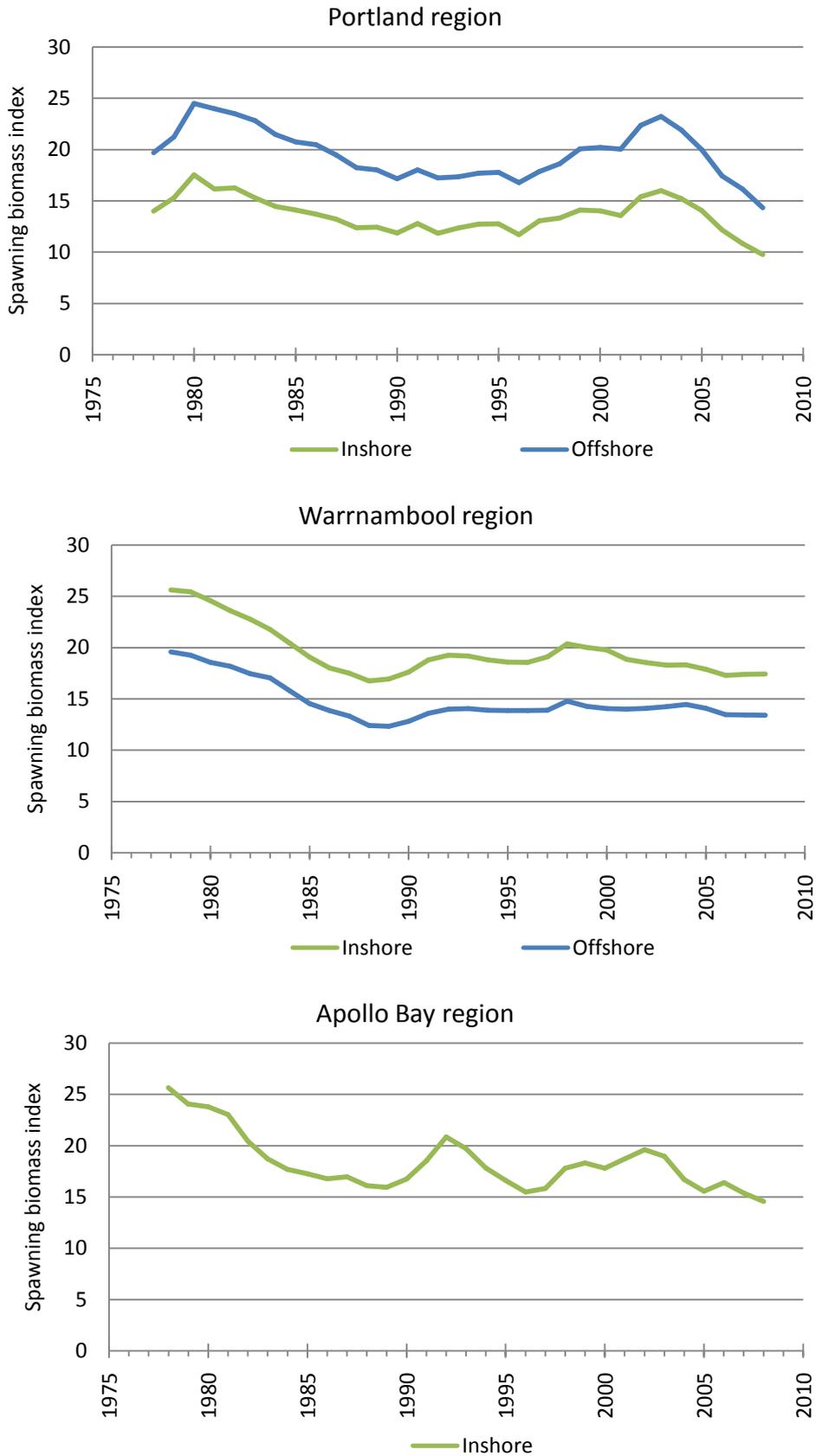
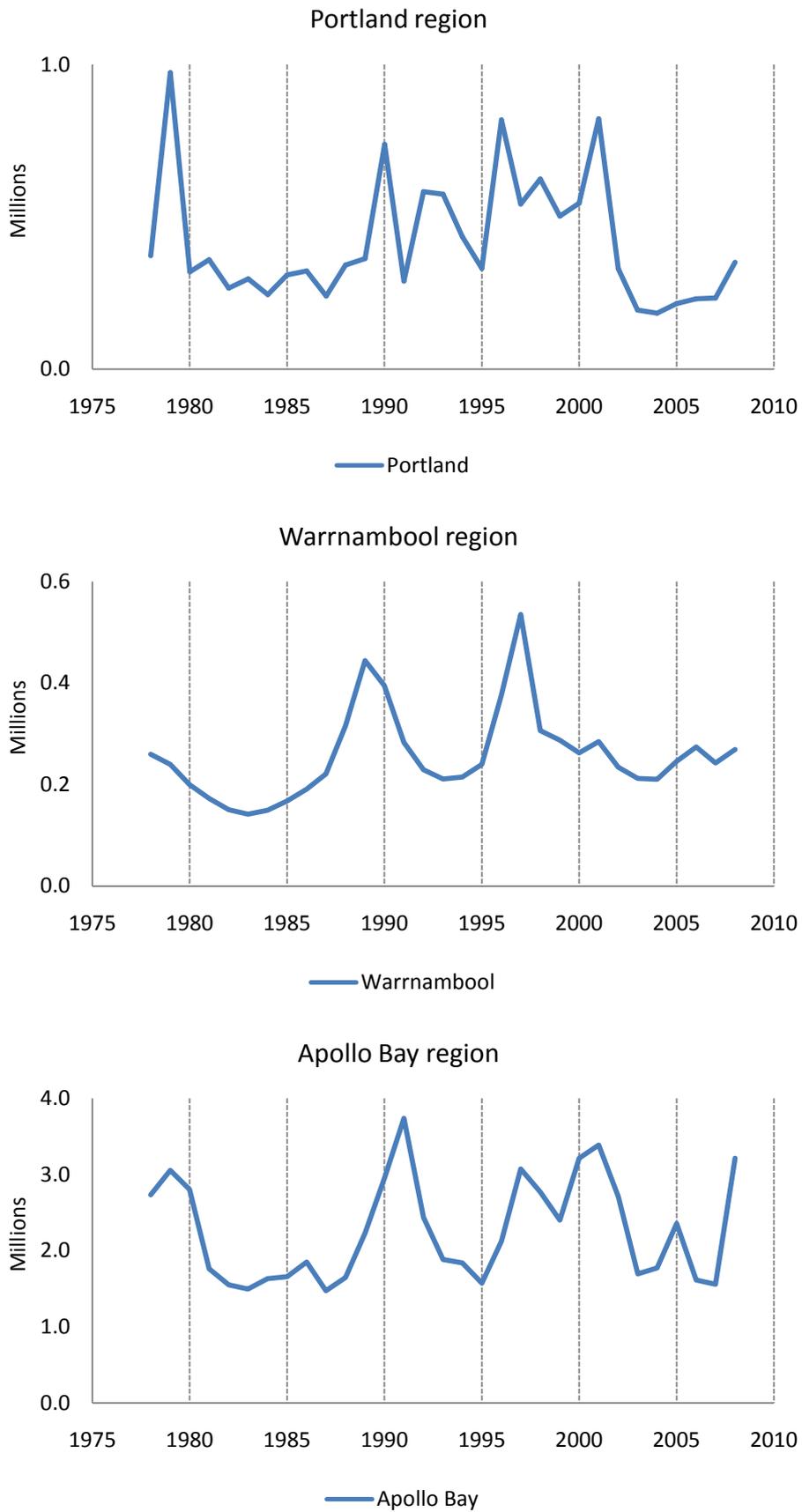
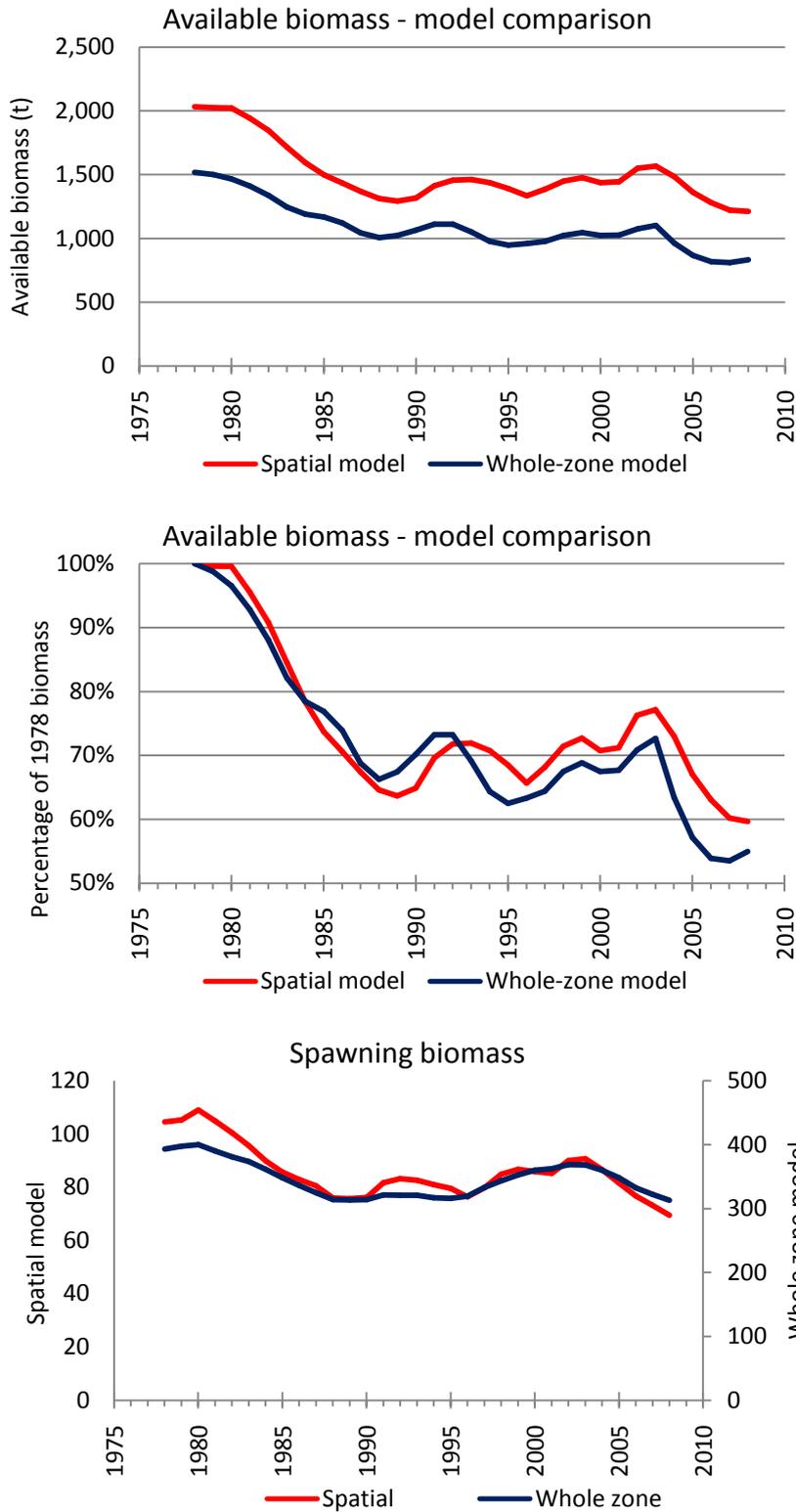


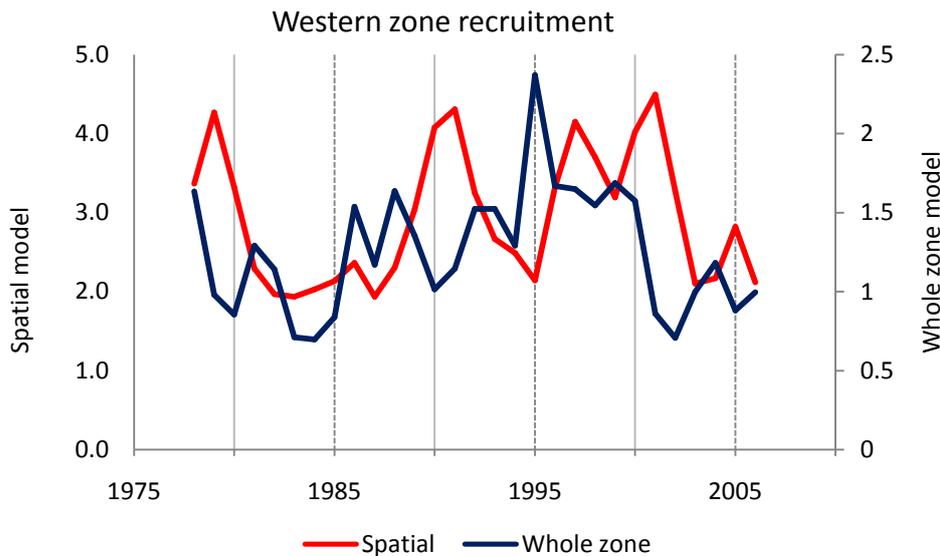
Figure 5-11 Spawning biomass estimates for the Western Zone regions.



**Figure 5-12** Model estimated recruitment at 80 mm size class for the Western Zone regions.



**Figure 5-13** Comparison of available biomass estimated from the spatial and whole-zone models (actual values (top) and as a percentage of 1978 biomass (middle)). Comparison of spawning biomass estimates from the spatial and whole zone models (bottom).



**Figure 5-14** Comparison of recruitment estimated from the spatial and whole-zone models.

### *Eastern Zone*

#### *Fits to catch rate and catch in numbers*

Model fits to catch rate and catch in numbers for the Queenscliff and San Remo were generally very good. The fit to catch rates in the Lakes Entrance region was not good in the early years.

#### *Fits to length frequency*

The model gave reasonable fits to the commercial length frequency however the male fits were not as good as the female. The model tended to underestimate the smaller size classes when fitting to the research length frequency. Fits to length frequency in the San Remo and Lakes Entrance regions were not as good as Queenscliff and this is probably a result of the poor sample sizes for these regions.

#### *Model estimates*

##### *Exploitation rates*

Exploitation rates were highest in the San Remo region where there was a significant decrease from around 80% to 50% since 2001 (Figure 5-15). Queenscliff and Lakes Entrance regions showed similar rates of 20-30% with a similar decline since 2001.

##### *Available biomass*

San Remo had the lowest available biomass estimates throughout the time series with Lakes entrance slightly higher and Queenscliff much higher and showing an increase since the mid 1990's (Figure 5-16).

*Spawning biomass*

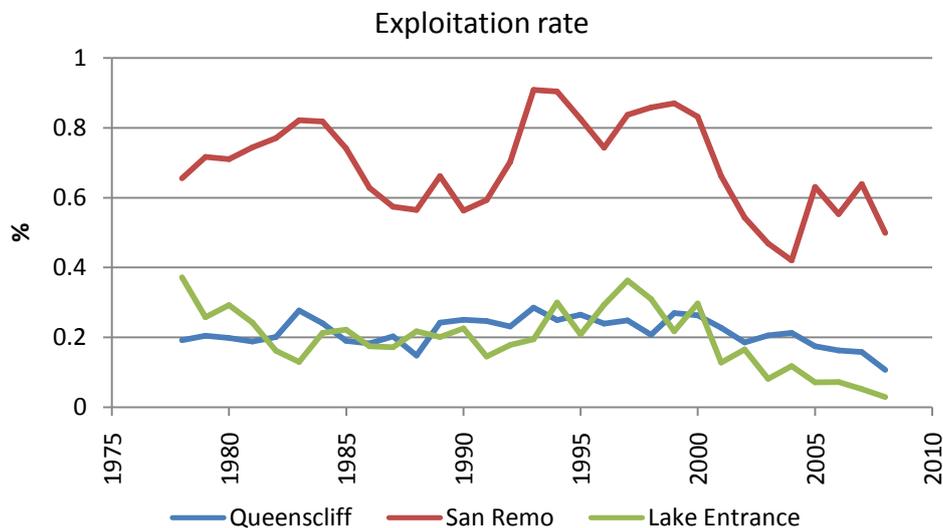
Spawning biomass was highest in the Queenscliff region and decreased moving east across the zone (Figure 5-17). As with available biomass, spawning biomass in Queenscliff has been increasing since the mid 1990's.

*Recruitment*

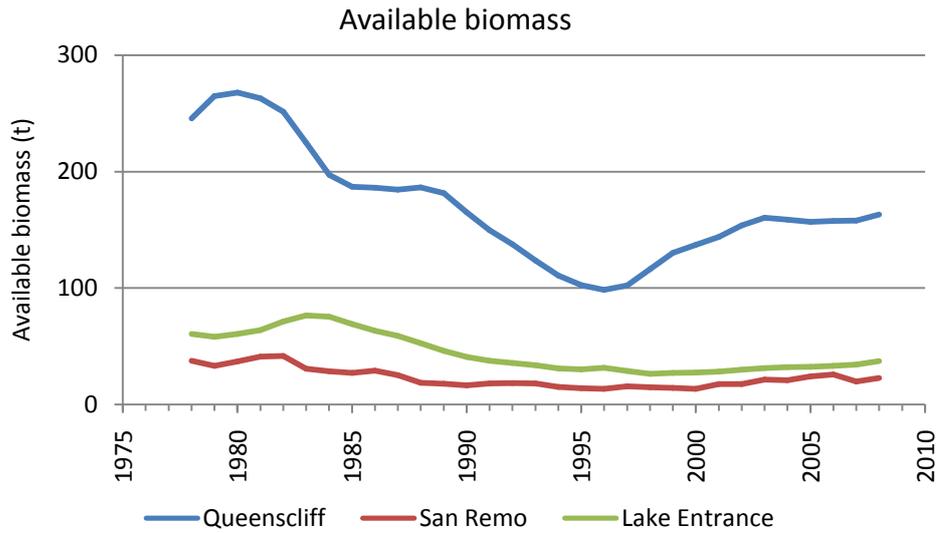
A strong settlement peak was observed in the Queenscliff region in 1997, corresponding to the 1995 puerulus settlement with a 2 year lag (Figure 5-18). Later puerulus settlements were not reflected in the Queenscliff recruitment estimates and there were no clear signals from the San Remo and Lakes Entrance regions.

*Comparison with whole-zone model*

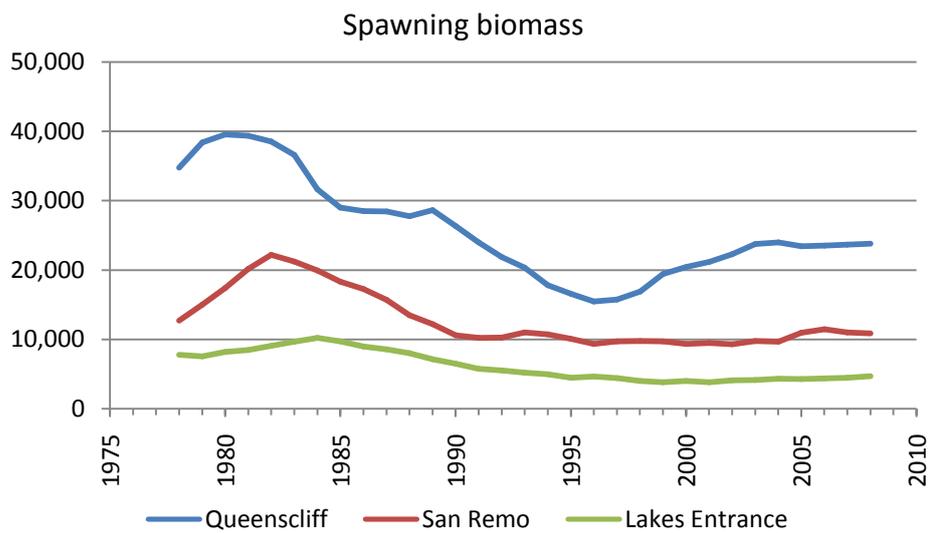
Available biomass estimates from the whole-zone model were higher than from the spatial model (Figure 5-19). This difference is probably due to the slower growth for the high biomass Queenscliff region compared with the whole-zone growth. The introduction of Eastern Zone MPAs is seen in the drop in available biomass in 2001 and not modelled in these runs with the spatial model. Similar trends in spawning biomass were noted from both models up until the introduction of MPAs in 2001 after which the spawning biomass in the whole-zone model increased due to the contribution of females in the MPAs which were equivalent to 16% of the 2001 available biomass.



**Figure 5-15** Model estimated exploitation rates for commercial inshore and offshore and recreational inshore for the Western Zone regions.



**Figure 5-16** Regional Eastern Zone model estimated exploitable biomass.



**Figure 5-17** Spawning biomass estimates for the Eastern Zone regions.

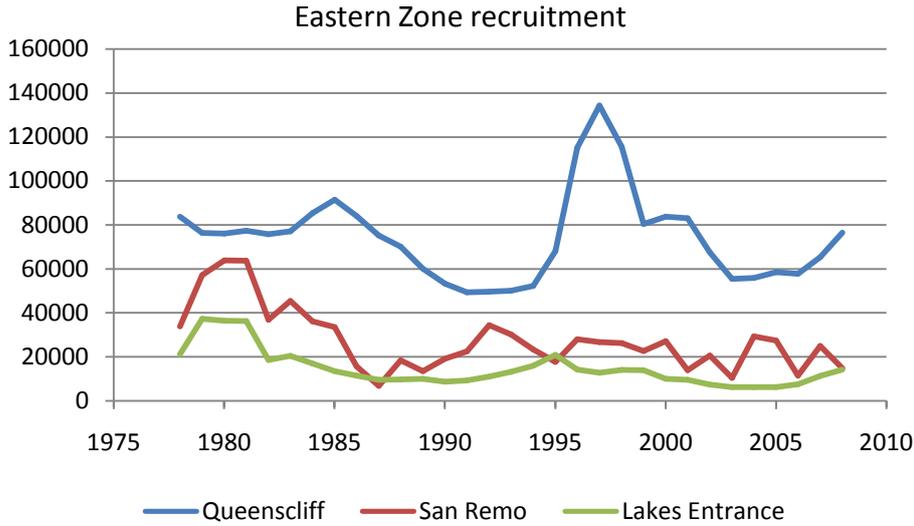


Figure 5-18 Model estimated recruitment for the Eastern Zone regions.

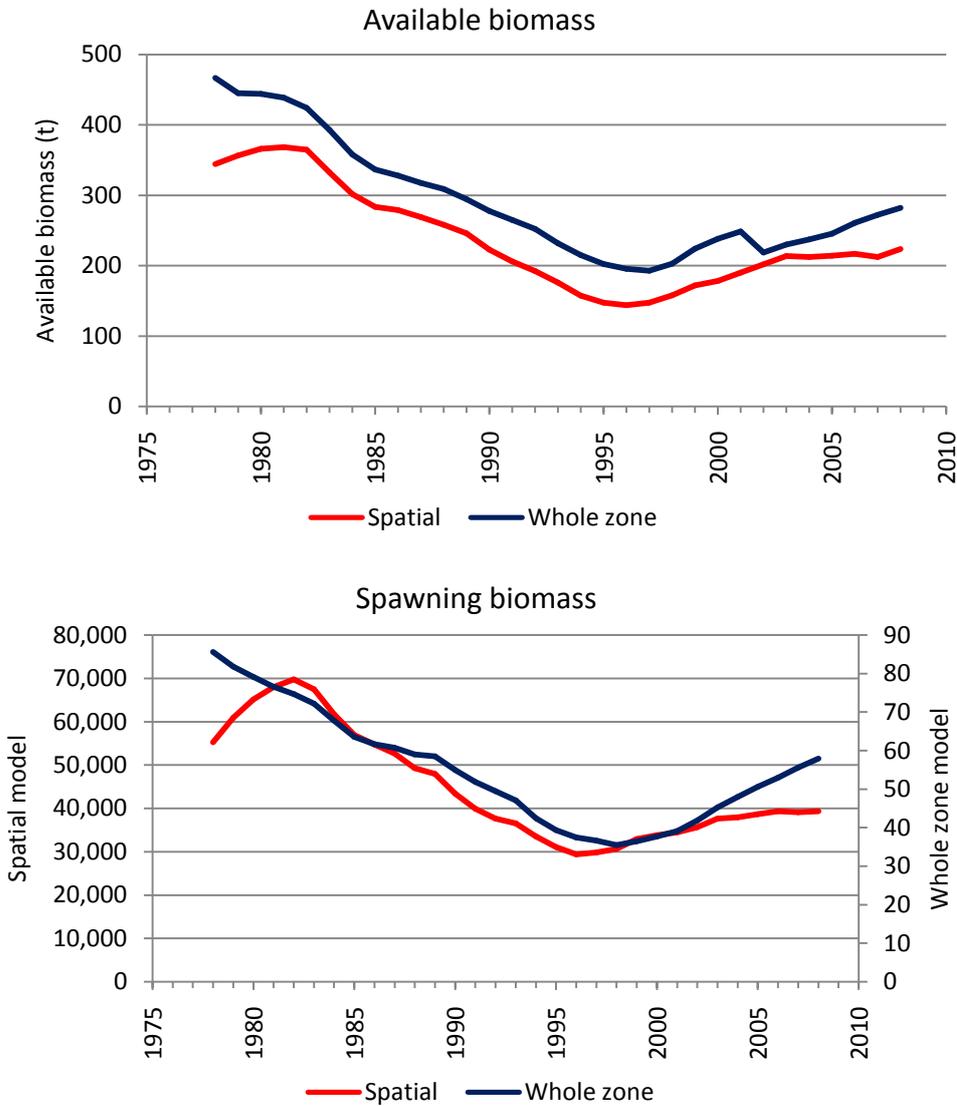


Figure 5-19 Comparison of available biomass (top) and spawning biomass (bottom) estimated from the spatial and whole-zone models.

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## *Discussion*

This project has developed the baseline data input procedures and successfully run the spatially explicit model in both Zones. The incorporation of regional biological parameters (particularly growth) has made the Western Zone spatial model slightly more productive. The whole-zone model shows an increase in available biomass over the past couple of years which has been an issue as the fishery continues to decline. The estimates from the spatial model are at least flat in the last years, fitting better with the continued decline in the fishery.

The failure of the Apollo Bay offshore component of the spatial model is of some concern. This may be resolved by a closer look at the boundaries of the inshore and offshore fisheries. As a major component of the fishery comes from a large offshore reef with water around 50 m depth, the division between the inshore and offshore fisheries may need to be a geographical one rather than by depth for this region.

As with the whole-zone model, the key to the success of the spatial model relied on catch rates providing an accurate representation of lobster abundance. The whole zone model currently used for stock assessment uses raw catch rates in the Western Zone and summer equivalent catch rates in the Eastern Zone. Many factors can influence the fishing power of a lobster pot and the subsequent catch rate data inputs to modelling. These can include changes over time in fishing technology such as colour sounders, GPS plotters; changes in fisher behaviour; differing experience levels of fishers; environmental changes and many more. The ongoing success of this model to accurately reflect the Victorian lobster fisheries will depend on the development of methods to standardise catch rates for the main factors so the catch rate inputs better reflect the historical abundance of lobsters. The critical component of this work is to involve industry in the process, particularly in defining the key factors which have influenced catch rates over time.

### ***5.1.2 South Australia.***

The code for the South Australian LenMod was adapted from the Victorian version of the model (Hobday and Punt 2001). The length-based lobster population fishery model is now completed and has been implemented for use in the stock assessment of the two South Australian zones. Outputs from the model, in collaboration with André Punt and based on coding and model development ideas proposed by the South Australian modellers (Rick McGarvey and John Feenstra), were provided in the most recent stock assessment reports for the SA Northern and Southern Zones (May 2012).

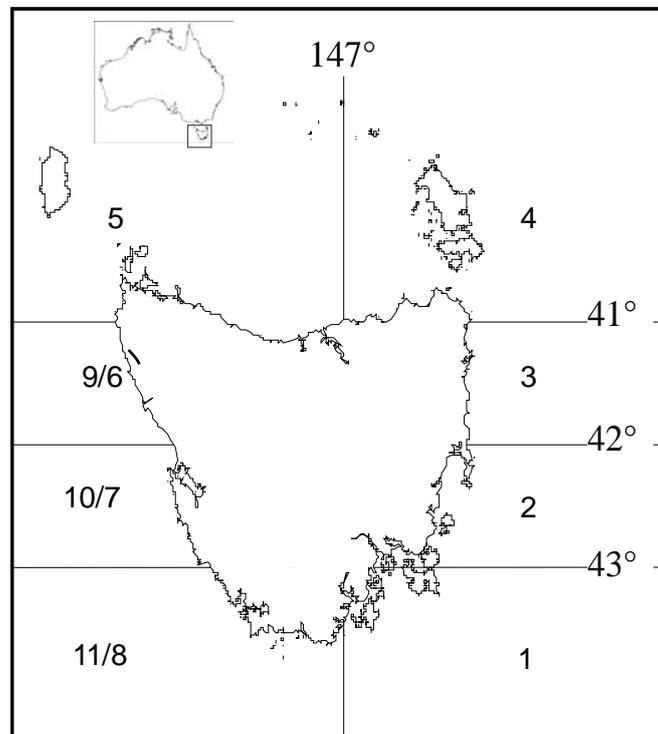
To account for spatial variation, notably between inshore and offshore fishing, the SA Southern Zone model was partitioned into two sub-regions, inside and outside 60 m depth. An estimation model of animal movement developed in a previous project

FRDC Project 1995/008 (Development of an integrated fisheries management model for King George whiting (*Sillaginodes punctata*) in South Australia), McGarvey and Feenstra 2002, using observed movements from lobster tag-recovery data between inshore and offshore SA Southern Zone sub-regions was integrated and parameterised. Differences in catch rate and fishing effort, and thus differing trends in stock abundance between inshore and offshore stocks were also modelled (McGarvey et al. 2010).

One major obstacle was not overcome. The spatial model was highly sensitive to the weighting of tag-recovery information in the overall length-based model likelihood. When zero weighting was given to tag-recoveries, the model estimated very high rates of movement. As weighting on tag-recoveries was raised, lower movement rates more consistent with other observation were estimated, but the trends in stock biomass were affected in ways that remained uncertain. Thus, the well understood confounding between movement and mortality (or abundance) was strongly acting, and these two data sources were not in agreement. For this reason, the spatial model has not replaced the single-zone Southern Zone SA lobster length-based model in yearly stock assessment.

### 5.1.3 Tasmania

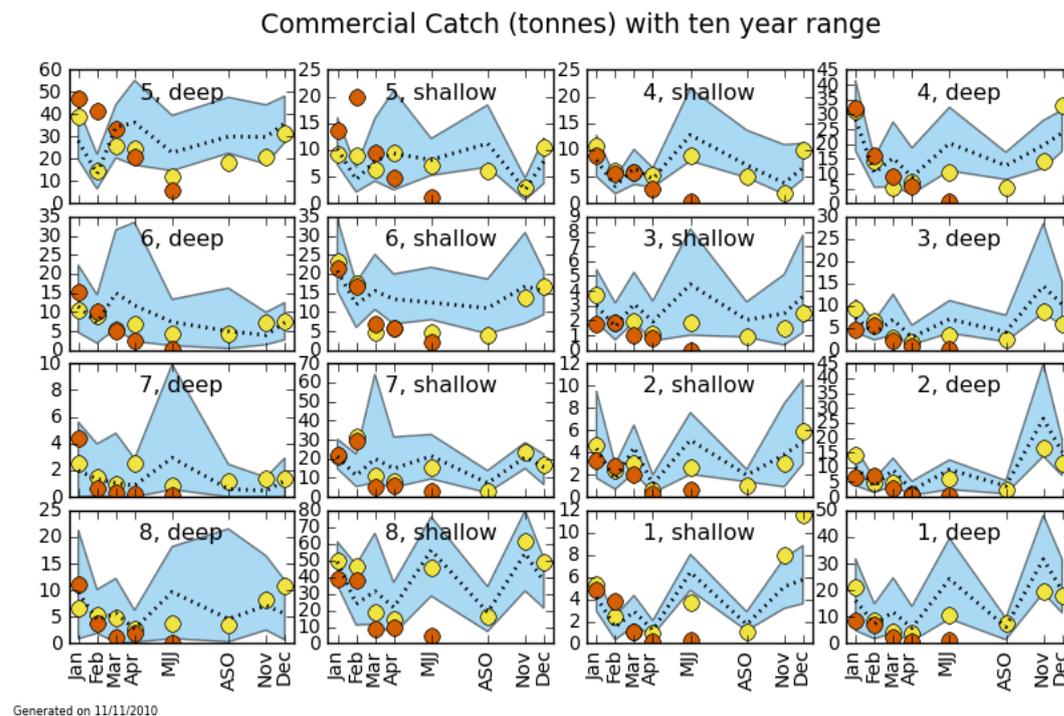
The Tasmanian rock lobster stock assessment model was divided into shallow and deep on the west coast of Tasmania in areas 6, 7 and 8 (Figure 7-20), and the deep water zones are now numbered 9, 10 and 11. There was not enough data on the east coast of Tasmania to implement this division yet.



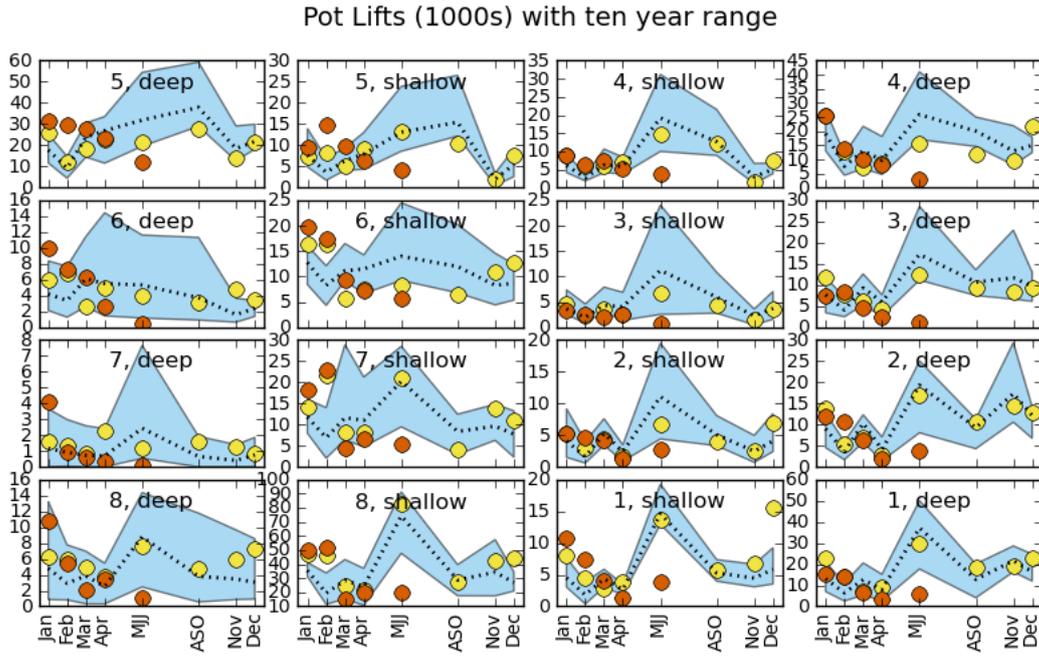
**Figure 5-20** Map of Tasmania and boundaries of the 11 stock assessment areas. Areas 9-11 are offshore from areas 6-8, delineated by the 62.18m depth contour

### Website automation of spatial fisheries information updates

A significant advance in the Tasmania fishery developed in the course of the project was the construction of a wiki, or editable website, which accesses raw data, from the government data entry system, and automatically updates the graphs daily. These data are plotted by 16 stock assessment areas, comprising the historic 8 areas used in stock assessments of the Tasmanian fishery further divided into shallow and deep zones (Figure 5-21, Figure 5-22). (N.B. there is currently not enough data to use all 16 areas in the formal stock assessment and so we can only plot catch data for 16 areas. Other estimations are made for the 11 areas pictured in Figure 5-20. On the west coast this divide occurs at 62.18 m depth and on the east coast it is 30 m. The capacity to provide regularly updated data has been a vital tool for informing discussions on spatial management by the Sustainability and Profitability Options Committee (SPOC) of the Tasmanian Rock Lobster Fishermen's association (TRLFA) and the Department of Primary Industry, Parks, Water and Environment (DPIPWE). These data reflect only the raw values from the DPIPWE logbooks and QMS. They do not reflect the projections or the calculations from the Tasmanian stock assessment model. The advances made in this model through this project are outlined in section 5.1.3.



**Figure 5-21** Commercial catches by model period in each of the sixteen areas. The blue band indicates the full range observed over the last ten years, and yellow dots are the 2009 calendar year and the orange dots are the 2010 calendar year, and therefore are incomplete at the time of publication.



**Figure 5-22** Potlifts by model period in each of the sixteen areas. The blue band indicates the full range observed over the last ten years, and yellow dots are the 2009 calendar year and the orange dots are the 2010 calendar year, and therefore are incomplete at the time of publication.

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## 5.2 Bioeconomic Modeling with an Application to TACC Setting

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### Summary

The length- and sex-based model used for population modelling across all three states was modified for the Tasmanian fishery to include economic data so that harvest strategies could be compared in terms of economic outcomes. The model was spatially and temporally structured to account for differences in costs of fishing and price. This capability was important for examining spatial management aspects of the project but was first applied in the context of TACC setting. Results showed that the current total allowable commercial catch (TACC) was too high to maximise economic yield and left the industry vulnerable to temporal changes in productivity. Alternative pathways to lower TACCs were explored but although these affected economic yield, differences were minor. This analysis showed that despite operating under ITQ management for over a decade, the presence of tradable catch shares were insufficient for the TACC to move towards MEY through normal processes of decision-making based on biological stock assessments. Industry and Government were motivated to exercise stewardship but struggled with acceptance of the concept that economic yield and asset values could increase with lower catches. This illustrates the value of formal analysis of economic outcomes as part of the suite of information used for making management decisions.

### Introduction

Individual transferable quota systems have become widely used in Australian coastal fisheries with almost of all of the larger state-based fisheries managed by this system. For example, 43% of national seafood production by gross value in 2007/08 was from State managed ITQ fisheries for abalone and rock lobster alone (ABARE-BRS 2010). These Australian ITQs tend to be well enforced and involve trading and leasing within season.

Although widespread, the objectives and policy of ITQs tend to be ambiguous in Australian coastal fisheries with the theoretical objectives of maximising economic yield or rationalising harvesting through market based mechanisms rarely articulated in management plans. Rather, management plans tend to describe the objective of ITQs around sustainability by maintaining the stock above historical lows in catch rate or thresholds of breeding stock indices. Although ITQs systems have a history of effective stock management, this is a function of the constraining TACC rather than the allocation of individual tradeable units (Costello et al. 2008). Hence, the management objectives of ITQs in Australian coastal fisheries are often vague due to the focus on biological rather than economic outcomes.

In the Tasmanian rock lobster fishery examined here, the quota system was introduced following a period of prolonged stock decline which a Legislative Select Committee

considered “concerning but not indicative of collapse”; the need for management change was then described as a mechanism to “constrain the catch to a sustainable level” (Ginn et al. 1997). ITQs were discussed as a tool to constrain the catch, largely because rock lobster fisheries elsewhere had implemented ITQ management and performance of those fisheries appeared encouraging, at least in terms of stock rebuilding (Batstone and Sharp 1999).

A year after the Legislative Select Committee report was produced, ITQ management was introduced to the Tasmanian rock lobster fishery and the objectives had been expanded to include the development of a market mechanism that promoted industry restructure (Ford, 2001). This desire to restructure the industry explains the use of individual traded catch shares but there was no objective for TAC setting other than to create sustainable harvests. The management plan for the fishery only sought to constrain catch so that biomass increased to some undefined level without mention of the economic objectives so pervasive in the theoretical discussions of ITQs (eg Hatcher et al. 2002; Wilen 2006; Libecap 2010).

In the decade following the introduction of ITQ management the general objectives had been achieved. Stock rebuilding had occurred as a consequence of the TACC so that biomass of the legal sized stock was double that of the historical lows, while the catch was stable and appeared sustainable (Gardner et al. 2011). Catch rates had increased and the transfer and leasing of units between operators resulted in a large contraction in the fleet, which was interpreted as an increase in efficiency (van Putten and Gardner 2010). Stakeholders in the fishery then began to question what management should be targeting in the future. Many commercial fishers were calling for an increase in the TACC while a minority argued for ongoing constraint or even a reduction in the TACC to continue the trajectory of increasing catch rates and reducing costs.

The Government was thus faced with the difficult decision on how to set TACCs when the objective was no longer stock recovery. The lack of formal targets for the TACC in the management plan was problematic but perhaps reflected an earlier expectation that fishers would propose and support TACCs that maximised future earnings, given their large financial stake in the fishery through the ITQ system (Sanchirico and Wilen 2007). However, the adversarial nature of the yearly TACC quota setting never completely disappeared with industry more supportive of higher TACCs than government. This apparent lack of strong resource stewardship has been observed in other ITQ fisheries and can be attributed to issues such as the free-rider problem (Hatcher et al. 2002). In this case an increase in MPA coverage and recreational catch contributed to weak stewardship in terms of conservative TACC setting by industry (TRLFA 2009).

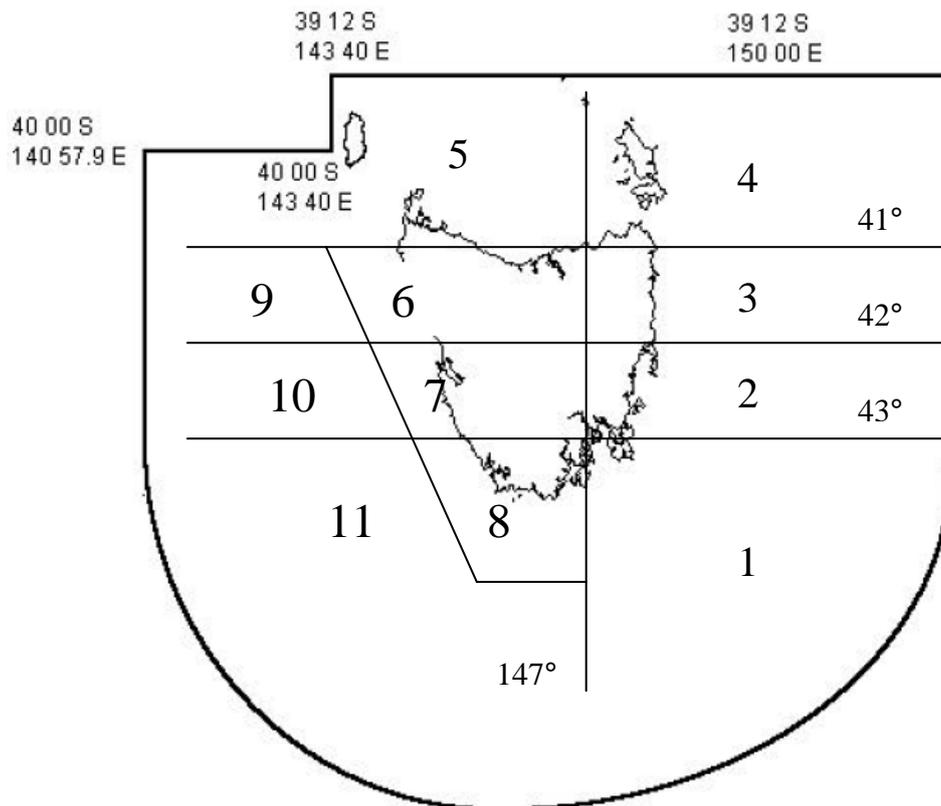
The research and bio-economic modelling reported here was subsequently proposed to assist stakeholders in the process of TACC setting. This process of formal analysis

of the fishery aimed to allow government and industry to explore options for TACC setting. This formal process also helped industry to make progress in developing a consensus position on future TACCs.

## Detailed Methods

### *Data collection*

The operational model was fitted to fishery catch (by mass and number) and effort (pot lifts) data obtained from compulsory commercial log book information from January 1970 to February 2008. Samples of catch by length and sex were from observer and research sampling conducted at sea throughout this period (Gardner et al. 2011). Biological parameter estimates with the exception of growth were from previously published research as noted in the model description. Data were separated spatially into 11 sub-zones to account for regional differences including costs of fishing and stock productivity (Figure 5-23).



**Figure 5-23** The sub-zones of the fishery used for bioeconomic modelling. There is no regional management within the fishery but these divisions were applied here to account for variation in biological and economic traits. Deep water sub-zones 9-11 off the west coast were separated from shallow water sub-zones by the 35 fathom contour.

The variable and fixed costs associated with commercial fishing were collected through interviews of 22 active fishers operating across all sub-zones. Interviews were conducted during 2007 and fishers provided cost details as they applied to their fishing operations. Business data were checked and validated against records of catch and effort from compulsory catch logbooks where possible, for example on levels of crewing and effort (potlifts). Fleet data were obtained from the Tasmanian Government catch and effort database and included pot allocations per vessel, potlifts per vessel, shots (deployments of the full set of pots) per day, and number of crew (Table 5.3).

Costs were estimated separately for each sub-zone based on traits of vessels fishing these locations. Vessels were allocated to a sub-zone based on where most of their fishing occurred (as they often fished across more than one sub-zone). Average fixed costs (AFC) were estimated from both fixed business costs (mooring, insurance, license, seaworthy survey, business administration, vessel and equipment maintenance) and the depreciation on capital (pots @ 3y; vessel @ 50 y; dingy @ 10 y; engine @ 25 y; gearbox @ 20 y; depth sounder, GPS, radar, computer, autopilot, radar and other electronics @ 12 y). Average variable costs (AVC) were estimated from costs dependent on the duration of the trip (labour, fuel and supplies) and the number of potlifts (bait). Labour was included as the opportunity cost of labour and was estimated by asking fishers and crew their expected annual income for their next best occupation. This was necessary because crew were often paid on catch share arrangements that varied between years depending on catch rate and price. Average total costs (ATC) were then apportioned on a per-potlift basis based on reported number of potlifts in catch and effort logbooks.

The weighted average (based on vessel number) of ATC per potlift was calculated for sub-zones with similar fishing traits to increase the sample size and smooth any sampling bias. This involved the grouping of sheltered east coast sub-zones 1-3; Bass Strait Island sub-zones (4-5), exposed west coast sub-zones (6-8), and deep water sub-zones (9-11).

The use of ATC per potlift enabled the cost of fishing to be readily linked to the fishery model but did involve an important assumption. This assumption was that the total cost and thus AFC can respond to changes in catch rate between years. This is equivalent to an assumption that capital can restructure readily and fixed costs will decrease as catch rates rise. This approach was justified on the basis that the fleet size has been volatile over the last decade dropping from 325 vessels at the start of ITQ management in 1998 to 210 in 2007 (Gardner et al. 2011). This appears to be driven by change in catch rate because the trend reversed in 2009/10 with 20 extra vessels entering the fishery following a fall in catch rate (Gardner et al. 2011).

Price data was recorded from invoice books supplied by a rock lobster processor for the period December 2007 to November 2008. The processor was one of the larger

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processors in the state and received product landed at all Tasmanian ports. Their prices were considered representative because of the scale of their operation and because prices tend to be consistent between processors due to competition for supply from fishers. Price data and subsequent modelling included price differences for size, time-step (usually month), and sub-zone (Table 5.3). Prices within each period were determined by weighted average based on weight of product involved in each transaction.

Several assumptions were made with price data to facilitate modelling. First, processors sell product into eight categories but average the price paid to fishers across one to four categories. In this analysis price at length was the price paid to fishers but in reality this masks some of the effects of change in size of product on price (we were unable to locate this finer-scale price data and it is an aspect of the modelling that could be improved in future research). Second, lobsters from deep water with paler shells termed “whites” or “brindled” were discounted except during periods of high demand (Chandrapavan et al. 2009b). In this analysis the price for pale lobsters was applied for all catch from deep water sub-zones (Areas 9-11) while all catch from shallow water sub-zones (Areas 1-8) was assumed to be red and thus receiving the higher price. Deep and shallow water sub-zones were separated at 35 fathoms as this approximates the boundary defined by Chandrapavan (2009b) for these colour grades. Third, lobsters were categorised into price classes based on weight, which was converted to length for modelling purposes assuming no change in the length-weight relationship between periods. This conversion resulted in slightly different price at length between males and females in some instances due to the different weight at length conversions applied:

$$W = \begin{cases} 0.000285L^{3.114} & \text{Males} \\ 0.000271L^{3.135} & \text{Females} \end{cases} \quad (1.1)$$

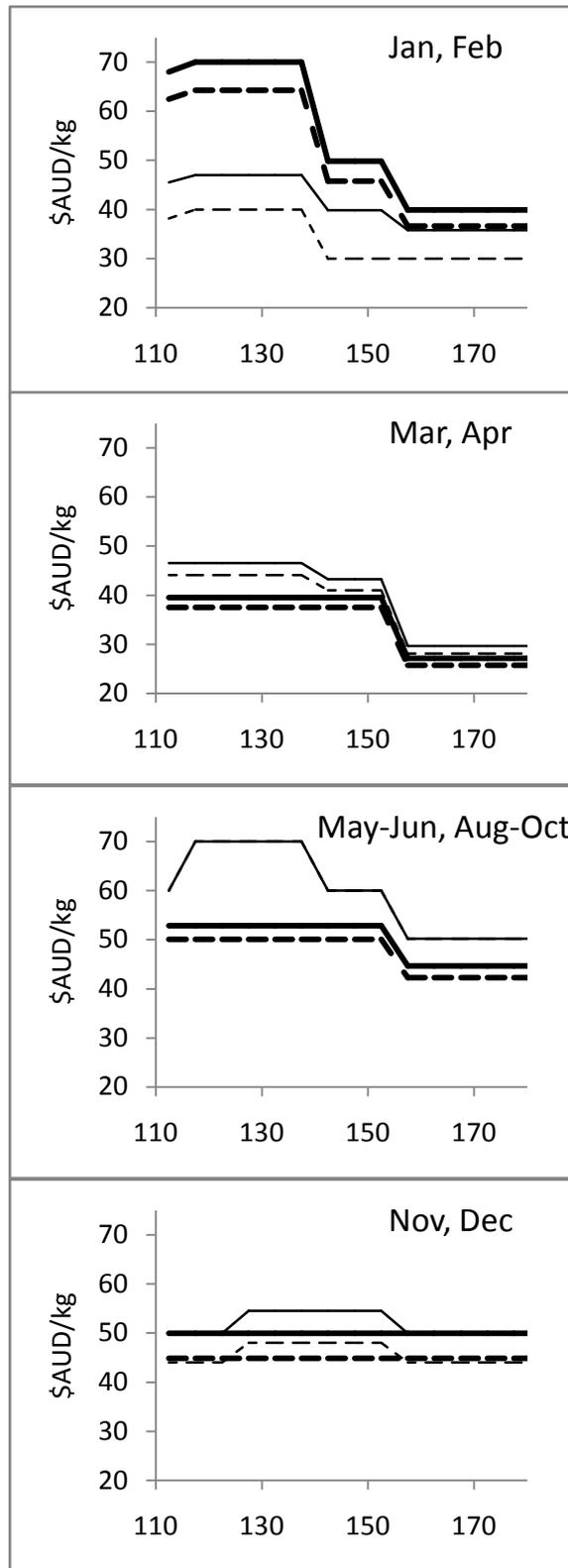
Lastly, it should be noted that the price received by fishers can be affected by factors that could not be included in this analysis such as the vitality of the load (and thus ability to survive live transport), loss of limbs or other damage, and presence of an undesirable morphotype from slow growth sub-zones termed “wedgetails”.

**Table 5.3** Average costs of fishing split by sub-zone. Regional traits in fishing businesses were recorded through compulsory daily catch and effort logbooks. Vessels often fish in more than one sub-zone and were allocated here on the basis of their most active sub-zone by vessel days. Estimated costs per potlift used in modelling (bottom row) were pooled across sub-zones with similar traits using averages of the individual areas, weighted by vessel number.

| Sub-zone                                     | 1    | 2    | 3    | 4    | 5     | 6     | 7     | 8     | 9     | 10    | 11    |
|--|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| N vessels                                    | 32   | 20   | 12   | 20   | 37    | 14    | 12    | 48    | 4     | 1     | 4     |
| potlifts (1000s)                             | 204  | 108  | 101  | 159  | 237   | 99    | 121   | 340   | 27    | 9     | 29    |
| active days per vessel                       | 106  | 115  | 158  | 124  | 126   | 121   | 113   | 127   | 96    | 96    | 106   |
| pot/vessel                                   | 40.8 | 38.5 | 38.9 | 44.7 | 46.4  | 47    | 47.1  | 44.7  | 49.9  | 49.9  | 49.1  |
| potlifts per vessel (1000s)                  | 6.40 | 5.40 | 8.42 | 7.98 | 6.41  | 7.07  | 10.08 | 7.09  | 6.83  | 9.50  | 7.23  |
| shots per day                                | 1.48 | 1.22 | 1.37 | 1.44 | 1.1   | 1.24  | 1.9   | 1.25  | 1.43  | 1.99  | 1.38  |
| vessel length                                | 13.3 | 12.9 | 13.2 | 14.7 | 14.9  | 15.1  | 15.9  | 13.8  | 16.1  | 16.9  | 14.6  |
| crew   | 0.7  | 0.55 | 0.59 | 0.73 | 0.75  | 1.02  | 1.23  | 0.93  | 1.02  | 1.23  | 0.93  |
| annual business costs (\$1000s) <sup>1</sup> | 25.5 | 25.4 | 25.4 | 25.6 | 25.73 | 25.76 | 25.76 | 25.67 | 25.87 | 25.87 | 25.84 |
| depreciation (\$1000s) <sup>2</sup>          | 12.5 | 10.0 | 10.1 | 14.2 | 14.39 | 11.24 | 11.25 | 11.04 | 11.49 | 11.49 | 11.42 |
| AFC / potlift                                | 5.95 | 6.57 | 4.23 | 5.00 | 6.26  | 5.23  | 3.67  | 5.18  | 5.47  | 3.93  | 5.16  |
| bait, fuel and supplies / potlift            | 8.03 | 10   | 8.94 | 7.86 | 9.26  | 8.89  | 6.53  | 9.24  | 7.49  | 5.68  | 7.8   |
| labour / potlift                             | 20.0 | 21.8 | 14.3 | 16.3 | 20.61 | 21.35 | 16.44 | 20.41 | 22.13 | 17.45 | 20.02 |
| AVC / potlift                                | 8    | 4    | 4    | 8    | 29.86 | 30.25 | 22.97 | 29.65 | 29.62 | 23.13 | 27.83 |
|  | 28.1 | 31.8 | 23.2 | 24.2 |       |       |       |       |       |       |       |
|  | 34.0 | 4    | 9    | 4    |       |       |       |       |       |       |       |
| ATC/potlift                                  | 5    | 1    | 1    | 4    | 36.13 | 35.48 | 26.64 | 34.83 | 35.1  | 27.06 | 32.98 |
| Model input                                  | 34.1 | 34.1 | 34.1 |      |       |       |       |       |       |       |       |
| ATC/potlift                                  | 9    | 9    | 9    | 33.7 | 33.7  | 33.63 | 33.63 | 33.63 | 33.26 | 33.26 | 33.26 |

<sup>1</sup>Annual business costs were: mooring, insurance, license, seaworthy survey, business admin., vessel and equipment maintenance.

<sup>2</sup>Depreciation costs were: pots @ 3y; vessel @ 50 y; dingy @ 10 y; engine @ 25 y; gearbox @ 20 y; depth sounder, GPS, radar, computer, autopilot, radar and other electronics @ 12 y.



**Figure 5-24** Price received by fishers for sale of male lobsters in relation to size, expressed here as carapace length (x-axis, mm). Price was averaged across sales data for each period, with the first chronologically in each plot shown by heavier lines. Paler coloured lobsters from deep water were discounted in all periods except Aug-Oct and illustrated by dashed lines. These patterns differed slightly for females (not shown) due to their different length-weight relationship.

### Population dynamics model structure

A population model of the lobster stock was first applied to define the size and structure of the stock, plus the between-period variation in recruitment to the initial size bin (60-64 mm carapace length) and builds on the structure described by Punt and Kennedy (1997) and Hobday and Punt (2001). Parameter estimates gained through this stock estimation process were then used to examine the economic and biological outcome of different management strategies in projections of the stock.

The population dynamics model was spatially and temporally structured with the spatial strata (Figure 5-23) indexed by “z”. There were eight time-steps each year (T), which were single months except for pooling of low catch periods May-July and August-October. The duration of the  $i$ th time-step ( $i=0,1,\dots,T-1$ ) is denoted  $t_i$  and, by definition,  $\sum_{i=0}^{T-1} t_i = 1$ .

The basic dynamic involves specifying the number of animals of sex  $s$  in 5 mm carapace length size-classes  $l$  (with smallest and largest bins 60-64 mm and 215-219 mm) in sub-zone  $z$  at the start of time-step  $i$  of year  $t$ , taking account of natural mortality, fishing mortality, movement, growth, and settlement. Harvesting of product was ordered to occur before growth and settlement after which movement occurs:

$$N_{y,i+1,l}^{s,z} = \sum_{z'} Y_i^{s,z,z'} \left[ \sum_{l'} X_{l',l,i}^{s,z'} N_{y,i,l'}^{s,z'} e^{-Mt_i} \{1 - \tilde{H}_{y,i,l'}^{s,z'}\} + \Omega_i^{s,z'} \Phi_l^s R_y^{z'} \right] \quad (2.1)$$

- where  $N_{y,i,l}^{s,z}$  is the number of animals of sex  $s$  in size-class  $l$  in sub-zone  $z$  at the start of time-step  $i$  of year  $y$ ,
- $X_{l',l,i}^{s,z}$  is the fraction of the animals of sex  $s$  in size-class  $l'$  in sub-zone  $z$  that grow into size-class  $l$  during time-step  $i$  (the possibility of shrinkage was ignored),
- $Y_i^{s,z,z'}$  is the fraction of the animals of sex  $s$  that move from sub-zone  $z'$  to sub-zone  $z$  at the end of time-step  $i$  (estimated only for movement between adjacent deep and shallow sub-zones)
- $M$  is instantaneous rate of natural mortality (assumed to be independent of sex, size, sub-zone, and time),
- $\tilde{H}_{y,i,l}^{s,z}$  is the exploitation rate on animals of sex  $s$  in size-class  $l$  and sub-zone  $z$  at the start of time-step  $i$  of year  $y$ :

$$\tilde{H}_{y,i,l}^{s,z} = \tilde{S}_{y,l}^{s,z} V_i^s F_{y,i}^z \quad (2.1)$$

- $\tilde{S}_{y,l}^{s,z}$  is the selectivity of the gear on animals of sex  $s$  in size-class  $l$  in sub-zone  $z$  during year  $y$  given the implications of the legal minimum length which were 105 mm for females and 110 mm for males in all sub-zones, periods and years,

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- $V_i^s$  is the relative vulnerability of males to females during time-step  $i$  ( $V_i^s = 1$  for males; 0 for females during the closed season in periods 5 and 6),  
 $F_{y,i}^z$  is the exploitation rate on fully-selected (i.e.  $\tilde{S}_{y,l}^{s,z} = 1$ ) animals in sub-zone  $z$  during time-step  $i$  of year  $y$ ,  
 $\Omega_i^{s,z}$  is the fraction of the settlement to sub-zone  $z$  that occurs to sex  $s$  during time-step  $i$  ( $\sum_s \sum_i \Omega_i^{s,z} = 1$ ),  
 $\Phi_l^s$  is the proportion of the settlement of animals of sex  $s$  that occurs to size-class  $l$  ( $\sum_l \Phi_l^s = 1$ ), and  
 $R_y^z$  is the settlement of animals to sub-zone  $z$  during year  $y$ .

Allowance was made for selectivity to differ among years to implement possible past and future changes in selectivity due to changes to minimum legal size limits, gear configurations and where fishing occurs within sub-zones. Allowance was also made for settlement to occur to any size-class, during any time-step and in different ratios for males and females. The annual settlements were parameterized as follows:

$$R_y^z = \bar{R}^z e^{\varepsilon_y^z - (\sigma_{R,y}^z)^2 / 2} \quad (2.3)$$

- where  $\bar{R}^z$  is mean settlement to sub-zone  $z$ ,  
 $\varepsilon_y^z$  is the “recruitment residual” for year  $y$  and sub-zone  $z$ ,  
 $\sigma_{R,y}^z$  is the standard deviation of the random fluctuations in recruitment for year  $y$ :

$$\sigma_{R,y}^z = \begin{cases} \tilde{\sigma}_R^2 \tilde{\tau}^{(y-y_{start})} & \text{if } y < y_{start} \\ \tilde{\sigma}_R^2 & \text{otherwise} \end{cases} \quad (2.4)$$

- $\tilde{\sigma}_R$  is the extent of variation in settlement for years after  $y_{start}$ , and  
 $\tilde{\tau}$  determines the extent to which  $\sigma_R$  changes with time.

Although the model did not explicitly include a stock recruitment relationship (between egg production and settlement), the size of the annual egg production was of interest to management. Egg production was given by the following equation for the case in which spawning is assumed to occur at the start of time-step  $i_m$ :

$$\tilde{B}_y^z = \sum_l Q_l^z N_{y,i_m,l}^{f,z} \quad (2.5)$$

- where  $Q_l^z$  is the expected number of eggs produced by a female in size-class  $l$  in sub-zone  $z$ , and  
 $i_m$  is the time-step in which spawning occurs.

The fully-selected exploitation rate during time-step  $i$  of year  $y$  in sub-zone  $z$ ,  $F_{y,i}^z$ , is calculated by:

$$F_{y,i}^z = \frac{C_{y,i}^{\text{comm},z} + C_{y,i}^{\text{rec},z} + C_{y,i}^{\text{ill},z}}{\sum_l \sum_s \tilde{S}_{y,l}^{s,z} V_l^s W_l^{s,z} \tilde{N}_{y,i,l}^{s,z}} \quad (2.6)$$

where

$C_t^{\text{comm},z}$  is the commercial catch in sub-zone  $z$  during time-step  $i$  of year  $y$  (from Haddon and Gardner, 2009),

$C_t^{\text{rec},z}$  is the recreational catch in sub-zone  $z$  during time-step  $i$  of year  $y$  (from Lyle 2008),

$C_t^{\text{ill},z}$  is the illegal catch in sub-zone  $z$  during time-step  $i$  of year  $y$  (assumed 2%; pers comm. DPIPWE Quota Audit Unit),

$\tilde{N}_{y,i,l}^{s,z}$  is the number of animals of sex  $s$  in size-class  $l$  in sub-zone  $z$  when the catch during time-step  $i$  of year  $y$  is removed, and

$W_l^{s,z}$  is the weight of an animal of sex  $s$  in size-class  $l$  and sub-zone  $z$ .

We have assumed that the selectivity pattern for commercial, recreational, and illegal fishers is the same, and that discard mortality is negligible compared to fishing mortality (Frusher and Hoenig 2003).

It was assumed that the population was in equilibrium with respect to the average catch over the first 25 ( $\omega$ ) years for which catches are available in years 1970 to 2008 ( $y_{\text{start}} - \mathcal{X}$ ). This approach to specifying the initial state of the stock differed from that traditionally adopted for assessments of rock lobster off Tasmania and Victoria (Punt and Kennedy 1997, Hobday and Punt 2001) in that no attempt is made to estimate an initial exploitation rate. The settlements for years  $y_{\text{start}} - \mathcal{X}$  to  $y_{\text{start}} - 1$  were estimated so that the model was not in equilibrium at the start of year  $y_{\text{start}}$ . The exploitation rate for the years  $y_{\text{start}} - \mathcal{X}$  to  $y_{\text{start}} - 1$  are set to the value used to calculate the size structure between years  $y_{\text{start}}$  and  $y_{\text{start}} + \omega$  ( $F_{\text{init}}^z$ ).

### *Model objective function*

The objective function summarised the information collected from the fishery and had contributions from four data sources: commercial catch rates; length-frequency data; commercial catches in number; and tagging data.

The contribution of the catch-rate data to likelihood function was given by:

$$L_1 = \prod_z \prod_y \prod_i \frac{1}{I_{y,i}^z \sqrt{2\pi} \sigma_{q,y,i}^z} \exp\left(-\frac{(\ln I_{t,i}^z - \ln(q_i^z B_{y,i}^{e,z}))^2}{2(\sigma_{q,y,i}^z)^2}\right) \quad (3.1)$$

where  $\sigma_{q,y,i}^z$  is the standard deviation of the random fluctuations in catchability for sub-zone  $z$ , year  $y$ , and time-step  $i$ ,  
 $q_i^z$  is the catchability coefficient for sub-zone  $z$  and time-step  $i$ ,  
 $I_{y,i}^z$  is the catch-rate index for time-step  $i$  of year  $y$  and sub-zone  $z$ , and  
 $B_{y,i}^{e,z}$  is the exploitable biomass in sub-zone  $z$  in time-step  $i$  of year  $y$  (the biomass available to the fishery less half of the catch during this time-step):

$$B_{y,i}^{e,z} = \sum_s \sum_l V_l^s \tilde{S}_{y,l}^{s,z} W_l^{s,z} \tilde{N}_{y,i,l}^{s,z} (1 - F_{y,i}^z / 2) \quad (3.2)$$

The maximum likelihood estimate for  $q_i^z$  can be obtained analytically:

$$\hat{q}_i^z = \exp\left(\frac{\sum_y \ln(I_{y,i}^z / B_{y,i}^{e,z}) / (\sigma_{q,y,i}^z)^2}{\sum_y 1 / (\sigma_{q,y,i}^z)^2}\right) \quad (3.3)$$

Allowance was made for the possibility that catchability changed between groups of years (1970-1983; 1984-1999; and 2000 onwards) by treating each period in which catchability was constant as a separate catch-rate index. This enabled the model to respond to change in fishing technology through the time series of data.

Length-frequency data were available for the commercial catch and from research sampling. Selectivity of these gears differed because commercial data was collected from pots with open escape gaps that reduced capture of undersize animals. Thus the commercial length-frequency data provide information on the proportion of the catch of each sex in each size-class above the legal minimum length, while the research length-frequency data also provide information on the number of animals of legal size and smaller. The observed fraction of the catch of animals of sex  $s$  in number during time-step  $i$  of year  $y$  in sub-zone  $z$  that are in size-class  $l$  is denoted  $\rho_{y,i,l}^{s,z}$ . The model-estimate of this quantity,  $\hat{\rho}_{y,i,l}^{s,z}$ , took account of the selectivity of the gear and the numbers in each size-class:

$$\hat{\rho}_{y,i,l}^{s,z} = \begin{cases} \tilde{S}_{y,l}^{s,z} \tilde{N}_{y,i,l}^{s,z} / \sum_{l'} \tilde{S}_{y,l'}^{s,z} \tilde{N}_{y,i,l'}^{s,z} & \text{Commercial data} \\ S_l^s \tilde{N}_{y,i,l}^{s,z} / \sum_{l'} S_{l'}^s \tilde{N}_{y,i,l'}^{s,z} & \text{Research data} \end{cases} \quad (3.4)$$

The observed value of  $\rho_{y,i,l}^{s,z}$  was assumed to have a multinomial distribution, which led to the following likelihood function (ignoring constants independent of the model parameters) for each of the two sources of length-frequency data:

$$L_2 = \prod_z \prod_s \prod_y \prod_i \prod_l (\hat{\rho}_{y,i,l}^{s,z})^{\omega_{y,i}^{s,z}} \quad (3.5)$$

where  $\omega_{y,i}^{s,z}$  is a factor to weight the length-frequency data relative to the other data for sex  $s$ , sub-zone  $z$  and time-step  $i$  of year  $y$  (the “effective sample size” for sex  $s$ , sub-zone  $z$  and time-step  $i$  of year  $y$ ).

The parameter  $\omega$  was needed because the likelihood (Equation 3.5) was based on the assumption that the length-frequency data are collected by means of a simple random sample from the catch. Unfortunately, using the raw data (i.e. set  $\omega_{y,i}^{s,z}$  in Equation 3.5 equal to the number of animals actually sampled) assigns too much emphasis to the length-frequency data because the sampling for length-frequency is not random and because the assumption that selectivity is time-invariant will be violated to some extent. Downweighting this data corrects to some extent for this.

The commercial catches in number,  $C_{y,i}^{N,z}$ , were assumed to be lognormally distributed about their expected values. The contribution of these data to the likelihood function was therefore given by:

$$L_3 = \prod_z \prod_y \prod_i \frac{1}{C_{y,i}^{N,z} \sqrt{2\pi\sigma_N}} \exp\left(-\frac{(\ln C_{y,i}^{N,z} - \ln \hat{C}_{y,i}^{N,z})^2}{2\sigma_N^2}\right) \quad (3.6)$$

where  $\hat{C}_{y,i}^{N,z} = \sum_s \sum_l V_l^s \tilde{S}_{y,l}^{s,z} F_{y,i}^{\text{comm},z} \tilde{N}_{y,i,l}^{s,z}$  and  $F_{y,i}^{\text{comm},z}$  is the fully-selected exploitation rate in sub-zone  $z$  imposed by the commercial component of the fishery during time-step  $i$  of year  $y$ :

$$F_{y,i}^{\text{comm},z} = F_{y,i}^z C_{y,i}^{\text{comm},z} / (C_{y,i}^{\text{comm},z} + C_{y,i}^{\text{rec},z} + C_{y,i}^{\text{ill},z}) \quad (3.7)$$

Tag-recapture data were used in the recapture conditional framework of McGarvey and Feenstra (2002) to determine movement rates between adjacent deep and shallow sub-zones (ie sub-zones 6 and 9; 7 and 10; 8 and 11). Specifically, the likelihood for the tag-recapture data is the product over recaptures of the probability of recapturing a tag in the sub-zone in which it was recaptured given its sub-zone of release, its time of release and the time that it was at liberty for. The recapture-conditioned recapture probability for tagged lobsters at large for just one movement time was:

$$f(z_r | z_t, t_t, t_r, s) = \frac{Y_{t_s}^{z_t, z_r} \left[ \prod_{t=t_s}^{t_r-1} (1 - \tilde{H}_{t,l}^{s,z_r}) e^{-Mt_t} \right] \tilde{H}_{t_r,l}^{s,z_r}}{\sum_{z'_t=1}^{n_z} Y_{t_s}^{z_t, z'_t} \left[ \prod_{t=t_s}^{t_r-1} (1 - \tilde{H}_{t,l}^{s,z'_t}) e^{-Mt_t} \right] \tilde{H}_{t_r,l}^{s,z'_t}} \quad (3.8)$$

where  $z_t$  is the sub-zone of release,

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- $z_r$  is the sub-zone of recapture,
  - $t_t$  is the time when the tagged animal was released,
  - $t_r$  is the time when the tagged animal was recaptured,
  - $t_*$  is the time-step between release and recapture when movement occurs,  
and
  - $n_z$  is the number of sub-zones in the model.

For computational ease, the dependence of  $\tilde{H}$  on size in the recapture probability of McGarvey and Feenstra (2002) was dropped by assuming selectivity was 1 for all tagged animals.

### *Economic model projections*

The population dynamics model on which the economic projections of alternative TACCs were based was identical to that on which the stock assessment was based. However, this projection model was extended to specify future catches as well as to calculate the output statistics related to costs, revenues and profits.

Annual catches from the commercial, recreational and illegal sectors (2% of commercial for each time-step and sub-zone) were specified.

The split of the recreational catch by time-step and sub-zone was assumed to be static so that the catch during time-step  $i$  of year  $y$  in sub-zone  $z$  by the recreational fishery,  $C_{y,i}^{\text{rec},z}$ , was given by:

$$C_{y,i}^{\text{rec},z} = C_y^{\text{rec}} \phi_i^{\text{rec},z} \quad (4.1)$$

where  $C_y^{\text{rec}}$  is total recreational catch during year  $y$  (at 2007 level of 140 tonnes in all scenarios), and

$\phi_i^{\text{rec},z}$  is the proportional of the recreational catch which was taken from sub-zone  $z$  during time-step  $i$  ( $\sum_i \sum_z \phi_i^{\text{rec},z} = 1$ ) in 2007 (Lyle, 2008).

The value of  $C_{y,i}^{\text{Comm},z}$  depended on the total allowable commercial catch, as well as the effort dynamics model.

The effort dynamics model first assigned catches to time-step within the year and then using a second model to allocate catches to sub-zone. Letting  $C_{y,i}^{\text{Comm},Z_z}$  denote the commercial catch during time-step  $i$  of year  $y$  for the catch limit in which sub-zone  $z$  is found,  $Z_z$ :

$$C_{y,i}^{\text{Comm},Z_z} = \lambda_i^{Z_z} C_y^{\text{Comm},Z_z} \quad (4.2)$$

where  $\lambda_i^{Z_z}$  is the proportion of the catch limit for sub-zone  $z$  which is taken during time-step  $i$ , and

$C_y^{\text{Comm},Z_z}$  is the catch limit for year  $y$  for sub-zone  $z$ .

$C_{y,i}^{\text{Comm},Z_z}$  is then allocated to sub-zone using the formula:

$$C_{y,i}^{\text{Comm},z} = \tilde{\lambda}_{y,i}^z C_{y,i}^{\text{Comm},Z_z} \quad (4.3)$$

where  $\tilde{\lambda}_{y,i}^z$  is the proportion for year  $y$  and time-step  $i$  of which the catch in sub-zone  $z$  is of the catch during time-step  $i$  of year  $y$  from the catch limit area in which sub-zone  $z$  is found:

$$\tilde{\lambda}_{y,i}^z = \Omega_{y,i}^z / \sum_{z' \in Z_z} \Omega_{y,i}^{z'} \quad (4.4a)$$

$$\ln \Omega_{y,i}^z = a_i^z + b_i^z B_{y,i}^{e,z} + c_i^z \tilde{\lambda}_{y,i-1}^z + d_i^z \tilde{\lambda}_{y-1,i}^z \quad (4.4b)$$

$B_{y,i}^{e,z}$  is the exploitable biomass in sub-zone  $z$  at the start of time-step  $i$  of year  $y$ , and  
 $a, b, c, d$  are coefficients.

Equation 4.4b allows the split of the catch among sub-zones (within a catch limit area) to respond to the biomass in each sub-zone as well as the split of the catch among sub-zones in the previous time-step and in the current time-step in the previous year. The constant (a) reflects inertia in the extent to which catch varies spatially.

Equation 4.4 can lead to catches which exceed the exploitable biomass in a sub-zone. In this case, the catch for the sub-zone concerned is set to the exploitable biomass and the catch which cannot be taken from the designated sub-zone is allocated to the remaining sub-zones in proportion to the catch limits allocated using Equation 4.4a.

The values for parameters of Equation 4.4b were estimated by fitting it to the proportion of the catch by sub-zone from 1997-2006. The likelihood function was assumed to be multinomial, but this is largely arbitrary because the model is not being fit to data for which the precision is known. In any case, the reason for this model is projection and not inference. Note that Equation 4.4b depends on the predicted (rather than observed) proportions in the previous period (same year) and previous year (same time-step). For the first year used to calibrate the model (1997), the observed rather than predicted proportions are assumed.

Recruitment of stock as juveniles in future years was through selection of a settlement at random from those estimated from data from 1998 to 2007. This time period was selected because it coincides with the duration of ITQ management in the fishery and thus reduces risk of bias from changes in fishing practices. In addition, this time period reduces bias from climate change impact on recruitment (Pecl et al. 2009), relative to the 30 year recruitment series used by Punt and Kennedy (1997).

The annual discounted profit from commercial fishing for year  $y$  was the difference between the costs and revenues for year  $y$ , discounted since the first year of the projection period, i.e.:

$$P_y = \frac{1}{(1+\beta)^{y-y_S}} \left[ \sum_z \sum_i (R_{y,i}^z - \tilde{C}_{y,i}^z) \right] \quad (4.5)$$

where  $P_y$  is the (discounted) profit during year  $y$ ,  
 $\beta$  is the discount rate (using an annual rate of 0.07 in analyses shown here),  
 $y_S$  is the first year of the projection period,  
 $R_{y,i}^z$  is the revenue generated from commercial fishing in sub-zone  $z$  during time-step  $i$  of year  $y$ , and  
 $\tilde{C}_{y,i}^z$  is the (variable) cost of commercial fishing in sub-zone  $z$  during time-step  $i$  of year  $y$ .

The revenue from commercial fishing in sub-zone  $z$  during time-step  $i$  of year  $y$  is given by:

$$R_{y,i}^z = \sum_l P_{y,i,l}^z \sum_s \tilde{S}_{y,l}^{s,z} V_i^s F_{y,i}^z N_{y,i,l}^{s,z} e^{-Mt_i/2} \quad (4.6)$$

where  $N_{y,i,l}^{s,z}$  is the number of animals of sex  $s$  in size-class  $l$  in sub-zone  $z$  at the start of time-step  $i$  of year  $y$ ,  
 $\tilde{S}_{y,l}^{s,z}$  is the selectivity of the gear on animals of sex  $s$  in size-class  $l$  in sub-zone  $z$  during year  $y$  given the implications of the legal minimum length,  
 $V_i^s$  is the relative vulnerability of males to females during time-step  $i$ ,  
 $M$  is instantaneous rate of natural mortality (assumed to be independent of sex, size, sub-zone, and time),  
 $t_i$  is the duration of time-step  $i$ ,  
 $F_{y,i}^z$  is the exploitation rate on fully-selected (i.e.  $\tilde{S}_{y,l}^{s,z} = 1$ ) animals in sub-zone  $z$  during time-step  $i$  of year  $y$ , and  
 $P_{y,i,l}^z$  is the price of a lobster in size-class  $l$  and sub-zone  $z$  during time-step  $i$  of year  $y$ .

The costs of commercial fishing in sub-zone  $z$  during time-step  $i$  of year  $y$  is given by:

$$\tilde{C}_{y,i}^z = c_i^z C_{y,i}^{\text{Comm},z} / (q_i^z B_{y,i}^{e,z}) \quad (4.7)$$

where  $c_i^z$  is the cost for a single potlift during time-step  $i$  in sub-zone  $z$  (Table 7.3), and  
 $q_i^z$  is the catchability coefficient for time-step  $i$  and sub-zone  $z$ .

**Table 5.4** Parameters of the model and their prior distributions. Parameter values fixed using auxiliary information are denoted as “known”.

| Parameter   | Description   | Prior distribution   |
|---|---|----------------------|
| $\varepsilon_y^z$                                 | The recruitment residuals   | $N(0; \sigma_R^2)$   |
| $\ln(\bar{R}^z)$                                  | Mean settlement   | $U(-\infty, \infty)$ |
| $\tilde{\sigma}_R$                                | The extent of variation in settlement for years after $y_{\text{start}}$  | Known                |
| $\tilde{\tau}$                                    | The extent to which $\sigma_R$ changes with time  | Known                |
| $X_{l',l,i}^{s,z}$                                | Fraction of the animals of sex $s$ in size-class $l'$ in sub-zone $z$ that grow into size-class $l$ at the end of time-step $i$ | Known                |
| $Y_i^{s,z,z'}$                                    | Fraction of the animals of sex $s$ that move from sub-zone $z'$ to sub-area $z$ at the end of time-step $i$ ,                   | Known                |
| $M$   | Natural mortality   | Known                |
| $S_{y,l}^{s,z}$                                   | Gear selectivity as a function of sex and length  | Known                |
| $\Omega_i^{s,z}$                                  | Fraction of the recruitment by time-step, sex and sub-zone  | Known                |
| $\Phi_l^s$  | Proportion of the recruitment of animals of sex $s$ that occurs to size-class $l$   | Known                |
| $Q_l^z$   | Egg production as a function of size and sub-zone   | Known                |
| $W_l^{s,z}$                                       | Weight as a function of size, sex, and sub-zone   | Known                |
| $i_m$   | The time-step in which spawning occurs  | Known                |
| $L_l^s$   | The lower limit of size-class $l$ for sex $s$   | Known                |
| $\chi, \omega$                                    | Parameters which define the initial state   | Known                |
| $\ln q_i^z / \ln \tilde{q}_i^z / \ln \tilde{q}^z$ | Catchability  | $U(-\infty, \infty)$ |
| $\sigma_{q,y,i}^z / \tilde{\sigma}_{q,y,i}^z$     | Standard deviation of the random fluctuations in catchability for sub-zone $z$ and time-step $i$ of year $y$                    | Known                |
| $\sigma_N$  | Standard deviation of the random fluctuations in mean weight  | Known                |
| $\sigma_{J,y}^z / \tilde{\sigma}_{J,y}^z$         | The standard deviation / CV of $J_y^z$  | Known                |
| $\beta$   | Annual real discount rate   | Known                |

## Results

Model projections of alternate TACCs indicated a strong stock effect with discounted economic yield highly responsive to the TACC (Figure 5-26). This analysis also

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indicated that TACCs lower than that currently implemented would be expected to increase NPV<sup>1</sup> of the fishery – that is, managing for a more rapid rate of stock rebuilding appeared likely to increase quota unit values. This simulation was not intended to provide prescriptive information on the optimal TACC for the fishery because future outcomes would be influenced by unknown changes in recruitment, prices, costs and more. Consequently, these results were intended to provide general insight to government and industry on the implications of TACC decisions.

The form of this curve (Figure 5-26) was of interest because the slope becomes increasingly steep at higher TACCs (or exploitation rates), such as those implemented at the time of this analysis. This presented a view of the current TACC which was consistent with opinions many of the commercial fishers expressed during the cost-data collection interviews. This was typically that economic yield under the current management arrangement was volatile and sensitive to interannual change in productivity of the stock, such as through natural variation in recruitment or catchability.

Results shown here are from simulations using a real discount rate of 7%, similar to that used by Holland et al. (2005, 8%) for a *J. edwardsii* fishery in New Zealand and Kompas et al. (2010, 5%) for a prawn fishery in Australia. Asset prices reflect discount rate (Asche 1999) and in this case the implied quota unit values in the fishery from the bioeconomic model with a 7% discount rate (at around \$11,000/unit) were lower than the current market value (around \$15,000/unit). Our conclusion from this was that the applied real discount rate of 7% is towards the upper end of discount rates applicable for commercial fishers in this market. This value of 7% was selected nonetheless following discussion with government and the commercial industry because sensitivity testing of discount rate showed that lower rates resulted in a stronger case for lower TACCs. Thus using the high rate of 7% meant that the broad conclusion that a higher NPV would be expected from lower TACCs was relevant across the range of stakeholders from government to fishing businesses more focussed on short term cash flow.

These results were prepared for the fishing industry that were especially concerned with the effect of price volatility and requested information on ranges in price of 20% relative to the base case. This range was considered extreme given that real price had been flat in the decade, prior changing over this period from \$32.73 to \$35.63 (indexed by national CPI, 2000). The general conclusion held that lower TACCs than the current limit resulted in higher NPV although NPV peaked at lower TACCs with lower price. Industry were less concerned with change in costs as these were dominated by stable labour costs rather than more volatile fuel inputs (Table 7.3).

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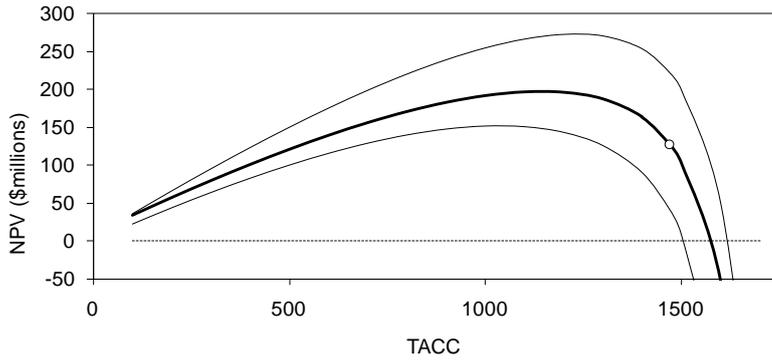
<sup>1</sup> Value of all future profits discounted back to present value. It tends to equal the value of the quota unit because value of quota unit reflects the value of future profits earned from owning that unit.

Nonetheless, change in cost per potlift by 20% produced almost identical results but with lower TACCs favoured by higher cost scenarios.

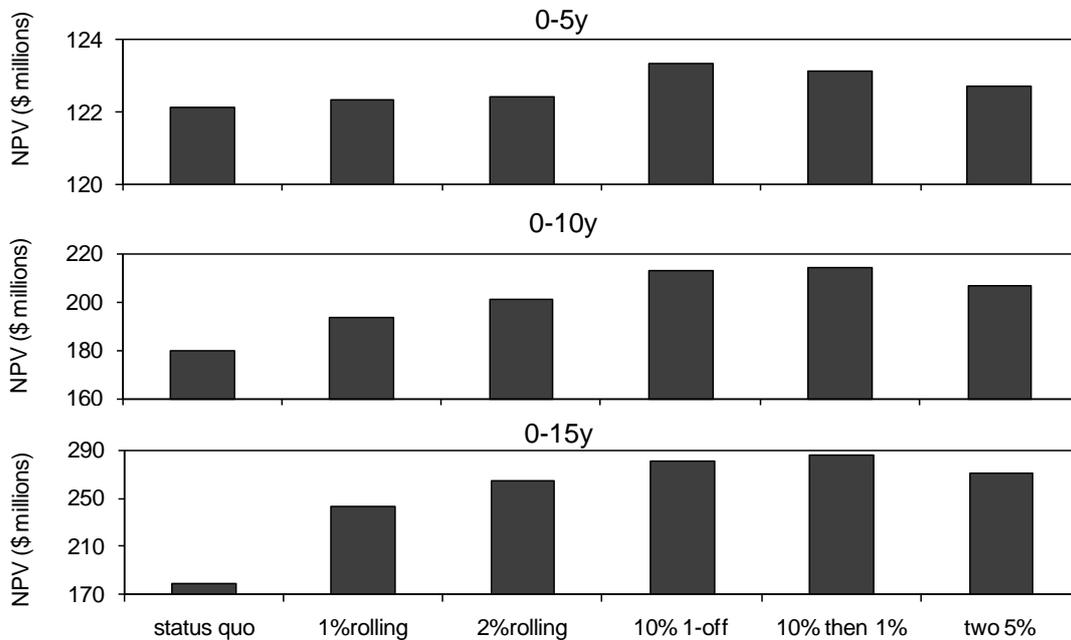
Although the observation that the TACC that optimises NPV varies with price and cost estimates was not surprising, there were two important implications for management decision making. The first was that variation in costs between individual firms operating in the fishery will result in different optimal TACCs. The second was that future change in price and costs would affect the application of this bioeconomic model for management decision making. Consequently, this process of comparing the current status of the fishery relative to the TACC that optimises NPV would need to be repeated in future years as per the standard process of assessing the biological status of the fishery.

The observation that lower TACCs would be expected to increase NPV raised the management problem of how to best move towards lower TACCs - should this be in a single immediate change or through gradual adjustment each year? Alternate possible scenarios were examined with immediate larger reductions tending to produce better outcomes in terms of NPV than smaller gradual reductions, even over the short term of the first 5 years (Figure 5-25). Difference between alternate approaches were small however, with large gains in NPV relative to status quo for all options – in effect moving towards TACC reduction is the critical decision rather than the specific path taken.

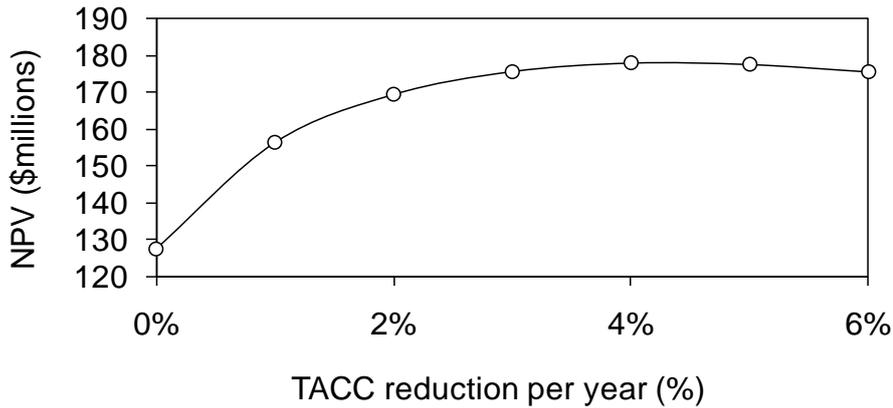
Industry views on single rapid change in TACC vs gradual small changes were mixed with some preferring a single large change because they viewed it as being more responsive, while others expressed a preference for gradual change to allow more orderly fleet adjustment. Different rates of TACC reduction were explored and this indicated that median NPV was maximized with a system of reducing the TACC by 4% each year. However, a pathway of even 1% reduction in the TACC per year appeared to provide a large improvement from the status quo (Figure 5-26). Proportionally greater gains in NPV were made in moving from status quo to 1% reduction per annum than from 1% to 4% reduction per annum. A gradual change in TACC of even 1% per annum also improved biological performance measures of the stock (Figure 5-27). Catch rate (and thus revenue per potlift) improved as stock rebuilding occurred through greater constraint on the TACC. Egg production is used as a measure of biological sustainability in this fishery and the projected median trend was downward under the status quo TACC but this trend was reversed by annual 1% TACC reductions. Likewise, the downward trend of biomass of large lobster was addressed by this TACC pathway, which is a management objective because of the role of large lobsters in urchin predation and thus ecosystem function (Ling et al. 2009).



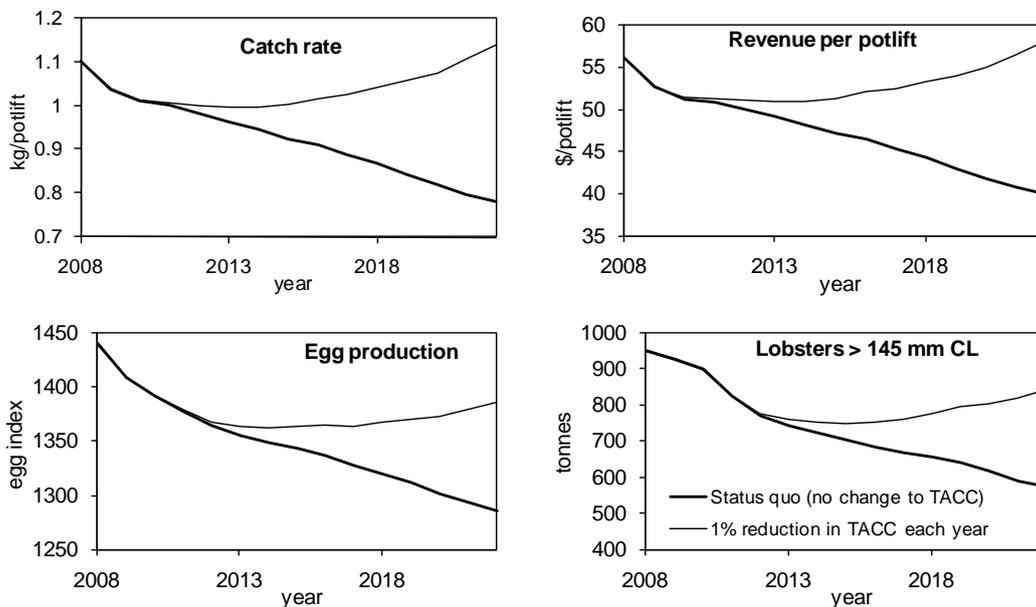
**Figure 5-25** Median NPV of the fishery under different TACCs (discount rate 7%, 20 y). The current TACC of 1470 tonnes is shown by the dot. The middle line shows the outcome with current costs and prices, while the lines either side indicate the effect of a 20% increase or reduction in prices.



**Figure 5-26.** The effect of different TACC reduction strategies on median NPV of the fishery over the short (0-5 y), medium (0-10 y) and long (0-15 y) term. Options shown are leaving the TACC at 1470 t (status quo), 1% or 2% reductions each year, a 10% reduction in year 1 with either constant catch thereafter (1-off) or 1% reductions thereafter, or a 5% cut for two years in succession.



**Figure 5-27.** The effect of varying level of quota reductions implemented each year on median NPV. Maintaining the TACC at the current level of 1470t is shown at the 0% level.



**Figure 5-28.** Projected trends in catch rate, revenue, egg production and large lobsters capable of eating long-spined urchins under 2 scenarios: the status quo TACC of 1470 tonnes; and a strategy of 1% reductions in the TACC each year.

## Discussion

The analyses presented here provided the first bioeconomic analysis of the Tasmanian rock lobster fishery since the introduction of ITQ management over a decade earlier in 1998. The main conclusion was that economic yield would be increased with lower levels of catch and this appeared robust to variation in price and costs. The analysis was not intended to be prescriptive on TACC setting because of the uncertainty in projections of future performance of the fishery. Rather, it contributes to the view of the state of the fishery in conjunction with the biological performance measures used in the fishery (Gardner et al. 2011) for management decision making.

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Options for changing the TACC of the fishery to increase economic yield were explored with greatest improvement from immediate large changes rather than slow gradual changes. The magnitude of these differences were not large however, which emphasised that the most critical decision for increasing NPV was to move towards a lower TACC rather than the exact pathway chosen. This outcome would be expected given the flat top to the NPV/TACC curve (Figure 5-25), which also implied that similar outcomes for economic yield could be achieved over a wide range of lower TACCs. Reid (2009) observed similar in the western rock lobster (*Panulirus cygnus*) with compensation between revenue and costs producing similar economic yield across a wide range of catches lower than the current catch.

Considerations in choosing between rapid large changes in the TACC versus slow incremental changes include the ability of the fleet to restructure efficiently, the effect of these changes on business function and the effect on allied industries such as processors were beyond the scope of the research described here but should be considered by industry and managers in extension of these results.

The conclusion of this research that the current TACC was well above that which would produce maximum economic yield is interesting given the history of the TACC setting process and the theory behind ITQ management systems. Campbell and Hall (1988) conducted a bioeconomic analysis of the fishery ten years before ITQs were introduced into this fishery and they concluded that levels of effort were well above that which could produce MEY. The analysis shown here for the same fishery some 20 year later demonstrates that harvesting above the levels that provide MEY is a persistent state in this fishery. Linnane et al. (2010a) reviewed the status of Australian *J. edwardsii* fisheries in the five ITQ management zones and found that all had undergone stock declines over the previous five years. This was not due to a widespread decline in recruitment with the only common factor across these zones being high exploitation rates that created vulnerability to natural variation in productivity. Industry tended to advocate for higher catches in many of these zones even in cases where the actual catch fell below the TACC and there were no cases of industry petitioning the government to lower TACCs to protect economic yield and thus the value of quota assets (Linnane et al, 2010a & b).

These observations of Australian *J. edwardsii* fisheries are contradictory to the theory of ITQs where industry are thought to champion TACCs that increase the value of ITQ assets, which are linked to the state of the stock (eg. Wilen 2006; Sanchirico and Wilen 2007; Libecap 2010). These observations of the history of the Tasmanian rock lobster fishery are not intended to suggest that there is no stewardship of the resource, indeed industry strongly support research on stock status and this analysis of economic yield. However it does appear that simply allocation of catch shares in a tradeable, permanent, well enforced ITQ system is inadequate to foster conservative TACC setting on a pathway to MEY.

It's beyond the scope of this project to explore in detail the conditions additional to ITQ management that would be required for TACCs to move on a pathway to MEY, however brief comparison can be made with the *J. edwardsii* fisheries in New Zealand and the abalone fishery in SE Australia. ITQ markets and fisheries in many of the New Zealand fisheries are functioning well (Newell et al. 2002), with some standout cases such as CRA8 that have had large increases in quota asset values

through targeting economic yield (Holland 2010). Likewise, abalone fisheries in the region have ITQ management and are generally stable and profitable. Indicators of stewardship in these abalone fisheries are high yet harvesting decisions have produced poor outcomes which Gilmour et al. (2011) have linked to perceptions of resource condition. That is, stewardship from private property rights is ineffectual if decisions are made based on perceptions that are inaccurate. This emphasises the need for objective information in decision making, such as through bioeconomic modelling. The modelling conducted here or by Holland et al. (2005) for CRA8 is uncommon but seems to be required in stimulating debate and overcoming the mental hurdle that lower catch can increase value of quota assets.

Another issue that prevents fishers promoting lower TACCs is the weak exclusivity of their catch shares. Commercial fishers in Tasmania who opposed further stock rebuilding specifically cited concerns that attempting to increase catch rates from lower TACCs would be negated by the loosely constrained and increasing recreational catch in addition to potential stock problems from MPAs that were proposed by the State Government. Sanchirico (2000) has noted that rights values interact with the MPA debate and in this case fishers were aware of declining lobster stocks in an adjacent fishery attributable in part to displaced catch from MPAs (Hobday et al. 2005a).

The discussion above deals with shifting a commercial ITQ fishery towards higher economic yield but it's important to note that there is debate around the merit of this target from a societal perspective. One argument is that the costs that are reduced in targeting MEY can also be viewed as inputs to links through the fish value chain, such as processors and suppliers (Bromley 2009; Christensen 2010). Béné et al. (2010) argued that this issue was of greatest concern where other employment opportunities are limited, specifically for the poor of developing countries. A related issue is the flow of rents if MEY is targeted. It has been argued that society as a whole should benefit from these rents because the resource is owned by the State (Macinko and Bromley 2002; Macinko and Schumann 2008). Hatcher et al. (2002) explored this issue in UK ITQ fisheries and noted that societal benefits can be obtained through a resource levy although this also raises issues of who should pay for costs such as quota monitoring and enforcement.

Results of this bioeconomic have subsequently been discussed and adopted in management decisions for the fishery with lower TACCs implemented. Over 220 vessels operate in this industry so the process of communicating bioeconomic model outcomes to such a large group was a significant challenge for the extension of this research. A sub-committee of the main industry organisation (TRLFA) served as the main point of contact and this group acted as champions for communicating to the wider group. This process highlighted some aspects of the bioeconomic model which were critical for industry acceptance. One was the explicit acknowledgement that increase in overall economic yield does not imply better incomes for the large portion of fishers who rely on leasing of quota units from quota holders (van Putten and Gardner 2010). As per New Zealand, it's clear that costs and harvesting capacity of individual businesses varies so a common approach to TACC setting across the fishery will create winners and losers (Holland et al. 2005).

The division of the Tasmanian stock assessment model into shallow and deep is described in detail in the next section.

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### 5.3 Deep-Water Quota

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#### *Summary*

The catch from deep water (>35 fm) off western Tasmania currently averages around 100t. Economic yield from the broader fishery would be increased if around 100 t of extra catch were shifted from shallow water into these deeper areas off the west coast. The opportunity cost of not responding to the management issue of deep water catch was high, estimated at around \$50 million discounted over 10 years or \$140 million over 15 years.

Gains in economic yield would be maximised by separate a 100t quota allocated to a west coast deep water zone. An alternate (less optimal) method was explored here which involved providing additional quota as an incentive for fishers to take catch in the deep water area. This was determined to be only beneficial under market conditions where the incentive was attractive if the additional quota is less than 52kg per unit (assuming a standard quota allocation of 140kg / quota unit).

The main benefits of managing deep water catch are that long term profitability is enhanced and the resource becomes more resilient to shocks such as years of low catchability or low recruitment.

The main disadvantages are that there is additional administration and enforcement.

A trial was conducted over two years. At this time the stock was in decline and this created an economic environment where fishers were unlikely to take up deep water catch incentives at levels that provide net economic gains to the broader fishery (ie 52kg or less per unit committed). The concept of zones which would be required for the alternative system of separate deep water quota allocations is controversial.

Deep water quota was thus not viable during the period of the trial, however, it remains a possible management tool for future application when the stock rebuilds and catch-rates become elevated in deep water again.

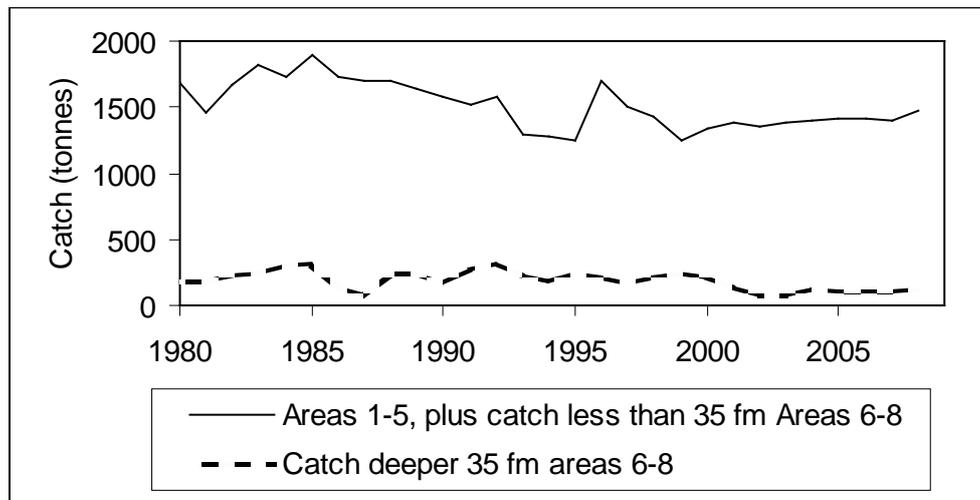
There were three keys aims for this research component.

- 1) To evaluate the potential for deep water quota to be used as a spatial management tool in Southern rock lobster fisheries for shifting effort from inshore to offshore.
- 2) To develop allocation, policy and legislative systems for the implementation of deep water quota.
- 3) To collect population data from deep water regions to estimate deep water population demographics and to establish the sustainable levels of deep water catch.

### 5.3.1 *The need for separate management of deep water stocks*

Catch had shifted into inshore areas over the last decade as fishers target higher value red lobsters. The intent of deep water quota was to drag catch offshore into habitat deeper than 35 fathoms in Areas 6, 7 and 8. Historical catch from these areas is shown in Figure 5-29. It can be seen that catch from this deep water area in recent years (around 100t) is much less than that taken through most of the 1980s and 1990s.

Economic modelling showed that the depth split in catch taken by the fishery was not optimal for yield – too much catch was being taken from shallow water. The economic implications of the current sub-optimal management are profound, equating to around \$50 million discounted over 10 years or \$140 million of lost economic yield when considered over a period of 15 years.



**Figure 5-29** Historical catch in deep water areas (>35 fathoms) in areas 6, 7 and 8 relative to the rest of the State. Catches in the deep water area peaked at 319 tonnes in 1985 and have stabilized at a little over 100 tonnes over the past 5 years.

### 5.3.2 *Potential of deep water quota as a spatial management tool*

We assessed the potential of offering additional quota to operators to fish in deep water in the Tasmanian southern rock lobster fishery. Through a two year trial run in conjunction with DPIPW, fishers were offered incentives to target their harvest in deep water. To participate in this trial, fishers were asked to commit to fish one unit of their normal quota in the deep water area to be able to take extra catch in a specified deep water trial area off western Tasmania. Thus the extra deep water catch was intended to offset the loss to fishers of catching the lower value deep water lobsters.

This concept was tested with a trial allocation of a total additional 35 tonnes of catch in the 2007/08 fishing year, equating to 50kg of deepwater catch for every unit (145kg) committed to fish in the deep water. Fishers were charged \$5/kg for any additional catch taken up. Under these incentives 114 quota units, or 16.5 t of quota were committed to the trial by 8 fishers. Catch rates dropped in this year, and this was the first year of four where the industry struggled to take the full TACC. Consequently only 6.4 t of the 8.1 t permitted deep water quota was caught. In an

attempt to increase the uptake, and in response to industry concerns that the initial incentives were not high enough, DPIPWE increased the incentive to 80kg of deepwater catch for every unit committed to fish in the deep water. This coincided with the first voluntary cut in the TACC, which resulted in the reduction of each quota unit from 145kg to 140kg. Consequently, while two extra fishers participated, 3.8 t less of quota was committed, and 2.8 t less was caught in the deep water research zone.

**Table 5.5** Catch and participation in the trial of deep water quota (DWQ).

| Year    | Number of fishers participating | No of units committed | Quota Kg committed | DWQ kg | Total Catch | Quota caught kg | DWQ caught kg |
|---------|---------------------------------|-----------------------|--------------------|--------|-------------|-----------------|---------------|
| 2007/08 | 8                               | 114                   | 16530              | 9120   | 14567       | 8164            | 6403          |
| 2008/09 | 10                              | 91                    | 12740              | 7280   | 10079       | 6480            | 3598          |

**Table 5.6** Quota price during and after the deep water trial. These prices reflect a sub-sample of quota units sold in this time, not a mean. The sharp decline in lease price in 2009 reduced the relative benefit of the deep water quota incentive.

| Year | Month     | Quota price/kg |
|------|-----------|----------------|
| 2007 | Dec       | \$18           |
| 2008 | July      | \$18           |
|      | September | \$16           |
| 2009 | May       | \$8            |
| 2010 | Feb       | \$3            |

As the TACC was harder to catch in the same period as the deep water catch trial occurred, the lease price of quota also decreased, to the point where it couldn't be sold. Consequently, paying \$5/kg for extra quota which could be bought for \$2-3/kg, with no restrictions on where it could be fished, was no longer attractive. While the planned incentive was \$20 cheaper per kilogram of quota during planning of the trial, as catch rates declined and the quota couldn't be caught, the lease price dropped dramatically and the trial incentive was inadequate.

### 5.3.3 *Setting the level of incentive for deep water quota*

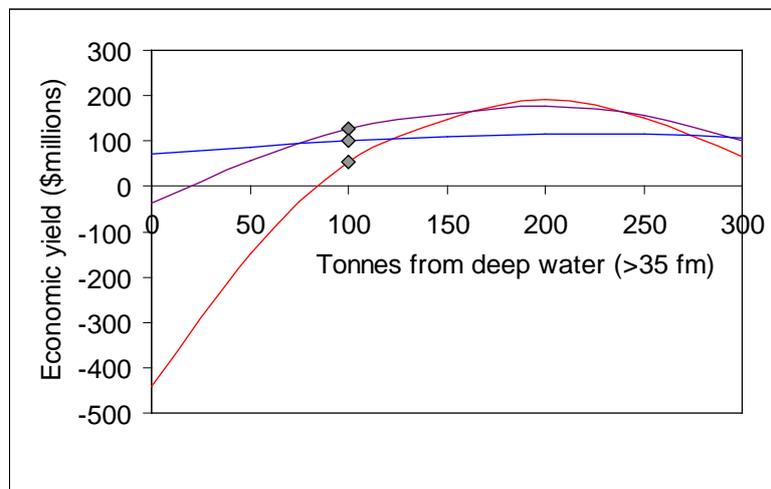
Pushing catch into deeper water would increase economic yield, but only up to a point; these areas have a limited capacity to absorb extra catch. As a result, there was an optimal balance in the split in catch between deep and shallow water. Given the TACC current at the time of the deep water quota trial of 1470 tonnes, this optimal

balance occurred at 200t taken from the deep water area, and 1270 tonnes taken from the remainder of the State (Figure 5-30, Figure 5-31). This outcome held regardless of future changes in price and costs.

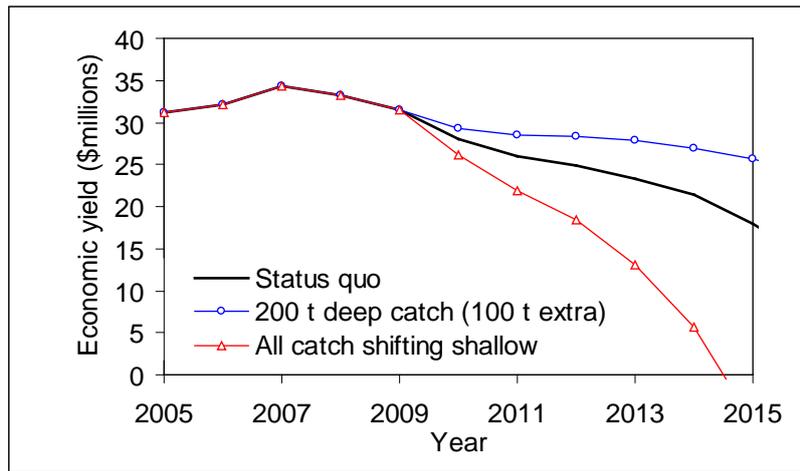
Responding to the opportunity for deep water quota is not simple. For the last 5 years fishers have taken around 100t and this pattern is stable. Providing deep water quota to these fishers does not drag any effort away from inshore areas. Smaller allocations of deep water quota drag more units from inshore areas, but if the incentive is too low then fishers will not take up the deep water quota (Figure 5-32). Thus there is a balance or optimal level of incentive.

The economic outcome of alternative deep water allocations is shown in Figure 5-33. There were a few simple conclusions from these analyses:

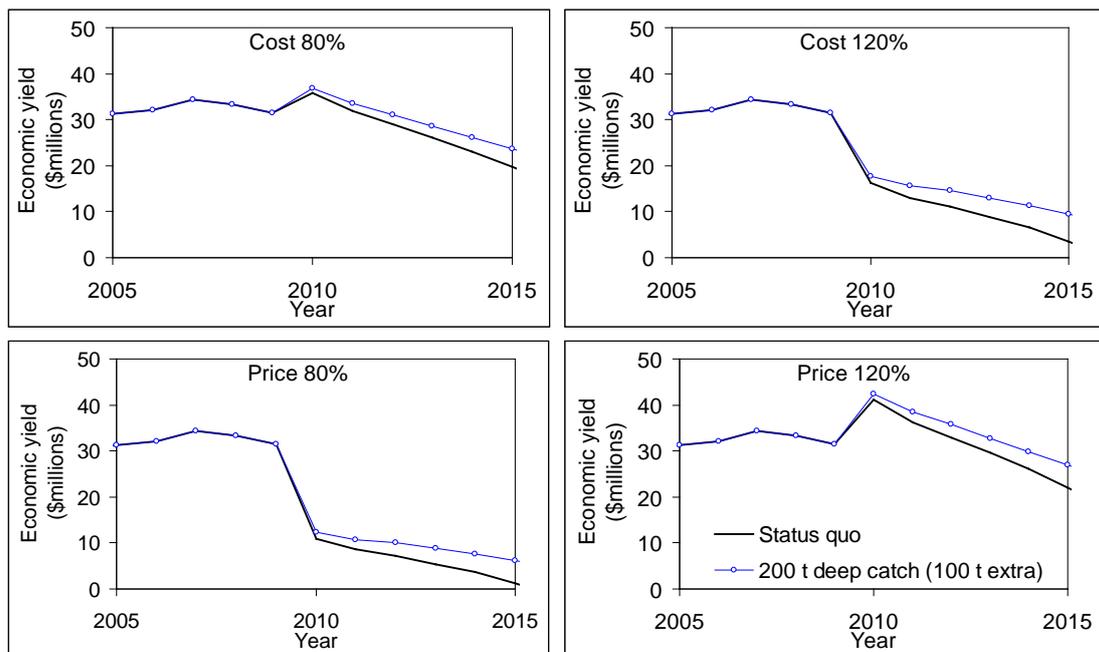
- the deep water quota on offer should aim to maintain total deep water catch at 200t;
- deep water quota only **increased** economic yield where the allocation of deep water quota was less than 52 kg of extra quota for each normal 140 kg unit fished;
- economic yield was **maximised** when deep water catch was maintained at 200t with no allocation of any additional quota, which could only be achieved with separate deep water quota



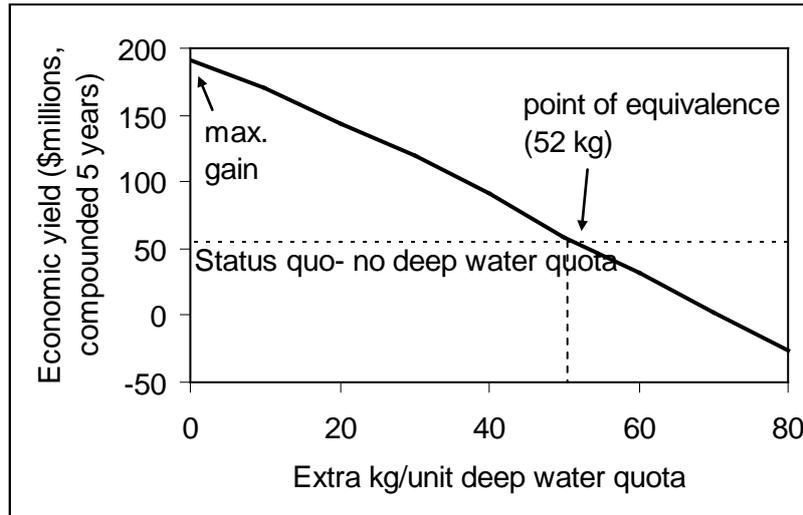
**Figure 5-30** The implications of different amounts of deep water catch on the economic yield of the fishery. The current deep water catch is around 100 t. If deep water catch dropped to zero, then all catch would be taken in inshore areas, which would reduce economic yield. The effect is minor over the short term (5 years; flat blue line) but becomes more pronounced over 10 years (middle purple line) and 15 years (red line) as catch rates fall and costs rise. The optimal balance between deep and shallow water catch with the current TACC of 1470 t was about 200 t from deep water and 1270 t from remaining areas. This is the case over both the short- and long-term.



**Figure 5-31.** The time trajectory of economic yields with 0, 100 and 200 tonnes of deep water catch. Annual deep water catch for the 5 years prior was around 100t – labelled “status quo” here. If deep water catches drops to zero, then all catch is taken in inshore areas. This scenario would reduce economic yield. Increasing deep water catch by 100t to a total of 200t increases economic yield from the first year.



**Figure 5-32.** A test of the effect of higher and lower costs and prices on trends in economic yield. If costs and prices change from those measured in the fishery over 2008/09 then the economic yield would change – however, regardless of price or costs, yield is always improved by shifting 100t of catch to the deep water area (to give a total deep catch of 200t).



**Figure 5-33.** The implications of providing extra deep water catch as an incentive for fishers to take 200t in the deep water area. Yield for the fishery is maximised if extra catch is taken from deep water without any extra incentive, which would require a zonal TACC. Providing high levels of extra quota as incentive to fish in deep water reduces the economic yield compared to the status quo of no deep water quota. The deep water quota allocation needs to be less than 52kg per unit to produce any economic gain.

#### 5.3.4 Developing systems for the implementation of deep water quota

##### *Allocation*

In 2007, fishermen were initially offered 50kg @ \$5 per kg of deepwater quota (DWQ) for each unit they committed to catch in the deepwater area. 27 fishers expressed interest originally, but many did not go through with the trial as the economic feasibility shifted with a decline in stock at the time. At the end of the first trial quota year (2007-08), eight fisher's participated and only 16.53 tonnes of the target 35 t had been filled. This resulted in 8.164 t of catch that would normally be taken from inshore being taken from the deep water research trial area (Figure 5-34).

With the decline in catch rate, the incentive of 50kg for each unit was no longer an attractive incentive. The quota offer was reassessed in 2008 to make it more attractive to the industry, and increase the uptake. There was further consultation with industry at this point to determine an attractive incentive. Many fishers suggested increasing the research quota offer to anywhere between 75 and 100kg. The project steering committee considered this, and decided to increase the deep water research catch from 50 kg to 80 kg. This level of incentive meant that there was no longer any additional catch shifted from inshore, but the trial proceeded as a test of the operational aspects of running a deep water quota system.

A second round of expression of interest was sent out. This time 32 EOI's were received and 10 fishers participated.

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### *Selecting boundaries for the deep water area*

The deepwater trial area went through a number of drafts; the main issue of contention was including the deepwater area off King Island (KI), on the north west of mainland Tasmania. Resident fishers from KI were concerned that the offer would increase effort off KI and would be especially attractive as the port of Currie, King Island was relatively close to the deep water area. Consequently, the northern boundary was moved to 41 degrees south, over concerns of egg production and that catch rates were declining in area 5. This influenced participation in the trial, with a handful of fishers pulling out when KI was excised from the trial deep water fishing area.

Industry members on the steering committee provided their input on the area and a number of small changes were made, where fishers thought the area included some shallower habitat where red lobsters could be taken. Navigation charts were primarily used to define the area. The deep water fishing trial was conducted under permit, specially issued for the trial.

#### **5.3.5 *Improved data collection from deep water regions***

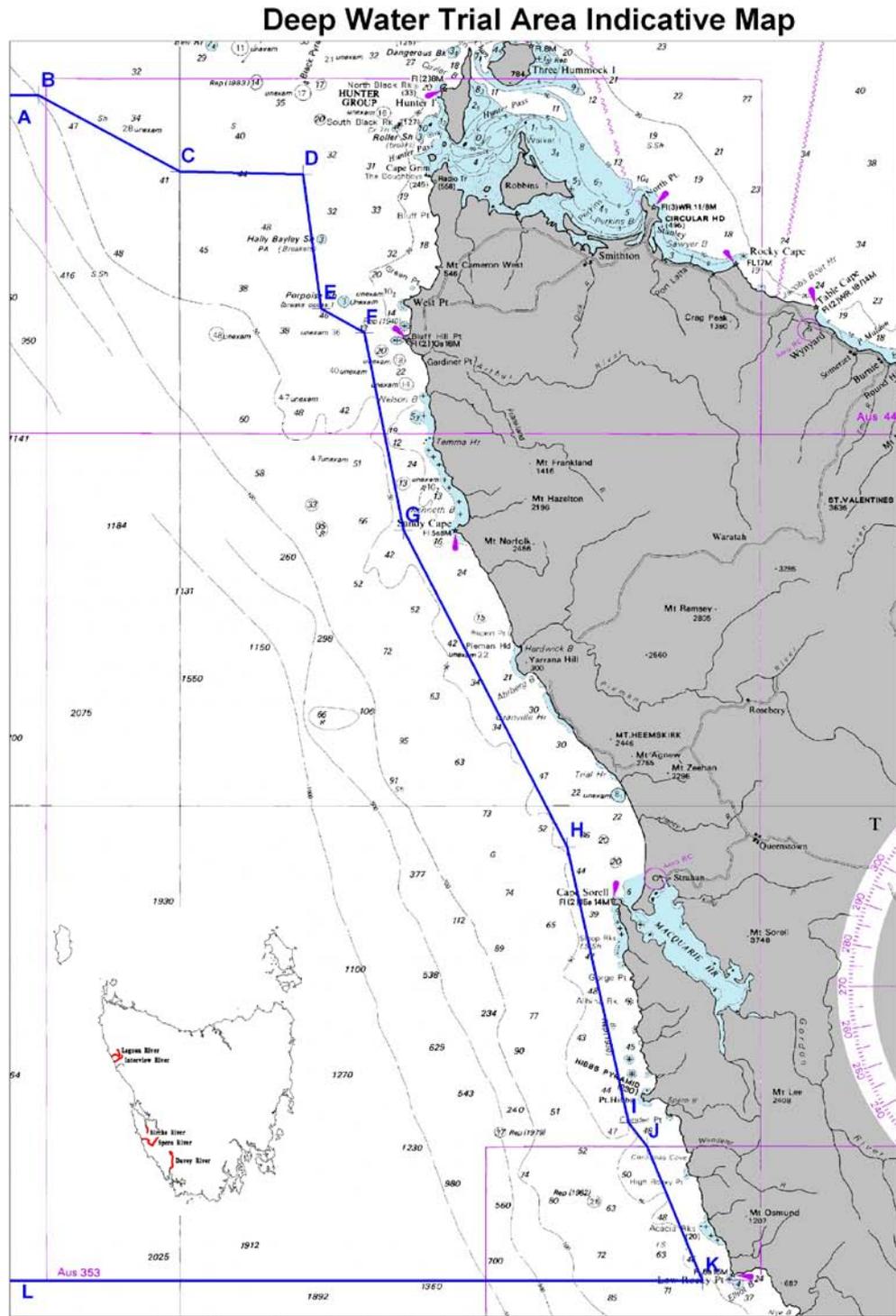
There were two data collection requirements of participating in the deep water trial:

- That the fisher would use electronic calipers supplied by UTAS and measure all the catch from one pot in ten (equating to 5 out of 50 pots each day), until 100 lobsters were measured per day;
- That fishers would be willing to take observers on their boat to measure all of the catch on those dedicated trips.

### **Results and Discussion**

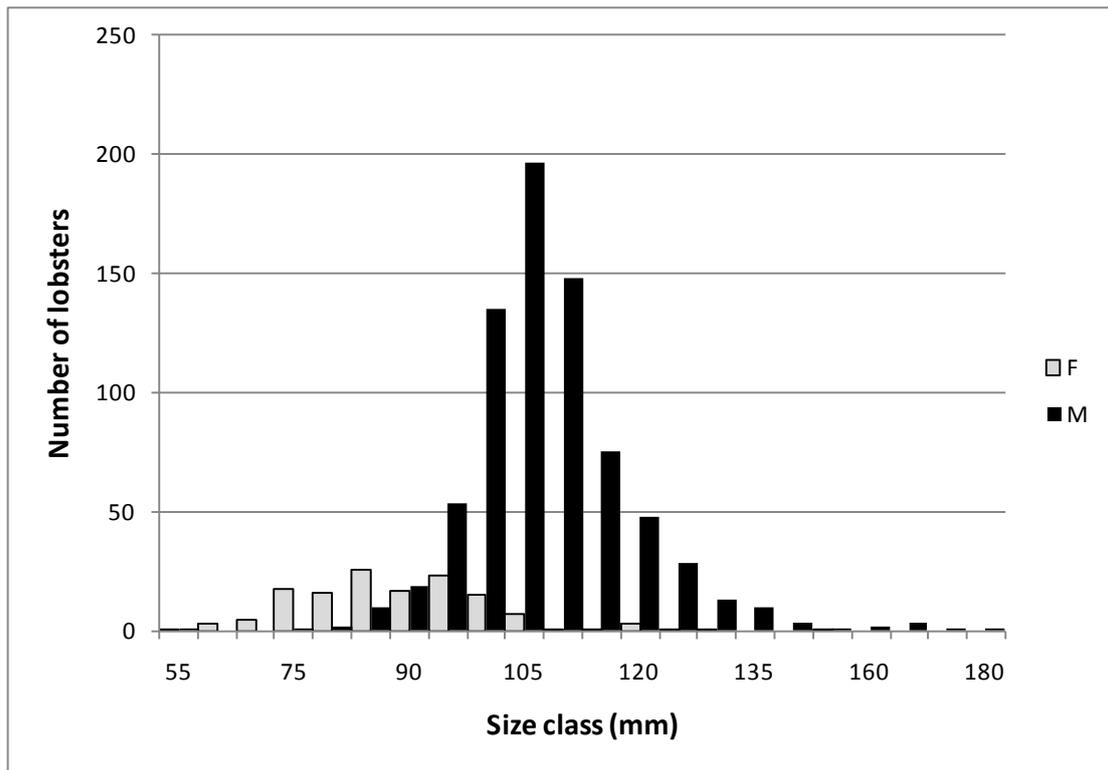
Compulsory population sampling through the DWQ trial resulted in the measurement of 27,168 lobsters from the deep water zone defined in Figure 7-34. A total of 891 lobsters were measured by fishers using electronic callipers and 26,277 lobsters were measured and tagged by observers on board commercial boats participating in the DWQ trial. There were 180 tagged lobsters recaptured through these methods.

Collecting data from the deep water using electronic callipers had only limited success, even though it was a compulsory requirement for taking deep water quota (it is also possible that not all the electronic callipers have been uploaded as there was trouble with the data not recording properly and data not uploading as a result of salt-water damaging the electronics). The data from electronic callipers presented in Figure 5-35 comes from areas 9 and 10. There were very few legal size females measured, which is indicative of sampling in some of the deepwater areas with small, pale, slow-growing lobsters. In these areas females seldom reach legal size. The majority of males measured were between 100 and 115mm carapace length (CL), just

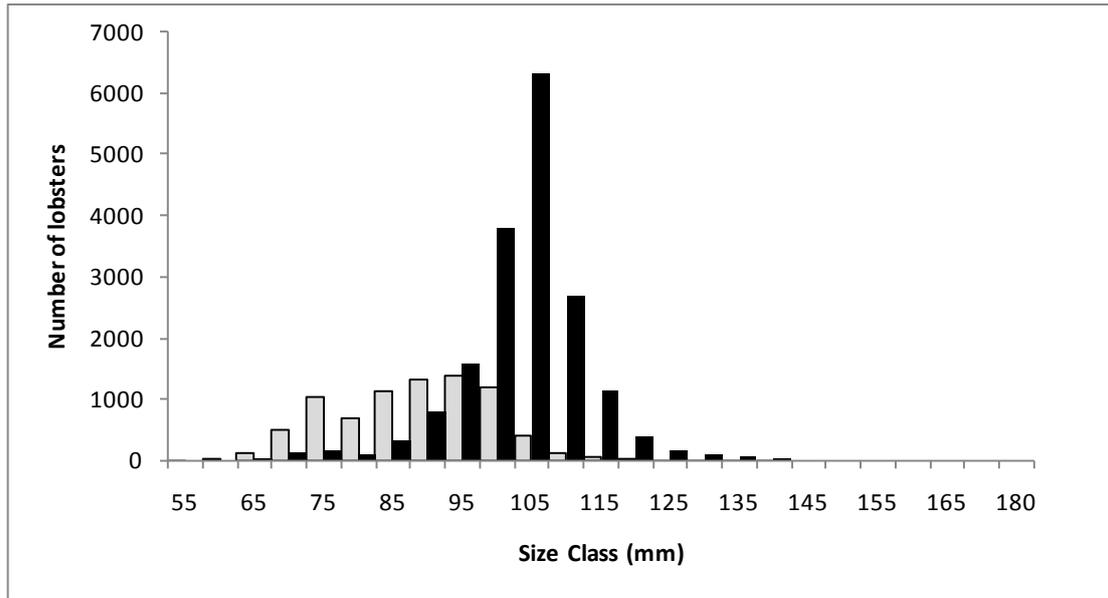


**Figure 5-34** Map of the area of the deep water fishing trial on the west coast of Tasmania. Blue line indicates the extent of the area for fishing deep water quota. Inset is Tasmania, Australia.

legal size and above. There were a few very large males and very small females. In contrast, the lobster measured by observers on deep water fishing trips were a more representative samples of the sexes, size classes and sexes within the size classes (Figure 5-36, Table 5.7). Measurements of lobsters by observers were taken in stock assessment areas 9, 10, and 11, although the majority (7357) came from stock assessment area 11 (Figure 5-37, Table 5.7). The majority of males measured by observers were sized between 90 and 115 mm CL, and females were between 85 and 105 mm CL. Only 62 females greater than 120 m CL were measured. Few very large males (>150 mm), and no large females were measured through observer sampling.



**Figure 5-35** Size frequency of lobsters measured by fishers participating in the deep water research catch trial using electronic callipers.



**Figure 5-36** Size frequency of rock lobsters measured during the deep water fishing trial by observers on board fishing boats.

#### *Estimating deep water population demographics*

Prior to this project the stock assessment model contained eight assessment areas each of which encompassed all depths. For the purpose of this project stock assessment areas 6, 7 and 8 were split into shallow and deep areas (Figure 5-37). This split required the population demographics (biomass, growth rate, size frequency, sex ratio) of the new deep water areas to be characterised.

The stock assessment model is driven by two main sources of data – tagging data and commercial fishing data. The commercial fishing data drives the model biomass estimates, higher catch rates are indicative of a higher rock lobster biomass in the region. The tagging data is used to estimate growth curves (a fundamental input for the model) and to estimate movement rates between areas, in particular between shallow and deep water. Unfortunately the data available from the deep water rock lobster stock off western Tasmania was limited due to low research tagging and sampling.

#### *Movement estimation*

Tag recapture data (Table 5.8) for shallow and deep water was used to estimate movement between shallow and deep water in this region.

In stock assessment area 6 tag recapture data suggest minimal movement between the shallow and deep regions with less than 10% of tagged animals moving from deep to shallow water or vice-versa. Area 8 had 10% movement from shallow to deep and 39% movement from deep to shallow.

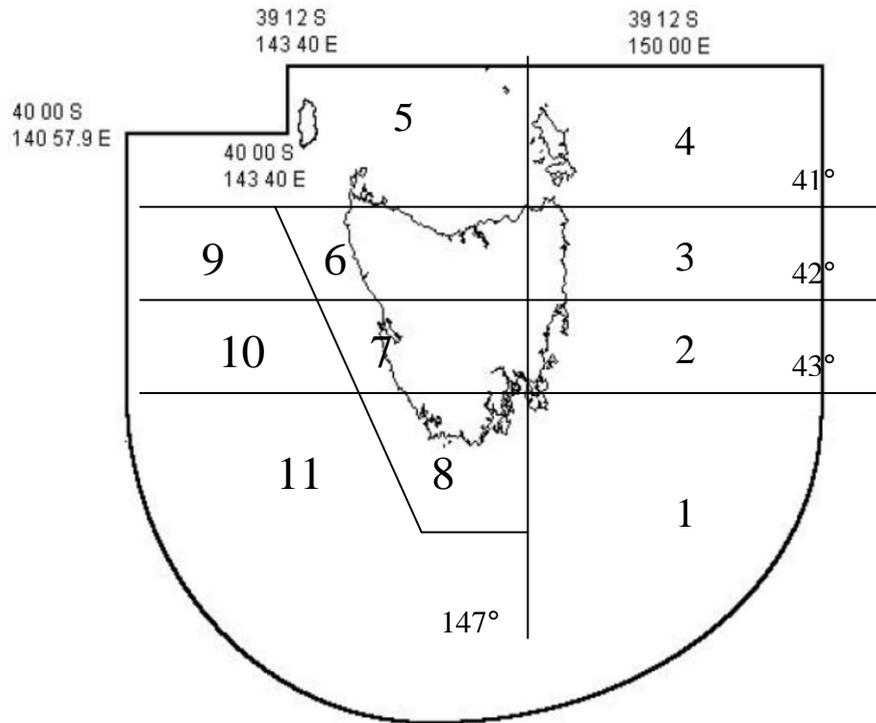
These trends are indicative only, the small number of deep water releases prevent a robust assessment of movement rates which would also need to consider spatial variation in effort including edge effects. Without good movement estimates it is

uncertain what proportion of recruitment in a given area is due to puerulus settlement and what proportion is due to nett migration from other areas. Due to the lack of information a constraint of 10% movement between shallow and deep water in each assessment area was enforced in modelling. This constraint was based on expert opinion.

**Table 5.7** Frequency distribution of lobster carapace length measured by observers on boats participating in the deep-water fishing trial.

This is the same data as in Figure 5-36, but it is included here to illustrate the tails of measurement. Measures lower 60 mm and higher than 150 mm are not visible in the figure due to scaling.

| size class 5 mm | SEX  |       | Grand Total |
|-----------------|------|-------|-------------|
|                 | F    | M     |             |
| 40              | 1    | 1     | 2           |
| 45              | 1    | 1     | 2           |
| 50              | 4    | 2     | 6           |
| 55              | 5    | 10    | 15          |
| 60              | 20   | 14    | 34          |
| 65              | 131  | 38    | 169         |
| 70              | 493  | 147   | 640         |
| 75              | 1031 | 167   | 1198        |
| 80              | 699  | 118   | 817         |
| 85              | 1140 | 339   | 1479        |
| 90              | 1322 | 812   | 2134        |
| 95              | 1379 | 1591  | 2970        |
| 100             | 1201 | 3791  | 4992        |
| 105             | 398  | 6342  | 6740        |
| 110             | 135  | 2689  | 2824        |
| 115             | 51   | 1164  | 1215        |
| 120             | 30   | 404   | 434         |
| 125             | 12   | 173   | 185         |
| 130             | 5    | 112   | 117         |
| 135             | 3    | 70    | 73          |
| 140             | 2    | 53    | 55          |
| 145             |      | 25    | 25          |
| 150             |      | 8     | 8           |
| 155             |      | 3     | 3           |
| 160             |      | 9     | 9           |
| 165             |      | 1     | 1           |
| 170             |      | 5     | 5           |
| 180             |      | 1     | 1           |
| Grand Total     | 8063 | 18090 | 26153       |



**Figure 5-37** Map of Tasmania with southern rock lobster stock assessment areas numbered 1-11.

*Deep water growth rates*

Calculating growth rates for the deep regions independently is not feasible given the limited data available. Existing growth curves for the assessment areas are indicative of shallow water growth (as most tagging records were obtained in shallow water), these were modified using the growth differential established to obtain growth curves for the deep water.

**Table 5.8** Recaptured lobster tags, rows show the release stock assessment area and columns the recapture stock assessment area.

|                  | <b>6 shallow</b> | <b>7 shallow</b> | <b>8 shallow</b> | <b>6 deep</b> | <b>7 deep</b> | <b>8 deep</b> |
|------------------|------------------|------------------|------------------|---------------|---------------|---------------|
| <b>6 shallow</b> | 626              | 1                | 0                | 27            | 0             | 0             |
| <b>7 shallow</b> | 0                | 444              | 5                | 0             | 4             | 1             |
| <b>8 shallow</b> | 0                | 0                | 2321             | 0             | 1             | 196           |
| <b>6 deep</b>    | 15               | 0                | 0                | 130           | 0             | 0             |
| <b>7 deep</b>    | 0                | 8                | 0                | 0             | 3             | 0             |
| <b>8 deep</b>    | 0                | 0                | 264              | 0             | 0             | 419           |

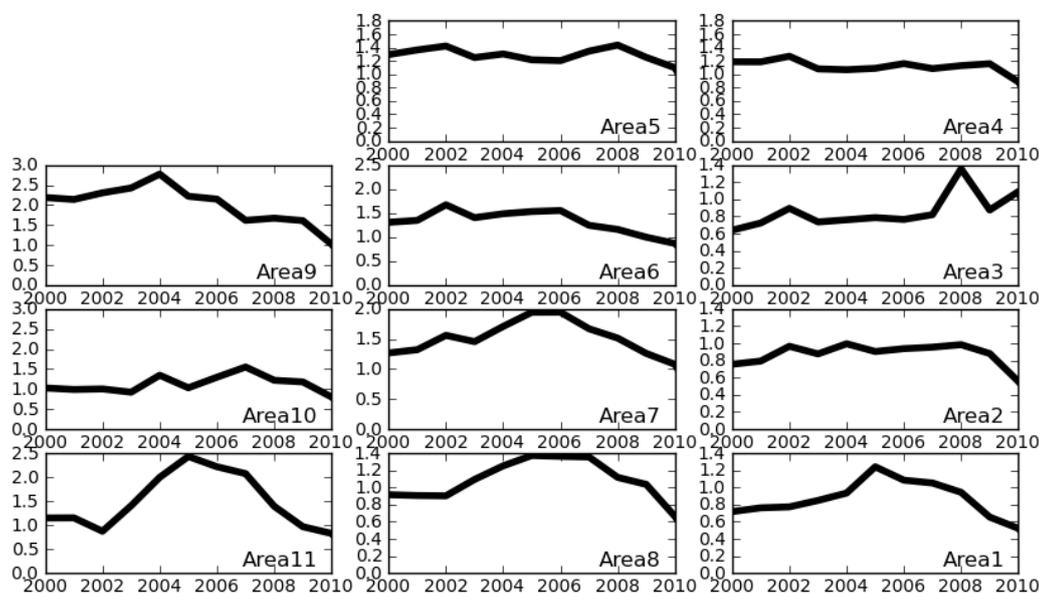
### Biomass and CPUE

When commercial catches by depth on the west coast (Table 5.9), the catches in the deep areas, particularly area 7, are extremely low such that variability in catch rates due to such factors as vessel and weather effects will obfuscate the effect of biomass on CPUE (Figure 5-38).

Model estimates of exploitable biomass show a substantial decline over the last five years across the fishery (Figure 5-39).

**Table 5.9** Catches (in tonnes) split between shallow and deep water in assessment areas 6, 7 and 8.

| Year | 6 Shallow | 7 Shallow | 8 Shallow | 6 Deep | 7 Deep | 8 Deep |
|------|-----------|-----------|-----------|--------|--------|--------|
| 2006 | 126       | 188       | 345       | 36     | 6      | 63     |
| 2007 | 107       | 171       | 365       | 33     | 9      | 71     |
| 2008 | 96        | 164       | 327       | 35     | 15     | 57     |
| 2009 | 91        | 131       | 302       | 55     | 12     | 46     |
| 2010 | 51        | 62        | 95        | 33     | 6      | 18     |



**Figure 5-38** CPUE (kg per potlift) by assessment area.

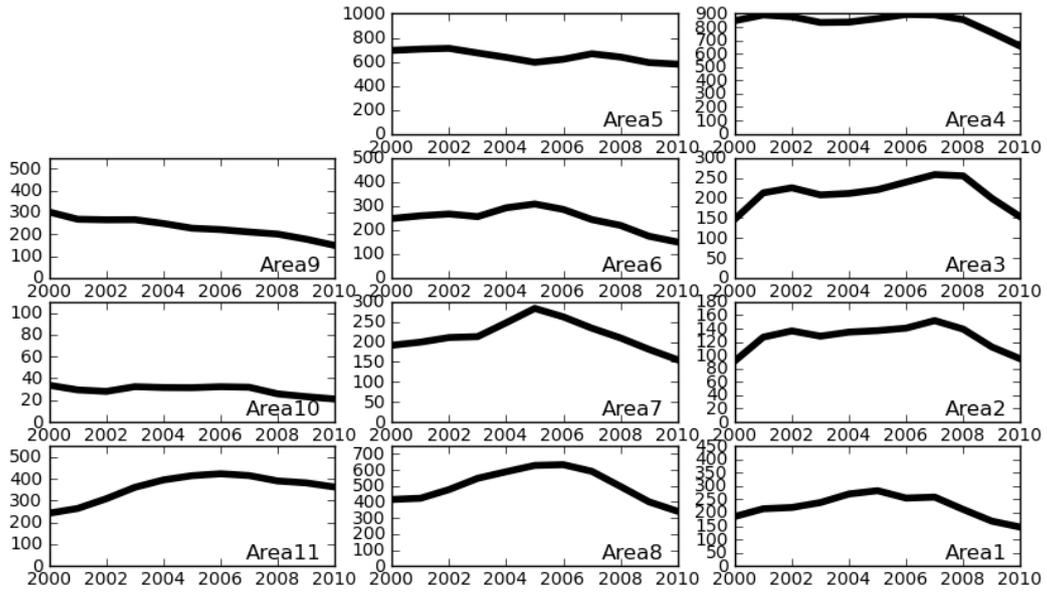


Figure 5-39 Exploitable biomass estimates by assessment area.

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## 5.4 Regional Size Limits

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### 5.4.1 Tasmania

Regional size limits were explored for the Tasmanian fishery with possible changes in both fast and slow growth areas.

Fast growth areas occur in the north of the state and these areas are susceptible to growth overfishing where yield is lost by taking animals at too small a size. At the other extreme, lobsters in the south grow slowly and yield is lost through natural mortality before lobsters reach legal size.

#### *Alternative size limits in fast growth, northern regions*

##### *Detailed Methods*

Changes to minimum legal size limits were examined by population modelling in relation to each of these issues.

The following scenarios were examined:

- (i) status quo (i.e. current management);
- (ii) a 1mm increase in female legal minimum legal size each year in areas 4 and 5 until the LML equals 120mm CL;
- (iii) a 1mm increase in female legal minimum legal size each year in areas 4, 5 and 6 until the LML equals 120mm CL; and
- (iv) 1% per annum decreases in the TACC plus transfer of catch to deep water (of 100t in the first year).

This final option was intended to provide scale of effect relative to other management options available.

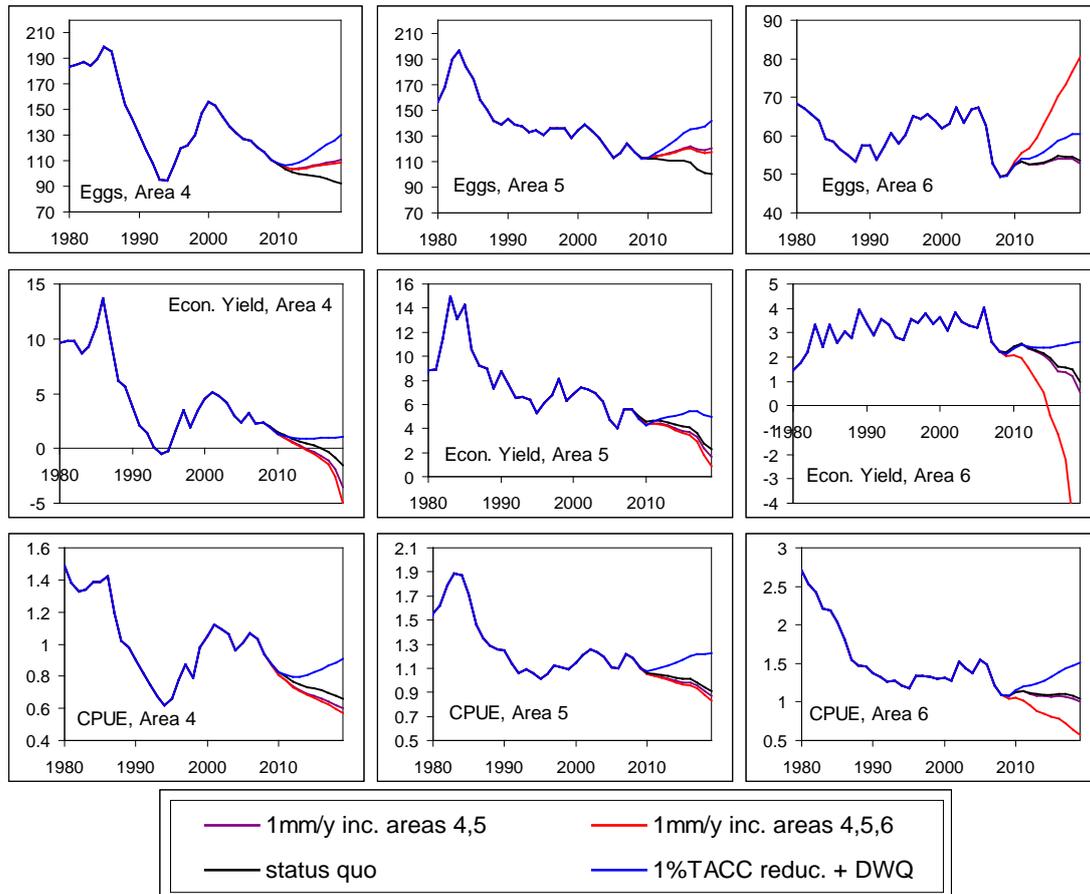
##### *Results and Discussion*

Areas 4 and 5 were expected to have continued deterioration of egg production and economic yield under the status quo management applied at the time (TACC=1470 t). This decline in egg production was expected to stabilise or increase slightly with the proposed system of steady increases in legal minimum size, however, catch rates and economic yield were not expected to improve relative to the “do nothing” status quo scenario.

Better outcomes for egg production, catch rate and economic yield were found to occur with a strategy of 1% annual reductions in the TACC combined with management to shift catch to deep water.

Egg production in area 6 was expected to increase rapidly under a system of 1mm increases in legal minimum length, however, this comes at the cost of severe decline in CPUE and economic yield.

It was noted that these conclusions assumed no feedback between egg production and future recruitment because this takes longer than the duration of projections.



**Figure 5-40** Projections of egg production (egg index), economic yield (\$millions) and catch rate (kg/potlift) with scenarios of: (i) status quo (i.e. current management); (ii) a 1mm increase in female legal minimum legal size each year in areas 4 and 5 until the LML equals 120mm CL; (iii) a 1mm increase in female legal minimum legal size each year in areas 4, 5 and 6 until the LML equals 120mm CL; (iv) a 1% per annum decrease in the TACC plus transfer of catch to deep water (of 100t in the first year).

*Alternative size limits in slow growth, southern regions*

The commercial industry wanted to explore smaller size limits in slow growth areas of the south for marketing as well as yield benefits. The marketing issue was that there are periods of the year when small, “A-grade” lobsters below 500 g are in demand and the Tasmanian fishery had no capacity to meet this market. This change to a focus on marketing through the course of this project was unexpected because reducing size limits in the south of the State had previously been rejected by industry due to a presumed limited market for these smaller lobsters.

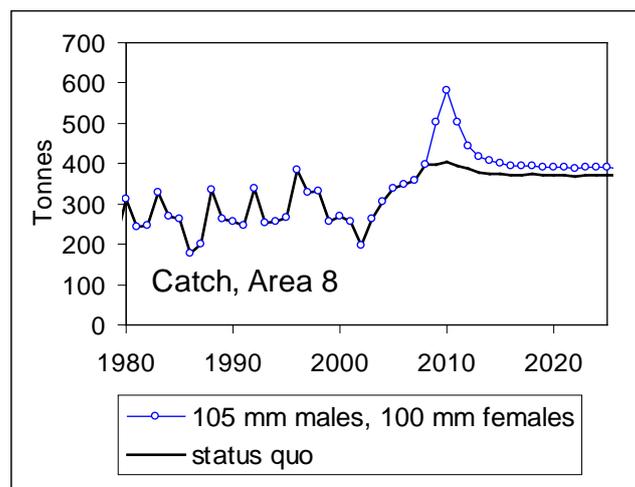
Population modelling suggested that the effect of lowering size limits by 5 mm in the SW (area 8) to 105 mm CL for males and 100 mm CL for females would lead to an initial spike in catch, which would then stabilise at a sustainably higher level because a smaller size limit is more appropriate to average growth rates across the region.

Egg production was modelled to benefit from the change with enhanced production in the currently depleted northern areas. Although benefits in egg production were predicted for the depleted northern parts of the fishery, total state-wide egg production would be almost unaffected

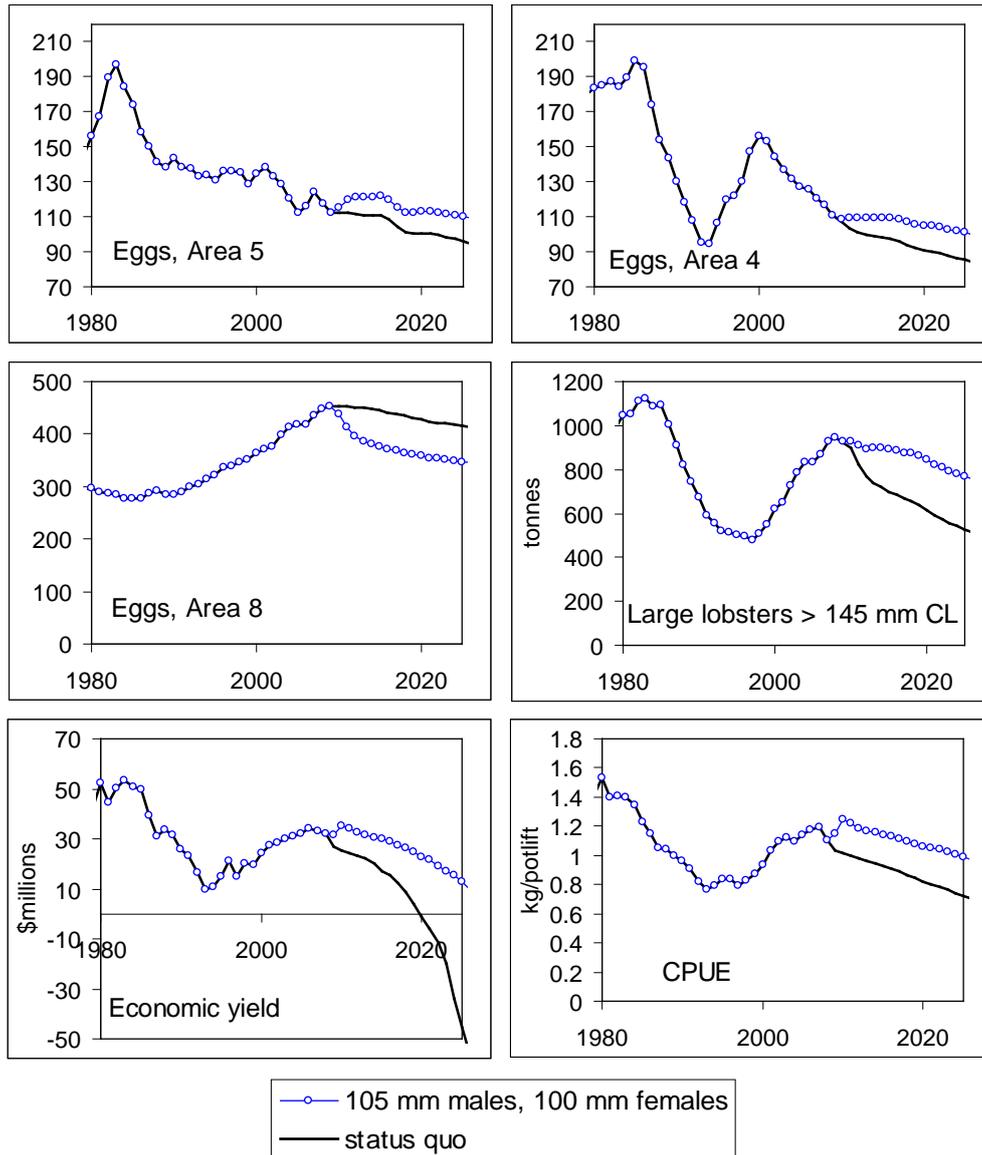
Biomass of large lobsters on the east coast would be enhanced because greater yields from the south west would drag effort from elsewhere and reduce harvest rates across the broader fishery. This change potentially reduces risk of urchin barren formation off the east coast.

A smaller size limit in the SW was expected to increase economic yield, with the opportunity cost of current management estimated at \$440 million (discounted at 7.5% over 15 years). In addition, reducing size limits in the SW would provide fishers with increased capacity to choose to fish in areas with sizes of lobsters that the market demands.

The main disadvantages identified were that the change would require administration of different size limits for the SW. Many fishers were opposed to discussion of smaller size limits in the SW as they mistakenly assumed this implied a regional zone for quota. There was also concern that an increased capacity to harvest large volumes from the SW in early summer could flood markets and cause price falls.



**Figure 5-41.** The expected effect on catch in area 8 of reducing the size limit by 5mm for each sex in Area 8 only. Catch would initially spike as catch rates would be very high, then stabilize at a slightly higher level than the status quo scenario because the smaller limits are better suited to the biology of lobsters from that region.



**Figure 5-42.** The effect on indicators of sustainability of reducing the size limit by 5mm for each sex. Status quo TACC at this time was 1470 t. Egg production was expected to increase in northern areas towards management targets, while egg production in southern areas is expected to fall but remain very high nonetheless and above management targets. Statewide catch rates are expected to rise. Abundance of large lobsters is expected to rise substantially thus reducing risk of urchin barren formation. Economic yield would rise sustainably, with a NPV increase of \$440 million discounted over 15 years.

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#### 5.4.2 Evaluation of regional regulation in South Australia with an emphasis on size limits

Published as “Assessing the effectiveness of size limits and escape gaps as management tools in a commercial rock lobster (*Jasus edwardsii*) fishery Fisheries Research 111:1-7 A. LINNANE, S. PENNY, M. HOARE, P. HAWTHORNE

##### Summary

Minimum legal sizes are a commonly used management tool within commercial lobster fisheries. This study examined its' effectiveness within the spatially expansive (~207,000 km<sup>2</sup>) northern zone rock lobster (*Jasus edwardsii*) fishery of South Australia. Firstly, spatially explicit estimates of size of maturity and relative reproductive potential were estimated to examine if the current minimum legal size of 105 mm carapace length (CL) was appropriate. Size of maturity ranged from 105 to 118 mm CL with 90% of reproductive potential coming from size classes above 105 mm CL. As maturity is age, rather than size dependent, these results may reflect differences in growth rates and highlight the importance of considering spatial variation in reproductive characteristics when applying size limits to lobster resources.

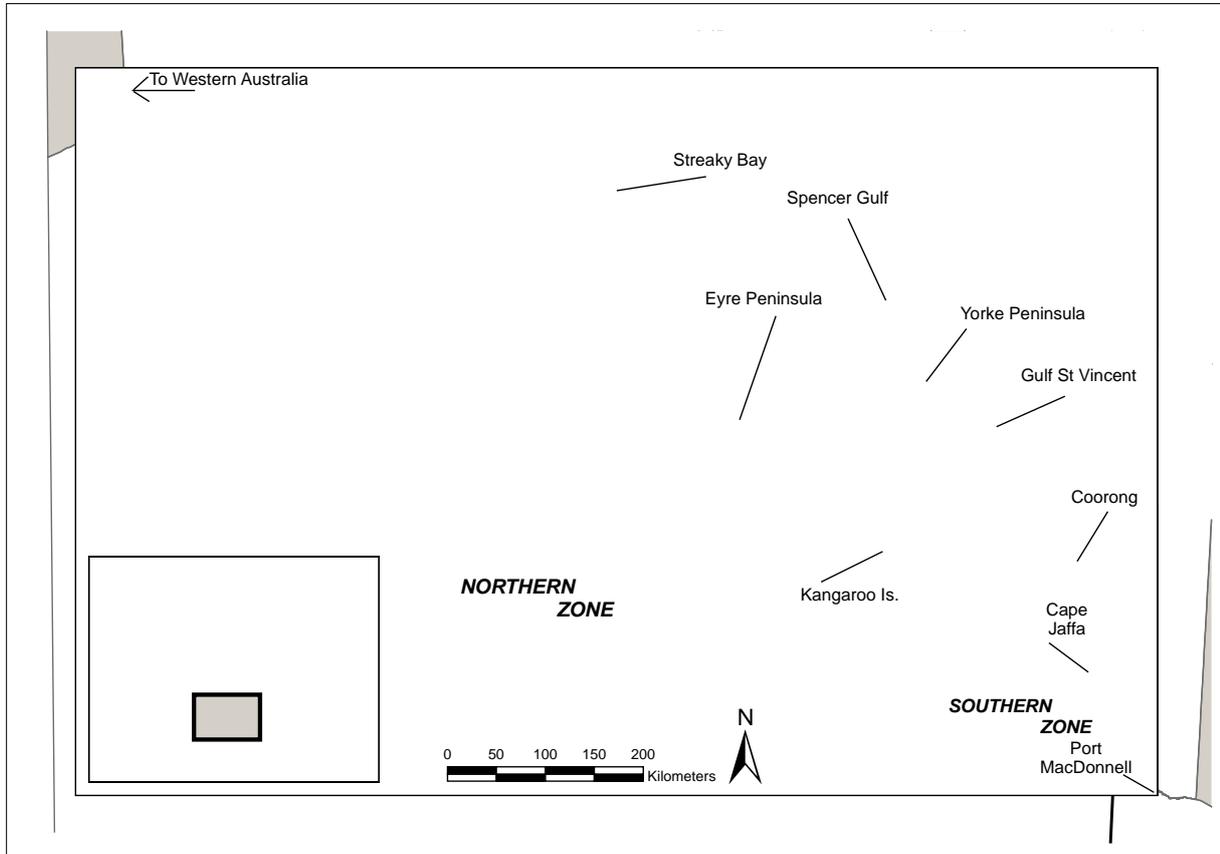
##### Introduction

The commercial fishery for southern rock lobster (*Jasus edwardsii*) is one of South Australia's most valuable fishery resources, worth in excess of AUS\$100 million annually (Knight and Tsolos 2009). Fishing is undertaken from October to May of the following year with an annual catch of 1,810 tonnes recorded during the 2008/09 season (Linnane et al. 2010). The fishery is divided into both Northern and Southern management zones, which are in turn sub-divided into Marine Fishing Areas (MFAs) for stock assessment purposes (Figure 7-43). Since the 1970s, the fishery has been managed under a range of both input and output controls. These include temporal and spatial closures, limited entry and gear restrictions (Sloan and Crosthwaite 2007). In addition, a total allowable commercial catch (TACC), in the form of individual transferable quotas, was introduced into the Southern zone in 1993 and the Northern zone in 2003. TACCs are set annually based on commercial catch rate trends as well as outputs from specifically developed stock assessment fishery models (McGarvey et al. 1997; Punt and Kennedy 1997).

This research was undertaken in the Northern zone rock lobster fishery which runs from the Coorong region to the Western Australia border (Figure 7-43). The zone is expansive, covering an area of ~207,000 km<sup>2</sup>. However, reef communities and habitats for lobsters are isolated, being confined to relatively small outposts of igneous rocks, particularly granites, which are interspersed by large expanses of sand.

The status of the Northern zone fishery has declined substantially over the last ten seasons. From 1998-2008, total catch decreased by 60% from 1015 to 403 tonnes. Catch rate decreased by 52% from 1.40 to 0.67 kg/potlift over the same period. As a

result of decreasing trends in fishery performance, the TACC was reduced from 625 tonnes in 2003, to 310 tonnes for the 2009 season.



**Figure 5-43** Northern and Southern Zone rock lobster fisheries of South Australia. Numbers show location of marine fishing areas (MFAs).

Prior to the introduction of the TACC system, limitations to days-at-sea and pot holding restrictions were the primary management tools in the fishery. In addition, a single minimum legal size (MLS) of 98.5 mm CL was introduced in 1966 which was gradually increased to 105 mm CL by 2000. However, despite the expansive nature of the zone, spatial variation in relation to size of maturity (SOM), which ultimately impacts on the MLS, was not accounted for. This is important, given that SOM has been shown to vary substantially within the smaller (24,000 km<sup>2</sup>) Southern zone fishery (Linnane et al. 2008b; Linnane et al. 2009).

The aim of this study was to investigate spatial variation in size of maturity (SOM) and relative reproductive potential (RRP) across the main MFAs of the fishery to assess the appropriateness of a single MLS within the zone.

## Detailed Methods

### *Study areas and data collection*

The size of maturity and relative reproductive potential analyses were undertaken in the ten Northern zone MFAs where over 90% of the catch is taken annually i.e. MFAs 7, 8, 15, 27, 28, 39, 40, 48, 49 and 50 (Figure 5-43). These MFAs run from west to

east and cover fishing grounds that extend from west of the Eyre Peninsula through to the Coorong region east of Kangaroo Island. The data were entirely fishery dependent. Since 1991, scientific observers and commercial fishers from the South Australian rock lobster fishery have collaborated in an at-sea voluntary catch sampling program. Fishers are requested to count, measure (mm CL), sex and record the reproductive condition of lobsters from up to 3 research pots per fishing trip. In total, 76,761 females were sampled across the 10 MFAs over the period 1991 – 2008 (Table 5.10).

**Table 5.10** Parameters for logistic function ( $P_m = 1/[1 + e^{-(a-bCL)}]$ ) fitted data for each Marine Fishing Area (MFA) of the northern zone rock lobster fishery.

| MFA | n     | a ±SE       | b ±SE      | L <sub>50</sub> (mm CL) |
|-----|-------|-------------|------------|-------------------------|
| 7   | 1522  | 14.62 ±3.59 | 0.13 ±0.03 | 113.1                   |
| 8   | 2055  | 12.58 ±1.10 | 0.11 ±0.01 | 112.4                   |
| 15  | 4894  | 16.40 ±1.20 | 0.15 ±0.01 | 108.4                   |
| 27  | 2665  | 17.01 ±2.31 | 0.16 ±0.02 | 106.8                   |
| 28  | 14797 | 18.42 ±2.09 | 0.18 ±0.02 | 104.6                   |
| 39  | 20386 | 9.28 ±3.19  | 0.08 ±0.03 | 109.9                   |
| 40  | 4822  | 14.26 ±5.14 | 0.12 ±0.04 | 118.0                   |
| 48  | 9096  | 16.17 ±0.60 | 0.15 ±0.01 | 107.2                   |
| 49  | 13487 | 14.34 ±2.57 | 0.14 ±0.02 | 105.7                   |
| 50  | 3037  | 16.86 ±0.63 | 0.16 ±0.01 | 105.1                   |

#### *Size of maturity*

All female lobsters were pooled according to MFA of capture. A female rock lobster was categorised as “sexually mature” if it possessed either eggs or ovigerous setae (Wenner et al. 1974). The percentage of sexually mature female rock lobsters was plotted against carapace length in each 1 mm CL size class and then fitted, using a SAS non-linear modelling procedure, to the logistic equation:

$$P_m = \frac{1}{[1 + e^{(a-b.CL)}]}$$

where  $P_m$  is the proportion of mature female rock lobsters,  $CL$  is the carapace length,  $e$  is the inflexion point of the curve and  $a$  and  $b$  are constants.

#### *Relative reproductive potential*

The relative reproductive potential (RRP) is defined by Morgan (1972) and later modified by (1997) by the relationship:

$$P_i = C_i^f . M_i . F_i$$

where  $P_i$  is the relative reproductive potential for size class  $i$ ,  $C_i^f$  is the sampled proportion in size class  $i$  of females in the commercial catch,  $M_i$  is the percentage of mature female rock lobsters at size class  $i$ , and  $F_i$  is the fecundity of female rock lobsters at size class  $i$ .

#### *Fecundity*

The majority of *J. edwardsii* larvae generally hatch from September – November across the range of the species (MacDiarmid 1991). In the Northern zone fishery of

South Australia, approximately 5-10% of females caught annually in November are ovigerous (Linnane et al. 2009). A total of 28 ovigerous females were sampled from MFAs 48 and 49 in Northern zone in November of the 2007/08 season.

Each female was individually measured, tagged, bagged and frozen after collection. On processing, the eggs were removed from the setae and pleopods and any excess water drained before oven drying for 48 hours at 50 °C (Hobday and Ryan 1997). Samples containing a large proportion of ruptured eggs after drying were discarded. For each egg mass sample, the total dry weight was determined. Three 0.04g sub-samples were hydrated in 75% ethanol and enumerated under a dissecting microscope.

For each sub-sample, fecundity ( $F$ ) was calculated according to the equation:

$$F = (W_t / W_s) \cdot E$$

where  $W_t$  is the total dry weight,  $W_s$  is the subsample weight, and  $E$  is the egg count of the sample. Data from all subsample estimates were then fitted, using a SAS non-linear modelling procedure, to the equation:

$$F = a \cdot CL^b$$

Where  $CL$  is the carapace length (mm) and  $a$  and  $b$  are constants.

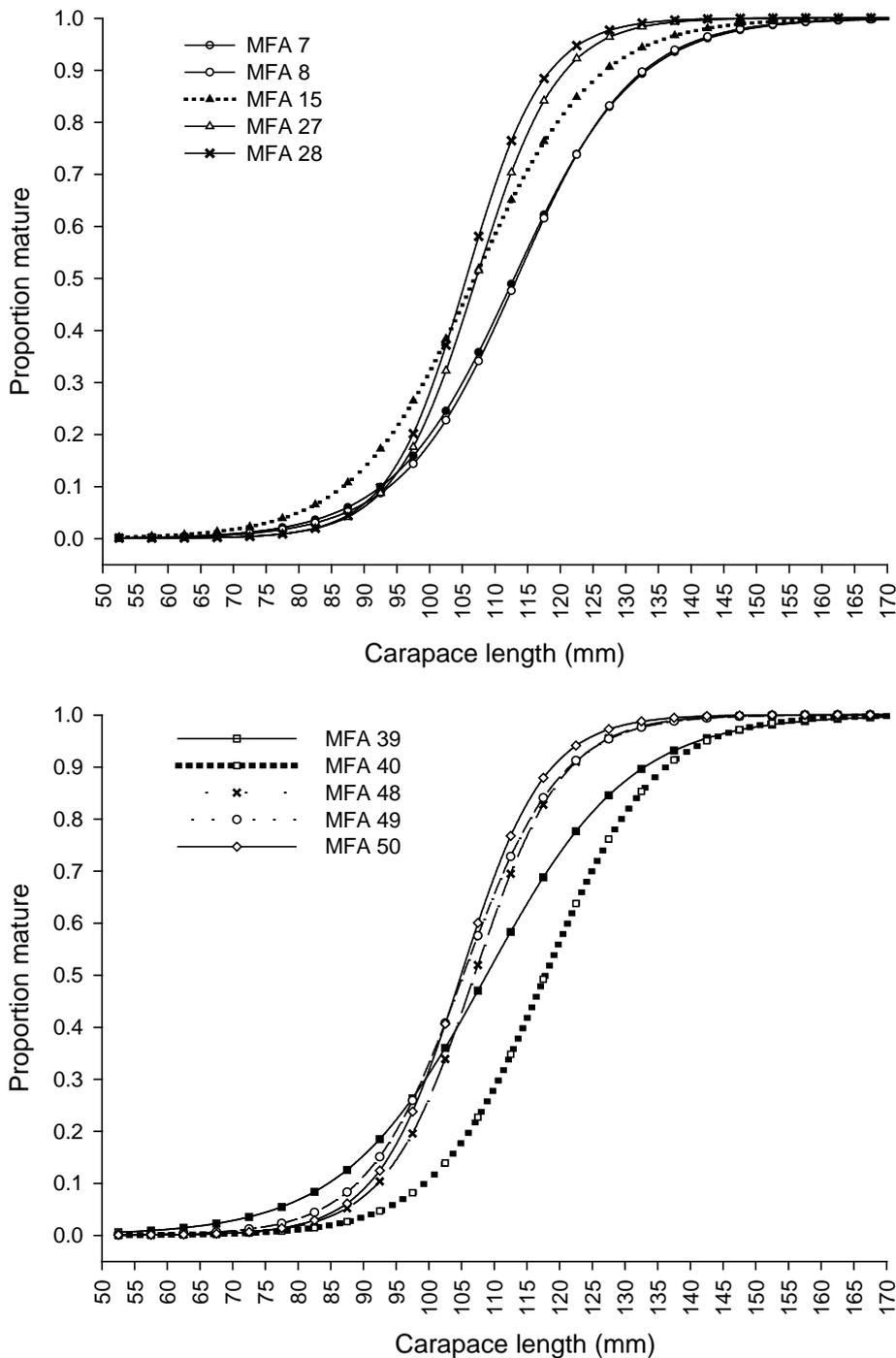
## Results

### *Size of Maturity*

The size at which 50% of female rock lobsters were sexually mature ( $L_{50}$ ) varied spatially (Table 5.10 and Figure 5-44). The  $L_{50}$  logistic curves for the proportion of mature female rock lobsters as a function of carapace length sampled from the western (top) and eastern (bottom) Marine Fishing Areas (MFAs) of the Northern zone rock lobster fishery. In general, SOM increased from east to west being highest in MFAs 7 and 8 and lowest in MFAs 48, 49 and 50 (with the exception of MFA 40). In relation to the MLS,  $L_{50}$  estimates were close ( $\pm < 1$  mm CL) to 105 mm CL in MFAs 28, 49 and 50 indicating that the legal size is appropriate in these areas. Similarly, MFAs 15, 27, 39 and 48 all had  $L_{50}$  estimates below 110 mm CL. However, in MFAs 7 and 8,  $L_{50}$  estimates were substantially higher than at 113.1 and 112.4 mm CL respectively. MFA 40 had the highest  $L_{50}$  estimate at 118 mm CL.

### *Fecundity*

The low sample size ( $n = 28$ ) was not sufficient to generate a size-fecundity curve across the appropriate size ranges. However, previous studies have confirmed that *J. edwardsii* size-specific fecundity does not vary spatially within South Australia (Linnane et al. 2008b). As a result, data from a previous study undertaken in the Southern zone were pooled with current data from the Northern region to generate a size fecundity curve for females ranging between 86.6 and 148.1 mm CL (Figure 5-45).



**Figure 5-44.** The  $L_{50}$  logistic curves for the proportion of mature female rock lobsters as a function of carapace length sampled from the western (top) and eastern (bottom) Marine Fishing Areas (MFAs) of the Northern zone rock lobster fishery.

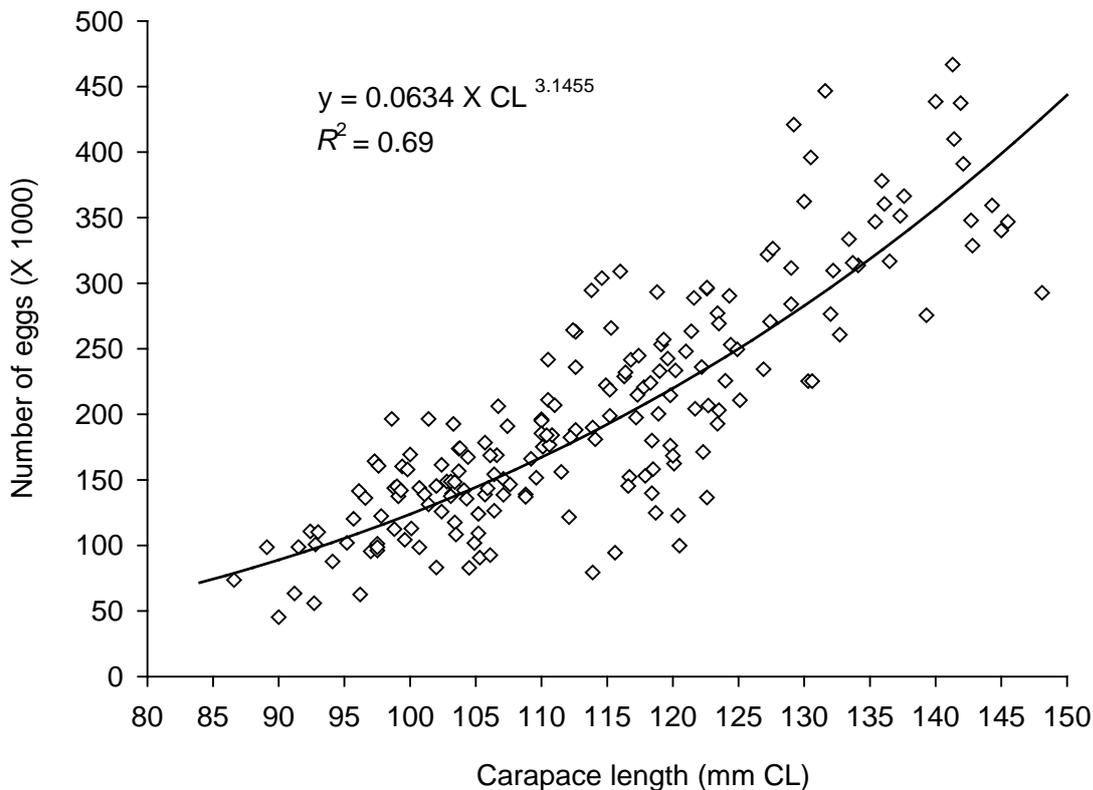
Using combined data from both zones, egg mass weight varied from 4.34 to 41.5 g with the power function relating egg mass weight to body size following the relationship: egg mass weight =  $8 \times 10^{-6} \times CL^{3.0728}$ ,  $R^2 = 0.66$ ;  $n = 190$ . The mean number of eggs per female ranged from 45,292 for a 90.0 mm CL to 466,800 for a

141.3 mm CL lobster. Fecundity (F) varied with CL according to the relationship:  $F=0.0634 \times CL^{3.1455}$ ,  $R^2 = 0.69$ ;  $n = 190$ .

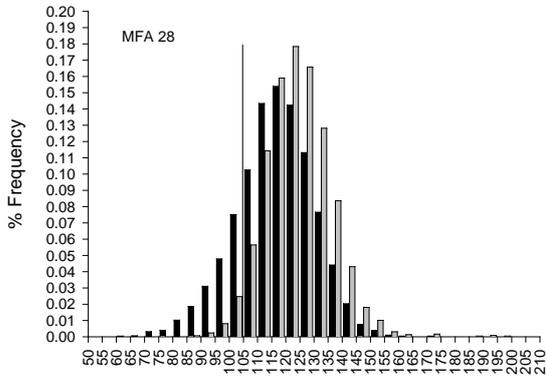
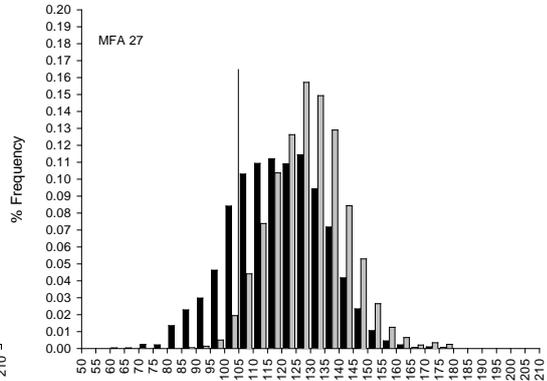
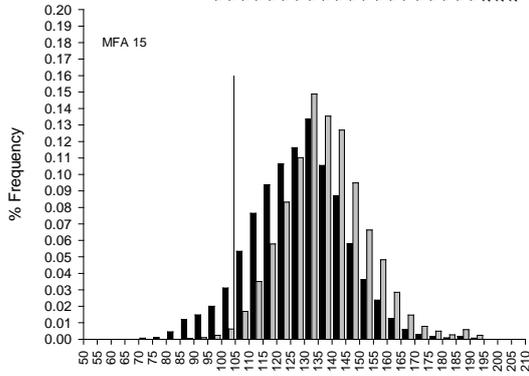
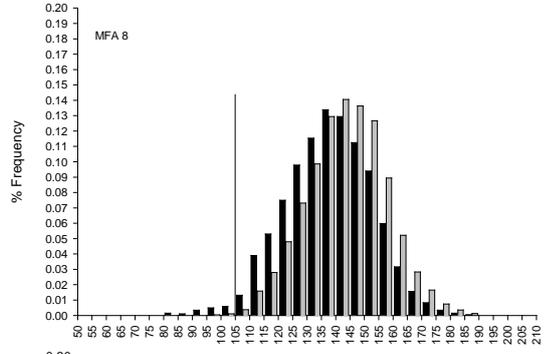
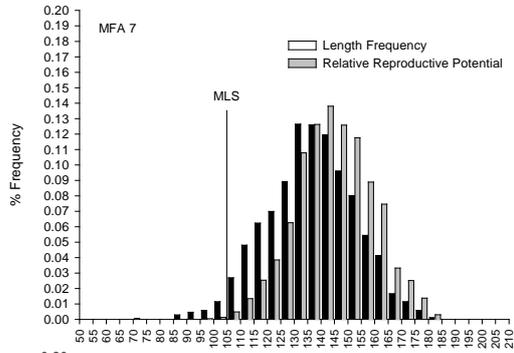
#### *Relative reproductive potential*

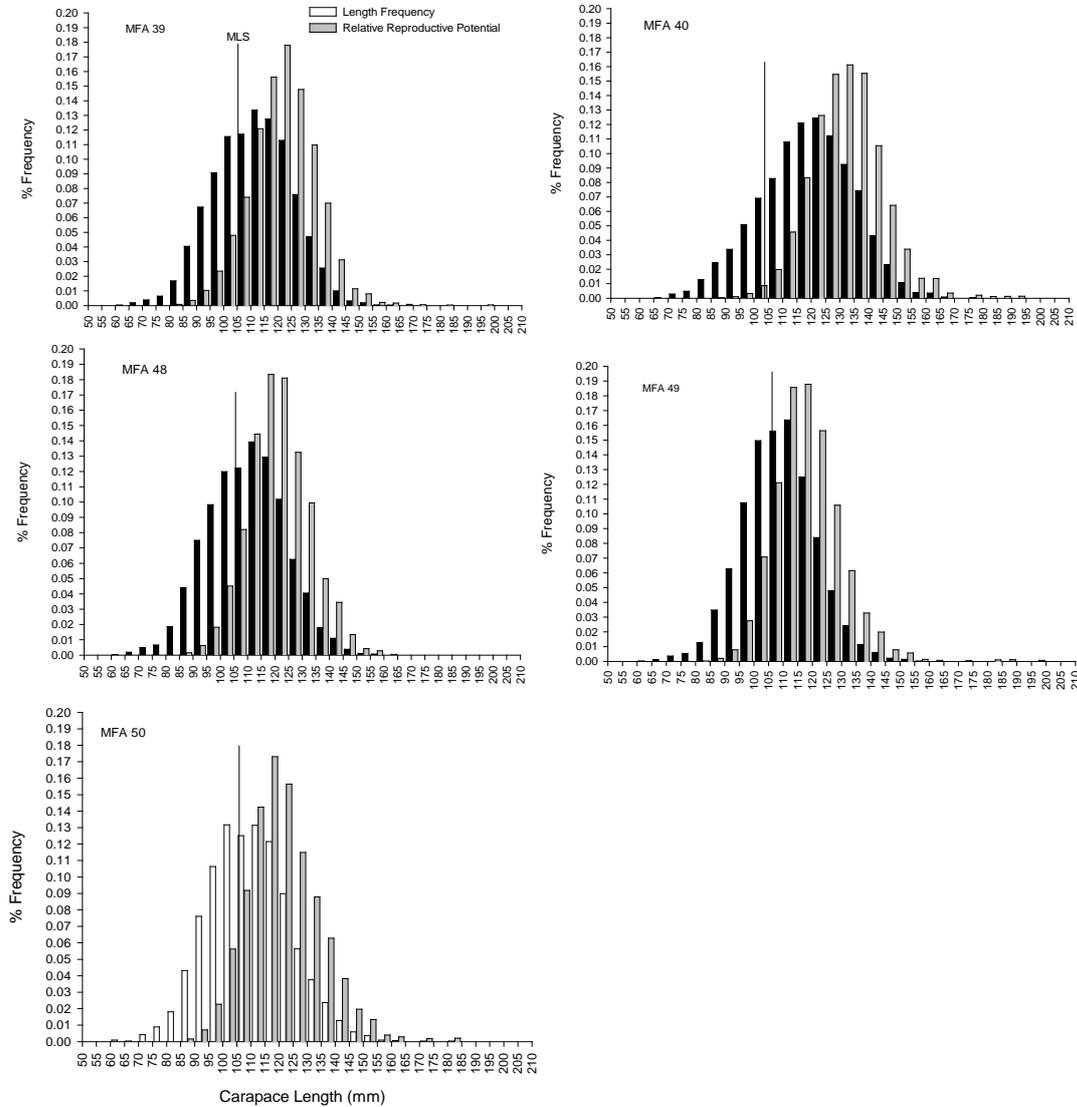
As with SOM, there was a distinct spatial trend in the size classes contributing to RRP across the fishery (Figure 5-46). In the western MFAs, reflecting larger SOM values, the reproductive potential was highest in the size classes above the MLS. For example, in MFAs 7 and 8, 99% of RRP was contributed by size classes above 105 mm CL. In both these MFAs, ~98% of the catch is also taken from size classes above the MLS. Within MFAs 15, 27 and 28, the percentage of RRP in size classes below the MLS increases marginally (e.g. ~3% in MFA 28) but the majority of RRP remains above 105 mm CL.

Within the eastern region of the NZ, the percentage of RRP contributed by size classes below the MLS increases but still remains low overall. For example, 8-10% of all RRP comes from size classes below the MLS in MFAs 48, 49 and 50. In all eastern MFAs, over 60% of RRP came from the 115 – 135 mm CL size classes.



**Figure 5-45** Size–fecundity relationship with fitted power model for female southern rock lobsters from both northern and southern fishing zones of South Australia (Southern zone data from Linnane et al., 2008).





**Figure 5-46** Relative reproductive potential in relation to carapace length (CL) plotted with the length frequency distribution of the commercial landings from the western (top) eastern (bottom) Marine Fishing Areas (MFAs) of the Northern Zone rock lobster fishery

**Discussion**

It is generally accepted that the purpose of a minimum legal size in lobster fisheries is to allow individuals to reproduce at least once before reaching their exploitable size (Chubb 2000). SOM and the relative reproductive potential of size classes in females are two key biological features which help to determine appropriate limits. However, when applying such limits to fisheries, it is important to consider possible spatial variations in both of these reproductive parameters.

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This study has shown that within the Northern Zone rock lobster fishery of South Australia, SOM varies between 105 to 113 mm CL depending on the region. Other commercially important fisheries for *J. edwardsii* have also shown distinct spatial variations in relation to female sexual maturity. For example, in Tasmania SOM varies from 59 mm CL in southern regions to 112 mm CL in areas further north (Gardner et al. 2006a). Conversely in New Zealand, SOM increases from north to south and ranges between 72 mm to 121 mm CL (Annala et al. 1980; MacDiarmid 1989). With Victoria, SOM tends to increase from west to east being 90 mm CL in the western zone fishery compared to 112 in the eastern region (Hobday and Ryan 1997). Within the Southern Zone fishery of South Australia, *J. edwardsii* SOM tends to increase from 92 mm CL in southern areas to 104 mm CL in the northern part of the fishery (Linnane et al. 2008b). Distinct spatial differences by depth were also observed in the Southern Zone where females from deepwater sites (>100m) matured at 68 mm CL compared to 103 mm CL for those sampled within inshore (<60 m) grounds (Linnane et al. 2009).

Despite obvious differences, the processes driving spatial variation in SOM within *J. edwardsii* are not clearly understood. As SOM in spiny lobsters appears to be age, rather than size specific (Beyers and Goosen 1987), temperature, acting on growth and ultimately SOM, has long since been considered. Specifically, it is assumed that growth rates are slower and therefore SOM lower, in regions where water temperatures are cooler. Gardner et al. (Gardner et al. 2006a) concluded that the spatial pattern in SOM was positively correlated with changes in water temperature around Tasmania where SOM decreased with increasing latitude and decreased temperatures (Cresswell et al. 1983) from north to south.

Similarly, the increases in SOM across South Australia from south to north may also reflect known regional differences in temperature. The southern region of the Southern Zone, where SOM is lowest, experiences an annual coldwater upwelling event known locally as the Bonney upwelling (Schahinger 1987). During summer the predominant south-easterly winds result in an upwelling of nutrient-rich, cold water (11-12°C) which intrudes onto the continental shelf. This coldwater upwelling tends to be confined to southern regions of South Australia and only occasionally impacts northern regions (McClatchie et al. 2006). The resulting temperature gradient reflects known growth rates of *J. edwardsii* across the State (McGarvey et al. 1999) with SOM being lowest at 93 mm CL in the southern MFAs of the Southern Zone and as observed in the current study, highest at 113 mm CL in MFA 7, located in the northern region of the Northern Zone.

It is important to note however that decreasing temperature with latitude does not always reflect decreases in SOM. For example, In New Zealand, the opposite appears with SOM negatively correlated with temperature (Annala et al. 1980) thus suggesting that other factors are contributing. Density dependence has been suggested but it should be highlighted that Gardner et al. (2006) tested this hypothesis by comparing SOM estimates from two high density marine reserves adjacent to fished sites; however, there was no evidence of a decline in SOM with increasing density as predicted. Other mechanisms suggested as possible drivers of spatial variation in SOM in lobster populations include habitat type (Howard 1980), fishing pressure (Lizarraga-Cubedo et al. 2003) and social interactions (Thomas et al. 2003).

The findings in relation to spatial variations in SOM across the Northern Zone fishery have possible implications in terms of resource management. The most recently published management plan for the fishery (Sloan and Crosthwaite 2007) highlights the importance of regional management to account for known spatial variation in biological characteristics. Currently, a TACC is the primary management tool with separate spatially defined quotas being proposed for the start of the 2011/12 fishing season. However, this study highlights that regional variations in legal sizes are also important given the spatial variations in SOM. Specifically, while the current MLS of 105 mm CL may be appropriate for MFAs in the eastern part of the fishery, higher MLS (>110 mm CL) should be considered for MFAs in the western region of the zone.

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## 5.5 Translocation

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### 5.5.1 *Survival after translocation*

Published as Green, B. S., and Gardner, C. 2009. *Surviving a sea-change: survival of southern rock lobster (*Jasus edwardsii*) translocated to a site of fast growth.* – *ICES Journal of Marine Science*, 66: 656-664.

#### **Summary**

In an experiment aimed at increasing the yield and value of the fishery for southern rock lobster (*Jasus edwardsii*), 1998 pale and slow-growing lobsters were translocated to sites where lobsters grow faster naturally and develop higher value market traits. Survival of lobsters in their new habitat was critical to the viability of this experiment. To estimate survival, the release site was surveyed every 1–3 months for two years. Apparent survival of translocated lobsters was compared with survival of resident lobsters tagged in a similar period using Cormack–Jolly–Seber modelling on mark–recapture data. Lobster survival was not influenced by size, gender, or origin (translocated or resident) alone. The four most parsimonious models suggested slightly lower apparent survival in translocated lobsters immediately after release compared with all other lobsters, but support for these models was weak ( $\Delta\text{QAICc}$  weights 62%). The differences in apparent survival were not likely to be significant because of large variance when averaged over all the models. Apparent survival of newly released translocated lobsters was 92% (72–98, 95% CI) compared with 97% (95–98, 95% CI) for all other lobsters. Potential sources of differences in survival are movement from the release site or greater predation on pale lobsters. Losses of lobster through release mortality were low and unlikely to influence the feasibility of translocation as a tool to enhance the value of the fishery, although it would be prudent to include 5% mortality of translocated lobsters in future models of translocation feasibility.

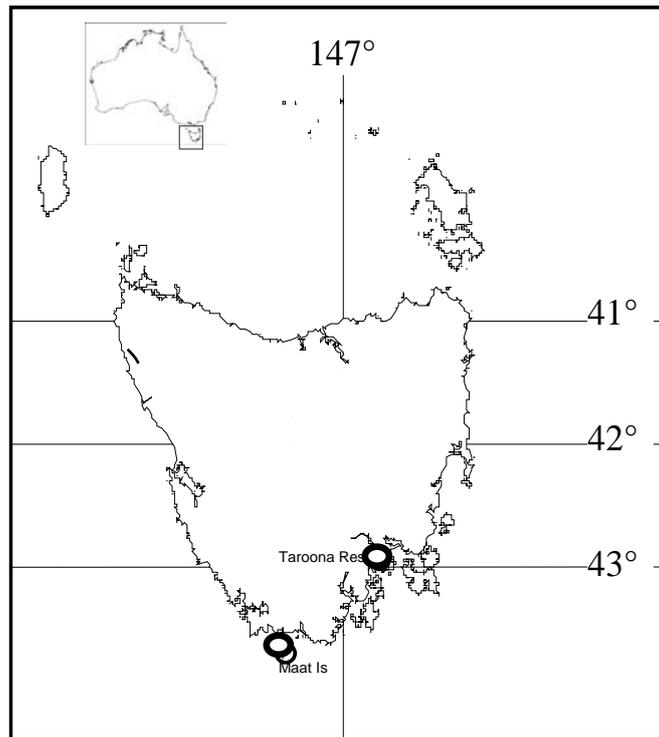
#### **Detailed Methods**

In all, 1012 resident lobsters at Taroom Reserve (Figure 5-47) were captured and tagged over ten days of sampling in January 2005, using the same method as for the translocated lobsters described above. Because of relatively low catch rates in the Taroom Reserve, more sampling effort was required over a longer period to capture and tag a similar number of lobsters as the translocated lobsters. During sampling for recaptures, all unmarked individuals were tagged and included in the mark–recapture analysis to increase the sample size, resulting in the ongoing tagging of residents (but not translocated animals, because translocation was a one-off event). There was a 9-month delay between the initial tagging of translocated and resident lobsters owing to the logistical constraints of field sampling.

After the translocation release in November, the Tarooma Reserve was resampled on nine occasions for resident and translocated lobsters, with the first resample two months after the release of the translocated lobsters (Table 5.11). During those sampling trips, a further 1656 resident lobsters were tagged, measured, and included in the analysis. For each re-sampling trip (except those in January), 20 baited pots (as above) were deployed haphazardly across the 600 m<sup>2</sup> of rocky reef within the Tarooma Reserve on each of four nights. Sampling effort was increased once per year as part of an ongoing sampling programme in the Tarooma Reserve, so in January of each year, 60 baited pots were deployed each night for seven nights in a grid layout in order to cover an area of 1000 m × 700 m. The grid was based on a numbered GIS grid. Pots were checked each morning and redeployed. All lobsters were measured for carapace length (CL), checked for a tag, and the gender recorded. Lobsters were released back to their capture site immediately after tagging.

**Table 5.11** Sampling catch and effort for *Jasus edwardsii* in the Tarooma Reserve, Tasmania, Australia, January 2006 – July 2007.

| Sampling start date | Effort (days) | Effort (pot lifts) | Number caught |              |
|---------------------|---------------|--------------------|---------------|--------------|
|                     |               |                    | Resident      | Translocated |
| 17 January 2006     | 9             | 548                | 719           | 187          |
| 28 February 2006    | 4             | 237                | 167           | 36           |
| 27 April 2006       | 8             | 100                | 71            | 26           |
| 31 July 2006        | 4             | 80                 | 141           | 46           |
| 26 September 2006   | 4             | 79                 | 134           | 36           |
| 07 November 2006    | 4             | 79                 | 105           | 32           |
| 10 January 2007     | 7             | 419                | 1 011         | 149          |
| 17 April 2007       | 4             | 80                 | 165           | 17           |
| 17 July 2007        | 4             | 80                 | 319           | 34           |



**Figure 5-47** Map of Tasmania, Australia, with the two study sites marked with circles: Maatsuyker Island, a southern, deep-water site, and Tarooma Reserve, the shallow, more northern site where lobsters were released for sea ranching. Inset is a map of Australia.

### *Estimating survival*

Maximum likelihood methods were used to estimate the conditional probability of apparent survival and resighting of translocated and resident lobsters. Survival ( $\phi$ ) and resighting ( $p$ ) estimates of lobsters were calculated using Cormack–Jolly–Seber (CJS) mark–recapture estimates (Cormack 1964; Jolly 1965; Seber 1965) and analysed with the program MARK (White and Burnham 1999). These modelling procedures were not hypothesis testing activities, but rather a comparison of a series of reduced models chosen a priori to establish which model best described the variability in the data and was biologically meaningful (Lebreton et al. 1992).

The modelling process commenced with testing the goodness-of-fit (GOF) of the most parameterized model with time-, origin- (translocated or resident), gender- (male or female), and size (small or large) dependence for survival. A parametric bootstrapping approach and the application of the program Release were used to test GOF. As minor overdispersion of data was detected, a variance inflation factor ( $\hat{c}$ ) was calculated to adjust the sensitivity of the model-selection process to the detection of fine-scale structural features within the data (Anderson et al. 1998). The variance inflation factor  $\hat{c}$  was estimated to be 1.89 by dividing the observed model  $\hat{c}$  by the mean  $\hat{c}$  from a bootstrap analysis used to examine the data for goodness-of-fit. Models were selected through an iterative process of pairwise comparisons between the parsimony of a starting model and that of related but simplified models from the candidate set. The

minimum value of the quasi-likelihood form of the Akaike Information Criterion,  $QAIC_c$ , was used to select the simplest adequate model of the hierarchy of possible models, incorporating where necessary the variance inflation factor ( $\hat{c}$ ) to allow for minor overdispersion in the data (Burnham et al. 1995; Anderson et al. 1998). This criterion is calculated as

$$QAIC_c = -2\ln L/\hat{c} + 2K + 2K(K + 1)/(n - K - L), \quad (1)$$

where  $\ln L$  is the log-likelihood for the model,  $\hat{c}$  the quasi-likelihood scaling parameter,  $K$  the number of separately identifiable model parameters, and  $n$  is the sample size (number of releases; (Burnham and Anderson 2002)). If the  $QAIC_c$  of the simplified model was lower than that of the starting model, the simplified model was adopted as the best general model against which further comparisons would be made. Although this method of model selection does not allow significance values to be attributed to tests between models, normalised  $QAIC_c$  weights provide a relative weight of evidence (support) for a particular model best describing the data (Burnham and Anderson 1998).  $QAIC_c$  weight is proportional to the differences between that model and the model set with the lowest  $QAIC_c$  (normalised to values which sum to 1), which lends to the interpretation of proportional support. Strong support for a model was interpreted as a high  $QAIC_c$  weight, and no support was assumed when the  $QAIC_c$  weights were 0.

Additionally,  $\Delta QAIC_c$  was used to interpret models and the likelihood of each model best representing the data further. If  $\Delta QAIC_c$  was  $<2$ , then those models had approximately equal weight in the data and were considered to have an equal likelihood of correctly describing the data; if  $\Delta QAIC_c$  was  $>2$ , then the models were considered to be sufficiently different (Burnham and Anderson 1998). Where support ( $QAIC_c$  weight) was not strong for the top model, model averaging was used to account for the uncertainty in model selection.

One constraint of mark–recapture models that rely on tag-resighting data for survival estimates is that the estimates are confounded by events such as tag loss or emigration that lead to a tag becoming unavailable for resighting. In our study, survival estimates from this method are apparent rather than actual, because the release site was open to movement, which introduces the possibility that estimated “mortality” may in reality be movement of live lobsters away from the sampling area. For this reason, we examined relative patterns in survival of translocated lobsters compared with resident lobsters, which were also able to move away from the release site. The analysis assumed that resident and translocated lobsters had equal emigration probability and that there were unequal resighting probabilities ( $p$ ) for each survey event owing to differences in sampling effort (pot lifts) and seasonal variation in catchability of rock lobsters (Lebreton et al. 1992). The former assumption was based on preliminary results from an acoustic tracking study that suggested that resident and translocated lobsters had the same rates of retention within a site. In addition to the standard CJS

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assumptions that (i) every marked animal in the population has the same probability of recapture, (ii) every marked animal has the same probability of surviving, (iii) marks are not lost or missed, and (iv) all samples are instantaneous and each release is immediately after sampling, there were the following additional assumptions in this analysis: (v) there was no impact of person (tagger) on tag loss, (vi) tag loss was equivalent between translocated and resident animals, (vii) season and period at large had no effect on tag loss, and (viii) moulting period is equivalent between sexes (although not timing).

Translocated and resident lobsters were tagged at different times owing to the logistic constraints of field sampling. Male and female rock lobsters moult at different times of the year, but at the same frequency. Females moult in April and May, males in September and October. Our sampling encompassed two moults for each sex. The possible effects of moulting at different times were examined by the inclusion of gender into the models.

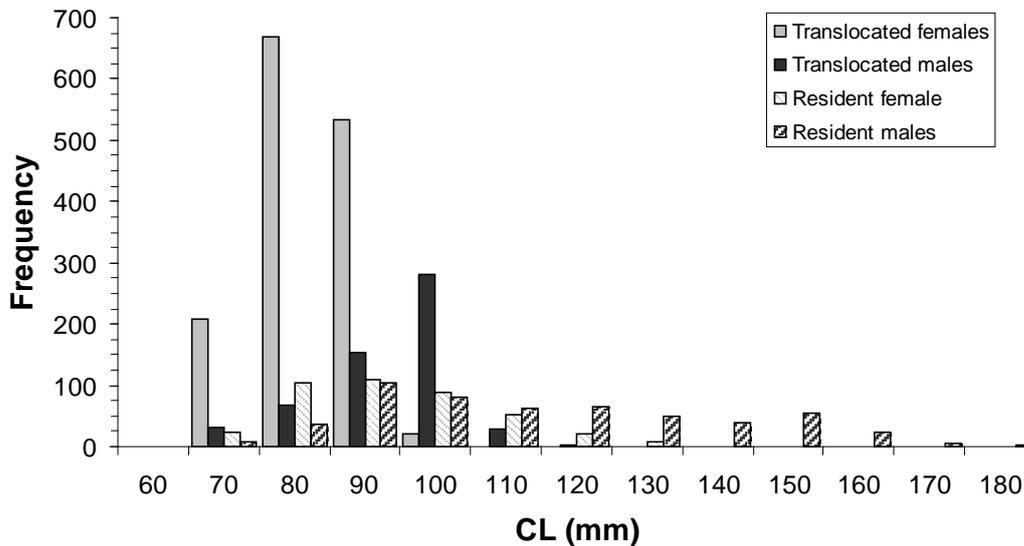
We examined models that compared the monthly survival of translocated lobsters with resident lobsters in the new habitat, then assessed whether gender or size influenced monthly survival rates of translocated lobster, and whether tagging influenced survival. To examine whether rock lobster demographics influenced monthly survival, we included lobster size (as CL) and gender as binomial attribute groups in the survival analyses, then tested for differences between and among groups. Gender was assessed as male or female, and size as small ( $\leq 110$  mm CL) and large ( $> 110$  mm CL, the LML for males). Two size classes were only available for resident lobsters, because 99.9% of the translocated animals were  $< 110$  mm CL.

To examine whether tagging *per se* influenced monthly survival, we examined survival of translocated lobsters two months after the initial tagging event and compared this with survival of resident and translocated lobsters throughout the subsequent sampling periods. We also examined the effect of moulting to assess whether exoskeleton colour (pale pre-moult cf. red post-moult of translocated lobsters) influenced survival. We assessed the effects of each attribute group (size, gender, and origin) and time, and the interactions of these factors on survival ( $\Phi$ ) and recapture probability ( $p$ ). Candidate models were ranked in order of most parsimonious based on the lowest QAIC<sub>c</sub> (Burnham and Anderson 1998). As the sampling time intervals were uneven, all time intervals were constrained to one month for comparison. The time between re-encounters does not have to be equal for the program MARK (White and Burnham 1999). The time interval was used as an exponent of the estimated survival rate to correct for the length of the time interval. In all, 30 models were tested, but only the top 18 based on QAIC<sub>c</sub> are presented for ease of presentation.

## Results

### *Size and recapture of tagged lobsters*

Of the 1998 *J. edwardsii* translocated from Maatsuyker Island to Tarooma Reserve in November 2005, 1433 were females and 565 were males (Figure 5-48). Translocated lobsters were smaller than Tarooma resident lobsters, and in lobsters from both locations, females were smaller than males (Figure 5-48). The mean size of translocated females was  $86.8 \pm 0.2$  mm CL, and of translocated males  $98.4 \pm 0.4$  mm CL. In comparison, the mean size of resident females was  $108.1 \pm 0.4$  mm CL, and of resident males  $135 \pm 0.6$  mm CL (Figure 5-48). In all, 1679 Tarooma resident males and 989 resident females were measured and tagged from January 2005 to July 2007, and 565 and 1433 translocated males and females, respectively, were moved from Maatsuyker Island in November 2005.



**Figure 5-48** Size frequency (carapace length) of resident (hatched bars) and translocated (solid bars) rock lobsters (*Jasus edwardsii*) tagged and released in the Tarooma Reserve. Resident *J. edwardsii* represented here are only those tagged in the Tarooma Reserve in January 2005, and translocated *J. edwardsii* were translocated from Maatsuyker Island in November 2005.

Almost 25% (457) of the translocated lobsters were resighted in the Tarooma Reserve over the subsequent 20 months of sampling (Table 5.12). A total of 1012 resident lobsters was tagged and released in January 2005 (Table 5.11), and over the subsequent resampling occasions, a further 1656 were tagged. In all, 2668 resident lobsters were tagged during the 30 months of sampling and more than 25% of these (797) were resighted at least once (Table 5.12).

**Table 5.12** The number of occasions that resident and translocated lobsters were resighted in Tarooma Reserve after tagging in January 2005 (resident) and November 2005 (translocation) up to July 2007. There were nine possible resighting occasions.

| Origin of lobsters | Number tagged | Number of occasions resighted |     |     |    |    |   |   | Resighted at least once |
|--------------------|---------------|-------------------------------|-----|-----|----|----|---|---|-------------------------|
|                    |               | 0                             | 1   | 2   | 3  | 4  | 5 | 6 |                         |
| Resident           | 2 668         | 1<br>871                      | 528 | 174 | 67 | 19 | 8 | 1 | 797                     |
| Translocated       | 1 998         | 1<br>541                      | 367 | 75  | 14 | 1  |   |   | 457                     |

### *Lobster survival*

From the 30 models tested, the most parsimonious CJS model was  $\phi(O_{1-2}^T; O_{3-10}^{TR})p(S*G*O*t)$ , i.e. lobster survival in Tarooma Reserve was different for translocated lobsters immediately after release and the same as residents thereafter, subsequently remaining constant through time (Model 1; Table 5.13). This model indicated that translocated lobsters had slightly lower rates of survival at release than residents at release and post-release (Figure 5-49a). However, this model did not get strong support (QAIC<sub>c</sub> weight 0.26), and was only about twice as likely as the next four models in the candidate set (Models 2–5; Table 5.13). Models 1–5 were all plausible models with similar likelihood and QAIC<sub>c</sub> weighting ( $\Delta$ QAIC<sub>c</sub> < 2; Table 5.13), so survival rates were estimated using model averaging (Figure 5-49b). Survival was not different between translocated lobsters at release and all other lobsters at or after release when averaged between models (Figure 5-49b). Estimated apparent monthly survival for translocated lobsters at release was 91% (71–98, 95% CI) compared with 97% (96–98, 95% CI) for all other lobsters at release and thereafter. Although the means of these two groups were different, there was high variance around the mean for translocated lobsters at release, so it is unlikely that this difference was significant. There was no apparent difference in lobster survival throughout the two years of sampling apart from the possible initial lesser survival in translocated lobsters (Figure 5-49b).

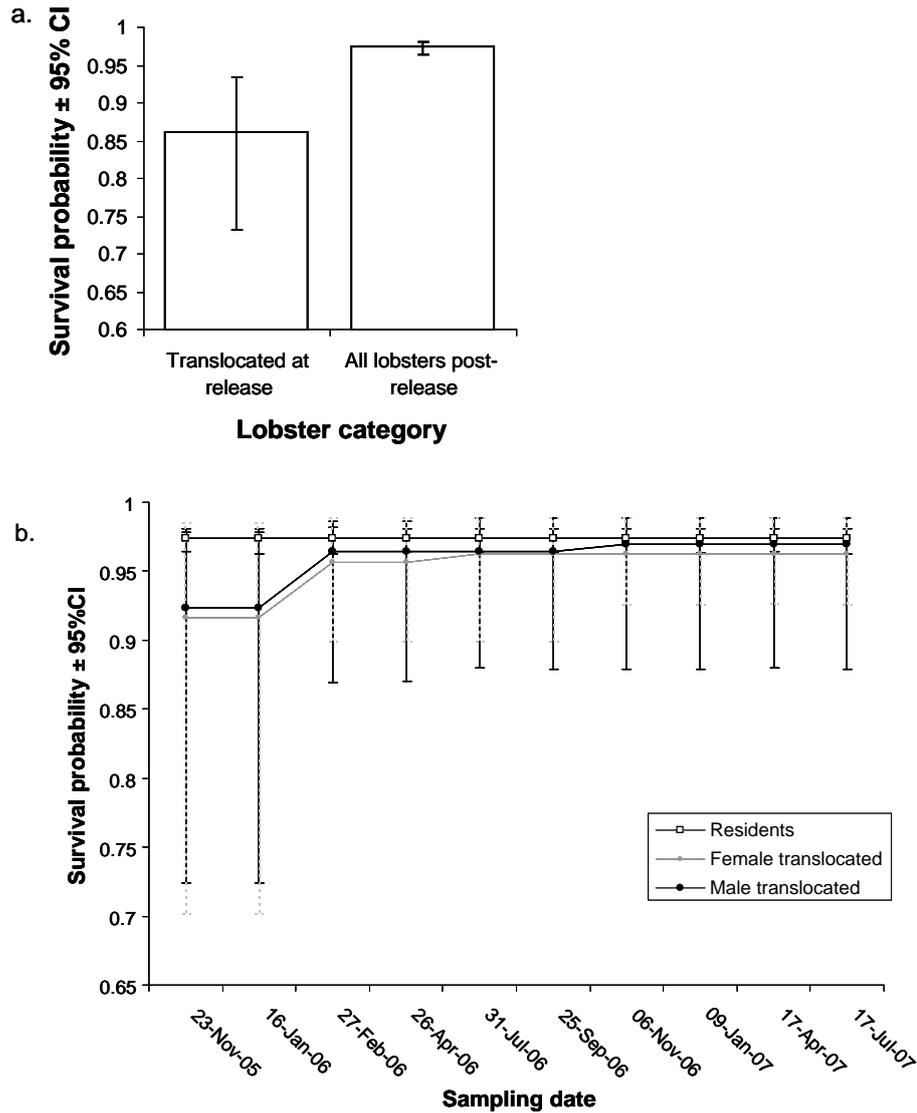
The relative importance to survival of lobster group attributes was explored by reducing the model terms and examining gender, origin, and size alone (Table 5.13, Models 2, 6, and 7). Lobster size, when compared as small and large lobsters delineated at 110 mm CL, was an unlikely source of variation in the dataset, because it had no support (QAIC<sub>c</sub> weight = 0) from the model based on QAIC<sub>c</sub>, and model parsimony was reduced by including size in fits (Table 5.13; Model 10 on). Lobster gender received little support either (Table 5.13; Model 6 on).

Translocated lobsters from deep water had pale shells, in contrast to the dark red shells of resident lobsters, but they changed from pale to red after moulting. The

hypothesis that paler shell colour influenced the lesser survival of translocated lobsters (because of greater visibility to predators) was explored by fitting different survival parameters for before and after the moult (Table 5.13; Model 2). Support for this model was low (QAIC<sub>c</sub> weight 0.15), but the model was ranked second most likely overall.

#### *Resighting probability*

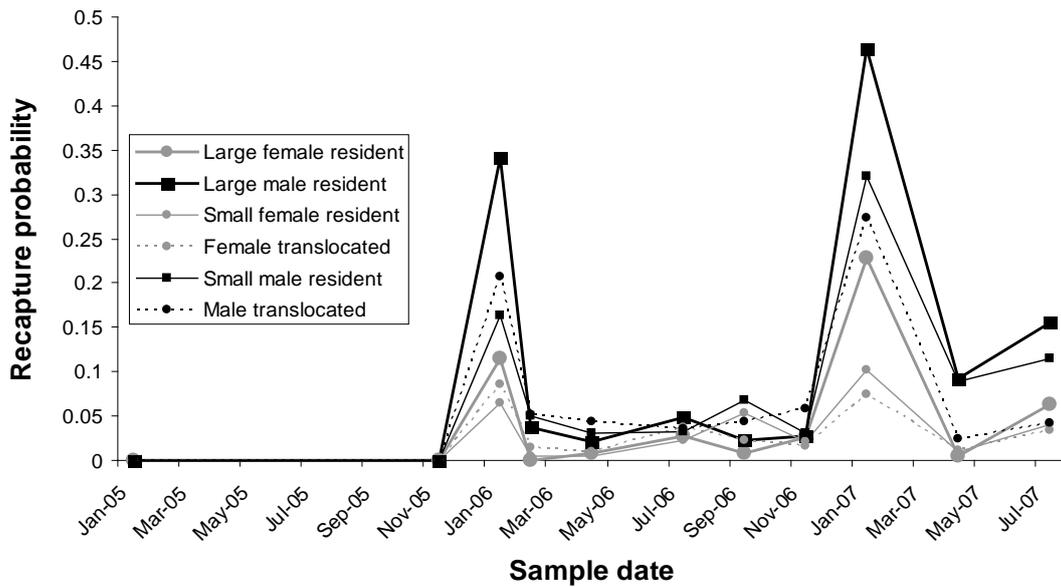
The top 11 models all indicated that resighting probability was a factor of time and attribute group (sex, origin, or size;). Resident lobsters had the greatest resighting probability, males were more likely to be resighted than females, and larger lobsters were more likely to be resighted than smaller animals (Figure 5-50). Monthly resighting probabilities were higher in December and January for all groups (Figure 5-50). Large male lobsters had up to 45% recapture probability.



**Figure 5-49** Monthly estimates of apparent survival of resident and translocated *Jasus edwardsii*. (a) Estimates derived from the most parsimonious model based on QAIC<sub>c</sub> alone  $\phi(O^T_{1-2}; O^T_{3-10}; O^R_{1-10})p(S*G*O*t)$ . (b) Survival estimates based on an average of Models 1–10. Residents were tagged in January 2005 and translocated animals were tagged and relocated in November 2005. Sampling occurred nine times after release. Error bars are 95% confidence intervals.

**Table 5.13** Model reduction summary of CJS estimates. Survival ( $\phi$ ) and resighting ( $p$ ) probabilities may be a function of group (size =  $S$ ; gender =  $G$ ; origin =  $O$ ), or time ( $t$ ). Subscripts refer to sampling periods (1–10); superscripts refer to resident ( $R$ ), translocated ( $T$ ), female ( $F$ ) or male ( $M$ ). A semi-colon separates the survival parameters in each model. Model QAIC<sub>c</sub>: a measure of the parsimony of each model. Model weight: a measure of the relative weight of evidence in support of a model and used for model averaging. #Par: the number of parameters in the model. Model terminology follows Lebreton *et al.* (1992) and Besnard *et al.* (2007).

| Rank | Model description   | Hypothesis  | QAIC <sub>c</sub> | QAIC <sub>c</sub><br>weight | $\Delta$<br>QAIC <sub>c</sub> | Model<br>likelihood | #Par |
|------|---|---|-------------------|-----------------------------|-------------------------------|---------------------|------|
| 1    | $\phi(O^T_{1-2}; O^T_{3-10} O^R_{1-10}) p(S^*G^*O^*t)$                                      | Translocated lobster survival is different immediately after release, and constant with period and same as residents thereafter; recapture varies with size, gender, origin, and time | 5644.4            | 0.26                        | 0                             | 1.00                | 60   |
| 2    | $\phi(O^T G^F_{1-4} O^T G^M_{1-6}; O^R_{1-10} O^T G^F_{5-10} O^T G^M_{7-10}) p(S^*G^*O^*t)$ | Survival of translocated lobsters differs before/after moult  | 5645.5            | 0.15                        | 1.1                           | 0.57                | 60   |
| 3    | $\phi(O) p(S^*G^*O^*t)$   | Survival varies between translocated and resident lobsters  | 5646.0            | 0.11                        | 1.7                           | 0.43                | 60   |
| 4    | $\phi(O^T_{1-2}; O^T_{3-10}; O^R_{3-10}) p(S^*G^*O^*t)$                                     | Translocated lobster survival is different immediately after release, then constant with period, but different from residents thereafter  | 5646.3            | 0.10                        | 1.9                           | 0.39                | 61   |
| 5    | $\phi(.) p(S^*G^*O^*t)$   | Survival does not vary  | 5646.3            | 0.10                        | 1.9                           | 0.39                | 59   |
| 6    | $\phi(O^T G^F) p(S^*G^*O^*t)$   | Survival was different for translocated females only  | 5646.4            | 0.09                        | 2                             | 0.36                | 60   |
| 7    | $\phi(G) p(S^*G^*O^*t)$   | Survival varies with gender only  | 5647.3            | 0.06                        | 2.9                           | 0.23                | 60   |
| 8    | $\phi(S) p(S^*G^*O^*t)$   | Survival varies with size only  | 5647.8            | 0.04                        | 3.5                           | 0.17                | 60   |
| 9    | $\phi(O^T G^F; G) p(S^*G^*O^*t)$  | Survival is different between males and females, and translocated female survival is different from all others  | 5648.0            | 0.04                        | 3.7                           | 0.16                | 61   |
| 10   | $\phi(G^*O) p(S^*G^*O^*t)$  | Survival varies with gender and origin, not size  | 5649.2            | 0.02                        | 4.8                           | 0.09                | 62   |
| 11   | $\phi(S^*G^*O) p(S^*G^*O^*t)$   | Survival and recapture vary with size, gender, and origin, and recapture varies over time   | 5653.1            | 0.00                        | 8.8                           | 0.01                | 64   |
| 12   | $\phi(t) p(S^*G^*O^*t)$   | Survival varies with time only  | 5657.3            | 0.00                        | 13                            | 0.00                | 67   |
| 13   | $\phi(S^*G^*O) p(t)$  | Survival varies with size, gender, and origin   | 5699.5            | 0.00                        | 55.1                          | 0.00                | 16   |
| 14   | $\phi(G^*O) p(t)$   | Survival varies with gender and origin  | 5701.5            | 0.00                        | 57.2                          | 0.00                | 14   |
| 15   | $\phi(S^*G) p(t)$   | Survival varies with size and gender  | 5728.5            | 0.00                        | 84.1                          | 0.00                | 14   |
| 16   | $\phi(S^*G^*O^*t) p(S^*G^*O^*t)$  | Saturated model   | 5728.9            | 0.00                        | 84.5                          | 0.00                | 106  |
| 17   | $\phi(S^*O) p(t)$   | Survival varies with size and origin  | 5747.0            | 0.00                        | 102.6                         | 0.00                | 13   |
| 18   | $\phi(G) p(t)$  | Survival varies with gender only  | 5757.3            | 0.00                        | 112.9                         | 0.00                | 12   |



**Figure 5-50** Monthly recapture-rate estimates from Model 1 for all lobsters recaptured in Taroona Reserve from January 2006 to July 2007.

## Discussion

CJS modelling indicated slightly greater mortality of translocated lobsters immediately after translocation, but the support for this model was weak. The top four models all described some difference in survival between translocated and resident lobsters, but when combined, those models had only 62% of the support in the data (assessed as QAIC<sub>c</sub> weight), suggesting that there was a 38% chance that none of them were right. When survival estimates were averaged, the small difference in monthly survival estimates between translocated and resident lobsters disappears as a result of the high variance in the survival estimate of translocated lobsters. It is unlikely that there was a significant difference in survival between translocated and resident lobsters.

Our research provided estimates of the magnitude of differences in apparent survival between translocated and resident lobsters, which will contribute to the analysis of the viability of translocation as a management tool to increase the value or quality of sectors of the fishery. Colour change from pale (deep-water lobsters) to the high-market-value red colour (shallow-water lobsters), and change in growth rate from 1 mm year<sup>-1</sup> at the slow growth sight to 10–20 mm year<sup>-1</sup> at the Taroona site occurs within the first moult, or 6–12 months after release (Chandrapavan et al. in press-b). Combined, these changes in traits and good survival suggest that translocation has the potential to increase the value of the slow-growing, sublegal portion of the stock, which would otherwise be inaccessible to the fishery.

Pilot predictions from simulations on the potential growth yields suggested that translocating *Jasus edwardsii* from the deep-water site at Maatsuyker Island to a shallow-water site at Tarooma Reserve could result in a 355% increase in biomass or an additional 0.62 t for each tonne of lobster translocated (Gardner and Van Putten 2008a). The primary stipulation of this sex- and size-structured model of translocations to eight sites around Tasmania was that mortality was no greater than 10% higher than resident mortality (Gardner and Van Putten 2008a). When model uncertainty was accounted for and the models were averaged, there was only a 5% difference in apparent monthly survival estimates between translocated lobsters immediately after release and all other animals. There was no detectable difference in survival between translocated and resident animals after the initial release. The potential economic benefits to the industry resulting from translocation from Maatsuyker Island to Tarooma Reserve was estimated at AUD \$2000–4000 year<sup>-1</sup> t<sup>-1</sup> of lobsters moved, and more if the lobsters were translocated farther north in the state where the natural growth rates are much higher (Gardner and Van Putten 2008b). As a precaution, it would be prudent to include a 5% increase in mortality in translocated lobsters in future estimates of the feasibility of translocation, to account for the uncertainty in initial survival.

Three potential causes of possible difference in survival between translocated lobsters at release and resident lobsters are tag-induced mortality, the paler colour of translocated lobsters, or movement away from the release site after translocation. As there was no evidence that tagging influenced mortality on any sampling occasion other than the initial release of translocated lobsters, tagging is an unlikely source of mortality.

Given that the pale colouration of the deep-water lobsters is not found in the wild on shallow reefs, such as the Tarooma Reserve translocation site, we had initial concerns that pale colouration (coupled with their smaller size) might make translocated lobsters more visible and, therefore, more susceptible to predation. There was only low support for lobster colour as a source of lesser survival in translocated lobsters, but because the model was one of the most parsimonious, pale colour could be considered as a source of mortality. If the paler colour of translocated lobsters influences survival in their new habitat, it is only a very small effect for a short time, because there is a rapid colour change to the high-market-value red within the first moult (6–12 months) after translocation (Chandrapavan et al. in press-b).

In testing for the effects of colour on survival, we incidentally examined the effects of moulting, because we assumed colour change to coincide with moulting. As *J. edwardsii* females moult from March to May and males from September to October, the sampling period covered two moult cycles for females and one full cycle for males. The results for testing for the effects of colour change suggested that tagging did not significantly increase mortality around moulting.

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There was no evidence of any other time-related difference in survival of either translocated or resident lobsters, suggesting that the long interval between the release of the translocated group and the release of the resident group did not exacerbate differences in emigration or apparent survival in general. As the release site was not closed to movement, the small difference in apparent survival might also be caused by a small number of translocated lobsters moving away from the site immediately after release. It is important to note that the monthly survival estimates of both translocated and resident lobsters are derived for comparisons between the groups, and are not actual estimates of monthly survival. One constraint of mark–recapture models, which rely on tag-resighting data for survival estimates, is that the estimates are confounded by events such as tag loss or emigration that lead to a tag becoming unavailable for resighting. We cannot discount movement from the immediate vicinity of the translocation site, rather than mortality, as a source of loss from the population. CJS models assume no movement from the release site, so treat any loss from the population as mortality. The study site, Tarooma Reserve, was surrounded by tracts of sand that would reduce the emigration of *J. edwardsii* from the site, because lobsters prefer rocky habitat for dens and foraging (Lucieer and Pederson 2008). A concurrent study on post-release movement is underway, and from preliminary data, it appears that post-release movement is similar between translocated and resident lobsters, and that 93% of lobsters do not emigrate (BSG, unpublished data).

Gender alone gained no support from the CJS models. In general, male southern rock lobsters grow faster than females and attain larger maximum size; as a result, males are subject to higher rates of exploitation by the fishery. Consequently, in fished areas, there is a gender bias towards females, and in the case of Maatsuyker Island, where growth is slower and females rarely reach the LML to enter the fishery (Gardner et al. 2006b), this bias is more marked. The sample of lobsters translocated in this study was skewed towards small females, which might raise an expectation of decreased survival, but there was no evidence to support this. There are often gender differences in survival estimates in similar studies owing to sex-specific behaviour patterns (e.g. recovering populations of lake trout, Pollock et al. 2007).

Differences in size between shallow-water and deep-water lobsters in Tasmania did not influence survival between translocated and resident rock lobsters. *Jasus edwardsii* is a gregarious species, and there is no evidence of the size-dominant hierarchies or conspecific aggression that exist in other lobster species, which can reduce survival of small individuals, e.g. clawed lobster, *Homarus americanus* (Karavanich and Atema 1998). Large and small *J. edwardsii* commonly share dens, although larger rock lobsters can forage on a broader size range and species composition of prey (Langlois et al. 2006), and migrate offshore at different times in New Zealand (MacDiarmid 1991). The commonly observed, size-related differences in the behaviour of *J. edwardsii* are more generally related to differences in age and maturation status (Gardner et al. 2006b). Even though lobsters from Maatsuyker were smaller than Tarooma lobsters, they mature earlier and live longer. Therefore, all

translocated lobsters were mature and likely to be of similar age or older than Tarooma resident lobsters (Gardner et al. 2006b).

One concern for sea ranching and stock enhancement in general is the possibility of displacing resident animals, which can occur if space is limited and the carrying capacity of the environment is reached. There were no signs of replacement of resident lobsters by translocated lobsters in this sea-ranching experiment, something that would have been indicated by lesser survival of resident lobsters as time progressed. There have been density-dependent changes in a number of other stock-enhancement programmes to the detriment of the native stock, generally because the carrying capacity of the environment was reached (Hamasaki and Kitada 2006; Kitada and Kishino 2006). In our study, Tarooma Reserve represents a low-relief, rocky-reef ecosystem (Lucieer et al. 2007) with an abundance of available den space, which is the most critical factor in survival of released lobsters (Phillips and Evans 1997; Hamasaki and Kitada 2008). If density-dependent factors were at play, they may have been apparent as lesser survival in translocated lobsters because the latter were smaller, more visible to predators, and lacked dens when they were first introduced. Given the minimal support for this hypothesis and the overlapping error bars around the survival estimates, it is very unlikely that density-dependent factors were at play.

Almost half the resident lobsters were tagged prior to the introduction of the translocated lobsters, because resources were unavailable to tag resident lobsters at the same time as translocating lobsters. An effect of time on lobster survival was evaluated in the CJS modelling and was not supported. If there was any bias attributable to the different timing of the commencement of tagging between populations, this would have been apparent in differing rates of survival over time. We assumed no effect of tag loss or person tagging. There were multiple taggers in this study, but their identity was not recorded and could not be assessed. We have assumed that any tag loss or effect of tagger would have affected resident and translocated lobsters equally. It is possible that high-density transport of translocated lobsters from Maatsuyker Island to Tarooma Reserve induced greater tag loss in translocated lobsters. This would result in higher mortality estimates for translocated lobsters at release, and although there is a hint of this, it is unlikely that this was a significant difference.

Resighting probability of *J. edwardsii* varied seasonally and with gender, size, and origin, along similar trends found in previous studies of this species (Ziegler et al. 2002a; Ziegler et al. 2002b). Resident lobsters had a greater resighting probability than translocated lobsters, males were more likely to appear in traps than females, and larger lobsters were more easily caught than smaller ones. A catchability study in the same area conducted eight years earlier by comparing visual census to catch rates in pots found that (i) catchability increased with size, (ii) recapture was more frequent for medium and larger males than for females of similar size (Ziegler et al. 2002a), and (iii) small males and females were frequently underrepresented in traps (Ziegler et

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al. 2002b). The peak in resighting probability in December/January coincided with peaks in effort and in catchability for this species at this site (Ziegler et al. 2002a). The similarity in trends of catchability between this study and the earlier work by Ziegler *et al.* (2002a, 2002b) suggests that our sampling design did not introduce any biases in resighting probability. Overall resighting probability was low, and 75% of the tagged animals were not resighted throughout the study. This is not uncommon in rock lobsters, because general catchability is low (Frusher and Hoenig 2003).

Resighting may be influenced by trapability, which depends on rock lobsters choosing to enter and then not escaping. In the case of *J. edwardsii*, trapability may be influenced by the presence of lobsters in the trap (Ihde et al. 2006), but we have assumed that any such effects would influence translocated and resident lobsters equally.

Mark–recapture techniques are generally applied to wild populations to assess fundamental demographic variables such as population size and density, individual growth and survival, and the effects of time, age, and categorical variables such as gender or colour morph (Lebreton et al. 1992). In the current application, CJS mark–recapture techniques have been successfully applied to test the viability of a large-scale translocation experiment designed to enhance the value and yield of a fishery.

Despite a hint that translocated lobsters had less apparent survival after release than residents and translocated lobsters after the initial release, there was unlikely to be a significant difference in survival between lobsters of different origin, size, or gender. The survival of translocated lobsters is sufficient to support the viability of translocation as a tool for increasing yield and value in a geographically diverse fishery.

### 5.5.2 Foraging ranges of resident and translocated lobsters

#### Summary

We examined behavioural interactions of resident and translocated *Jasus edwardsii* rock lobster after an introduction of 1,961 ‘small pale’ (SP) phenotypic morphs to an area populated by the resident ‘large red’ (LR) phenotypic morph. This translocation was an experimental stock enhancement conducted as part of a larger study to increase the yield and value of the fishery. Most translocated individuals established home range within a couple of days of release (generally <2 days) and these ranges were generally less than 1.0ha in size. Home range kernels and foraging ranges overlapped between the two morphs, and there was no evidence of avoidance (Jacob’s cohesion index 0.01,  $Z=1.06$ ,  $p=0.28$ ). This case of translocation for stock enhancement between ecotypes had no detectable adverse effect on either the resident or the translocated population, and in this species stock enhancement could become part of an integrated conservation and harvest optimisation strategy.

#### Detailed Methods

1961 *J. edwardsii* (1308 females, 653 males) were captured from a deep water site (65 m) at Maatsuyker Island (43°40'30S 146°12'56E) Tasmania, Australia, and moved north to a shallow water site (9 m) at Emerald Bay, Tasmania (42°36'55S 147°56'35E) in December 2007. Emerald Bay is an inshore temperate site with habitat of rocky reef bounded by large expanses of sand, on Tasmania’s east coast.

#### *Acoustic tracking*

To examine impacts of the translocation event, movement of 11 resident and 29 (20 females and 20 males, of the 1961) released lobsters was tracked for 32 d after release using coded V9, and continuous V13 and V16 acoustic transmitters and a VRAP telemetry system (AMRIX, Vemco Division). Each of the transmitters emits a unique identification code at a random interval of 180-300 s once activated. Transmitters were attached to the carapace of translocated and resident individuals using standard rapid setting (5 min) epoxy resin. Transmitters were 24mm L x 9mm D, and weighed 2.2g. The smallest lobster weighed 300g (78 mm Carapace Length) and the average lobster size was 500 g and 95 mm CL, and therefore the V9 transmitters were 0.7 % and 0.4% of the animal weight respectively. Spiny lobsters of the family Palinuridae, such as *Jasus edwardsii*, have large, spiny antennae and rostrum protruding from their head, sometimes above the height of the carapace. They are slow-moving and not streamlined. The 9mm transmitters glued to the dorsal surface of the carapace were very unlikely to increase the costs of locomotion or reduce speed of these slow-moving animals, due to their small size and low profile relative to the antennae and rostrum.

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The VRAP system was deployed forming an equilateral triangle spanning 160m +/- 2.5 m on each side, above the rocky reef at the research site. The VRAP system successfully tracked the movement of the tagged resident and translocated lobsters with a positional accuracy of ca. 2m over a 300m range from the centre of the receiver array with a sampling periodicity of approximately 3min. Resident lobsters were captured from the site, tagged and released and allowed to re-acclimatise to the habitat for a period of 2.5 d prior to the release of the translocated individuals. After 32 d of tracking lobsters, divers retrieved the tagged lobsters and removed the transmitters from the carapace using a scalpel. No damage was done to the calcified exoskeleton in removing transmitters.

### *Analyses*

An animal's home range (HR) is an estimation of the area travelled by an animal in its day-to-day activities of food gathering, mating and caring for its young (Burt 1943). We calculated home ranges (95% fixed kernel Worton 1989) with a least-square cross validation method (LSCV), as fixed Kernel estimates were least biased in the outer contours (Seaman et al. 1999). The kernel method further defines the home range as the area in which there is 95% probability of locating the animal. To assess whether the animals avoided, ignored or were attracted by one another we calculated Jacob's index of avoidance or cohesion (Jacobs 1974; Brown et al. 2000), with the time window set to 5 min to match the time delay of coded tag transmissions. Jacob's index rises towards 1 if two animals are closer to each other than by chance alone, is close to 0 if the animals ignore each other, and falls towards -1 if the animals avoid each other. This analysis was based on the geometric mean distance (Walls and Kenward 2001). To test the significance of the association, we compared the values of Jacobs's index with zero in a Wilcoxon signed-ranks test.

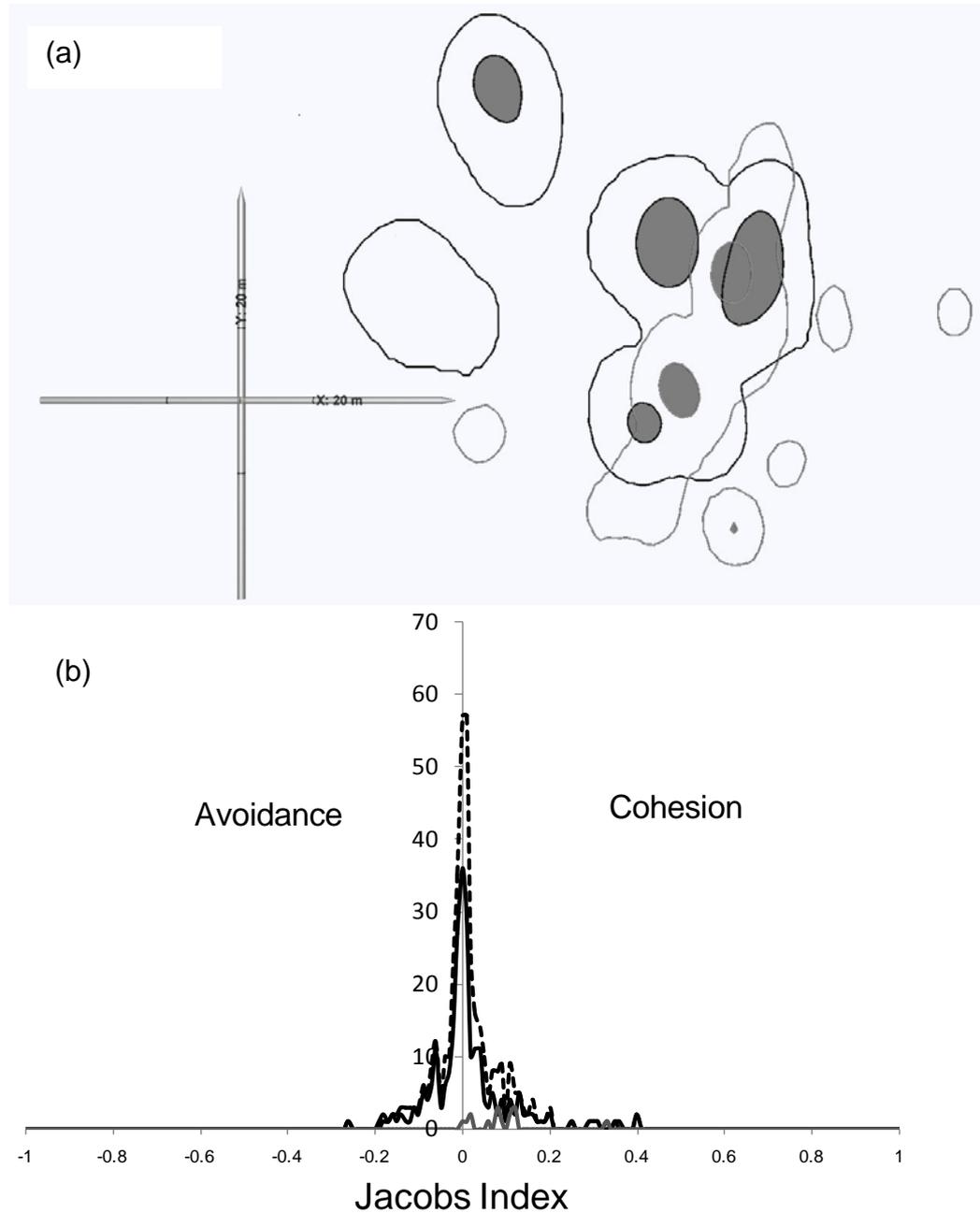
## **Results**

### *Overlap of resident and translocated morph home ranges*

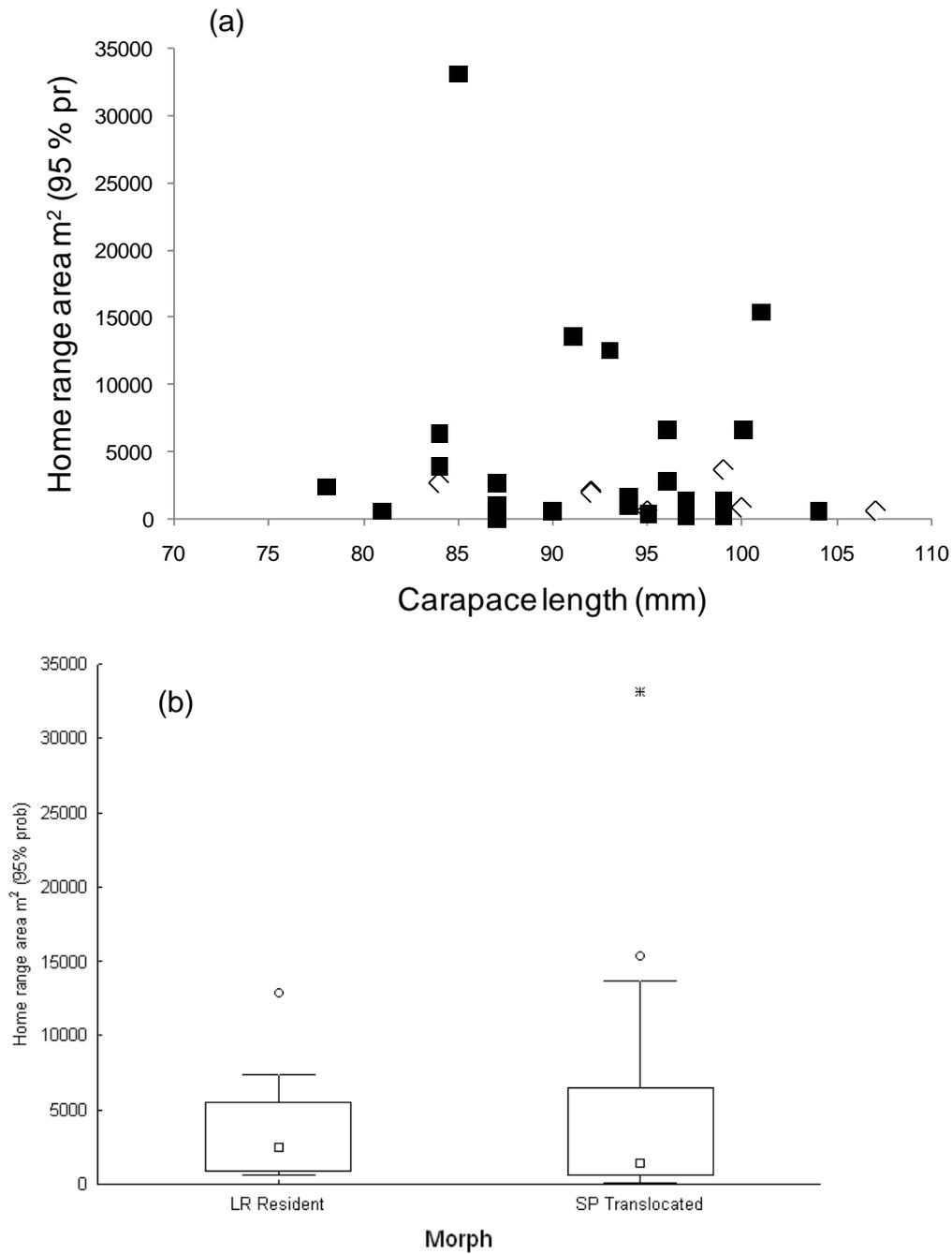
The home ranges of residents and translocated lobsters overlapped in time and space (Figure 5-51a), suggesting no exclusion of individuals within either grouping by the other. The average spatial overlap in kernel home ranges (0.95 kernel probability contours) between tagged individuals was 25% with each tagged lobster co-occupying habitat with one or more other tagged individuals (Figure 5-51a). There was no distinct preference for cohesion or avoidance between individual lobsters ( $Z=1.06$ ,  $p=0.28$ ), and no avoidance between resident and translocated lobsters, that is, lobsters generally ignored each other (Figure 5-51b).

There was no relationship between home range area and lobster size (Figure 5-51a), and home range areas were variable between individuals of similar size. Most translocated SP individuals established home range within a couple of days of release

(generally <2) and were generally less than 1.0ha in size. Home ranges of translocated SP lobsters were similar in size to LR resident animals tagged at the site (Figure 5-51b,  $p > 0.1$ , Kolmogorov-Smirnoff). Timing of activity on a daily level were similar between translocated and resident animals (K-S=0.011  $p = 0.117$ ).



**Figure 5-51(a)** Home range kernels of resident and translocated lobsters, tracked for 30 days using acoustic telemetry. Black contours represent 95% home range for translocated animals (probability of 0.95 that a positional estimate would have occurred within the contour) and grey lines for 95% home range contours for resident animals. Contours which are filled (grey shade) represent 50% probability contour (probability of 0.5 that a positional estimate occurred within the contour) of the activity centre of lobsters. **(b)** Jacobs index of cohesion/avoidance within and between treatment groups. Solid black line: translocated, solid grey line: residents, broken black line: all lobsters together.



**Figure 5-52** a. Home range area (95% probability contour) of resident and translocated lobsters, tracked for 30 days using acoustic telemetry. Size of lobster is carapace length at release. ■ SP translocated, ◇ LR resident b. Home range size of small pale translocated lobsters and large red residents. Boxplots represent median and 25-75%, whiskers illustrate non-outlier ranges, ○ outliers, \* extreme outliers.

*Displacement from release site*

Residents had a sharp increase in the instantaneous displacement distance from release site at around 2.5-3 d following release (a), coinciding with the release of the

translocated individuals from the sea cage. Translocated individuals rapidly dispersed from the immediate release area but stayed within 60-80 m of the release site. Individuals who dispersed greater distances initially moved closer to the release site after a couple of days with several individuals continuing to disperse further from the release site over the 32 d period.

Total displacement (straight line distance between the release location and the final positional coordinates distance) or distance moved did not differ between LR resident and SP translocated lobsters, (Figure 5-53, Pillai's trace,  $F_{2,28} = 0.07$ ,  $P > 0.05$ ). Displacement distance was variable between animals with no clear size effects for either translocated or resident animals ( $R^2 = 0.01$ ,  $P < 0.54$ ). The mean displacement distances were 63 m ( $n = 29$ ) and 65 m ( $n = 11$ ) for translocated and resident lobsters respectively, and the mean distance moved ( $\pm$  SE) were  $1201 \pm 211$  m and  $1335 \pm 405$  m. The greatest variability in movement and displacement metrics is observed by intermediate size classes (90-100 mm CL, Figure 5-53b).

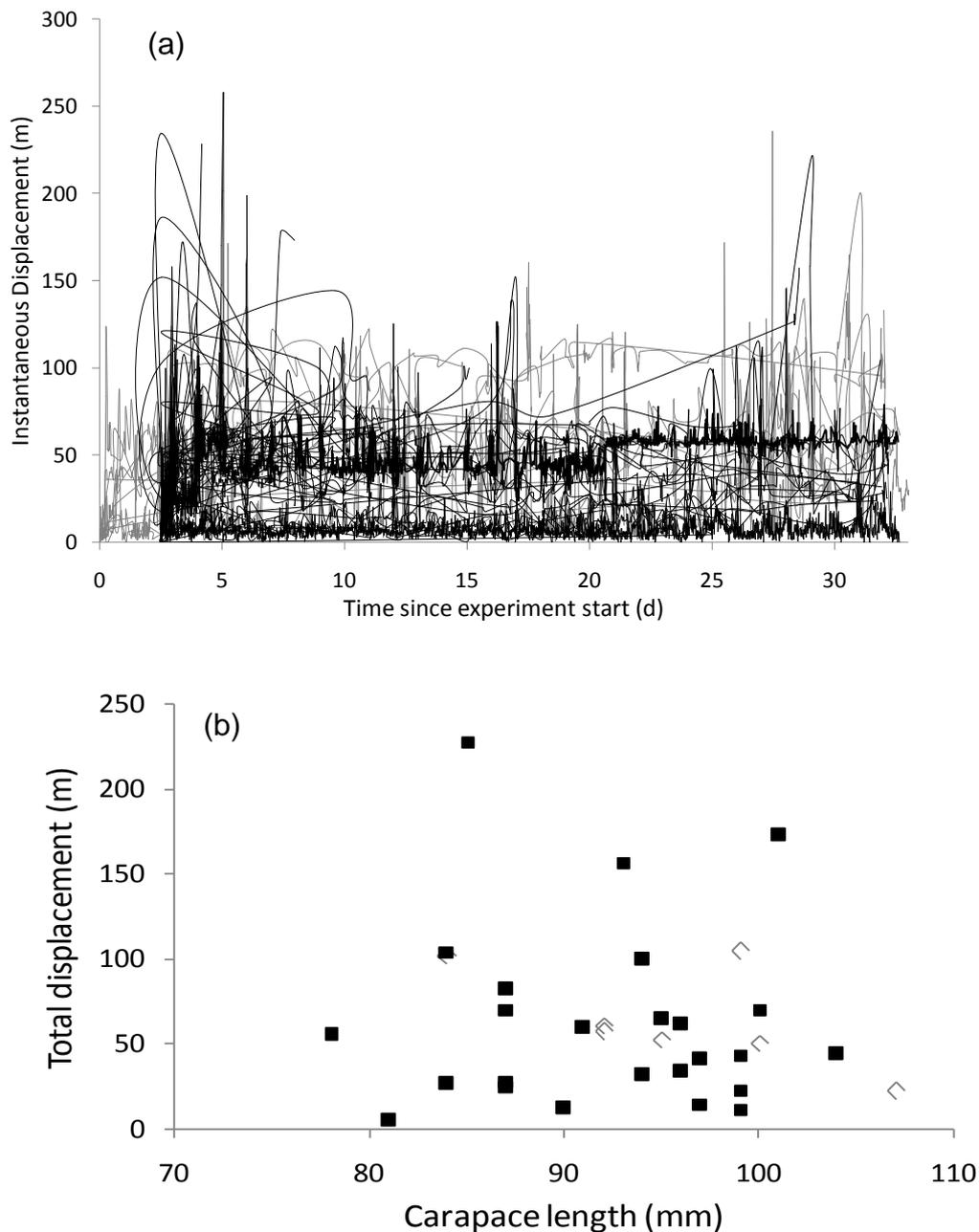
#### *Tagged lobster retention rates*

All 29 SP translocated lobsters were detected during the study period of 32 days. Some individuals were recorded multiple times each day and constantly monitored by the telemetry system whereas several individuals were positioned on multiple occasions with gaps in detections of several days in duration. The scale and reception range of detection array ensured that tagged lobsters anywhere within the entire study site would be within range of the system and therefore positioned if moving in open habitat. All 29 SP translocated lobsters were positioned at least once within the study area within the last 24 hours of the study. Of the 29 translocated lobsters only one individual failed to give sufficient data to calculate all metrics described in this summary. Similarly, all 11 tagged resident individuals were retained at the site for the duration of the study.

## **Discussion**

Unlike many restocking experiments which do not meet expectations (Hilborn 1998), this translocation experiment has exceeded expectations. There was no evidence of displacement or avoidance due to either prior residence and larger size or introduction in large numbers in this translocation of the southern rock lobster, *Jasus edwardsii*. Individuals of the two different morphs, resident 'large red' morph and translocated 'small pale' morph, co-existed after translocation with a large amount of home range overlap, and with similar daily foraging and movement patterns. Coupled with the other positive outcomes of this large-scale translocation and stock enhancement trial, this evidence of immediate cohabitation and fidelity to the release site demonstrate the success of translocating southern rock lobsters.

Displacement distance of lobsters from the point of release after tagging, (Figure 7-53) further confirms that the *J. edwardsii* fishery can be enhanced through the assisted migration of low-value low-productivity stock to areas of faster growth and improved market traits, as predicted (Gardner and Putten 2008a). The economic success of this stock enhancement depends on the mode of translocation, but there is a large scope for improving profit to the industry (Gardner and Putten 2008b).



**Figure 5-53** Displacement distance of lobsters from the point of release after tagging. (a) instantaneous displacement distance, and (b) total displacement of resident and translocated lobsters, Black lines or markers: SP translocated, Grey lines or markers LR resident.

The LR morph of *Jasus edwardsii* is gregarious (MacDiarmid 1994), and there is no evidence of the conspecific aggression that exist in other lobster species, e.g. clawed lobster, *Homarus americanus*, which can reduce survival of small individuals (Karavanich and Atema 1998). Large and small *J. edwardsii* commonly share dens, and during the daytime *J. edwardsii* occur in aggregations of up to 105 individuals (MacDiarmid 1994), although larger rock lobsters can forage on a broader size range and species composition of prey (Langlois et al. 2006), and exclude small lobsters from entering traps (Frusher and Hoenig 2001). This paper is the first observations on the social behaviours of the SP morph, whose small size, pale colour, spindly legs and narrower abdomen are physical characteristics generally associated with being weaker and subordinate. This morph demonstrated similar home ranges and significant overlap in home range usage as the LR morph. The size of the home ranges, or preferred habitat area, in this study were similar to those described for the LR morph at a nearby site in 2005 (Lucieer and Pederson 2008). Importantly we have not detected any level of avoidance, and in fact a large amount of overlap in habitat usage of individuals of different morphs, indicating the success of this assisted migration and sea-ranching.

Colour is frequently a secondary sexual characteristic used to demonstrate fitness or aggression, as it signals better health (Ressel and Schall 1989; Olson and Owens 1998), higher reproductive performance (e.g., access to mates, Evans and Norris 1996; sperm velocity, Janhunen et al. 2009) and better access to critical resources (Luchiari et al. 2007) in a large range of taxa. In the study species, *J. edwardsii*, size and morph were not indicative of any dominance hierarchy, and size and colour do not influence survival in translocated SP *J. edwardsii* compared with resident LR 's (Green and Gardner 2009).

In fisheries that are managed using capped quotas such as individual transferrable quota's (ITQ's), which limit the biomass removed by the fishery, a method to increase profits is to increase the value of the catch (Bradshaw 2004). One of the unplanned consequences of the introduction of ITQ's is the movement of fishing effort to inshore waters where the value of the catch is higher, even though catch rates are lower, and thus costs higher (Linnane and Crosthwaite 2009a). Catch price tends to fluctuate with demand and quality of the product (Hundloe, 2002), which presents an opportunity to maximize profits by targeting high-value product or landing it when demand is great. A fishery management strategy that permits both of these possibilities is stock enhancement through sea ranching, and in this species it had potential to increase production and reduce costs (Gardner and Putten 2008b). As translocation increases the productivity of recruits the economic yield from the fishery is increased, either through lower costs associated with higher catch-rates, or through larger TACs (Dupont et al. 2005). Within the adaptive management framework if the risks are monitored and addressed then translocation is a real solution to conserving ecosystems (Rout et al. 2009; Sutherland et al. 2009) and maintaining sustainable fisheries (Stottrup and Sparrevohn 2007).

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The translocation experiment described here was part of a large study that increased the yield and value from the translocated SP morphs (Chandrapavan et al. 2009b; Chandrapavan et al. in press-a). Our results on co-habitation presented here show that these benefits came without any apparent cost in terms of displacement or behavioural impacts on resident LR morphs' sustainability. As demand for seafood increases concurrent with increasing costs of fishing, novel ways of increasing quality and productivity of seafood will become central to maintaining seafood supply. Enhancement regimes such as assisted migrations and translocation will become useful tools to ameliorate habitat loss, reductions of naturally occurring populations, and bring fish stocks closer to shore. Climate change is only adding to these existing issues, and translocation or assisted migration is one tool advocated as a remedy (Sutherland et al. 2009; Vitt et al. 2009). Assisted migrations and translocations are increasingly likely to be considered in integrated marine management strategies. Translocation of low productivity stock to areas of higher productivity is one means of overcoming the challenges of improving productivity in wild capture fisheries. This case of assisted migration between ecotypes within a species range had no detectable adverse effect on either the resident or the translocated population, and in *J. edwardsii* it could become part of an integrated management strategy to increase economic yield and to reduce ecosystem effects of fishing.

### 5.5.3 *Effects of translocation on maturity and egg production parameters.*

Published as “The good, the bad and the recovery of an assisted migration” 2010 Green, BS., Gardner, C., Linnane, A., Hawthorne, P., *PLoS One* 5(11): e14160.

#### Summary

Assisted migration or translocation of species to ameliorate effects of habitat loss or changing environment is currently under scrutiny as a conservation tool. A large scale experiment of assisted migration over hundreds of kilometres was tested on a morph from a commercial fishery of southern rock lobster *Jasus edwardsii*, to enhance depleted populations, improve the yield and sustainability of the fishery, and test resilience to a changing climate.

Approximately 10,000 lower-valued, pale coloured lobsters were moved from deep water to inshore sites (2 in Tasmania [TAS] and 2 in South Australia [SA]) where the high-value, red morph occurs. In TAS this was a northwards movement of 1 latitude. Pale females (TAS) grew 4 times faster than resident pale lobsters from the original site and twice as fast as red lobsters at their new location. Approximately 30% of translocated pale lobsters deferred reproduction for one year after release, and grew around 1 mm yr<sup>-1</sup> less compared to translocated pale lobsters that did not defer reproduction. In spite of this stress response to translocation, females that deferred reproduction still grew 2-6 mm yr<sup>-1</sup> more than lobsters at the source site. Lobsters have isometric growth whereby volume increases as a cube of length. Consequently despite the one year hiatus in reproduction, increased growth increases fecundity of translocated lobsters, as the increase in size provided a larger volume for producing and incubating eggs in future years. Assisted migration or translocation to areas representing future climate change scenarios improved egg production and growth, despite a temporary stress response, and offers a tool to improve the production, sustainability and resilience of the fishery.

#### Detailed Methods

##### *Sites*

This experiment was undertaken in two fishery jurisdictions: Tasmania (TAS) and South Australia (SA), Australia. A total of 5 sites were used in the section as these were the only sites which provided sufficient growth data: the TAS source site (Maatsuyker Island); two TAS transplant sites (Riedle Bay and Taroon Reserve) (Figure 5-47); 1 offshore SA source site within Marine Fishing Area (MFA) 55 of the SA southern zone rock lobster fishery; and two SA transplant sites near Southend (37°34'090'S, 140°07'504'E) in MFA 56 and Robe (38°03'398'S, 140°41'949'E) in MFA 56 (Figure 5-43). Maatsuyker Island (43°40'30'S 146°12'56"E) is a southern, deep-water (60-100 m) rocky reef 12 nm offshore where lobsters grow slowly, are pale in colour (Chandrapavan et al. 2009b), size at first reproduction (SOM) is small at around 60 mm carapace length (CL) and females rarely reach the minimum legal size of 105 mm (CL) (Gardner et al. 2006b). Mean summer SST for Maatsuyker Is.

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ranges from 12-14°C, and is predicted to increase to 14-17°C in 2030 and 17-19°C in 2070 under mid-range Intergovernmental Panel on Climate Change scenarios (IPCC 2007; Pecl et al. 2009). Tarooma Reserve (42°57'08"S 142°21'20"E) and Riedle Bay (42°40'09"S 148°6'13"E) are shallow rocky reefs approximately 1° latitude north of the source site, where lobsters grow faster and are red in colour (Chandrapavan et al. 2009b). Tarooma Reserve is a shallow estuarine rocky reef bounded by large expanses of sand, with depth 7 - 15 m. The area is approximately 1.24 km<sup>2</sup> including a surrounding no-take buffer zone. Population density of *J. edwardsii* within the reserve is high (approximately 13 000 individuals), and the reserve has been closed to both commercial and recreational fishing since 10 November 1971 when it was proclaimed as a marine reserve for rock lobster research. Riedle Bay is an inshore exposed rocky reef of granite boulders and macroalgae, with continuous reef to 60 m. The average depth is 15 m. Mean summer SST for both Tarooma and Riedle Bay is 15-17°C (Pecl et al. 2009).

The offshore South Australian site where lobsters were caught for translocation was located at in MFA 55 at a depth of ~100m. Catch rates within this area have been historically high (up to 3 kg/potlift) which presumably reflects low fishing effort in offshore regions of the fishery (Linnane and Crosthwaite 2009a). The SOM at this site was ~68 mm CL (Linnane et al. 2009). The inshore SA sites at Southend and Robe to which lobsters were translocated were broadly similar consisting of limestone reef matrices, eroded to form ledges, crevices, undercuts and holes. Both were located in 15-20 m depth. Pre-site selection dive surveys indicated that the reefs were dominated by encrusting invertebrates (sponges, ascidians, bryozoans), spiny urchins (*Heliocidaris erythrogramma*), red foliose, green foliose (*Caulerpa sp.*), brown branching (*Ecklonia radiata*, *Macrocystis angustifolia*), and encrusting coralline algae. The SOM in the region was ~93 mm CL (Linnane et al. 2008b).

### *Translocation*

Translocations occurred at different times in the two fisheries. In Tasmania, in the austral summer from 2005 to 2007, mature female lobsters were captured from Maautsuyker Island and moved to the 2 experimental sites. Lobsters were caught using 50 metal mesh lobster pots baited with a barracouta head (*Thyrsites atun*) and a jack mackerel (*Trachurus declivis*) and deployed in an area 500 m x 120 m. Pots were emptied twice daily, once at daybreak, then redeployed and emptied again after midday. At capture, *J. edwardsii* were measured and tagged on the ventral surface of the first or second segment of the abdomen with a uniquely coded t-bar tag (Hallmark, Victor Harbour, South Australia). All rock lobsters for translocation were immediately placed in 2 x 4000 l flow-through tanks onboard the RV "Challenger" under ambient water conditions where they were held until release at the new location (2-3 d). Lobsters were released at the water surface into an 80-m diameter net, height 1.5 m with braided nylon mesh (stretched mesh size of 21 mm diagonal) set on the sea floor in the Tarooma Reserve for 24 h to reduce their initial flight response away from

the release site (Mills et al. 2006) and subsequent predator mortality upon release (van der Meeren 2000). The base of the net was open and weighted by chains, and the walls were suspended by foam floats. The cage was roofless. Release of translocated lobsters onto the reef within the cage occurred at night-time to reduce predator mortality. After 24 h, the cage was lifted and the lobsters were then free to move around the reef.

**Table 5.14** Summary of maturational status of female rock lobster recaptured 1 year after translocation from deep to shallow water.

| Area              | % deferred reproduction | Number recaptured |
|-------------------|-------------------------|-------------------|
| <b>TAS</b>        |                         |                   |
| Riedle Bay        | 20.5                    | 78                |
| Taroona           | 26                      | 157               |
| Maatsuyker Island | 0                       | 531               |
| <b>SA</b>         |                         |                   |
| Robe              | 32.5                    | 80                |
| Southend          | 36                      | 150               |

In South Australia in summer of 2007, 4589 lobsters, including 3073 females were captured over two trips, using the same gear as described for TAS. Lobsters were transported in 2 x 3000 l flow-through tanks on board a commercial fishing vessel chartered for the operation. Lobsters were in transit for 2-8 h from the time of capture until they were released late afternoon onto highly complex habitat chosen for its availability of refuges at the release site. The release sites were highly exposed with large swell, and these conditions did not allow for net to be set up for acclimation and initial protection.

*Sampling at transplant sites*

*Tasmania* - In June and July 2008 sampling took place at two of the transplant sites (Taroona and Riedle Bay) using the same capture method as for the translocated lobsters described above. Sampling occurred in the austral winter to coincide with timing of egg bearing for females. Pots were set for 3 days at each site, and checked each morning and redeployed. All lobsters were measured for carapace length (CL), checked for a tag, gender, maturational status, and berried status.

*South Australia* - In Oct-May 2008/09 sampling for females occurred through 2 designated trips using the methods described above, although most of the data on reproductive status was collected through a commercial tag return program (Linnane et al. 2009).

*Grading maturational status*

*J. edwardsii* females mate in the austral autumn, and females brood their eggs on their abdomen for 3-4 months. Eggs are attached to the endopodite processes on pleopods

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by ovigerous setae. The presence of ovigerous setae was used as an indication of maturity (Gardner et al. 2005), and their absence indicated animals were incapable of carrying eggs on the abdomen. All lobsters from Maatsuyker Is. were observed to have mature setose pleopods when transplanted, so any record of absence of setae was an indication of deferred or regressed reproduction.

### *Analyses*

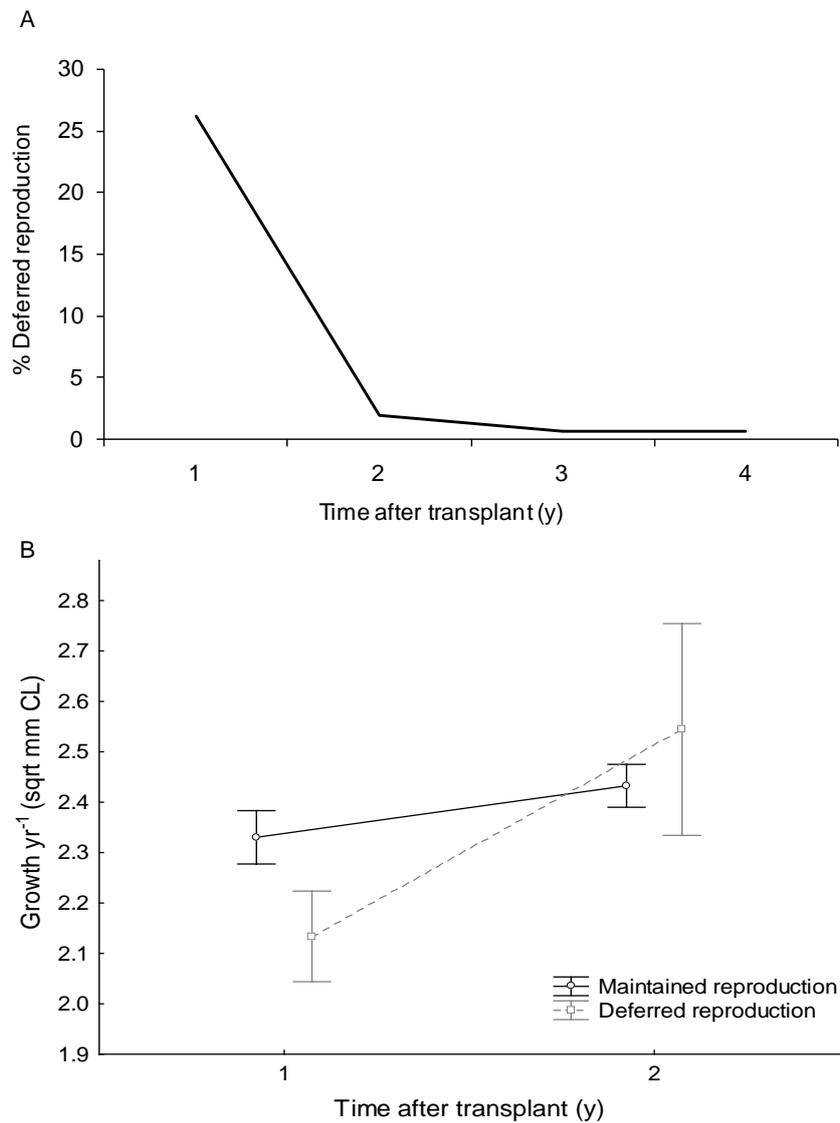
In SA there was no transplant control and growth measures could not be taken from residents, so comparison of growth at source and translocated sites were made on TAS *J. edwardsii* only. Analyses of growth comparing lobsters of different maturational status were performed on females from TAS (Taroona Reserve, Riedle Bay) and SA (Robe and Southend) one year after translocation, with initial size as a covariate.

### **Results**

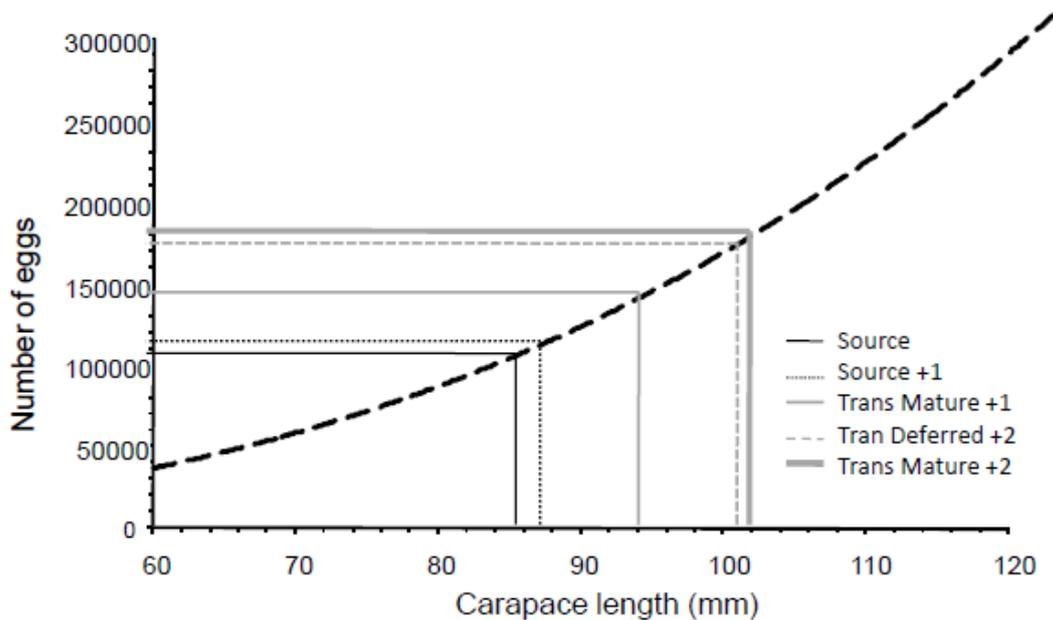
External changes to accessory reproductive limbs occurred within one moult in pale females after the assisted migration to the new habitat. Approximately 30% of translocated pale female lobsters deferred reproduction for the first year in their new habitat by changing the structure of their pleopods at moult and producing endopodites without ovigerous setae. The exact proportion of females that deferred reproduction varied with site: of the 157 female transplants recaptured at Taroona, 26% of females deferred reproduction, and in SA between 32 and 36% of females ceased reproducing (Table 5.14). For lobsters translocated within Tasmania, growth of all translocated lobster exceeded growth of resident lobsters at the sites to which they were translocated by 3 to 6 mm yr<sup>-1</sup> in the first year after translocation (Table 5.1), and was more than four times the growth rate of lobsters at the source site Maatsuyker island,  $6.4 \pm 0.5$  mm c.f  $1.4 \pm 0.06$  mm yr<sup>-1</sup> ( $F_{1,362} = 121$ ,  $p < 0.0005$ ). Growth rate of lobsters that deferred reproduction was reduced at 3 of the 4 translocation sites, and remained the same at one site (Riedle Bay, TAS, Table 5.15), compared to translocated lobsters that maintained maturity, but was still significantly higher than growth rate at the source site. Two years after translocation 93% of females who had become non-reproductive had recommenced reproduction a), and growth of lobsters that had regressed reproduction matched growth of translocated lobsters that had continued reproduction (b). Despite 30% of females suspending reproduction for a season, estimated egg production improved with translocation by approximately 35,000 eggs yr<sup>-1</sup> for translocated individuals beyond what would occur after one year at the source site. This is because lobsters that deferred reproduction for 1 yr, egg production increased by 65,000 eggs yr<sup>-1</sup> in the second year after translocation, and lobsters that remained mature increased egg production by approximately 80,000 eggs yr<sup>-1</sup>.

**Table 5.15** Summary of ANCOVA of *J. edwardsii* growth at sites of translocation in the first year after translocation. Length was covariate

|                   | DF  | MS  | F   | p      |
|-------------------|-----|-----|-----|--------|
| Carapace length   | 1   | 942 | 63  | <0.005 |
| Site              | 3   | 327 | 21  | <0.005 |
| Maturation status | 1   | 74  | 5   | <0.05  |
| Site*Mat status   | 3   | 8   | 0.5 | 0.655  |
| Error             | 381 | 14  |     |        |



**Figure 5-54** Females with deferred reproduction. a. Percentage of female *J. edwardsii* that deferred reproduction over 4 years of sampling at Taroom Reserve. b. Growth rate of translocated lobsters that deferred reproduction or maintained reproduction for two years after translocation.



**Figure 5-55** Estimated change in annual fecundity after translocation. Estimation change in annual fecundity after translocation for an 86mm *J. edwardsii*, from on length-fecundity estimates from Green et al (2009). “Source” is Maatsuyker island, +1 is after 1 year and + 2 is after two years. Mature refers to lobsters that maintained reproduction and ‘deferred’ refers to the 30% that deferred reproduction for 1 year.

## Discussion

This transplant experiment demonstrated a complex response in reproduction and growth in *Jasus edwardsii* to assisted migration which varied throughout the range of the species. In popular parlance these results can be summarised as “the good, the bad and the recovery” of demographic traits following an assisted migration. Increased growth in the new location was a positive outcome in terms of the goals of this assisted migration, offering a method of increasing the biomass of the stock independent of recruitment, and demonstrating increased growth of cold water, pale lobsters when shifted to a warmer environment. Faster growth of translocated lobsters increases the average weight of lobsters which in turn would reduce the total number of lobsters harvested by the commercial sector under ITQ management. On the negative side, reproduction was deferred in approximately 30% of females for one year, which reduced the fecundity of the population for that year, and is a possibly indicator of stress resulting from the translocation. Encouragingly, there was recovery of in reproductive output so that the majority of females became reproductively active in the second year after release. These had maintained significantly higher growth

rates compared to lobsters from both their site of origin and the residents of the translocation site. The increased growth for all females that occurred in this time would result in a total higher egg output, increasing the resilience of the fishery by improving population fecundity.

*The good: Improved fishery productivity and inherent resilience to climate change*

Translocated lobsters increased growth rate to more than double that of the residents in the area to which they were moved and four times that of the lobsters in their original location. Increased growth rate, coupled with a colour change to the more valuable red colour within 12 months of translocation (Chandrapavan et al. 2009b) and survival comparable to residents (Green and Gardner 2009) increases the biomass and value of the lobsters available to the fishery. This increase in stock occurred in inshore areas which are those most impacted currently in response to economic processes and overfishing (Bradshaw 2004; Gardner and Van Putten 2008b). Increased inshore productivity and larger average size could reduce ecological effects of fishing, as localised depletion coupled with climate change are the sources of devastating phase shifts (Ling et al. 2009).

Equally importantly, the growth increase after the northward translocation of the southern morph denotes plasticity in response to mid-range climate change scenarios (IPCC 2007; Pecl et al. 2009). While an increase in growth rate of an ectotherm is not an unexpected result following an increase in temperature (Yamahira and Conover 2002), it does demonstrate an inherent plasticity within *J. edwardsii* populations to a range of temperature regimes and to a short-term change in temperature, offering a positive contrast to the many gloomy climate change forecasts (e.g., Hughes et al. 2003; Harley et al. 2006). An increased growth rate above that of the locals under the same temperature regime is more notable, indicating that not all *J. edwardsii* are growing at the maximum possible in their environment. It is an ongoing curiosity in ecology that most animals do not grow at their maximum rate (Atchley 1984; Alonso-Alvarez et al. 2007) given the importance of somatic growth rates to fitness and survival (Roff 1992; Stearns 1992). Assisted migration offers a way of moderating human impacts on local marine ecosystems, sustaining the delivery of harvestable resources, and understanding potential changes to sectors of the fishery under changing temperatures and environment.

*The bad: Skipped spawning a response to stress?*

Deferred reproduction occurred at all four translocation sites in approximately the same proportions. Skipped spawning is uncommon in rock lobsters and the recorded change in maturational status based on pleopod morphology was unambiguous. In contrast there has been no observed change in pleopod morphology of animals in the control site sampled in this study or in the 28,700 lobster recaptures analysed in previous research of the Tasmanian *J. edwardsii* population (Gardner et al., 2005).

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This suggests that skipped spawning in 30% of females recorded after assisted migration is not part of a normal strategy to increase lifetime fecundity by optimising energy allocation (Bull and Shine 1979; Stearns and Koella 1986; Fischer et al. 2009), rather it appears to be a stress response to one or more of the elements of assisted migration. Animals with accessory reproductive costs such as migration or brooding (for example *J. edwardsii*), are expected to have a higher incidence of skipped spawning as they optimise energy allocation to reproduction and accessory reproductive activities (Bull and Shine 1979). When there are conflicts in the allocation of energy, a trade-off between competing processes can occur (Ricklefs et al. 1994). Prior to first maturation, this trade-off occurs between growth and the physiological changes required to produce gametes or secondary sexual characteristics or behaviours in order to attract a mate. After maturation, individuals repeatedly select between allocation of energy to reproduction or maintenance (Fischer et al. 2009), and despite being physiologically equipped for reproduction and having the potential to spawn, many individuals will divert energy into other processes such as growth, maintenance or a stress response to maximise their fitness (Stearns and Koella 1986). Skipped spawning has been documented in animals such as birds and fish frequently when conditions are poor (Bull and Shine 1979; Burton 1994; Rideout and Rose 2006; Johnston and Post 2009) and rarely when conditions are good (Stelzer 2001; Jørgensen et al. 2006). The potential causes of the stress response in this case include transport, increased temperature at the new site, disorientation upon release, or unfamiliar habitat. Capture and tagging can be ruled out due to the absence of any previously recorded hiatus in reproduction despite years of capture and tagging (Gardner et al. 2005).

#### *The recovery: more eggs in bigger baskets*

These experiments suggest there are opportunities for increasing fishery productivity and egg production by moving slow growing lobsters to sites that are more favourable to growth, and therefore egg production (Gardner and Van Putten 2008a; Gardner and Van Putten 2008b). These movements could be used to target specific management issues such as improving biomass and egg production in locally depleted areas (Gardner and Van Putten 2008a; Ling et al. 2009). While translocating lobsters increases growth and therefore capacity for egg production, it also exposes females from the deep water to increased risk of fishing mortality as they grow to legal size more rapidly. Currently egg production in deep water areas of SW Tasmania is estimated to approximate virgin levels due to the slow growth to legal size, while at some inshore sites it is below 15% (Gardner and Ziegler 2010). So while translocation exposes females to fishing mortality that they would otherwise avoid through size limit refuge, it also increases individual egg production and shifts egg production to areas where it was previously depleted, buttressing egg production over a wider area. Thus translocation has the potential to be used as a tool for management of the spatial distribution of egg production, plus should raise global egg production provided the TAC is not increased to remove the increased productivity from faster growth.

This study demonstrates the utility of assisted migration to improve the biomass of a stock and rebuild depleted stocks or sub-populations, but highlights that while overall growth rates improve, there are biological costs to transport and acclimation to a new habitat that were seen in deferred reproduction. Assisted migration via translocation of undersized and low value lobsters is a means to increase social-ecological resilience in southern rock lobster fisheries, which can align ecological and economic interests (Hughes et al. 2005) with lower harvest of high value fish. This experiment demonstrated resilience and plasticity within the pale morph to an increase in temperature in line with climate change predictions within this area (Pecl et al. 2009). The establishment of plants beyond their native range is essential for successful agriculture and the economies built around that (Mack and Lonsdale 2001). Similarly, assisted migration is a tool for stock enhancement in a healthy marine fishery, and would increase the degree to which the ecosystem can absorb human perturbation and regenerate from local depletions.

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#### 5.5.4 *Changes in growth following translocation*

*Published as “Growth rate of adult rock lobsters *Jasus edwardsii* increased through translocation” 2010 Chandrapavan, A., Gardner, C., Green, B.S., Fisheries Research, 105: 244–247.*

##### **Abstract**

This section deals with growth observations from slow-growing lobsters from Tasmanian deep-water regions translocated to shallow-water, inshore areas. Within their first moult, lobsters that were moved increased their growth rates, exceeding that of resident deep-water lobsters from the original site. Growth of translocated females increased to the extent that it exceeded resident shallow-water females in the first year post-release. The increased growth rate of deep-water southern rock lobsters after translocation and the magnitude of the growth changes achieved in a short period highlight the plasticity in growth of this species. Rapid increases in lobster growth achieved through translocation suggest that translocation could be applied to increase the productivity of the fishery.

##### **Introduction**

Variable growth of the southern rock lobster *Jasus edwardsii* is the basis of ongoing spatial management challenges across the Australian fishery (McGarvey et al. 1999). Around the coast of Tasmania, growth rates of *J. edwardsii* decrease from north to south of the State and also decrease with depth (Punt et al., 1997). For example, the mean annual growth increment for females of carapace length 75 mm is 1-2 mm in the southern regions while in the north of the State it is more than 20 mm per annum. Likewise for males of carapace length 75 mm, the mean annual growth increment is 10 mm in the southern regions and 22 mm in the north of the State (Punt et al. 1997). Differences in growth are also reflected in the spatial differences in L50% (length at which 50% of lobsters are mature) for female southern rock lobsters around Tasmania which is estimated to be 60-65 mm in the south and 100-105 mm in the north of the State (Gardner et al. 2006).

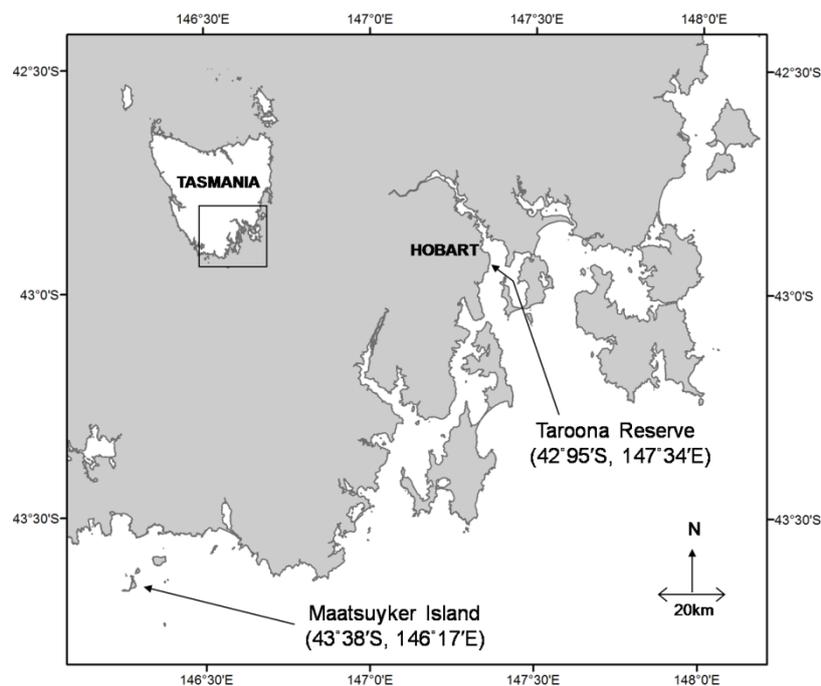
The first phase in exploring translocation as a management tool was assessing its economic feasibility under assumed growth scenarios, and this predicted greatest increase in economic rent from the fishery when translocations occur between regions with greatest differences in growth (Gardner and van Putten, 2008b). Here we present results on the short-term growth response of translocated lobsters from a deep-water region in the south of the state to a shallow-water reef on the east coast of Tasmania.

##### **Detailed Methods**

###### *Translocation of lobsters*

In November 2005, 1998 adult, male and female deep-water lobsters (68 – 120 mm CL) were trapped using baited metal pots in depths around 60 - 80 m from around Maatsuyker Island (43.38°S, 146.17°E) in the south of the State, and were transported

in flow-through holding tanks onboard a research vessel and released into depths of 5 – 15 m at a marine protected area, Tarooma Research Reserve (42.95°S, 147.34°E) on the east coast of Tasmania (Figure 5-56). All translocated lobsters were tagged ventrally with T-bar tags (coloured Hallprint T-bar anchor tag), carapace length (CL) measurements and sex were recorded, and one pleopod was clipped as an indicator for moulting. Tarooma Reserve was surveyed at 5 (April 2005), 8 (July 2005), 12 (November 2005) and 14 (January 2006) months after the translocation for the collection of growth data from resident and translocated lobsters. Ongoing tag-recapture research surveys at Tarooma Reserve and around Maatsuyker Island provided growth information of the resident lobster populations for the years 2000 - 2005.



**Figure 5-56.** Map of south-east Tasmania showing the deep-water capture site (Maatsuyker Island) and the shallow-water translocation release site (Tarooma Marine Reserve).

### *Data analyses*

Data analyses of annual moult growth increments were restricted to setose (mature) females between 70 – 110 mm CL (at time of capture) and males between 70 – 130 mm CL. Only lobsters that were recaptured after the annual moulting season (April to May for females and September to October for males) were included, to ensure the lobster had moulted. Carapace length measurements were collected by numerous personnel over a number of years, and so we have assumed measurement errors of equal magnitude across all lobsters. Carapace length and growth increment data were transformed ( $\log_{10}$ ) to achieve normal distribution. Differences in growth moult increments were analysed using a combination of analysis of covariance (ANCOVA)

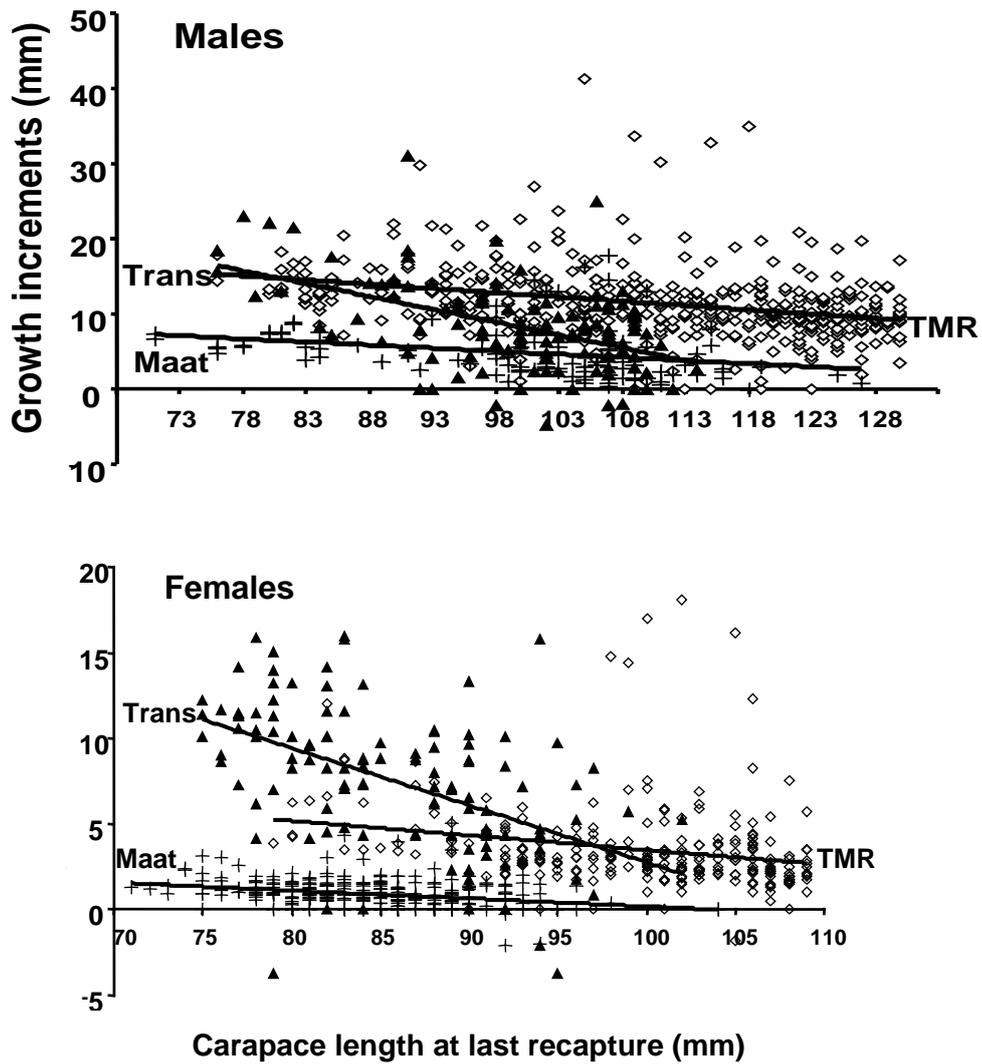
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using CL as covariate, and separate slope analyses (applied when the homogeneity of slopes assumption was violated). Pillai's trace test was used as multivariate test of significance and significant effects were further explored using Tukey's post-hoc analysis. All statistical analyses were performed using Statistica v7.1 (Statsoft Inc. Tulsa OK USA). Growth differences among small (80-85 CL, well under the legal size) and large (Males; 100-105 CL, Females; 90-95 CL) those approaching the legal size) males and females were also examined.

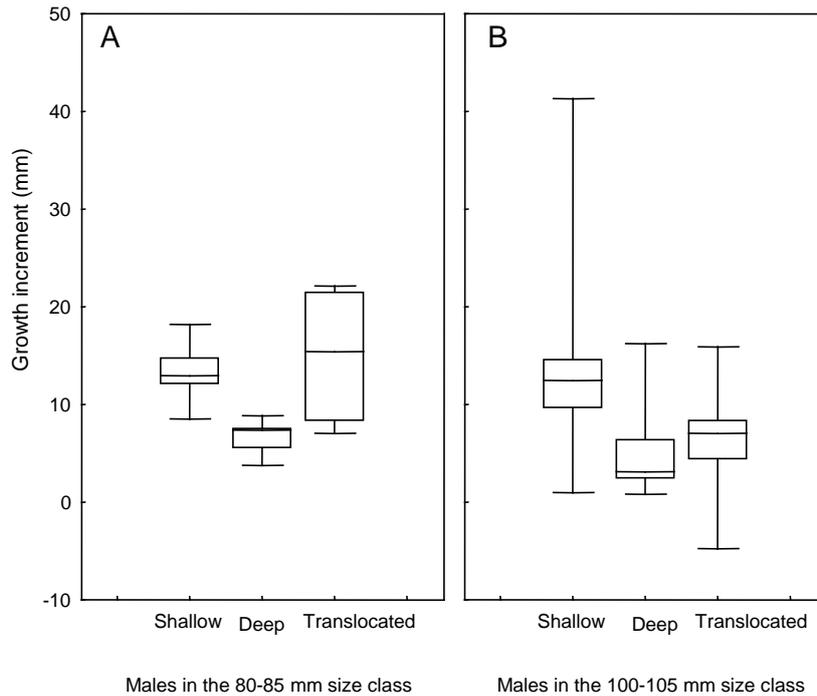
## Results

Moult increments decreased with size and were highly variable across the size ranges for both males and females of the resident deep-water, resident shallow-water and translocated populations. The growth of translocated males (after their first moult) was significantly greater than resident deep-water lobsters but less than the growth rate of the resident shallow-water male lobsters ( $F(2,559) = 6.20$ ,  $p < 0.001$ ) (Figure 5-57). For male lobsters ranging between 70 and 130 mm CL, the median growth increment for the shallow-water population was 11 mm, 3.9 mm for the deep-water population and 8 mm for translocated males. For small males (80 – 85 mm CL), the median growth increment was higher in shallow-water males (13.0 mm) than in deep-water males (7.4 mm) but was highest in translocated males with 15.4mm (Figure 5-58). For large males (100 – 105mm CL), median growth increment was highest in shallow-water males with 12.4 mm, followed by translocated males with 7.1 mm and lowest in deep-water males with 3.1 mm (Figure 5-58).

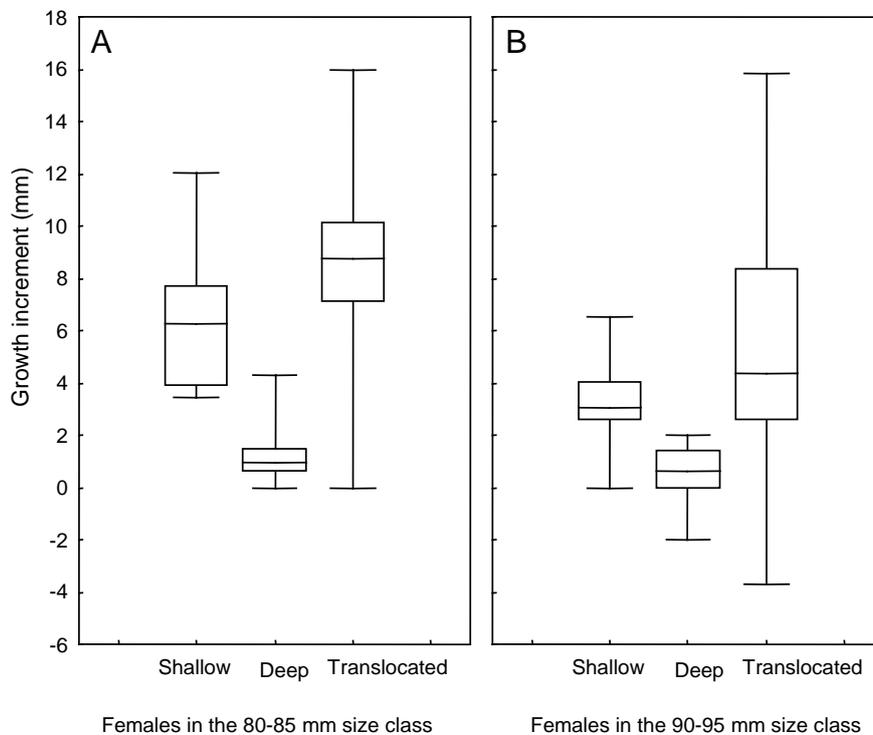
The growth rate of translocated females was significantly higher than that of either resident deep-water or shallow-water females ( $F(2,606) = 4.48$ ,  $p = 0.01$ ) (Figure 5-57), and across all size classes. For female lobsters ranging between 70 and 110 mm CL, the median growth increment for shallow-water population was 2.1 mm, 0.9 mm for the deep-water population, and 8 mm for translocated population. For small females (80 – 85 mm CL), median growth increment was highest in translocated females (8.8 mm), followed by shallow-water females (6.2 mm) and lowest in deep-water females (1.0 mm; Figure 5-59). For larger females (90 – 95 mm CL), median growth increment was again highest in translocated females (4.4 mm), followed by shallow-water females (3.0 mm) and lowest in deep-water males (0.6 mm).



**Figure 5-57.** Growth regressions of resident male lobsters at Maatsuyker Is (Maat) ( $y = -0.082x + 13.17$ ,  $r^2 = 0.06$ ), resident males at Taroon Marine Reserve (TMR) ( $y = -0.118x + 27.49$ ,  $r^2 = 0.06$ ) and translocated male lobsters (Trans) ( $y = -0.341x + 42.34$ ,  $r^2 = 0.24$ ). Also shown are the growth regressions of resident females at Maatsuyker Is ( $y = -0.046x + 4.85$ ,  $r^2 = 0.09$ ), resident females at Taroon Marine Reserve ( $y = -0.172x + 21.76$ ,  $r^2 = 0.16$ ) and translocated female lobsters ( $y = -0.333x + 36.08$ ,  $r^2 = 0.25$ ).



**Figure 5-58.** Comparisons of growth increments between deep, shallow and translocated male lobsters in the (A) 80 – 85 mm and (B) 100-105 mm size range. The box and whisker plot shows: box = 1st-3rd quantiles; centre line = median value; whiskers = minimum-maximum values.



**Figure 5-59.** Comparisons of growth increments between deep, shallow and translocated female lobsters in the (A) 80 – 85 mm and (B) 95-95 mm size range. The box and whisker plot shows: box = 1st-3rd quantiles; centre line = median value; whiskers = minimum-maximum values.

## Discussion

This translocation experiment provided a unique opportunity to exploit the site-specific variation in growth rate in *Jasus edwardsii*. We were able to increase growth rates in the slow-growing, sub-legal portion of the population by moving them to areas of faster growth, and therefore increase the biomass of the stock. Growth in translocated females exceeded that of resident females of both the shallow and deep-water populations. This increases productivity and exploitable biomass available to the fishery, given that commercial harvests are constrained by quota.

The overall economic feasibility evaluation of translocation identified both the operational costs of translocation and change in growth to increase with distance from Maatsuyker Island (Gardner and van Putten 2008b). Under the assumption that translocated lobsters would match the growth rate of resident lobsters, greatest yield gain resulted when growth differences between capture and release sites were large. We found growth increments of translocated lobsters to be greater than resident deep-water lobsters thus achieving the primary goal of translocation, but the magnitude of growth change varied among small and large males and females. This suggests that gains in economic yield through translocation may be a function of size at release and gender in addition to growth differences between regions. The key outcome from the experimental trials was that growth of small yet mature males and females exceeded the growth of resident males and females within the first 12 months of translocation. Translocating small sized lobsters would, however, require additional effort for grading on board thus increasing the cost of capture, but overall translocation costs will be reduced by the greater tonnages (from smaller sized lobsters) transported over smaller distances especially as catch rate of under-sized females is high.

Modelled translocation from Maatsuyker Island to Taroona predicted a 347% increase in total biomass, with assumptions of constant harvest rate, that lobsters adopt the growth rate of resident lobsters in the first year after translocation, and that release mortality is no greater than 10% (Gardner and van Putten, 2008a). Increased growth from the first year after translocation presented here support the predicted increased biomass and survival of translocated lobsters was similar to resident lobsters, and was less than 10% (Green and Gardner 2009). Given that none of the modelled scenarios considered growth of translocated lobsters to exceed that of the residents in the first 12 months, the results from this study would need to be factored into future economic and biological evaluations for translocation operations. The magnitude of the growth changes in translocated lobsters in the current study is compelling in terms of its commercial implications, but longer term monitoring is needed to determine how growth rates change with subsequent moults, as this will influence the time period for translocated lobsters to enter the fishery.

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### 5.5.1 *Effect of translocation on the deep reef ecosystem*

#### **Summary**

At the outset of the project, one of the key concerns was that the removal of large numbers of small, pale lobsters from small areas of deep water habitat would have detrimental effects on deep water habitats and communities. No broad-scale changes in deep water reef habitat or phase shifts in community structure were identified in this study. The coarse level and frequency of the sampling could not rule out any small-scale community changes, but as local community structure is generally dynamic, we have monitored the scale of importance to such an exercise.

#### **Detailed Methods**

##### *Equipment*

A SeaBotix LBV300S2 (Figure 5-60) remotely operating vehicle (ROV) for deep sea exploration was used to collect images and video footage for quantitative analysis in order to examine the ecosystem at the impact (removal) site at Maatsuyker island. This ROV via a camera with a 270° field of view, manual focus controls and a wide angle lens, had the capability of recording video footage at depths up to 300 m. It was a tethered ROV, operated at the surface via a 200m fibre optic cable.



**Figure 5-60** Photograph of the Remote Operating Vehicle used for collecting images from the removal and control sites at Maatsuyker Island, Tasmania. Model SeaBotix LBV300S2, [www.seaviewsystems.com](http://www.seaviewsystems.com)

##### *Sampling design*

Video transects were taken of the removal site (m2), and 3 adjacent sites where lobsters haven't been removed (m1,3,4), (Figure 4-2). In 2008, 3 transects of 40 min were recorded at 50-90m depths. In 2009, five transects were recorded between depths of 50-90m. This video footage was reviewed and flora and fauna in the footage was semi-quantitatively examined.

##### *Analysing video*

Benthos diversity was analysed from the video footage from still frames grabbed from

the footage. Frames were selected by generating a random number series and then finding the image from the corresponding time code. Fifteen images per site were selected. The size of the frame was approximately 0.5 m<sup>2</sup>. When assessing benthos diversity, each image was firstly scored for % composition of reef vs. sand. The reef portion of the image was then scored for % cover (ie. invertebrates and algae). The diversity of the reef cover was then assigned a ranking of low, medium or high which corresponded to the presence of 0-10, 10-20 or 20+ taxonomic groups respectively (some groups were to genus level and others to family. Invertebrate diversity was recorded on a coarse scale as the footage quality did not allow for identification to species level (Table 5.16).

**Table 5.16** Taxonomic grouping used to assess benthic diversity of images recorded by the ROV. Level of identification was limited by the resolution of the footage.

### Taxa common name

#### BENTHIC

##### *Sponge (Phylum Porifera)*

- finger sponge (brown)
- orange sponge (round)
- white/grey sponge
- fan sponge (grey)
- red/pink patchy sponge
- finger sponge (Black)
- tall tube sponge

##### *Octocorals (Order Alcyonacea)*

- soft coral fan
- sea whips (*Primnoella* sp.)

##### *Zooanthid*

- Zooanthids, yellow (*Parazoanthus* sp.)

##### *Cnidarian*

- Hydroid cover (basic)

##### *Ascidian*

- ascidian (*Herdmania*)
- soft coral

##### *Algae*

- red algae (disc)
- red leaf

#### FISH

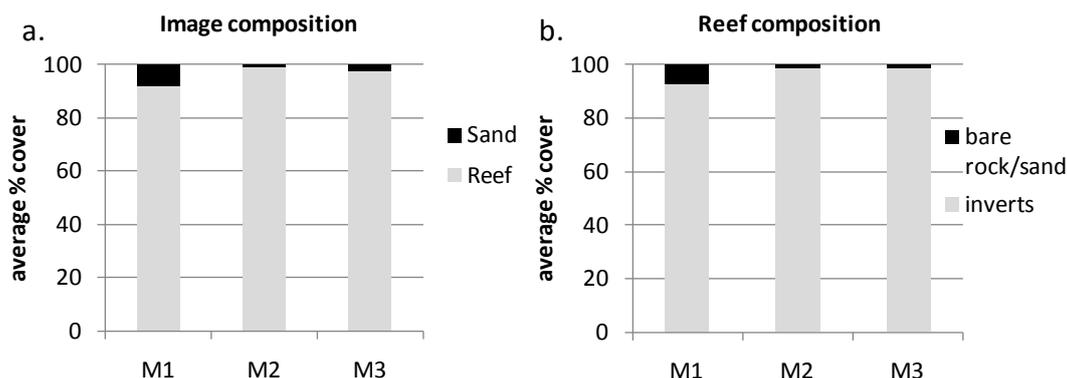
- butterfly perch (*Caesioperca lepidoptera*)
- barber perch (*Caesioperca razor*)
- Striped trumpeter (*Latris lineata*)
- Unknown sp.
- Wrasse unidentified
- Toad fish unidentified
- Unidentified fish
- small schooling sps

Transects for counting fish were selected randomly along 10 x 20 s transects per site. Fish were identified to species where possible, otherwise they were just recorded to genus or family, depending on the resolution of the video footage (Table 5.16). A total count of all fish observed in the transect was made as well as the maximum number of different taxonomic groups counted.

## Results

### *Benthos*

The primary assessment of the benthos categorised it into sand or reef, and by this division all 3 Maatsuyker Island sites were primarily reef sites, with greater than 90% of the site made up of reef. M2, the removal site and M3 were 1 and 2% sand respectively (Figure 5-61a). Of the area classified as reef, >90% was composed of invertebrates for all 3 sites, and only 1% of M2 and M3 was bare rock (Figure 5-61b).



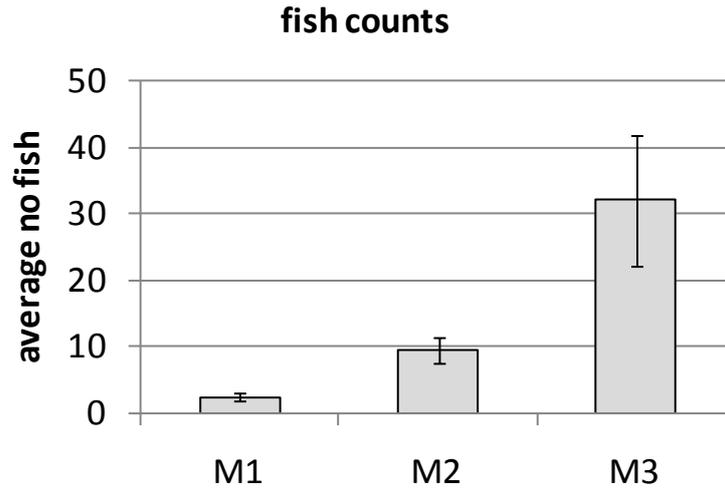
**Figure 5-61** % composition of 3 sites at Maatsuyker island. M2 is the removal site, M1 and M3 are adjoining sites. a) site composition is an estimate of % coverage of the site by sand and reef. b) The proportion of the reef identified in a. made up of bare/ rock and sand and invertebrates.

M2 and M3 had the highest diversity of invertebrates, represented by more 20 taxa recorded per frame (0.5m<sup>2</sup>). M1 had fewer taxa per frame (Table 5.17).

| <b>Table 5.17</b> Average values of invertebrate diversity of benthos. |               |              |
|--|---------------|--------------|
| <b>Site</b>  | <b>Rank</b>   | <b>Taxa</b>  |
| <b>M1</b>  | <b>Medium</b> | <b>10-20</b> |
| <b>M2</b>  | <b>High</b>   | <b>20+</b>   |
| <b>M3</b>  | <b>High</b>   | <b>20+</b>   |

### *Mobile fauna*

M1 had the lowest number and diversity of mobile fishes, M3 had the highest whilst M2 was intermediate in number and diversity of fishes (Figure 5-62, Table 5.18). The highest number of taxa observed in one transect was 5 taxa at M3. The number of mobile fishes was <5 at M1, <10 at M2 and > 30 at M3 (Figure 5-62).



**Figure 5-62** Average fish count per 20 s timed transect at the 3 Maatsuyker Island sites. Error bars are standard errors.

**Table 5.18** Average values of Fish diversity per 20 s timed transect at the 3 Maatsuyker island sites

| Site | Rank (av) | Taxa (av) | > no taxa obs in one tsect | av no taxa obs |
|------|-----------|-----------|----------------------------|----------------|
| M1   | L         | 0-10      | 2                          | 1.2            |
| M2   | L         | 0-10      | 4                          | 1.8            |
| M3   | L         | 0-10      | 5                          | 2.1            |

**Discussion**

There was no evidence of a large-scale phase shift at M2 caused by the removal of almost 30,000 small lobsters, equivalent to approximately 9 T, for the translocations undertaken in this project. The diversity of both mobile fish fauna and the benthos was very similar at M2 as to the adjacent site M3. On all measures M1 had lower diversity, lower coverage and lower numbers of fish. The level of detail in these transects and the absence of measures taken before the removals began will not allow for more detailed conclusions to be drawn. However, more detailed surveys were undertaken in shallow water habitat with finer scale surveys, repeated over short time frames before and after the introductions of lobsters to new environments, and similarly no impacts were found.

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### 5.5.2 *The effect of translocation on Tasmanian shallow reef communities*

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#### **Summary**

At the outset of the project, one of the key concerns was that the addition of small, pale lobsters to inshore shallow water habitats would have detrimental effects on the shallow reefs and communities. Diver surveys of fish, invertebrate and algal communities were conducted at each of the shallow-water translocation sites once per year after translocation, starting in 2005, until 2009. No broad-scale changes in the shallow reef habitat or phase shifts in community structure were identified in this study. While dive surveys were very detailed, with taxonomic experts recording everything along 100m transects, the frequency of the sampling could not rule out any small-scale community changes, but as local community structure is generally dynamic, we have monitored the scale of importance to such an exercise.

#### **Introduction**

Almost 30,000 lobsters were moved from waters near Maatsuyker Island in the state's south-west to 8 sites around Tasmania, over 4 years (Table 4.1). Six sites were surveyed by divers to assess whether the addition of large numbers of lobsters had discernible impacts on the shallow water marine environment. These sites were Emerald Bay, Trumpeter Bay, Georges Rocks, Reidle Bay, Gull Island and Taroonna (see Figure 3-3).

#### **Detailed Methods**

Environmental surveys were conducted between September 2005 and November 2009. Initial baseline surveys were conducted prior to the removal or translocation of any lobsters in 2005. The sampling period was limited to 'spring' (between September and November) each year. Not all sites were surveyed every year. Emerald bay was not surveyed in 2006, and Gull Island was not surveyed in 2007. A 5-m depth contour limit was placed on all surveys to reduce variability in comparisons. All surveys were conducted following the methods from Barrett et al (Barrett et al. 2009).

#### *Fish and invertebrates*

Fish and invertebrates were entered as number and size (mm) according to standard measurement practices (e.g. carapace for rock lobsters, widest part of the shell for abalone, total length for fish) during data entry. Where no measurement had been recorded only the number (presence) was entered. The size measurement for fish were recorded and thus entered according to the following categories (with inches converted to millimeters instantly upon entry). As either 1, 2, 3, 4 or 5 inches or between 6 - 8, 8 - 10, 10 - 12, 12 - 14, 14 - 15, 15 - 20, 20-25 mm. Fish were recorded and thus entered as the minimum size, in a size range class (e.g. if a fish was estimated to be in the 10-12 inch category it was recorded as 10 inches).

## Algae

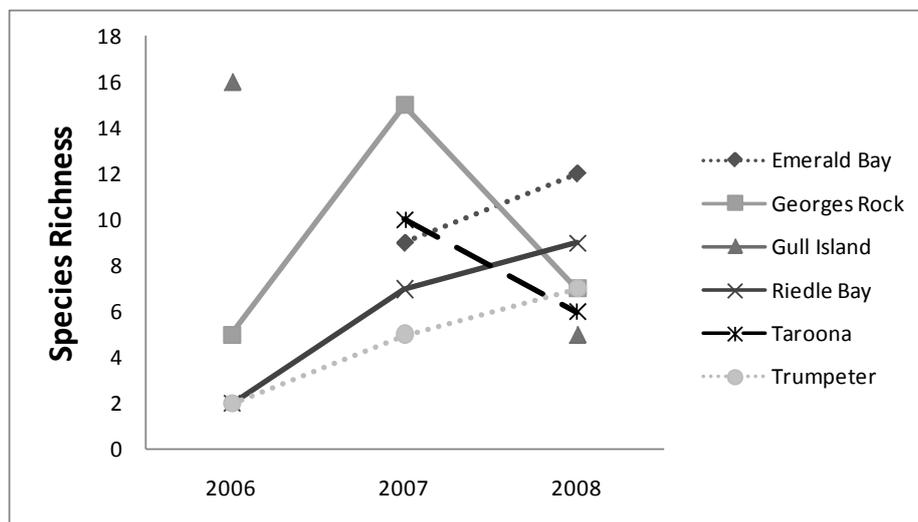
Algal species were surveyed according to the method described above. Due to difficulties in identification, some species were only identified to family or class. In the case of reds (Rhodophyta) they were identified to species or classified as either corallines- incrusting or erect; or thallus, branching, or turfing reds. Modifications were made to the database to allow the entering of data to match the recoding by the divers.

Sessile creatures including sponges, hydroids, bryozoans, and ascidians were recorded during the algal transects and were thus entered under the algal method in data entry. These animals were recorded only to phylum level by divers and thus entered accordingly.

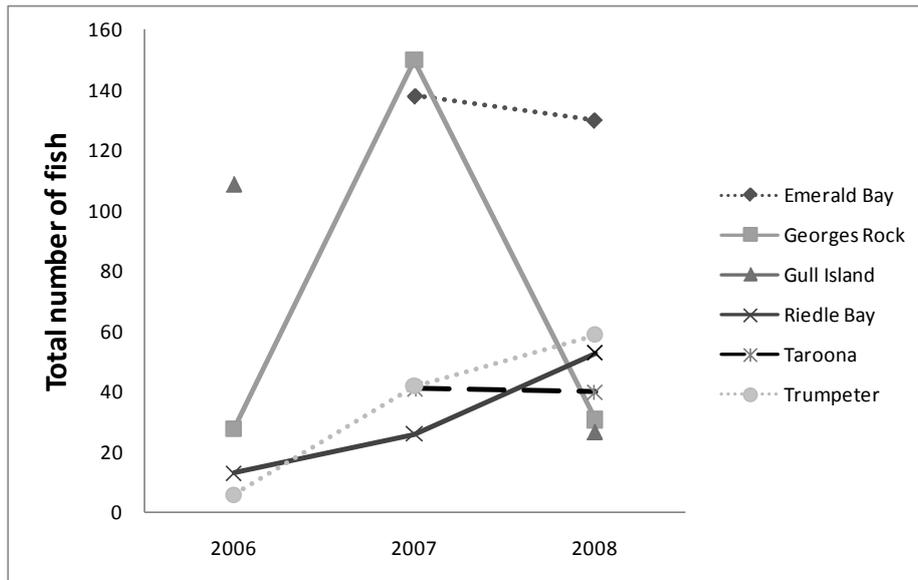
## Results

### Fish

In three of the sites that pale lobsters that translocated to, species richness increased throughout the period that translocations occurred (Riedle Bay, Trumpeter Bay and Emerald Bay), species richness declined at two sites (Taroona and Gull Island) and at Georges Rock it bounced around, increased in 2007 and then decreasing in 2008 to the same level it started at (Figure 5-63).



**Figure 5-63.** Fish species richness of translocation source and sink sites during the large-scale translocation experiment.



**Figure 5-64.** Number of fish per 200m at translocation source and sink sites during the large-scale translocation experiment.

The number of fish recorded per transect increased for most sites during the translocation experiment (Figure 5-64). The only significant decline in number of fish occurred at Georges Rocks. Fish abundance at Gull Island increased in 2007 and then declined to match abundances at the commencement of this experiment. Abundances at Emerald Bay and Tarooona stayed the same throughout the surveys.

**Table 5.19.** Number of fish at each site throughout the monitoring of the large-scale translocation experiment. (Emerald Bay not surveyed in 2006 and Gull Island not in 2007).

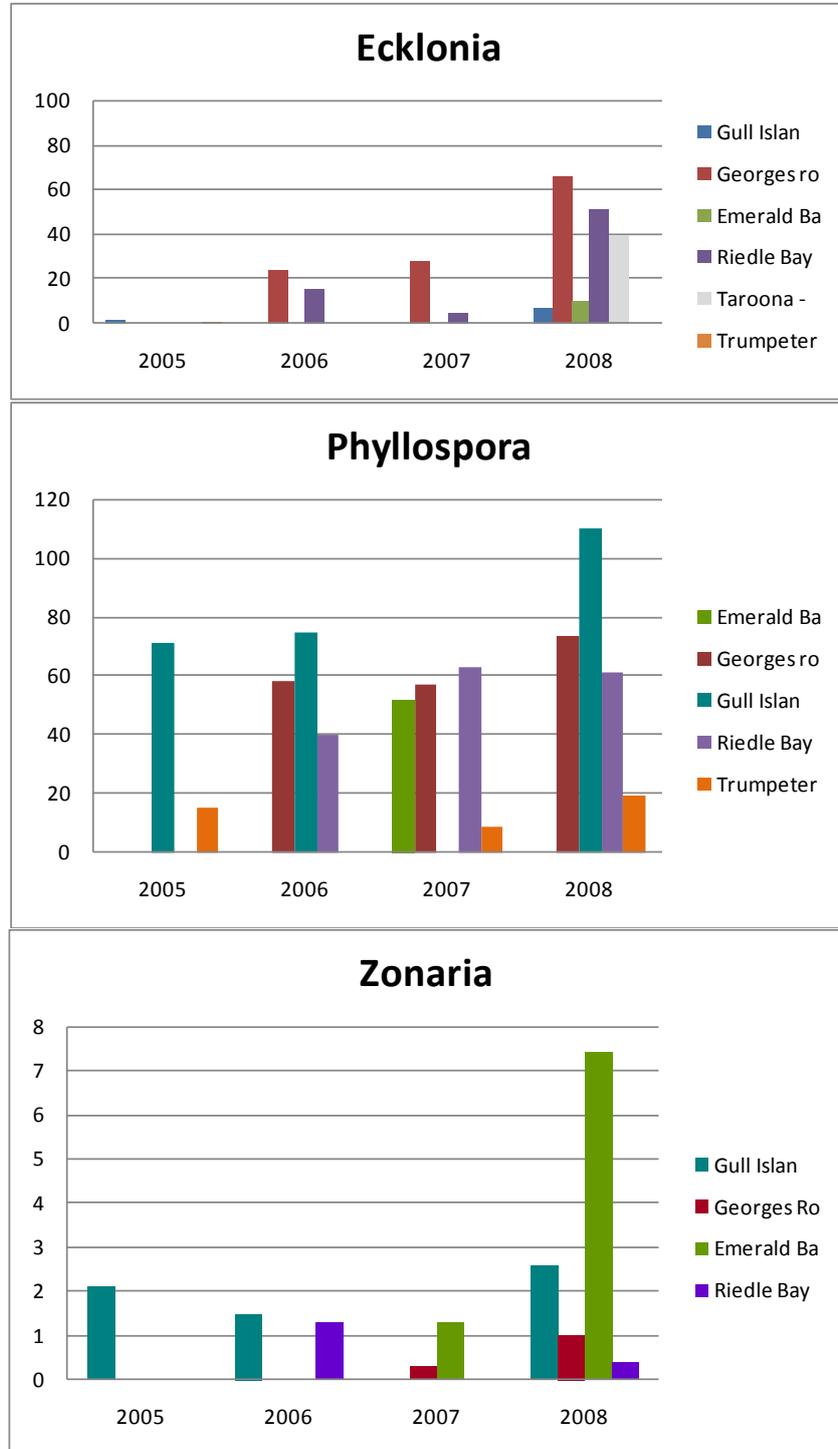
| <b>Location</b>             | <b>2006</b> | <b>2007</b> | <b>2008</b> |
|-----------------------------|-------------|-------------|-------------|
| <b>Emerald Bay</b>          |             |             |             |
| Banded stingaree            |             |             | 2           |
| Barber perch                |             |             | 9           |
| Blue-throat wrasse          |             | 44          | 55          |
| Bridled leatherjacket       |             | 16          |             |
| Brown-striped leatherjacket |             | 4           |             |
| Gunns leatherjacket         |             |             | 1           |
| Herring cale                |             | 3           |             |
| Hulafish                    |             | 18          |             |
| Long-fin pike               |             | 14          |             |
| Magpie perch                |             |             | 1           |
| Purple wrasse               |             | 35          | 22          |
| Rosy wrasse                 |             |             | 8           |
| Senator wrasse              |             | 1           | 21          |
| Shaws cowfish               |             |             | 1           |
| Toothbrush leatherjacket    |             | 3           | 7           |
| Warty prowfish              |             |             | 1           |
| White-ear                   |             |             | 2           |
| <b>Georges Rock</b>         |             |             |             |
| Banded morwong              |             | 1           | 2           |
| Barber perch                |             | 3           |             |
| Bastard trumpeter           |             |             |             |
| Blue-throat wrasse          |             | 15          | 7           |
| Degens leatherjacket        | 1           |             |             |
| Draughtboard shark          |             | 1           |             |
| Globe fish                  | 2           |             |             |
| Gunns leatherjacket         |             | 1           |             |
| Herring cale                |             | 2           | 5           |
| Hulafish                    |             | 13          |             |
| Long-fin pike               |             | 15          | 3           |
| Long-tail weed-whiting      |             | 6           |             |
| Mackerel scad               |             | 30          |             |
| Marblefish                  |             | 1           |             |
| Purple wrasse               | 20          | 32          | 12          |
| Rough bullseye              |             | 3           |             |
| Sea sweep                   |             | 25          |             |
| Senator wrasse              |             | 2           |             |
| Toothbrush leatherjacket    | 4           |             |             |
| Unidentified leatherjacket  | 1           |             |             |
| Zebra fish                  |             |             | 2           |
| <b>Gull Island</b>          |             |             |             |
| Banded morwong              | 8           |             | 8           |
| Blue-throat wrasse          | 33          |             | 6           |
| Degens leatherjacket        | 1           |             |             |
| Globe fish                  | 1           |             |             |

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|                                |     |     |     |
|--------------------------------|-----|-----|-----|
| Herring cale                   | 16  |     | 4   |
| Long-snouted boarfish          | 1   |     |     |
| Magpie perch                   | 3   |     |     |
| Old wife                       |     |     | 3   |
| Purple wrasse                  | 39  |     | 6   |
| Sea sweep                      | 5   |     |     |
| Senator wrasse                 | 1   |     |     |
| Short-nose weed-whiting        |     |     |     |
| Six-spine leatherjacket        | 1   |     |     |
| <b>Riedle Bay</b>              |     |     |     |
| Blue-throat wrasse             | 3   | 3   | 7   |
| Purple wrasse                  | 10  |     |     |
| Banded morwong                 |     | 3   | 3   |
| Brown-striped leatherjacket    |     |     | 2   |
| Bullseye                       |     |     | 1   |
| Long-fin pike                  |     | 8   |     |
| Purple wrasse                  |     | 3   | 22  |
| Red gurnard perch, Ocean perch |     |     | 3   |
| Rosy wrasse                    |     | 3   |     |
| Senator wrasse                 |     | 2   | 12  |
| Toothbrush leatherjacket       |     | 4   | 2   |
| Unidentified Cardinalfish      |     |     | 1   |
| <b>Taroona</b>                 |     |     |     |
| Bastard trumpeter              |     | 1   | 4   |
| Blue-throat wrasse             |     | 29  | 18  |
| Marblefish                     |     |     | 1   |
| Purple wrasse                  |     | 1   | 14  |
| Shaws cowfish                  |     |     | 1   |
| Wrasses                        |     |     | 2   |
| Eastern hulafish               |     | 3   |     |
| Flathead                       |     | 1   |     |
| Little rock whiting            |     | 1   |     |
| Rosy wrasse                    |     | 1   |     |
| Senator wrasse                 |     | 1   |     |
| Toothbrush leatherjacket       |     | 1   |     |
| Whitleys skate                 |     | 1   |     |
| <b>Trumpeter</b>               |     | 42  |     |
| Blue-throat wrasse             |     | 19  |     |
| Draughtboard shark             |     | 2   |     |
| Long-tail weed-whiting         |     | 2   |     |
| Purple wrasse                  |     | 18  | 19  |
| Shaws cowfish                  |     | 1   |     |
| Globe fish                     | 1   |     | 2   |
| Purple wrasse                  | 5   |     |     |
| Blue-throat wrasse             |     |     | 5   |
| Brown-striped leatherjacket    |     |     | 16  |
| Herring cale                   |     |     | 1   |
| Long-fin pike                  |     |     | 665 |
| Toothbrush leatherjacket       |     |     | 16  |
| Grand Total                    | 150 | 397 | 947 |

*Algal cover*

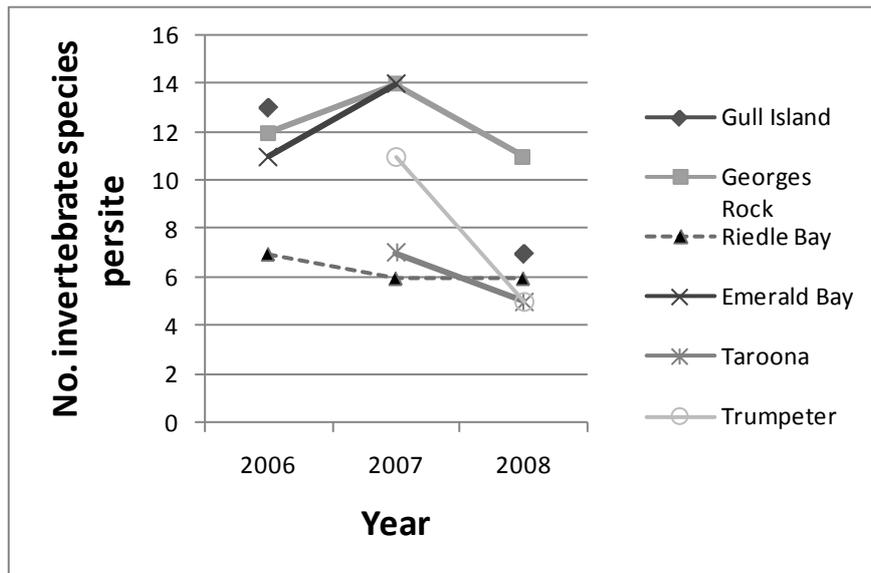
Ecklonia was recorded at high levels at 3 sites, Georges Rock, Riedle Bay and Tarooana. Percentage cover of ecklonia increased throughout the translocation experiment, from 20% or below in 2006 to 40% or above in 2008 (Figure 5-65). Zonaria increased at all sites it was present at except Riedle Bay (Figure 5-65), and phyllosopora remained at similar levels at most sites throughout the experiment. These 3 algal species make up the main canopy forming species in Tasmanian waters.



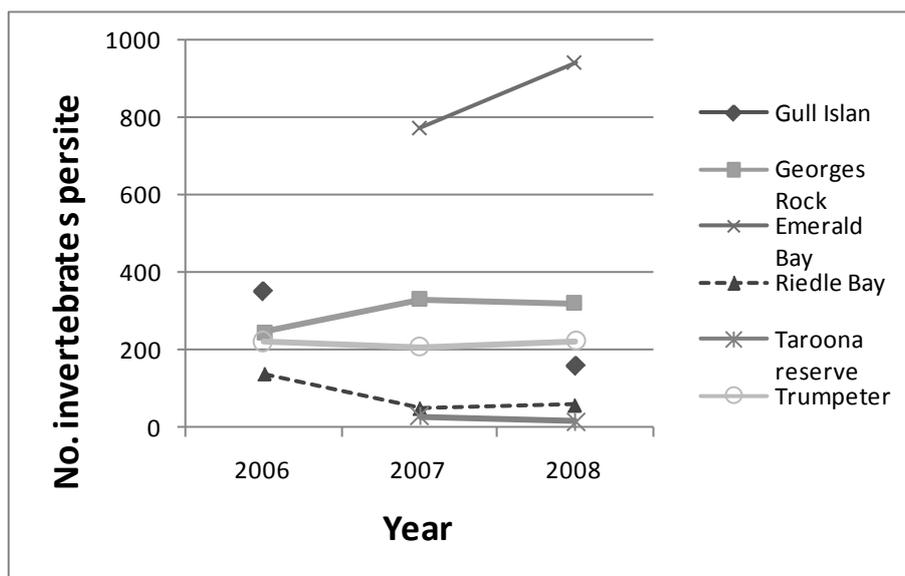
**Figure 5-65.** Percentage cover for common macroalgal species and canopy forming species.

*Invertebrates*

Invertebrate species richness (number of species per site) was similar in 2008 as it was in 2006 for all sites except Gull Island. Species richness increase in 2007 for all sites except Riedle Bay where it remained relatively stable throughout the translocation experiment (Figure 5-66) The number of invertebrates remained stable at all sites from 2006 through to 2008, except at Emerald Bay where there was an increase after the introduction of 2000 deep water lobsters in 2007. The three species that increased at this site were *Comanthus* sp (feather star), *Heliocidaris erythrogramma* (purple sea urchin) and *Herdmania momus* (red throat ascidian).



**Figure 5-66** Species richness at all sites.



**Figure 5-67** Total number of invertebrates per site.

## **Discussion**

Interannual variation in richness and abundance of fish, invertebrates and algae are greater than any apparent effects of the introduction of large numbers of lobsters into the experimental shallow water sites. We could not detect any overall negative impact on shallow water communities in the form of major phase shifts or changes in community structure. There was no detectable impact on invertebrate assemblages or the number of invertebrates at shallow water translocation sites throughout this experiment. The addition of between 1800 and 5800 deep water lobster to these sites over 3 years has not influenced the composition or density of invertebrates at these sites. While the number of fish increased at a couple of sites, it declined slightly at other sites. Fish are highly mobile and so the numbers fluctuate regularly. The magnitude of interannual fluctuations in this short-term study were well within the range of variation identified using the same survey techniques in studies on marine protected areas, where species richness and diversity showed large natural fluctuations (Barrett et al. 2009).

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### 5.5.3 *The effect of translocation on South Australian shallow reef communities*

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#### **Abstract**

Translocation of 2010 deep-water (>100 m) southern rock lobster (*Jasus edwardsii*) to an inshore rocky reef off the south east coast of South Australia was undertaken to promote colour change and improve subsequent market value. A BACI experimental design incorporating dietary analysis of resident inshore and translocated lobsters, coupled with dive surveys of mobile benthic macroinvertebrate ledge assemblages was used to assess potential predatory impacts. Translocated lobster abundance initially increased at the release sites ledges but then decreased ~ 43 weeks later. Translocated lobsters preyed upon similar taxa to resident inshore lobsters, consisting mainly of the spiny urchin *Heliocidaris erythrogramma*, crab and prosobranch species. However, no significant impacts were detected in the abundance of prey assemblages (including resident inshore lobsters) within ledges at the translocation site over time. Furthermore, the translocation of deep water rock lobsters had no detectable impacts on the diet of resident inshore lobsters. Translocated lobster movement was identified as probably the main contributing factor to the decrease in translocated lobster numbers over time and the likely reason why no significant predatory impacts were detected. Specifically, tag returns revealed that the average distance moved by lobsters away from ledges (1.9 km) was further than their known median foraging range (24 m), which reduced their predatory and competitive pressure. Lobster abundance increased with topographic complexity as ledges became deeper and narrower. Susceptibility of lobsters to predation from inadequate ledge shelters may explain this relationship and why translocated lobsters moved over time. Future translocation site selection should consider habitat complexity and available refugia to minimise lobsters vulnerability to predation and maximising the commercial benefits of this management strategy. Lobsters without adequate shelter are more susceptible to predation, and so we suggests ledges are limiting lobster abundance as lobsters without suitable refugia moved away to more adequate habitat.

#### **Introduction**

The South Australian commercial rock lobster trap fishery is currently worth ~AUS\$100M annually (Knight et al. 2007), and is the State's most valuable fishery resource. This fishery is divided into a southern zone (SZ) and northern zone (NZ), each of which is separated into marine fishing areas (MFAs) for management purposes (Linnane and Crosthwaite 2009a). A range of input and output controls are used for sustainable management of the fishery, with a total allowable commercial catch (TACC) set annually for each zone (Sloan and Crosthwaite 2007).

Different morphological colour variations of *J. edwardsii* exist at different depths. "Red" coloured lobsters are generally found inshore (< 60 m depth), while "speckled"

or “white” coloured lobsters are found at greater depths offshore (Linnane et al. 2009). Currently, 90 % of South Australian lobsters are exported to China, where for cultural reasons, smaller sized (<1kg) red coloured lobsters are preferred (Chandrapavan et al. 2009b). As a result, higher prices are paid for inshore red lobsters with differences in value as much as \$10/kg. This in turn had lead to increased commercial fishing effort in shallow grounds, while offshore sites remain largely unexploited. For example, ~80 % of the annual TACC in the SZ is currently taken in depths of < 60 m (Linnane and Crosthwaite 2009a).

Translocation involved moving low value “white” deepwater individuals into shallow water reefs to improve their colour and value (Gardner and Putten 2008a). Shell colouration of translocated lobsters changed to red after a single moult (Chandrapavan et al. 2009b). Small-scale translocation trials were proposed for the southern zone rock lobster fishery (SZRLF) of South Australia in 2007 as an experiment to examine the value, utility and impact of translocation as a larger scale management tool. Critical to this was the examination of the potential impacts rock lobster translocation might have on resident inshore temperate reef communities.

The southern rock lobster is a benthic, decapod crustacean that generally inhabits aeolianite limestone reefs or outcrops of igneous rocks. Within these rocky reefs, *J. edwardsii* gregariously occupies topographically complex crevice and ledge habitats (Fielder 1965). They are generally considered omnivores, but primarily carnivores of slow moving benthic invertebrate prey (Jernakoff et al. 1993; Mayfield et al. 2000b; Johnston 2003). *J. edwardsii* exert top-down control of biological communities on temperate rocky reefs, whereby their predatory effects on herbivores can indirectly cause a trophic shift on plant biomass, leading to altered primary and secondary productivity (Shears and Babcock 2002; Shears and Babcock 2003; Pederson and Johnson 2006). For example, in New Zealand and Tasmanian marine protected areas (MPA) it is thought that increasing lobster abundance lead to a reduction in urchin density and the re-establishment of macroalgal dominated reefs (Edgar and Barrett 1997; Babcock et al. 1999; Shears and Babcock 2003). Studies from New Zealand also suggest that the median foraging range of *J. edwardsii* does not exceed 24 m from their daytime shelters or ledges, thus restricting any impact lobsters might have on prey populations to the vicinity of daytime shelters (Macdiarmid et al. 1991). Translocation increases the number of predatory lobsters on a rocky reef within a short space of time. As a result, there is a need to examine the potential predatory effects of translocation on the resident reef communities into which the lobsters are moved.

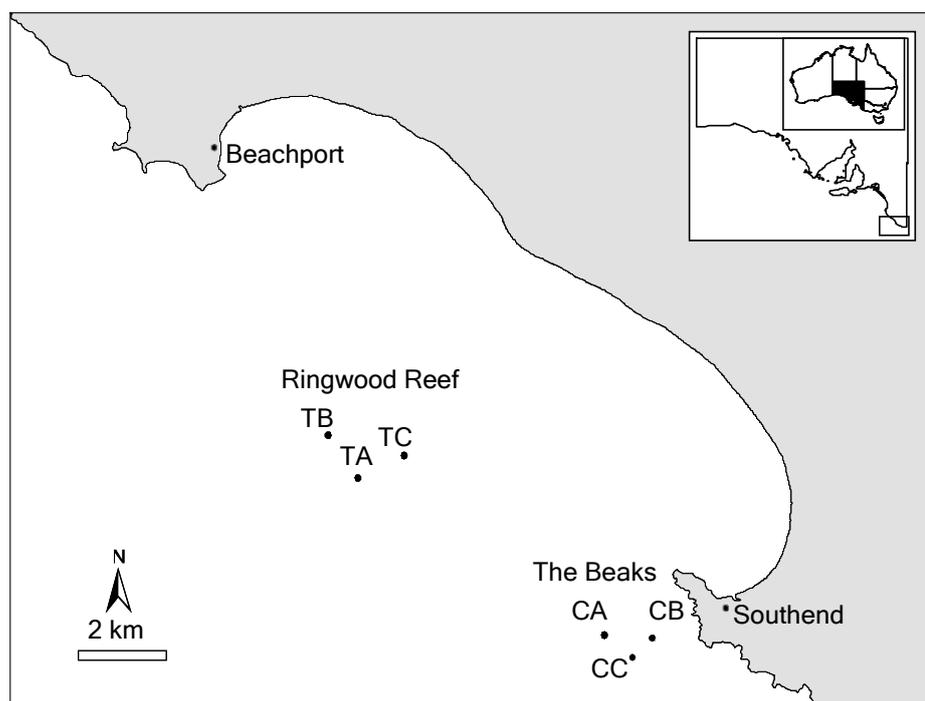
We aimed to quantify the predatory effects of translocated lobsters on the inshore reef community through dietary analysis comparisons of resident inshore and translocated lobsters, coupled with abundance surveys of mobile benthic macroinvertebrate prey assemblages on permanent ledge transects. This information is combined with field

experiments on translocated lobster movement and ledge topographic complexity to estimate the ecological effects of this management strategy.

## Detailed Methods

### *Study site*

A before-after control-impact (BACI) study was undertaken off the southeast coast of South Australia, near the commercial fishing port of Southend (37°34'S, 140°07'E; Figure 5-68). The treatment site (Ringwood Reef) and control site (The Beaks) were separated by 5.4 km. Study sites were chosen with a similar depth profile of 14 ( $\pm$  2) m to reduce spatial variability in faunal communities among sites, and also to allow commercial rock lobster vessels access to facilitate translocation and engage in commercial fishing. Preliminary dive surveys revealed that both sites had similar sea-floor geology, consisting of an aeolianite limestone reef matrix, eroded to form ledges, crevices, undercuts and holes. The communities at each site were dominated by encrusting invertebrates (sponges, ascidians, bryozoans), spiny urchins (*Heliocidaris erythrogramma*), red foliose, green foliose (*Caulerpa sp.*), brown branching (*Ecklonia radiata*, *Macrocystis angustifolia*), and encrusting coralline algae.



**Figure 5-68** Location of replicate limestone ledge transects at the Ringwood Reef treatment site (TA, TB & TC) and The Beaks control site (CA, CB & CC).

### *Translocation*

In January 2007, a total of 2020 sub-legal sized speckled/white lobsters (64-158 mm) were caught in depths > 100 m off Southend. A commercial rock lobster fishing

vessel and standard baited traps were used to catch all lobsters. To maintain condition, lobsters were held in circulated wells at sea surface temperature onboard the vessel. Lobsters were tagged with white Hallprint T-bar anchor tags using a Denssion tag-fast<sup>®</sup> III tag applicator. Tags were inserted ventrally into the anterior oblique muscle between the first and second abdominal sterna. For each lobster the tag number, gender, carapace length (CL), and shell colour (red/brindle/white using a standardised colour chart) were recorded. Approximately 670 lobsters were then translocated to each of three treatment ledges at Ringwood Reef. This involved removing lobsters of known tag numbers from wells in plastic bins and releasing them into the water from the boat once positioned over ledges. Lobsters were released *en masse* to increase chances of survival from predators on descent to the seafloor (Oliver et al. 2005). Release coordinates and depth were recorded for every lobster.

#### *Diet analysis*

In September 2006, thirty six resident lobsters were captured on SCUBA from the Ringwood Reef treatment site. As stress causes lobsters to regurgitate food matter, specimens were anaesthetized in a salt water ice slurry on transportation for dissection (Mayfield et al. 2000c). Lobsters were killed by lowering their body temperature in a freezer for two hours. The gastric-mill stomach and intestinal tract were then removed and stored at  $-20\text{ }^{\circ}\text{C}$  for further analysis. On analysis, contents were thawed then flushed into a Petri dish, and visually examined using a dissecting microscope (8x magnification). The presence of diagnostic prey fragments was used to identify prey to the lowest possible taxonomic unit, and their percent frequency of occurrence (FOO%) across all samples calculated after Berg (1979). Data from both sexes were combined.

$$\text{FOO \%} = \frac{\text{Number of lobsters with item } i}{\text{Number of lobsters examined}} \times 100$$

#### *Resident vs translocated diet*

To assess the assumption that post-translocation, translocated lobsters would consume similar food sources to resident inshore lobsters we collected samples of both lobsters from the same area. To compare the diet of translocated and resident inshore lobsters at Ringwood Reef, samples were collected for dietary analysis seven (translocated  $n = 5$ ; resident inshore  $n = 7$ ) and forty three weeks (translocated  $n = 9$ ; resident inshore  $n = 4$ ) after translocation. The FOO% was used to test the null hypothesis that there was no difference in diet between resident inshore and translocated lobsters at the treatment site. Data was arcsine transformed before analysis (Zar 1996). An nMDS and a two-way crossed ANOSIM was used to determine the similarity of diets between resident inshore and translocated lobsters and across both times.

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### *Macroinvertebrate census methodology*

Dietary analysis revealed the most frequently occurring prey items in Ringwood Reef resident lobster samples were mobile benthic macroinvertebrates. During November 2006, six limestone ledges at 14 ( $\pm 2$ ) m depth were identified using a Furuno sounder and marked with a hand held Garmin GPS at both the treatment and control sites. A free-swimming SCUBA diver then performed a 50 m habitat survey of each ledge to determine if it contained suitable lobster territory. Suitable lobster habitat was defined as ledges that already had lobsters living in them or could potentially support lobsters based on their depth and height (relief) (Rios-Lara et al. 2007). Three ledges which met this criteria were randomly selected from each site for surveys; TA, TB, and TC (Ringwood Reef); CA, CB, and CC (The Beaks) (Figure 5-68). These ledges were separated by at least 300 m and were all  $> 50$  m in length. Using GPS and weighted markers, the start and finish point of a permanent 50 m transect were identified for each ledge.

Before translocation on the 10<sup>th</sup> November and 18<sup>th</sup> December 2006, macroinvertebrate surveys were carried out at each of the three permanent ledge transects at Ringwood Reef and The Beaks respectively. Surveys consisted of a pair of divers laying a weighted 100 m tape reel directly below the opening of each 50 m ledge transect between the two weighted markers. Divers counted the abundance of mobile benthic macroinvertebrates  $> 3$  cm to the lowest classification level possible, within the area from the transect line to the back of the ledge, and then to the roof of the ledge opening for 25 m each. *A priori* power analysis was performed to determine the macroinvertebrate survey designs minimum detectable effect size (MDES) (Zar 1984).

Where  $s^2$  is the sample variance,  $n$  is the number of replicate ledges,  $\nu$  is the degrees

$$\delta = \sqrt{\frac{s^2}{n}} \left[ t_{\alpha, \nu} + t_{\beta(1), \nu} \right]$$

of freedom,  $\alpha$  is the level of significance, and  $\beta$  is the probability of committing a type II error.

On the 20<sup>th</sup> and 21<sup>st</sup> of March 2007, approximately 7 weeks after translocation, surveys were repeated at both the Ringwood Reef treatment and The Beaks control sites. When counting lobster abundance at treatment site ledges, translocated and resident inshore lobsters were differentiated visually through shell colour (speckled/white versus red) and the presence of white abdominal tags. On the 27<sup>th</sup> and 28<sup>th</sup> November 2007, Ringwood Reef and The Beaks sites were resurveyed. This was approximately 43 weeks after translocation.

A mixed design analysis of variance (ANOVA) was used to test the null hypothesis that there was no difference in resident inshore lobster abundance between the treatment and control site across all sampling times. Time was the within subject effect and site the between subject effect. Mauchly's test of sphericity tested for significant differences between the variances of the differences between sampling periods. Levene's test was also used to test for homogeneity of variances for each site of the repeated measures variable (time). The null hypothesis that lobster translocation would not affect the ledge community structure of mobile benthic macroinvertebrates at the treatment site was tested using the statistical package PRIMER version 6.0. An nMDS and a two-way crossed ANOSIM was used to determine the similarity of macroinvertebrate communities between the Ringwood Reef treatment and The Beaks control sites across all times.

#### *Translocated lobster movement*

Translocated lobsters were recaptured by commercial and recreational fisherman during the 2007 and 2008 SZRLF fishing season. Data recorded on recapture were the same as when first captured. Distance moved by recaptured lobsters was calculated as in Linnane *et al.* (2005), taking the straight-line distance between release and most recent recapture point using Arc GIS version 9.2.

#### *Topographic complexity*

The topographic complexity of each 50 m ledge transect at the treatment and control site was assessed by measuring the depth and height along ledges using a 10 m steel tape measure. Depth was defined as the distance (m) from the base directly below the opening of the ledge to the back of the ledge. Height was taken as the distance from the roof of the ledge opening to the base directly below. Measurements were taken at increments of 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 m along each ledge for both indices. Depth and height variables were converted to a ratio as a measure of ledge topographic complexity:  $\text{Topographic Complexity} = \text{Depth/Height}$ .

To test the null hypothesis that there was no difference in the topographic complexity (depth/height ratio) of ledges within the treatment and control site, univariate analysis was performed using SPSS 14.0 software. The data failed to meet assumptions of normality and homogeneity of variance, so a Kruskal-Wallis non-parametric test was used to determine variability in topographic complexity between ledges within each site. A Mann-Whitney U test was utilized to test the null hypothesis of no difference in the topographic complexity of ledges between the treatment and control site.

A linear regression analysis was performed in Microsoft Excel to test the null hypothesis that there was no relationship between topographic complexity of ledges and the abundance of lobsters residing in them. For each site, the mean depth/height

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ratio from 0 to 25 m and 30 to 50 m for each ledge was plotted on the x-axis. On the y-axis, the total lobster abundance (combined resident and translocated abundance from macroinvertebrate surveys) from 0 to 25 m and 30 to 50 m for each ledge was plotted for each of the three sampling periods. A linear trend line was applied to each of the three sampling periods and the corresponding  $R^2$  value calculated to determine the strength of the correlation. The significance of positive linear relationships were tested using a Spearman correlation.

## **Results**

### *Diet analysis*

Fourteen taxa were identified in gut content analysis (Table 7-20). Seven of these taxa were classified to genus or species level. Taxa were grouped into eight prey categories (*H. erythrogramma*, crabs, algae, hydroids, prosobranchs, *J. edwardsii*, bryozoans, and bivalves) for analysis purposes. The most frequently occurring prey items in samples were mobile benthic invertebrates (78 FOO%). Prey taxa within this category were crabs (22 FOO%), the sea urchin *H. erythrogramma* (15 FOO%), prosobranchs (28 FOO%), and conspecifics (13 FOO%). Sessile benthic invertebrates were also found, but in smaller frequencies (hydroids 3 FOO% and bryozoans 3 FOO%). Algal species were 16% of FOO.

**Table 5.20:** Percent frequency of occurrence (FOO%) of prey items found in the diet of resident (R) and translocated (T) *Jasus edwardsii* ~ 8 weeks before (n = 36), ~ 7 weeks after (R n = 7; T n = 5), and ~ 43 weeks after (R n = 4; T n = 9) translocation.

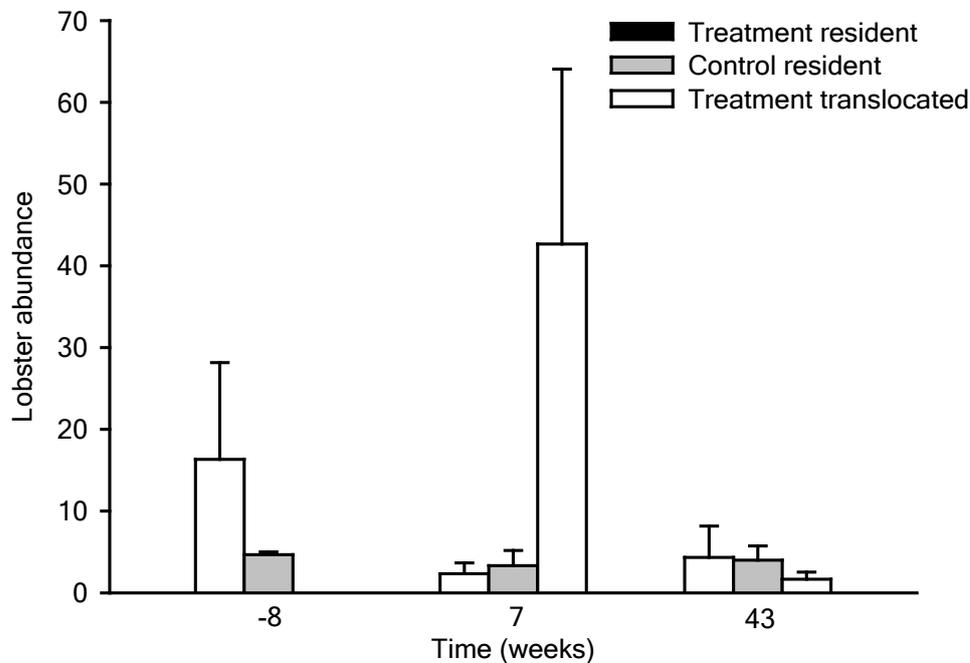
| Prey category <sup>A</sup>        | Common name    | ~ 8 weeks before |           | ~ 7 weeks after |           | ~ 43 weeks after |  |
|-----------------------------------|----------------|------------------|-----------|-----------------|-----------|------------------|--|
|                                   |                | R                | R         | T               | R         | T                |  |
| <b>Crab</b>                       |                | <b>22</b>        | <b>6</b>  | <b>11</b>       | <b>21</b> | <b>33</b>        |  |
| Unidentified sp.                  |                | 19               | 6         | 11              | 21        | 33               |  |
| <i>Plagusia chabrus</i>           | Red bait crab  | 3                | 0         | 0               | 0         | 0                |  |
| <b>Echinoderm</b>                 |                |                  |           |                 |           |                  |  |
| <i>Heliocidaris erythrogramma</i> | Spiny urchin   | <b>15</b>        | <b>27</b> | <b>24</b>       | <b>25</b> | <b>33</b>        |  |
| <b>Algae</b>                      |                | <b>16</b>        | <b>40</b> | <b>34</b>       | <b>13</b> | <b>21</b>        |  |
| <i>Plocamium</i> sp.              | Red algae      | 4                | 0         | 0               | 0         | 0                |  |
| Unidentified                      | Red algae      | 9                | 38        | 30              | 13        | 21               |  |
| <i>Rhodophyta</i> sp.             |                |                  |           |                 |           |                  |  |
| Unidentified                      | Brown algae    | 3                | 2         | 4               | 0         | 0                |  |
| <i>Phaeophyta</i> sp.             |                |                  |           |                 |           |                  |  |
| <i>Jasus edwardsii</i>            | Rock lobster   | <b>13</b>        | <b>0</b>  | <b>0</b>        | <b>13</b> | <b>0</b>         |  |
| <b>Prosobranch</b>                |                | <b>28</b>        | <b>15</b> | <b>21</b>       | <b>21</b> | <b>6</b>         |  |
| Unidentified sp.                  |                | 22               | 14        | 20              | 21        | 5                |  |
| <i>Haliotis</i> sp.               | Abalone        | 2                | 0         | 0               | 0         | 0                |  |
| Family Trochidae                  | Top shell      | 2                | 1         | 1               | 0         | 1                |  |
| <i>Phasianella ventricosa</i>     | Pheasant shell | 2                | 0         | 0               | 0         | 0                |  |
| <b>Hydroid</b>                    |                | <b>3</b>         | <b>0</b>  | <b>6</b>        | <b>0</b>  | <b>0</b>         |  |
| Unidentified sp.                  |                | 3                | 0         | 6               | 0         | 0                |  |
| <b>Bryozoan</b>                   |                | <b>3</b>         | <b>0</b>  | <b>0</b>        | <b>0</b>  | <b>6</b>         |  |
| Unidentified sp.                  |                | 2                | 0         | 0               | 0         | 6                |  |
| <i>Triphylozoon</i> sp.           | Lace coral     | 1                | 0         | 0               | 0         | 0                |  |
| <b>Bivalve</b>                    |                | <b>0</b>         | <b>12</b> | <b>4</b>        | <b>8</b>  | <b>0</b>         |  |
| Unidentified sp.                  |                | 0                | 12        | 4               | 8         | 0                |  |

<sup>A</sup>Prey items are summarised to eight categories for analysis purposes (bold text).

#### *Resident vs translocated diet*

Ten different prey taxa were identified in the stomach and intestinal tract samples from 25 lobster specimens (11 resident and 14 translocated) collected from Ringwood Reef ~ 7 and ~ 43 weeks after translocation (Table 5.20). At each sampling period for both resident and translocated lobsters, mobile benthic invertebrates were again the most frequently occurring prey items. Sessile benthic invertebrates also occurred in the diet of samples, but in smaller frequencies. In addition to faunal species, algal

species frequented lobster samples. Results from two-way crossed ANOSIM confirmed no significant differences in diet between resident and translocated lobsters (global  $R = -0.028$ ,  $p > 0.05$  %), and sampling times at a significance level of 5 % (global  $R = 0.018$ ,  $p > 0.05$  %).



**Figure 5-69** Mean abundance of resident inshore and translocated lobsters from three replicate 50 m fixed ledge transects at the Ringwood Reef treatment site (black bars = resident inshore; white bars = translocated) and The Beaks control site (grey bars = resident inshore), ~ 8 weeks before, ~ 7 weeks after, and ~ 43 weeks after translocation. Error bars indicate  $\pm 1$  SE.

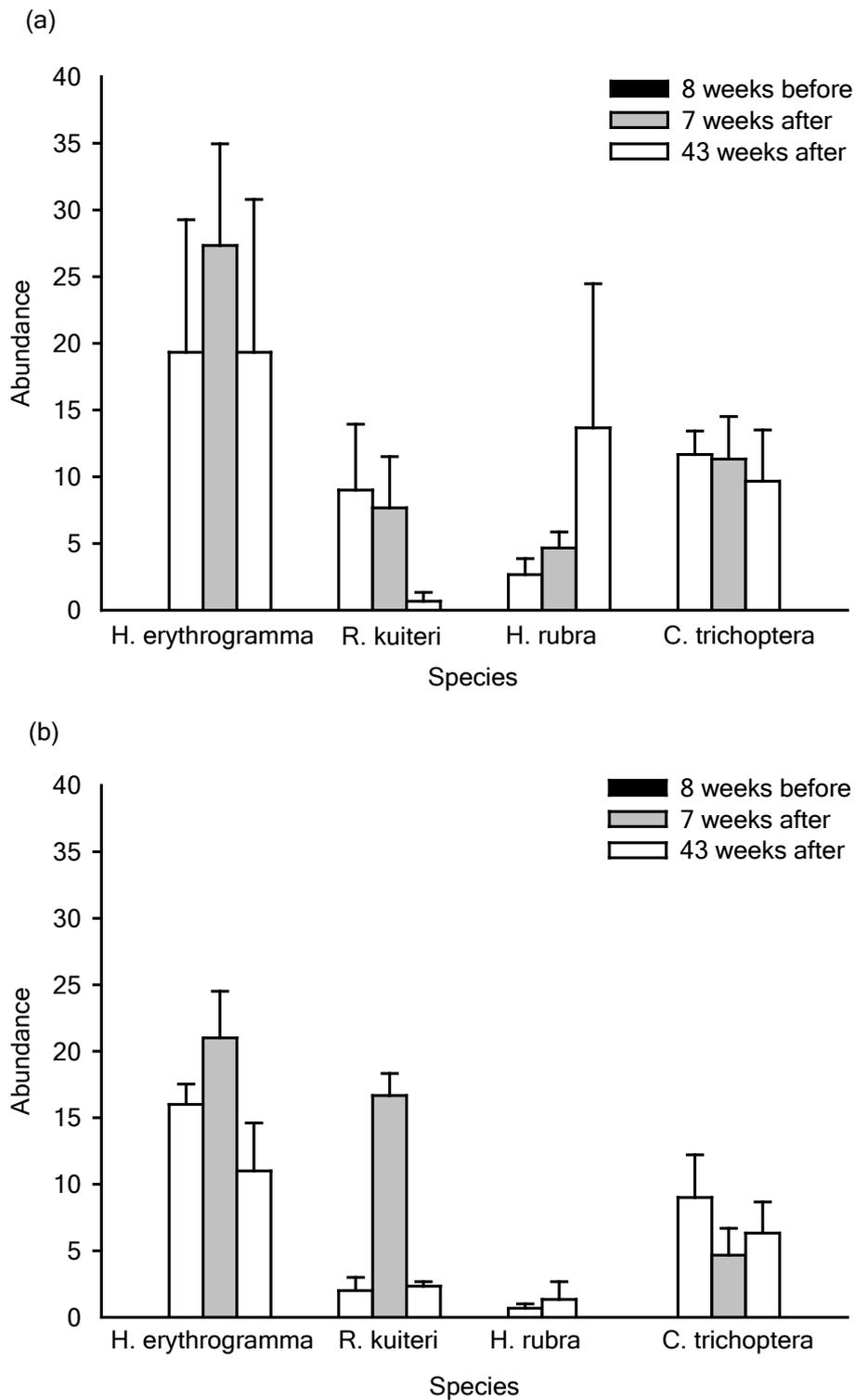
Initial abundance of resident inshore lobsters ~ 8 weeks before translocation was higher at the treatment than the control site, however at the treatment site abundance varied between ledges (Figure 5-69). Approximately 7 weeks after translocation, mean lobster abundance at the treatment site decreased to levels similar to the control site. At this time abundance of translocated lobsters was higher than that of resident inshore lobsters at both the treatment and control sites. Following a period of ~ 43 weeks after translocation, both treatment and control sites had similar levels of resident inshore lobster abundance. Translocated lobster abundance after 43 weeks had decreased to levels slightly below that of resident inshore lobsters at both sites. Results from ANOVA indicated that there were no significant differences of resident inshore lobster abundance between sampling times ( $F(2, 100.667) = 2.079$ ,  $p = 0.187$ ), and between sites ( $F(1, 60.50) = 0.409$ ,  $p = 0.557$ ). There was also no significant interaction between time and site ( $F(2, 72.667) = 1.501$ ,  $p = 0.280$ ).

**Table 5.21** Mean topographic complexity (m) and total abundance of combined resident inshore and translocated lobsters from three replicate 50 m fixed ledge transects at the Ringwood Reef treatment site (TA, TB & TC) and The Beaks control site (CA, CB & CC) ~ 8 weeks before, ~ 7 weeks after, and ~ 43 weeks after translocation.

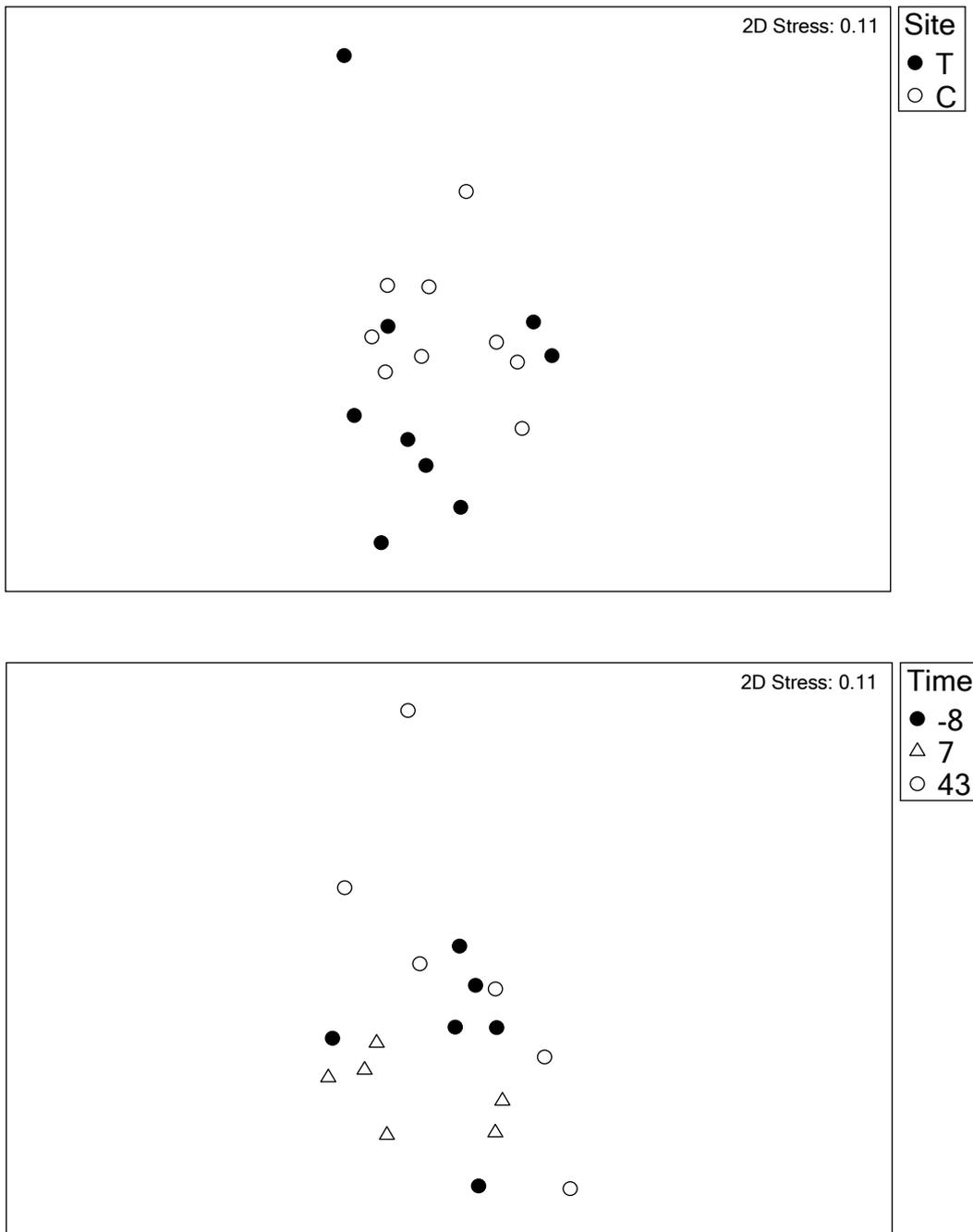
| Ledge | Complexity<br>(m) | Total lobster abundance $\pm$ 1 S.E. |                |                    |
|-------|-------------------|--------------------------------------|----------------|--------------------|
|       |                   | ~8 weeks<br>before                   | ~7 weeks after | ~43 weeks<br>after |
| TA    | 1.37 $\pm$ 0.49   | 40                                   | 32             | 14                 |
| TB    | 0.74 $\pm$ 0.14   | 5                                    | 86             | 3                  |
| TC    | 0.45 $\pm$ 0.16   | 4                                    | 17             | 1                  |
| CA    | 2.08 $\pm$ 0.77   | 5                                    | 1              | 7                  |
| CB    | 2.32 $\pm$ 0.54   | 4                                    | 2              | 1                  |
| CC    | 1.95 $\pm$ 0.61   | 5                                    | 7              | 4                  |

At the treatment site, the total abundance of resident inshore lobsters on each of the three ledges ~ 8 weeks before translocation was highest at ledge TA (Table 5.21). Approximately 7 weeks after translocation, total abundance (combined resident and translocated) had increased at ledges TB and TC, but decreased at ledge TA. Ledge TB had the highest number of lobsters during this time. Following a period of ~ 43 weeks after translocation, total abundance (combined resident and translocated) had decreased at all ledges.

*Macroinvertebrate prey assemblages*



**Figure 5-70** Mean abundance of dominant macroinvertebrate species recorded during benthic surveys of 50 m ledge transects at (a) the treatment site Ringwood Reef and (b) the control site The Beaks, ~ 8 weeks before (black bars), ~ 7 weeks after (grey bars), and ~ 43 weeks after (white bars) translocation. Error bars indicate  $\pm 1$  SE.



**Figure 5-71** Two-dimensional nMDS ordination of macroinvertebrate species assemblages from each ledge with (a) site superimposed (Ringwood Reef-T and The Beaks-C) and (b) time superimposed (~ 8 weeks before, ~ 7 weeks after, and ~ 43 weeks after translocation).

A total of 26 macroinvertebrate species (>3 cm) were recorded during benthic surveys between the Ringwood Reef treatment site and The Beaks control site across the sampling periods ~ 8 weeks before, ~ 7 weeks after, and ~ 43 weeks after translocation. For every sampling period at each site, the spiny urchin *H. erythrogramma* was the most dominant taxa (35 %). The mean abundance of dominant macroinvertebrate species observed on ledges across both sites and all three sampling times are shown in Figure 5-70.

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An MDS analysis showed that macroinvertebrate assemblages overlapped between the treatment and control site when sampling times were combined (Figure 5-71a). Assemblages overlapped between all three sampling periods when sites were combined (Figure 5-71b). There was also variation within each site and time. Two-way crossed ANOSIM confirmed no significant differences between sites (global  $R = 0.216$ ,  $p > 0.05$  %) and sampling times (global  $R = 0.165$ ,  $p > 0.05$  %).

#### *Power analysis*

The MDES *priori* power analysis was calculated only for the spiny urchin *H. erythrogramma* as it had the highest mean abundance. With a sample size of three replicate ledges and a significance level of 0.05, the smallest difference in urchin abundance that was able to be detected 90 % of the time was 171.14 individuals.

#### *Translocated lobster movement*

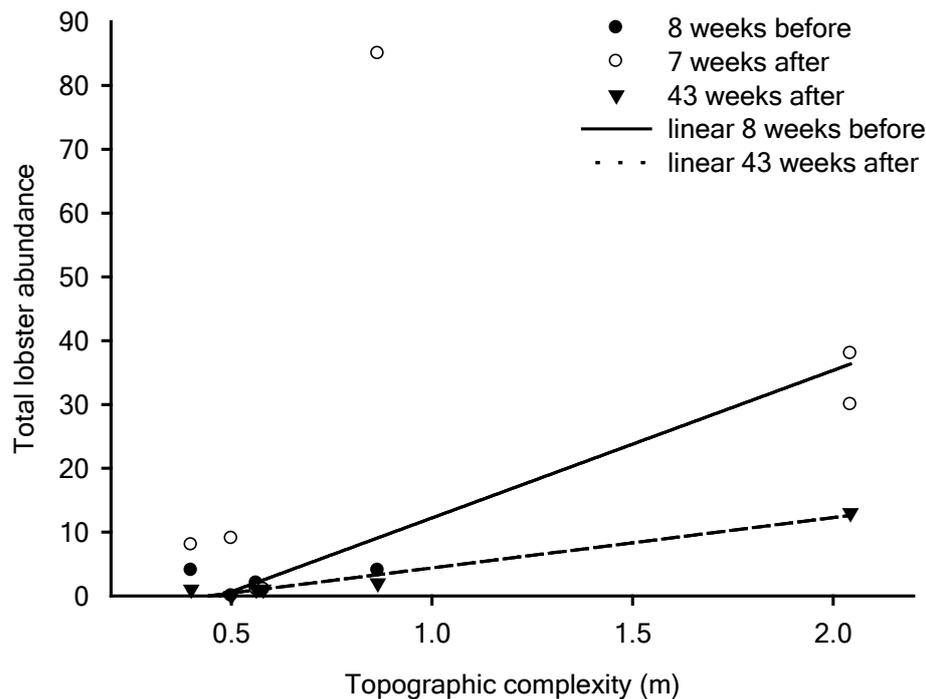
The mean overall carapace length (CL) of translocated lobsters was 100.9 mm ( $\pm 0.23$  SE) (females = 97.1 mm  $\pm 0.12$  SE, males = 110.3 mm  $\pm 0.46$  SE). In total, 50.3 % of all lobsters translocated were undersized i.e. below the minimum legal length of 98.5 mm carapace length. Since translocating 2020 lobsters to the Ringwood Reef treatment site in late January 2007, a total of 106 or 5.3 % have been recaptured and reported to date. Recaptured lobsters from all release locations moved a mean distance of 1.941 km ( $\pm 0.235$  SE). Movement from all recaptures tended to be from inshore to offshore sites. No recaptures were found in the immediate vicinity of the control sites, with the nearest recapture being 3.2 km from The Beaks.

#### *Topographic complexity*

At the translocation site, topographic complexity appeared to be highest at ledge TA, followed by TB, then TC (Table 5.21). Complexity at the corresponding control site seemed relatively similar between all ledges. There was no significant difference in topographic complexity between ledges within Ringwood Reef ( $\chi^2 = 2.9$ ,  $df = 2$ ,  $p = 0.230$ ) and The Beaks ( $\chi^2 = 1.1$ ,  $df = 2$ ,  $p = 0.578$ ). When comparing between sites (T = 0.85 m  $\pm 0.19$  SE; CA = 2.12 m  $\pm 0.36$  SE), topographic complexity was significantly greater at the control site than the translocation site ( $Z = -3.1$ ,  $df = 1$ ,  $p = 0.002$ ).

Approximately 8 weeks before translocation there was a linear correlation between topographic complexity and lobster abundance on ledges at the treatment site ( $R^2 = 0.94$ ) (Figure 5-72). This indicated that as topographic complexity increased (i.e. as ledges depth > height), lobster abundance residing in ledges also increased. Approximately 7 weeks after translocation this linear relationship was no longer apparent ( $R^2 = 0.11$ ). However, ~ 43 weeks after translocation, the linear correlation returned ( $R^2 = 0.97$ ). Spearman correlation revealed that the linear relationship ~ 8

weeks before translocation was statistically not significant ( $r_s = 0.493$ ,  $N = 6$ ,  $p > 0.05$ ), but at  $\sim 43$  weeks it was and positive ( $r_s = 0.820$ ,  $N = 6$ ,  $p < 0.05$  \*). At the corresponding control site, The Beaks, there was no linear relationship between topographic complexity and total abundance of lobsters residing in ledges, over all three sampling times ( $\sim 8$  weeks:  $R^2 = 0.03$ ;  $\sim 7$  weeks:  $R^2 = 0.03$ ;  $\sim 43$  weeks:  $R^2 = 0.24$ ).



**Figure 5-72** X-Y scatterplot of linear regression analysis between topographic complexity of ledges (depth/height ratio) and total abundance of lobsters (resident and translocated) residing in ledges at the Ringwood Reef treatment site,  $\sim 8$  weeks before,  $\sim 7$  weeks after, and  $\sim 43$  weeks after translocation.

## Discussion

Palinurid lobsters predatory behaviour plays an important trophic role in shaping rocky reef ecosystems. Fluctuations in their abundance can cause substantial flow-on effects to ecosystem structure and function (Mayfield et al. 2000c; Shears and Babcock 2002; Pederson and Johnson 2006; Ling et al. 2009).

The most frequently occurring prey taxa identified within resident and translocated lobsters gastric-mill stomach and intestinal tract were mobile benthic invertebrates. In particular, the spiny urchin *H. erythrogramma*, crab species, and prosobranchs dominated. Algal fragments were also found in samples but whether lobsters were deliberately consuming the algae itself or epiphytic prey items attached to them, remains to be established (Barkai and Branch 1988; Johnston 2003). These findings

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concur with previous studies described for inshore *J. edwardsii* in the southeast waters of South Australia (Fielder 1965) and other spiny lobster species in general (Joll and Phillips 1984; Barkai and Branch 1988; Edgar 1990; Mayfield et al. 2000a). Prey items with a hard exoskeleton or hard chitinous parts were highly represented in the diet samples compared to soft-bodied organisms. This trend may be due to the macerating feeding action of lobsters mandibles and gastric mill ossicles rendering soft-bodied prey items unidentifiable (Redd et al. 2008). Variability in evacuation rates of hard and soft prey items from lobster stomachs may also explain this overestimation (Waddington et al. 2008).

Based on the frequency of occurrence of diagnostic prey fragment categories, it appears that resident inshore and translocated lobsters prey upon similar taxa. This corresponds with dietary comparisons of inshore and translocated lobsters in Tasmania through fatty acid composition analysis of the hepatopancreas and muscle tissue (Chandrapavan et al. 2009c). While conclusions are based on a relatively small sample size, we are confident that the organisms identified are representative of general lobster diet given that prey items were similar to those found in previous studies.

The macroinvertebrate ledge assemblages studied included taxa that were identified as potential prey items of translocated lobsters i.e. spiny urchins, crabs, and prosobranchs. The spiny urchin *H. erythrogramma* was the most abundant mobile benthic macroinvertebrate species (> 3 cm) observed on ledges at both the treatment and control site. Previous studies on Tasmanian temperate rocky reef benthic habitats also identified spiny urchins as the dominant large macroinvertebrate species (Edgar and Barrett 1997; Edgar and Barrett 1999). Macroinvertebrate taxa on ledges also included large carnivorous species such as the red bait crab *P. chabrus*, velvet crab *N. integrifrons* and resident inshore lobsters. These species are not only potential prey items, but are also potential competitors of translocated lobsters for space and prey (Pederson and Johnson 2006).

No detectable differences in mobile benthic macroinvertebrate assemblages (including resident inshore lobsters) on ledges were identified in this study. This implies that at least in the short term, increased predation from translocation did not affect these assemblages. This is in contrast with research into the efficacy of marine protected areas where natural increases in abundance of lobsters within marine reserves are coupled with a decline in spiny urchin abundance (Edgar and Barrett 1997; Babcock et al. 1999; Shears and Babcock 2003; Pederson and Johnson 2006). Previous studies by MacDiarmid *et al.* (1991) have indicated that the median foraging range of *J. edwardsii* on temperate reefs does not exceed 24 m distance from their shelters. This implies that macroinvertebrate taxa on ledges were potentially within the foraging range of lobsters, however the amount translocated was not high enough to negatively impact the ledge community.

The likelihood of detecting translocation effects on macroinvertebrate ledge assemblages could have been reduced by low transect replication and the resulting large minimum detectable effect size needed from power analyses. However, higher lobster numbers were only detected at the treatment site approximately seven weeks after the translocation. During the next survey, approximately 43 weeks after the translocation, lobster numbers had decreased to pre-translocation levels. Consequently, this short term increase in lobsters at the translocation site may have been insufficient to cause any detectable impacts on the local macroinvertebrate assemblages. Indeed, 96 % of the recaptured translocated lobsters moved further from treatment ledges than their suggested median foraging distance of 24 m. As a result, their predatory and possible competition effects were likely to be removed from ledges at the translocation site.

Fishing and natural mortality of translocated lobsters might also explain the decrease in lobster numbers after the third sampling period at the translocation site. Based on tag returns, fishing mortality was at least 5 %. We did not directly measure lobster survival at these sites, however concurrent studies in Tasmania estimated survival of translocated lobster as similar to residents lobsters (Green and Gardner 2009). Combined, these two sources of mortality are unable to account for the observed decrease in lobster abundance between the second and third sampling period. As a result it is more likely that movement is responsible for their reduction.

The size of the translocated lobsters may also have contributed to there being no impacts detected on the macroinvertebrate assemblages at the translocation site. Predation ability of lobsters increases as a function of carapace length (Mayfield et al. 2000a). In Tasmania, only large adult rock lobster (> 120 mm carapace length or CL) are capable of consuming large adult sea urchins (81 – 100 mm test diameter or TD), while small lobsters (< 100 mm CL) are only able to consume small juvenile sea urchins (< 60 mm TD) (Pederson and Johnson 2006). Urchin test diameter was not measured in this study, however, from visual observations the majority appeared to be large adults. The fact that juvenile urchins are rarely seen during the daytime due to their highly cryptic behaviour, supports the notion that the bulk of urchins enumerated on ledges were probably not juveniles (Andrew and Macdiarmid 1991). The mean carapace length of lobsters translocated was 100.9 mm CL  $\pm$  SE 0.24, with approximately 55 % less than 100 mm CL. This may imply that impacts were not detected on urchin abundance due to the fact that the majority of lobsters were not large enough to prey upon the size class of urchins observed in benthic surveys.

Another possible reason as to why impacts were not detected relates to the actual number of lobsters translocated. Being a trial study only, the number of translocated lobsters was not high compared to the actual numbers of lobsters that can exist on inshore reefs. For example, 2.1 million lobsters are harvested from inshore reefs annually which is believed to be an exploitation rate of ~30 % (Linnane et al. 2007). Therefore, the capacity of inshore reefs to maintain large abundances of lobsters is

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high, and the observed impacts of translocating the small numbers in this study are likely to be negligible at a local level.

The survey design used to enumerate macroinvertebrate assemblages did not measure species that were < 3 cm or sessile invertebrates such as sponges. Previous studies on the South African rock lobster *J. lalandii* and western rock lobster *P. cygnus*, have demonstrated that spiny lobsters do consume prey items <3 cm, such as mysid shrimps, juvenile abalone and trochid molluscs, as well as sponges (Barkai and Branch 1988; Edgar 1990; Mayfield et al. 2001). Resident inshore and translocated *J. edwardsii* are capable of consuming sessile organisms, as diagnostic prey fragments of bryozoans and hydroids were identified in dietary analysis of both lobster forms. Logistical constraints with dive times prevented intensive sampling of quadrats during benthic surveys, which would have been required to quantify prey items below 3 cm and sessile invertebrates. Consequently, potential translocation impacts on these species remain unknown.

Topographic complexity analysis indicates that *J. edwardsii* exhibits a preference for deep ledges with narrow openings. This was confirmed by the linear relationship (both before and ~ 43 weeks after translocation) between increasing lobster abundance on ledges and increasing topographic complexity i.e. as ledges became deeper and narrower, the number of lobsters inhabiting them also increased. Previous research on *J. edwardsii* habitat preference concurs with these findings (Lucieer and Pederson 2008), as well as research on *Homarus americanus* (Wahle 1992; Wahle and Steneck 1992), *Homarus gammarus* (Ball et al. 2001), *Panulirus argus* (Rios-Lara et al. 2007), and *Panulirus guttatus* (Wynne and Cote 2007) lobster species. This is primarily due to the fact that deep, narrow shelters or topographically complex habitats restrict the access of most predators (Eggleston et al. 1992) (Briones-Fourzan and Lozano-Alvarez 2008; Weis et al. 2008).

The absence of a topographic relationship approximately 7 weeks after translocation was due to the total number of lobsters (majority translocated) increasing to higher levels within a ledge (TB) of relatively low topographic complexity. This may be due to the high susceptibility of translocated lobsters to predation immediately after release, causing lobsters to inhabit in the short term shelters which are not ideal for protection. However, in the long term (approximately 36 weeks later) lobster abundance sharply decreased at this ledge to restore the linear relationship, possibly as a result of translocated lobsters moving to more topographically complex protective habitat.

Topographic complexity at each of the ledges at the control site was higher than that of any at the translocation site i.e. ledges were deeper with narrow openings. Using the linear relationship between lobster abundance and topographic complexity, it would be expected that ledges at the control site would have a higher number of lobsters than the translocation site. This was not observed however, and may be due to

the site receiving higher recreational fishing pressure than the treatment site, due to its proximity to the nearest boat ramp.

The potential habitat preference of lobsters for deep ledges with narrow openings may also explain why the octopus *Octopus maorum* and southern conger eel *Conger verreauxi* are two of the major predatory species of *J. edwardsii* in the SZRLF (Brock et al. 2007). Their physiological adaptations probably enable them access to narrow undercut ledges more freely than larger predatory species such as sharks and large finfish. This observation has important implications when choosing sites for future translocation experiments. Specifically, it highlights the importance of dive surveys on inshore reef sites before translocation to ensure their suitability in terms of ledge complexity. This will not only benefit the overall goals of translocation by reducing the susceptibility of lobsters to predation but also minimise the chance of translocated lobsters moving to deeper waters where their colour and condition are less likely to improve.

This study has demonstrated that translocation of deep water *J. edwardsii* from offshore to inshore reefs has no significant negative effects on resident inshore lobsters diet. Translocated lobsters preyed upon similar taxa to resident inshore lobsters, however the specific identity of some prey items, their actual size, and relative contribution to lobsters diet remain largely unknown. In addition, the overall abundance of mobile benthic macroinvertebrate assemblages (including resident inshore lobsters) within inshore ledges was not affected. Movement of translocated lobsters was probably the main contributing factor decreasing translocated lobster numbers at ledges over time and hence why no significant impact of translocation was detected on macroinvertebrate communities. The topographic complexity of ledges appears to play an important role in controlling lobster abundance within sites. As a result, it is recommended that future site selection of inshore reefs for translocation should be based on preliminary dive surveys that measure the level of ledges topographic complexity in order to reduce subsequent levels of lobster mortality and movement. Also, potential impacts of removing lobsters from deep-water ecosystems for translocation requires further investigation, as their diet has been shown to differ from lobsters residing in shallow-water reefs (Chandrapavan et al. 2009c).

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### 5.6.1 Changes in market traits

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Published as : Chandrapavan, A, C. Gardner, B.S. Green, A. Linnane, D. Hobday (in press). *Improving marketability through translocations: a lobster case study from southern Australia. ICES Journal of Marine Science: 68: 1842-185.*

#### Summary

This chapter explored translocation as a method to increase the value of less marketable deep-water southern rock lobster *Jasus edwardsii*. Firstly, variation in the commercially important shell colouration and body shape between deep-water and shallow-water Tasmanian populations and among South Australian and Victorian populations was quantified. Deep-water *J. edwardsii* were pale coloured with longer walking legs but less meat content than shallow-water, red coloured *J. edwardsii*. Body shape traits were highly variable among deep-water populations across the three States and between sexes in each population. Deep-water lobsters were then translocated to a shallow-water inshore reef to determine if the observed variation in traits was plastic, and whether translocation could be used to improve the quality of deep-water lobsters. Translocated lobsters were then monitored over a 14 month post-release period and during this time they changed from a pale/white colour to the more marketable red colour within one moult. Plasticity was observed in tail morphology but not leg morphology. The translocation experiment was successful in transforming pale/white deep-water lobsters into red lobsters with higher market value in a phenotypic response to habit manipulation. Translocation appears to have commercial application for exploiting natural plasticity in market traits of lobsters to increase price.

#### Detailed Methods

##### *Colour analysis*

Natural variation in shell colour was determined from wild-caught, deep-water and shallow-water Tasmanian rock lobsters. Shell colour was quantified by image analysis of digital photos. Only hard-shelled lobsters with minimal carapace fouling were selected (all lobsters have fouling recorded when tagged) and colour was measured on five locations on the body, including the dorsal and lateral surface of the carapace, dorsal region of the tail closest to the carapace, the dorsal surface of the telson and the ventral surface of the sternum (Figure 5-73). Colour changes in translocated lobsters were examined in all five body locations of recaptured moulted and non-moulted lobsters at each of the resampling surveys. The exoskeleton was blotted dry before being photographed with a Nikon Coolpix 5400 digital camera with a Nikon SL1 Macro Cool Light ring flash attached by a Nikon UR-E1 1step-down ring lens adapter. A black cloth hood was attached at the base of the ring flash to exclude external light. A 10 cm metal rod was also attached at the base of the camera to ensure constant distance from the exoskeleton. The camera was manually set under the macro operating function (shutter speed - 1/8 second, aperture - F4.4, picture quality - "normal", light metering - "spot", white balance - "speed light", sensitivity -

“ISO100”, image adjust and sharpness set to “auto”). Colour of the different body locations were quantified using the histogram function in Adobe Photoshop 7.0. Each image was opened in the RGB colour mode and a circular region (diameter of 1000 pixels) was measured for the mean values (darkest = 0 to lightest = 255) of each of the red, green and blue channels. These three individual channel values were added together to produce a single value for each image ranging from 0 – 765 (range of combined RGB value). This method was selected for analysis because we were only interested in the final colour produced by the three colour channels and not the changes or differences in the individual colour channels between the colour categories. In all five body locations the red channel dominated in intensity over the green and blue channels, therefore only variants of the colour red was present in our samples. However the proportions of the green and blue channel values relative to the red value often determined the final intensity /shade of the overall red colouration.

### *Morphometric analyses*

For analysis of spatial variation in body-shape traits, the fourth walking leg and the tail (abdomen) shape measured for comparisons between deep and shallow-water populations across the three States and between translocated and resident lobsters. To estimate leg length and meat yield, the fourth walking leg was removed by applying pressure to the base of the coxa to induce autotomy, and immediately placed in ice, then later stored in a -30°C freezer. Lobsters with regenerated or damaged legs were not sampled. A sub-sample of the deep-water and shallow-water populations was photographed for measurements of body-shape traits. For translocated lobsters, the fourth walking leg (non-injured, non-regenerated) was removed. If a previously sampled lobster was caught, the fourth walking leg in the pair that is non-regenerated was removed for analysis. A sub-sample of translocated lobsters (10 – 20 lobsters) were also photographed for measurements of body-shape traits.

Spatial and depth variation in leg length were compared among shallow and deep-water lobsters collected from TAS, SA and VIC sites. Prior to measurement, leg samples were thawed at room temperature and blotted dry. Periopods were measured along the dorsal length of the merus and the ventral length of the propodus (excluding the connective tissues). Total leg length (LL) was calculated from the combined lengths of the merus and propodus. To determine meat yield of the fourth walking leg, wet weight was recorded for the whole leg sample and the moisture content was determined by drying overnight at 100C and then reweighing the sample. Samples were then placed in a muffle furnace for three hours at 550C and reweighed to determine the ash weight. The difference between the wet and ash weights provided an estimate of the combined moisture and organic weights of the meat content (g). Note that this method overestimates the meat yield as our calculations also include the water and organic content of the exoskeleton.

Spatial and depth variations in tail dimensions were assessed from digital image analysis using Image J v1.33 software (Wayne Rasband, National Institute of Health, USA, <http://rsb.info.nih.gov/ij/>). Lobsters were restrained on a stable platform in a fully extended position underneath a camera stand fitted with an external light source. Photos were taken of the dorsal and ventral surface of the carapace and the tail region of each lobster. In order to minimise variation through different measurement techniques, carapace length was also calculated from the digital images. Tail

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measurements were taken from the ventral surface of the abdomen and included the anterior tail width (ATW) measured across the grooves between the pleurons of the first and second abdominal segments, posterior tail width (PTW) measured from the base of the sixth abdominal segment across the width of the sixth sternite, and the area of the tail inclusive of the ventral surface area of the abdomen covering the second to the sixth abdominal segment extending down to the anus.

### *Data analyses*

Differences in shell colouration of the abdomen between moulted and non-moulted translocated lobsters recaptured five months after release were analysed using a one-way ANOVA. There were insufficient lobsters in each moult category in subsequent surveys for statistical analyses. Analyses were performed using Statistica (V7.1 Statsoft Inc, Tulsa OK USA).

Allometric relationships among body-shape traits were examined using a combination of standardised major axis (SMA) and major axis (MA) regression analyses (types of Model II regression) using SMATR v2.0 software (Standardised Major Axis Tests and Toutines by D. Falster, D. Warton and I. Wright; <http://www.bio.mq.edu.au/ecology/SMATR>). These slope fitting techniques were considered most appropriate for describing bivariate growth relationships given all the measured variables (tail, leg and carapace measurements) had variation associated with them due to both measurement error and natural variability (Sokal and Rohlf 1981). The SMATR procedure is analogous in principal to ANCOVA, thus MA and SMA slopes were fitted between the desired two morphometric traits and tested for homogeneity of slopes and differences in slope elevation (if a common slope was present), followed by post-hoc pair-wise comparisons using the Wald statistic (for details of statistical procedures see Warton et al. (2006). All statistical analyses were tested for significance at  $p = 0.05$ .

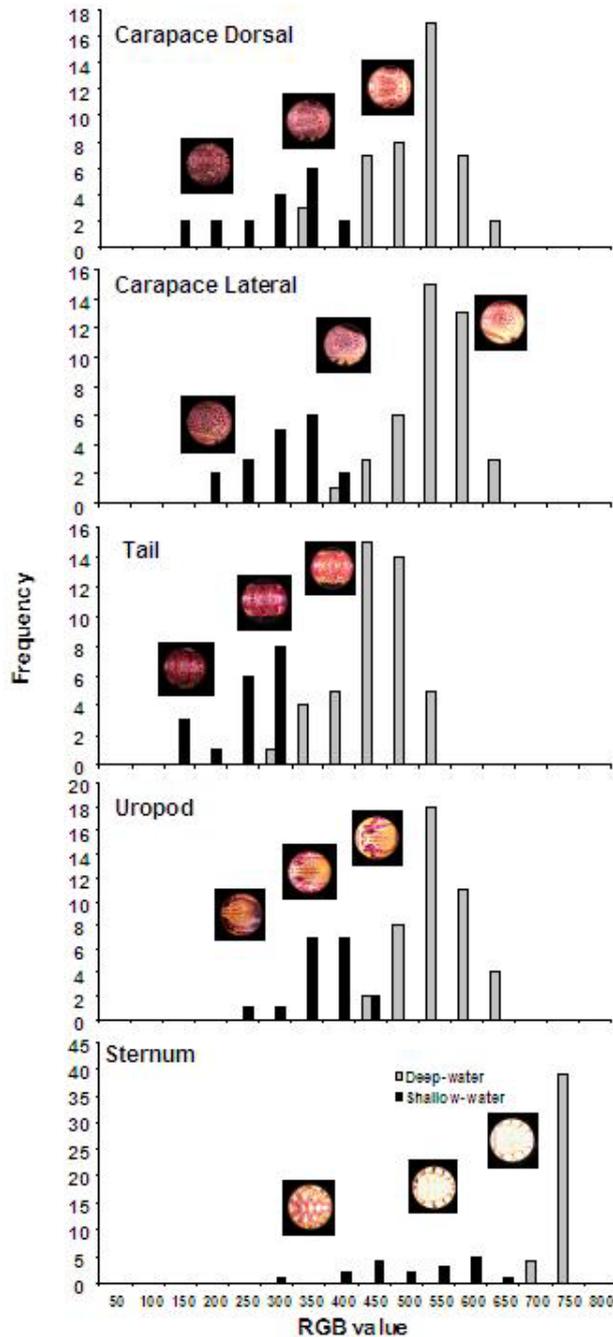
All variables (tail, leg, carapace and meat yield measurements) were  $\log_{10}$  transformed to achieve linearity and normality. Since tail morphometry is a secondary indicator of sexual maturity in female lobsters, only mature females were included in the analyses. An estimate of setation development of the pleopod was first determined to identify mature and immature females (Gardner et al. 2005). Further removals of immature females were based on observed data points that deflected and formed an angular delineation from the regression slope. Immature females were only detected in our samples from shallow-water TAS and deep-water SA lobsters. Allometric comparisons were made among Tasmanian populations (deep, shallow and translocated) and between deep and shallow-water sites (TAS, SA and VIC) separately for each sex and also between males and females (M and FM).

## **Results**

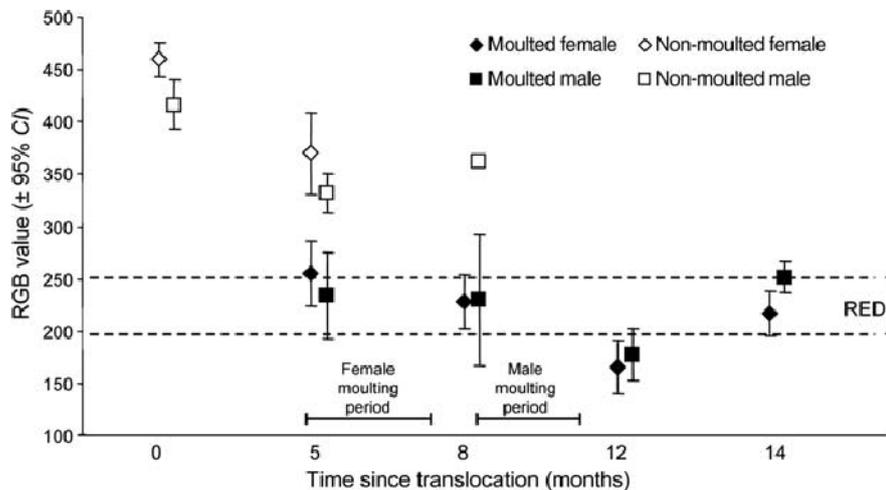
### *Shell colour variation*

Among all five-body locations measured, there was little overlap in the RGB range between deep and shallow-water *J. edwardsii* (Figure 5-73). The dorsal surfaces were generally more pigmented than the ventral surfaces. For example the carapace (dorsal and ventral surfaces) ranged from 150 – 400 for shallow-water lobsters and 300 - 700

for deep-water lobsters, while the sternum showed high variation in shallow-water lobsters with a RGB range of 300-650 in contrast to deep-water lobsters with 700-750 (Figure 5-73). Five months after translocation, moulted lobsters were significantly darker than non-moulted lobsters, and both females and males had changed from pale or brindle coloration to the high market value red colouration (females,  $F_{1,13} = 14.5$ ,  $p = 0.01$ ; males  $F_{1,6} = 14.0$ ,  $p = 0.01$ ). By the end of the moulting period (10 months after translocation), all translocated lobsters had changed colour from pale or white to the red colour range. Colour change was proportional in all body locations, therefore only the results for the tail region are presented (Figure 5-74).



**Figure 5-73** Natural colour variation of wild-caught shallow-water and deep-water lobsters with image examples of each of the five body locations.



**Figure 5-74** Mean colour differences (mean  $\pm$  95% confidence intervals) of the tail region between moulted (filled) and non-moulted (open) recaptured translocated female (diamond) and male (square) lobsters from four post-release sampling surveys.

Moulting time periods for shallow-water male and female lobsters are indicated by horizontal bars above axis. RGB value range (mean  $\pm$  95% confidence intervals) for the tail region of red coloured lobsters ( $n = 13$ ) are indicated by the dotted lines. RGB value for time zero was calculated from combined RGB values of the tail of pale and white lobsters (from Figure 5-73) (RGB range : 0 (darkest) – 765 (lightest)).

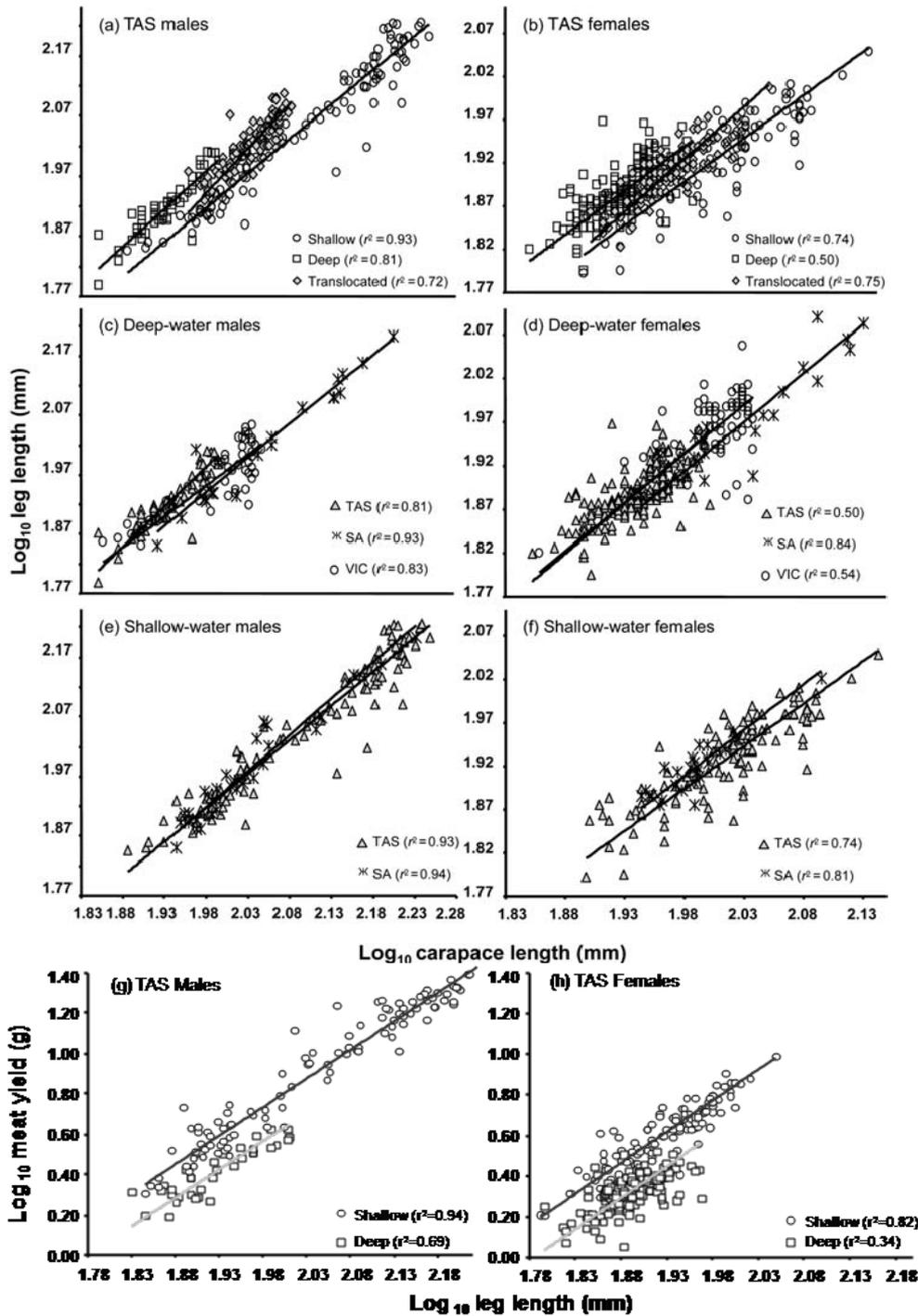
### *Body-shape variation*

Deep-water male and female TAS lobsters had longer legs than shallow-water lobsters, but relative to their leg length, significantly less meat content than shallow-water lobsters (Figure 5-75). Males had longer legs than females among TAS deep- and shallow-water populations ( $p < 0.05$ , Table 5-22). However, for a given leg length, meat yield was greater in shallow-water TAS females than males, but there were no differences in meat yield between the sexes of deep-water TAS lobsters (Table 5-22). After their first moult, there was no difference in leg length of translocated lobsters (in either sex) compared with deep-water lobsters. The tail area of shallow-water TAS males was greater than the tail area of deep-water males (Figure 5-76), but no difference was detected among TAS females (Figure 5-76). There was an increase in the tail area of translocated males to a size similar to that of shallow-water males (Table 5-23). No change was detected in the tail area of translocated females. In both sexes, the posterior tail width relative to anterior tail width was wider in deep-water TAS lobsters than in shallow-water TAS lobsters (Figure 5-77; Table 5-23). In translocated males, the changes in the relative width of the posterior tail width were not significantly different in shallow- and deep-water males, and conversely in translocated females, the posterior tail width was significantly less than in deep-water lobsters and greater than in shallow-water lobsters. Deep-water TAS male lobsters had longer legs than VIC males, and SA males were intermediate to TAS and VIC males (Figure 5-75 c). Among deep-water female populations, SA females had significantly shorter legs than TAS and VIC females (Figure 5-75 d). There were no

differences in leg length between TAS and SA shallow-water males (Figure 5-75 e), but shallow-water SA females had longer legs than TAS females (Figure 5-75 f). Among deep-water sites, VIC lobsters had a larger TA than TAS and SA lobsters, for both sexes. TA did not differ between SA and TAS deep- and shallow-water populations (Figure 5-76 c and d). There was no difference in the width of the posterior tail width between deep-water SA and VIC males, but both populations had narrower posterior tail width than TAS males (Figure 5-77 c). Conversely in deep-water females, the posterior tail width was significantly different in width between all three sites. For any given anterior tail width, the posterior tail width was widest in TAS females, followed by SA, and narrowest in VIC females (Figure 5-77 d).

**Table 5.22** Regression statistics of the major axis (MA) regression analysis of (a) leg length and carapace length and standardised major axis (SMA) regression analysis of (b) meat yield and leg length. Results of comparisons between shallow, deep and translocated TAS populations and of deep and shallow-water lobsters are shown separately for each sex. Results of comparisons between males and females within each population are also given. Regression parameters of individual MA or SMA slope, common slope (CS) and intercept are indicated with (lower, upper 95% confidence intervals), differences in slope ( $\Delta\beta$ ) and in elevation ( $\Delta E$ ) among populations were then tested for at the significance level of  $p = 0.05$ . Significant differences are indicated by different superscripts from post-hoc pair wise comparisons. Non-significance ( $p > 0.05$ ) indicated by the notation ‘ns’.

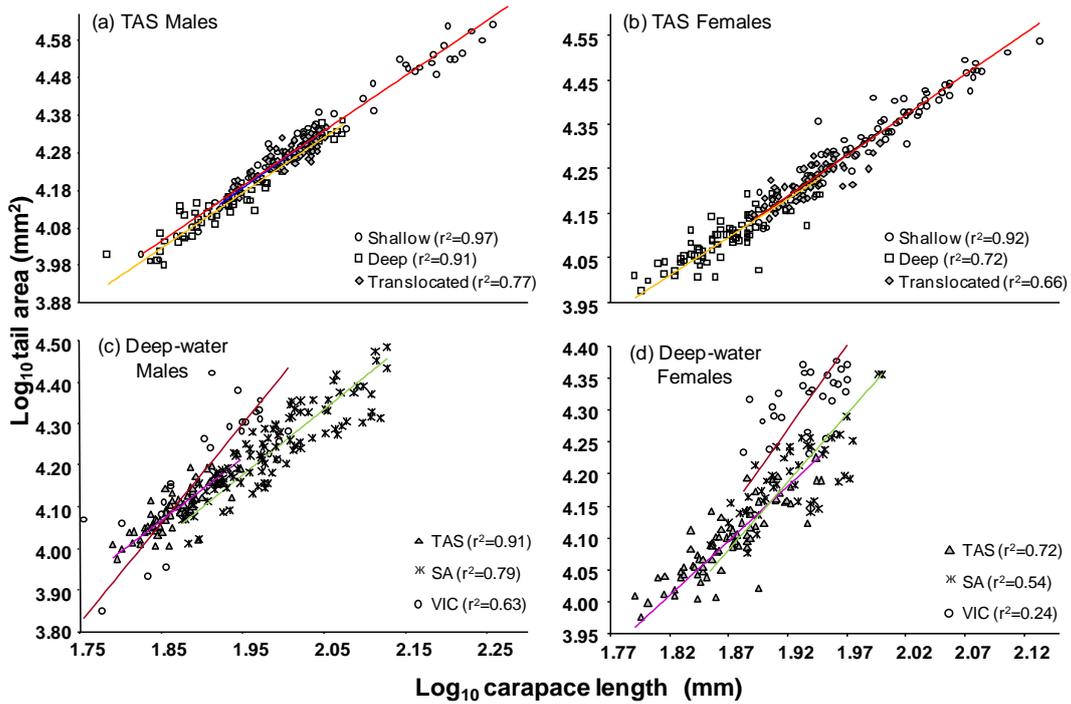
| a. LEG LENGTH   | MA slope<br>( $\pm$ 95% conf.int)  | $\Delta\beta$ , CS<br>( $\pm$ 95% conf.int) | intercept<br>( $\pm$ 95% conf.int) | $\Delta E$   |
|---|------------------------------------|---|------------------------------------|--------------|
| <b>TAS Males</b>  |                                    |   |                                    |              |
| Shallow   | 1.14 (1.08, 1.20) <sup>a</sup>     | } $p < 0.01$                                | -0.34 (-0.47, -0.23)               |              |
| Deep  | 1.35 (1.17, 1.55) <sup>b</sup>     |   | -0.38 (-1.04, -0.32)               |              |
| Translocated  | 1.49 (1.33, 1.67) <sup>b</sup>     |   | -1.00 (-1.35, -0.65)               |              |
| <b>TAS Females</b>  |                                    |   |                                    |              |
| Shallow   | 0.98 (0.87, 1.10) <sup>a</sup>     | } $p = 0.02$                                | -0.40 (-0.27, -0.18)               |              |
| Deep  | 1.23 (1.07, 1.44) <sup>b</sup>     |   | -0.50 (-0.85, -0.14)               |              |
| Translocated  | 1.18 (1.06, 1.33) <sup>b</sup>     |   | -0.43 (-0.69, -0.17)               |              |
| Males vs Females : $p_{\text{shallow}} = 0.02$ ; $p_{\text{deep}} = 0.42$ , ( CS = 1.30, $\Delta E$ $p < 0.01$ ) ; $p_{\text{translocated}} < 0.01$ |                                    |   |                                    |              |
| <b>Deep-water Males</b>   |                                    |   |                                    |              |
| TAS   | 1.35 (1.74, 1.55) <sup>a</sup>     | } $p = 0.03$                                | -0.68 (-1.04, -0.32)               |              |
| SA  | 1.14 (1.01, 1.29) <sup>a,b</sup>   |   | -0.32 (-0.60, -0.40)               |              |
| VIC   | 1.04 (0.92, 1.18) <sup>b</sup>     |   | -0.11 (-0.37, 0.14)                |              |
| <b>Deep-water Females</b>   |                                    |   |                                    |              |
| TAS   | 1.24 (1.07, 1.44)                  | } ns. CS = 1.21<br>(1.01, 1.35)             | -0.50 (-0.85, -0.14) <sup>a</sup>  | } $p = 0.01$ |
| SA  | 1.20 (0.98, 1.48)                  |   | -0.45 (-0.94, -0.05) <sup>b</sup>  |              |
| VIC   | 1.19 (0.96, 1.49)                  |   | -0.42 (-0.93, 0.09) <sup>a</sup>   |              |
| Males vs Females : $p_{\text{SA}} = 0.72$ (CS = 1.16, $\Delta E$ $p = 0.1$ ); $p_{\text{VIC}} = 0.02$   |                                    |   |                                    |              |
| <b>Shallow-water Males</b>  |                                    |   |                                    |              |
| TAS   | 1.14 (1.08, 1.20)                  | } ns. CS = 1.16<br>(1.10, 1.21)             | -0.34 (-0.47, -0.23)               | } ns.        |
| SA  | 1.21 (1.01, 1.34)                  |   | -0.48 (-0.72, -0.24)               |              |
| <b>Shallow-water Females</b>  |                                    |   |                                    |              |
| TAS   | 0.98 (0.87, 1.10)                  | } ns. CS = 1.16<br>(1.10, 1.21)             | -0.04 (-0.27, 0.18) <sup>a</sup>   | } $p < 0.00$ |
| SA  | 1.05 (0.87, 1.28)                  |   | -0.17 (-0.57, 0.23) <sup>a</sup>   |              |
| Males vs Females : $p_{\text{SA}} = 0.19$ (CS = 1.18, $\Delta E$ $p = 0.03$ )   |                                    |   |                                    |              |
| b. MEAT YIELD   | SMA slope<br>( $\pm$ 95% conf.int) | $\Delta\beta$ ,CS<br>( $\pm$ 95% conf.int)  | intercept<br>( $\pm$ 95% conf.int) | $\Delta E$   |
| <b>TAS Males</b>  |                                    |   |                                    |              |
| Shallow   | 2.83 (2.70, 2.96)                  | } ns. CS = 2.82<br>(2.69, 2.95)             | -4.86 (-5.13, -4.58) <sup>a</sup>  | } $p < 0.00$ |
| Deep  | 2.75 (2.26, 3.35)                  |   | -4.90 (-5.94, -3.86) <sup>a</sup>  |              |
| <b>TAS Females</b>  |                                    |   |                                    |              |
| Shallow   | 3.07 (2.82, 3.33)                  | } ns. CS = 3.06<br>(2.85, 3.27)             | -5.30 (-5.79, -4.81) <sup>a</sup>  | } $p < 0.00$ |
| Deep  | 3.04 (2.68, 3.43)                  |   | -5.41 (-6.13, -4.71) <sup>a</sup>  |              |
| Males vs Females : $p_{\text{shallow}} = 0.09$ (CS = 2.88, $\Delta E$ $p = 0.02$ ); $p_{\text{deep}} = 0.19$ (CS = 2.70, $\Delta E$ $p > 0.05$ )    |                                    |   |                                    |              |



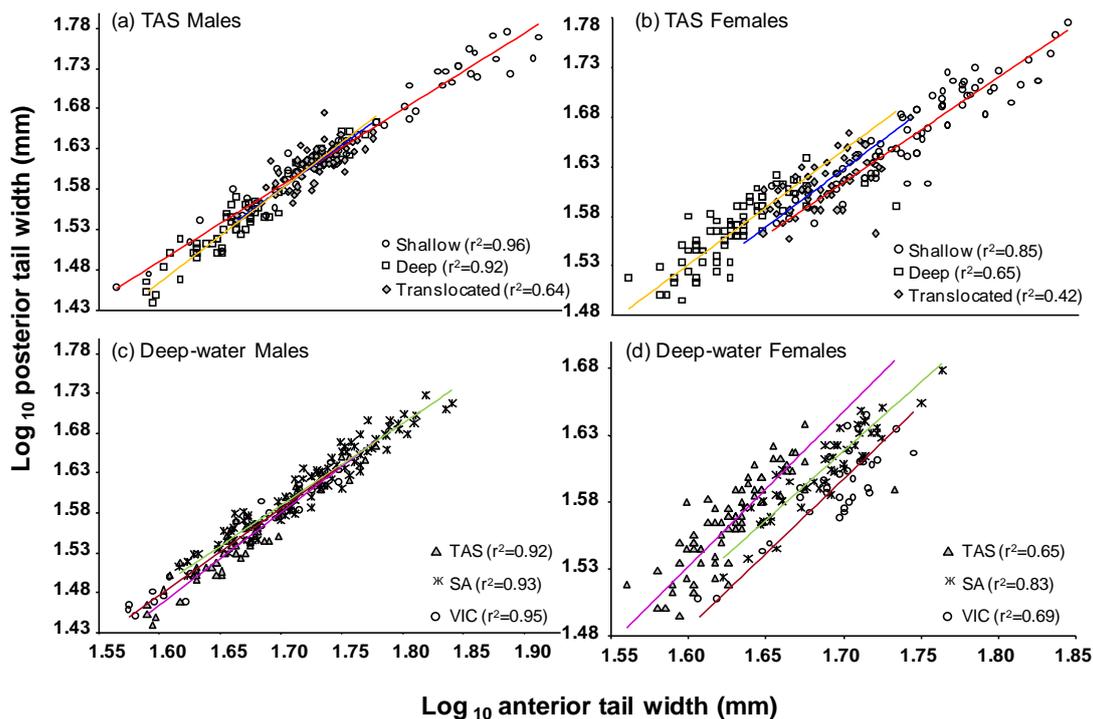
**Figure 5-75** Leg length relative to carapace length of translocated (blue regression line) and resident shallow (red regression line) and deep-water (yellow regression line) lobsters from different sites (a) TAS males (b) TAS females (c) resident male deep-water lobsters from all states (d) resident female deep-water lobsters from all states (e) resident male shallow-water lobsters from all states (f) resident female shallow-water lobsters from all states (TAS = purple, VIC = brown, SA = green regression lines). Scatter plots of meat yield and leg length of TAS shallow-water and deep-water males (g) and (h) females. Results of regression analyses based on these plots are presented in Table 5.22. Correlations values ( $r^2$ ) are shown on the legend of each plot.

**Table 5.23** Regression statistics of the major axis (MA) regression analysis of (a) tail area and carapace length and of (b) the posterior and anterior tail width.

| a. TAIL AREA  | MA slope<br>(± 95% conf.int)    | $\Delta \beta, CS$<br>CS (± 95% conf.int) | intercept<br>(± 95% conf.int)     | $\Delta E$   |
|---|---------------------------------|---|-----------------------------------|--------------|
| <b>TAS Males</b>  |                                 |   |                                   |              |
| Shallow   | 1.47 (1.40, 1.54)               | } ns. CS = 1.48<br>(1.42, 1.54)           | 1.33 ( 1.18, 1.48) <sup>a</sup>   | } $p < 0.01$ |
| Deep  | 1.48 (1.36, 1.61)               |   | 1.30 ( 1.06, 1.53) <sup>b</sup>   |              |
| Translocated  | 1.52 (1.37, 1.71)               |   | 1.22 ( 0.88, 1.56) <sup>a</sup>   |              |
| <b>TAS Females</b>  |                                 |   |                                   |              |
| Shallow   | 1.84 (1.72, 1.96)               | } ns. CS = 1.82<br>(1.72, 1.93)           | 0.66 ( 0.43, 0.90)                | } ns.        |
| Deep  | 1.71 (1.49, 1.99)               |   | 0.89 ( 0.43, 1.35)                |              |
| Translocated  | 1.86 (1.56, 2.26)               |   | 0.62 (-0.04, 1.28)                |              |
| Males vs Females : $p_{\text{shallow}} < 0.01$ ; $p_{\text{deep}} = 0.07$ (CS = 1.53, $\Delta E p < 0.01$ );<br>$p_{\text{translocated}} = 0.07$ (CS = 1.62, $\Delta E p < 0.01$ )                                  |                                 |   |                                   |              |
| <b>Deep-water Males</b>   |                                 |   |                                   |              |
| TAS   | 1.48 (1.36, 1.61) <sup>a</sup>  | } $p = 0.01$                              | 1.30 ( 1.06, 1.53)                |              |
| SA  | 1.59 (1.43, 1.77) <sup>a</sup>  |   | 1.08 ( 0.74, 1.42)                |              |
| VIC   | 2.42 (1.80, 3.50) <sup>b</sup>  |   | -0.41 (-1.89, 1.07)               |              |
| <b>Deep-water Females</b>   |                                 |   |                                   |              |
| TAS   | 1.71 (1.49, 1.99)               | } ns. CS = 1.84<br>(1.62, 2.10)           | 0.89 ( 0.43, 1.35) <sup>a</sup>   | } $p < 0.00$ |
| SA  | 2.13 (1.63, 2.94)               |   | 0.09 (-0.08, 1.27) <sup>a</sup>   |              |
| VIC   | 2.63 (1.42, 8.71)               |   | -0.77 (-4.43, 2.89) <sup>b</sup>  |              |
| Males vs Females : $p_{\text{SA}} = 0.05$ ; $p_{\text{VIC}} = 0.84$ (CS = 2.45, $\Delta E p = 0.08$ )   |                                 |   |                                   |              |
| b. TAIL WIDTH   | MA slope<br>(± 95% conf.int)    | $\Delta \beta, CS$<br>(± 95% conf.int)    | intercept<br>(± 95% conf.int)     | $\Delta E$   |
| <b>TAS Males</b>  |                                 |   |                                   |              |
| Shallow   | 0.95 (0.90, 1.01) <sup>a</sup>  | } $p < 0.00$                              | -0.03 (-0.13, 0.06)               |              |
| Deep  | 1.16 (1.08, 1.26) <sup>b</sup>  |   | -0.40 (-0.55, -0.24)              |              |
| Translocated  | 1.09 (0.93, 1.27) <sup>ab</sup> |   | -0.26 (-0.56, 0.03)               |              |
| <b>TAS Females</b>  |                                 |   |                                   |              |
| Shallow   | 1.01 (0.96, 1.16)               | } ns. CS = 1.09<br>(1.00, 1.18)           | -0.18 (-0.35, -0.00) <sup>a</sup> | } $p < 0.00$ |
| Deep  | 1.16 (0.97, 1.38)               |   | -0.32, (-0.64, 0.01) <sup>b</sup> |              |
| Translocated  | 1.18 (0.87, 1.62)               |   | -0.37 (-1.00, 0.23) <sup>c</sup>  |              |
| Males vs Females : $p_{\text{shallow}} = 0.07$ (CS = 0.98, $\Delta E p < 0.01$ ); $p_{\text{deep}} = 0.95$ (CS = 1.16, $\Delta E p < 0.01$ );<br>$p_{\text{translocated}} = 0.67$ (CS = 1.11, $\Delta E p < 0.01$ ) |                                 |   |                                   |              |
| <b>Deep-water Males</b>   |                                 |   |                                   |              |
| TAS   | 1.16 (1.08, 1.26)               | } ns. CS = 1.08<br>(1.03, 1.12)           | -0.40 (-0.55, -0.24) <sup>a</sup> | } $p < 0.00$ |
| SA  | 1.03 (0.98, 1.09)               |   | -0.17 (-0.26, -0.07) <sup>b</sup> |              |
| VIC   | 1.09 (0.99, 1.20)               |   | -0.26 (-0.43, -0.09) <sup>b</sup> |              |
| <b>Deep-water Females</b>   |                                 |   |                                   |              |
| TAS   | 1.16 (0.98, 1.38)               | } ns. CS = 1.08<br>(0.98, 1.19)           | -0.32 (-0.64, 0.01) <sup>a</sup>  | } $p < 0.00$ |
| SA  | 1.03 (0.90, 1.18)               |   | -0.13 (-0.37, 0.10) <sup>b</sup>  |              |
| VIC   | 1.10 (0.86, 1.43)               |   | -0.28 (-0.74, 0.19) <sup>c</sup>  |              |
| Males vs Females : $p_{\text{SA}} = 0.98$ (CS = 1.03, $\Delta E p < 0.01$ ); $p_{\text{VIC}} = 0.91$ (CS = 1.09, $\Delta E p = 0.01$ )  |                                 |   |                                   |              |



**Figure 5-76** Tail area (TA) relative to carapace length of translocated and resident shallow and deep-water lobsters from different sites (a) TAS males (b) TAS females (c) resident male deep-water lobsters from all states (d) resident female deep-water lobsters from all states. No data were available from resident shallow-water lobsters in SA and VIC sites. Correlations values ( $r^2$ ) are shown on the legend of each plot.



**Figure 5-77** The posterior tail width (PTW) relative to anterior tail width (ATW) of translocated and resident shallow and deep-water lobsters from different sites (a) TAS males (b) TAS females (c) resident male deep-water lobsters from all states (d) resident female deep-water lobsters from all states. No data were available from resident shallow-water lobsters in SA and VIC sites.

## Discussion

### *Natural variation in market traits*

The observed variation in red colouration, and the relative growth differences between carapace length, leg length, tail area and tail shape between deep and shallow-water populations may reflect differences in diet and/or adaptation to the local environment driven by trade-offs between survival, growth and reproduction. Shell colouration is influenced by the availability of carotenoids derived from the diet (Rao 1985). The carotenoid astaxanthin is produced by macro- and encrusting-algae species and through its subsequent consumption by herbivores and larger predators it becomes the primary pigment in crustacean shell colour (Goodwin 1960; Meyers and Latscha 1997). In juvenile southern rock lobsters, manipulation of tissue carotenoid levels and shell colouration has been achieved through incorporating differing astaxanthin levels in artificial feeds (Crear et al. 2003). Tlusty and Hyland (2005) also produced similar results in juvenile American clawed lobsters *Homarus americanus* and further suggested that differences in the rates of carotenoid uptake and deposition in the cuticle could additionally control phenotypic colour variation. Aquaculture studies have also reported that neither background colouration nor photoperiod affected

colouration of juvenile southern rock lobsters (Stuart et al. 1996; Crear et al. 2003). Sea-cage experiments aimed at colour enhancement in pale, deep-water adult *J.edwardsii* had produced red lobsters with supplemented feeding, but colour improvement in starved, pale lobsters also occurred, with the authors concluding that the experimental lobsters consumed biofouling organisms from cage surfaces (Bryars and Geddes 2005). For adult *J.edwardsii* shell colour may depend on diet but it is unclear as to what extent colour expression reflects an adaptive plastic response to its physical environment or to physiological and behavioural stimuli.

There were morphological differences between deep and shallow-water Tasmanian lobsters when assessed by leg length, tail shape and tail area. These differences in body-shape imply differences in meat yield as evident from the analysis of one of the walking legs. The narrow tail shape reported for deep-water lobsters was however not observed and rather the reverse trend with shallow-water lobsters with narrower tails than deep-water lobsters. There was substantial variation in the body-shape of *J.edwardsii* populations across the three states although not with any systematic pattern such as a latitudinal trend. Allometric differences in morphology were also pronounced between the sexes. Sexual dimorphism may be responsible for the differences in tail characteristics, while differences in leg length and meat yield between the sexes could be due to differences in their metabolic rates. Similar differences have been observed in the clawed lobsters *Homarus americanus* and *Homarus gammarus*, where males and females from geographically different sites show variations in morphology despite their lack of movement and genetic differentiation (Debusse et al. 2001; MacCormack and DeMont 2003). The proposed causative factors of phenotypic plasticity were lobster density, water temperature, food availability and interactions among conspecifics. All of these factors potentially contributed to the observed differences between deep and shallow water lobsters in this study.

#### *Market traits response to translocation and its commercial significance*

Colour change in translocated *J.edwardsii* was a significant outcome of this study and consistent with colour change resulting from a change in diet. It contrasts with the colour transformation observed in the western rock lobster *Panulirus cygnus*, which changes from a red to paler colouration prior to its migration to offshore breeding grounds (Melville-Smith et al. 2003). In this case, the distinct red to white colour transition in *P. cygnus* is assumed to have a genetically controlled mechanism (Wade et al. 2005). Changes in colour within a moult are also possible (Davis et al. 2005), but this is unclear from our results as increase in fouling during inter-moult masks any minor colour change. For deep-water *J. edwardsii* moulting was required following translocation in order for a more marketable red colouration and from a commercial point of view this increases its marketability and value.

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Allometric changes in morphology after translocation varied among the body-shape traits and were also influenced by gender. The relative growth of the tail area of translocated males was similar to those of the resident shallow-water males after their first moult in the new habitat, demonstrating a high degree of plasticity. In another instance, the posterior tail width (PTW) of translocated females was statistically different but growth changes intermediate between deep and shallow-water females, while the PTW of translocated males were indistinguishable from both shallow and deep-water males. While there was no significant change in the leg length to carapace relationship in translocated lobsters, graphical plots (Figure 7-75) indicate a transitional shift towards the resident population. Leg length may be less responsive to habitat change than the other traits examined and may require several moults for a complete transformation.

While there are many stock enhancement operations based on hatchery reared juveniles (Bell et al. 2008; Zohar et al. 2008), the capture, translocation and release of adults in the marine environment is less common. However translocation has been adopted for similar value-adding strategies in other commercial species. For example, in France the roe size and quality of sea urchins are being enhanced by transplanting adults with poor quality gonads from polluted and barrens areas into areas dense in algal assemblages (Martin 2004). Abalone is another high value seafood product where transplant experiments improved the growth rates of stunted populations (Dixon and Day 2004). The success of all stock enhancement and sea ranching strategies depend on its economic feasibility (Bartley and Bell 2008) amongst other associated factors. For the Australian southern rock lobster industries this study highlights translocations' potential in providing an opportunity to add value to its less marketable product through improving its key market traits of colour and morphology.

## **Conclusion**

Translocation appears to have commercial application for exploiting natural plasticity in market traits of lobsters to increase beach price. For deep-water *Jasus edwardsii* translocated to shallow-water, a single moult was sufficient to elicit significant changes in colour and a range of changes in body-shape traits as they grew in their new environment. Although colour has a higher impact than body-shape traits when setting the market price, there may still be a low risk of continued discounting by processors for translocated red lobsters with narrow tails or short legs. These issues need to be addressed through further market research to assess industry and market response to market traits in translocated lobsters and determine if both the consumer and the processor are able to discriminate between legal size shallow and translocated lobsters. For the Australian southern rock lobster industry, this study highlights the potential of translocation to add value through transforming lobsters from undesirable phenotypes to desirable ones and offer a novel approach to fisheries management.

### 5.6.2 *Change in nutritional condition and omega-3 content*

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*Published as: Translocating southern rock lobsters (Jasus edwardsii) from deep-water to shallow inshore water enhances nutritional condition through omega-3 long-chain polyunsaturated fatty acid content. Chandrapavan A, Guest M, Nichols P, Gardner C (2009) Journal of Experimental Marine Biology and Ecology 375: 9-15.*

#### **Summary**

We assessed changes in nutritional condition in adult, deep-water lobsters before and 12 months after translocation through variations in the lipid and fatty acid profiles in the hepatopancreas and muscle. Fatty acid compositions were similar between shallow and translocated lobsters and both were different from deep-water lobsters, suggesting a dietary difference between the deep and shallow-water lobsters, and a dietary change in deep-water lobsters after translocation. Nutritional condition indices, such as total lipid and triacylglycerol content, did not significantly vary between the lobster populations which may be due to within-population variability driven partly by differences in the moult stage of lobsters. Mean concentrations of fatty acids, lipid content and essential polyunsaturated fatty acids (PUFA) were higher in translocated lobsters than in both deep and shallow-water lobsters. Mean omega-3 long-chain PUFA content, in particular eicosapentaenoic acid (EPA, 20:5n-3) increased by 30% in the muscle of translocated lobsters, resulting in an enhanced nutritional value and a change in overall body condition. This enhancement of key fatty acids, achieved through translocation, highlights the market potential of translocation for the commercial industry.

#### **Introduction**

After their first moult event in the new habitat, translocated lobsters change from a pale colouration to the marketable red colour of the resident lobsters, and growth increments showed a 2–3 fold increase. This section deals with the role of diet in these transformations and to what extent nutritional condition of rock lobsters has been altered through translocation.

Indices of nutritional condition that are sensitive to dietary changes include total lipid content (energy reserves), the proportion of structural (phospholipid) versus storage lipid (triacylglycerol), fatty acid composition and ratios of specific fatty acids (Kanazawa and Koshio, 1994; Ju and Harvey, 2004). These indices have been used to examine differences in body condition caused by dietary stress such as starvation in crustaceans (Jones and Obst, 2000; Moore et al., 2000; Parslow-Williams et al., 2001), spatial variation within populations of the same and related species (Iverson et al., 2002; Murphy et al., 2002; Phillips et al., 2003a,b) and between wild and cultured populations (Navarro and Villanueva, 2003; Nelson et al., 2005). For crustaceans, interpretation of nutritional information must also consider the physiological condition of animals such as reproductive and moult cycle (Chang and O'Connor, 1983; D'Abramo, 1997), and the functional role of the tissue analysed as these can alter the relative quantity and type of lipid reserves. For example, the digestive gland (hepatopancreas) of decapod crustaceans is primarily involved in the digestion and

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absorption of food material, lipid synthesis and storage, and in regulating energy metabolism (O'Connor and Gilbert, 1968; Gibson and Barker, 1979). Lipid reserves found in this gland are typically high and respond rapidly to changes in physiological and environmental parameters such as dietary stress caused by altered feeding rates, moulting and production (Sargent, 1974; McLeod et al., 2004). By contrast, muscular tissues such as walking legs are low in lipid which is predominantly present in biomembranes as phospholipids, and do not respond readily to short-term changes in physiological and environmental parameters (Cockcroft, 1997). This slow tissue turnover rate means they are useful in understanding the longer term dietary changes experienced by the animal (Corraze, 1999).

In the present study, we quantified the lipid content, lipid class and fatty acid compositions of both the digestive gland and leg muscle of shallow-water, deep-water and recaptured translocated lobsters to examine differences in their nutritional condition through short-term and long-term changes, and to understand the dietary plasticity of *J. edwardsii* through the *in situ* change of lobster habitat and diet.

## **Detailed Methods**

### *Translocation and lobster collection*

This section deals with the translocation conducted between Maatsuyker Island and Taroon Reserve. Moulting growth increments of more than 5 mm and the partial or complete regeneration of the cut pleopod were used as moulting confirmation (Ziegler et al., 2004).

We compared triacylglycerol (TAG) concentrations in the digestive gland with blood refractive index (BRI) values of shallow-water and translocated lobsters to examine the influence of moulting cycle. Haemolymph samples (1 ml) were taken from the pericardial sinus of only the shallow and translocated lobsters. Pigment stage (PS) of the haemolymph was noted (Musgrove, 2001) and then an aliquot of the sample was placed in a hand-held refractometer (Model UR-2, Industrial and Scientific Supply Co.) to measure blood refractive index. The blood protein/pigment stage index developed by Musgrove (2001) was used as an additional condition index. The BRI is directly proportional to the concentration of protein in blood of *J. edwardsii* (Oliver and MacDiarmid, 2001; Musgrove, 2001), which increases as body condition improves from the post-moulting to pre-moulting stage of the moulting cycle. Haemolymph colour is indicative of the pigment astaxanthin, which increases in concentration during the late inter-moulting to pre-moulting stage and can be visually assessed for colour change. Both BRI and PS provide a crude indication on the moulting stage, particularly in differentiating the beginning, middle and end phases of the cycle. Animals in post-moulting to early-inter-moulting stage will have low BRI values and PS of clear/grey colour. During the long inter-moulting period as water is replaced by tissue growth in lobsters, BRI increases while the PS remains colourless. As lobsters approach the pre-moulting stage, reabsorption of the old shell causes blood pigment to change progressively from clear to dark red colour and BRI levels are at their highest. Although we selected hard-shelled lobsters for analysis, these additional indices provide more precise information on the moulting condition of the lobsters. Animals were killed in freshwater before a single lobe of the digestive gland was dissected for lipid and fatty acid analyses. Muscle tissue from the fourth right or left walking leg was also removed and all samples stored in a -20 °C freezer prior to analysis.

*Lipid and fatty acid analyses*

All lobster digestive gland and muscle samples (as wet tissues) were quantitatively extracted overnight using a modified Bligh and Dyer (1959) one-phase methanol : chloroform : water extraction (2:1:0.65 v/v/v). Phases were separated the following day by addition of chloroform and water (final solvent ratio, 1:1:0.9 v/v/v methanol: chloroform : water). Lipids were recovered in the lower chloroform phase, solvents removed under vacuum, the concentrated lipid recovered through rotary evaporation at 40 °C, then weighed to obtain total lipid content. An aliquot of the total lipid extract (TLE) was analysed using an Iatroscan MKV TH10 thin layer chromatography flame ionisation detector analyser (Tokyo, Japan) to determine the proportions of individual lipid classes. A polar solvent system (60:17:0.1 v/v/v ratio of hexane: ether: acetic acid) resolved TAG, free fatty acids, sterols and phospholipids. Peaks were quantified with DAPA Scientific Software (Kalamunda, Western Australia).

An aliquot of the TLE was transmethylated at 80 °C for 2 h in a 10:1:1 v/v/v mixture of methanol: hydrochloric acid: chloroform to produce fatty acid methyl esters (FAME). FAME were partitioned by the addition of water and extracted with 4:1 hexane: chloroform (v/v, 3×1.5 ml), the solvent removed under a stream of nitrogen, then silylated at 60 °C for 2 h in N, O-bis-(trimethylsilyl)-trifluoroacetamide (BSTFA). FAME were analysed by gas chromatography (GC) using a Agilent Technologies 6890N GC (Palo Alto, California, USA) equipped with an Equity™-1 fused silica capillary column (15 m×0.1 mm i.d., 0.1 µm film thickness), an FID, a split/splitless injector and an Agilent Technologies 7683 Series auto sampler and injector. Helium was the carrier gas, and pressure was maintained at 65 kPa. Samples were injected in splitless mode with an oven temperature of 120 °C, and temperature was increased to 250 °C at 10 °C/min, and finally to 270 °C at 3 °C/min. Peaks were quantified with Agilent Technologies Chem Station software (Palo Alto, California, USA). Individual components were identified by mass spectral data and by comparing retention time data with those obtained for authentic and laboratory standards. GC results are typically subject to an error of up to ±5% of individual component area. GC-mass spectrometric (GC-MS) analyses were performed on a Finnigan Thermoquest GCQ GC-mass spectrometer fitted with an on-column injector and using Thermoquest Xcalibur software (Austin, Texas, USA). The GC was equipped with an HP-5 cross-linked methyl silicone fused silica capillary column (50 m×0.32 mm i.d.) of similar polarity to that used for GC analyses and helium was used as carrier gas.

*Statistical analyses*

A combination of analysis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA) were used to compare total lipid content, TAG content and fatty acid compositions between shallow-water, deep-water and translocated lobster populations using lobster size (carapace length) as a covariate. All variables were normally distributed after transformations of  $\log_{10}$  of digestive gland data and  $\log_2$  transformation of leg muscle data (Shapiro–Wilk *W* test and normal probability plots) and there was no violation of the homogeneity of slopes assumption. Pillai's trace test was used as a multivariate test of significance and significant effects were further examined using Tukey's post-hoc analysis. Statistical analyses were performed using Statistica (V7.1 Statsoft Inc, Tulsa OK USA). All identified individual fatty acids (expressed as percentage of total fatty acids) were compared among deep-water,

shallow-water and translocated lobsters using principal components analysis (PCA). PCA reduces the number of variables by producing components using linear correlations between variables to identify those fatty acids that contribute most to the separation between observed groups and was performed using PRIMER 6 software (PRIMER-E, Plymouth, UK).

## Results

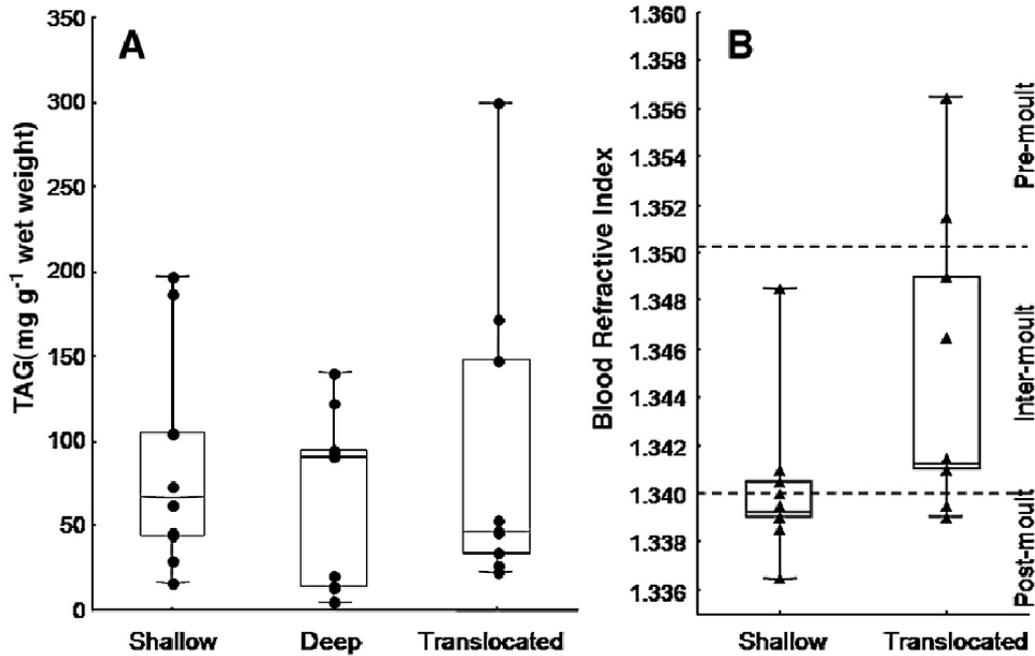
### *Total lipid content and lipid class composition*

Mean total lipid content (mg g<sup>-1</sup> wet wt.) of the digestive gland did not significantly vary between deep-water, shallow-water and translocated lobster populations ( $F_{2,25}=0.56$ ,  $p=0.58$ ). The major lipid class in the digestive gland was triacylglycerol (TAG) followed by phospholipid (PL), free fatty acid (FFA) and sterol (ST) (Table 5.24). TAG concentrations in the digestive gland did not vary between the lobster populations ( $F_{2,24}=0.41$ ,  $p=0.66$ ). Total lipid content in the leg muscle constituted less than 1% of the muscle (wet weight basis) and within populations was less variable than in the digestive gland. Phospholipids made up approximately 95% of the lipid content in the leg muscle of lobsters from each population, and the remaining lipid was ST, with minor proportions of FFA and TAG (Table 5.24).

**Table 5.24.** Total lipid content (mg·lg sample wet weight) and lipid class composition (as % of total lipid) of the digestive gland and leg muscle expressed as mean  $\pm$  SE from shallow-water, deep-water and translocated (recaptured after 12 months) lobsters.

|                              | Digestive gland  |                  |                  | Leg muscle     |                |                |
|------------------------------|------------------|------------------|------------------|----------------|----------------|----------------|
|                              | Shallow          | Deep             | Translocated     | Shallow        | Deep           | Translocated   |
| n                            | 10               | 9                | 10               | 10             | 9              | 9              |
| Size range (mm)              | 110–160          | 85–132           | 96–118           | 118–147        | 78–97          | 96–118         |
| (mg g <sup>-1</sup> wet wt.) | 113.6 $\pm$ 19.4 | 107.1 $\pm$ 15.8 | 140.9 $\pm$ 26.4 | 8.8 $\pm$ 0.5  | 9.6 $\pm$ 0.5  | 9.5 $\pm$ 0.7  |
| Total lipid                  |                  |                  |                  |                |                |                |
| (Percent comp.)              |                  |                  |                  |                |                |                |
| TAG                          | 68.8 $\pm$ 5.9   | 51.9 $\pm$ 9.6   | 59.7 $\pm$ 7.7   | 0.2 $\pm$ 0.1  | 0.1 $\pm$ 0.1  | 0.3 $\pm$ 0.1  |
| FFA                          | 3.6 $\pm$ 0.7    | 10.5 $\pm$ 5.1   | 10.0 $\pm$ 2.8   | 0.2 $\pm$ 0.1  | 0.5 $\pm$ 0.1  | 0.5 $\pm$ 0.2  |
| ST                           | 0.8 $\pm$ 0.2    | 2.8 $\pm$ 0.8    | 1.6 $\pm$ 0.5    | 4.7 $\pm$ 0.4  | 3.9 $\pm$ 0.3  | 4.1 $\pm$ 0.4  |
| PL                           | 26.8 $\pm$ 5.3   | 34.8 $\pm$ 6.8   | 28.7 $\pm$ 5.5   | 94.9 $\pm$ 0.4 | 95.5 $\pm$ 0.3 | 95.2 $\pm$ 0.5 |

The median BRI values for shallow (1.339) and translocated lobsters (1.341) were similar (Figure 5-78), indicating that most lobsters were in their late post-moult to early inter-moult stage of the moult cycle. Several translocated lobsters appear to be in their late inter-moult to pre-moult, indicated by their darker (reddish) blood pigment colour and higher BRI, and these same lobsters had higher TAG level (Figure 5-78). Generally, lobsters in their late inter-moult and pre-moult stage are nearing the end of their maximum TAG accumulation phase and our results suggest that the low and high ranges in TAG concentrations in shallow-water and translocated lobsters (Figure 5-78) may be associated with the early and late phases of the moult cycle respectively.

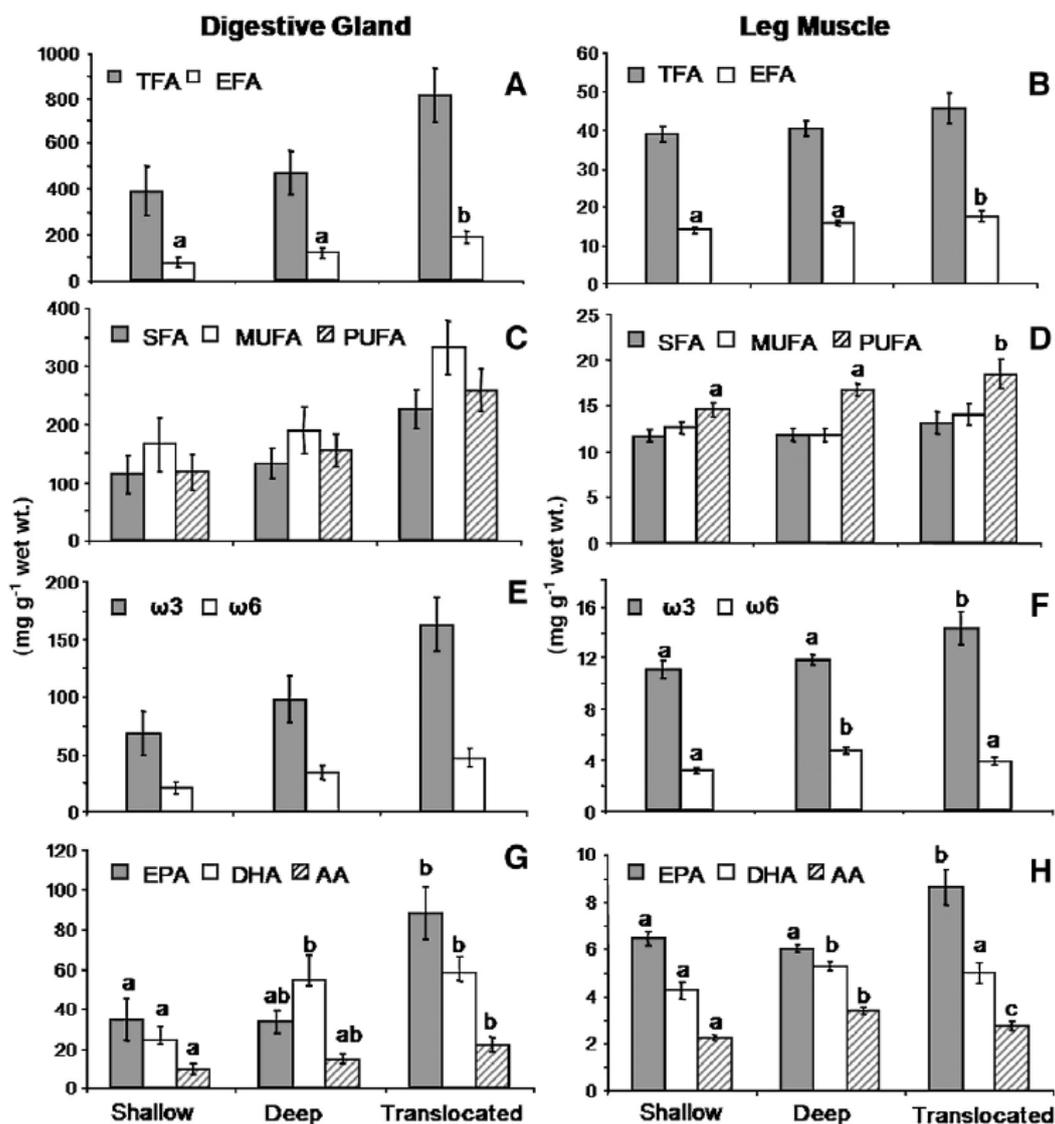


**Figure 5-78.** Body condition indices of shallow-water, deep-water and translocated (recaptured after 12 months) lobsters. (A) TAG concentrations from the digestive gland and (B) haemolymph refractive index values of only shallow-water and translocated lobsters. Also indicated are the broad BRI ranges associated with the moult cycle of *J. edwardsii* (see Musgrove, 2001): Postmoult 1.335–1.3400; inter-moult 1.3400–1.3450; pre-moult 1.3460–1.3600. The box and whisker plot shows: box=1st–3rd quantiles; centre line=median value; whiskers = minimum–maximum values. Note, no blood information collected for deep-water lobsters.

#### *Fatty acid compositions*

##### *Digestive gland*

The most abundant fatty acids in the digestive gland (N5% of total fatty acids for all populations) were 16:1n-7c, 16:0, 18:1n-9, 18:1n-7, 18:0, 20:5n-3 (eicosapentaenoic acid: EPA), 20:1n-9+11 and 22:6n-3 (docosahexaenoic acid: DHA). Monounsaturated fatty acids (MUFA) were the dominant group of fatty acids ( $40.2 \pm 4.9\%$  to  $41.8 \pm 1.9\%$ ) with similar proportions of saturated fatty acids (SFA) ( $27.7 \pm 1.7\%$  to  $28.6 \pm 1.9\%$ ) and polyunsaturated fatty acids (PUFA) ( $29.6 \pm 3.0\%$  to  $31.8 \pm 3.4\%$ ). Mean concentrations of EFA were significantly higher in translocated lobsters than in shallow-water and deep-water lobsters ( $F_{12,22}=5.27$ ,  $p < 0.001$ ) (Figure 5-79A). Concentrations of total fatty acids (TFA) in the digestive gland did not vary significantly between deep-water, shallow-water and translocated populations ( $F_{2,25}=2.68$ ,  $p=0.88$ ), nor did total concentrations of SFA, MUFA and PUFA ( $F_{6,46}=1.25$ ,  $p=0.30$ ) (Figure 5-79C). Analyses of selected (n-3) and (n-6) PUFA that typically indicate dietary differences also were not different between lobster populations ( $F_{4,48}=1.57$ ,  $p=0.197$ ) (Figure 5-79E). Mean concentrations of EPA and AA were significantly higher in translocated lobsters than in shallow-water lobsters, but not different from deepwater lobsters. Mean concentrations of DHA were higher in deep and translocated lobsters than in shallow-water lobsters (Figure 5-79G).



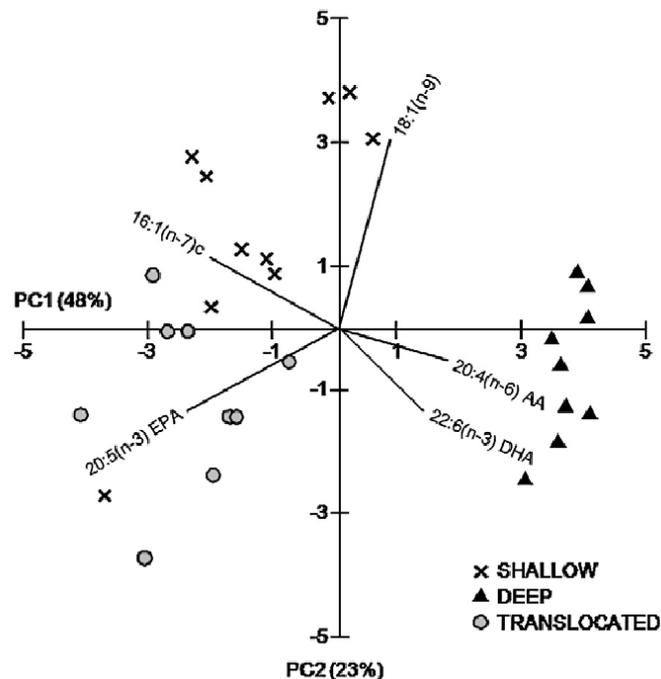
**Figure 5-79.** Comparisons of key fatty acid groups (A–F) and individual essential fatty acids (G–H) (mean  $\pm$  SE, mg g<sup>-1</sup> sample wet weight) from the digestive gland and leg muscle tissues of shallow-water, deep-water and translocated lobsters (recaptured after 12 months): TFA=total fatty acids; EFA=essential fatty acids; SFA=total saturated fatty acids; MUFA=total monounsaturated fatty acids; PUFA=total polyunsaturated fatty acids;  $\omega$ 3=total omega-3 long-chain fatty acids;  $\omega$ 6=total omega-6 long-chain fatty acids; EPA=eicosapentaenoic acid; DHA=docosahexaenoic acid; AA=arachidonic acid. All groups were analysed using ANCOVA or MANCOVA and the results of the post-hoc Tukey's test are indicated by superscripts where significant difference among lobster populations are indicated by different (a, b, c) letters.

#### *Leg muscle*

The most abundant fatty acids in the leg muscle were the same as those in the digestive gland with the addition of 20:4n-6 (AA). Both AA and EPA were found in higher proportions in leg muscle than in the digestive gland (N5% and N10% of total fatty acids respectively). Concentrations of fatty acids in the leg muscle were less than 10% of the total fatty acids in the digestive gland. Concentrations of EFA were also

higher in translocated lobsters than in shallow and deepwater lobsters ( $F_{12,36}=6.48$ ,  $p<0.01$ ) (Figure 5-79B). Although there was no significant difference in the concentrations of total fatty acids between shallow, deep and translocated lobsters ( $F_{2,23}=5.60$ ,  $p=0.10$ ), PUFA were significantly higher in translocated than in shallow-water lobsters ( $F_{6,42}=3.99$ ,  $p<0.01$ , Figure 5-79D). The sum of (n-6) PUFA was significantly higher in deep-water lobsters than in shallow and translocated lobsters, while the sum of (n-3) PUFA was higher in translocated lobsters than in shallow-water and deep-water lobsters ( $F_{4,44}=5.37$ ,  $p<0.01$ ) (Figure 5-79F). Eicosapentaenoic acid (EPA) was higher in translocated lobsters than in shallow and deep-water lobsters while DHA was slightly higher in deepwater lobsters, but not different between shallow and translocated lobsters. Arachidonic acid (AA) was significantly different between all lobster populations, and was highest in deep-water lobsters (Figure 5-79H).

Leg muscle fatty acid profiles were grouped separately for each of the three populations on the PCA plot, although there was slight overlap between the FA profiles of translocated lobsters and shallow water lobsters along the secondary axis (PC2, 23%, Figure 5-80). Deep-water lobsters were distinct from the other two populations along PC1, which accounted for 48% of the variance. Separation among groups along PC1 was driven strongly by 16:1(n-7)c and EPA while the main fatty acid causing separation between shallow and translocated lobsters along PC2 was 18:1(n-9), with additional influences from EPA and DHA.



**Figure 5-80.** Two-dimensional PCA plot of the first two principal components derived from the leg muscle fatty acid profiles (as % of total fatty acids) of shallow-water, deep-water and translocated (recaptured after 12 months) lobsters. The percentage of variance explained by each component is indicated on the axis title. Key fatty acids responsible for the directional displacements are indicated by vectors.

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## Discussion

### *Fatty acid differences*

Fatty acid profiles were different in lobsters from deep-water, shallow-water, and translocated lobsters. Overall FA compositions of translocated lobsters were comparable to those of shallow-water lobsters than to deep-water lobsters, while concentrations of some individual FA were similar to deep-water lobsters (e.g. 20:1n-9+11). These differences in FA profiles are consistent with differences in diet between lobster populations at different depths and thereby confirm the change in diet in translocated lobsters. Identification of prey items from lipid signature analyses, as has occurred for a number of other marine species, may further resolve dietary differences between deep and shallow-water populations. Our results also showed that fatty acid profiles of deep, shallow and translocated lobsters were similar between muscle and hepatopancreas, demonstrating that a period of 12 months was sufficient (although not the maximum time period required) for the biochemical signature of the new prey items to be assimilated by translocated lobsters. This is supported by aquarium feeding trial studies where lipid profiles of adult *J. edwardsii* (tail and leg muscle) changed in response to different feed types after 4 months (Nelson et al., 2005), and after 3 months in juveniles (whole body) (Johnston et al., 2003).

Both tissue types revealed concentrations of n-3 and n-6 FA were higher in deep than in shallow-water lobsters, and highest in translocated lobsters. The ratio of n-3/n-6 was also lowest in deepwater lobsters and markedly higher in shallow and translocated lobsters. Eicosapentaenoic acid (EPA) and DHA were the two main PUFA driving the separation of deep-water lobsters from shallow and translocated lobsters in our principal component analysis. These essential fatty acids play an important role in the growth and development of crustaceans, especially during the early larval and juvenile stages (Nelson et al., 2006). Essential fatty acid deficiency has been linked to slow growth rates and a decrease in feeding efficiency in several fish species and a reduction in egg production and deformities in larval morphology (Corraze, 1999). The production of aquaculture feeds is a prime example of the importance of nutrient balance in achieving positive growth and condition outcomes. An imbalance can lead to competition between fatty acids and the inefficient synthesis of prostaglandins (D'Abramo, 1997). Therefore it is possible that an imbalance in the proportions of EFA in the diet (e.g. AA/EPA, DHA/EPA ratios) in conjunction with insufficient levels of essential nutrients may be contributing factors in the slower growth rates of deep-water lobsters.

### *Nutritional condition*

Total lipid and TAG content were not different between the three lobster populations, despite differences in the fatty acid compositions. The most plausible reason for similarity in TAG and lipid is the influence of the moult cycle. For crustaceans, growth is achieved through the cyclic accumulation and depletion of organic reserves, a significant and important feature of decapod physiology (Passano, 1960). During the long inter-moult period of the moult cycle, TAG reserves are accumulated for the next moult event. Lipid content is therefore constantly changing in addition to supplying the demands from reproduction, daily energetics, and environmental and seasonal fluctuations in food availability. In the present study, a high BRI in a number of translocated lobsters indicated they were in the intermoult or pre-moult phase, while

the majority were in the post-moult phase. These same lobsters had high levels of TAG. These differences in the moult phases within populations, especially among translocated lobsters, highlight the physiological heterogeneity among the lobsters used for analysis. This highlights the importance of moult staging when quantifying lipid content, which many previous studies have overlooked.

Most interesting was the finding of higher concentrations of EFA in the hepatopancreas and muscle of translocated lobsters than in shallow or deep-water lobsters. In particular very high mean concentrations of total and selected PUFA groups were found in the muscle of translocated lobsters. Rates of metabolism, digestion and catabolism which are hormonally controlled (Santos et al., 1997) and driven by several factors such as temperature, light and diet (Childress et al., 1990), may change in response to a new habitat and the ensuing environmental changes. Translocated lobsters analysed in our study had experienced 12 months in the new environment and had also changed in appearance and growth (Chandrapavan, unpublished data). Initial differences in growth rate may have been due to metabolic differences, assuming significant differences in metabolism were present between deep and shallow-water lobsters, although this is largely speculative at this point. Translocated lobsters may have experienced increased nutrient uptake or a greater absorption rate indicative of the higher concentrations of lipid and fatty acids in the digestive gland that may reflect modifications to the digestive physiology due to greater quantity of food being digested. This may be a compensatory response whereby an increase in the size and volume of the digestive gland and enzyme activity occurred in response to the new habitat.

Leg muscle of translocated lobsters had higher concentrations of PUFA and in particular EFA than in shallow and deep-water lobsters. Given the accelerated growth in translocated lobsters over a short period of time, increased tissue synthesis including incorporation of associated lipid, may be a possible explanation for this observation which is similar to a compensatory response that is sometimes induced by a period of starvation or reduced nutrient intake (Ali et al., 2003). Compensatory responses can include hyperphagia, rapid weight increase, repletion of energy reserves and increased nutrient intake. For small and pale coloured translocated lobsters, risk from cannibalism is high. One way to avoid this situation is to eat and grow as fast as possible. This catch-up growth behaviour in habitats of high predation has been shown in several fish studies where there is a trade off between escape performance and growth acceleration (Alvarez and Metcalfe, 2007). Since compensatory responses are reported to be short-lived, it is unclear if this will be maintained over several moults by translocated lobsters or if it is regulated at optimal or maximal rates.

From a commercial and marketing point of view, increased concentrations of EFA in edible tissues are highly favourable. Recent studies have shown that consumption of oily fish has associated health benefits in humans, as they decrease cholesterol levels and the subsequent occurrence of cardiovascular disease (Gebauer et al., 2006; Jarvinen et al., 2006). In particular, the emphasis is on the richness of omega-3 long-chain PUFA, which in our study were 30% higher in concentration in the muscle of translocated lobsters than in shallow and deep-water lobsters. This is a significant and novel finding given the marketing issues surrounding the importance of omega-3 long-chain PUFA in cultured fish species comparable to their wild counterparts. Nelson et al. (2005) found the lipid and fatty acid content of muscle of cultured and

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wild *J. edwardsii* to be similar, but the animals differed in their quality attributes such as taste, texture and colour. Therefore enhanced nutrition in translocated lobsters may also implicate enhanced flavour and flesh quality thus providing the basis for further research.

## **Conclusion**

Differences in fatty acid profiles between deep and shallow-water populations and the change in their FA profile after translocation highlight the dietary plasticity of adult *J. edwardsii*. Changes in key market traits, in particular the health benefiting omega-3 long-chain PUFA, were also observed, although it is presently unclear if these differences arise from nutritional condition and/or result from changes in PUFA desaturating enzyme activity at the higher temperature that may occur in the shallow-water location. Further research is required to examine the mechanisms associated with changes in PUFA profiles in translocated lobsters. This study is the first to show nutritional enhancement through the *in situ* manipulation of lobster habitat. This finding suggests translocated deep-water lobsters have enhanced nutritional condition and quality, beyond that of legal sized shallow-water lobsters, thus raising its market potential. This response may diminish with time as lobsters adjust to their new habitat.

### 5.6.3 *Surviving transport.*

*Submitted for publication as: Effects of translocation from deep water to shallow water inshore reefs on the physiological condition of southern rock lobster (Jasus edwardsii) in response to live transport simulations. Peter Hawthorne, Adrian Linnane*

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#### **Abstract**

*Jasus edwardsii* from deep water (>60m) are perceived by industry to experience higher mortality than those from shallow water (<60m) when exported live. This study examined the effect of translocation from deep to shallow inshore reefs on haemolymph pH, condition index and mortality rate during simulated live transport compared to resident deep and shallow water caught *J. edwardsii*. Haemolymph pH is a measure of the accumulation of carbon dioxide, and therefore reduction in uptake of oxygen. During immersion, haemolymph pH decreased significantly, but recovered to initial values when lobsters were reimmersed. There was no relationship between lobster mortality, haemolymph pH or condition index score in pack out simulations. The significantly higher mortality rate of deep water lobster compared to shallow and translocated lobsters suggests a difference in physiology between deep and shallow lobsters and that translocation may improve lobster physiological condition to better cope with the stress of live transport to valuable overseas markets.

#### **Introduction**

The Southern rock lobster (*Jasus edwardsii*) is an important commercial species of South Australia worth an estimated AUD\$92M annually (Pham and Peat 2009). Over 90% of the commercial catch is exported live to markets mainly in Asia (Linnane et al. 2008a). *J. edwardsii* is a sub-tidal crustacean and although these animals can survive short term aerial exposure, immersion times of up to 30 hours are required to reach overseas markets.

The physiological responses to immersion have been rigorously studied for decapod crustacean species such as *J. edwardsii* (Taylor and Waldron 1997; Morris and Oliver 1999a; Morris and Oliver 1999b; Speed et al. 2001), *Jasus lalandii* (Haupt et al. 2006), *Homarus americanus* (Lorenzon et al. 2007; Qadri et al. 2007), the sub-tidal crab, *Cancer pagurus* (Lorenzon et al. 2008) and the tiger prawn, *Penaeus japonicus* (Chen and Chen 1998) to establish optimal packing conditions to reduce stress, minimise mortality and ensure the product arrives alive, vigorous and intact at the market place.

Out of water, the internal acid-base balance becomes problematic as the gills collapse in air which reduces the surface area for gas exchange (Taylor and Waldron 1997; Morris and Oliver 1999a) reducing the uptake of oxygen and the elimination of carbon dioxide from the haemolymph. Further, anaerobic metabolism can lead to an

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accumulation of lactate/lactic acid in the tissues. Changes in intra-cellular pH that would result from accumulation of carbonic and lactic acids can affect the functional properties of proteins, such as enzymes, and thus cell metabolism while changes in extra-cellular pH affect the function of respiratory proteins (Henry and Wheatly 1992; Wheatly and Henry 1992).

Acid-base regulation and lobster survival is greatly improved by chilling prior to pack-out (Morris and Oliver 1999a; Morris and Oliver 1999b; Speed et al. 2001). Chilling in sea water at 5-6°C for up to several hours reduces respiratory requirements and anaerobiosis (Morris and Oliver 1999a). Chilled lobsters are then packed into Styrofoam containers with wood wool and ice packs for the journey by road and air. Several holes are punched into the walls of the containers for ventilation.

Despite improvement in live export practices, there is an industry perception that lobsters from deeper water have higher mortality rates during transport. Lobsters inhabiting shallow (<60m) waters have a deep red coloured shell – a characteristic which demands premium prices in overseas markets. Lobsters captured from deeper waters (>60m) begin to exhibit a much paler, speckled shell colour that becomes progressively paler with depth (Chandrapavan et al. 2009a) and these lobsters are considered to be less robust than shallow water lobsters (Bryers and Geddes 2005).

Translocation of pale, deep-water lobsters to shallow water as described in previous sections would have limited benefit to industry if recaptured translocated rock lobsters were more likely to die during live export than resident shallow water lobsters. The present study aimed to assess the effect of translocation of lobsters from deep to shallow water on mortality rate and haemolymph pH during simulated live transport experiments compared to resident shallow and deep water lobsters.

## **Detailed Methods**

### *Live transport simulation*

#### *Source of lobsters*

##### South Australia

Lobsters of all sizes were caught in deep water (73-115m) off the coast of Southend, South Australia and translocated to Ringwood Reef (15m) in Rivoli Bay in January, 2007 using chartered commercial fishers. Biological data was recorded and each lobster was tagged with an individually numbered T bar tag (Hallmark, South Australia) in the first abdominal segment.

For live transport simulations, adult *J. edwardsii* (male and female) were obtained from commercial fishers during routine fishing operations and surveys of the translocation site on three occasions – November 2007, February and March 2008. Carapace length (CL) ranged from 97.3 to 153.0mm. Deep water (>100m), shallow

water (<15m) and recaptured translocated lobsters (<15m) were transported to a local processing facility in chilled vans as per routine fishing operations. Lobsters were measured, sexed and tagged around the base of the antennae to allow individual identification and maintained in a recirculation system at 11-12°C. Translocated lobsters had been in their new shallow water site for between 10 and 14 months and moulted at least once prior to recapture.

### Tasmania

Resident and translocated *J. edwardsii* (male and female) were obtained by IMAS staff during routine pot sampling operations in the Taroona reserve, Hobart in February 2009. Translocated lobsters were originally moved in October 2006 and 2007 from Maatsuyker Island (Figure 5-47), southwest of Hobart. CL ranged from 89.0 to 139.4mm. Deep water lobsters were purchased from a local processor and had been caught in waters (>80m) off Sandy Cape on the west coast of Tasmania. All lobsters were stored at the IMAS research centre in flow through tanks at 16°C.

In all trials, lobsters were allowed to recover from capture and transport to the storage facilities for 4 to 7 days prior to experimental procedures. Only intermoult (hard shell) lobsters were used in trials.

### *Acid-Base State*

A 1mL haemolymph sample was taken from each lobster by inserting a 23 gauge needle between the dorsal carapace and the first abdominal segment into the post-branchial cavity and dispensed into an Eppendorf tube. To prevent clotting, syringes (3mL Terumo) and Eppendorf tubes were chilled on ice. Each sample was measured immediately for pH with a TPS WP-80 pH meter and an Ionode IJ44 probe calibrated with pH 4 and pH 7 buffers prior to sampling.

Lobsters in processing facilities may be chronically stressed (Speed et al. 2001) so haemolymph pH of lobsters was measured at point of capture on board during routine commercial fishing operations to estimate baseline haemolymph pH.

### *Transport simulation*

Three simulated commercial transportation experiments were conducted at two processing facilities in the south-east of South Australia and one experiment at the IMAS research facility in Hobart, Tasmania.

Lobsters in trials 1 and 2 were not chilled prior to packing, which severely stresses the lobsters (Morris and Oliver 1999a) allowing for comparison of chilled and non-chilled treatments. Lobsters were packed into 20kg Styrofoam shipping containers along with wood wool to restrict movement (Figure 5-81). An ice pack and foam mat was placed on the bottom of the box and on top of the upper layer of lobsters. Boxes were left in

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ambient temperatures which ranged from 16 to 20°C for 30 h - the time it takes for shipments to reach Asian markets. In trials 3 and 4, lobsters were chilled prior to packing as per industry protocols at 5-6°C for a minimum of one hour prior to pack-out. Lobsters from the three treatments were packed randomly into the boxes. A group of control lobsters was used in trial 4 and sampled as per experimental lobsters but maintained in tanks to assess any effect from handling. At initial haemolymph pH sampling, lobsters were tagged around the base of the antenna to allow for individual identification then allowed to recover from handling overnight before packing.

a.



b.



**Figure 5-81** Packout of lobsters following commercial packing procedures, a) lobsters packed into wood shavings, b) sealed Styrofoam box ready for export.

**Table 5.25** Sampling procedure for transport simulation trials. \* indicates that his measure was taken for this method

| <b>Response measure</b> | <b>Initial</b> | <b>Post pack (30h)</b> | <b>Recovery 24h</b> | <b>Recovery 48h</b> |
|-------------------------|----------------|------------------------|---------------------|---------------------|
| Haemolymph pH           | *              | *                      | *                   | -                   |
| Condition Index         | -              | *                      | -                   | -                   |
| Mortality               | *              | *                      | *                   | *                   |

After 30 h of immersion haemolymph pH was measured and lobsters were placed into holding tanks and allowed to recover for 24 h. A further 1mL of haemolymph was taken from lobsters and pH measured after the 24 h recovery period. pH calibrations were carried out before each sampling occasion.

#### *Condition index*

Lobsters were given a behavioural condition index immediately upon opening the Styrofoam container (Table 5.25) similar to that used by Rettke and Musgrove (2006). Categories of the scale were: 0 = Dead, 1 = Barely alive (moribund, gills working, very slow movement in legs), 2 = Fair (Weak tail flap, movement in legs and antenna), 3 = Active (strong tail flap, lifting body, crawling around). In addition, mortality was recorded throughout the various stages of the experimental procedure.

#### *Statistical Analysis*

Results are expressed as mean values  $\pm$  SD. The residual plots were examined and the data satisfied assumptions of homogeneity of variance before analysis. Haemolymph pH and condition index for lobsters in transport simulations was analysed using one-way ANOVA to detect differences between group means. Significance level was taken at the probability level of  $\alpha < 0.05$ . Mortality rate was analysed using Fisher's exact test for contingency tables with significance level was taken at the probability level of  $\alpha < 0.05$ .

## **Results**

### *Transport simulation trials*

#### *Haemolymph acid-base state*

Haemolymph pH was not compared between trials as the experimental procedure between trials could not be replicated. Trials 1 and 2 were non-chilled and conducted at two different locations under different physical conditions. Trials 3 and 4 were chill treatments with one trial conducted in South Australia and the other in Tasmania. The

latter was necessary due to difficulty recapturing translocated lobsters in South Australia. Haemolymph pH for translocated lobsters in trial 2 was not used in statistical analyses due to the small sample size (n=2). Due to an oversight, recovery pH values were not taken for trial 1.

There was no significant difference in mean haemolymph pH between deep water, shallow water or translocated lobsters prior to conducting the four transport simulations (Table 5.26). Over the four trials, initial pH for shallow water lobsters ranged from 7.25 to 7.49. For deep and translocated lobsters it was 7.22 to 7.46 and 7.30 to 7.44 respectively.

**Table 5.26** pH values for chilled and non-chilled transport simulation trials prior and post pack-out and after 24 h recovery, and condition index score and percent mortality.

|                         | <i>Initial</i>   | <b>Mean pH ± SD (n)</b> |                 |                        | <b>Mean</b> | <b>% Mortality</b> |
|-------------------------|------------------|-------------------------|-----------------|------------------------|-------------|--------------------|
|                         |                  | <i>Post Pack-out</i>    | <i>Recovery</i> | <b>Condition index</b> |             |                    |
| <b>Trial 1 No chill</b> |                  |                         |                 |                        |             |                    |
| Translocated            | 7.32 ± 0.03 (14) | 6.98 ± 0.11 ^           | nr              | 2.96                   | 29          |                    |
| Shallow                 | 7.32 ± 0.05(14)  | 6.82 ± 0.14 a^          | nr              | 2.54a                  | 21          |                    |
| Deep                    | 7.31 ± 0.05 (14) | 7.04 ± 0.07 ^           | nr              | 2.88                   | 36          |                    |
| <b>Trial 2 No chill</b> |                  |                         |                 |                        |             |                    |
| Translocated*           | 7.30 ± .014 (2)  | 7.00 ± 0.22             | 7.43 ± 0.07     | 2.30                   | 0           |                    |
| Shallow                 | 7.25 ± 0.09 (12) | 6.84 ± 0.10 ^           | 7.13 ± 0.39     | 2.75                   | 25          |                    |
| Deep                    | 7.22 ± 0.06 (12) | 6.90 ± 0.13 ^           | 7.18 ± 0.48     | 2.88                   | 33          |                    |
| <b>Trial 3 Chilled</b>  |                  |                         |                 |                        |             |                    |
| Translocated            | 7.44 ± 0.02 (6)  | 7.20 ± 0.12 ^           | 7.49 ± 0.07     | 2.78                   | 0           |                    |
| Shallow                 | 7.49 ± 0.07 (6)  | 7.15 ± 0.15 ^           | 7.45 ± 0.03     | 2.88                   | 0           |                    |
| Deep                    | 7.40 ± 0.10 (6)  | 7.23± 0.09 ^            | 7.44 ± 0.04     | 2.55                   | 50          |                    |
| <b>Trial 4 Chilled</b>  |                  |                         |                 |                        |             |                    |
| Translocated            | 7.38 ± 0.12 (8)  | 7.07 ± 0.19 ^           | 7.46 ± 0.13     | 2.88                   | 0           |                    |
| Shallow                 | 7.43 ± 0.08 (8)  | 6.97 ± 0.12 ^           | 7.3 ± 0.30      | 2.85                   | 13          |                    |
| Deep                    | 7.37 ± 0.11(8)   | 6.98 ± 0.38 ^           | 7.17 ± 0.60     | 2.45                   | 38          |                    |
| <b>Trial 4 Control</b>  |                  |                         |                 |                        |             |                    |
| Translocated            | 7.33 ± 0.14 (9)  | 7.52 ± 0.12 ^           | 7.57 ± 0.04     | N/A                    | 0           |                    |
| Shallow                 | 7.39 ± 0.09 (8)  | 7.56 ± 0.10 ^           | 7.53 ± 0.14     | N/A                    | 0           |                    |
| Deep                    | 7.46 ± 0.09 (8)  | 7.58 ± 0.05 ^           | 7.59 ± 0.08     | N/A                    | 25          |                    |

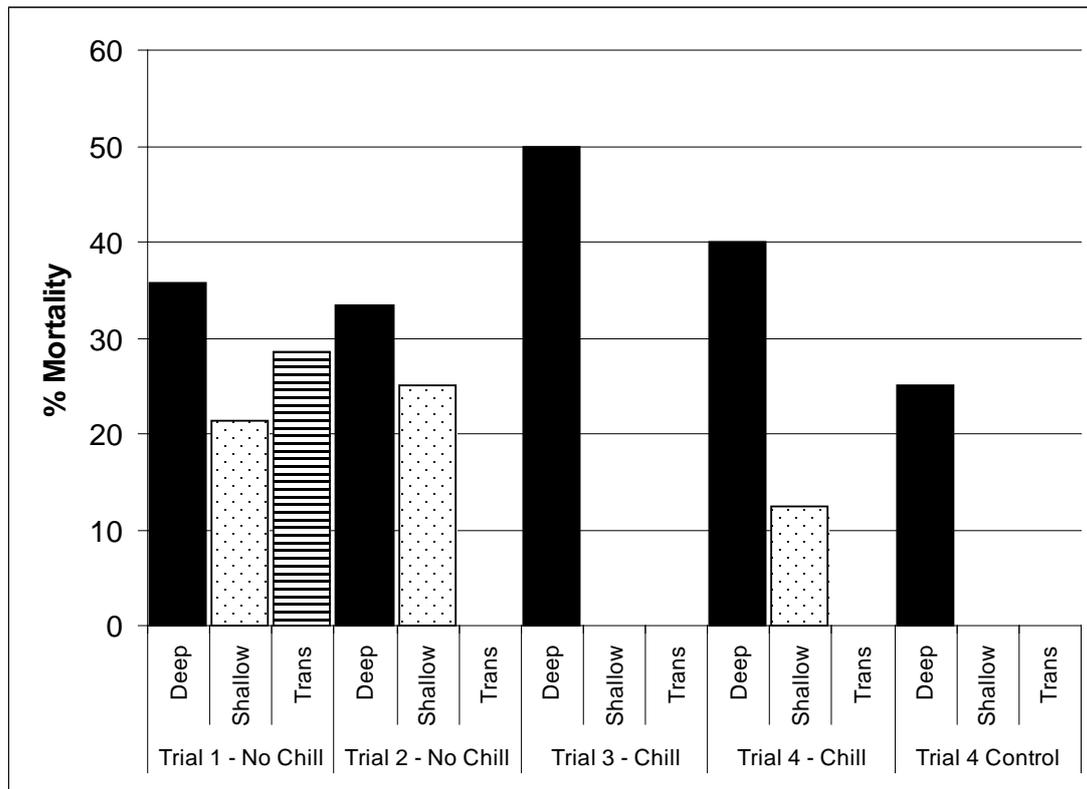
Mean lobster pH was significantly lower at the end of the 30 h transport simulation in all trials (Table 5.26) but recovered to pre-transport simulation levels 24 h after re-immersion. In all pack-out simulations shallow water lobsters recorded the largest drops in mean haemolymph pH although this was only statistically significant in Trial 1.

### *Mortality*

Mortality was higher in deep water lobsters for all of the experimental trials (Figure 5-82). Mortality of deep water lobsters was highest in the simulations which most closely matched commercial packing methods (Trials 3 and 4). Mortality was reduced in deep water lobsters after they had been translocated to shallow water for 10-14 months (Table 5.26 and Figure 5-82). When chill treatments were combined,

mortality in deep water lobsters was significantly higher (Fisher's exact test  $P < 0.05$ ) but there was no difference in combined non chilled treatments. When mortality was analysed across all trials combined, lobster mortality overall was significantly higher in deep water lobsters compared to shallow and translocated lobsters (Fisher's exact test  $P < 0.05$ )

For the non chill treatments, translocated lobsters in trial 2 were the only group not to register any mortality and deep water lobsters had the highest mortality rates with 36 and 33% for trials 1 and 2 respectively. Translocated lobsters had higher mortality than shallow water lobsters in trial 1 but zero mortality in trial 2 (Figure 5-82).



**Figure 5-82** Mortality rate for deep, shallow and translocated *J. edwardsii* used in live transport simulations with chill and no-chill pre-treatments.

Deep water lobsters had 50 and 38% mortality in chilled treatments which was higher than that recorded in non-chilled treatments. Zero mortality was recorded for translocated lobsters in both chilled trials while shallow water lobsters recorded zero and 13% for trials 3 and 4 respectively. Trial 4 control lobsters recorded zero mortality in translocated and shallow water lobsters but had 25% mortality in deep water lobsters. Only one lobster died during the pack-out phase of the trial – a deep water lobster in trial 4. All other mortality occurred post pack-out after lobsters were placed into recovery tanks.

#### *Condition Index*

Lobsters were given a condition index score when removed from the pack-out boxes (Table 5.26). In trial 1, shallow water lobsters had a significantly lower condition index than translocated and deep lobsters. In all other trials there was no significant difference between translocated, shallow or deep water lobster condition index scores.

Mean condition index scores for translocated, shallow and deep water lobsters in all trials was plotted against per cent mortality for each treatment and subject to linear regression analysis. There was no correlation between condition index score and mortality ( $r^2 = 0.0002$ )

## **Discussion**

This study demonstrated that deep water lobsters were more susceptible to stress conditions associated with live transported for export and that translocation of deep water *J. edwardsii* into shallow inshore reefs improved survival through live transport simulations.

#### *Acid-base state, mortality and condition index during transport simulation*

Haemolymph pH, mortality and condition index of translocated, shallow and deep water *J. edwardsii* were measured before, during and after simulated live transport. Shallow water and translocated lobsters had lower mortality rates than deep water lobsters, and translocation may improve a lobster's response to stressors such as immersion and fitness for live export.

There is a clear, well-documented effect of immersion on haemolymph pH as a measure of acid-base regulation and increase in carbon dioxide loading during live shipment of crustaceans (Paterson et al. 1997; Spanoghe and Bourne 1997; Morris and Oliver 1999a; Morris and Oliver 1999b; Haupt et al. 2006; Rettke and Musgrove 2006; Lorenzon et al. 2007). Although some work has been done on manipulating diet during live-holding of deep water lobsters (Bryers and Geddes 2005), depth of capture has never been analysed as a factor that may affect lobster health during live transport. This experiment was aimed at addressing the industry perception, noted by Bryers and Geddes (2005), that deep water lobsters have a higher mortality rate than those from shallow water and to investigate if lobster condition can be improved by translocation. Not chilling lobsters prior to pack-out was designed to exacerbate the effects of immersion.

The decline in lobster haemolymph in all trials is similar to previous work on *J. edwardsii* (Morris and Oliver 1999b; Rettke and Musgrove 2006), and other crustaceans such as *Homarus americanus* (Lorenzon et al. 2007), *J. lalandii* (Haupt et al. 2006), the spider crab *Maia squinado* (Durand et al. 2000) and *Penaeus japonicus* (Chen and Chen 1998). Shallow

water lobsters had the largest mean decrease in haemolymph pH, although this was only statistically significant in trial 1. As pH haemolymph is a measure of increased acidity from increased CO<sub>2</sub> loading, this difference suggests that CO<sub>2</sub> was produced at a greater rate in shallow water lobsters compared to deep water lobsters. Metabolism declines with depth in decapod crustaceans (Childress et al. 1990a) due to changes in temperature and light regimes which might explain smaller pH decreases in deep water lobsters. This may indicate that gill structure and function of shallow water lobsters is different to that of deep water lobsters which could have an effect on acid-base regulation.

After 24 h reimmersion, haemolymph pH had returned to corresponding initial values which was also reported for the spider crab, *M. squinado* (Durand et al. 2000) and *H. americanus* (Lorenzon et al. 2007). Of the mortalities, all but one lobster died in recovery, some after haemolymph pH had returned to initial values. The gill is ventilated primarily to supply O<sub>2</sub>, not remove CO<sub>2</sub> with the underlying reason for this being that the solubility of O<sub>2</sub> in water is only about one-thirtieth that for CO<sub>2</sub> (Henry and Wheatly 1992). Damage to the respiratory surface of the gill would reduce O<sub>2</sub> uptake causing the haemolymph to become progressively hypoxic, but CO<sub>2</sub> diffusion would still have occurred due to its much higher solubility, hence a return to initial haemolymph pH values. As the haemolymph became more hypoxic, the lobster would become gradually weaker and possibly die which was observed in animals after reimmersion during recovery.

Deep water lobsters had the highest mortality rate in all trials. This supports the widely held industry perception that deep water lobsters are 'weaker' than those from shallow water and have a higher mortality rate during live export. If mortality of deep water, pale coloured lobsters in South Australia is estimated at 5% and approximately 15% of the season's catch came from depths greater than 60m (Linnane et al. 2008a) the losses through mortality could be as high as \$690,000 a season based on Australian fishery statistics for 2008 (Pham and Peat 2009). Market and economic forces have led to a concentration of fishing effort in waters less than 60m (Linnane and Crosthwaite 2009b) but if this trend was to change, the economic losses due to mortality of deep water lobsters could be far higher, impacting on the profitability of local fishers and processors and affecting local economies. Not to mention the wastage of high quality, valuable seafood product.

Mortality in pre-chilled lobsters was lower for translocated and shallow water lobsters than in lobsters not chilled prior to pack-out. Mortality for deep water lobsters was higher in chilled treatments which was most unexpected but may indicate a physiological difference between deep and shallow water lobsters. Morris and Oliver (1999a) reported chilling reduced the physiological impact of immersion for *J. edwardsii*, which was the case for shallow water and translocated individuals but not for deep water lobsters. It was not reported by Morris and Oliver (1999a) from what depth the lobsters used in their experiments were taken. It is possible that optimal chilling temperatures may vary for lobsters from different depths.

A recent study demonstrated that translocated lobsters can improve nutritional condition and quality, surpassing that of shallow water lobsters (Chandrapavan et al. 2009d). In this study, translocated lobsters had similar mortality rates to shallow water lobsters, and in some trials

lower rates, but both had significantly lower mortality rates compared to deep water lobsters when all mortality data was combined. This is evidence that physiological differences exist between shallow and deep water lobsters and that physiological responses of deep water lobsters to stressors associated with live transport can be improved by translocation. Translocated lobsters in this study had been in shallow water for 10-15 and 16-28 months in South Australia and Tasmania, respectively. For translocated lobsters, this was enough time (at least one moult) for a change in physiological condition that resulted in significantly reduced mortality rates during live transport compared to that of lobsters from the deep water environment from which they originated. Translocated lobster condition improved to match the strong survival rate of shallow water lobsters.

Condition index scores and haemolymph pH values of *J. edwardsii* did not appear to be good long term predictors for lobster health as they showed no relationship to transport mortality. Apart from shallow water lobsters in trial 1, there was no significant difference in the CI score or haemolymph pH between treatments within the trials. Only one lobster died during the pack-out phase with the rest dying during recovery - some after haemolymph pH had returned to initial pre pack-out levels. Mortality was also observed in *M. squinado* (Durand et al. 2000) 24 h after reimmersion when recovery of haemolymph ammonia, urate and glucose was achieved. Rettke and Musgrove (2006) also reported that mortality in *J. edwardsii* began after lobsters were placed back in holding tanks following simulated live transport. Clearly, when reimmersed, haemolymph biochemistry has the ability to recover to pre-immersion levels which suggests that definitive physiological damages were suffered. And furthermore, that condition index, based on lobster vitality, and pH at unpacking are probably not useful indicators of lobster stress and/or predictors of fate.

Deep water lobsters incurred higher mortality rates than shallow water and translocated lobsters. The low mortality of translocated lobsters, especially compared to deep water lobsters, is evidence of improved capacity to cope with stressors associated with live transport. Deep water lobster mortality was significantly higher than shallow and translocated lobsters when all data was combined and also in combined chill treatments. The slightly lower mortality rate of translocated lobsters compared to shallow water lobsters could be due to translocated lobsters surpassing the condition of shallow water lobsters (Chandrapavan et al. 2009d) through compensatory growth where condition and energy reserves are rapidly improved after a period of low food availability (Ali et al. 2003b).

Mortality in deep water lobsters may be reduced if given a longer recovery time at the processor after unloading from the fishing vessel. Bryers and Geddes (2005) reported low mortality in deep water *J. edwardsii* used in diet studies in two 30 week trials where lobsters were held in sea cage experiments. The low mortality rates during this experiment may indicate that deep water lobsters need more time to recover after capture. Live export immediately or soon after arrival at a processor may not be optimal. Holding deep water lobsters longer in processing plants with some nutritional supplement may allow the lobster time to make physiological adjustments to changes in pressure gradients, temperature, light and other stressors such as capture and handling prior to live export.

An alternate method to investigate if there is a physiological difference between deep and shallow water lobsters may be to investigate total haemocyte counts. The role of haemocytes in decapods includes defence against foreign material, haemolymph coagulation, phagocytosis and wound healing (Hose et al. 1990; Jussila et al. 1997; Athanassopoulou et al. 2004). Moribund *Panulirus cygnus* had lower total haemocyte counts than healthy and fresh arrival lobsters but there was also a difference between white (sexually maturing) and red (immature) lobsters (Jussila et al. 1997) that may have indicated a biological difference. Although there may be an industry held perception in the *J. edwardsii* fishery that deep water lobsters are 'weaker' than shallow lobsters, a biological difference might be identifiable by closer inspection of haemolymph and tissue biochemistry, immunology and histopathology.

In this study there was enough evidence to suggest that lobster physiology varied with depth and could be altered by translocation. Translocated and shallow water lobsters had a significantly lower mortality rate than deep water lobsters during live transport simulations but the reasons for improvements in physiological condition to cope better with the stress of immersion during live export were unclear. The physiological change associated with depth and the changes that occur with translocation are areas that require more work as it could be beneficial to a fishery that relies on live export.

#### 5.6.4 Translocation in Victoria

Victoria initially planned a large scale translocation similar to South Australia and Tasmania. However catch rates in Victoria declined significantly in 2007 and the fishing industry no longer felt they had enough lobsters available to participate in translocation. Here are the results of the preliminary Victorian translocation.

There was one translocation of deepwater lobsters to inshore grounds in Victoria, which occurred in May 2007. 131 lobsters were released in 18 metres of water off Portland. There were a total of 15 recaptures, giving a recapture rate of 10% (Table 5-27). All lobsters were caught within a few hundred metres of point of inshore release, had grown from between 5 and 11 mm in carapace length (CL) and in all but one instance had shown a darkening of carapace colour.

**Table 5.27** Showing growth and colour change in recaptured lobsters, translocated from offshore to an inshore site near Portland, Victoria.

| Tag   | Release date | Capture date | Days at liberty | Sex | Release length (CL,mm) | Capture length (CL,mm) | Growth (CL,mm) | Release colour | Capture colour |
|-------|--------------|--------------|-----------------|-----|------------------------|------------------------|----------------|----------------|----------------|
| 68002 | 17/05/07     | 22/11/07     | 189             | M   | 106                    | 116.6                  | 10.6           | Speckled       | R              |
| 68013 | 17/05/07     | 10/01/08     | 238             | M   | 109                    | 117.4                  | 8.4            | White          | R              |
| 68030 | 17/05/07     | 27/11/07     | 194             | M   | 108                    | 117                    | 9              | Red            | R              |
| 68038 | 17/05/07     | 03/12/07     | 200             | M   | 109                    | 115                    | 6              | W              | R              |
| 68054 | 17/05/07     | 27/11/07     | 194             | M   | 98                     | 104.5                  | 6.5            | S              | R              |
| 68065 | 17/05/07     | 20/11/07     | 187             | M   | 109                    | 116                    | 7              | S              | na             |
| 68073 | 17/05/07     | 22/11/07     | 189             | M   | 101                    | 112                    | 11             | W              | R              |
| 68090 | 17/05/07     | 27/11/07     | 194             | M   | 104                    | 113                    | 9              | R              | R              |
| 68095 | 17/05/07     | 13/02/08     | 272             | F   | 101                    | 98?                    | -3?            | W              | S              |
| 68102 | 17/05/07     | 07/12/07     | 204             | F   | 99                     | 105.9                  | 6.9            | S              | R              |
| 68118 | 17/05/07     | 23/01/08     | 251             | M   | 109                    | 114                    | 5              | W              | R              |
| 68120 | 17/05/07     | 27/11/07     | 194             | M   | 106                    | 113                    | 7              | W              | R              |
| 68121 | 17/05/07     | 28/11/07     | 195             | M   | 108                    | 116                    | 8              | S              | R              |
| 68126 | 17/05/07     | 29/08/07     | 104             | M   | 109                    | 115.2                  | 6.2            | S              | S              |
| 68128 | 17/05/07     | 27/11/07     | 194             | M   | 100                    | 109                    | 9              | W              | R              |

### 5.6.5 Well mortality during research trials

#### Summary of well mortality

Well mortalities occurred during transportation of lobsters from deep water lobsters to shallow water (Table 5.28) due to poor tank design. There was one large mortality event (trip 3, Table 5.28) where 13% of translocated lobsters died in transit. On trip 7 from Maatsuyker Island in Tasmania south to the two most northerly sites Gull Island and Georges Rocks, 194 lobsters died in the wells out of a total of 3325 transported for translocation (5% mortality, Table 5.28). Most trips had minimal or no well mortality.

**Table 5.28** Rock lobster captures and transport trips for the IMAS translocation project since 2006.

| Trip no. | START_DATE | END_DATE   | Dead | Moved | Translocated |
|----------|------------|------------|------|-------|--------------|
| 1        | 8/02/2006  | 10/02/2006 |      | 749   |              |
| 2        | 16/10/2006 | 2/11/2006  | 5    | 18    | 5539         |
| 3        | 4/12/2006  | 11/12/2006 | 409  | 4     | 3036         |
| 4        | 13/07/2006 | 23/07/2006 |      |       |              |
| 5        | 14/10/2007 | 19/10/2007 | 6    | 12    | 2080         |
| 6        | 22/10/2007 | 26/10/2007 |      | 10    | 3131         |
| 7        | 28/10/2007 | 2/11/2007  | 194  |       | 3325         |
| 8        | 26/11/2007 | 30/11/2007 | 14   | 5     | 1349         |
| 9        | 3/12/2007  | 10/12/2007 | 79   | 40    | 1961         |

#### Causes of well mortality

The mass well mortalities recorded were primarily due to poor circulation within the tanks and unsuitable well design, created by the multi-purpose nature of the research vessel used for the experimental translocations. A further problem was that wells or tanks on lobster fishing boats are designed for the transport of legal sized lobsters, with planking on the sides with small gaps between planks. This allows legal sized lobsters to hold on, but reportedly can allow undersized lobsters to exit the wells into the space between the well and the hull.

#### Avoiding well mortality

Research translocations resulted in some well mortality, consequently, we recommend that:

1. Only vessels with wells used for best practice transport of lobsters are considered.
2. The industry committee involved in vessel charters will be experienced in well design and this experience should be utilised in the selection of the successful tender.
3. Small meshed nets be used within the live wells when undersize lobsters are being transported. All translocated lobsters should be contained within these small meshed nets within the live wells.

### 5.6.6 Bioeconomic model based evaluation of translocation

#### Summary

A length- and sex- based spatial bioeconomic model of the Tasmanian rock lobster fishery was used to examine the effects of translocation. Change in stocks in response to translocation were assessed in comparison to the change in TACC that would be required to produce the same effect. The scenario examined was based on the scale of operations proposed by industry for initial operations, which was 100,000 lobsters moved per year with movements either directly inshore or with a slight northward component. When combined with TAC management, this scale of operation appears to increase most performance measures on a similar scale as would be achieved by a reduction in TACC of 10 kg per unit. This conclusion held broadly across total biomass, legal sized biomass, biomass of large lobsters (>145 mm CL), catch rates and egg production.

Gains occurred in regions on the east coast although translocation operations were restricted to the west coast. This was through the effect of the limiting TAC forcing effort to the west if the fleet was to respond to the higher stock abundance in that area. This process was helpful from a management perspective with egg production expected to increase in the depleted northern areas, and biomass of large, urchin-predating lobsters increasing along the east coast. This is of management interest in dealing with *Centrostephanus* urchin barrens with gains equivalent to a TACC reduction of 15 kg per unit.

Economic outcomes were summarised by the discounted cash flow method, which is widely used in valuing share or business value. Market capitalisation of quota units was currently estimated at \$210 million (10507 units @ \$20,000). Ongoing translocations would be expected to increase catch rates so that costs would decline for the same revenue. The discounted cash flow effect of this change was estimated at \$47.4 million (\$4,515 per unit).

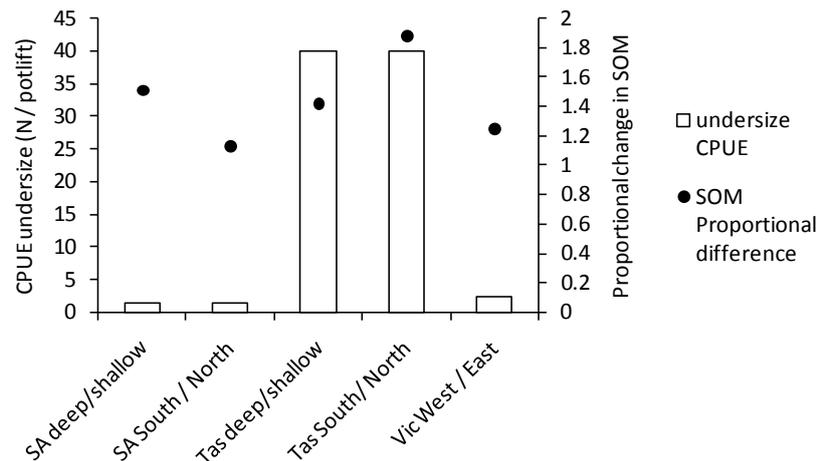
## **Introduction**

The economic feasibility of translocation is a cost-benefit problem where the benefits such as increased catch, higher price or lower cost (through higher catch rate) need to exceed costs of translocation, plus opportunity costs including foregone yield at the removal site. This approach was taken to assess feasibility of translocations of *Jasus edwardsii* by Gardner and van Putten (2008a, b) utilising a length-based bioeconomic model. Translocation was examined with scenarios involving movements from different slow growth areas to higher growth areas around the state of Tasmania in Australia. Two different methods of translocation were examined, which affected both costs and benefits of the operation. The low cost system involved the capture of undersize lobsters from slow growth areas through normal fishing operations with these undersize lobsters then moved inshore. This approach had very little marginal cost because fuel, labour and other costs were already sunk in harvesting operations. In the second approach, vessels could be chartered and funded to fish exclusively for the purpose of collecting animals for translocation. Both options appeared economically feasible but the higher cost, chartered option was favoured both in the analysis by Gardner and van Putten (2008b) and also subsequently by the commercial industry. This was because chartering provided greater control over the scale and location of removals.

A general lesson from that early work on the feasibility of lobster translocations was that translocation of lobsters can have large economic benefits with internal rate of return exceeding 400% in some scenarios examined by Gardner and Van Putten (2008b). Some of the biological traits of lobsters contributed to this outcome including their ability to be captured and released with low discard mortality, the low rates of movement of *J. edwardsii* in this region, and spatial heterogeneity in growth and recruitment. Not all of the translocation scenarios examined were economically feasible as movements over short

distance sometimes led to trivial gains in growth that were outweighed by the costs of translocation.

Lorenzen (2005) examined the economic feasibility of flatfish as a generalised case of the feasibility and pitfalls of enhancement. His conclusions included that the costs of released animals strongly influence optimal policy, so that high levels of stocking and fishing effort are only feasible where cost of release is low, relative to gains in yield. In the case of lobster translocation, this situation only occurs where both catch rates at the removal site are exceptionally high and also where there is large variation in growth rate over short distances (Figure 5-83).



**Figure 5-83.** Regional comparison in the opportunity for translocation. Tasmania appears to have greater opportunity than other jurisdictions because of the combination of large regional differences in growth (as indicated by size at onset of maturity (SOM) and also populations of undersize with high catch rates.

Opportunities for rock lobster translocation occur where there is both large spatial variation in growth (so that productivity benefits are large) and an abundance of undersize lobsters (so that costs of capture are low). Translocations appear more feasible in the Tasmanian *Jasus edwardsii* fishery than in South Australia or Victoria because there is greater capacity to catch large numbers of undersize lobsters at lower marginal cost. In addition, there is large spatial difference in growth, indicated here by the proportional difference in size at onset of maturity (SOM) between either deep or shallow water sites or along the coast (Gardner et al. 2006a; Gardner and van Putten, 2008a; Hobday and Ryan 1997; Linnane et al. 2008b; Linnane et al., 2008, 2009, 2010).

The earlier work by Gardner and van Putten (2008a) is extended here with a more extensive population model as described in Section 5.2. This extension allowed impacts to be assessed in terms of regional changes in biomass and the interactions between translocation and broader management objectives such as rebuilding of lobster stocks of eastern Tasmania.

### Specification of translocation population dynamics

The dynamics of translocated animals generally follow those of non-translocated animals described in Section 5.2 (for example translocated animals contribute to spawning and can be caught during fishing). Translocated animals are selected at random (within a pre-specified range of size-classes) from the sub-zone in they were taken and become indistinguishable from the animals in the sub-zone to which they are translocated after a pre-specified time.

Between translocation and being indistinguishable from other animals, the biological parameters for translocated animals may differ from those for the animals in the sub-zones from which they were taken and to which they were relocated. The following options were available.

- Natural mortality for a translocated animal can exceed the nominal rate before the animal becomes indistinguishable (Section 5.5.1)
- The animal may not produce eggs (even if they are mature) for a pre-specified time after being located (Section 5.5.3).
- Egg production as a function of length can change smoothly between that for the sub-zone from which the animal was taken and that to which it was relocated (Section 5.5.3):

$$Q_l = (\chi^{\text{mat}})^t Q_l^{\text{From}} + (1 - \chi^{\text{mat}})^t Q_l^{\text{To}}$$

where  $Q_l^{\text{From/To}}$  is egg production for animals in size-class  $l$  in the sub-zone from which the animal from taken (From) and to which it has been relocated (To),

$t$  is the time since the relocation occurred, and

$\chi^{\text{mat}}$  is a parameter which determines how quickly egg production changes from the original to the new sub-zone.

- Growth as a function of length can change smoothly between that for the sub-zone from which the animal was taken and that to which it was relocated (Section 7.5.4):

$$\mathbf{X}_i^s = (\chi^{\text{grow}})^t \mathbf{X}_i^{s,\text{From}} + (1 - \chi^{\text{grow}})^t \mathbf{X}_i^{s,\text{To}}$$

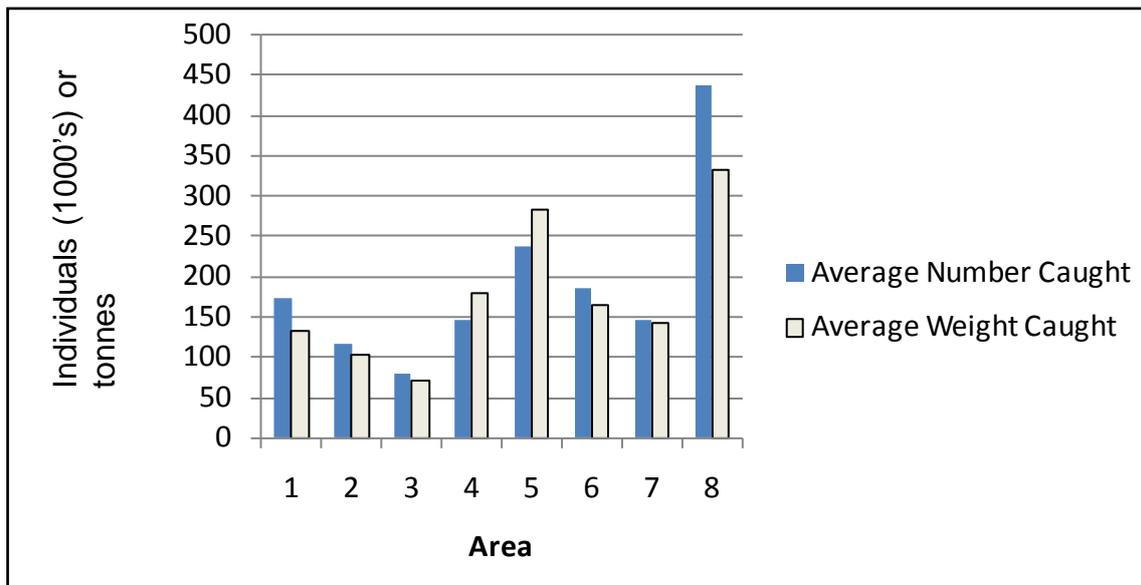
where  $X_i^{s,\text{From/To}}$  is the size-transition matrix for animals of sex  $s$  during time-step  $t$  in the sub-zone from which the animal from taken (From) and to which it has been relocated (To), and

$\chi^{\text{grow}}$  is a parameter which determines how quickly egg production changes from the original to the new sub-zone.

## Source stocks

The west coast dominates lobster production with an average split over the last decade between west and east coasts of roughly 65%: 35%. Of west coast areas, Area 8 in the south west has been by far the most important contributor to the fishery averaging around 25% of the state production over the last decade by weight (Figure 5-84).

The number of lobsters harvested each year from the west coast areas 6, 7 and 8 averaged 772,000 over the last decade.



**Figure 5-84.** The average number and weight of lobsters harvested from each of the 8 assessment areas over the last decade.

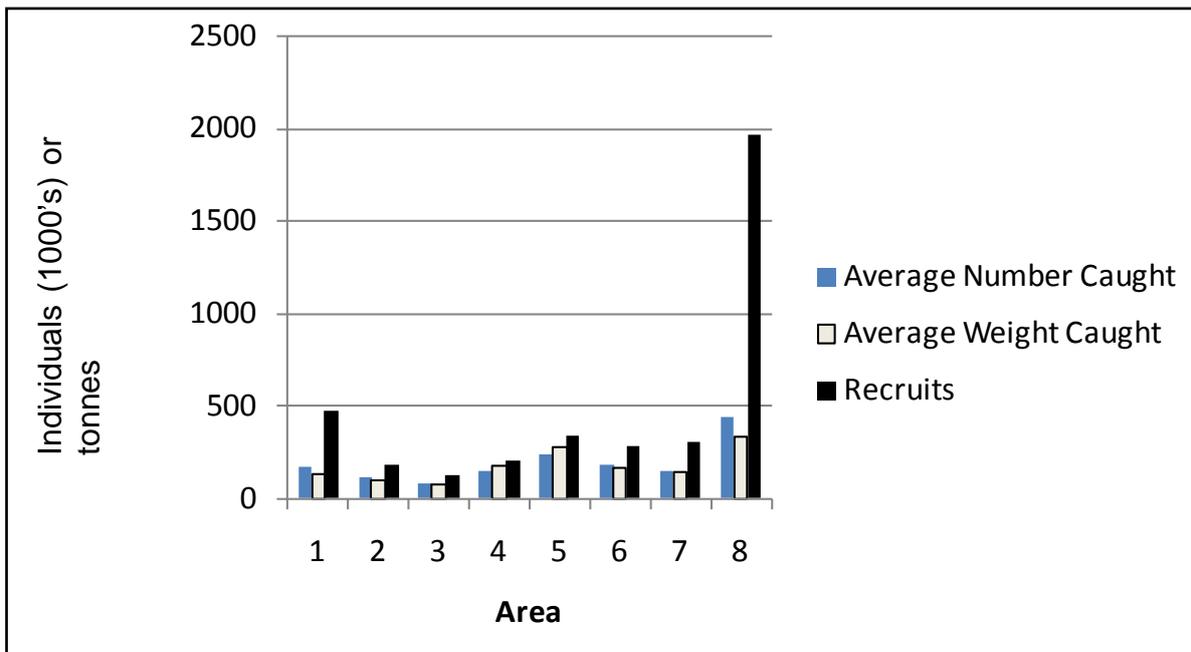
Many stakeholders viewed the shifting of 100,000 lobsters between areas as a large portion of the stock given that the total catch averages 772,000 lobsters. However, the animals being moved are undersize and not all of these lobsters reach legal size or contribute to the harvest.

Figure 5-85 below repeats the average catch number and catch weight data shown above, but in addition the average number of lobster recruiting to the 60-65 mm size category are also shown. There are some obvious but important points here. One is that the south west (area 8) has far higher recruitment than other areas of the state. Around 50% of the state's recruitment of juvenile lobsters occurs in this region. This area is known to be the beneficiary of lobster larvae that originate from eggs produced to the west, especially the southern zone of South Australia.

Another important observation here is that the number of recruits does not lead to an equal proportion of lobsters being harvested. Very few 60-65mm lobsters from area 8 grow to legal size and contribute to the catch (average of 22%). Of those that do reach legal size, their average weight is lower than anywhere else in the fishery at an average of only 757 g for the last decade.

At the other extreme, most small 60-65 mm lobsters from Area 4 in the north east grow to legal size and contribute to the fishery (average of 72%). These lobsters are 60% larger by weight at harvest with an average weight of 1227 g.

Why are the patterns so different between areas 4 and 8? The reason is that lobsters in the south west grow far slower on average so natural mortality severely erodes the number of lobsters in cohorts before they reach legal size. This point is critical – there are a massive number of juvenile lobsters recruiting into the south west each year which don't contribute to the fishery. These could benefit the fishery with a change in management.



**Figure 5-85.** The average number and weight of lobsters harvested from each of the 8 assessment areas over the last decade. In addition, the average number of lobsters recruiting into the 60-65 mm size category per year is shown (this size class is used because it's the first size class that is captured to any extent in traps).

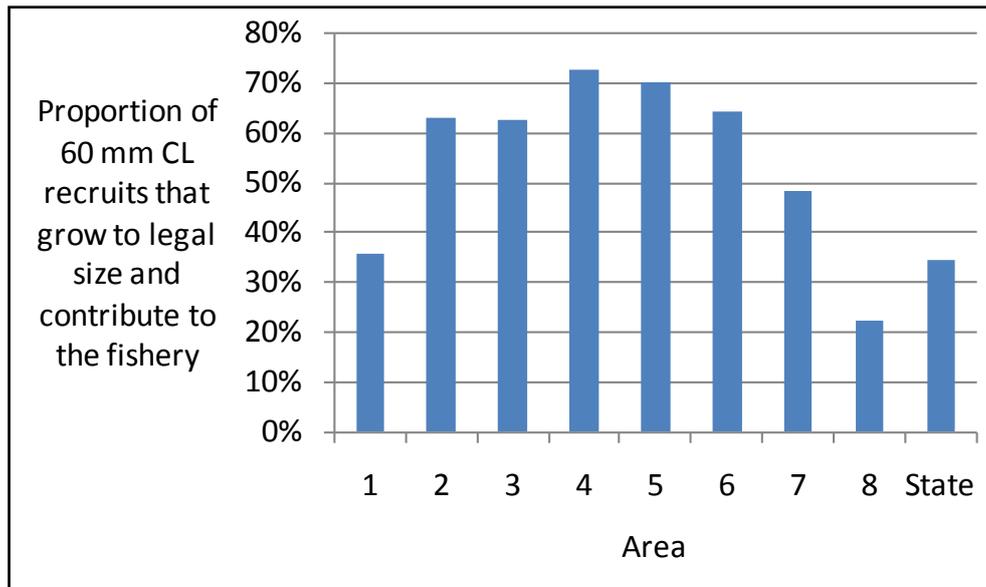
Lobster translocations from area 8 into area 4 were not considered by industry or government, but to illustrate the concept and need for a change in our approach to the fishery:

- An estimated average 1.97 million lobsters have recruited to the 60-65 size class in Area 8 for each year for the last decade.
- Over the last decade an average of only 22% of these reached legal size and were caught in Area 8. If this proportion was changed to 72% as per area 4 in north east, then 988,000 extra lobsters could be harvested with the same catch rate.
- If the extra catch were taken at the same average weight as in Area 4, then this extra catch would equal 1,213 tonnes per annum.

This example relies on a change in management that would cause an average lobster from area 8 to grow at the same rate as an average lobster from area 4. The only method at our disposal to change growth rates of lobsters is translocation.

Additional figures summarising the scale of the lost opportunity through our current management of lobsters in slow growing areas are shown below. These illustrate why the movement of 100,000 undersize lobsters from slow growth areas does not mean that fishers in deep water areas will have access to 100,000 fewer lobsters each year. This is because most undersize in slow growth areas do not reach legal size.

The values shown in figures are average rates across the whole assessment zone. Translocation removal sites to be used by industry are to be locations where growth is below average for the zone so that the effect of removing undersize on later catches is overstated here.

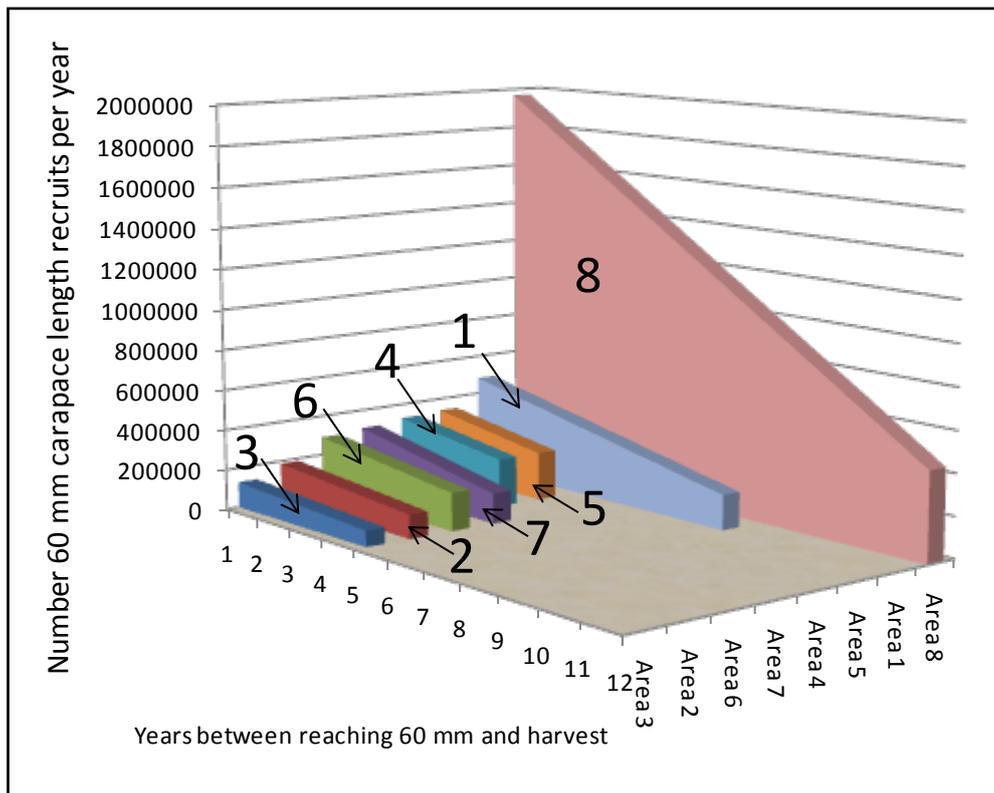


**Figure 5-86.** The average proportion of 60 mm lobsters that grow to legal size and are harvested by the fishery. Most of the recruits in slow growing areas like Area 8 never contribute to the fishery with an average rate of only 22%. The benefit to the fishery from each recruit is around 3 times higher in most of the fishery.

### Bioeconomic projections

The expected average outcomes from translocation are shown in the following series of figures. These projections were based on the following:

- 100,000 lobsters translocated per year in ongoing operations
- translocations move undersize lobsters from deep water sites in areas 6, 7 and 8 at a ratio of 4:1:8 respectively. This means: 30,770 lobsters from area 6; 7,690 lobsters from area 7; and 61,540 lobsters from area 8 (Figure 5-88).
- moves to one area north as well as simply inshore were considered. To be clear – the northward movement options were a single area to the north, so from area 8 to area 7, area 7 to area 6, and area 6 to area 5.
- growth of translocated lobsters was greater than locals for the first year by 4 mm as per observations from earlier trials. Thereafter growth was the same as locals.
- There was assumed to be 5% mortality caused by capturing, moving and releasing lobsters. This is higher than was observed in field trials.
- The location of fishing effort by the fleet was modelled on past patterns. These are a combination of fishers moving to better catch rates elsewhere, however there is also an element of fishers operating in the same location regardless.

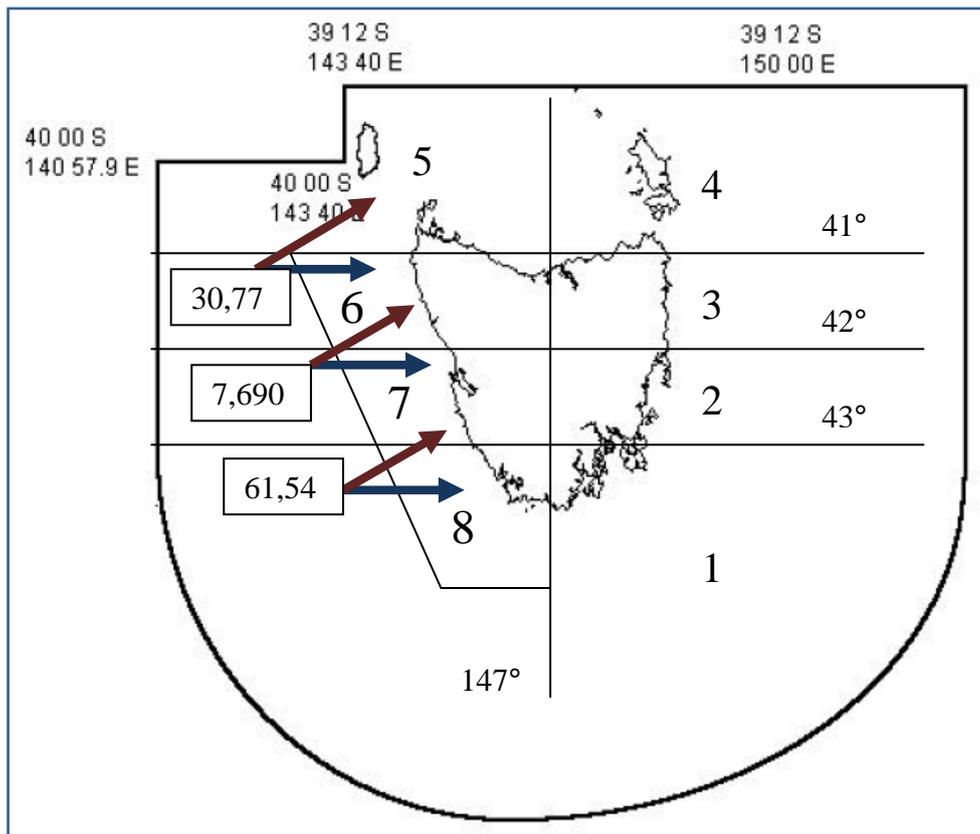


**Figure 5-87.** The scale of the variation in contribution of recruits to the fishery in different areas. Each wedge represents a different area of the fishery numbered by assessment area. The height of the wedge at the left is the average number of 60 mm carapace length lobsters recruiting each year over the last decade. The height of the wedge at the right is the number harvested. In area 8 the growth is slow so lobsters spend many years below the legal size, most recruits are lost through natural mortality, and the final harvest is modest despite the very high number of recruits to this region.

Impacts were assessed by asking the question- what change in the TACC would be required to produce the same effect as translocation? So how effective would translocation be at avoiding cuts in the TACC if there was a period of low recruitment? Or how much could translocation increase the TACC if stocks were stable?

The effect of translocations inshore on legal sized biomass appears to be roughly equivalent to change of 5 kg per quota unit while translocations northward are roughly equivalent to a change in quota of a little more than 10 kg per unit (Figure 5-92).

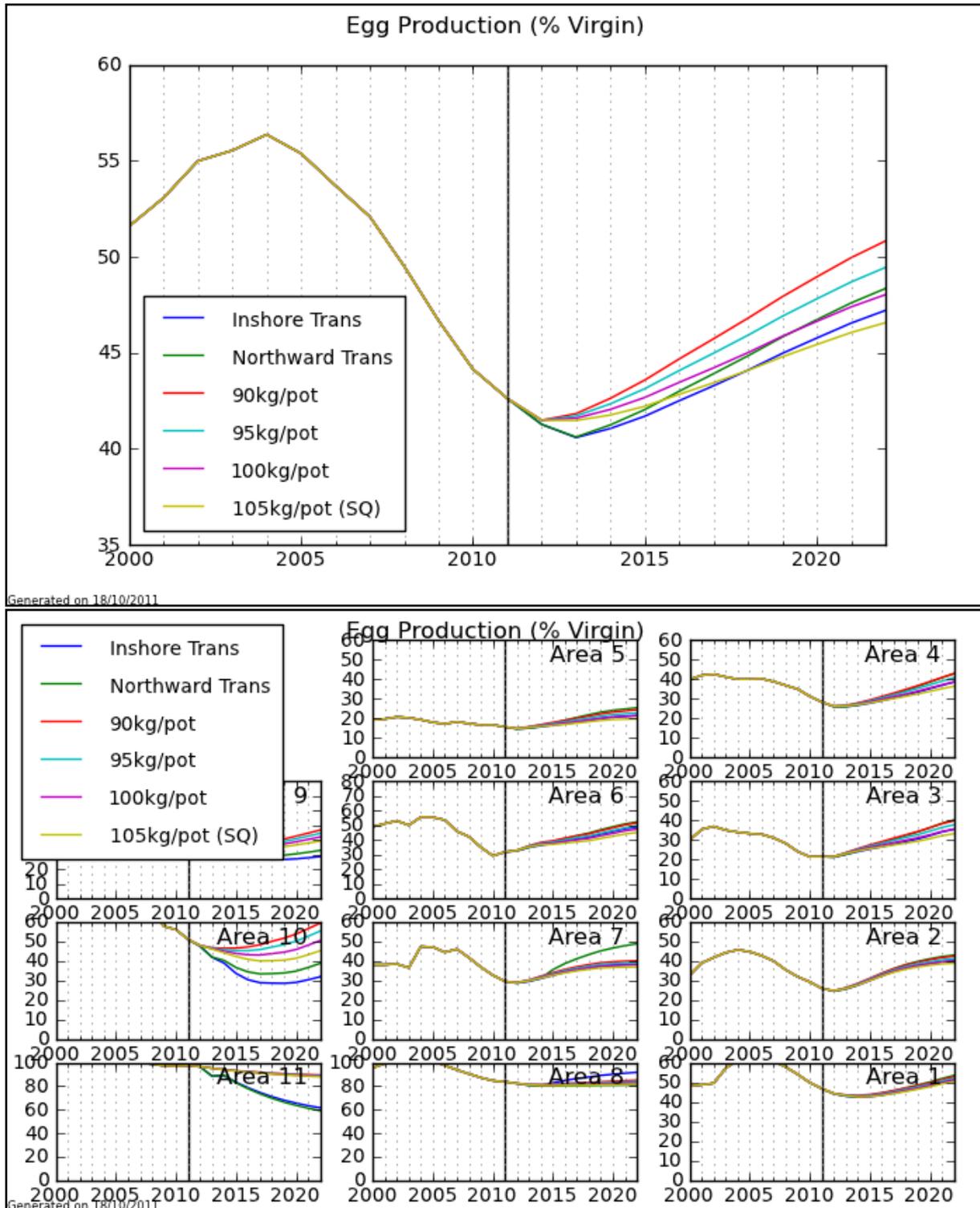
The scale of the effect of translocation on catch rate and legal sized biomass appeared to differ (Figure 5-92 and Figure 5-93), which is because the model assumes that a portion of the fleet will continue to fish in the same location regardless of whether there are higher catch rates available in other locations. This is one aspect of the model that has not been possible to test experimentally – that is, we have no data on how the fleet will move to locations that have been enhanced. If this occurs then catch rate trajectories would be expected to be higher than those shown for translocation scenarios in Figure 5-93.



**Figure 5-88.** The two alternate options for translocation. Either movement inshore or movement one area to the north. Number next to arrows are the approximate number of lobsters to be moved in each area.

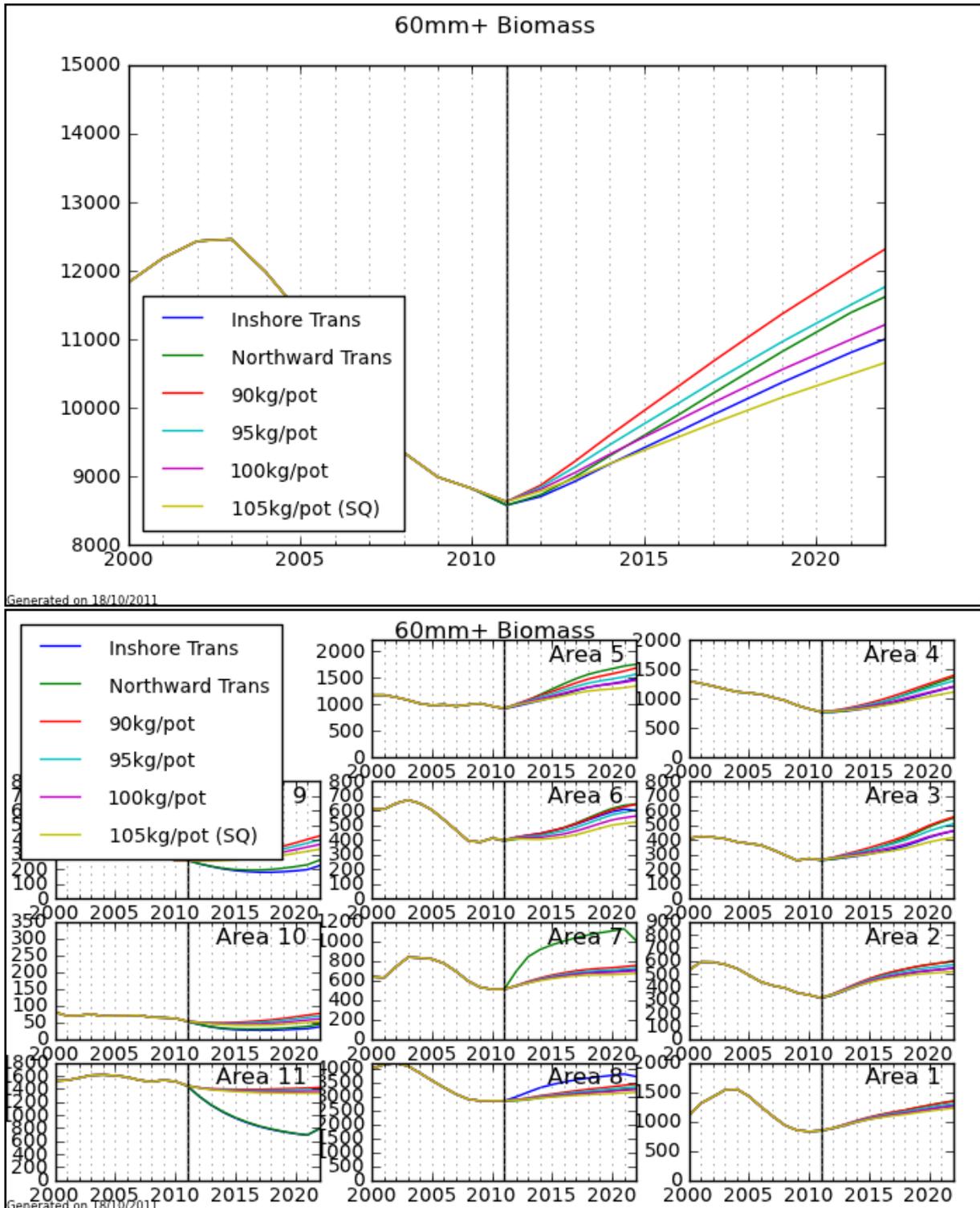
The effect of translocation on egg production was complex with many different factors to consider: (i) females growing larger so being exposed to fishing at an earlier age; (ii) more eggs for each year of spawning as females are a larger size; (iii) some translocated females skipping egg production in the first year; (iv) reduced fishing pressure on the entire stock as production increases through faster growth. The combined effect of these factors was that translocation modestly improves egg production, despite accounting for the observed temporary stress response in some animals for the first 12 months. Importantly, egg production was increased in the northern areas which are main areas of concern for management (Figure 5-89).

Ecosystem measures also improved in translocation scenarios with improvement in both total biomass and large lobster biomass. The outcome that translocation of lobsters off western Tasmania increases legal size biomass and catch rates off the east coast is of special interest to the issue of *centrostephanus* barrens with gains equivalent to a TACC reduction of 15 kg per unit (Figure 5-91).

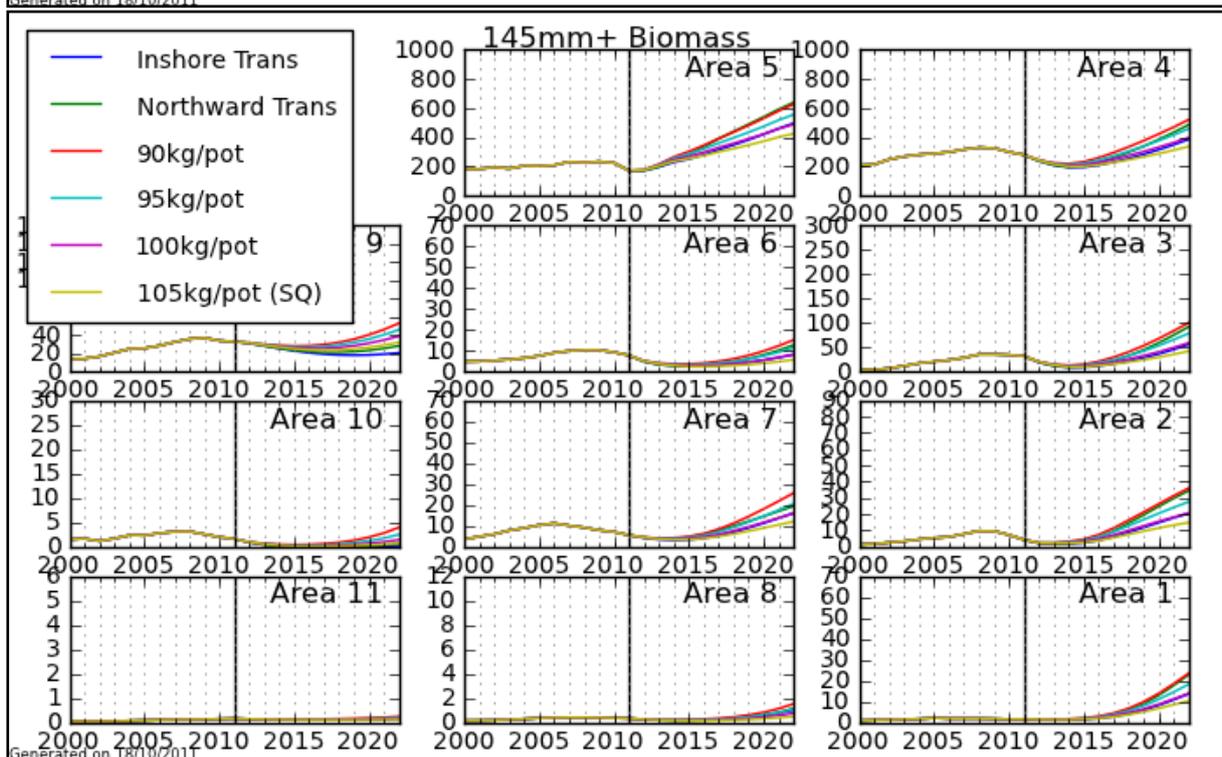
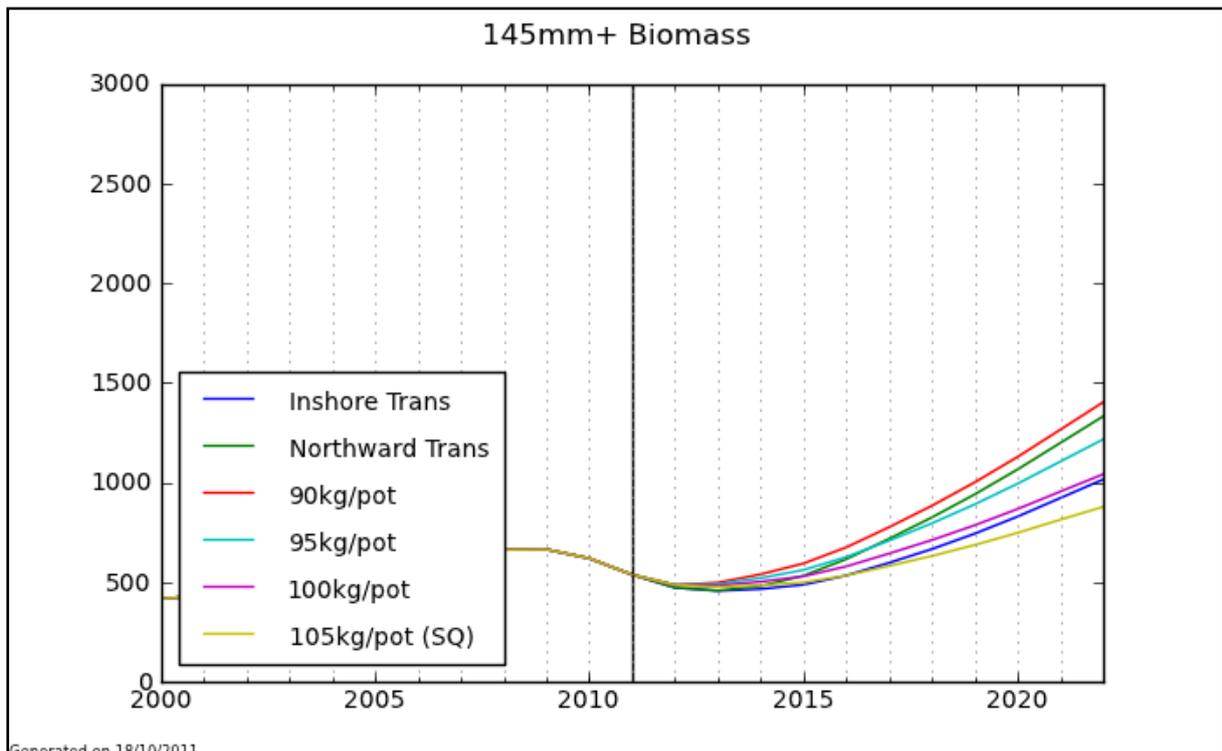


**Figure 5-89.** Median projections of egg projections under different scenarios for Statewide (upper) and by areas (lower). Translocations northward by one area produced a change in egg production approaching a 5 kg per unit change in the TACC. Benefit to egg production was modest compared with ecosystem and economic benefits because it involves harvest of females that would otherwise not be captured. The overall effect of translocation is nonetheless an increase in egg production above the status quo and the spatial pattern in change is consistent with management goals (e.g. more in area 5).

Ecosystem indicators

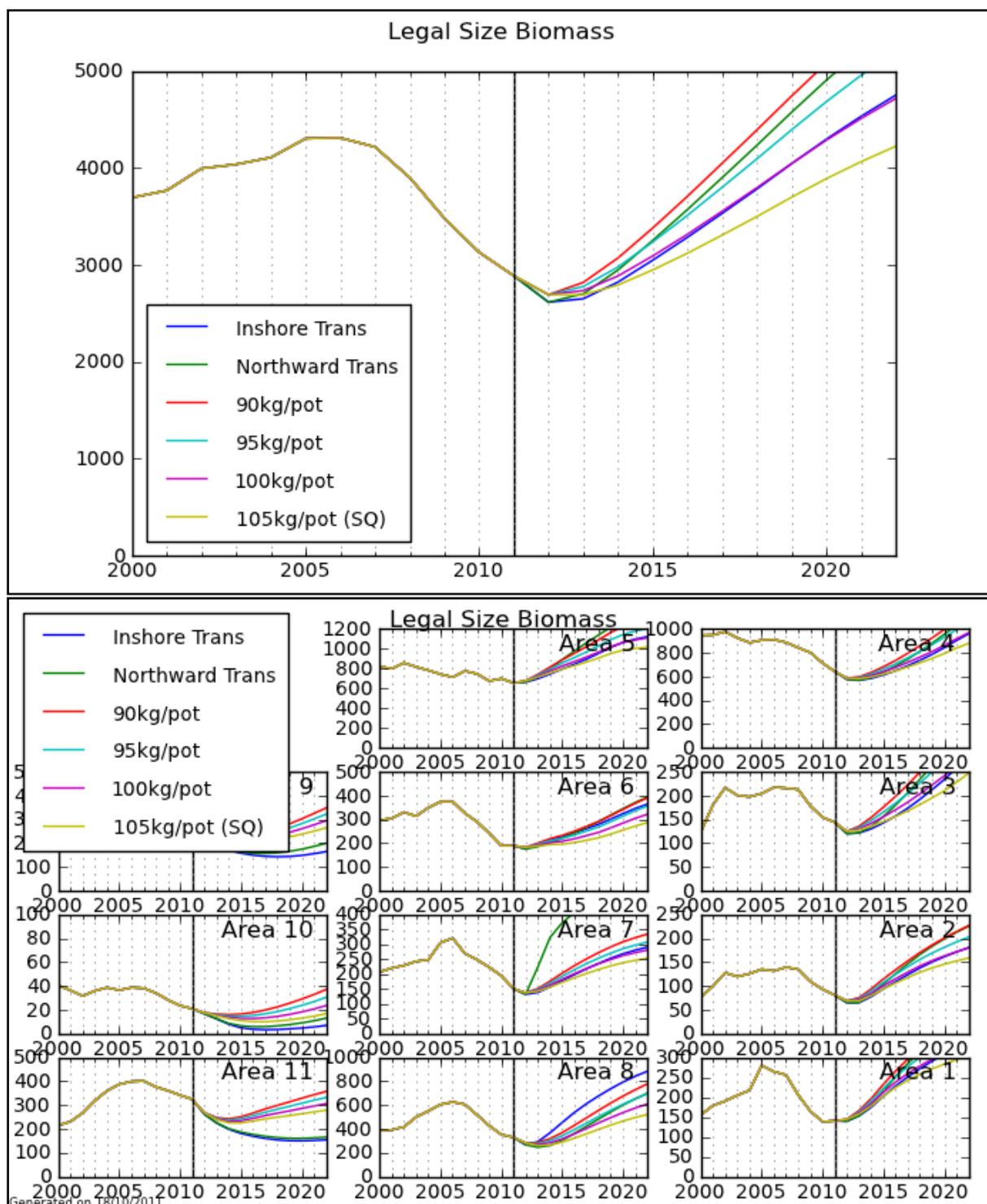


**Figure 5-90.** Median projections of **total biomass** greater than 60 mm CL under different scenarios for Statewide (upper) and by areas (lower). This biomass measure includes undersize lobsters and is of interest for ecosystem function. Biomass is depleted in deep water and enhanced in shallow areas / northern areas. This implies the ecosystem effect of fishing is more distributed across deep and shallow areas, a current management objective (ie a more diffuse weaker effect, rather than concentrated in shallow waters).

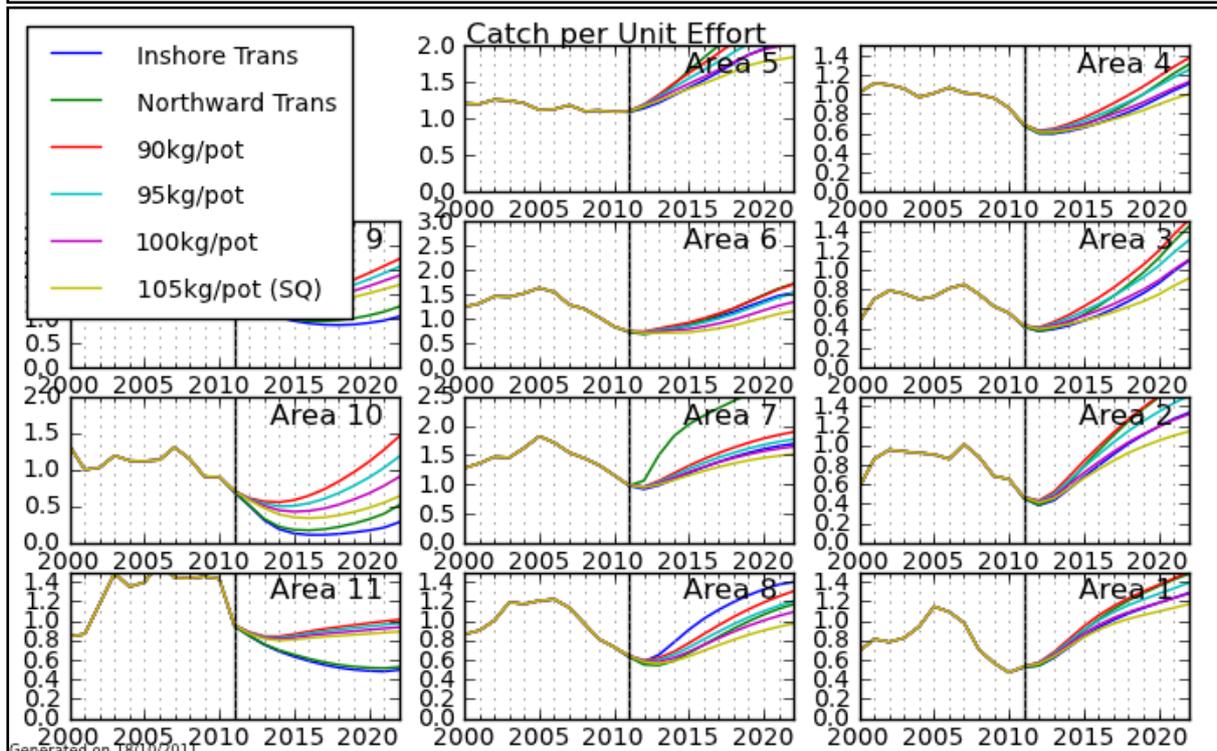
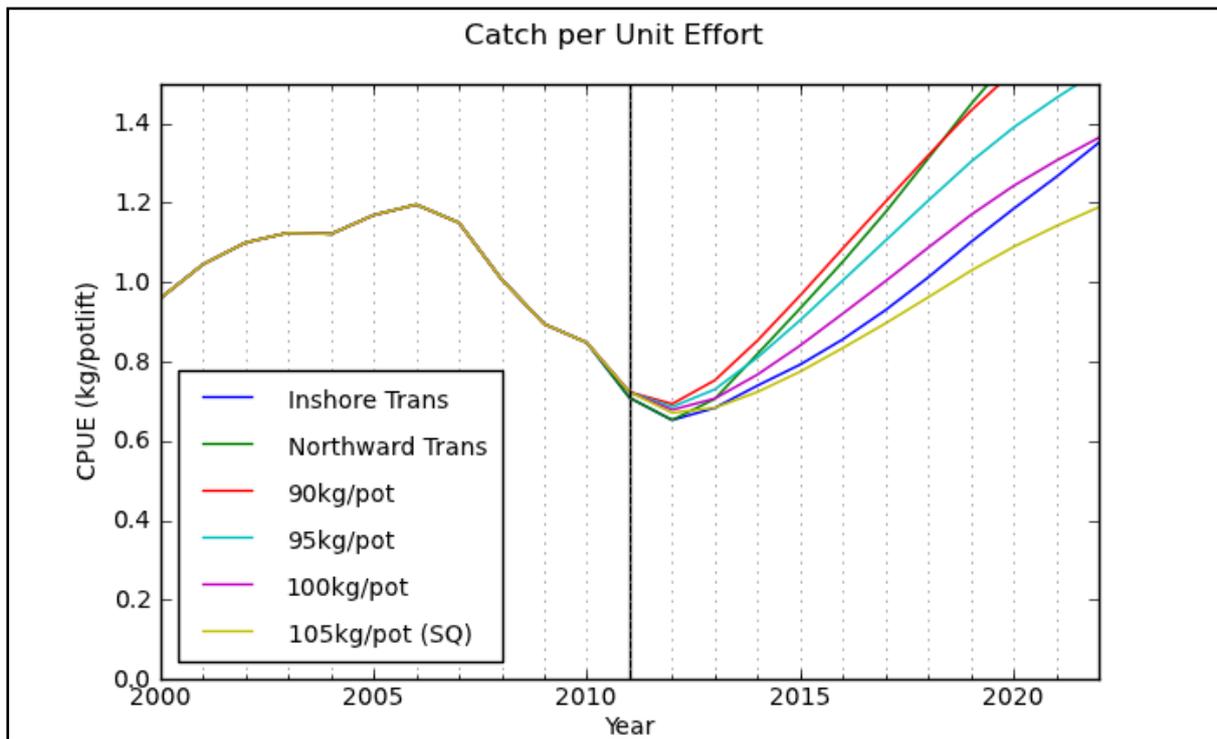


**Figure 5-91.** Median projections of **large lobster biomass** under different scenarios for Statewide (upper) and by areas (lower). This biomass measure is of interest in relation to predation of barren forming urchins by lobsters. Translocations northward by one area produced an outcome for east coast Tasmania similar to a 15 kg/unit reduction in the TACC.

*Economic indicators*



**Figure 5-92.** Median projections of **legal biomass** under different scenarios for Statewide (upper) and by areas (lower). This biomass measure is only for the available catch and is an economic indicator. Translocations inshore produced stock effects similar to a change in the TACC of 5 kg per unit. Translocations northward by one area produced a slightly better change in stock than a 10 kg per unit change in the TACC. Benefits are expected to occur across both east and west coasts and in all shallow water areas.



**Figure 5-93.** Median projections of **catch rate** under different scenarios for Statewide (upper) and by areas (lower). Catch rate only relates to the legal sized portion of the stock and is thus an economic indicator. Translocations inshore had a modest effect on catch rate and less than a change in the TACC of 5 kg per unit. Translocations northward by one area produced a significant change in stock approaching a 15 kg per unit change in the TACC. Benefits are expected to occur across both east and west coasts and in all inshore areas, although catch rate is expected to reduce in deep water areas.

Economic outcomes were summarised by the discounted cash flow method, which is widely used in valuing share or business value. It is also termed “fundamental valuation” because it

is driven by the basic components of profitability being costs and revenue. A 7.5% discount rate was applied to future income, based on business lending rates.

Market capitalization of quota units was estimated at \$210 million (10507 units @ \$20,000). Ongoing translocations would be expected to increase catch rates so that costs would decline for the same revenue. The discounted cash flow effect of this change was estimated at:

\$12.2 million for inshore translocations for the industry (\$1,163 per unit)  
\$47.4 million for northward translocations, (\$4,515 per unit)

## **5.7 Management and Monitoring for Extension**

Special attention has been given to extension of translocation because structures were in place for most other options. Structures for the commercialisation have been developed involving the commercial Tasmanian rock lobster fishing industry funding vessels to move lobsters from deep water to shallow water. This was agreed through a vote by industry which had overwhelming support.

The operation is to involve industry participants contributing \$10 per quota unit which is believed to be sufficient to fund charter operations to the scale described in Section 5.6.6.

Oversight of tenders and contacts is to be through a committee convened by industry and with research and government membership. Ongoing monitoring is to be through dedicated observers on all trips who will also tag and measure 10% of all translocated lobsters. Translocation removal and release sites for ongoing operations were defined by the industry committee (Figure 5-94, Figure 5-95, Figure 5-96, Figure 5-97, and Figure 5-98).

### ***Other options discussed for translocation***

Two key choices in the management application of translocation discussed by the TRFLA were an ad-hoc translocation or whether it is prescribed and managed, and therefore monitored by a government department or research body.

#### *Ad-hoc*

In an ad-hoc approach, under permit fishers retain their sub-legal catch and release these on their return trip to port. The release sites can be pre-determined or decided by the fisher as the most convenient to the planned travel route. This method is the most economically feasible (Gardner and Putten 2008b), but is more difficult to monitor for improvements in yield, survival and colour and also harder to assess the density effects as density may not be known.

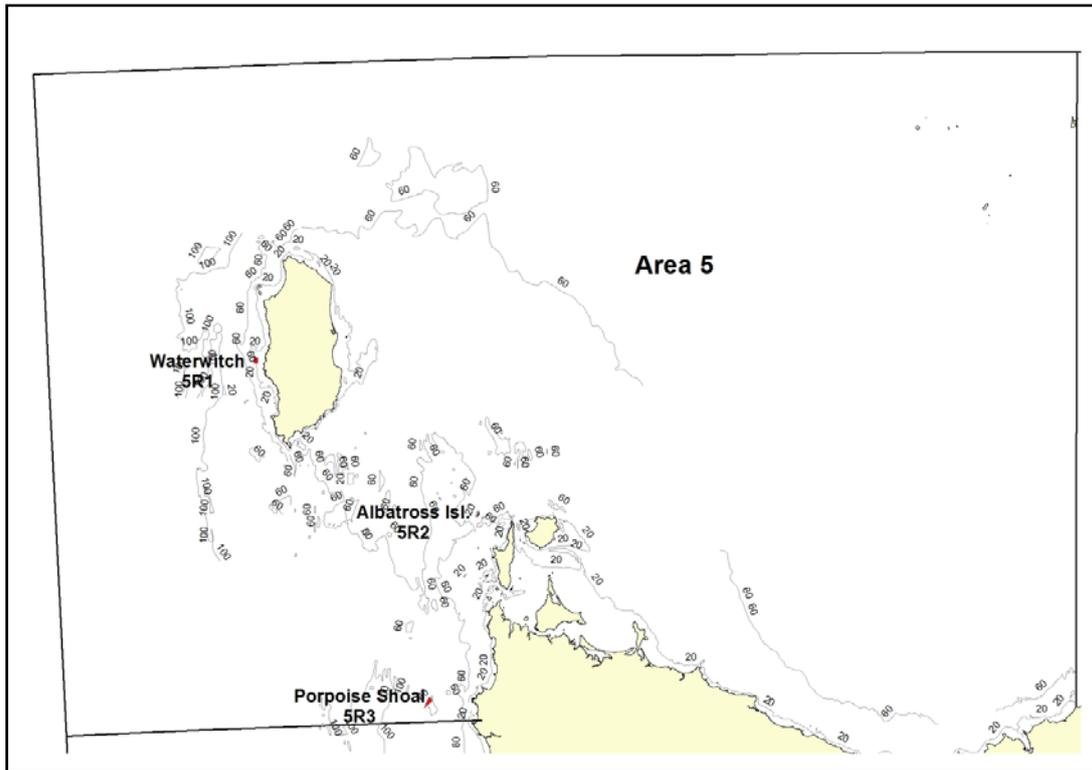
#### *Managed*

In the managed approach to translocation, industry boats would be chartered to capture and release deep water lobsters to and from pre-determined sites. The costs of this operation would be higher than the ad-hoc approach as the costs of charter for the sole purpose of translocation would need to be met. The advantage of this method is that it would allow for closer monitoring of capture and release activities, as well as numbers, sizes and colour of

lobsters. Translocation under this model would operate under permit from the appropriate management authority, which in Tasmania is DPIPWE. An example of the permit for commercial scale translocation can be seen in Appendix IV.



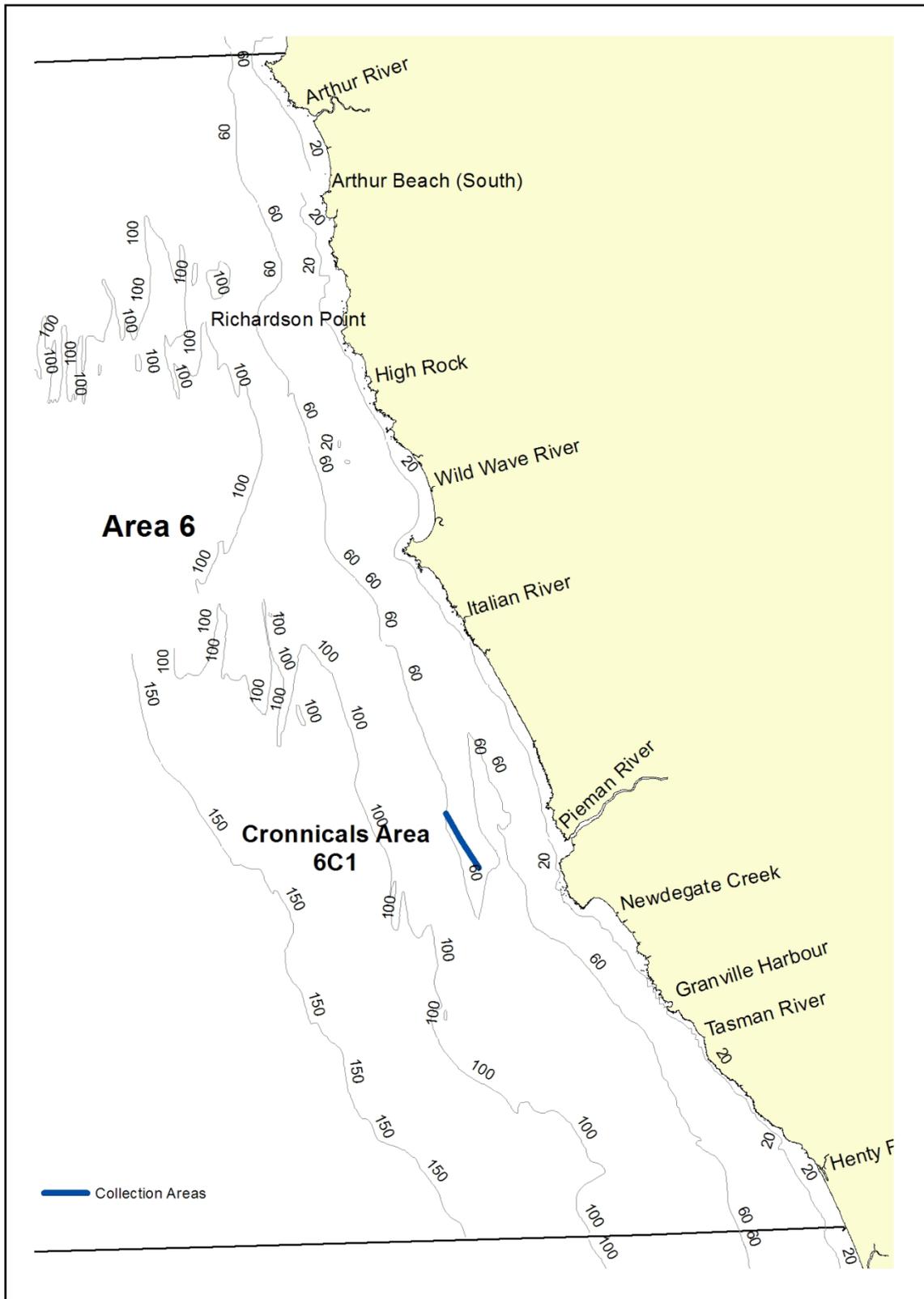
**Figure 5-94.** Summary of translocation operations at the proposed initial level of 100,000 per annum. Blue boxes show the number of lobsters to be moved from capture to release sites. Tenders can be for the Northern, Southern, or entire operations.



**Figure 5-95.** Area 5 release sites.

Assessing lobster growth and therefore the success of large-scale translocation, requires data on size from recaptured lobsters. Here are three options to collect this data:

- a. Offer financial incentives to fishers and processors for tag returns, such as a cash reward of \$5 per lobster. This would enable monitoring of growth and possibly survival of legal-sized recaptures only.
- b. Have observers on board fishing vessels fishing at the translocation sites, which would enable monitoring of growth of legal and sub-legal lobsters.
- c. Require that fishers measure size, colour, damage, reproductive status of all recaptured translocated lobsters. This could be part of the permitting requirements, although this would not encompass recaptures caught by recreational fishers.



**Figure 5-96.** Area 6. Collection site at Conicals. Release site (not shown) north of Pieman River in < 12 fm.

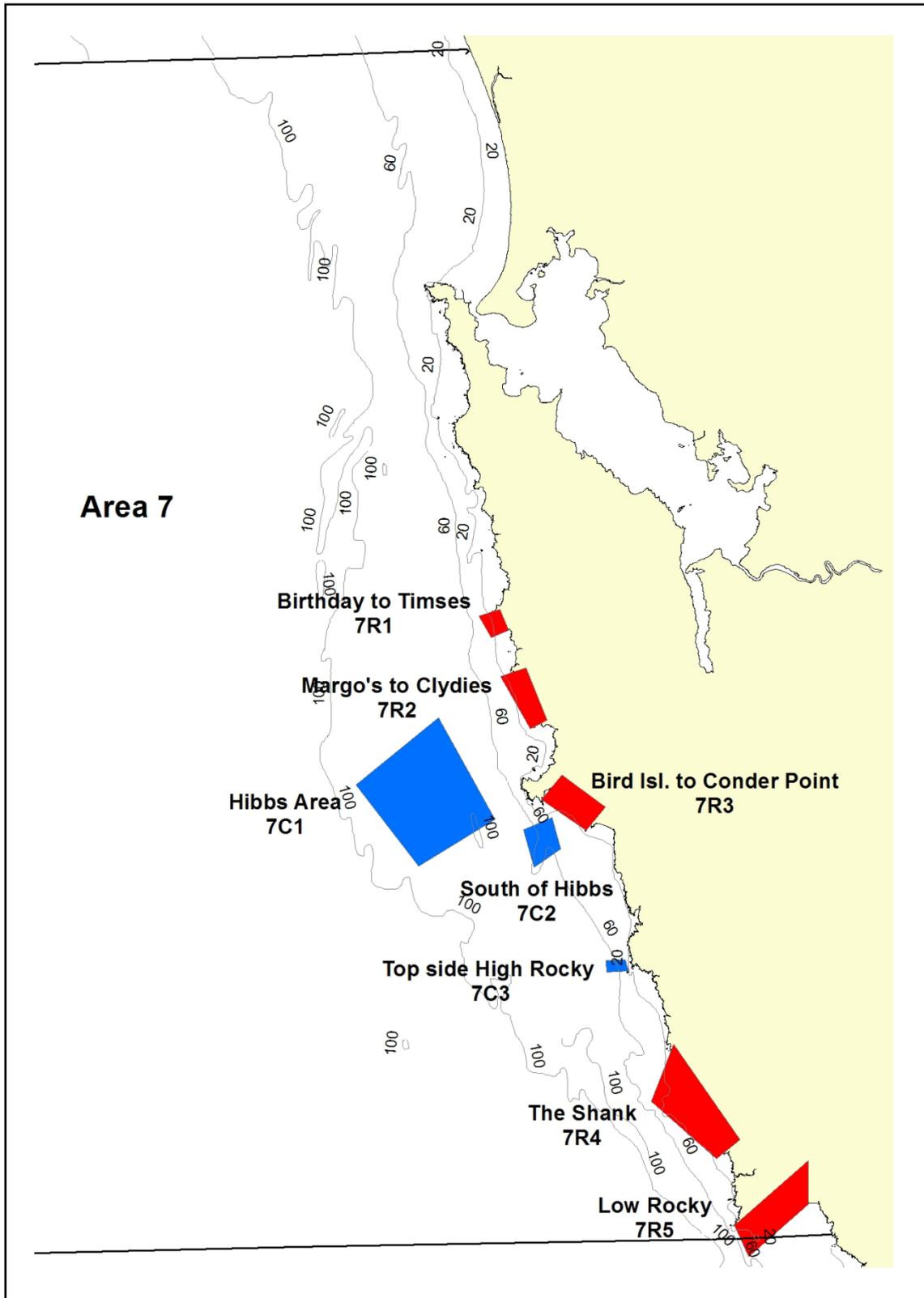
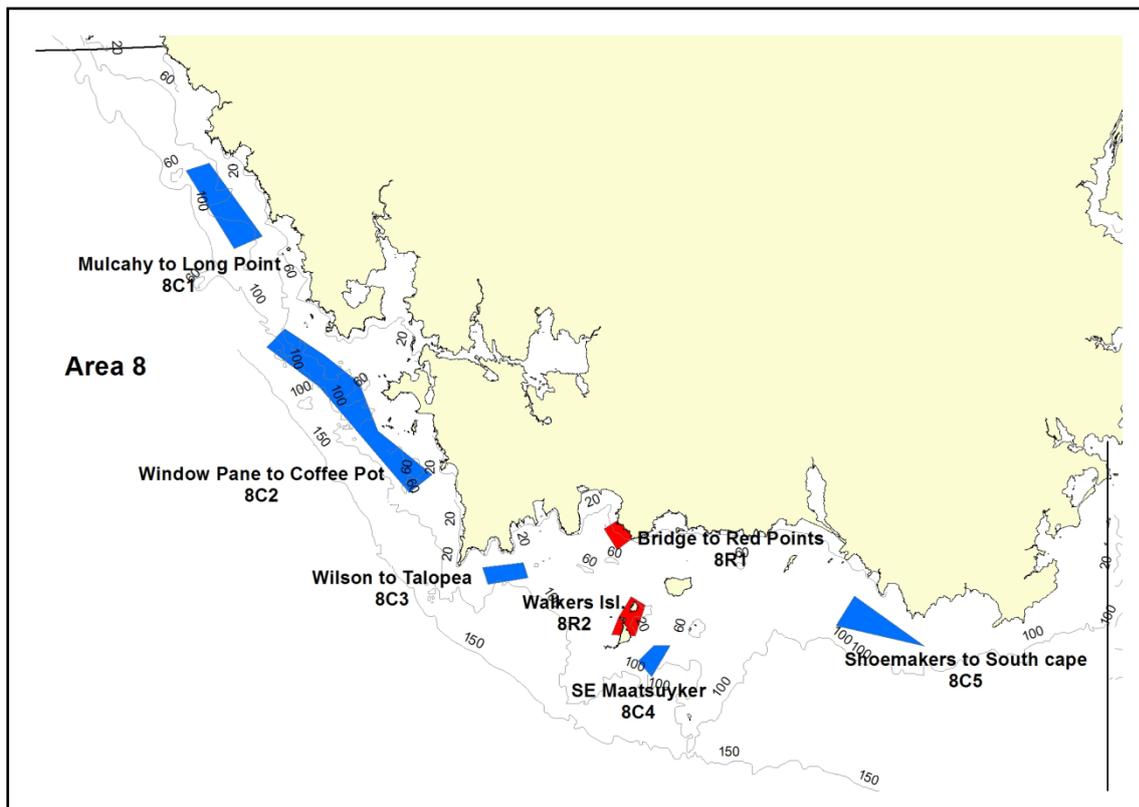


Figure 5-97. Area 7. Capture sites (blue) and release sites (red).



**Figure 5-98.** Area 8. Capture sites (blue) and release sites (red).

### 5.7.1 Biosecurity

Biosecurity risks were reviewed in this project. DPIPWE’s biosecurity officer, Rod Andrewartha considered whether translocation offered any extra biosecurity threats to the Tasmanian rock lobster industry. Andrewartha determined that the movement of adult lobsters presented a negligible biosecurity risk to the industry as any disease present in Tasmanian populations has the potential to be homogenous throughout the population already due to two dispersal routes. Firstly, there was already large-scale dispersal of the larvae; and secondly that the transport methods of adult lobsters in flow-through tanks moved water with lobsters and their biota around the state.

#### *Critical Issues to monitor:*

1. Lobster health/appearance of disease and biosecurity risk. We recommend that a number of lobsters from each translocation would be examined for any signs of disease or bad health.
2. On-board mortality. Any mortality would need to be reported immediately and the causes investigated, so that any modifications to the process could be identified and implemented immediately.

### 5.7.2 Tender process

To ensure best practice for the capture, handling, transport and release of lobsters for future translocations we recommend a tender committee from the industry be responsible for oversight. They would set the guidelines in the tender documents and review the boat quality of all tenders, including the design of the well for holding the lobsters, and the proposed method of releasing large numbers of lobsters. An example of the tender specifications for commercial scale translocation in Tasmania can be seen in Appendix V.

## 6 BENEFIT AND ADOPTION

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The project has had adoption and benefit in rock lobster fisheries across all three jurisdictions involved:

### *South Australia*

Benefits from the project in South Australia were related to adoption of the length based model as applied in the other two states so that there was consistency across the region. This improved assessment capability has led to improvements in stock assessment and provided a platform for the development and adoption of a decision rule process in 2011. Quantifying the benefit of this system is difficult but substantial given the scale of these fisheries which have a market capitalisation of \$513 million in the southern zone and \$89 million in the northern zone (2011). Capacity to improve management decisions would be expected to have a large effect on the marginal economic yield of this fishery so an attribution of 5% or \$30.1 million is a conservative estimate.

### *Victoria*

As per South Australia, no spatial management changes were adopted as a result of this project although the project provided benefit nonetheless through improved assessment capability and thus better management of the TAC setting process. The Victorian fishery had depressed stock and thus catch rates since around 2004 but these started to recover in 2011. Some of this gain can be attributed to the benefit of improved stock assessment processes feeding into decision making processes.

### *Tasmania*

Several management decisions were made in Tasmania on the back of this project.

Reference points for performance measures were altered to be aligned with maximum economic yield. This was adopted by both government and industry and included an industry vote to reduce the TAC by 20% in 2009. The market capitalisation of the Tasmanian lobster fishery rose from \$200 million early in 2011 to \$265 million later that year despite continued low recruitment and stability in price. This gain in capitalisation of \$65 million thus appears to be attributed to management decision making in reducing the TAC. We can only speculate on whether this change would have occurred without the bioeconomic guidance of this project, but it was clearly a factor. Thus gains in the order of \$10's millions appeared to be as a result of this project through TAC advice.

Deep water quota was trailed and this involved a small additional research catch that would not have been taken otherwise, valued at approximately \$500,000. The more substantial benefit of this research was the development of a management tool that is expected to yield \$10's million in increased capitalisation if applied. This management approach has a lower economic benefit than translocation, which deals with the same problem differently. Thus deep water quota remains on the shelf while translocation is pursued.

Regional seasonal closures were introduced in 2011 in response to the issues highlighted in this project. This allowed the fishery to remain open in October in the region where higher quality, hard shelled lobsters were available.

Translocation has been adopted by government and industry at a small pilot scale initially. Even this level has an estimated increase in NPV of \$47.4 million. This estimate is based on industry discount rates and thus we'd expect translocation to have this level of impact on market capitalisation over the next few years.

Translocation also has other benefits less easily quantified including increased catch rates and thus utility of the recreational sector and stock rebuilding of large lobsters on the east coast of Tasmania. These large lobsters are expected to reduce risk of barren formation, thus a degree of protection of the East Coast Tasmanian abalone fishery is attributable to this project. That component of the fishery of the fishery has a market capitalisation of \$256 million with an estimated 50% or \$128 million of this at risk from barren formation.

## **7 PLANNED OUTCOMES**

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The planned outcomes were to:

- improve egg production, catch rates and economic yield for fishers and the State.;
- lead to greater conceptual understanding of spatial patterns in SRL fisheries;
- provide improved capacity to monitor these in the future.

The principle outcomes for fishers and community will be increases in:

- catch rate;
- exploitable biomass;
- egg production; and
- economic yield.

Through this project on spatial management options for the SRL fisheries there is a much wider discussion within the SRL fisheries on spatial management options, particularly within the Tasmanian fishery. This includes the adoption of translocation, regional changes in season length, and regional zones. Discussion of management options to address the current mismatch between biological parameters and management measures is ongoing, and continues to be addressed by the industry and government. In Victoria and South Australia there was reticence in pursuing translocation to improve yields and increase exploitable biomass. Their rock lobster stocks declined while this project was underway, and consequently their priority was initial stock rebuilding by setting a limiting TACC. Translocation, as examined in this document, remains a future option for both States.

This project has advanced the capacity to monitor changes in the rock lobster fishery in the future. Model developments have occurred including spatial division of shallow and deep water populations. Research data collection has been extended in deep water areas, greatly improving the capacity to examine management changes in these areas with low exploitation rates. Translocation can substantially increase the value of the fishery by improving yields and increasing the exploitable biomass.

## **8 FURTHER DEVELOPMENTS**

To commercially exploit the results of the research the next step is to undertake a commercial-scale trial of translocation. The industry has been fully-briefed on the results from this research trial and has voted in support of developing a commercial-scale translocation. At the TRFLA general meetings in November 2011 they will be asked to vote on the financial support they might give such an option.

## **9 CONCLUSIONS**

The majority of the southern rock lobster (*Jasus edwardsii*) fishery in Australia occurs within Victoria, Tasmania and South Australia. As an output of this project, each state now conducts assessments with the same length-based stock assessment model structure which includes demographic traits, fleet movements and catch rates from that region. This creates efficiencies between states, in particular, better sharing of new development in code. Each model was

separately parameterised to enable more detailed reporting of trends in biomass and egg productions by depth. This has led to improvements in reporting and management decision making, such as in the setting of TACs.

The model was modified for the Tasmanian fishery to include economic data so that harvest strategies could be compared in terms of economic outcomes. This capability was important for examining spatial management aspects of the project but was first applied in the context of TACC setting. Results showed that the current total allowable commercial catch (TACC) was too high to maximise economic yield and left the industry vulnerable to temporal changes in productivity. Alternative pathways to lower TACCs were explored but although these affected economic yield, differences were minor. This analysis showed that despite operating under ITQ management for over a decade, the presence of tradable catch shares were insufficient for the TACC to move towards MEY through normal processes of decision-making based on biological stock assessments. Industry and Government were motivated to exercise stewardship but struggled with acceptance of the concept that economic yield and asset values could increase with lower catches. This illustrates the value of formal analysis of economic outcomes as part of the suite of information used for making management decisions.

Spatial management options explored included regional quotas, regional size limits, and translocation.

A trial of regional quotas was undertaken to better utilise deep water stocks. The catch from deep water (>35 fm) off western Tasmania currently averages around 100t. Economic yield from the broader fishery would be increased if around 100 t of extra catch were shifted from shallow water into these deeper areas off the west coast.

The method explored involved providing additional quota as an incentive for fishers to take catch in the deep water area. This was determined to be only beneficial under market conditions where the incentive was attractive if the additional quota is less than 52kg per unit (assuming a standard quota allocation of 140kg / quota unit). The main benefits of managing deep water catch are that long term profitability is enhanced and the resource becomes more resilient to shocks such as years of low catchability or low recruitment.

The main disadvantages are that there is additional administration and enforcement. The trial of deep water quota was conducted at a time the stock was in decline and this created an economic environment where fishers were unlikely to take up catch incentives at levels that provided net economic gains to the broader fishery. Deep water quota was thus not viable during the period of the trial, however, it remains a possible management tool for future application when the stock rebuilds and catch-rates become elevated in deep water again.

Alternate size limits were explored in both Tasmania and South Australia. Population modelling in Tasmania suggested that the effect of lowering size limits by 5 mm for both sexes in the SW (area 8) to 105 mm CL for males and 100 mm CL for females would lead to an initial spike in catch, which would then stabilise at a sustainably higher level because a smaller size limit is more appropriate to average growth rates across the region.

Egg production was modelled to benefit from the change with enhanced production in the currently depleted northern areas. Although benefits in egg production were predicted for the depleted northern parts of the fishery, total state-wide egg production would be almost unaffected. A smaller size limit in the SW provides substantial opportunity to increase economic yield. In addition, reducing size limits in the SW would provide fishers with increased capacity to choose to fish in areas with sizes of lobsters that the market demands.

Size limits were also examined in the expansive (~207,000 km<sup>2</sup>) northern zone of South Australia. Spatially explicit estimates of size of maturity and relative reproductive potential were estimated to examine if the current minimum legal size of 105 mm carapace length (CL) was appropriate. Size of maturity ranged from 105 to 118 mm CL with 90% of reproductive potential coming from size classes above 105 mm CL. As size of maturity is age, rather than size dependent, these results may reflect differences in growth rates and highlight the importance of considering spatial variation in reproductive characteristics when applying size limits to lobster resources.

Translocation was examined through a series of field trials that provided data on change in growth, egg production, market traits and ecosystem effects. Model projects were then used to examine the effects of translocation. Change in stock in response to translocation was assessed in comparison to the change in TACC that would be required to produce the same effect. The scenario examined was based on the scale of operations proposed by industry for initial operations, which was 100,000 lobsters moved per year with movements either directly inshore or with a slight northward component. When combined with TAC management, this scale of operation appears to increase most performance measures on a similar scale as would be achieved by a reduction in TACC of 10 kg per unit. This conclusion held broadly across total biomass, legal sized biomass, biomass of large lobsters (>145 mm CL), catch rates and egg production.

Gains occurred in regions on the east coast although translocation operations were restricted to the west coast. This was through the effect of the limiting TAC forcing effort to the west if the fleet was to respond to the higher stock abundance in that area. This process was helpful from a management perspective with egg production expected to increase in the depleted northern areas, and biomass of large, urchin-predating lobsters increasing along the east coast. This is of management interest in dealing with *Centrostephanus* urchin barrens with gains equivalent to a TACC reduction of 15 kg per unit.

Economic outcomes were summarised by the discounted cash flow method, which is widely used in valuing share or business value. Market capitalisation of quota units was currently estimated at \$210 million (10507 units @ \$20,000). Ongoing translocations would be expected to increase catch rates so that costs would decline for the same revenue. The discounted cash flow effect of this change was estimated at \$47.4 million (\$4,515 per unit).

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## 11 APPENDICES

### 11.1 Appendix I, Intellectual Property Arising

Nil.

### 11.2 Appendix II, List Of Publications

1. Chandrapavan, A., Gardner, C., Green, B.S., (2010). Growth rate of adult rock lobsters *Jasus edwardsii* increased through translocation. **Fisheries Research**, 105: 244–247.
2. Linnane A, Gardner C, Hobday D, Punt A, McGarvey R, Feenstra J, Andrews J., Green B (2010) Evidence of large-scale spatial declines in recruitment of southern rock lobster *Jasus edwardsii*, across south-eastern Australia. *Fisheries Research* 105(3):163-171
3. Linnane A, Sloan S, McGarvey R, Ward T (2010) Impacts of unconstrained effort: Lessons from a rock lobster (*Jasus edwardsii*) fishery decline in the northern zone management region of South Australia. **Marine Policy** 34: 844-850
4. Linnane A, Crosthwaite K (2009) Spatial dynamics of the South Australian rock lobster (*Jasus edwardsii*) fishery under a quota-based system. *New Zealand Journal of Marine and Freshwater Research* 43: 475-484
5. Chandrapavan A, Gardner C, Linnane A, Hobday D (2009) Colour variation in the southern rock lobster *Jasus edwardsii* and its economic impact on the commercial Industry. **New Zealand Journal of Marine and Freshwater Research** 43:537-545
6. Chandrapavan A, Guest M, Nichols P, Gardner C (2009) Translocating southern rock lobsters (*Jasus edwardsii*) from deep-water to shallow inshore water enhances nutritional condition through omega-3 long-chain polyunsaturated fatty acid content. **Journal of Experimental Marine Biology and Ecology** 375:9-15
7. Linnane A, Penny S, Hawthorne P, Hoare M (2009) Spatial differences in size at maturity and reproductive potential between inshore and offshore fisheries for southern rock lobster (*Jasus edwardsii*) in **South Australia**. **Fisheries Research** 96: 238-243
8. Linnane A, Penny S, Ward T (2008) Contrasting fecundity, size at maturity and reproductive potential of southern rock lobster *Jasus edwardsii* in two South Australian fishing regions. **Journal of the Marine Biological Association of the United Kingdom** 88: 583-589
9. Green BS, Gardner C (2009) Surviving a sea change: survival of southern rock lobster (*Jasus edwardsii*) translocated to a site of fast growth. **ICES Journal of Marine Science** 66(4): 656-664
10. Green, B.S., Gardner, C., Kennedy, R.B., 2009. Generalised linear modelling of fecundity at length in southern rock lobsters, *Jasus edwardsii* **Marine Biology** 156, 1941-1947
11. Green, B., Gardner, C. and Linnane, A. (2010). The good, the bad and the recovery in an assisted migration. **PLoS ONE**. 5(11): e14160.

12. Chandrapavan, A., Gardner, C. and Green, B. Haemolymph condition of deep-water southern rock lobsters (*Jasus edwardsii*) translocated to inshore reefs. **Marine & Freshwater Behaviour & Physiology**. In press.
13. Green, B.S., Gardner, C., Lipcius, R.N. and Van der Meeran, G. (in press). Translocating lobsters to improve yield and value of fisheries. In Lobsters: Biology, Management, Aquaculture and Fisheries (Ed. B.F. Phillips).
14. Chandrapavan, A., Gardner, C., Green, B.S., Linnane, A., Hobday, D. (2011). Improving marketability through translocations: a lobster case study from southern Australia, ICES Journal of Marine Science: 68 (9) pp. 1842-185
15. Green, B.S., Pederson, H.P., Gardner, C., (in press) Overlap of home ranges in two morphs of the southern rock lobster after assisted migration. **Reviews in Fisheries Science**.

### **11.3 Appendix III, Staff Involved**

#### **IMAS**

Caleb Gardner, Bridget S. Green, Arani Chandrapavan, Klaas Hartmann, Gary Carlos, Ruari Colquoun, Kylie Cahill, Sam Ibbott, Craig Mackinnon, Dave Faloon, Kevin Redd, Mikaela Guest, Hugh Pederson, Dane Jones, Matt Francis, Jac Gibson

#### **SARDI**

Adrian Linnane, Rick McGarvey, Peter Hawthorne, Matthew Hoare, John Feenstra,

#### **DPI VIC**

David Hobday, David Reilly

#### **TRFLA**

Rodney Treloggen, John Sansom

#### **DPIPWE**

Hilary Revill, James Parkinson

## 11.4 Appendix IV Translocation permit from DPIPWE

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### **LIVING MARINE RESOURCES MANAGEMENT ACT 1995**

PERMIT ISSUED UNDER SECTION 14 TO TAKE AND POSSESS SOUTHERN ROCK LOBSTER FOR THE PURPOSES OF TRANSLOCATION

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**PERMIT NUMBER:** <Permit Number>  
**PERMIT HOLDER:** Mr <Name>  
<Address 1>  
<Suburb> <State> <Post Code>  
**DATE OF ISSUE:** 1 February 2012  
**DATE OF EXPIRY:** 30 April 2012

#### **ACTIVITIES AUTHORISED BY THIS PERMIT:**

This permit is issued for the purpose of scientific research. It authorises the permit holder or agent to:

- I). Set and use up to a maximum of 100 rock lobster pots, without escape gaps, to take rock lobster; and,
- II). take and possess up to a maximum of XXXXX southern rock lobsters (*Jasus edwardsii*) of any size in State waters;

from the fishing vessel <Vessel Name> (<vessel dist mark>) in accordance with the terms and conditions set out below.

#### CONDITIONS

It is a condition of this permit that the permit holder or agent:-

1. must only use an agent who is the master of the vessel <vessel name>;
2. must only take quantities rock lobsters as required for the purposes of scientific research;
3. must only set rock lobster pots authorised under this permit in locations specified by an Institute of Marine and Antarctic Studies (IMAS) officer;
4. must release all rock lobster caught under this permit in State waters at a place and in a manner as directed by an IMAS officer;
5. must not land any rock lobster taken under the authority of this permit;
6. must not sell or transfer to another person or company any rock lobster taken under the authority of this permit;
7. must mark each rock lobster pot set under the authority of this permit with a surface buoy with the work "permit" clearly and legibly written on it [is this practical?????????];
8. must not take or possess any other fish whilst operating under this permit;
9. must abide by any protocols for the take, handling, storage and release of rock lobster as supplied by IMAS when engaged in activities authorised under this permit;
10. must collect and supply any data in accordance with instructions provided by officers of IMAS, when engaged in activities authorised under this permit;

11. must adhere to any other reasonable instructions provided by officers of the IMAS or DPIPWE in relation to activities authorised under this permit;
12. must carry an IMAS or DPIPWE authorised observer when undertaking any activities authorised under this permit;
13. must contact the Tasmania Police - Marine Division, Hobart, (phone 6230 2475 or fax 6230 2598 or email Robert.dunn@police.tas.gov.au at least one day prior to undertaking activities under this permit notifying of the date of that activity, the vessel to be utilised and area of operation;
14. shall permit any officer from the Department of Primary Industries, Parks, Water and Environment to have access at any reasonable time to any records relating to activities under the authority of this permit;
15. must carry a copy of this permit whenever engaged in activities under the permit; and
16. must comply with the *Living Marine Resources Management Act 1995* and all regulations and rules made thereunder other than those activities authorised by this permit.

Grant Pullen  
MANAGER (WILD FISHERIES MANAGEMENT)

## **11.5 Appendix V Tender Specifications for Tasmanian Commercial Translocation**

### **TENDER SPECIFICATIONS**

#### **Overall Objective**

To translocate rock lobsters from offshore West Coast locations in Areas 6, 7 and 8 to inshore locations in Areas 5, 6, 7 and 8.

Translocation of about 100,000 lobsters will occur over about six weeks, beginning on or about February 5 2012.

An individual tenderer may contract to translocate them all, or approximately half on a north-south geographical split. The north tender involves shifting lobsters from Area 6 and 7 to Area 5 and 6 (~ 40,000 lobsters). The south tender involves shifting lobsters from Area 8 to inshore Area 8 and Area 7 (~60,000 lobsters).

#### **Vessel Requirements**

1. The Vessel is and will be maintained by the Operator in Marine and Safety Tasmania (MAST) Survey class 2B and 3B survey throughout the Charter Period.
2. Vessel will be required to have high quality facilities suitable for transporting large numbers of lobsters without impacting the health and vitality of lobsters.
3. The vessel is required to provide accommodation and access to a satellite phone for an observer. Victualling costs for the observer will provided separately to the observer and are thus not covered by the tender.

#### **Insurance**

The Operator will procure and maintain insurance in full force and effect throughout the Charter Period at its sole cost and expense in respect of:

- 1.1 Loss or damage to the Vessel, the Equipment and the Safety Gear for their respective full replacement values.
- 1.2 Workcover and any other accident or other compensation insurance required by any applicable law of any State in which any voyage may be undertaken during a Charter Trip and the Commonwealth in respect of the Skipper and Crew.
- 1.3 Third Party/Public Risk Liability Insurance for at least \$20,000,000

#### **Capture and movement of lobsters**

- All undersize lobsters are to be translocated, that is, there is no grading. Legal sized lobsters will be released rather than translocated where possible.
- Operations will be conducted by research permit and the number of pots that can be used is only limited by the vessel survey requirement.
- IMAS pots and buoy lines may be used by the tenderer where available with any lost gear replaced.
- Other gear can be modified to increase retention of undersize lobsters, particularly the meshing up of escape gaps.
- Observers will be responsible for estimating the number of lobsters harvested and progress will be reported back on a daily basis to the project committee.

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| <b>12 8.0      COMPLETION CHECKLIST</b> |
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|  |  |                          |
|--|--|--------------------------|
| Provided five bound copies of the final report - ensure that if colour figures are used they are included (in colour) in all five copies?                                      | <input type="checkbox"/>                         |                          |
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| ⇒ CSIRO Library  | ⇒ National Library (note any embargo conditions) | <input type="checkbox"/> |
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| ⇒ FRABs  | ⇒ Beneficiaries                                  | <input type="checkbox"/> |
| ⇒ Stakeholders, including fishing industry councils, recreational groups and representative fishing industry bodies  | <input type="checkbox"/>                         |                          |