FRDC FINAL REPORT

ROCK LOBSTER ENHANCEMENT AND AQUACULTURE SUBPROGRAM: THE FEASIBILITY OF TRANSLOCATING ROCK LOBSTERS IN TASMANIA FOR INCREASING YIELD

Caleb Gardner and Ingrid Van Putten

October 2005

FRDC Project No. Project 2005/217

Australian Government

Fisheries Research and Development Corporation

National Library of Australia Cataloguing-in-Publication Entry

Gardner, C. (Caleb), 1968- .
Rock lobster post-harvest subprogram : the feasibility of translocating rock lobsters in Tasmania for increasing yield

Bibliography.
Includes index.
ISBN 186295 283 3

Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Private Bag 49, Hobart, Tasmania 7001. E-mail: Caleb.Gardner@utas.edu.au

Ph. (03) 6227 7277 Fax (03) 6227 8035

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a federal statutory authority jointly funded by the Australian Government and the fishing industry.

2005/217 Rock Lobster Enhancement and Aquaculture Subprogram: The feasibility of translocating rock lobsters in Tasmania for increasing yield

PRINCIPAL INVESTIGATOR: Dr C. Gardner

ADDRESS: University of Tasmania
Tasmanian Aquaculture and Fisheries Institute
Private Bag 49
Hobart 7000
Telephone: 03 6227 7233 Fax: 03 6227 8035

1. Objectives

1. To determine the costs associated with translocating lobsters.
2. To model the economic outcomes of translocation based on available biological data.
3. To combine the cost and economic outcomes into a bio-economic model.
4. To model the economic viability of large-scale translocation operations to achieve yield increases.
5. To identify crucial input data that impact on the economic viability of translocation.
6. To identify further data requirements from field-experiments.
7. To evaluate cost recovery options for a long-term operational system for translocation.

2. Non-Technical Summary

OUTCOMES ACHIEVED

Translocation involves the shifting of undersize rock lobsters to new areas to increase productivity and/or quality of product. We modelled the translocation of rock lobsters from four original sites to four release sites with a range of growth rates.

Most model scenarios led to increases in yield at least double the status-quo. Greatest gain occurred with simulations of the translocation of females from the SW to the NW – in these cases the translocation of 1 tonne led to almost no loss of yield at the origin site but a 1.6 tonne gain at the release site.

Levels of egg production in northern regions are a management issue for the Tasmanian fishery and the model indicated that these would be improved by translocation. Modelling suggested that both yield and egg production benefits would be greatest when smaller females are translocated and when translocation is integrated with increased regional size limits in the north.

Economic modelling of scenarios that involved the movement of five tonnes of lobsters by charter indicated that it is possible to generate an additional kilogram of catch for around $2.60. This compares favourably with current lease costs of over $15/kg. Net state benefit was $160,000 per five tonne trip by a chartered vessel. The internal rate of return for these operations was around 200%, which constitutes an extremely attractive investment.

Three possible systems for funding translocation were developed and each involved an allocation of additional quota to fishers. Translocation appears to offer a feasible option for sustainably and substantially increasing yield by converting low growth, low value lobsters into more productive, higher value lobsters.

The outcomes of translocation of lobsters in Tasmania were examined to determine if the practice is feasible for increasing economic yield. Biological and economic models were developed and linked. This allowed the simulation of the translocation of a cohort of undersize lobsters between four sites of origin and four release sites. Sites were selected on the basis of existing data and spanned a range of growth rates from low-growth, deep-water SW sites (Maatsuyker Island and Port Davey) to rapid growth areas (King Island).

The model process involved the capture and translocation of a cohort of lobsters between the origin and release sites. The dynamics of this cohort were then modelled and contrasted against expected outcomes if the lobsters had been left at their original site. Modelling of the catch of translocated lobsters was based on current estimated harvest rates and selectivity at release sites.

Results indicated large gains in yield were possible through translocation. Capture rates of undersize lobsters at origin sites were high so that harvest of one tonne of lobsters would be expected to require less than a day (with closed escape gaps). Gains in yield of greater than 100% were possible through many scenarios although generally greatest when distances between sites were greatest. Gains in yield were trivial when lobsters were simply shifted from deep water to inshore within a region and these moves do not appear to be worthwhile. The largest gain in yield predicted was that of shifting one tonne of female lobsters from Port Davey to King Island. In this scenario, almost no yield was forgone and around 1.6 tonnes of catch was gained.

Total egg production was generally reduced by translocation although under scenarios where smaller females were translocated, both yield and total egg production could be increased. Egg production was increased in the release site for all scenarios, which implies that translocation would assist the management policy of rebuilding northern egg production. Increase of northern size limits in conjunction with translocation would act to further increase both yield and egg production.

Additional field experimentation is needed to provide input data before translocation is adopted. Results were sensitive to the survival and movement of lobsters at release, the time required for lobsters to transit growth, and the patterns in onset of maturity at the new site. Data on density dependent growth and mortality is required to evaluate the outcomes of large-scale translocations. Increased density at release sites would be expected to increase yield as harvest rate would decline, but this gain may be reduced by slower growth if translocation operations became extensive. Lower density at the origin sites would also be expected to increase yield.

The biological model contributed a range of inputs to the economic model. In addition to data on gains in yield through translocation, the biological model estimated the days required to catch a given tonnage of undersize lobsters with or without grading for sex and size, and the size structure and thus the market price categories of the catch.

The economic model considered two different options for translocating lobsters, shifting by specific charter, or by fishers retaining their undersize catch and releasing at a different site on their return journey. This analysis indicated that the cost to generate an additional kg of quota through chartered translocation was \$2.60 and \$2.84 for translocations from Maatsuyker Island and Port Davey to King Island respectively. Under a worst-case scenario for all biological parameters the cost rose to \$10/kg, which is still considerably less than the current lease price of over \$15/kg. Thus translocation appears to provide an economically feasible option for increasing catch and profitability of fishers.

State benefit from translocation was maximised where translocations were charter operations between slowest and fastest growth areas. Net State benefit for operations involving the transport of 5 tonnes was \$160,000 for these scenarios. The internal rate of return for these operations was around 200%, which constitutes an extremely attractive investment.

Translocations by fishers had lower cost than charter operations but also lower State benefits, as longer distance translocations were less feasible. Translocations by fishers between deep water SW and inshore SE provided substantial yield benefits and appear economically feasible with the caveat that a management mechanism must be developed to increase quota. This process appears problematic because the sites and quantities involved were less regulated than for charter operations.

Gains through translocation were largely associated with the increase in productivity rather than the increase in marketability. As a result, translocations from deep-water sites in the SW to shallow-water sites do not appear economically feasible.

A shortcoming of the analyses presented here was the inability to scale up scenarios to provide information on the total increase in catch and economic yield that could be achieved through translocation. This requires improved modelling of Tasmanian lobster stocks with assessment cells split into deep and shallow water. In addition, information on density dependent processes is required to determine the effects of altered density on productivity at both the origin and release site.

Management options for increasing yield through translocation were developed through port meetings. The three options developed were: (a) that fishers would transport some of their undersize catch through normal fishing operations; (b) that a government business unit would lease additional quota and this revenue would be used to fund charter and monitoring operations; and (c) that a levy on all quota holders would be used to fund operations through a government business unit. The motivation for all scenarios was that quota would be increased as some fraction of the gain in exploitable biomass (say 50%). The remaining fraction would create a net gain to the resource through translocation so that in addition to quota, egg production, opportunity for recreational catch, and environmental values would also be increased.

Under these conservative scenarios where only 50% of the increase in yield was allocated to commercial fishers, the cost for commercial fishers would be less than $10/kg of additional quota. This cost includes charter operations for the capture and release of lobsters plus research and observer costs for the operations. As lease costs in 2005 rose to in excess of $17/kg, translocation appeared to provide a feasible and economically attractive option for sustainably increasing yield and value in the fishery.

KEYWORDS: rock lobster, *Jasus edwardsii*, translocation, yield increase, sustainable development, bio-economic modelling.

3. Acknowledgments

This project was completed with the help of numerous individuals in the Tasmanian Commercial Fishing Industry who volunteered financial information about their businesses. Special mention is made of the assistance of Rodney Treloggen (TRLFA) and Ian Heathorn (Red Rock Lobster) in this area. Analyses relied on biological data collected by numerous people over several decades but was especially reliant on that collected by Stewart Frusher (TAFI). Malcolm Haddon (TAFI) assisted through the construction of size transition matrices and Tom Kompas (ANU) provided advice on the economic analysis.

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4. Background

The Tasmanian lobster resource is characterized by large spatial differences in growth and reproduction parameters. Although the biology is variable spatially, the same management rules are applied across the fishery. Fleet dynamics are also uneven and effort increasingly targets depleted inshore areas where high value, hard-shelled, red lobsters are located. Problems with the current approach include (a) massive loss of yield through growth overfishing/underfishing depending on growth rate; (b) egg production concentrated in one region, rather than naturally distributed; (c) reduced economic yield through discounting of deep water lobsters; (d) stock rebuilding objective of quota management impaired; (e) elevated potential for ecological impacts of fishing.

In 2004, management and industry requested a review of options to address these spatial problems. Of the 8 options reviewed, only translocation addressed all issues. The TRLFA, TAFI and DPIWE subsequently undertook an experiment to test some of the premises of translocation. That experiment indicated improved growth and colour change and thus further investigation was warranted. The project has been discussed and strongly supported at CFAC, CRAG, TRLFA meetings, and port meetings. In August 2004, the industry voted on the need for research to overcome spatial management options – and the motion was passed with strong support.

A research proposal to examine the potential of translocation was subsequently submitted to FRDC who requested preliminary modelling on the economic feasibility of the system. That research is presented here.

5. Need

Modelling of the Tasmanian lobster resource has indicated that loss of yield through spatial differences in growth of lobsters is greater than 25% of the TACC. Fishery management is the same across the State yet growth rates vary dramatically. Consequently, catch rates are far below their potential in northern and southern regions.

Effects of fishing on egg production/recruitment and ecology also appear poorly managed spatially with high levels of depletion in some areas while other regions are virtually unfished. Latest stock assessments have shown that regions in the north of the State have levels of egg production below 20% of virgin which is well below management targets of 25% (Gardner et al., 2005). Of concern, recruitment in some regions of the fishery have declined relative to the 1960's (Frusher et al., 2003) and model project indicate low probability of improving egg production under current management systems (Gardner et al., 2005).

Increasing catch targets high priority areas in the strategic plans of each stakeholder. The Tasmanian Government has stated their intent to pursue growth in primary industry as a key strategic area through the “State of Growth” strategy. The project squarely targets all aspects of the University of Tasmania's “EDGE agenda”, particularly through “Engagement” with the community by delivery of a substantial economic benefit. The need for this research has been identified by the commercial and recreational lobster sectors in each strategic plan for crustacean research since the first plan was produced by the CRAG in 1996, specifically under the topics of “stock enhancement” and “translocation”.

6. Abbreviations and symbols

a	Pot allocation
CL	Carapace length
co	Market colour category
com	Commercial (associated with *res*)
CP	Captured in pots (associated with *RP*)
f	female
F	Instantaneous fishing mortality (associated with *M* and *Z*)
FC	Fixed cost (associated with *VC* and *TC*)
IRR	Internal rate of return
K	von Bertalanffy growth parameter (associated with
l	Length
LEASE	Quota lease cost or opportunity cost of owned quota
LML	Legal minimum length
m	male
M	Instantaneous natural mortality (associated with *F* and *Z*)
MAINT	Maintenance costs
N	Number (associated with *W*)
NPV	Net present value
o	Origin site (associated with *r*)
p	a) Site or place in relation to cost; b) price in relation to revenue
Q	Proportion females mature (associated with *V* and *SB*)
q	Quantity (associated with *p*)
r	Release site (associated with *o*)
R	Revenue
REL	Release cost
res	Research (associated with *com*)
RL	Rock lobster
RP	Retained in pots (associated with *CP*)
S	Selectivity
s	Sex
SB	Egg production (associated with *V* and *Q*)
T	Emigration loss post-translocation (associated with *Ω*)
TAC	Total allowable catch
TACC	Total allowable commercial catch
TC	Total cost (associated with *VC* and *FC*)
tl	Translocation option (charter vs fishers retaining undersize)

TLC	Total translocation cost
TR	Total Revenue
TRA	Transport cost
TRIP	Fishing trip costs
U	Undersize capture cost
V	Eggs produced per female (associated with *SB* and *Q*)
VC	Variable cost (associated with *TC* and *FC*)
W	Weight (associated with *N*)
Y	Yield (weight)
Z	Total mortality (associated with *F* and *M*)
δ	Discount rate (annualised risk free rate of return)
π	Profit function
Ω	Transport and post-translocation mortality (associated with *T*)
L_∞	von Bertalanffy growth parameter (associated with *K*)

7. Yield and egg production.

7.1 Introduction

This section describes the development of a biological model that provides input data for economic analyses. In addition it contributes to objective 6: identifying the need for further field experiments for data collection.

The biological model incorporates a range of input data, which are described in more detail in Appendix 3.

The Tasmanian rock lobster fishery consists of the harvest of around 1500 tonnes per annum by the commercial sector and an additional 150 tonnes by the recreational sector (Lyle and Morton, 2004; Gardner et al., 2005). Quota management was introduced in 1998, which reversed the previous trend of declining catch rates and led to an increase in legal size biomass for the state as a whole. Management attention is now more focussed on regional management issues and also on opportunities for growth in the industry.

Spatial issues are a recurrent issue for management of *Jasus edwardsii* (Hutton, 1875) fisheries in Australia and New Zealand due to regional differences in the biology lobsters and the behaviour of the fleet. In Tasmania, quota management compounded the heterogenous distribution of effort by driving fishing effort into regions where catch rates were lower but the value of individual lobsters is highest – shallow water (Bradshaw, 2004). As a result, there is now a trend of increasing stocks in deeper water areas around Tasmania; similar patterns appear to be occurring across the range of the species where quota management has been introduced (Pers. comm. David Hobday, DPI Victoria; Adrian Linnane, SARDI South Australia).

Heterogeneity in biological parameters has been of concern for *J. edwardsii* management well prior to quota management as basic input controls such as size limit are poorly suited to many regions. Effects include vastly different levels of egg production and biomass relative to virgin stocks between regions. Management response to these differences includes different size limits and regional quotas although this is at a very coarse scale. For example, only two different LML regimes have been implemented across southern Australia.

Several specific issues of a spatial nature now confront managers of rock lobster stocks across southern Australia. Egg production is close to virgin levels in some areas while others are highly depleted. Biomass follows similar trends with concerns about local ecological effects in depleted areas. Yields are consequently sub-optimal in many regions with harvest at sizes well above or below that suggested by per-recruit analyses (Punt et al., 1997).

Numerous management options have been discussed to deal with these spatial problems. They include lower size limits in slow growth regions and higher limits in others, special quota incentives to push commercial effort offshore, closed areas, and maximum size limits. An option that has been promoted by the commercial industry is the shifting or translocation of lobsters from one region to another. This proposal involves shifting lobsters from regions where growth is slow so that yield is being lost through sub-optimal LML or from deep-water areas that are lightly fished due to lower prices for pale-coloured deep-water lobsters. Lobsters could be released into inshore regions where growth is faster, market process higher, and where there is a desire to rebuild stocks due to concerns about the possible ecological effects of lobster fishing (Lafferty, 2004). Discussions on the adoption of translocation as a management tool have also included discussion of increased size limits (LML) in the north with the objectives of raising the exploitable biomass, catch rates and egg production. Managers and Industry are interested in the way that translocation could interact with any changes in LML.

The presence of extreme spatial heterogony in growth has led to several translocation trials over many years. Winstanley (1975) discussed translocations in the 1940s to manipulate egg production and again in 1971 to increase yield. Experimental translocation of around 1200 lobsters was undertaken in 2004 and this demonstrated that lobsters adopt the colour and growth rates of their new location. However, numerous issues have been raised that require further research before translocation could be considered for management and pilot scale trials would clearly be warranted. This type of research is potentially costly and thus needs to be both justified and well targeted. The modelling presented here provides a guide to the effect of translocation on yield and egg production plus it serves to identify biological parameters that have greatest influence on translocation outcomes and thus should be targeted in any future research.

7.2 Methods

7.2.1 Assumptions and limitations of the biological model

Assumptions have been made in the construction of the model that influences outcomes. These relate to data inputs of biological and also the model structure.

Sites

The model uses information from several sites around the Tasmanian coast that have received a high level of research sampling. There is an implicit assumption that these sites represent broader regions around the coast, both in terms of biological information such as growth, and also in terms of fishery characteristics such as catch rate and expected sex ratio in catches.

Growth

Growth was estimated for this model from tag recapture data. We have assumed that tagging does not retard growth and that the von-Bertalanffy growth model described in Appendix 3 provides an appropriate basis for construction of the size transition matrices. Crustacean growth is step-wise through moulting, and this can create biases in the estimation of growth parameters. For example, consider the case where a lobster grows 10 mm in a single annual moult. If tagging and recapture occur one week before and after the annual moult, growth would appear very rapid over the two-week period of data collection. Conversely, if the lobster were tagged immediately after the moult and recaptured 11 months later, no growth would be recorded despite the protracted 11-month period at large. The lobster would be growing at the same rate in both cases, but estimates of growth parameters would differ markedly.

Risk of bias was reduced by restricting analyses to sites with extensive recapture data and where tagging occurred over a protracted period of time. Future modelling would be improved by incorporating interannular time-steps in the estimation of growth parameters.

Time to transit growth

The biological model of translocation contrasts populations of lobsters left at their original site or moved to a new site. Lobsters that are translocated are assumed to adopt the growth rate of their new site. While preliminary field trials have demonstrated that this is a valid assumption, there is still some uncertainty about the time required for lobsters to transit between the different rates. We have examined the effect of different transit times with sensitivity testing.

Length-weight

Length-weight parameters were estimated for each sex and for deep- and shallow-water lobsters separately. The length-weight relationship varies with moult stage, which was not incorporated in to the model because an annual time step was used.

Natural mortality

Population models such as that used here are typically sensitive to estimates of natural mortality, yet natural mortality is typically poorly estimated. We estimated natural mortality here from two extensive data sets and tested the sensitivity of these analyses on model outcomes (Appendix 3).

We assumed constant natural mortality with length on the basis of the form of residuals from the length-based catch curve analysis described in Appendix 3.

Female size at maturity

Female size at maturity was estimated by a standard approach of fitting a logistic curve to catch data. This has the implicit assumption of equal catchability of immature and mature lobsters of the same length.

Transition of maturity

As per growth, lobsters that are translocated are assumed to adopt reproductive traits of local lobsters at their new site. Maturity has an added complexity as it is unclear what will occur if a small but mature lobster is translocated to fast growth site where local lobsters of the same size would normally be immature – do these females revert to being immature or remain mature? We used sensitivity testing to examine both the effect of different times to transit to local maturity pattens, and also the issue of whether or not small mature females can revert to being immature.

Sperm limitation

Egg production was assumed to be independent of the male population.

Density dependence

Density dependent interactions can be expected to influence the outcomes of enhancement operations through changes in both growth and mortality (Lorenzen, 2005). Incorporation of density dependence into a model of translocated animals is more complex as increases in density at the release site will be accompanied by decreases in density at the harvest site. Thus there would be a prediction of translocation leading to increased yield per recruit at the harvest site and decreased yield per recruit at the enhanced site. This aspect of translocation was not addressed in the current model as data were not available - it appears to be an important issue for future research.

Fishing mortality

Estimates of regional Tasmanian fishing mortality were obtained from several sources, described in Appendix 3. None of these sources provided separate estimates for deep and shallow water although differences clearly exist due to fishers targeting higher value lobsters in shallow water. The sensitivity of translocation benefits to estimates of fishing mortality from different depths was tested here. Obtaining estimates of deep and shallow fishing mortality is an important research need were translocation to be adopted.

Catch rates

Two types of catch rate data are used here: commercial catch rates and research catch rates. Research catch rates from pots without escape gaps were assumed to estimate catch rates of undersize lobsters in translocation operations. This was a conservative assumption because research trapping is not conducted with the objective of maximising catch rates.

Stock size

Analyses conducted here were intended to examine the feasibility of translocation. No attempt was made to structure the model so that it would provide guidance on the scale of possible translocation. This would require information on deep water stock sizes, for which there is currently inadequate catch sampling data.

Release mortality

Release mortality was assumed to be equivalent to that of 35 mm, tank-reared juveniles released by Mills et al. (2005). This was conservative because translocated lobsters would be larger and experienced in living with predators (rather than in tanks).

Movement at release

Estimates of survival by Mills et al. (2005) incorporated loss through movement. We conservatively assumed that a lobster that walked away from the release site was lost from the fished population.

Fleet dynamics

The model presented here does not incorporate fleet dynamics as there is no estimate of total stock involved, and fleet movements are also a function of the TAC. Fleet dynamics would be expected to lead to shift in effort towards release sites as catch rates increased. If translocation led to an increase in exploitable biomass, harvest rates would drop relative to the fixed rates used in this model – which would lead to more positive outcomes for the fishery. Hence our approach was considered conservative.

7.2.2 Sites

Eight sites around Tasmania were chosen to examine translocation exercises (Figure 1). Each site had been sampled for previous research projects so extensive data were available. The four deep-water sites were between 70 and 120 m depth with the exception of Sandstone Bluff, which was 40-60 m. All shallow sites were less than 40 m. The Taroona site is a marine reserve and was assumed to be representative of fished waters in the region in terms of growth rates and maturation. This range of sites allowed the evaluation of translocations over short distances from deep to shallow reef, and also longer distance translocations from south to north.

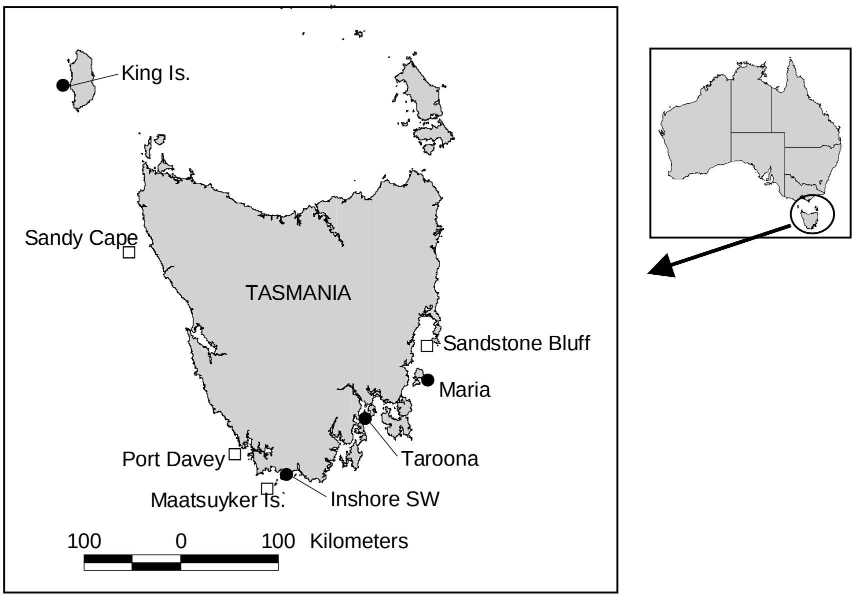

Figure 1. Sites selected for model evaluation of the translocation of lobsters. Maatsuyker Is., Pt. Davey, Sandy Cape and Sandstone Bluff were selected as slow-growth, deep-water sites for capture of lobsters (hollow squares). Remaining sites were shallow water (<40 m) release sites (solid circles).

7.2.3 Population dynamics model

The outcomes of translocation were modelled with a sex and size structured model that had 2 mm size categories from 60 to 200 mm CL and yearly time steps. The model had three modules. First, lobsters below the legal minimum length (LML) were captured at deep-water sites. Scenarios included taking all lobsters below LML or the grading of catch by sex or size. Two outcomes for this sample of lobsters were then examined. Lobsters could be transferred to a new, shallow-water site with more rapid growth rates. The alternative fate was the control or status quo situation where lobsters were allowed to remain at their original site.

Selection of lobsters for translocation

The expected number of lobsters of each sex s in each length (size bin) l captured per potlift $N_{s,l}^{CP}$ was based on the numbers captured in research sampling trips $N_{s,l}^{res}$. These were scaled by the catch of the legal-sized component of the research catch ($N_{f,\geq 105}^{res}$ for females and $N_{m,\geq 110}^{res}$ for males) relative to the legal-sized catch of commercial operators in weight C^{com} in the same depth range and in the same logbook fishing block (roughly a 50 x 50 km block) for years 2002 to 2004 inclusive. Effort in both research and commercial fishing operations was in units of potlifts (f^{res} and f^{com}). This scaling on the basis of legal-sized catch rate was necessary to account for greater efficiency of commercial operators who would conduct translocation exercises, relative to the catch rates achieved in research voyages where length frequency information was collected.

$$N_{s,l}^{CP} = \sum_s \sum_l N_{s,l}^{res} \left[\frac{C^{com} / f^{comm}}{\left(\left(\sum_l N_{f,\geq 105}^{res} W_{l,d}^{f} \right) + \left(\sum_l N_{m,\geq 110}^{res} W_{l,d}^{m} \right) \right) / f^{res}} \right]$$

Mass at length for each sex $W_{l,d}^{s}$ was determined using parameters estimated from samples of deep-water (>60 m) lobsters.

$W_{l,deep}^{female} = 0.000271 l^{3.124}$ $W_{l,deep}^{male} = 0.000285 l^{3.102}$ (unpublished data, TAFI).

The sex and length composition of the sample of undersize lobsters selected for translocation affected the economic outcomes through differences in the population dynamics of released lobsters and also through the cost required for additional fishing effort if undersize lobsters were graded prior to translocation. The weight of lobsters retained per potlift for translocation W^{RP} varied through grading to alter the sex and length of the number of lobsters retained per potlift for translocation ($N_{s,l}^{RP}$),

$$W^{RP} = \sum_s \sum_l N_l^s W_l^s$$

Weights and numbers of lobsters retained for translocation were determined in terms of number of lobsters in each sex and size category per tonne of wet-well capacity $N_{s,l}^{wetwell}$ and the number of potlifts $f^{capture1}$ required to capture a given tonnage of wet-well capacity $W^{wetwell}$. Both these measures affect cost of capture and thus contribute to understanding the potential cost of translocation.

$f^{capture1} = W^{wetwell} / W^{RP}$ and

$$N_{s,l}^{wetwell} = f^{capture1} N_{s,l}^{RP}$$

Dynamics of translocated lobsters after release

The equation that describes the number of animals of each sex s from each initial size l class after one year $t+1$ takes account of the number in each sex and size class at the beginning of the year $N_{t,l'}^{s}$ (in the first year, specifically the number released), the proportion of lobsters that grow from size class l into size class l' according to a transition matrix $X_{l',l}^{s}$, instantaneous natural mortality M, selectivity of the gear $S_{l'}^{s}$, exploitation rate of fully selected lobsters greater than the minimum legal length $F_{t,\geq LML}$, proportion emigrating from the release region T_t, and the proportion dying through the process of transport and release Ω_t (comparable to discard mortality):

$$N_{t+1,l}^{s} = \sum_{l'} X_{l',l}^{s} N_{t,l'}^{s} e^{-M} \left\{1 - S_{l'}^{s} F_{t,\geq LML}\right\}(1 - (T_t + \Omega_t))$$

Von Bertalanffy growth curve parameters estimated from each capture and release site described changes in size through time with values shown in Table 1. No estimates were available for females from Port Davey so parameters from the adjacent site, Maatsuyker Is. were used for model scenarios. It is unclear how long lobsters take to adopt the growth rate of their new location so the time to transit between growth rates was varied from 0 to 2 years.

Table 1. Von Bertalanffy growth curve parameter estimates. Insufficient recaptures of female lobsters from Port Davey were obtained for growth to be estimated. (source: unpublished data, TAFI).

	Females				**Males**			
Site	**n**	L_∞	K	σ	**n**	L_∞	K	σ
Deep								
Maatsuyker Is.	1862	106.61	0.0437	0.9457	4144	122.42	0.1954	2.6006
Port Davey	-	-	-		1182	116.26	0.1938	1.8507
Sandstone Bluff	4677	107.40	0.4072	1.3251	2667	122.28	0.4592	3.2661
Sandy Cape	166	127.39	0.1701	5.5053	124	178.12	0.1390	7.6030
Shallow								
Inshore SW	2768	112.28	0.0978	1.2171	1496	122.67	0.3014	2.7679
Maria Is.	539	112.73	0.0979	2.4228	366	122.67	0.3015	3.9531
Taroona	5304	132.41	0.1760	2.7050	7413	182.44	0.2279	4.2466
King Island	375	147.79	0.3029	3.1428	472	184.26	0.2601	4.2871

Yield resulting at the release site Y_r from each translocation exercise was determined by:

$$Y_r = \sum_t \sum_s \sum_{l \geq l_{\min}^s} N_{t,l}^s W_{l,d}^s S_l^s F_t$$

where $l_{\min}^s$ is the legal minimum length for each sex and weight at length and depth for each sex $W_{l,d}^s$ was generally based on data from shallow depths.

$W_{l,shallow}^{female} = 0.000271 l^{3.146}$ $\quad W_{l,shallow}^{male} = 0.000285 l^{3.125}$ (unpublished data, TAFI).

Exceptions to this occurred when testing the effect of the time taken to undergo transition from deep- to shallow-water morphology and thus adopt the new weight length relationship. This was allowed to vary from 0 to 2 years.

No attempt was made to differentiate the catch likely to be taken by different sectors as commercial, recreational, illegal and aboriginal are all encompassed in the estimates of fishing mortality applied.

The effects of translocation on egg production was of interest as most proposed release sites are considered to have low levels of egg production:

$$SB_p = \sum_t \sum_l Q_{l,p} V_l N_{t,l}^{fem}$$

where SB_p is the egg production at each place or site p. This was determined from the number of female lobsters surviving in each year and size class $N_{t,l}^{fem}$, the proportion of females in each size class that were mature $Q_{l,p}$ and the number of eggs produced by a female in each size class V_l.

$Q_{l,p}$ was a function of both size class l and the place or site p where the lobsters were either taken from or released into:

$$Q_{l,p} = e^{(\alpha+\beta l)} / (1 + e^{(\alpha+\beta l)})$$

where α and β are the parameters of the relationship with values given in Table 2. Two alternatives for $Q_{l,p}$ were examined: females could adopt Q_l of the new site, which may entail mature females becoming immature again, or they could retain Q_l of the original site.

V_l was determined from the power relationship (Hobday and Ryan, 1997):

$$V_l = 0.03161 l^{3.359}$$

Total egg production per translocation release was determined by:

$$SB = \sum_t SB_t$$

Table 2. Values for the parameters of the relationship describing maturity of females (source: unpublished data, TAFI).

Site (p)	**Deep /Shallow**	α	β
Maatsuyker Is.	Deep (>70 m)	-27.64	0.4122
Port Davey	Deep (>70 m)	-12.89	0.1980
Sandstone Bluff	Deep (40-60 m)	-16.46	0.2063
Sandy Cape	Deep (>70 m)	-6.426	0.0895
King Island	Shallow (<40 m)	-19.52	0.1795
Taroona	Shallow (<40 m)	-18.94	0.2270
Inshore SW	Shallow (<40 m)	-17.18	0.2556
Maria Is.	Shallow (<40 m)	-14.91	0.1900

Dynamics of lobsters at original site

All translocation scenarios were contrasted with the alternative of leaving the undersize lobsters in their original location where a portion may reach legal size and be captured by the fishery. At the original site, the equation that described the number of animals of each sex from each initial size class after one year $t+1$ was the same as for the release site except that no allowance was made for mortality through movement and release:

$$N^s_{t+1,l} = \sum_{l'} X^s_{l',l} N^s_{t,l'} e^{-M} \left\{ 1 - S^s_{l'} F_{t,\geq MLL} \right\}$$

Yield that resulted from fishing of the lobsters that were not translocated and left at the original site was determined by:

$$Y_o = \sum_t \sum_s \sum_{l \geq l^s_{\min}} N^s_{t,l} W^s_{l,d} S^s_l F_t$$

where weight at length $W^s_{l,d}$ was based on deep water lobsters.

Parameter estimation

All parameters used for the model fit were assumed to be known and were varied for sensitivity analyses. Base case values of instantaneous natural mortality were set at 0.1, which is lower than length-based catch curve analyses of data from two sites used in this study, Maatsuyker Is. and Taroona (Appendix 3). Those analyses were unadjusted for selectivity and estimates of 0.1 have been used in modelling stocks of *J. edwardsii* elsewhere (Punt and Kennedy, 1997; Hobday and Punt, 2001).

Base case estimates of selectivity and exploitation rate parameters were derived by the length-based model developed by Punt et al. (1997; Gardner et al., 2005).

Base case values of the proportion dying through the process of transport and release Ω_t and emigration T_t were from Mills et al. (2005). They reported total loss ($\Omega_t + T_t$) of 5% from the release of juvenile *J. edwardsii* around 35 mm CL following culture for 12 months in tanks. We expect that their losses would be greater than with the larger, wild lobsters modelled here but have conservatively assumed similar outcomes by using base case rates of 2.5% for each parameter. Additional information on rates of movement comes from Gardner et al. (2003) where 90% of lobsters moved less than 1 km per annum. Note that loss through movement requires lobsters to move away from the release site to areas not otherwise fished, that is, to be lost from the fishable population.

7.3 Results

7.3.1 Outcomes for yield and egg production

Estimated increases in yield through translocation were greatest when lobsters were translocated from southern regions to northern regions with most increase from the translocation of females (Figure 2). The greatest estimated gain in yield was a 1.6 t increase from the translocation of 1 t of female lobsters from Port Davey to King Island. Short distance movements from deep to shallow waters in the SW had little impact on yield.

Effort required to catch 1 tonne of undersize lobsters is of interest as this affects the economics of translocation. Estimates of the days required to capture one tonne of undersize lobsters in deep water were based on 150 pot lifts per day, being three cycles of the maximum pot holding of 50. Days required to capture 1 tonne of undersize lobsters was least for the southwestern sites with only partial days required when the catch is not graded.

Although grading of undersize lobsters on the basis of sex or size increases the effort and thus cost of translocation, this may provide nett gains as yield can be increased. Results shown in Figure 2 indicated that if the catch were graded to increase the proportion of females, with no grading for size, then gains in yield would be increased. This conclusion appears mainly a function of the size structure of females in the undersize catch as they tend to be smaller than males. If lobsters were graded by size in addition to sex, greatest gains would be made by translocating smaller lobsters, with the effect of sex less pronounced and inconsistent between sites when scaled by size (Figure 3). A greater number of lobsters will be translocated if they are graded to select smaller sizes, which clearly contributes to the patterns seen in Figure 3.

The effect of size of translocation on egg production followed a similar trend to that of yield although in contrast, total egg production was often reduced (Figure 4). Egg production was reduced most when larger females were translocated. Increased egg production was indicated for translocations from Maatsuyker Island when very small females were shifted, generally less than 75 mm CL for most release sites. It is unknown how the maturity of translocated females will respond, whether they will adopt the maturity patterns of their new site, which could involve mature females reverting to immaturity. This uncertainty had little impact on predicted egg production at most release sites except the highest growth site, King Island, where substantially different outcomes are indicated.

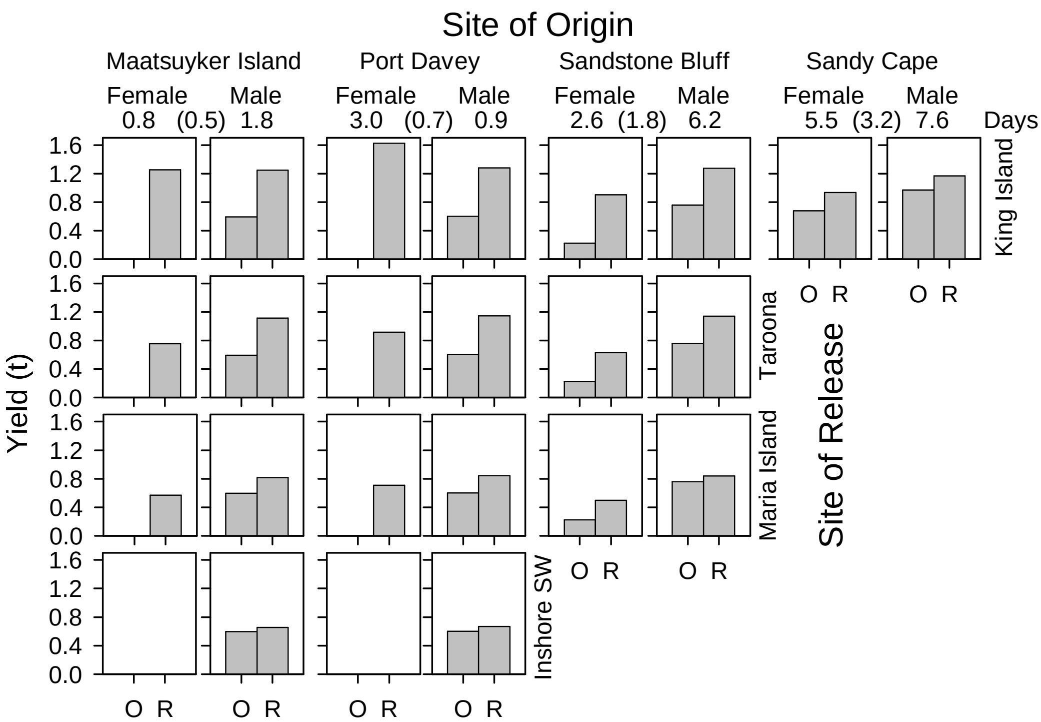

Figure 2. Estimated future yield from 1 t of undersize lobster catch either left at the site of origin (O) or translocated to the release site (R) under base-case conditions. Values for "Days" are the average number of days required to catch 1 tonne of undersize lobsters in the deep-water sites assuming 150 trap lifts per day (3 cycles of the maximum trap limit of 50). Note that this assumes catch was graded by sex but not size of undersize lobsters. Values in parentheses are days required if catch was not graded by sex.

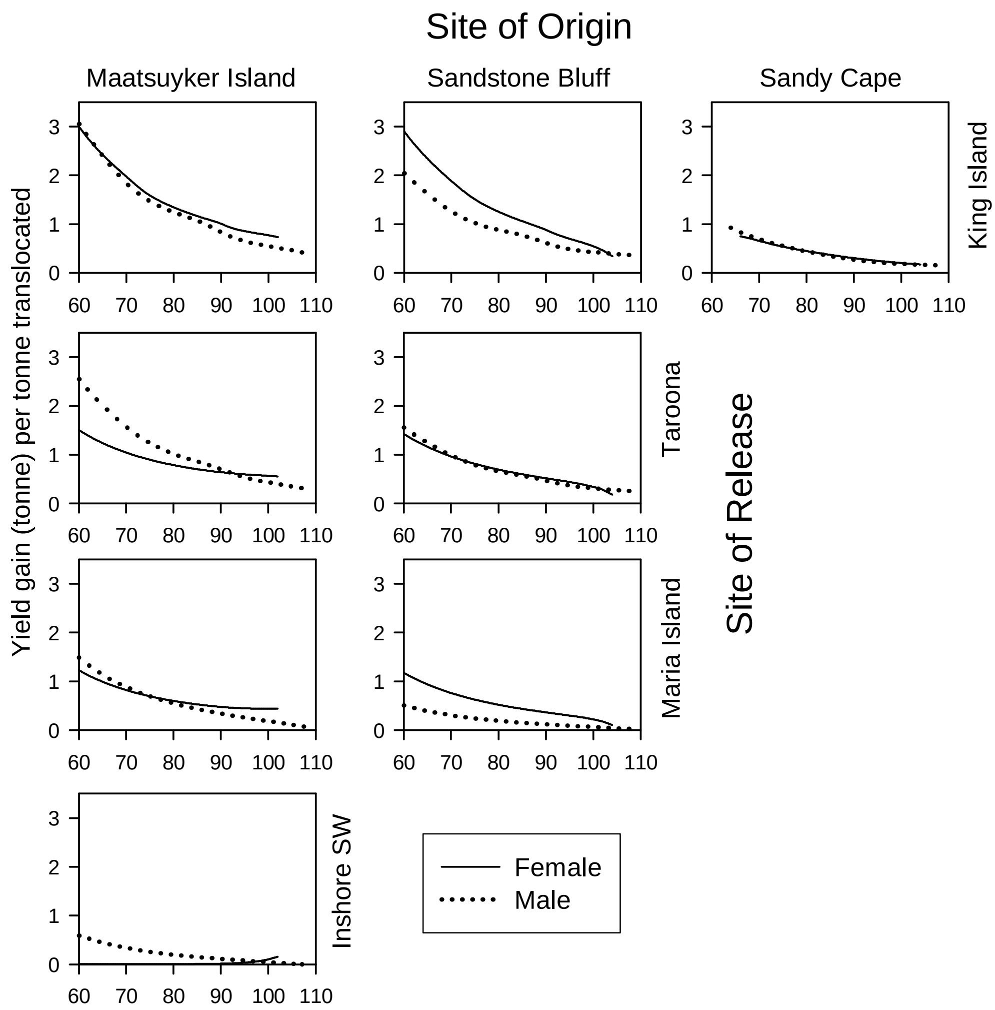

Figure 3. Effect of size and sex of translocated lobsters on gain in yield (Y_r - Y_o) through translocation. Results from lobsters originating from Port Davey were similar to those from Maatsuyker Is. and are not shown.

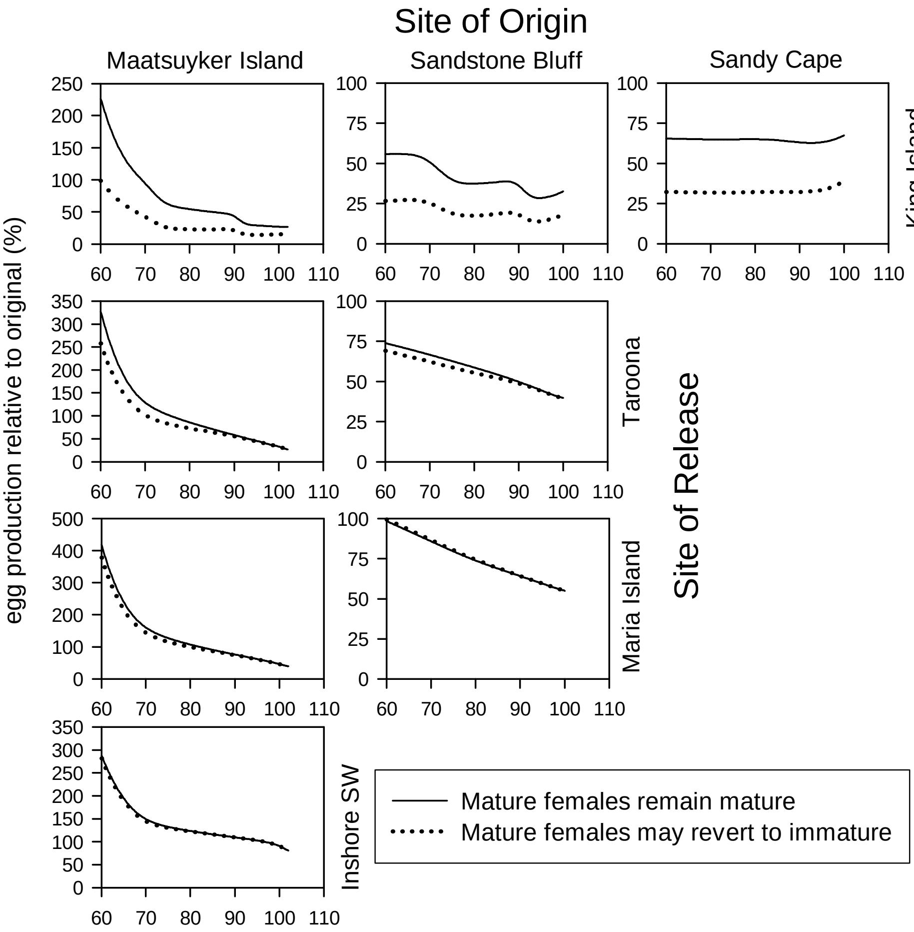

Figure 4. Effect of size of translocated lobsters on percentage change in egg production $\left(SB_{release} - SB_{original}\right)/SB_{original}$ through translocation. Two options for female size at maturity ($Q_{l,p}$) were explored: translocated mature females could remain mature at their new site or they could adopt the $Q_{l,p}$ of their new site, which in many cases would involve reverting to an immature state. Results from lobsters originating from Port Davey were similar to those from Maatsuyker Is. and are not shown.

7.3.2 Interaction of translocation with other management measures

The increased exploitable biomass resulting from translocation will reduce harvest rates in fisheries where fishing mortality is managed, such as with output control management of the commercial Tasmanian lobster fishery. This reduction in harvest rates would tend to compound yield benefits from translocation with gains indicated by reductions in harvest rates (Figure 5). Note that our model did not include density dependent mortality or reduction in growth, which would lead to less optimistic predictions of yield at lower harvest rates than shown in Figure 5.

Recent length based model estimates of harvest rates from the regions chosen here as possible release sites ranged from 0.36 in the King Island area to 0.61 at the Maria Island area (Punt and Kennedy 1997; Gardner et al., 2005). Those estimates were for all depths combined and thus higher harvest rates would be expected from the shallow water areas that would be targeted as translocation release sites. Our base-case scenario for King Island was a harvest rate of 0.5, which results in predictions of reduced levels of total egg production through translocation, possibly less than 50% of the level at the original location. Reduction in harvest rate at the release site would offset this lower egg production.

Increases in female size limits from the current 105 mm CL have been proposed for Northern Tasmania, including King Island, to improve catch rates and regional egg production. Increases to LML appear to have little impact on yield from translocation except at relatively large changes of greater than 130 mm CL. Impacts on egg production were more substantial indicating that changes in LML could be used in conjunction with translocation to increase yield and maintain total egg production.

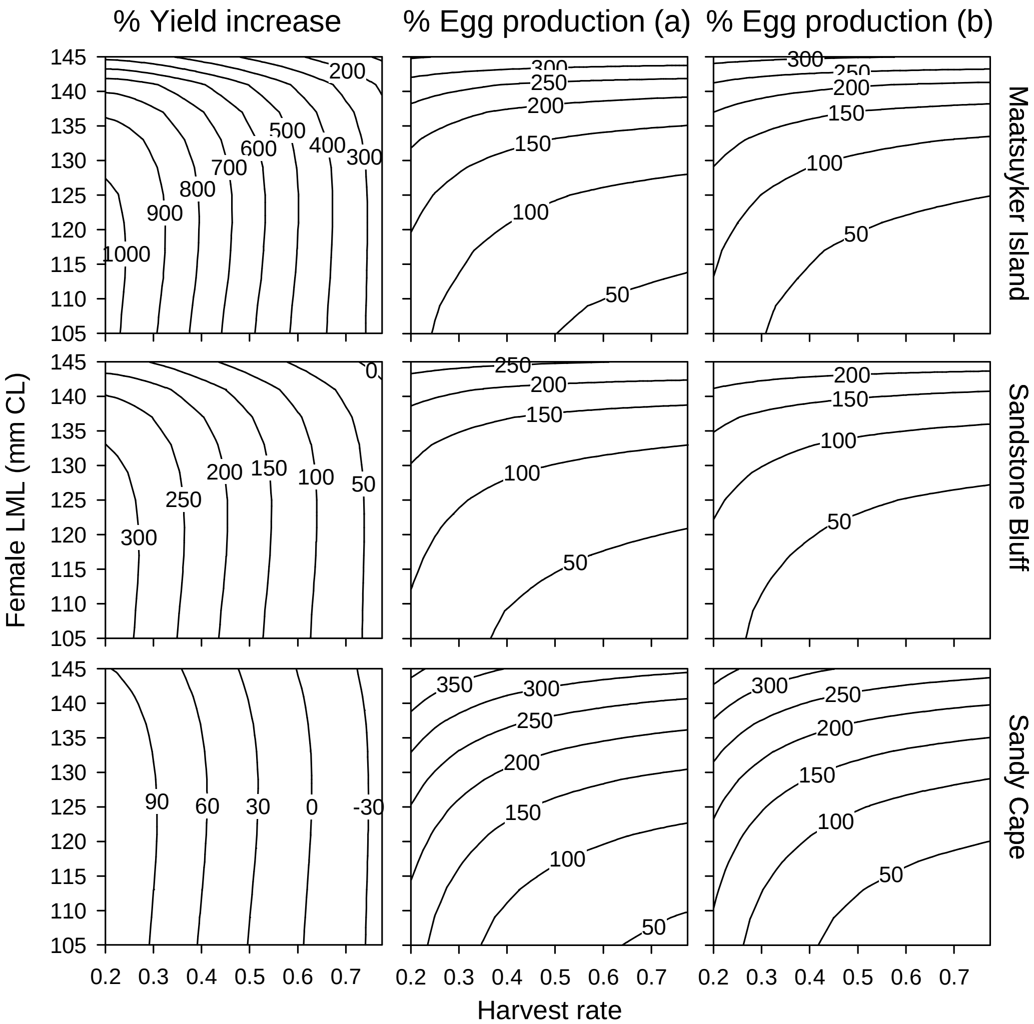

Figure 5. Effect of change in harvest rate and legal minimum length LML at the King Island release site on percentage change in yield $\left(Y_{release} - Y_{original}\right)/Y_{original}$ and egg production $\left(SB_{release} - SB_{original}\right)/SB_{original}$ from translocated lobsters. Translocation scenarios are based on movement of both male and female lobsters (ungraded undersize catch). Current LML for all sites is 105 mm CL but there is interest in increasing this limit in northern regions, represented here by King Island.

7.3.3 Sensitivity analysis

Model outcomes for yield were sensitive to changes in natural mortality, especially when some degree of density dependence was evaluated by lowering mortality in shallow sites and rasing it in deep water sites (Table 2). Other parameters with relatively large influence were the rate of adoption of the growth rate of their new site, and the loss of released lobsters through release mortality or emigration loss.

Table 2. Estimates of absolute increase in yield from translocation of 1 tonne of ungraded undersize lobsters and the percentage increase relative to the same cohort left at their original site. Results are for the base-case specifications and for a range of sensitivity tests.

	Gain in yield (additional tonnes per tonne translocated, % increase)			
Model scenario (base case values)	Maat. Is. to Inshore SW.	Maat. Is. to Taroona	Maat. Is. to King Is.	Sandy Cp. to King Is.
Base-case	0.02, 13%	0.68, 390%	1.08, 614%	0.23, 29%
Emigration loss T (0.025) OR Release mortality Ω (0.025)				
0.00 yr^{-1}	0.03, 16%	0.71, 403%	1.11, 633%	0.26, 32%
0.05 yr^{-1}	0.02, 10%	0.66, 379%	1.05, 597%	0.21, 26%
0.10 yr^{-1}	0.01, 5%	0.62, 355%	0.99, 563%	0.16, 20%
Natural mortality M (0.1)				
0.07 yr^{-1}	0.02, 9%	0.79, 377%	1.16, 558%	0.21, 24%
0.2 yr^{-1}	0.03, 25%	0.44, 426%	0.83, 799%	0.25, 45%
Natural mortality M spatial difference (deep, shallow)				
0.15 yr^{-1}, 0.07 yr^{-1}	0.10, 71%	0.86, 645%	1.24, 928%	0.45, 68%
0.20 yr^{-1}, 0.05 yr^{-1}	0.15, 143%	1.00, 957%	1.36, 1303%	0.62, 112%
Adoption of new growth rate (0 yr)				
1 yr	0.02, 9%	0.61, 347%	0.96, 550%	0.16, 20%
2 yr	0.01, 6%	0.54, 308%	0.86, 489%	0.09, 12%
Adoption of new morphology (0 yr)				
1 yr	0.02, 13%	0.68, 390%	1.08, 614%	0.23, 29%
2 yr	0.02, 12%	0.67, 386%	1.06, 607%	0.20, 25%

7.4 Discussion

These analyses were intended to serve as an indicator of the probable impacts of translocation on total biomass available to the fishery and egg production. Gains in yield were often substantial with greatest increases when lobsters were translocated from Port Davey or Maatsuyker Island to King Island. In these examples, yield could be increased several fold. In contrast, small-distance translocations from deep water in the SW to nearby inshore areas do not appear to be worthwhile.

There appears to be scope for additional benefits to the fishery through combining translocation with other spatial management techniques. Regional size limits appear to provide significant opportunity for increasing yield with gains in yield obtained through changes in the size limit of females to 125 mm CL or more. Translocation appears to integrate well with elevated northern size limits because it would act to reduce harvest rates, thus compounding gains in yield. The two systems effectively produce a process of positive feed back on yield. While density-dependant processes ultimately counter positive feedback, there is likely to be scope for considerable gains to be made before gains are affected. This is based on the rapid rise in catch rates of *Jasus edwardsii* in South Australia, which was attributed in part to positive feedback of declining harvest rates on fishers catch rates (Ward et al., 2002).

While our results show that translocation can lead to substantial gains in yield, the need for further research before the approach could be adopted for management is also indicated. Economic analyses are also required to determine the costs and economic benefits of translocation and ultimately if the exercise is feasible. The model developed here provides economic inputs of effort and yield, plus size composition of catch, which is important because of grading of lobsters for sale by size and colour.

The magnitude of possible translocation operations needs to be evaluated with population modelling akin to stock assessment modelling. The length based model developed by Punt and Kennedy (1997) for Tasmanian stocks provides estimates of undersize stocks by region and this would serve as a basis for future population model development. That model currently provides estimates of around 3 million undersize females in the SW that never reach legal size (Haddon et al., 2005).

Field-testing of translocation and quantification of some of the biological input parameters appears warranted. These parameters include release mortality, movement at release, and time to transit growth. Our model did not include density dependent processes but this is required for modelling of large-scale translocation and estimation of the total magnitude of gains in yield that could be made. Without the inclusion of these processes the ultimate conclusion of any modelling would presumably be that all lobsters from the SW should be moved to the NW. Density dependent processes would also be expected to be influencing current yield in the SW so modelling of translocation should aim to quantify the improved productivity in that region. Insight and quantification of these processes would be gained by a pilot trial that removed lobsters from a site in the SW and enhanced a site in the NW.

A concern of fishers in south western regions is that translocation would lead to depletion of the reefs that they often operate in. While it is true that translocation would be expected to reduce the number of lobsters recruiting to the fishery in these regions (ignoring productivity gains from reduced density), the effect that this would have on catch rates cannot be predicted. This is because the response of the fleet to increased catch rates in northern areas is not clear. Historically the fleet has been highly responsive to spatial differences in catch rate with effort shifting either through movement of boats or change in the spatial distribution of leasing of quota (Frusher et al., 2003a). Our expectation then is that translocation of lobsters from south to north would lead to similar shift in effort with a net increase in exploitable biomass across both regions.

Industry were also interested in the effect of translocation on egg production and we observed net declines in total egg production under most translocation scenarios. This was effectively the result of increased fishing mortality of females that previously had almost complete protection from the minimum legal size limit. Harvest of females inevitably reduces egg production so the aim of management of the Tasmanian lobster is not to avoid egg production but to maintain it above desired levels. Current estimates of egg production relative to the unfished state are around 100% in the SW but only around 15% in the NW (Haddon et al., 2005). Due to these spatial differences, management policy is directed to increasing levels of egg production in the northern region and our results show that translocation would be beneficial for this policy. Although egg production may be reduced in the south, there appears ample scope for some reduction without impacting sustainability.

The outcomes of translocation on egg production were complex and a function of size at onset of maturity, fecundity at size, growth rates and removals from both harvest and natural mortality. While most translocation scenarios led to a reduction in total egg production, some scenarios led to an increase in total egg production. Greatest gains in total egg production were made when small females (<70 mm CL) were transported from the SW to more moderate growth areas such as Maria Island.

8. Economic feasibility and outcomes of translocation

8.1 Introduction

This section describes the structure and outcomes of an economic model that interacts with the biological model described in Chapter 7. Results address objectives 1 (To determine the costs associated with translocating lobsters), 2 (To model the economic outcomes of translocation based on available biological data), 3 (To combine the cost and economic outcomes into a bio-economic model), 4 (To model the economic viability of large-scale translocation operations to achieve yield increases), and 5 (To identify crucial input data that impact on the economic viability of translocation).

The Rock Lobster (RL) industry makes a significant contribution to the Tasmanian economy with a total beach value of 65 million AUD in 2002-03 and 46 million AUD in 2003-04. An estimated 700 people are employed directly through the RL fishing, processing and handling sectors.

Current management of the commercial sector is based on both input and output controls. Input controls including limited entry, closed seasons and restrictions on pot (trap) number. The 240 active vessels are licensed to carry varying numbers of traps ranging from 15 to 50. In 2005, the quota allocation was 145 kg of rock lobster per pot.

The fishery has exhibited a trend of increasing biomass and catch rates over the last decade although this stock rebuilding has not been evenly distributed around the coast (Witt et al., 2004; Gardner et al., 2005). These spatial patterns are substantially the result of socio-economic changes that have occurred since the introduction of quota management. Bradshaw, Wood and Williamson (2001) showed that effort has become concentrated on higher priced rock lobsters from inshore waters because fishers have lost the ability to increase revenue through increasing catch. The reason for the higher market price for inshore lobsters is their higher survival in overseas shipments and their deeper red colour, which is preferred by consumers in Asian markets (Ford 2001). The consequence of this shift in effort inshore is that catch rates can be less than half of those offshore (Gardner et al., 2005).

Traditionally stock enhancement of marine fish populations were aimed at rebuilding, enhancing or augmenting natural populations for recreational or commercial purposes. This management approach has been implemented over many years both in Australia (Taylor et al., 2005) as well as internationally (Hilborn 1998, Lorenzen 2005). There are many marine enhancement programs worldwide for example for salmon (Kaeriyama 1989, Ishida *et al*. 1993, Boyce *et al.* 1993), cod (Svasand *et al.* 2000), and flounder (Kitada *et al.* 1992).

The proposed translocation of Tasmanian RL is similar to a marine enhancement program in that the aim is to enhance the natural wild population. The concept of translocation is to shift undersize RL from areas where they grow slowly to areas where they achieve higher growth rates and thus generate gains in stock productivity. In a fished stock the aim is to capture revenue that would otherwise not be realised.

Economic evaluation was one of the 10 critical steps outlined by Blankenship and Leber (1995) in the responsible development of an enhancement program. These are ideally undertaken prior to their implementation and incomplete information is the norm in these *ex ante* evaluations. This approach is the one adopted here and is preferred to the *ex post* economic assessment of enhancement programs as *ex post* assessments increase the risk of poor investment in unviable enhancement programs (Hilborn 1998).

The purpose of this paper is to report the results of a bio-economic model used to evaluate the biological and economic consequences of translocating RL from four different slow growth areas to four higher growth areas around the State of Tasmania. The fisher may not directly incur the cost of translocating RL. However, a translocation program is only likely to be sustainable if the cost of translocation is known and any potential benefits can be weighed against costs incurred.

This is an *ex-ante* bio-economic analysis with a need for an *ex post* bio-economic assessment to determine the actual success of the program. Parameters that significantly affect outcomes are identified and these should be targeted in future field trials.

8.2 Methods

8.2.1 The Tasmanian Rock Lobster fishing industry

Each vessel in the RL fleet has a maximum rock lobster pot allowance based on the size of the vessel. Quota units are tied to the number of pots so that a skipper is able to buy or lease quota units up the maximum number of pots permitted for the vessel. The quota allocation per vessel is a function of the total allowable catch (TACC; 1523 tonnes) and the total number of pots so that in 2005 the allocation was 145 kg per pot.

The larger vessels in the RL fleet travel longer distances to more remote offshore areas and often stay out for 10–14 days at a time. Between up to 5 tonnes of live catch is stored in their wells or tanks until they return to shore. Smaller vessels (with fewer pots on board) are generally not suited for fishing in the more exposed off shore areas. They tend to make shorter trips, remain closer to port and work east coast rather than west coast waters. The variable cost structure will therefore be different for the different vessel sizes.

The peak period for lobster fishing has been in the months of November to January each year although this seasonal trend has become less pronounced in more recent years (Gardner et al., 2005 and Hurn and McDonald 1997). Beach prices are driven by international levels of supply and market demand, which tends to peak around Chinese holidays or festivals (Harrison, 2004). Most rock lobsters are sourced from the southern hemisphere and biological cycles follow similar patterns. This results in periods of greatest catchability and supply from several fisheries coinciding around the November to January period. An important point here is that although the Tasmanian beach price varies in line with supply, this does not imply cause and effect between supply and price on the level of the Tasmanian region. Over 90 percent of the total catch is purchased by processors, while the remainder is sold directly by the fisher in Tasmania or is landed outside of the State (Harrison, 2004).

The price also depends on carapace size or weight, and colouring. Processors interviewed for this study report that the preferred weight is between 0.8 kg and 2 kg. Lobsters weighing over 2 kg or under 800 grams fetched on average $5 / kg less for red lobster (seasonally corrected for 2004 and 2005). White lobsters are already discounted by around $5 / kg regardless of size although animals over 2 kg often receive further discounting of $2 / kg. The average weighted beach price between 1995 and 2002 was around $30 / kg but reached in excess of $55 / kg during periods of high demand and favourable exchange rates.

Around 80 percent of Tasmanian lobsters are exported with the majority of these sent to China (Harrison, 2004). As a result, the beach price and export price is influenced by external factors such as freight costs, world income and exchange rates (Holland et al. 2005). This is also to say the beach price has no impact on the export price (Felmingham 2004). The availability of substitutes from other States in Australia and internationally, and the high reliance on one market destination, supports the assertion that RL fishers are price takers.

8.2.2 Model Structure

The bio-economic implications of translocating RL is based on the biological model (Section 7) combined with an economic model described in this section. Four off shore locations were identified with slow growth rate so that existing size limits are too large for optimal harvest: Maatsuyker Island, Port Davey, Sandstone Bluff, and Sandy Cape (Figure 1). These sites are the source of translocated lobsters (*original*). The four higher growth release sites (*release*) were King Island, Taroona, inshore southwest, and Maria Island.

The two models interacted through effort factors affecting costs (pot lifts or days required to catch a given tonnage and distances between sites of origin and release) and yield factors affecting benefits (yield forgone at the original site and yield gained at the release site). 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).

The economic model was developed by surveying a selection of fishers to determine the normal variable and fixed costs associated with commercial fishing. We surveyed 14 rock lobster fishers (from a total of 239 active vessels) representing all 8 RL fishing regions in Tasmania during the middle of 2005. Fishers provided their cost and revenue details as it applied to their fishing operation. Each fisher was also asked to comment on costs and revenue estimates as reported by others, whose identity was not revealed. The revenue figures were further verified by records of catch previously submitted by fishers to the Department of Primary Industries, Water and Environment (DPIWE).

The survey data allowed translocation costs to be estimated under policy and management scenarios. Key outcomes of the economic model were the cost to translocate lobsters by unit weight and the net revenue gain or loss. The Internal rate of return for 12 different translocation scenarios was also assessed.

Analyses were conducted over a 20-year period post translocation of lobsters as this allowed modelled cohorts of lobsters to be reduced to zero through fishing and natural mortality, plus it allowed depreciation of fishing business assets to zero. Structure of industry participants in the model was varied between small, medium and larger fishers (15, 30 and 50 pot holdings respectively). This range included the minimum and maximum permitted pot numbers that can be operated.

8.2.3 The Economic Model

Total cost associated with lobster fishing *TC* was determined by estimating the annual fixed cost *FC* and the variable cost *VC* per fisher (*i*).

$$TC^{a,i} = FC^{a,i} + VC^{a,i} \qquad \text{(Equation 1)}$$

The variable cost in this case varies by pot allocation size (where *a* is 15, 30, or 50) by the fisher.

Fixed costs are independent of harvest and in some studies have been regarded as irrelevant to the decision-making. However, it is an implicit assumption in this study that the owner of a fishing vessel aims to cover fixed costs, which includes the value of the vessel, with the revenue of the catch. Fishers interviewed stated that the need to cover fixed costs in their business was a motivation for increasing revenue through leasing quota – hence it is clear that these costs are driving business choices in this industry. Attributing fixed costs can be complicated if fishers use their vessel for other fishing purposes. However the return on incidental species caught with RL is negligible due to the specialised trapping equipment used in this fishery. Therefore no problems exist with attribution joint costs to other harvesting activities and by-catch will not be further considered in this analysis.

Fixed costs *FC* include an estimate of standard annualised straight-line capital depreciation (*DEPR*) for the vessel, dinghy, engine, gearbox, and onboard equipment such as depth sounder, radar, automatic pilot, radio, GPS and computer. Depreciation on the pots operated by the vessel is also included. Other fixed costs include annual mooring and port fees (*MOOR*), insurance cost (*INS*), boat licence fees/registration charges (*LIC*), survey fees (*SUR*), and annual accounting and business administration costs and satellite phone (*ADMIN*)[1].

$$FC^{a,i} = DEPR^{a,i} + MOOR^{a,i} + INS^{a,i} + LIC^{a,i} + SUR^{a,i} + ADMIN^{a,i} \qquad \text{(Equation 2)}$$

The variable cost was represented by:

[1] The annual fixed cost averaged over the estimated annual catch was $4.94, $5.41 and $7.37 per kilo of rock lobster for 15, 30 and 50 pot vessels respectively.

$$VC^{a,i} = TRIP^{a,i} + MAINT^{a,i} + LABOUR^{a,i} + LEASE^{i}$$ (Equation 3)

The cost of supplies per trip (*TRIP*) includes bait, fuel and oil, and ice. These costs all vary with the number of pots carried by the vessel and consequently the catch. Food cost is dependent on the number of crew as is the cost of work clothing and gloves. The cost of cleaning products is calculated on an annual basis. Maintenance cost (*MAINT*) includes repairs to fishing gear (including pots) and boat repairs that vary with the number of days spent fishing.

Labour cost (*LABOUR*) varies with and the number of crew (including the owner operator) and the number of days spent fishing. The wages of crew is generally based on a percentage of the catch value per fishing trip. The variable cost are all standardised to cost per kilo of rock lobster caught[2].

Anecdotal information suggests that an estimated 33% of the RL fleet now leases their quota. The cost of leasing quota in 2005 has risen to $16 per kg (*LEASE*) from about $12 in 2000. A large proportion of fishers bear the added lease cost which affects profitability and ultimately viability (Ford 2001). We estimate costs both for fishers who lease their quota and those who own their quota. In estimating State benefit of translocating RL we assume that 30 percent of 50 pot vessels and 10 percent of 30 pot vessels lease their quota.

Total revenue (*TR*) for each fisher is the price (p) multiplied by the weight of lobsters captured (q)[3]. Hurn and McDonald (1997) found that revenue was strongly driven by beach price. In our economic model we are only concerned with the beach price and not export price and thus our results only apply to commercial fishers rather than processors or the broader economic benefits of the fishery. The beach price received by fishers is a function of two physical qualities: size (l) and colour (co). The price and catch are not varied seasonally in the economic model as annual aggregates are used. The realism of the economic model would increase with seasonal price variation but this was not possible due to limitations of the biological model.

$$TR^{a,i} = p_{l,co} q^{a,i}$$ (Equation 4)

The price data was averaged from 2003 and 2005 for 5 different qualities:

- Red RL of more than 2 kg $26.25/kg,
- Red RL of between 0.8 and 2 kg $31.53/kg,
- Red RL smaller than 800 grams $26.40/kg,
- White RL greater than 2 kg $24.25/kg, and
- Other White RL $25.75/kg.

[2] The average variable cost (excluding lease fees) was $11.88, $14.50 and $16.39 per kilo of rock lobster for 15, 30 and 50 pot vessels respectively.

[3] The symbol for weight (q) is using the standard economic nomenclature for quantity – not to be confused with the biological nomenclature for fecundity.

Prices remain constant over time[4] in our model as insufficient information is available to predict into the future the direction and the amount of the change. However, a simulation where prices are varied is undertaken to determine their effect on some of the crucial economic variables.

The RL catch figures (q) are based on the compulsory logbook catches submitted by RL fishers for four full quota years from March 2000 to February 2005.

The profit function ($\pi^{a,i}$) for fisher i per pot size allocation a is dependent on the price of lobsters, the number captured, and the fixed and variable costs associated with commercial harvesting.

$$\pi^{a,i} = f(p_{l,co}, q^{a,i}, VC^{a,i}, FC^{a,i}) \qquad \text{(Equation 5)}$$

8.2.4 Translocation cost

Two alternative capture and transportation options (tl) were explored for deriving the cost to capture undersize RL. One option was that fishers retain undersize lobster captured through the course of normal fishing operations and release these lobsters on their journey home. Vessels typically have unutilised capacity to hold and transport undersize RL during normal operations, and lobsters could be released to a high growth area on the return trip to port. The second option is using a dedicated charter vessel for translocation trips where movements of greater distances or at targeted locations are desired. We assumed charters would operate with larger vessels able to carry up to 5 tonnes of undersize RL to the high growth destination.

The total translocation cost TLC_j is a function of the variable costs to capture undersize lobsters U_j per trip (j), transportation costs between sites per trip TRA_j, and the cost of release REL_j.

$$TLC_j = U_j + TRA_j + REL_j \qquad \text{(Equation 6)}$$

The variable cost to capture the RL for translocation includes the cost of bait and the cost of labour. Grading of undersize catch prior to translocation alters the yield outcomes (Section 7) and also alters the time required to catch a given tonnage of undersize. Our base case scenario is that catch is not graded and falls with the size 60 to 104 mm for females and 60 to 109 mm CL for males (sex s and size l). Grading to alter the size and sex composition entails more pot lifts to fill the capacity of the vessel but may increase the eventual gain in yield. Finally the weight ($W^{wetwell}$) of RL to be transported will impact on the variable capture cost. For charter vessels the cost of bait used to capture the undersize RL and the cost of chartering the vessel for the time required to catch the RL is included in U_j.

[4] Prices are discounted as per equation 11.

Daily charter fees that were quoted by survey respondents varied widely from \$600/day to \$5,000/day. Allowing for the cost of two crew at \$800/day and an average daily charter cost of \$2,000/day, the total daily cost equals \$3,600, which has been rounded to \$150/hr. Charter cost are conservative as charter cost for research sampling conducted in 2005 ranged from \$1,300 to \$1,800 day, including 2 crew members. The high cost estimate allows for a profit margin for the charter vessel.

No bait or labour costs are incurred if the fisher model was used for translocation. The undersize RL that are normally returned to the water are now set aside for translocation.

$$U_j^{w,tl} = \begin{cases} f_{s.l}(VC^w) & \text{if } tl = \text{charter}, \\ 0 & \text{otherwise}, \end{cases} \qquad \text{(Equation 7)}$$

Transportation costs per trip are a function of the costs of travelling a given distance V, the distance that lobsters are shifted D between the site of origin o and the release site r, and the distance travelled to and from port. It is assumed that the charter vessel port is chosen on the basis of minimising the distance travelled. The three potential ports are Hobart (south), King Island (northwest), and Beauty Point (north). We have assumed that chartered operations would utilise large 50 pot vessels capable of transporting 5 tonnes. Cost of transport is zero if lobsters are simply released along the course of normal travel, as in the fisher model.

$$TRA_j^{tl} = \begin{cases} D^{o,r}V + D^{port}V & \text{if } tl = \text{charter}, \\ 0 & \text{otherwise}, \end{cases} \qquad \text{(Equation 8)}$$

The cost of releasing the undersize RL at high growth destination (REL_j) includes the cost of buoyed nets with chain lead lines if lobsters are to be released in to temporary pens (*FENCE*) as conducted with releases of juveniles by Mills et al., (2006). The release cost includes an estimated labour cost based on rates of unloading of commercial catch at one tonne per hour for two crew, for both the fisher and charter model.

$$REL_j^w = FENCE_j + LABOUR_j^w \qquad \text{(Equation 9)}$$

After translocation of RL to areas of high growth the RL are re-captured as part of the normal fishing process, incurring normal fishing cost.

In the original site, some of the RL may have eventually reached legal size and been available for harvesting. The yield forgone at their original, slow growth location ($q_{trl}^{foregone}$) multiplied by the price that may have been obtained, may be referred to as revenue foregone ($R_{trl}^{foregone}$).

$$R_{trl,t}^{foregone} = p_{l,co,t}\, q_{trl,t}^{foregone} \qquad \text{(Equation 10)}$$

The State revenue resulting (R_{trl}) from translocating RL is based on the catch projections as determined by the biological model. State revenue from translocation is corrected for the revenue foregone in the original site. Annual time steps are included to allow discounting of revenue to its present value.

$$R_{trl,t} = -TLC_j + \sum_{t=0}^{20} \frac{(p_{l,co,t} q_{trl,t}) - R_{trl,t}^{foregone}}{(1+\delta)^t} \qquad \text{(Equation 11)}$$

The value of translocating the RL to the fishers is the additional profit that may be earned as a result of translocation and in addition to the profit from a normal fishing trip. This is assuming that the quota is adjusted to allow the catch to increase due to the increase in exploitable biomass.

We use a simple indicator of economic performance to assess the overall performance of translocating RL in Tasmania. The Internal Rate of Return (IRR) is the return that can be earned on the capital invested in the translocation project. The IRR is equivalent to that discount rate that would yield a Net Present Value (NPV) of zero (Equation 11). The rate can be compared to the rate of return of other investments including an appropriate risk premium. The translocation project is a good investment proposition if its IRR is greater than the rate of interest. The IRR is defined so that the NPV of the management strategy implemented at time t=0 over a 20 year period is zero[5]. Note that the comparative risk premium of quota increase through translocation for an individual fisher is equivalent to that for normal fishing operations. This is because their increased quota will allow the capture of any legally available lobster in the population, not only those that have been translocated.

7.3 Results

Several aspects of translocating RL from four original sites to four different release sites are evaluated in this section. Firstly the impact of the transportation method on the translocation cost per kilo of RL was analysed followed by an estimate of the State revenue increase. The impact on fisher profits are then analysed for the original site and release site combinations most attractive in terms of the above indicators. The IRR is reported and the economical outcomes for each of the original site and release site combinations are evaluated.

As mentioned previously, the main difference between the translocation by charter vessels and fishers is the inclusion of the charter fee of $150 per hour in the former model. Both models incur the cost of release including labour plus fencing off the release site with a surface-deployed net.

The translocation cost per kilogram gain in yield falls rapidly with increasing tonnes. For the cost of translocation to be worthwhile for fishers it will need to be less than buying quota (which was reported to be between $12/kg and $18/kg). The lowest cost of translocating the maximum wet well capacity of 5 tonnes of RL using a charter

[5] The average discount rate (δ) is 7 percent.

vessel is $2.40/ kg gain in yield for translocating RL from Maatsuyker to Taroona (Figure 6 and Table 3). The highest translocation cost is $87.49/ kg gain in yield for translocating RL from Maatsuyker to Inshore SW. These costs are a function to the distance, thus time travelled from the charter port to the original site to the release site and back to port, and the expected gain in yield through translocation (Chapter 6).

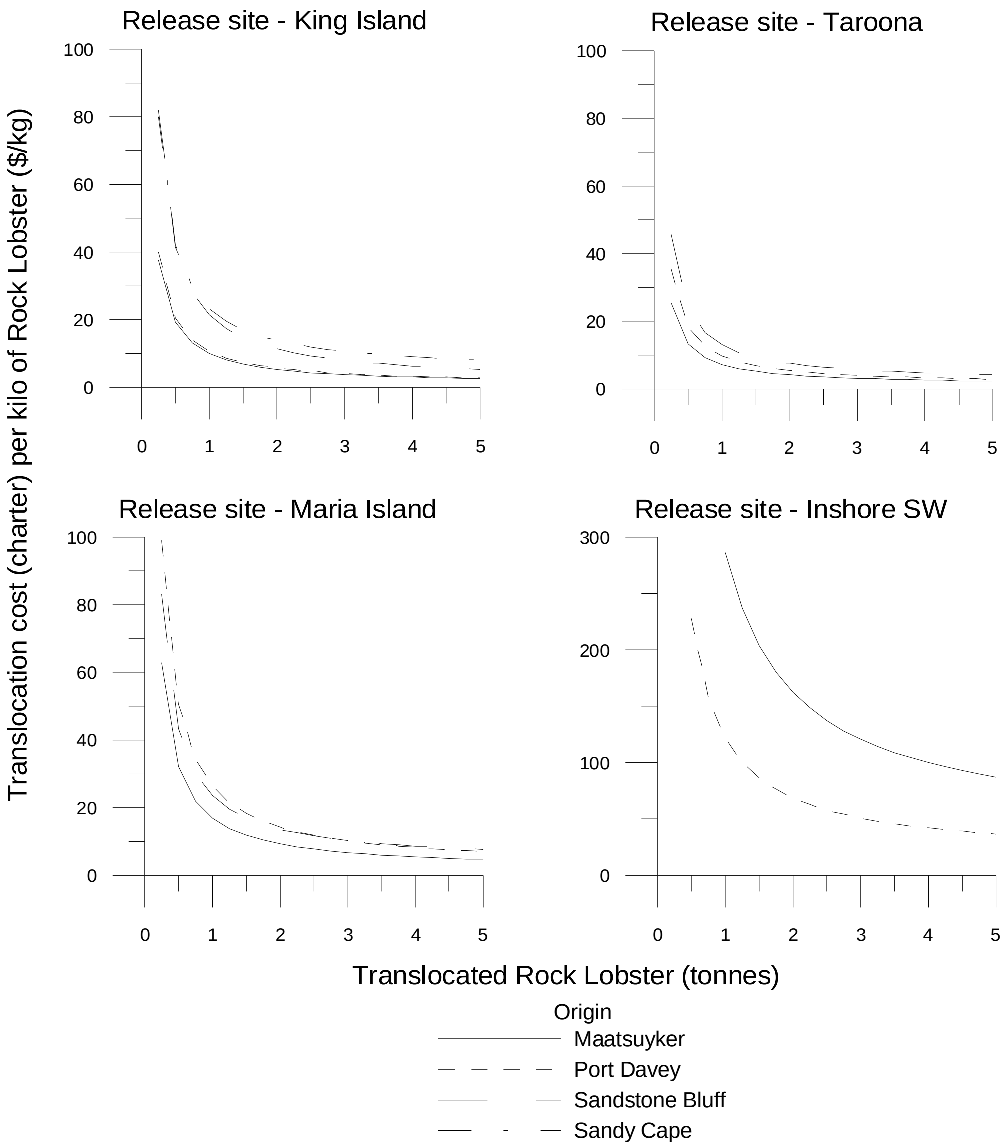

Figure 6. Cost of translocating Rock Lobster per gain in kilogram of yield from 4 original sites to 4 different release sites around Tasmania using a *charter vessel* for transportation (note the scale on the y-axis for release site - Inshore SW).

To break even at a quota price of $16/kg a minimum weight of RL will need to be transported, which is at least 0.750 tonnes between Maatsuyker/Port Davey and King Island and 1.75 tonnes between Maatsuyker/Port Davey and Maria Island.

Whereas the charter translocation method may apply to all origin and release site combinations, translocation of RL by fishers on return to port (as part of their "normal" fishing trip) is not applicable to all combinations. Some routes cannot logically and/or logistically be part of a "normal" trip. The lowest cost of undertaking 5 trips and each time translocating the maximum spare capacity of 1 tonne of rock lobster is \$0.32/kg for translocating RL from Maatsuyker to Taroona and the highest is \$10.24/kg for translocating RL from Maatsuyker to inshore southwest.

The cost per kilo of translocated RL is significantly lower when translocation takes place as part of a normal fishing trip. The latter method only applies to six original site and release site combinations (Figure 7).

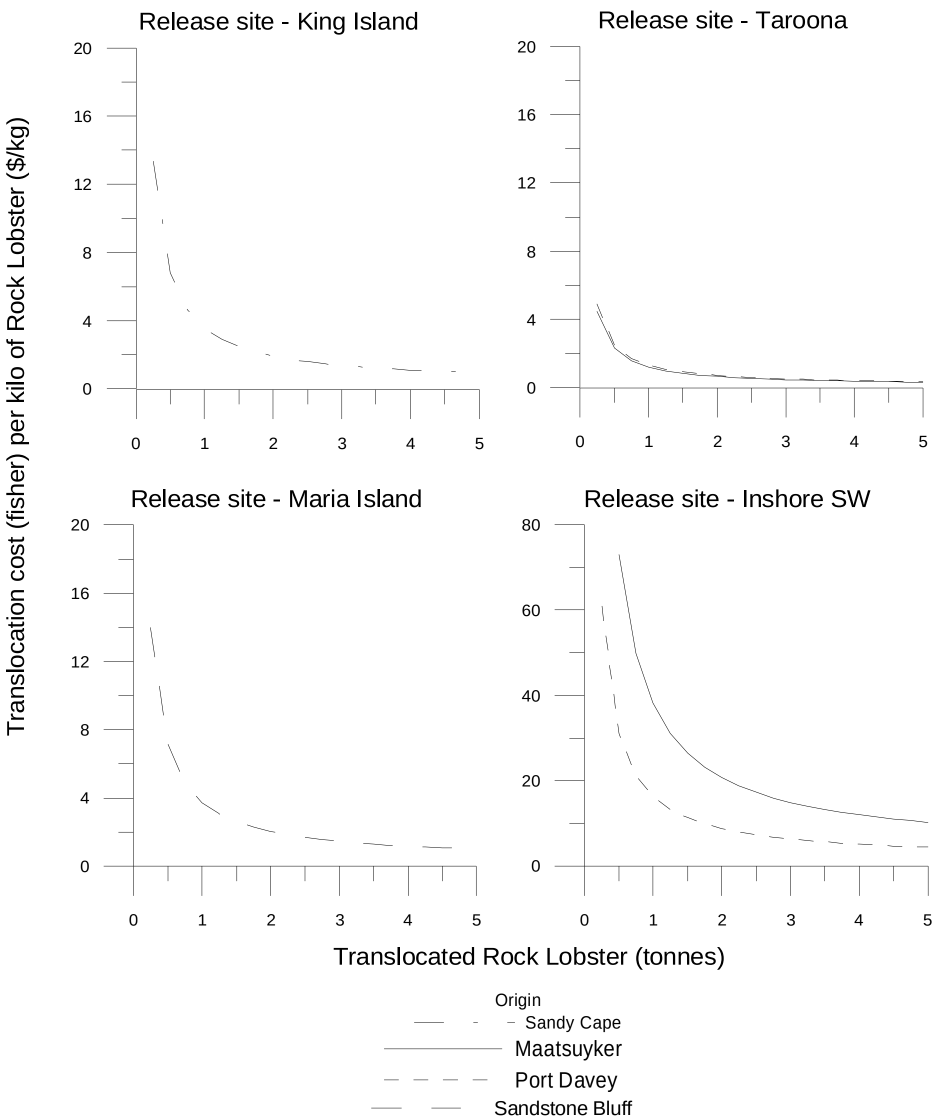

Figure 7. Cost of translocating Rock Lobster per gain in kilogram of yield from 4 original sites to 4 different release sites around Tasmania as part of *normal fishing* trip (note the scale on the y-axis for release site - Inshore SW).

The cost per kilogram gain in exploitable biomass is informative but ultimately this needs to be related to the predicted increase in net State benefit (Figure 8).

In the economic model the benefits in the release site increase linearly with increasing tonnes of translocated RL. The timing of the annual benefits of increase catch of translocated RL over a 20 year timeframe is not linear but is dependent on the estimates of the biological growth model. If the revenue foregone in the original sites is also considered the increase in state revenue will not return to zero (Figure 8) but rather will fall below zero for some years over a 20 year period when the RL from the original site may have reached legal size. Note that it is presumed that the model overstates the real impact of this revenue foregone as some reduction in density dependent growth and mortality appears inevitable which will lead to increased productivity.

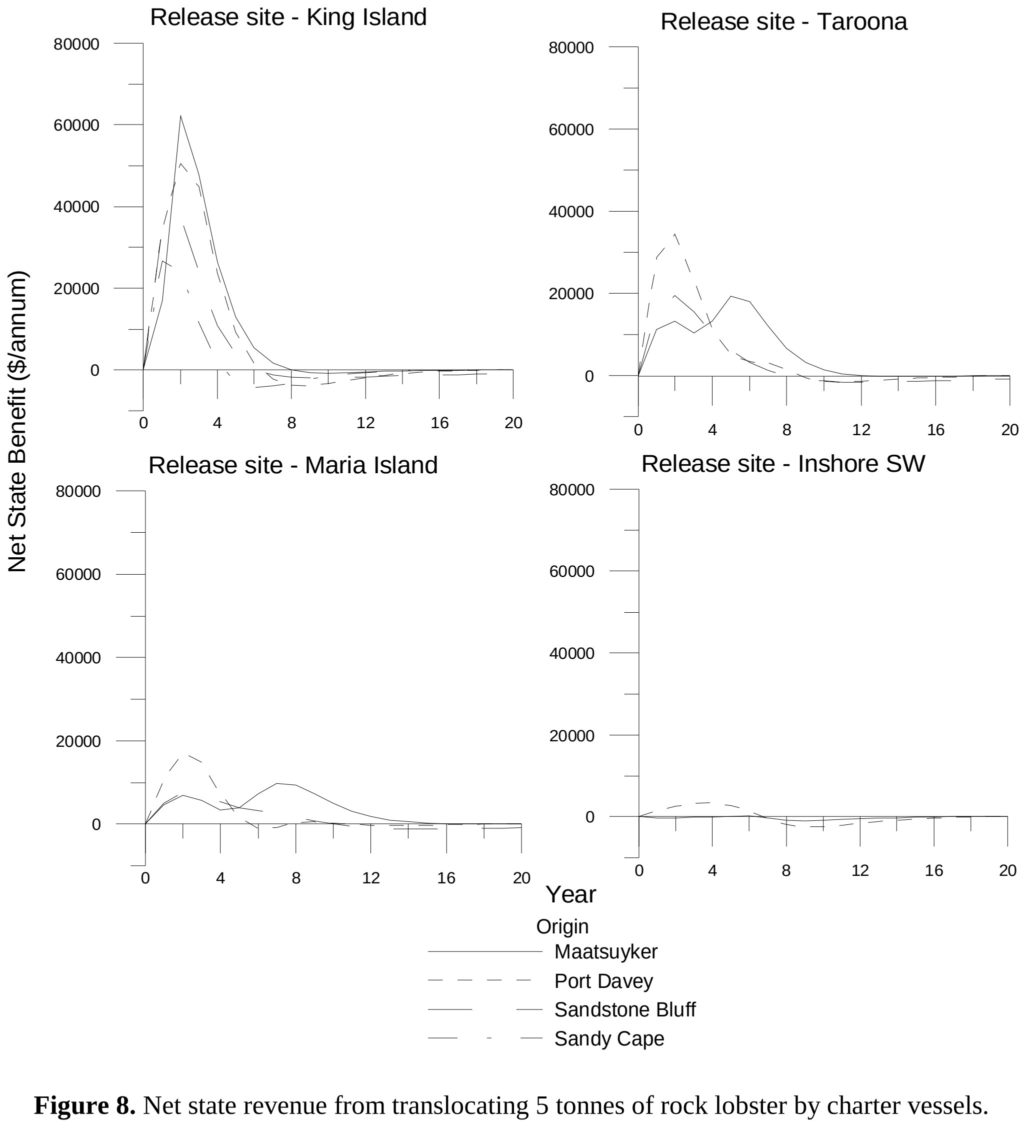

Figure 8. Net state revenue from translocating 5 tonnes of rock lobster by charter vessels.

If biological requirements permit, ideally the translocation would be repeated prior to the total net State benefit becoming negative (approximately between years 2 and 6).

The total State benefit taken over a 20 year period and the translocation cost per kilo of RL are combined in Table 3.

Table 3. Cumulative net State benefit (over 20 years) and translocation cost per kg gain in yield for a one-off translocation of 5 tonnes from 4 original sites to 4 release sites around Tasmania using charter vessels or fishers for transportation.

		Charter translocation		Fisher translocation	
Origin site[6]	Release site[7]	Net State Benefit* ($/20 years)	Translocation cost ($/kg gain)	Net State Benefit * ($/20 years)	Translocation cost ($/kg gain)
Maat	KI	$169,133	$2.60		
Pt.D	KI	$142,772	$2.84		
Maat	Tar	$109,352	$2.40	$116,447	$0.32
PtD	Tar	$103,321	$2.97	$111,512	$0.35
SBf	KI	$90,940	$5.35		
Maat	Mis	$70,639	$4.79		
SBf	Tar	$57,426	$4.28		
PtD	Mis	$49,979	$7.12		
SBf	Mis	$43,017	$8.18	$51,327	$0.96
SCp	KI	$27,656	$7.78	$35,097	$1.00
PtD	InSW	$1,131	$36.88	$9,321	$4.37
Maat	InSW	-$4,788	$87.49	$3,508	$10.24

* State revenue is the increase in revenue at the release site minus revenue foregone at the original site.

From the above table it is clear that highest State benefit increases can be obtained from translocating RL from Maatsuyker and Port Davey to King Island. However, for both these sites the translocation cost is higher than for some of the other sites. The lowest benefits were achieved from translocating RL from Maatsuyker and Port Davey to inshore SW areas.

For all six scenarios where fishers were used to translocate the RL, the model indicates lower translocation cost per kg gain in yield and higher State benefits, than for charter vessel translocation to these same sites. However, the highest State benefit increase in fisher transported RL is around $116,000, which is considerably lower than the highest charter model benefit increase. This is because fishers are unlikely to be able to move lobsters the large distances that would be possible by charter.

Thus far the translocation cost per kilo and increase in State benefit has been considered for fisher and charter translocated RL. The fishers who are able to increase their catch in the release sites as a result of translocating the rock lobster are expected to increase their profits (this assumes that the quota is adjusted to allow their catch to increase). The magnitude of the recruitment of lobsters to legal size may be reduced at the origin site but the impacts of this on catch rates is dependent on fleet dynamics. It is feasible that the catch rates and thus variable costs may become more favourable at the site of origin because the total exploitable biomass is increased and each fisher is competing for harvest in a mobile fleet.

[6] PtD = Port Davey, Maat = Maatsuyker Island, SCp = Sandy Cape, SBf = Sandstone Bluff

[7] KI = King Island, Tar = Taroona, MIs = Maria Island, InSW = Inshore South West

As the size of translocation operations increase, the cost per gain in kg of yield decreases. Conversely, costs for smaller translocations increase so that at some level there is no net gain in profitability. This is effectively the break even point and is the minimum amount of rock lobsters that need to be translocated to make charter operations worthwhile for the fisher (Figure 9).

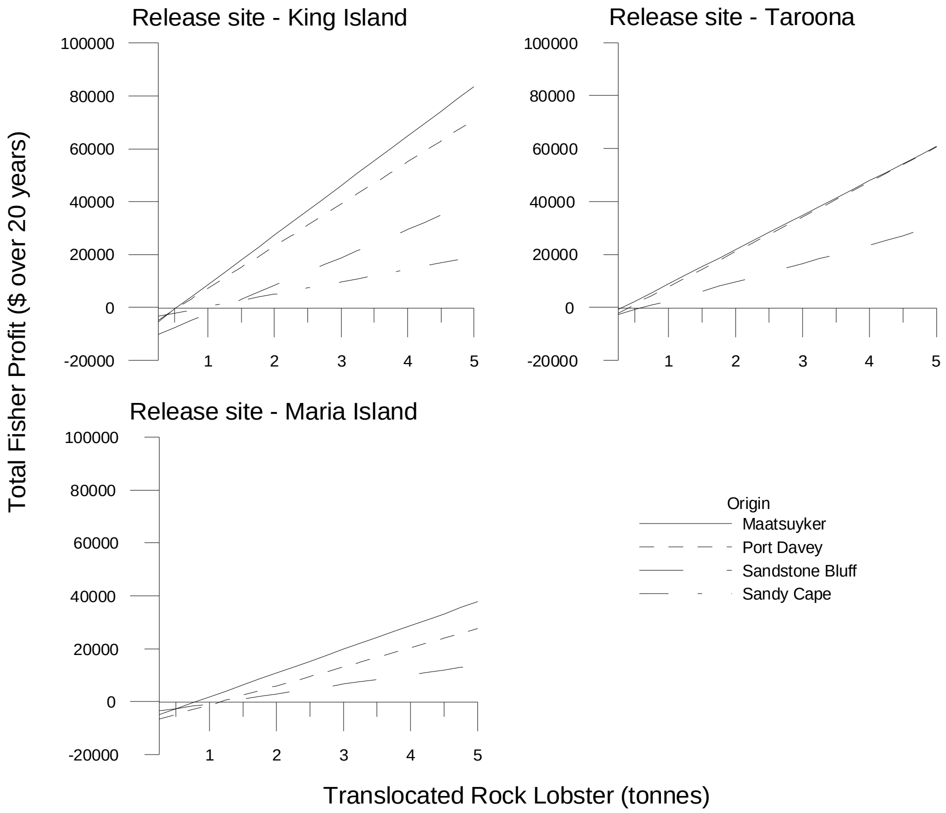

Figure 9. Total fisher profit increase as a result of translocating rock lobster by charter vessel from 4 original sites to 4 release sites around Tasmania.

The scenarios for RL release inshore in the SW is not shown as no profit was generated. Between at least 1 and 1.5 tonnes of RL needs to be translocated from Maatsuyker or Port Davey to King Island to generate a positive profit for fishers in the King Island region. As expected, predicted yearly fisher profit increases over a 20 year period closely resembles the pattern observed for State revenue increases.

In order to evaluate the economic effectiveness of translocating RL the cost per kg gain in yield was estimated, as well as predicted increases in State revenue and fisher profit in the release site. A standard approach to evaluating the economic viability of any investment proposal[8] is to determine the IRR (Figure 10).

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[8] In this case the investment is the expenditure on translocating the RL. The cash flow over time is the State benefit minus benefits foregone in the origin (see equation 12).

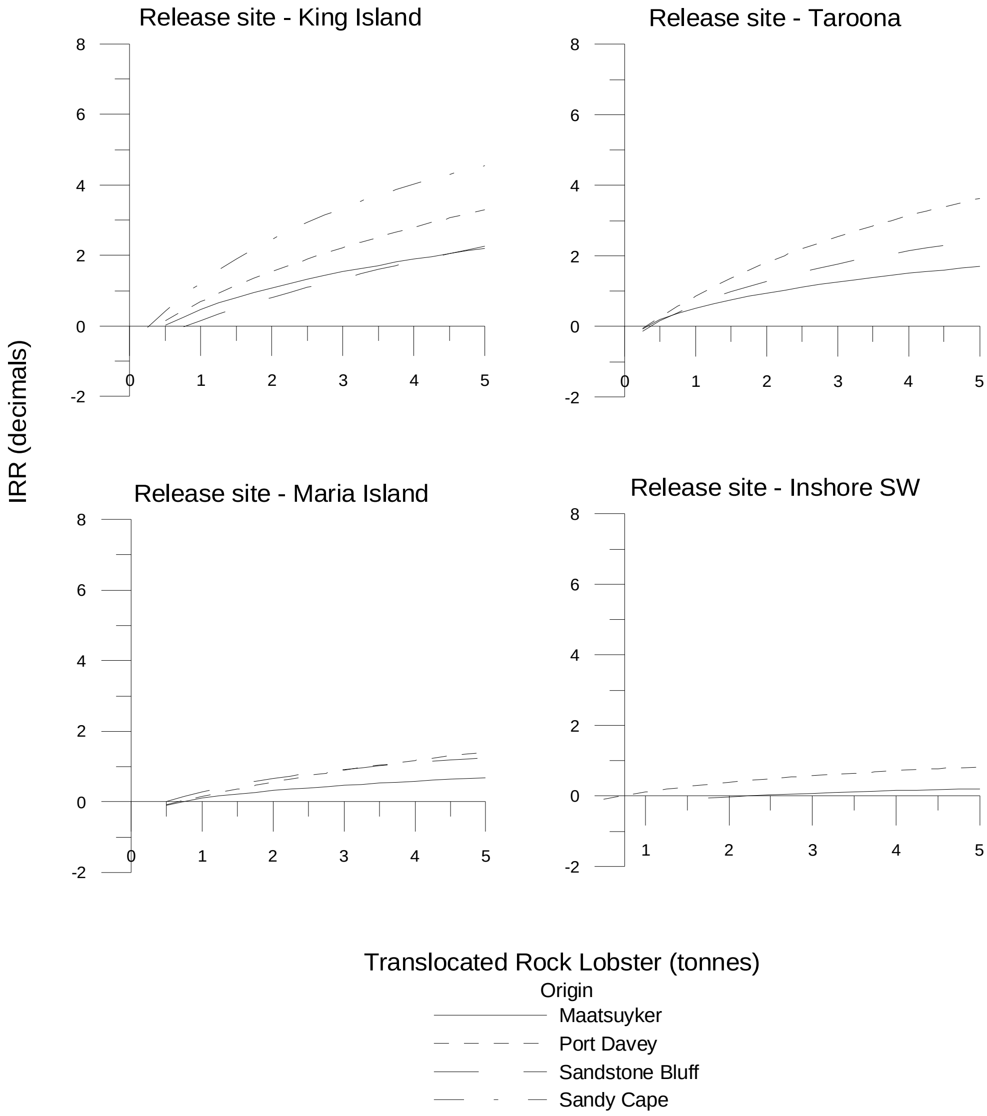

Figure 10. IRR as a result of translocating 5 tonnes of rock lobster by charter vessel from 4 original sites to 4 release sites around Tasmania.

The rate can be compared to the rate of return on other investments including an appropriate risk premium. The translocation project is a good investment proposition if its IRR is greater than the rate of interest. The IRR is sensitive to the size of the upfront investment and the flow of revenue from the translocated RL caught. The lowest upfront investment is for translocation from Sandy Cape to King Island (for 5 tonnes translocated by charter vessel). Even though this translocation option does not generate as much revenue as translocation from Port Davey and Maatsuyker to King Island, the IRR for the former is greater. In fact the IRR for translocation from Maatsuyker of Port Davey to King Island is much the same as from these same two origins to Taroona.

A sensitivity analysis carried out to ascertain the effect of RL price level on the economic variables indicates that should prices fall by 50 percent translocation to Maria Island becomes unattractive from all origins. The rest of the locations maintain an IRR greater than 40 percent for translocating more than 1 tonne of RL suggesting they remain financially attractive investments.

In the base-case scenario it was assumed that 10% of 30 pot vessels and 30% of 50 pot vessels lease their quota. The cost of leasing a quota is include in the variable cost and thus reduces the profit margin of a RL fishing operation. If no vessels leased their quota the overall profit to be gained by fishers from RL translocation to King Island from Maatsuyker or Port Davey would increase by 5 percent (to around $70,000 and $80,000 respectively). If the variable cost assumptions in the basecase were also lower (as well as not lease costs), the overall fisher profit from translocation would increase by 62 percent for these same origins and release sites.

A sensitivity analysis carried out for the main biological variables (shown in Table 4) indicates that the greatest price increase will result from a change in the grading by sex. If only undersize males are translocated the cost per kilo would increase by for instance 66% from Maatsuyker to King Island[9]. Comparing the worst case scenario to the base case illustrates that even with all biological variables set at very conservative levels, translocation from Maatsuyker to King Island or Taroona and Port Davey to King Island remains around $10/kg.

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[9] Ignoring the price changes for the SW inshore destination as the initial cost per kilo indicates these scenarios are not economically viable.

Table 4. Estimated cost per kilogram of translocated rock lobster with a one-off translocation of 5 tonnes of undersize lobsters by charter vessel. Results are for the base-case specifications and for a range of sensitivity tests. Figures as a proportion of the base case and the direction of the effect (increase ↑, decrease ↓).

Origin site	**Maatsuyker Island**				**Port Davey**				**Sandstone Bluff**				**Sandy Cp.**
Release site	**K.I.**	**Tar**	**SW**	**Maria**	**K.I.**	**Tar.**	**SW**	**Maria**	**K.I.**	**Tar.**	**SW**	**Maria**	**K.I.**
BASECASE	$2.60	$2.40	$87.49	$4.79	$2.84	$2.97	$36.88	$7.12	$5.35	$4.28	*	$7.78	$8.18
WORST CASE SCENARIO	$9.45	$10.13	*	$25.41	$11.97	$14.00	*	$43.68	$21.30	$18.46	*	$48.61	*
No grading – natural sex ratio													
No females	↑ .66	↑ .34	↓ .62	↑ 1.11	↑ .35	↑ .20	↓ .18	↑ .48	↑ .23	↑ .05		↑ 1.65	↑ .01
All females	↑ .23	↑ .57	↑ .78	↑ .27	↓ .03	↑ .39	↑ 14.22	↓ .13	↑ .07	↑ .29		↑ .04	↑ .07
Grading of undersize lobster (basecase = No)													
Yes (60-80)	↓ .16	↑ .03	↑ .36	↓ .13	↓ .33	↓ .15	↑ .07	↓ .40	↑ .15	↑0.94		↑ .79	↑ 3.13
Yes (80-105)	↑ .02	-	↓ .08	↓ .01	↑ .17	↑ .07	↓ .20	↑ .15	↑ .03	↑0.04		-	↑ .04
Time to transit marketability (basecase = 0)													
Time to transit = 2	↑ .01	↑ .01	↑ .10	↑ .01	↑ .03	↑ .04	↑ .10	↑ .04	↑ .05	↑0.04		↑ .03	↑ .15
Time to transit = 3	↑ .06	↑ .03	↑ .30	↑ .03	↑ .08	↑ .09	↑ .32	↑ .10	↑ .10	↑0.09		↑ .09	↑ .36
Time to transit growth (basecase = 0)													
Time to transit = 1	↑ .12	↑ .12	↑ .50	↑ .13	↑ .15	↑ .16	↑ .51	↑ .20	↑ .15	↑0.16		↑ .17	↑ .42
Time to transit = 2	↑ .26	↑ .27	↑ 1.50	↑ .27	↑ .34	↑ .38	↑ 1.61	↑ .46	↑ .35	↑0.37		↑ .39	↑ 1.48
Emigration loss T and Release mortality Ω (basecase = 0.025)													
0.00 yr^{-1}	↓ .05	↓ .06	↓ .32	↓ .07	↓ .07	↓ .08	↓ .34	↓ .11	↓ .08	↓-0.09		↓ .12	↓ .19
0.05 yr^{-1}	↑ .06	↑ .06	↑ .81	↑ .07	↑ .08	↑ .09	↑ 1.00	↑ .13	↑ .08	↑0.11		↑ .15	↑ .28
0.10 yr^{-1}	↑ .20	↑ .21	↓ 1.00	↑ .24	↑ .27	↑ .32	↓ 1.00	↑ .49	↑ .29	↑0.38		↑ .62	↑ 1.66
Harvest rate (basecase Deep = 0.4, Shallow = 0.5)													
Deep = 0.2, Shallow = 0.25	↓ .37	↓ .31	↓ .56	↓ .20	↓ .48	↓ .45	↓ .60	↓ .32	↓ .45	↓-0.42		↓ .34	↓ .65
Deep = 0.5, Shallow = 0.6	↑ .27	↑ .22	↑ .58	↑ .17	↑ .36	↑ .34	↑ .69	↑ .24	↑ .34	↑0.31		↑ .25	↑ .76

* denotes that translocation is not economically viable.

Origin site	Maatsuyker Island				Port Davey				Sandstone Bluff				Sandy Cp.
Release site	**K.I.**	**Tar**	**SW**	**Maria**	**K.I.**	**Tar.**	**SW**	**Maria**	**K.I.**	**Tar.**	**SW**	**Maria**	**K.I.**
BASECASE	$2.60	$2.40	$87.49	$4.79	$2.84	$2.97	$36.88	$7.12	$5.35	$4.28	*	$7.78	$8.18
WORST CASE SCENARIO	$9.45	$10.13	*	$25.41	$11.97	$14.00	*	$43.68	$21.30	$18.46	*	$48.61	*
Natural mortality M (basecase = 0.1)													
0.07 yr^{-1}	↓ .07	↓ .13	↑ .24	↓ .18	↓ .04	↓ .05	↑ .56	↓ .05	-	0.00		↓ .01	↑ .08
0.2 yr^{-1}	↑ .30	↑ .54	↓ .16	↑ .78	↑ .19	↑ .22	↓ .27	↑ .21	↑ .11	↑0.15		↑ .22	↓ .08
Charter hourly rate (basecase = $150/hr)													
$200/hr	↑ .23	↑ .15	↑ .18	↑ .20	↑ .22	↑ .18	↑ .18	↑ .22	↑ .26	↑0.19		↑ .19	↑ .21

Base case assumptions:

1. Quantity of translocated RL = 5 tonnes
2. Method =Charter vessel from closest port
3. Reds>2KG$ 26.25, Reds 0.8-2 kg$ 31.35, Reds <800G $ 26.40, Whites>2kg $ 24.25
4. 10% of 30 pot vessels and 30% of 50 pot vessels leasing quota (however, this only affects fisher profit)
5. Average variable cost $11.88/kg (15 pots), $14.50/kg (30 pots), and $16.39/kg (50 pots)
6. Average lease cost $16/kg for all fleet sizes
7. Average fixed cost $4.94/kg (15 pots), $5.41/kg (30 pots), and $7.37/kg (50 pots)

Worst cast scenario:

1. marketability=2,
2. growth =2,
3. emigration loss=0.10,
4. harvest rate, deep=0.5, shallow=0.6,
5. natural mortality=0.2,
6. charter cost =$200/hr

8.3 Discussion

The economic implications of translocating RL from slow growth to higher growth areas around Tasmania were analysed in this study. Analogous to the cost of rearing hatchery fish in other studies (for example Lorenzen 2005) we applied translocation cost to the additional RL biomass translocated to augment the natural population, corrected for mortality.

The cost per kg of RL was determined for two transportation methods serving as a primary indication of the feasibility of potential future translocation. If the cost of quota gained through translocation is below the cost of leasing quota there would seem to be a financial benefit of translocation to fishers.

The cost of translocation is sensitive to changes in the biological model, which estimates the growth rates and emigration and mortality losses. However, even under a worst-case scenario for all biological variables, the cost of translocating 5 tonnes of RL from two areas in the Southwest of Tasmania (Maatsuyker and Port Davey) to King Island is still lower at around $10 per additional kg of yield than buying quota at $16. Assuming a base case scenario involving charter based translocation of 5 tonnes of RL from these sites, the cost of each additional kg of quota is $2.60 and $2.84 respectively. Should charter costs increase by one third, the cost of additional quota is likely to increase by only around 24 percent.

Translocation by fishers as opposed to charter vessels is possible for areas that are passed on the return trip to port. For example, this translation method is viable for translocation from the SW to areas close to the port of Hobart (represented here by biological data from Taroona). The cost per kilogram of gain in yield is significantly lower than the cost by charter vessel, but the estimated State benefit is also lower due to the impact of differential growth rates between the origin and the release site (this outcome is also observed for translocations between the deep water site Sandstone Bluff and shallow water areas at Maria Island).

Translocation to inshore areas in the southwest is not viable regardless of transportation method. The cost of additional quota by translocation using the charter method is greater than leasing quota. A lower cost can be achieved when fishers transport the RL but the net State benefit would only be between $4000 and $9,000 per 5 tonnes transported, much less than any of the other release sites due to the low growth differential. A conclusion from this aspect of the analysis is that the gains made through translocation are largely related to increasing yield, the benefits gained through changing product quality and beach price by translocating inshore are much more modest.

Net State benefit from translocating 5 tonnes of RL is considerable at between $140,000 and $160,000 in the two most attractive options (Maatsuyker or Port Davey to King Island). The IRR for 5 tonnes is around 200 percent due the relatively low cost of the actual translocation and the substantial differential in productivity between the sites. Even if translocation were considered high-risk, this IRR is extremely high indicating that this is an attractive investment option.

Note that the risk profile of translocation differs for the State and for individual fishers. For individual fishers the risk profile is equivalent to that of normal fishing operations because quota derived from translocation would be indistinguishable from that of quota leased from any other source. For the State, the risk profile of translocation may be different to that of normal quota. Normal quota is allocated on the basis of estimates of sustainable total allowable catch from commercial catch records finishing 12 months prior to the allocation of quota. In contrast, quota allocated from translocation would be on the basis of model-projected outcomes of translocation, with data collection occurring in the future. One approach to managing this risk would be to only allocate part of the projected gain in yield as additional quota. Our estimates of the cost of additional quota through translocation show that there is ample scope for this. For example, if only 50% of the projected additional yield gained through translocations between Port Davey and King Island were allocated to fishers, the cost per additional kg of quota would be less than $5.00. This remains attractive to fishers given that leased quota is around 3 times this cost.

Fishers can expect a significant increase in profits assuming that the translocated RL in the release sites contributes to catch and that quota is increased as a result. Taking into consideration the variable cost of catching additional RL, fishers can expect around $7,000 in additional profit from translocation only 5 tonnes from Maatsuyker or Port Davey to King Island. Given that the biological model indicates that there are significantly high numbers of undersize RL in these origins, additional profits are a multiple of the conservative estimate above. It is important that any future research consider the fact that profits are regional and likely to affect the various fleet sizes differently, mainly due to the concentration of smaller vessels in the inshore areas.

A shortcoming of this research is the lack of data on regional deep and shallow water stock sizes to estimate optimal numbers of RL to be transported. As this stock data is currently not available it didn’t allow the optimisation of financial and economic indicators. Increasing the information available on spatial distribution of stocks, plus the understanding of density dependent processes, particularly at the site of origin, should make optimisation of economic indicators possible in the future. Improved quantification of other parameters such as release mortality, movement at release, and time to transit growth through field trials should further assist the development of economic models in the future.

This research did not consider the differential effect of translocation on RL prices. The potential increased availability of inshore RL that are redder in colour with better survival in transport, may result in an overall downward pressure on the premium price categories. The industry would benefit from an analysis that investigates the potential effect of translocation on the supply of higher value RL on the overall price level and consequently fisher income.

Overall, this research clearly indicates that translocation is economically feasible, both in terms of the cost per RL and the resultant State benefits. This is especially true for translocations between sites with larger growth differential such RL collected in deep water SW areas and released in the NW. The high IRR for the latter sites indicates that the bio-economic model for this project predicts significant positive financial gains from translocating RL.

9. Cost recovery options for translocation

Systems for cost recovery of translocation were discussed with attendees at 10 port meetings around Tasmania in May 2005. Three models were proposed:

1) Fishers shift undersize lobsters under permit during normal operations.

2) Additional quota generated through translocation is issued in part by the Government or a Government business unit and leased to fund charter operations. Allocation of increased biomass is by a proportion or share such as: 1 translocation biomass share= (legal biomass increase by translocation –cost of shifting)/2.

   The amount apportioned to one share is allocated to the good of the resource, or more formally: community/ecology/egg production. The second share is added to the Total Allowable Catch (TAC) and divided between the Total Allowable Recreational Catch and the Total Allowable Commercial Catch as per the existing management.

3) A levy is placed on all fishers to fund charter operations. Additional quota is allocated to all fishers. For the exercise to be feasible, this additional cost to fishers must be less than the gain made through the allocation of increased quota. Again, quota allocated to fishers need not be 100% of increased legal sized biomass.

As would be expected, there was no industry consensus on a preferred option with most fishers of the opinion that more information was required to assist in formulating a preferred policy position.

9.1 Shifting lobsters incidentally to routine fishing operations

Under this option fishers shift undersize lobsters under permit during normal operations.

Pros:

- Negligible cost.
- Simple to implement.
- Predicted significant yield benefits (for example, increase in legal size biomass by translocating lobsters to Taroona (or Storm Bay) from Maatsuyker Island of 390%.
- Increase in total egg production if females less than 80 mm transported (around 1/3 of catch of undersize when escape gaps closed).
- Increase in market value of catch as deep-water lobsters adopt shallow water characteristics.

- Increase in shallow water stocks and associated ecological benefits.

Cons:

- Possible increased enforcement costs for trips involving translocation.
- Lack of control over release method.
- Unregulated volume and sites involve create uncertainty in estimating the magnitude of associated quota increases.
- South to North translocations that lead to greatest yield and quota increases are less probable.
- Lower probability of harvesting undersize lobsters from regions with lowest harvest rates (ie fishers will be conducting least normal fishing operations in the regions where harvest would most be preferred).
- Limited ability to manage regional ecological or egg production issues.
- Increased supply of product may reduce market price.

9.2 Lease of additional quota

Translocation generates additional exploitable legal size biomass that would not have been available to the fishery otherwise. If the TAC were increased by the same amount as the increase in exploitable biomass, then there would be no nett impact on the resource in terms of biomass. If the additional legal size biomass were only partially allocated then there would be gains to both the TAC and the residual standing stock of legal sized lobsters.

Under this management concept, the additional quota generated through translocation is partially leased out by the Government or a Government business unit with funds generated used for charter operations. Allocation of increased exploitable biomass is by a proportion or share.

Part of the increase in biomass (say 50%) is allocated to the good of the resource, or more formally: community/ecology/egg production. The second part is added to the Total Allowable Catch (TAC) and divided between the Total Allowable Recreational Catch and the Total Allowable Commercial Catch as per the existing management. The additional commercial component could be leased to commercial fishers to fund translocation operations, including research and monitoring.

For example: if a translocation exercise is conducted that generates 1 kg of additional exploitable legal size biomass at a cost of $2, then 0.5 kg is left unfished to increase the standing stock and increase catch rates. The remaining 0.5 kg is added to the TAC and 0.45 kg of this is allocated to the commercial sector (allowing for a 10% recreational harvest). Commercial fishers can then gain the right to harvest this quota unit of 0.45 kg at a cost of $2.

As shown in Table 5, this system has the potential to deliver quota to fishers at prices considerably less than the current lease prices, which are around $16/kg.

Table 5. Sale price of additional quota required to fund chartered translocation operations with vessels capable of translocating 5 tonnes per trip and conducting 150 pot hauls per day. Values given are the cost per additional kg of quota to be generated. If only 50% of the additional yield is allocated to commercial fishers then costs increase but other benefits accrue including reduced harvest rates, reduced risk of ecological impacts, increased egg production, and increased catch rate for recreational sector. Research levy applied here is based on T-bar tagging of each translocated lobster at $1 per lobster. Options of translocating females only may be considered in regions where sex ratio of origin sites is strongly skewed towards females.

Cost to fishers per additional kg quota	Sandy Cape to King Island		Port Davey to King Island	
	All undersize	Females only	All undersize	Females only
All extra yield allocated	$2.37	$2.22	$2.45	$2.62
50% allocated as quota	$4.73	$4.44	$4.91	$5.24
50% allocated as quota + a research levy	$7.88	$9.67	$7.18	$7.57

Pros:

- Ownership of the lobsters is retained by the state, which overcomes conflicts between different sectors.
- Translocation maximises yield in the fishery by pursuing translocations that are optimal for productivity (not simply convenient for fishers as per option 1).
- Research and monitoring is fully funded.
- The magnitude and destinations of translocations are monitored and quantified so quota increases can be justified.
- Enforcement needs are removed by funding of independent chartered translocation operations with independent monitoring staff.
- Provides for stock rebuilding and increased northern egg production while also increasing catch and economic yield.
- Release method is controlled.
- Ability to target specific regions for capture and release sites, such as areas with special ecological concerns.
- The market price of these additional quota units could be raised further to create savings elsewhere for all participants in the fishery (eg fund the State's FRDC contribution or reduce license fees to commercial and recreational fishers).

Cons:

- Lease price to fishers may be difficult to manage. A lease price of < $10/kg creates downward pressure on investor returns (currently around $16/kg). Presumably demand for these additional quota units will be great given that they could be offered at a substantial discount to normal market price. Thus an allocation option is required, such as a lottery, which may introduce perception of inequality.

- Increased supply of product may reduce market price.

- Perception of loss of opportunity for those fishers operating in regions from which lobsters are removed. These concerns may be defrayed because the option increases the statewide exploitable biomass and thus increases the ability of fishers to take catch at all times of the year. The option also raises the likelihood of quota increases for all fishers under the standard TACC provision.

9.3 Levy based on quota holding

This scheme is similar to scheme #2 except that the costs of translocation are distributed across all fishers, as are the gains. Under this scheme, additional quota is allocated to all fishers. This additional quota is a portion of the gains in exploitable biomass generated through translocation, perhaps 50%.

All fishers would be charged a fee based on their current quota holding and be issued additional quota. Gains for each fisher are essentially those shown in Table 5 (ie <$10 per extra kg of catch allocated).

Pros and cons are similar to those for option 2 except in the following instances:

Pros:

- Benefits are spread broadly across all fishers so that there is no perception of loss for fishers who tend to operate in southern waters.

Cons:

- All fishers will be required to participate even if they have no desire to increase business earnings.

10. Industry concerns with translocation

Although there was widespread interest in the concept of translocation, fishers at port meetings also expressed several concerns about translocation and felt there was need for more research in some areas. These were:

- That the capture and removal of lobsters in southern regions could reduce catch rates for fishers who work in those areas.
- That translocation involves interfering with natural ecosystems.
- That translocation may not be the optimal management tool for managing the inshore depletion/offshore reduction in effort issue? Another idea involved separate zones for deep and shallow with extra quota for deep water (and less for shallow water). There was also discussion of different size limits in different zones.
- That translocation is a patch for bad management – the underlying issue of uneven distribution of fishing effort is not addressed.
- That the shift of effort away from deep water is really a marketing issue and could be solved by the development of new markets outside China.
- That egg production in southern regions should not be altered as it may be sustaining recruitment.
- That translocation of slow growing lobsters from southern regions may spread the genotype for slow growth.
- If translocation leads to increase in quota, how do we ensure that shifted lobsters are harvested rather than lobsters elsewhere?
- If translocation increases the availability of lobsters in inshore areas, won’t this lead to even greater shift of effort inshore and thus even more depleted inshore reef.

Insight into some of these issues is provided by analyses conducted here, while other aspects require further research.

10.1 Are catch rates of fishers in southern regions harmed by translocation?

Fisher’s concerns about this issue were not related to movements from deep to shallow water in the same region, but rather larger distance movements such as from deep water south to shallow water north.

The outcomes of the biological model (Section 7) showed that translocation leads to increased legal sized biomass in the fishery as a whole. In many cases this gain was substantial so that significant increases in the fishery appear feasible.

The potential for catch rates of fishers in southern regions to be reduced by translocation is thus a function of the ability of fishers to shift effort to areas of higher catch rates. This shift could be through actual movement of fishers or a change in the dynamics of the leasing of quota.

Predicting how fleet dynamics will change with greater access to premium grade lobsters in northern regions was not analysed here as estimating the magnitude of possible translocation operations was beyond the scope of this project. Such an analysis would require the development of a length-based assessment model extending that done by Punt and Kennedy (1997).

However, historical catch information provides some insight into how the fleet would behave with increased abundance of high value lobsters in shallow waters. Historical patterns in effort in a given area suggest that the fleet is highly dynamic (Figure 11). Frusher et al. (2003a) confirmed that fishers continued to respond to changes in catch rate and market demand for grades of product when quota was introduced.

The responsive historical distribution of effort in the fishery indicates that a portion of the fishing effort would respond to the increase in catch rate elsewhere. In the case of translocation, the additional exploitable biomass would be from shallow water and there has been a clear trend of fishers preferentially directing effort to these darker red lobsters.

Improved growth rates of lobsters in the south after removals for translocation may help to dampen any impact on southern fishers. McGarvey et al. (1999) examined growth of lobsters in South Australia and observed an increase in growth with decreasing density so that productivity would be expected to increase. Deep-water stocks in the south are currently at very high density and density dependent effects on growth and mortality are assumed to important in SW Tasmania under basic principles of population dynamics.

A key point on this issue is that the magnitude of loss of yield from southern areas is trivial relative to the gain in yield achieved through translocation in many cases. This is shown to extreme in Figure 12 for movements of lobsters from Maatsuyker Island to King Island. Similar results were obtained for translocations from Port Davey to King Island and indicate that the scale of any forgone yield in southern areas would be minor.

Lastly note that fishers operating in southern regions experience an opportunity cost by failing to work towards management that benefits the whole State. Decisions on management such as levels of TAC tend to be based on the weakest region. This means that opportunity for quota increases for southern fishers will likely be forgone unless stock rebuilding and improved egg production is promoted in northern regions.

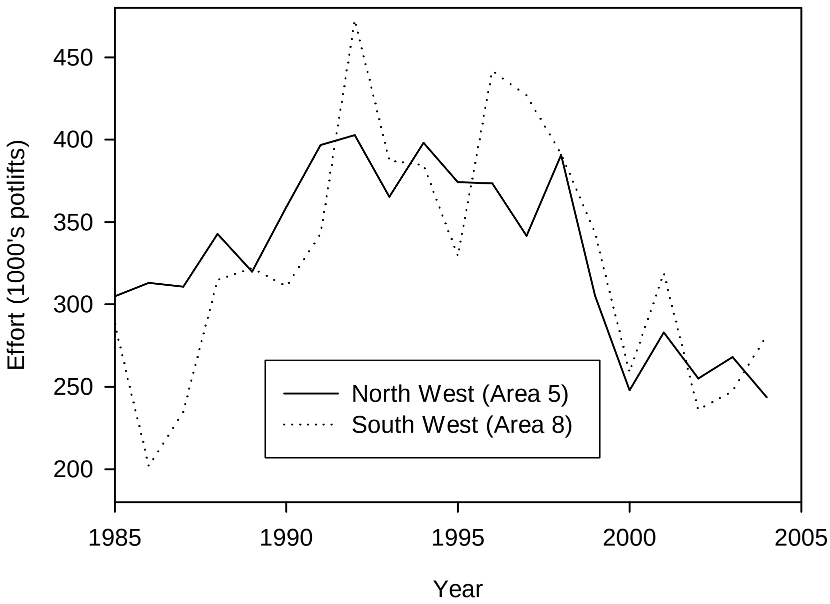

Figure 11. Change in effort for assessment regions in the south west and the north west over the last 20 years. Effort is volatile from year to year which is a function of fishers moving between regions, fishers using more or less effort in regions each year, and more recently – the leasing of quota between regions.

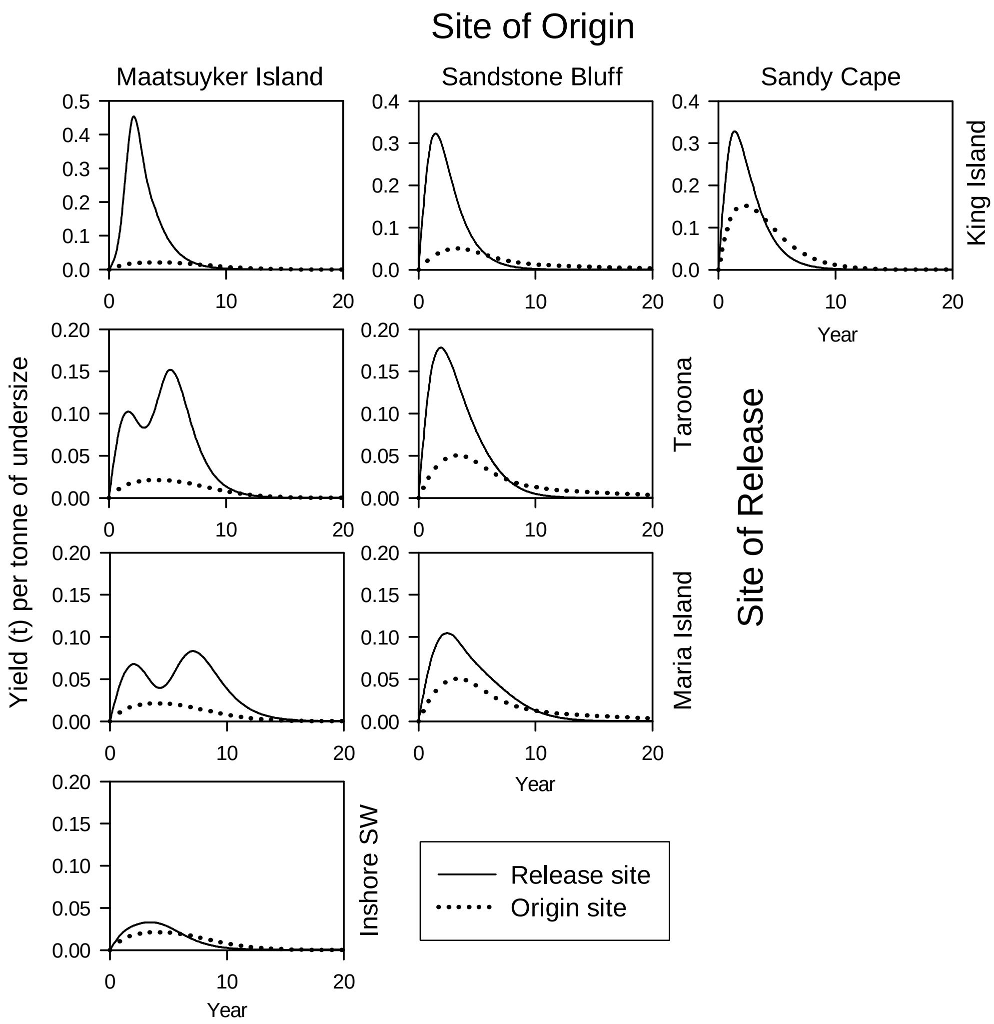

Figure 12. Annual pattern of yield through translocation for different sites of origin and release. Results from lobsters originating from Port Davey were similar to those from Maatsuyker Is. and are not shown. These simulations are based on the translocation of all undersize in catches (ie. no grading of lobsters for sex or size prior to translocation). Double peaks in yield gains occur on occasion as males and then females recruit to the fishery.

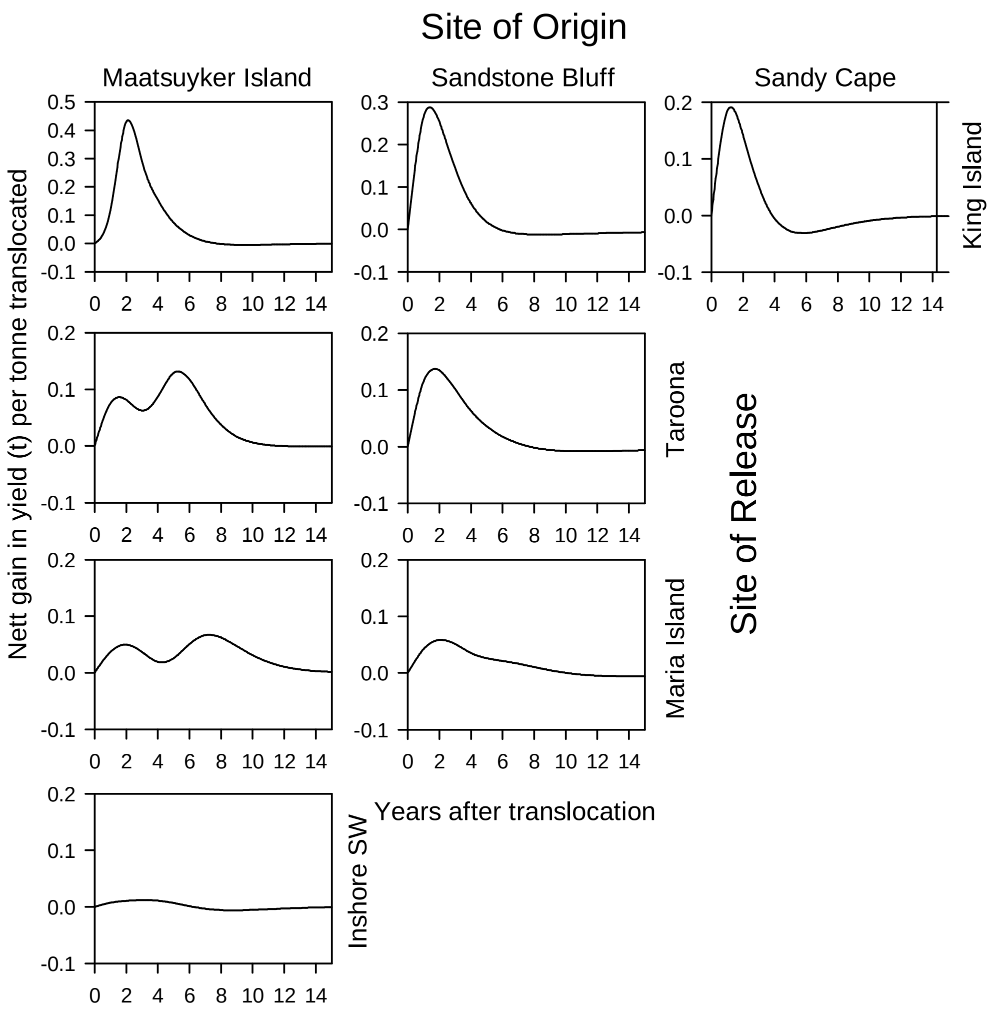

Figure 13. Annual pattern of gain in yield (Y_r - Y_o) through translocation for different sites of origin and release. These results show the difference between lines in Figure 12. Results from lobsters originating from Port Davey were similar to those from Maatsuyker Is. and are not shown. These simulations are based on the translocation of all undersize in catches (ie. no grading of lobsters for sex or size prior to translocation). Double peaks in yield gains occur on occasion as males and then females recruit to the fishery. Gains become negative on occasion when the cohort of lobsters at their new site have mainly all been caught, while slower growth at the old site results in a longer period of low-level recruitment to the fishery.

10.2 Does translocation interfere with natural ecosystems?

The removal of rock lobsters through fishing or translocation introduces the risk of undesirable community change in habitats utilised by rock lobsters. Habitats that are utilised by lobsters include both rocky reef and also silty/sandy substrates (Kelly et al., 1999). Silty and sandy substrates tend to be more important to lobsters at deeper depths because less time is spent sheltering on reef during the day and sandy substrates become increasingly important for foraging.

Research on the effects of the removal of lobsters on habitats has been mainly directed to the role of lobsters on regulating urchin populations. The concern here is that the removal of rock lobsters may allow urchin numbers to increase to the extent that barren formation occurs (Andrews and Macdiarmid, 1991). This risk has been investigated in Tasmania through an FRDC funded project "Range extension of the long-spined sea urchin (*Centrostephanus rodgersii*) in eastern Tasmania: Assessment of potential threats to fisheries" (FRDC 2001/044; C. Johnson, S. Ling, S. Shepherd and K. Miller).

In Tasmania, extensive experiments have indicated that legal-sized rock lobsters are important predators of urchins, and that fishing of legal-sized rock lobsters is sufficient to account for increases in urchin populations to levels where barrens can form. Rebuilding of lobster stocks in Tasmania through QMS has been least effective in shallow-water northern regions where barren formation is of greatest concern (Gardner et al., 2005).

Translocation would thus be expected to be a positive process in terms of ecological impacts as it raises the total biomass of large, legal sized lobsters statewide with greatest change in those regions with most depleted stocks. Translocation releases could target regions with incipient urchin barrens to reduce risk of barren formation.

Impacts on deep-water habitats would be expected to be lower risk as stocks in these regions will remain at high levels of biomass relative to the unfished state. However, it needs to be acknowledged that little is known of these deep-water habitats so monitoring of these areas as part of translocation exercises would be prudent.

Figure 14. Urchin abundance regulated by predation, including that by rock lobsters. Increasing abundance of rock lobsters in inshore areas through translocation would be expected to reduce the risk of barren formation. Little information is available on the nature of rock lobster fishing : ecosystem interactions in deep water so the effect of removals for translocation should be monitored.

10.3 Are there better management options for the issue?

Fishers have suggested that alternative management options may be available to deal with the shift in effort to inshore waters.

One option that has generated much discussion is the zoning of the fishery into deep and shallow water zones with additional quota allocated for deep-water fishing. This option may also entail a reduction in shallow water quota, given that the current TAC allows for catch in both depth zones. An example is that fishers may be allowed to take

10 kg in addition to the standard quota per pot (currently 145 kg) if they fish below 80 m depth.

This option may provide opportunity for increases in quota by reducing management concern for inshore stocks, although the magnitude of any increase in yield appears much smaller than through translocation. This is because of the reduced productivity of individual lobsters in deeper water, which drives the patterns seen in Figure 12.

The option requires an evaluation of the potential quota from both deep and shallow water, which is currently beyond the scope of the existing stock assessment model. Consequently, model development and probable additional data collection would need to be undertaken to pursue this option.

No feasible apportioning system for additional deep-water quota has been developed. There has been a suggestion that the magnitude of additional quota for deep water could be based on the price forgone by not catching higher value shallow water lobsters. That option does not address the different variable costs for fishing in deep and shallow water or the fact that the price ratio between shallow and deep-water lobsters is not constant (Figure 15).

If a population model were developed to allow the estimation of separate TACs in deep and shallow water zones, then the shallow and deep TACs combined create the global TAC for the fishery. This process could be used to develop different quotas for fishers operating in deep or shallow water, however an allocation process would need to be developed. A key point is how to deal with excess demand for additional deep-water quota beyond the deep-water zone TAC – how would this be apportioned?

Other options to manage the spatial aspects of the fishery include area closures, regional size limits and regional zones with separate TACs.

Regional size limits have the potential to raise yields through both lower size limits in southern regions and higher limits in northern regions (Figure 5). Current modelling is adequate to recommend regional size limits that increase yields and the TAC. The introduction of regional size limits would require discussion of enforcement systems. Marketing effort may also be required because although lower size limits in the south would optimise yield, these lobsters have very low market value and may not be harvested. Some fishers operating in deep water are already discarding small but legal size lobsters, so further reducing the size limit in the south may not lead to an increase in retained catch.

Area closures and regional zones with separate TACs had little support at port meetings.

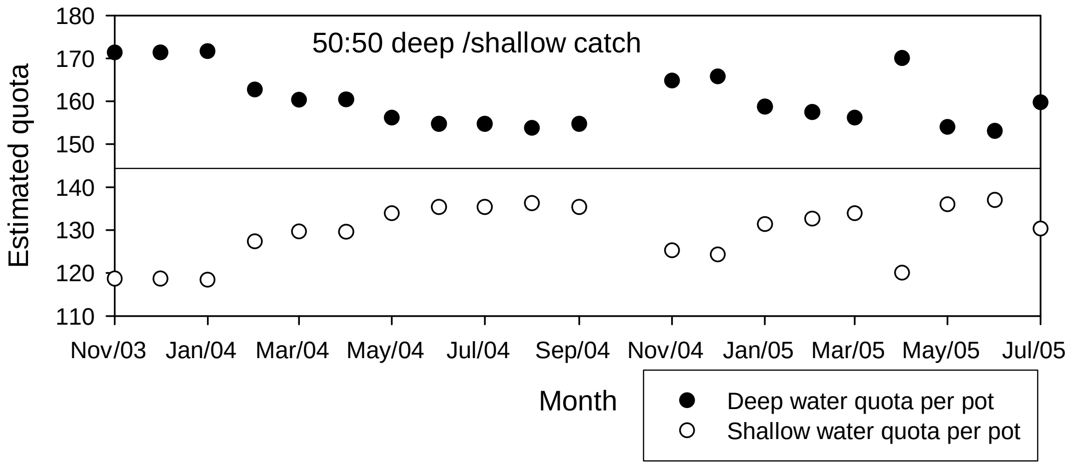

Figure 15. Quota allocation for deep water / shallow water zones if based on the price differential between shallow and deep-water catch, and if the TAC were based on the current assessment model. This analysis is based on average monthly beach price for lobsters in the median size categories and is based on current model estimates of sustainable quotas per pot (145 kg). Two issues are indicated: there is no standard ratio that could be applied, it varies from month to month; and given that current quota includes some deep-water catch, this option may need to involve an unpopular reduction in shallow water quota. If the current assessment model were altered to provide separate estimates of stocks in deep and shallow water, then it would be possible to provide estimates of separate deep and shallow zone TACs. We expect that this would indicate that more catch could be taken from deep water. Thus it may then become possible to allocate extra deep-water quota without reducing normal quota.

10.4 Can the issue be addressed by marketing instead?

Highest prices for Tasmanian rock lobster are currently obtained in China (Harrison, 2004) and it is this market that has driven fishing effort into inshore waters. If alternative markets were developed that paid equivalent premium prices for deep water lobster then the motivation for fishers to direct effort inshore would be removed.

Marketing thus appears to present some opportunity although is clearly difficult for a commodity product. Successful marketing initiatives with deep-water southern rock lobsters have included creating processed products from meat and tail segments. However, although these initiatives generate additional profit for the industry, they are predicated on access to lower priced deep-water lobsters and don’t remove the market incentive that drives effort inshore.

Translocation has some attributes that appear difficult to cover by marketing. First, substantial additional yield is generated so that production is increased. Secondly, it is probable that translocation will transform deep-water lobsters with narrow tails, poor survival in transport and low meat yields into shallow-water lobsters with better meat recovery, which is still desirable to markets where shell colour or vitality is less critical.

10.5 Can we afford to reduce egg production in southern Tasmania?

There appears to be low risk of affecting recruitment by translocation. This is because egg production in southern Tasmania is well in excess of the management target of 25% of production in an unfished state and is estimated to be around 100% (Gardner et al., 2005). In contrast, egg production estimates from northern regions indicate very low levels less than 18% of the unfished state. Translocation would thus act to improve egg productions in regions where it's most depleted, albeit at a loss from southern regions. This type of outcome is a lower risk management strategy relative to the current, where egg production is highly depleted in some areas but virtually untouched in others. Given the uncertainty about the location of regions that are important for larval supply, the conservative approach to management of egg production is to have reasonable levels of egg production in all regions. This is the current management objective and would be assisted by translocation rather than harmed.

Model outcomes shown in Figure 5 indicate that total egg production after translocation may be equivalent or greater than that without translocation. This is because of the greater growth and size of females after translocation, plus the effect of decline in harvest rate. Harvest rate would decline after translocation where the increase in quota was less than the increase in exploitable biomass. The economic evaluations in Table 5 are based on the harvest of only 50% of the additional exploitable biomass generated by translocation.

10.6 Is there a risk of spreading lobsters with "slow growing" genes?

Lobster larvae are widely dispersed (Booth and Stewart, 1992) so it is clear that regional characteristics such as slow growth rates are not controlled by genetics. Larval transport between Tasmania and New Zealand appears feasible and stocks in these regions are genetically indistinguishable (Chiswell et al., 2003). Larval mixing between regions within Tasmania is therefore assumed.

10.7 What if local lobsters are harvested instead of the translocated lobsters?

The TAC is based on model projections of TAC scenarios and what impact these are likely to have on egg production and biomass. The intent of translocation is to increase biomass and egg production so that the TAC can be increased. The origin of lobsters is not relevant to this process, simply the sustainable yield generated from the total biomass. Put simply, for the purposes of setting the TAC and for managing egg production, a lobster is a lobster, regardless of origin. This is effectively also true genetically (Section 10.6).

Given that it is intended to target translocation releases to sites where there are concerns about local levels of biomass and egg production, the harvest of lobsters in other regions instead would actually be preferred (from an egg production, not economic perspective).

10.8 Will effort shift inshore and deplete inshore reef?

Some fishers expressed a concern that translocation would increase the availability of lobsters in inshore areas, which would then lead to increased effort in these areas and ultimately even more depleted inshore reef.

This concern seems unlikely to be realised as translocation does not alter the business decisions of fishers when choosing where to fish. For example, a fisher would be no more likely to continue fishing in an inshore area when catch rates were very low simply because translocation had once occurred at the site.

We would expect catch rates to increase following a translocation event and then gradually decline as the cohort of lobsters is removed by fishing and natural mortality. There appears no reason why fishers would continue to expend effort at the site at levels beyond their normal intensity.

Also note that under operational proposals in Chapter 9, the residual exploitable biomass and catch rates would be expected to increase under all translocation scenarios. This is because the quota is not increased to the extent of the increase in exploitable biomass. This provides reduced risk of regional depletion of biomass relative to the status quo of no translocation.

11. Benefits and adoption

The project has met objectives of evaluating the feasibility of translocation. The work was intended to be an evaluation of this management option to assess if further research expenditure was warranted.

This process has demonstrated the economic feasibility of translocation. The commercial and recreational Tasmanian rock lobster industries have reiterated interest in pursuing increased catch in the fishery through this method.

Adoption and subsequent benefits to the fishery cannot occur until further research is conducted. This research must (a) improve estimates of some of the biological model parameters, and (b) provide advice on the scale of translocation operations that are optimal.

12. Further development

Direction for further research was provided by sensitivity analyses. Issues include:

- density dependent growth and mortality through large scale field trials;
- time to transit growth rates at new site;

- release mortality and emigration; and
- patterns in SOM transition of translocated females.

In addition, population modelling of deep and shallow water stocks is required to evaluate the magnitude of possible translocation operations (and thus the probable annual gain in quota and economic yield).

The economic analysis conducted here should be repeated following that additional research to enable discussion of appropriate fees for quota generated by translocation.

13. Planned outcomes

As predicted in the project plan, this project had no commercial outcomes because it was intended to serve as a test of wether additional research was warranted. Given the positive results of the project, subsequent research is expected to have significant commercial outcomes. These will be as increased catch and economic yield in the fishery.

14. Conclusion

Translocation involves the shifting of undersize rock lobsters to new areas to increase productivity or quality of product.

We modelled the translocation of rock lobsters from 4 original sites to 4 release sites that have a range of growth rates. Most scenarios led to increases in yield at least double the status-quo. Greatest gain was from the translocation of females from the SW to the NW – in these cases the translocation of 1 tonne led to almost no loss of yield at the origin site but a 1.6 tonne gain at the release site.

Levels of egg production in northern regions are a management issue for the Tasmanian fishery and these were increased by translocation. Both yield and egg production benefits were greatest when smaller females were translocated and when translocation was integrated with increased regional size limits in the north.

Economic analysis of scenarios that involved the movement of 5 tonnes of lobsters by charter indicated that it is possible to generate an additional kg of catch for around $2.50. This compares favourably with current lease costs of >$15/kg. Net state benefit was $160,000 per 5 tonne trip by a chartered vessel. The internal rate of return for these operations was around 200%, which constitutes an extremely attractive investment. Three possible systems for funding translocation were developed and each involved an allocation of additional quota to fishers.

Translocation appears to offer a feasible option for sustainably and substantially increasing yield by converting low growth, low value lobsters into more productive, higher value lobsters.

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16. Appendix 1: Intellectual Property

No compelling reason was identified to restrict distribution of results so these have been made publicly available with no protection or confidentiality.

17. Appendix 2: Staff

Project staff were:

Dr Caleb Gardner, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania

Ingrid van Putten, School of Economics, University of Tasmania.

18. Appendix 3: Estimation of biological parameters

18.1 Growth

Growth was estimated from tag recapture data from 7 sites, Maatsuyker Island, Port Davey, Sandstone Bluff, shallow South-Western Tasmania, Eastern Maria Island and Tasman Peninsular, Taroona and King Island. Data were collected between 1990 and 2004.

Von Bertalanffy growth curve parameters were estimated from tag.recapture data by using the GROTAG estimator of Francis (1988) with modifications by McGarvey et al. (1999). This method, based on a reparameterization of the Fabens (1965) von Bertalanffy equation, expresses predicted mean change in length ($\Delta\hat{L}$) as a function of time-at-large (Δt) and length at time of tagging (L_1). The growth parameters K and L_∞ are replaced by ga and gb, defined as the mean annual growth rates at two lengths chosen by the modeller, a and b.

These growth curves were applied to lengths of lobsters using the mid-point of each size bin. While this was adequate for the purposes of this model, more detailed modelling exercises of translocation would utilise a size transition matrix approach to describe individual variation in growth rate within size bins (Punt et al., 1997).

Table 6. Von Bertalanffy growth curve parameter estimates. Insufficient recaptures of female lobsters from Port Davey were obtained for growth to be estimated.

	Females			**Males**		
Site	**n**	L_∞	K	**n**	L_∞	K
Deep						
Maatsuyker Island	1862	106.61	0.0437	4144	122.42	0.1954
Port Davey	-	-	-	1182	116.26	0.1938
Sandstone Bluff	4677	107.40	0.4072	2667	122.28	0.4592
Sandy Cape	166	127.39	0.1701	124	178.12	0.1390
Shallow						
shallow South-Western Tasmania	2768	112.28	0.0978	1496	122.67	0.3014
Eastern Maria Island and Tasman Peninsular	539	112.73	0.0979	366	122.67	0.3015
Taroona	5304	132.41	0.1760	7413	182.44	0.2279
King Island	375	147.79	0.3029	472	184.26	0.2601

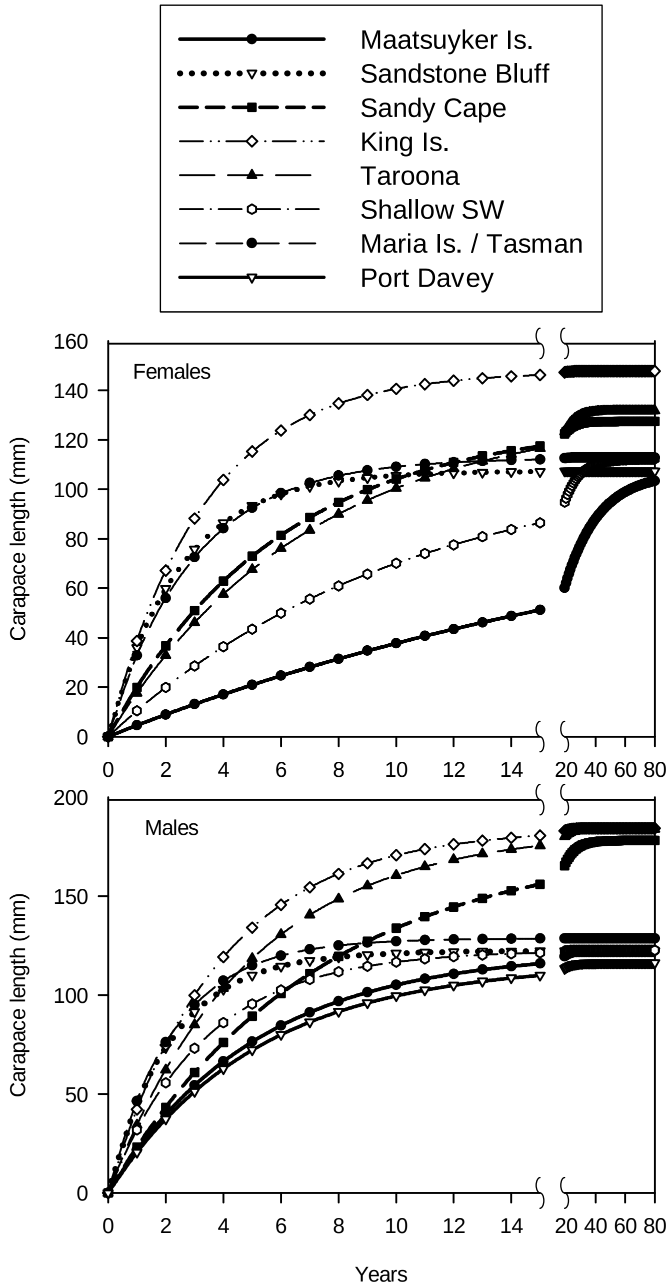

Figure 16. Von Bertalanffy growth curves for male and female lobsters from each site.

18.2 Length Weight

Length-weight parameters were estimated for each sex and for deep- and shallow-water lobsters separately. This accounted for the lower weight at size for deep-water lobsters.

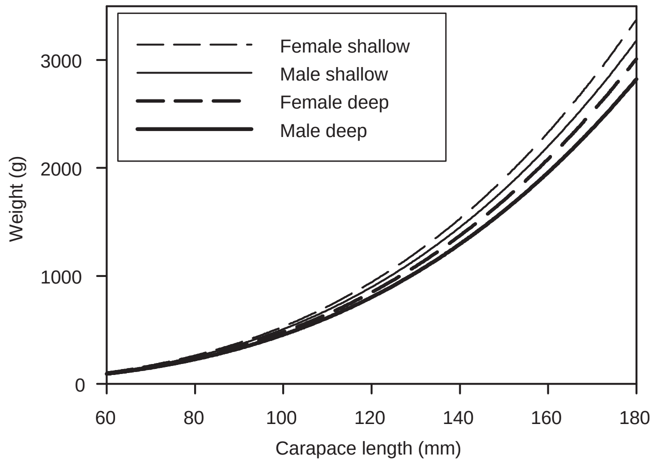

Figure 17. Change in weight with carapace length of male and female lobsters from deep and shallow water.

18.3 Natural Mortality

Lorenzen (2005) recommended enhancement operations be modelled with account of the typically inverse relationship between natural mortality and length. We did not take this approach and instead assumed that natural mortality was constant with length. This was because the lobsters being released by translocation operations were much larger and proportionally older than the finfish juveniles discussed by Lorenzen (2005). Thus the assumption of constant natural mortality was not expected to be violated to a large extent. Analyses of natural morality shown below (Figure 18) indicated constant natural mortality with length down to lobsters of 88 mm CL, which is around the size of full recruitment to research gear without escape gaps.

Natural mortality was estimated from samples of lobsters from regions where no fishing mortality occurred. These were (i) female lobsters from the Maatsuyker Island site and (ii) male and female lobsters from the Taroona Waters marine reserve. Although the Maatsuyker Island site is open to fishing, few females reached legal size (10 of 75994 lobsters in research samples) so total mortality (Z) estimated from this site was effectively natural mortality only (M).

Mortality was estimated by a length-converted catch curve using the method of Pauly (1983). This method used data on the frequency or number of individuals in length bins (F ; total n=75994) with age of the midpoint in length bins estimated from the inverse of the von Bertalanffy growth curve, with t_0 set to zero as only relative age was required. Parameters to define the von Bertalanffy growth curve were estimated from tag recapture data collected through the same sampling exercises n=1862; L_∞ = 106.6055, K =0.04367). This allowed determination of dt which is the time taken to grow through a length class.

The catch curve equation is:

$$\ln(F / dt) = a - Zt$$

which enabled Z to be estimated by linear regression. The regression was restricted to data from lobsters fully recruited to the gear.

The number of tagged and recaptured lobsters used to derive growth parameters are shown in Table 6. Numbers of lobsters used for length frequency data were 75944 (Maatsuyker females), 10852 (Taroona females), and 12988 (Taroona males).

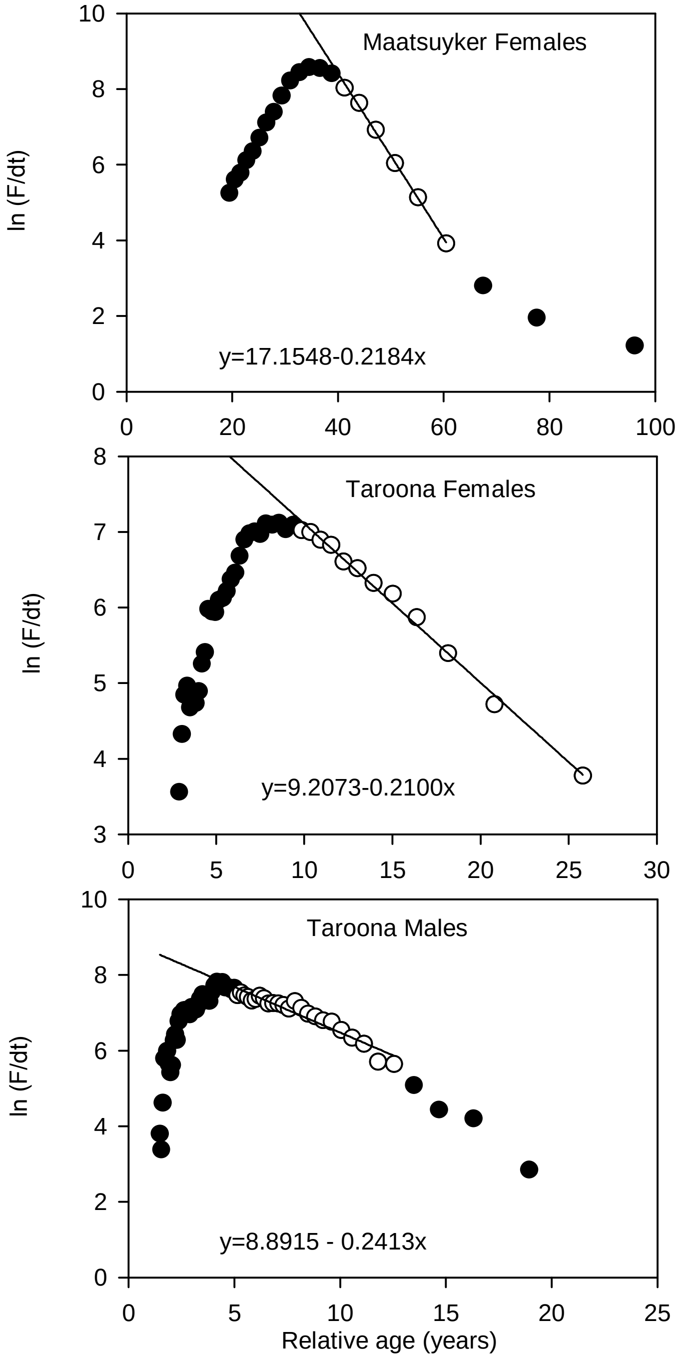

Figure 18. Estimation of natural mortality with a length converted catch curve for southern rock lobsters from off Maatsuyker Island and Taroona Marine Reserve. F is the number of lobsters in each size bin and dt is the time taken to grow through the bin. Linear regression of fully recruited data (excluding data points close to L_∞) produced an estimate of the slope, or instantaneous total mortality. Instantaneous total mortality estimates were 0.22 y^{-1} (females, Maatsuyker), 0.21 y^{-1} (females, Taroona), and 0.24 y^{-1} (males, Taroona). These equate to annual survival of 80%, 81% and 79% respectively.

Results from analyses of natural mortality indicated that similar rates exist in deep-water and in-shore areas. Thus the same values were applied for both removal and release sites.

18.4 Density dependence

Density dependent interactions can be expected to influence the outcomes of enhancement operations through changes in both growth and mortality (Lorenzen, 2005). Incorporation of density dependence into a model of translocated animals is more complex as increases in density at the release site will be accompanied by decreases in density at the harvest site. Thus there would be a prediction of translocation leading to increased yield per recruit at the harvest site and decreased yield per recruit at the enhanced site. This aspect of translocation was not addressed in the current model but appears an important issue for future research.

Modelling approaches are available to incorporate the effect of density dependent growth and mortality into translocation analyses (Lorenzen, 2005). However, incorporation of even hypothetical scenarios is difficult here as responses of lobsters to increased density defy generalisation.

Previous research presents mixed guidance on the likely importance of density dependent processes in Tasmanian lobster stocks. McGarvey et al. (1999) examined growth of lobsters in South Australia and observed a decline in growth with increasing density so that a 10% decrease in CPUE increased growth by between 1.9% and 4.9 %. Gardner (2004) examined processes affecting size at onset of maturity of female lobsters around Tasmania and found only a weak influence of density, which implies similar for growth as these are generally linked.

18.5 Fishing mortality

Estimates of fishing mortality of lobsters in different regions around Tasmania have been derived from different methods. The length-based model developed by Punt and Kennedy (1997) produces estimates of fishing mortality from 8 assessment regions around the State. Recent estimates from this model were reported in Gardner et al. (2005). Frusher and Hoenig (2003) used tag-recapture data to estimate fishing mortality using multi-year tagging models. All sources provided similar estimates of instantaneous fishing mortality of around 1, which equates to annual fishing mortality of around 65%. None of these sources provide separate estimates for deep and shallow water although differences clearly exist due to fishers targeting higher value lobsters in shallow water. The sensitivity of translocation benefits to estimates of fishing mortality from different depths was tested here.

18.6 Catch rates

The number of pot lifts required to catch the desired number, size and sex of undersize lobsters influences the economic cost of capturing lobsters from deep-water sites. Catch rates of undersize lobsters by 2 mm size bin were determined from research sampling conducted between January 2000 and January 2005 at the Maatsuyker Island, Port Davey and Sandstone Bluff sites. This research sampling was conducted using traps with the escape gaps tied closed, which would also be the case with any translocation exercises.

Research sampling was conducted in a manner different to that of commercial operators; potlifts were less frequent, sampling was not conducted during periods of peak catchability and pots were not set with the intent of maximising catches. To provide more realistic estimates of probable undersize catch rates in translocation exercises, research catch rates from each site were scaled to commercial catch rates from the same fishing block. Commercial CPUE was calculated as total catch / total effort (potlifts) per year. Catch rates of legal size lobsters in research sampling are recorded as number of animals per potlift, which was converted to weight using the length weight relationship for deep water lobsters described previously.

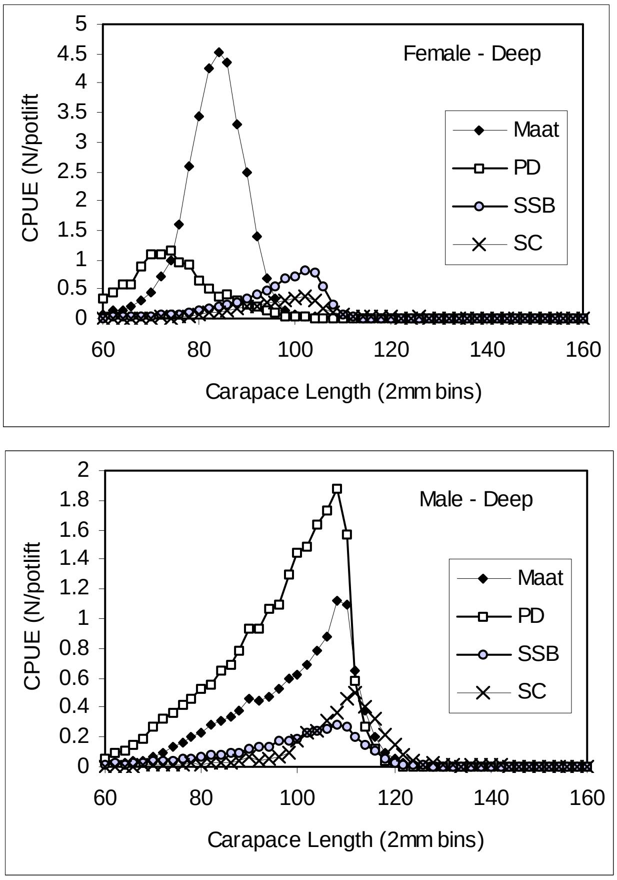

Figure 19. Predicted commercial catch rates of lobsters per 2 mm size bin using traps with escape gaps closed. Sites are Maatsuyker Island (Maat), Port Davey (PD), Sandstone Bluff (SSB) and Sandy Cape (SC).