Bioeconomic decision support tools for Southern Rock Lobster

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Table of Contents

Non-Technical Summary

2009/714.20 Bioeconomic decision support tools for Southern Rock Lobster

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PROJECT OBJECTIVES:

1. Define baseline economic performance of participating Southern Rock Lobster fisheries.
2. Produce bioeconomic analysis tools for Southern Rock Lobster fisheries.
3. Determine economically optimal management strategies using integrated stock and economic models, including seasonal, size and total allowable catch (TAC) combinations.
4. Communicate management and harvest strategy opportunities identified in Objective 3.

OUTCOMES ACHIEVED AND PLANNED

In this project, (1) economic data for Tasmania were collected, and (2) a lobster fishery projection model was produced which permitted the testing of a wide range of strategies including in terms of economic performance. (3) Using this bioeconomic model, the expected economic yield from a range of alternate management strategies were estimated. (4) A series of meetings with Tasmanian and South Australian lobster fishery industry and fishery managers were held to present and discuss the results of evaluating strategies, most of which were requested by industry or managers for assessment.

For outcomes achieved using tools developed in this project, examples are listed of uses of the bioeconomic model for management decision making in Tasmanian and South Australian Rock Lobster.

1. In Tasmania, some fishers requested an increase in the minimum size of lobsters to better protect spawning females. The bioeconomic model examined variations on this objective. Results found that because females grow slowly in parts of the jurisdiction, the larger size limit would displace effort to other, faster growth, regions of Tasmania, increasing exploitation there. This displaced effort would reduce catch rates overall and reduce egg production in those target regions such that (1) economically the fishery would be worse off, (2) gains in egg production would be small, and (3) egg production would be reduced in the more depleted fast growth areas. **Accordingly, an output from the project was the decision to not raise the minimum size limit in Tasmanian lobster.** (See Chapter 5)

2. In parts of northeast Tasmania, populations of urchins have exploded, in part due to southward extensions of the warm urchin-favourable waters of the East Australian Current. Overgrazing by urchins has devastated some kelp forests in

this region of the Tasmanian coastal shelf. Because (only) large lobsters predate on these species of urchins, one solution proposed to reduce urchin numbers was to increase the population density of larger Southern Rock Lobster. Environmental lobby groups were strongly endorsing a maximum size limit for harvested lobsters. The bioeconomic model was utilised to evaluate this strategy, and it was found that a maximum size limit would severely reduce economic yield. An alternative strategy of reducing overall levels of exploitation in this region, using a catch cap, essentially a spatially-restricted total allowable commercial catch (TACC), would increase number of larger lobsters even more than a maximum size limit, without the attendant economic reduction. **This strategy identified by the bioeconomic model was adopted, preserving economic benefit to the fishing industry and regional Tasmanian communities, while still achieving ecological management objectives.**

3. In South Australia (SA), the existing harvest strategy implemented in 2011 underwent formal review. At November 2013 meetings of the Management Advisory Committee (MAC) Harvest Strategy Review Working Groups (Northern Zone and Southern Zone), **the harvest strategy review committees requested the bioeconomic testing of a range of management strategy options for implementation in the two SA lobster fisheries**. Strategies evaluated with the bioeconomic modelling tools developed in this project were selected by representatives of industry, Primary Industries and Regions South Australia (PIRSA) fishery managers, and South Australian Research and Development Institute (SARDI) stock assessment scientists. These results were reported to industry in February and to the two Harvest Strategy Review Working Groups in early March 2014. The Working Groups refined this to a set of final strategies that were evaluated by the bioeconomic model and presented to the two Working Groups on 14 April 2014.

4. In the South Australian Southern Zone, harvest strategy modifications were recommended, which await approval by wider industry, the PIRSA Executive Director, and the Minister. **Three modifications found to be economically optimal or to enhance catch stability in model testing were recommended by the Southern Zone Harvest Strategy Review Working Group: (1) a revised procedure for quota setting when the fishery falls below the limit reference point catch per unit effort (CPUE) of 0.6 kg/potlift, (2) narrowing the width of CPUE bands into which yearly TACCs under the harvest control rule are assigned, and (3) a revised set of hybrid TACC levels for yearly quota setting.**

5. Future application: In the South Australian Northern Zone, industry are advocating a new management regime, combining spatial management to access outlying fishing grounds and opening winter fishing to capture a higher export price. Winter fishing was examined under this project (Chapter 10) but insufficient information was available to assess its likely future performance. A new FRDC project is now approved to gather information on winter fishing in the Northern Zone. **In a projected second stage of this upcoming project, the bioeconomic modelling tools will be used to assess the economic performance of this industry-led Northern Zone strategy of winter fishing and spatial management**.

LIST OF OUTPUTS PRODUCED

1. Powerpoint presentations to industry peak body groups (Tasmania and South Australia), PIRSA fishery managers (South Australia), the MAC Research Sub-Committee (South Australia), the MAC Harvest Strategy Review Working Groups (South Australian Northern Zone and Southern Zone), and Seafood CRC workshop of lobster fishery managers, industry peak body representatives, fishers, processors, and scientists from New Zealand and Australian lobster fisheries (Melbourne 28-29 May 2013), and to the Trans-Tasman Lobster Congress (Sydney, 1-2 September 2013).

2. In Tasmania, project co-investigators Caleb Gardner, Klaas Hartmann and Eriko Hoshino met with industry and government extensively during the project. These meetings will continue to take place to ensure uptake of results obtained during this project.

3. In South Australia, half-day workshops presenting project objectives, bioeconomic decision making tools developed, and important lessons learned in lobster fishery management to enhance industry profitability, held with all lobster industry participants invited in the South Australian Southern Zone (18 September 2013, Millicent SA) and South Australian Northern Zone (19 September 2013, Adelaide SA). Once modelling results for the MAC Working Group to evaluate the two SA harvest strategies were completed, presentations to the Northern Zone Executive Committee, and in the Southern Zone for all industry members, were presented in February 2014.

4. For reviewing the harvest strategy in South Australia, a series of meetings in 2013/14 with PIRSA managers, Executive Committees or peak body representatives of industry, Research Sub-Committee (chaired by Cathy Dichmont) and Harvest Strategy Review Working Group of the SA lobster fishery MAC (chaired by Richard Stevens) were undertaken. Outputs included the bioeconomic tests of three sets of harvest strategies, refining down the selection of economic optimal strategies from November, and March to the final set considered by the two Harvest Strategy Review Working Groups on 14 April 2014.

PROJECT SUMMARY

The detailed outcomes achieved under each of the four Seafood CRC project Objectives are summarised below.

Objective 1: Define baseline economic performance of participating Southern Rock Lobster fisheries.

Under Objective 1, with profitability as the focus, two important sources of economic information are needed to compute yearly fishery profit: landed price of lobster and costs of fishing. In South Australia, on-going cost data, as well as estimates of average yearly profit, are supplied to PIRSA Fisheries and Aquaculture in yearly reports by EconSearch, interviewing a sample of active fishers in each fishery every three years. An EconSearch economic survey of the Tasmanian lobster fishery was carried out under this project.

Profits, under different strategies, can be improved by increasing revenues or by reducing costs. Fixed costs include administrative and accounting costs,, and the purchase cost of the vessel as depreciation. Variable costs include bait, fuel, and labour. In evaluating management strategies, only savings in variable costs are made when fishing effort is reduced. In this project, analysis of fishing costs achieved two outcomes for South Australia: (1) A yearly estimate of fixed cost was obtained for the two fishery zones (Chapter 2). (2) For variable cost, SARDI and EconSearch collaborated to estimate per potlift dollar values (Chapter 2).
The report on the Tasmanian economic survey by EconSearch is attached as Appendix 5.

The questionnaire used by EconSearch for interviews with active fishers in the economic survey is attached as Appendix 6.

The estimates for landed price of lobster, the second component of Objective 1, are reported in Chapter 3. Tasmanian lobster prices were gathered by collaboration with a Tasmanian processor, quantifying the variation in landed (beach) price by month, lobster size, and lobster colour. The Tasmanian data reported in Chapter 3 and discussions with South Australian fishers confirmed with some variation that price by size in both Tasmania and South Australia varies by a ‘price split’ of lower price for lobsters above 1.5-2 kg due to lower demand for large lobsters in Asian markets, notably after Christmas. Monthly variation in lobster price to fishers was also quantified and used in modelling.

<u>Objective 2. Produce bioeconomic analysis tools for Southern Rock Lobster fisheries</u>.

The second Objective was to develop bioeconomic modelling tools to evaluate management strategies. The specific performance measure we sought to optimise for managing these lobster fisheries was future average profit. Bioeconomic modelling tools were constructed for South Australia, and the previous Tasmanian model was extended. Chapter 4 summarises this modelling capability. Appendices 1, 2, 3 and 4 provide mathematical and technical details of these modelling tools.

To provide reliable bioeconomic projections, four model components are required:
1. A stock assessment model is fitted to all available historical data. This produces estimates of the critical features of the exploited population, such as total lobster biomass, lobster numbers by size grouping, capture length selectivity, and seasonal variation in the catchability of an average lobster pot. The ROCK stock assessment model, developed mainly by André Punt, is used in all five Australian Southern Rock Lobster fisheries.
2. The second component needed is data on the economics of the resource, fishing costs and price, gathered in this project under Objective 1.
3. The third component is a projection model, to allow projections of the lobster fishery dynamics, population numbers, catch, egg production, fishing costs and thus profit, going forward in time. The projection model uses the same model equations, and the same maximum-likelihood estimated parameters as the stock assessment model, so these projections are based in a statistically rigorous fashion on the same data and inference used in stock assessment. Assumptions about future recruitment are important. A range of projected recruitment scenarios were tested in evaluating different harvest control strategies.
4. The fourth component are submodels which simulate the various fishery management strategies that stakeholders, the fishing industry and fishery managers, may wish to evaluate. Outputs under each strategy tested include future changes in egg production, average catch rate, fishing costs, and a measure of average profit over future years (net present value, NPV).

These four components of the bioeconomic harvest strategy decision support tools for Southern Rock Lobster fisheries were completed for South Australia and extended for Tasmania under this project.

Objective 3. Determine economically optimal management strategies using integrated stock and economic models, including seasonal, size and TAC combinations.

Objective 3 was to evaluate a range of management strategies for enhancing the economic performance of Southern Rock Lobster fisheries. A wide range of strategies were tested for Tasmania (Chapters 5-7) and South Australia (Chapters 8-10). Here we summarise highlights of these management strategy performance evaluations, notably emphasising strategies shown to provide the most profitable outcomes.

Maximum size limits were found to be a highly economically unfavourable strategy suggesting these should not be considered further for Southern Rock Lobster. This was found in model testing for both Tasmania, with application to managing the enhancement of larger lobsters in the Tasmanian northeast stock to control urchin populations (Chapter 7), and in South Australia’s Southern Zone (Chapter 8).

Raising the minimum size limit enhances profitability when lobster growth rates and/or exploitation rates are higher. Raising minimum size is projected to be economically beneficial in the South Australian Southern Zone (Chapter 8), but have no measurable impact in the Northern Zone. In the Tasmanian south, raising the minimum size would be economically unfavourable (Chapter 5).

For the South Australian Southern Zone, policies that use a harvest control rule to set quota yearly in such a way as to approximately target a constant exploitation rate (a constant fraction of the stock removed yearly) were found to be economically superior to constant quotas or any form of size limit policy, yielding substantially higher projected net present values (NPV) (Chapter 8).

Versions of a constant-exploitation-rate policy were implemented in South Australia, within a 4-part harvest strategy, in the two zones in 2011. These harvest strategies were programmed into the bioeconomic model and tested against the policy found to be the best economic performer. The current South Australian harvest strategies, which were designed in 2011 with strong industry input, were projected by the bioeconomic model to achieve very nearly maximum economic yield if recruitment were to be maintained at historical levels.

Recruitment has been trending lower in all five Australian Southern Rock Lobster fisheries. Under scenarios of lower average recruitment going forward, in both South Australian (Chapter 9) and Tasmanian (Chapter 6) projections, lower levels of exploitation rate yield relatively higher profitability.

Objective 4. Communicate management and harvest strategy opportunities identified in Objective 3.

Objective 4 was to communicate these strategy evaluation outcomes to industry and managers. This was undertaken in a series of meetings with formal management bodies, fishing industry peak bodies, and in workshops with the fishers in each management zone directly. For South Australia that included presentations by the PI to the MAC (Management Advisory Committee) Research Subcommittee, twice to the industry peak body SARLAC (South Australian Rock Lobster Advisory Council), and for Tasmania and South Australia by Rick McGarvey (PI) and Caleb Gardner (co-investigator) at the Trans-Tasman Lobster Congress. Three major workshops were held in South Australia with all industry stakeholders invited for the South Australian Southern Zone and Northern Zone. A summary of these meetings and outcomes, for Tasmania and South Australia, are given in Appendix 7. And, as summarised above, extensive communications, written summaries of harvest strategy evaluations and oral presentations, were made by the project PI, mainly, in the South Australian Harvest Strategy review in 2013/14, to the MAC Harvest Strategy Review Working Group, to PIRSA managers, to industry peak bodies and their executive officers, and to the wider lobster fishing industry community.

ACKNOWLEDGEMENTS

The project was supported by the Australian Seafood CRC and the Fisheries Research and Development Corporation (FRDC). It involved collaboration between the South Australian Research and Development Institute (SARDI), Institute for Marine and Antarctic Science (IMAS), CSIRO Wealth from Ocean Flagship: CSIRO Marine and Atmospheric Research, and EconSearch Pty Ltd. The lobster fishing industries of Tasmania and South Australia contributed funding for this work via SRL Ltd, who contributes industry funding directly to the Seafood CRC and advises FRDC on industry research priorities. SRL Ltd played a critical role in directing lobster fishery research effort to economic management objectives. We also thank the assistance and advice provided by the industry peak bodies, the Northern Zone Rock Lobster Fisherman's Association (NZRLFA, Executive Officer Kyri Toumazos), the Southeast Professional Fishermen’s Association (SEPFA, Executive Officer Justin Phillips), and the peak body for both zones of SA rock lobster, SARLAC (SA Rock Lobster Advisory Council Inc., also with Executive Officer Justin Phillips). Direct fisher advice used in or informing model development came from Roger Rowe, Trent Gregory and Richard Leach in the Northern Zone, and Joel Redman and Dave Mansur in the Southern Zone. Justin Phillips, Kyri Toumazos, and Gary Morgan provided advice on project work and assisted liaison with industry. Annabel Jones, with Alice Fistr, the PIRSA lobster fishery managers, assisted communication and the two industry workshops. Ian Cartwright acted as facilitator for the industry workshops. Caleb Gardner was instrumental in putting this, and other economic modellings projects in place under the Seafood CRC, and the PI sought his assistance frequently throughout the project. The researchers for EconSearch, Stacey Paterson, Lisa Rippin and Julian Morison, were instrumental in timely delivery and statistically rigorous economic information gathering. SARDI researchers who played important contributing roles were Richard McGarvey (PI), Paul Burch, John Feenstra, Janet Matthews, and Adrian Linnane. IMAS researchers were Caleb Gardner, Klaas Hartmann, and Eriko Hoshino. André Punt, of CSIRO, wrote the majority of the ADMB and Fortran code used in the ROCK estimator and projection models.

1. Introduction and Background

Richard McGarvey and Caleb Gardner

This project forms part of a series of projects within the Seafood CRC on decision support tools for fisheries, with the other projects directed to Western Rock Lobster, prawns and abalone. In each case, biological and economic data are combined to enable stakeholders to make decisions about their fishery with the goal of enhancing profitability.

The Southern Rock Lobster fishery is the most developed of the fisheries included in this series of projects because sophisticated bioeconomic models and stock projection capacity had already been advanced through previous research (CRC project 2006/042). The research reported here takes the process further to extend the modelling tools to other states and examine the use of economic control rules. This means, for example that it would be possible to evaluate how feasible it would be to target maximum economic yield in the face of price volatility. This level of bioeconomic analysis capability is only available elsewhere in Australia in the Northern Prawn Fishery; Australia's best example of the use of economic data for management to increase profits.

Southern Rock Lobster fisheries are predominant in terms of gross value of production in three Australian states, constituting the largest (by value) wild stock fisheries in South Australia and Victoria and the second largest, after abalone, in Tasmania. All three fisheries are quota managed. The setting of quota, and other management decisions, rest primarily upon biological assessment. Performance targets are usually based on trends in catch rate or catch, and are informed (South Australia) or primarily determined (Victoria and Tasmania) by the use of the ROCK fishery stock assessment model. The current process of making management decisions in each state typically incorporates limited formal analysis of the economics of the fishery, either in tracking change or guiding management decisions. The benefit of moving away from this current catch-focused management towards setting economic goals for the fishery are becoming widely understood with changes in several larger fisheries such as Western Rock Lobster and the Northern Prawn Fishery.

This project extends the use of the lobster fishery population model used for stock assessment in Tasmania and South Australia, to provide tools for economic evaluation of Southern Rock Lobster fisheries. In the last few years, the lobster fisheries in all three states have experienced substantial declines in catch rates, and corresponding reductions in total allowable commercial catch (TACC). This enhances the need for incorporating economic guidance in management as the value of the fishery is large, and costs of fishing relatively high, so that new strategies are sought to realise gains in economic return despite declining recruitment. This project seeks to realise that opportunity, in searching for strategies that increase economic return.

The research undertaken is summarised as follows:

(i) Baseline economic data were gathered in economic surveys of both fisheries to describe their current state, estimate costs of fishing, and enable changes in economic indicators to be tracked. An economic consulting firm, EconSearch, carried out the survey of economic information from interviews of active fishers. Line-by-line fishing costs were recorded and summarised. EconSearch currently runs these economic surveys (on all major South Australia fisheries, including lobster) under contract with PIRSA Fisheries and Aquaculture, surveying each fishery every three years, the only such surveys carried out for lobster in Australia. The EconSearch survey method was applied in the Tasmanian lobster fishery under funding from this project, with questions added to the interview questionnaire. These surveys provide critical economic input data for lobster fishery bioeconomic modelling in the two states. The details of the methods used to estimate variable and fixed costs of fishing are given in Chapter 2. The price of lobsters at time of landing, broken down by month and lobster size, was also gathered for the two states (summarised in Chapter 3). Thus, the first goal of this project was to gather baseline economic data on (1) fishing costs, both variable and fixed, and (2) on the price of landed lobsters, providing essential input data for economic modelling analysis.

(ii) The second goal was to develop and extend bioeconomic modelling tools to provide data-based advice to industry and managers about which management strategies are likely to provide higher profitability going forward in time.

This was achieved by extending the stock assessment modelling tools which currently describe the population biology and fishery harvest of Australian Southern Rock Lobster. The length-based modelling of the lobster population, including processes of lobster natural mortality, harvest, catchability, length selectivity, and growth, underlies our understanding and statistical description of the fishery, based directly on the available data, by statistical fits to the multiple data sources over historical years.

The fishery data sets available include reported catch in lobster landed weight, catch in lobster numbers, effort as total potlifts set, and from pot sampling, proportions captured by carapace length bin and sex. Tag recovery data were used to model lobster growth. These strongly data-based model fits thus make maximum statistical use of the available information about the fishery. These inform the estimated model stock dynamics.

The estimated stock assessment model parameters, and model equations for each lobster fishery, were used as the basis of a bioeconomic projection model (described in Chapter 4 and Appendices 1-4) which estimates the profitability of different proposed management strategies going forward in time. Three such bioeconomic models, which can test management strategies for each management zone, were parameterised and either extended (Tasmania) under this project or developed and completed (South Australian Southern Zone and South Australian Northern Zone).

These tools were used in the project to test a wide range of proposed fishery management strategies for Tasmanian and South Australia lobster, seeking in particular those that yield a higher than average profit. In future years, these tools will remain available for use in seeking economically favourable, and more highly sustainable fishery management.

Informative outputs these models can report on include future profitability as net present value (NPV), total yearly egg production as an indicator of stock sustainability, average catch volume in future years, and average extent of yearly variation in catch, since a more stable volume of supply is another management objective that industry identified.

(iii) Options explored for improving sustainable profitability. The bioeconomic modelling tools were used to evaluate the economic and sustainability performance of a wide diversity of management strategies in the three lobster fishery zones

(Tasmania and two South Australian zones). For all strategies tested, we report the level of average future profitability, as NPV.

The project management strategy testing outcomes are presented below in six report Chapters, Chapters 5-10.

Tasmanian lobster management strategy comparisons are given in Chapters 5-7, and those for South Australia in Chapters 8-10. Most strategies evaluated (Chapters 5-7, 10) were proposed by industry on steering committees, or management subcommittees and in peak bodies, or were comparisons of recently implemented (2011) South Australian harvest strategies (Chapter 9). Here we summarise, by chapter, these outcomes for Southern Rock Lobster fishery management.

Chapter 5 presents the model investigation requested by Tasmanian industry of the impact of raising the minimum size of females to protect egg production. The analysis of this strategy showed that the Tasmanian rock lobster fishery faces a significant management challenge if the objective of maintaining high levels of egg production in all sub-zones is to be achieved. High spatial variation in growth means that the industry proposal for an increase in a jurisdiction-wide female legal minimum length (LML) will be counterproductive to the objective of rebuilding stocks and egg production in all sub-zones. This occurs because harvest rates would be increased in northern areas as a result of effort and catch displaced from slower growth areas in the south.

In Chapter 6, the sensitivities of maximum economic yield in Tasmania and South Australia to different assumptions are reported. The potential complications in applying management regimes explored are (1) the delay from the time changes that occur in a fish stock to the time that management can react and (2) inefficiencies arising from historic input controls.

Chapter 7 presents an example where the bioeconomic model identified an economically, and also ecologically, superior strategy between two approaches analysed. In northeastern Tasmanian waters, urchins are proliferating, and severely over-grazing kelp forests. Large lobsters eat these urchins. One proposed method to control the urchins was to promote higher densities of larger Southern Rock Lobster. Two strategies to increase large lobster numbers were tested. One strategy was a maximum size limit, above which larger lobsters brought up in pots are returned to the sea. The second strategy was to reduce overall exploitation rate, by imposing a regional quota. Lower exploitation rates permit more lobsters to survive to larger sizes. The result was somewhat counter-intuitive. While a maximum size increases larger lobster numbers meaningfully, it does so at a large economic reduction. Industry profits are greatly reduced. However, a strategy of reduced regional quota, taken by fishing fewer potlifts, increased the numbers of larger lobsters more even than a maximum size and also improved the economic return. The regional quota was implemented in the northeastern region of the Tasmanian lobster fishery in 2013/14.

Chapter 8 reports the comparison of four broadly different approaches to managing a lobster fishery. The bioeconomic model for the largest Southern Rock Lobster fishery, the South Australia Southern Zone, was used. The four ‘policies’ tested for highest fishery profitability were (1) minimum, and (2) maximum size limits, (3) fixed (constant-over-time) quotas, and (4) quotas that were set yearly under a harvest control rule that sought to keep the rate of exploitation (the yearly fraction harvested) approximately constant. The model results were definitive: Policy (4) was considerably more profitable than the other policies tested, producing higher average yearly catches, higher egg production, and much higher average profit, by achieving higher average catch rates, and lowering average fishing costs for 20 years forward in time. Policy (4) produced a higher NPV than all other policies for all three levels tested of constant exploitation rate tested, where quotas were set yearly based on the previous year's catch per unit effort (CPUE) to take either 30% of the available biomass, or 40%, or 50%. Policy (4), however, had the least stable catches.

Chapter 9 extends the systematic comparison of policies, examining the dynamic harvest strategy implemented in the two South Australian fishery zones, which was proposed by industry. We compared its performance with the best policy identified in Chapter 8; Policy (4). Both of these policies involve a quota-setting rule which seeks constant exploitation rate. The outcomes showed the existing South Australian harvest strategies to be remarkably close to economically optimal. Peak values of NPV were achieved with the specific TACC levels adopted for each CPUE band in 2011 harvest strategies of both zones. One complication is that these outcomes applied for recruitment at historical sampled levels. Lower levels of exploitation rate than implemented in 2011 would be more economically favourable in both fishery zones if more recent lower recruitment trends continued. A scenario of 25% lower recruitment was tested.

Chapter 10 investigates the effects of a 12-month fishing season in South Australia. For both zones, the bioeconomic model could not identify any difference in profitability from the current 7- or 8-month season. This reflects a lack of data on winter fishing, which has never been undertaken in South Australia. An FRDC project proposal has now been approved and will commence 1 June 2014 to provide experimental fishing data from the Northern Zone. Winter fishing will be examined in combination with spatial management of the Northern Zone.

(iv) The fourth goal was to communicate these model outputs to industry and management decision makers. This is summarised, for Tasmania and South Australia, in Appendix 7.

Consultation

This project has been developed with SRL involvement and support. The initial concept was proposed by SRL at the initial Seafood CRC Future Harvest workshop in relation to their needs, which they described as:

- Establish management tools and models to optimise market returns.
- Develop techniques to increase economic yield per fish.
- Benchmark harvest performance.

The project was later prioritised by the SRL Board above other research identified for possible CRC support. The project draft was developed, supported and modified by the SRL Board. Additional comments and input have been obtained through circulating the project concept to CRC and FRDC Boards.

The need for the research was presented and discussed at the Lobster Congress, at SRL Board meetings, and in several smaller state-specific meetings including those with PIRSA (Primary Industries and Regions South Australia), SPOC (Tasmanian Sustainability and Profitability Options Committee), SEPFA (South East Professional Fishermen's Association), Government Southern Rock Lobster meeting (Melbourne), and the TAFI Review. Articles explaining the project have also been published in SRL News and Fishing Today.

During the project, ongoing communication and consultation was undertaken in a series of meetings with formal management bodies, fishing industry peak bodies, and in workshops with the fishers in each management zone directly. For South Australia that included presentations by the PI to the MAC (Management Advisory Committee) Research Subcommittee, twice to the industry peak body SARLAC (South Australian Rock Lobster Advisory Council), and for Tasmania and South Australia by Rick McGarvey (PI) and Caleb Gardner (co-investigator) at the Trans-Tasman Lobster Congress. Three major workshops were held in South Australia with all industry stakeholders invited for the South Australian Southern Zone and Northern Zone. A summary of these meetings and outcomes, for Tasmania and South Australia, are given in Appendix 7 and summarised above, extensive communications, written summaries of harvest strategy evaluations and oral presentations, were made by the project PI, mainly, in the South Australian Harvest Strategy review in 2013/14, to the MAC Harvest Strategy Review Working Group, to PIRSA managers, to industry peak bodies and their executive officers, and to the wider lobster fishing industry community.

1.1. Need

The needs addressed by the project were identified and developed through the extensive consultation process. They were:

1. The collection of information on the economic performance of the fishery in each state and incorporation of this information into the annual assessment process. The intent here was to better integrate economic and biological data into the decision making process for management.
2. Bioeconomic modelling capability is required by modifying the existing stock assessment model used across the fishery to incorporate economic data and an economic submodel to compute net economic return under different harvest strategies or management regimes. This economic analysis capability has been developed in Tasmania (and will be improved) but there is no capacity in the other two states. A bioeconomic model will provide the capacity for managers and industry to formally conduct cost-benefit analyses on decisions about future management of the fishery.
3. There needs to be effort put into exploring better management for the fisheries (using the bioeconomic model). This includes different TACC options, size limits, and seasons (i.e. harvest strategy evaluation). This requires industry and government participation to propose new strategies and review model outputs. It also requires a shift in decision making where management tries to target the best economic outcome for industry within sustainable limits.
4. There needs to be testing of the pathway in making Southern Rock Lobster fisheries more profitable. Steps 2 and 3 above can be used to define better management approaches but how would they be implemented?

1.2. Objectives

1. Define baseline economic performance of participating Southern Rock Lobster fisheries.
2. Produce bioeconomic analysis tools for Southern Rock Lobster fisheries.
3. Determine economically optimal management strategies using integrated stock and economic models, including seasonal, size and TACC combinations.
4. Communicate management and harvest strategy opportunities identified in Objective 3.

2. Fishing costs

Paul Burch, Richard McGarvey, Stacey Paterson, Lisa Rippin and Julian Morison

2.1. Introduction

Costs of undertaking fishing operations are an important data input given the objective of this project to estimate fishing industry profit under management or harvest strategies that industry or managers would seek to test. To compute fishing industry profit in any given model time step, total fishing costs are subtracted from gross landed revenues.

In this chapter, we present the methods and some outcomes of the EconSearch surveys as they relate to the bioeconomic modelling presented in subsequent chapters. Fishing costs are broken down into two categories: fixed and variable. We provide details of how the EconSearch cost data were compiled to produce an estimate of (1) industry wide fixed costs, and (2) a variable cost per potlift. Estimates of fixed and variable costs from the 2010/11 EconSearch surveys of South Australian rock lobster fishers are used in the bioeoconomic modelling undertaken in Chapters 8, 9 and 10.

The first EconSearch survey in Tasmania was carried out as a funded outcome of this project. In South Australia, these EconSearch surveys are carried out every three years, and they produce an updated report in the two intervening years, based on known changes in fuel costs and CPI.

2.2. Methods

The ROCK projection model (Chapter 4; Appendices 3 and 4) accepts two input types for cost data: fixed and variable costs. Fixed costs comprise those expenses that do not vary with fishing effort (potlifts) and are expressed relative to the number of active vessels in the fishery. Variable costs comprise expenses that vary with fishing effort and are expressed on a per potlift basis. ROCK has the capacity for variable costs to change with each monthly time-step. However, there is no information relating to within season variability of costs so we have assumed that costs are constant over the fishing season.

2.2.1. Survey of South Australian Fishers

EconSearch collected information on the fishing/business costs of South Australian rock lobster operators by means of a survey of active licence holders in the two fisheries. Surveys for the 2010/11 season in the South Australian Northern Zone (NZRLF) and Southern Zone (SZRLF) rock lobster fisheries were undertaken by EconSearch in May/June 2012. The surveys are described in detail in Section 2.2.1 and in the EconSearch reports for the NZRLF (EconSearch 2012a) and SZRLF (EconSearch 2012b) fisheries. An example of the questionnaire for South Australian fishers is provided in Appendix 6.

The sampling frame for the surveys in each zone consisted of all active licence holders, defined as those who fished one or more days in the 2010/11 season. The survey consisted of a questionnaire (Appendix 6) designed to collect economic and social information from fishers. Questions were divided into five categories: capital costs, expenditure, employment, sales and additional comments. The bioeconomic modelling used information from the first three categories to inform the costs of fishing. Questions relating to capital costs included the age, value and replacement costs of items such as vessels, fishing gear, shed and vehicles used by the fishing operation. Expenditure included items such as fuel, bait, wages, licence fees, repairs, maintenance and administrative costs including insurance, legal costs, interest on borrowing and leasing fees. Employment was measured as the number of full time equivalent people employed by the business and included unpaid labour by the licence holder and their family members.

In the NZRLF in the 2010/11 season there were 48 licences actively fishing out of 68 total licences. Of the active licence holders contacted, 22 completed the survey, comprising 46% of active licences in the fishery. Of the survey participants, 19 (40% of active licences) consented to having their data used in the bioeconomic modelling project and provided sufficient information to be included in the estimation of variable fishing costs and 18 (38% of active licences) provided sufficient information to be included in the estimation of fixed fishing costs.

In the SZRLF in the 2010/11 season 164 licence holders out of 181 total licences were actively fishing. Of the active licence holders contacted, 45 responses were received, representing 27% of active licences in the fishery. Of the survey participants, 37 (23% of active licences) consented to having their data used in the bioeconomic modelling project and provided sufficient information to be included in the estimation of fishing costs.

Estimates of costs differ slightly from the fixed and variable costs reported by EconSearch (EconSearch 2012a, 2012b) because not all of the survey participants consented to having their information used in the bioeconomic modelling project and because licence fees were assigned to fixed costs, not variable costs as reported by EconSearch.

2.2.2. Fixed costs

We separated fixed costs for active licences into three categories: licence fees, administration costs and depreciation of vessels and equipment, each of which is described below.

Licence Fees

In the 2010/11 season the total licence fees were $1.243 million in the NZRLF and $2.965 million in the SZRLF (EconSearch 2012a; 2012b). The licence fees for individual fishers vary depending on the number of quota units (pot entitlements) held. In both fisheries, each licence holds one quota unit entitlement for each pot entitlement held. In the SZRLF, if a pot entitlement is transferred, a quota unit must also be transferred at the same time to the same licence, and vice versa (Linnane et al. 2012a; 2012b).

In the 2010/11 season there were 68 licence holders, 3,997 pot entitlements and 62,500 quota units held in the NZRLF with a fixed licence fee of $2,967 plus $15.64 per quota unit. In the SZRLF fishery in 2010/11 there were 181 licence holders, 11,923 pot entitlements and 11,923 quota units with a fixed licence fee of $5,118 plus $148.35 per pot or quota unit. For the purposes of the bioeconomic modelling, information on licence fees from the survey was used.

Administration

The administrative costs for a business comprised a large number of items. They included insurance for vessels and other assets, repairs to buildings, motor vehicles and plant, along with rates and rent. Legal and accounting fees, telephone and power were also classified as administrative costs along with leasing charges or fees, borrowing costs including interest, association membership expenses and travel costs. The value of any unpaid administrative work was imputed using Table 2.1. Survey participants were asked to estimate unpaid labour assuming that the standard was an 8 hour day.

Depreciation

Depreciation refers to the annual reduction in the value of an asset, such as a vessel or engine due to general wear and tear or the reduction in value of an item over time. We have assumed depreciation to be a fixed cost and it was estimated using the equation below

$$\text{depreciation} = \frac{\text{replacement value} - \text{current value}}{\text{age}},$$

where ‘age’ is the age of the asset in years and if age is zero then the depreciation is zero.

Calculation of Fixed Costs

Fixed costs were scaled to the number of number of active vessels in the fleet in the season of interest (this is done in the projection model - we provide an estimate of fixed costs per vessel). Average fixed costs were estimated from survey responses using the equation:

$$\$/\text{vessel} = \frac{1}{n} \sum_{\text{licences}} \text{Fixed costs},$$

where *n* was the number of survey participants who provided sufficient information and consented to it being used in the bioeconomic modelling project.

2.2.3. Variable Costs

Variable costs for active licences were subdivided into six categories: vessel fuel including lubricants, bait including ice, wages of the skipper and crew, unpaid labour undertaken by owner operators, repairs to vessels and fishing equipment and all other variable costs. The wages of the crew and hired skippers are generally paid as a percentage of the total value of the season’s catch, commonly referred to as a crew share. The value of unpaid labour undertaken by owner operators and their family members was imputed assuming an 8 hour workday (Table 2.1). All other variable costs comprised provisions, protective clothing, freight, marketing and other imputed unpaid fishing costs.

Table 2.1. Value of unpaid labour used by EconSearch to estimate total fishing costs in the NZ and SZRLF.

Unpaid labour	$/hr	$/day
Fishing	$15.00	$120.00
Repairs & maintenance	$15.00	$120.00
Management & administration	$30.00	$240.00

Calculation of Variable Costs

Variable costs were scaled in proportion to total effort (number of potlifts from logbooks) in the NZRLF and SZRLF in the 2010/11 fishing season. To preserve the confidentiality of survey respondents, EconSearch provided the survey data to SARDI with the number of potlifts assigned an error of ±5%. This preserved the confidentiality of individual licence holders, but provided sufficient precision in the number of potlifts for the bioeconomic modelling. The variable cost per potlift was calculated using the equation below

$$\$/\text{potlift} = \frac{\sum_{\text{licences}} \text{Variable costs}}{\sum_{\text{licences}} \text{potlifts}}.$$

2.3. Results

2.3.1 Fixed Costs

Total fixed costs were $143,027 and $147,820 per vessel per annum in the SZRLF and NZRLF, respectively (Table 2.2). In the SZ, administration and depreciation represented 44.3% and 42.1%, respectively, of fixed costs, the remaining 14.6% of fixed costs was accounted for by licence fees. In the NZ, administration represented 52.2% of fixed costs, the remainder of fixed costs were depreciation (34.0%) and licence fees (13.8%).

Table 2.2. Fixed costs per active licence estimated from EconSearch surveys of the NZRLF and SZRLF in the 2010/11 season.

Item	Southern Zone	% Fixed costs	Northern Zone	% Fixed costs
Licence fees	$19,384	13.6%	$20,451	13.8%
Administration	$63,376	44.3%	$77,169	52.2%
Depreciation	$60,266	42.1%	$50,200	34.0%
$/Vessel	$143,027	100.0%	$147,820	100.0%

2.3.2. Variable Costs

Total variable costs were $26.75 per potlift in the SZRLF and $28.20 per potlift in the NZRLF (Table 2.3). The greatest single variable cost in both fishery zones was skipper and crew wages, accounting for 41.0% of variable costs in the SZRLF and 49.1% in the NZRLF. Vessel fuel and lubricants was the second greatest cost and represented approximately 17% of variable costs in each zone. The remainder of the variable costs were attributed to bait, repairs, unpaid labour and other costs.

Table 2.3. Variable costs per potlift estimated from EconSearch surveys of the NZRLF and SZRLF in the 2010/11 season.

Item	Southern Zone	% Variable costs	Northern Zone	% Variable costs
Vessel fuel & lubricants	$36,285	17.1%	$25,059	17.0%
Bait & ice	$19,312	9.1%	$9,474	6.4%
Skipper & crew wages	$86,746	41.0%	$72,216	49.1%
Imputed unpaid fishing labour	$14,042	6.6%	$13,278	9.0%
Vessel & equipment repairs	$23,576	11.1%	$21,975	14.9%
Other variable costs	$31,638	15.0%	$5,020	3.4%
Total variable costs	**$211,598**	**100.0%**	**$147,021**	**100.0%**
Potlifts	**7,912**	**-**	**5,214**	**-**
Cost/pot lift	**$26.75**	**-**	**$28.20**	**-**

2.4. Discussion

In our calculation of fixed and variable costs we have assigned licence fees to fixed costs, where EconSearch treat licence fees as a variable cost. For the bioeconomic modelling it is assumed that all costs are in Australian dollars and fixed at values estimated from the 2010/11 survey. This was done because we have no way of accurately predicting how these costs may change over time.

By separating fixed and variable costs, we have held the number of vessels in the fishery constant. This is somewhat unrealistic as changes in fleet size may be expected over time in response to changes in total allowable commercial catch (TACC) and catch per unit effort (CPUE). One alternative to permit fleet size to vary would be to treat all costs as variable costs, thereby assuming that the number of vessels would instantly adjust to catch the TACC each fishing season. However, using only variable costs also has problems because we would not expect the fleet to restructure instantly but for this process to occur over several years. In addition, it probably would not be possible to test maximum effort strategies using variable costs alone, as fleet size might change in some unexpected manner.

We have assumed that depreciation, such as wear and tear on the engine and vessel, does not increase with increasing fishing, whereas it would in reality, but this is difficult to quantify, and if accounted for, would result in favouring more conservative (lower effort) strategies, because it represents an unaccounted for increased variable cost of more fishing effort. Additionally, we are not reducing fleet size, as might happen as CPUE increases. Different fishery management zones have different cultures, reflecting different extents to which they are purely owner-operator. The SZRLF is still largely owner-operator, while the Tasmanian fishery is increasingly moving toward the culture of extensive leasing of quota, on both annual, and shorter within-season time frames. In the NZRLF, quota leasing has also become more widespread, and the number of vessels reduced when catches declined by nearly two-thirds over 10 years, but the decline in vessel numbers was proportionally less than the reduction in total catch.

2.5. Acknowledgements

We thank Trent Gregory, Kyri Toumazos, Roger Rowe, Andrew Ferguson and Justin Phillips for helpful discussions on industry economics. We also thank fishers from the South Australian Northern Zone and Southern Zone rock lobster fisheries who participated in the EconSearch surveys.

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3. Price

Eriko Hoshino, Paul Burch, Richard McGarvey and Caleb Gardner

3.1. Introduction

Southern Rock Lobster is Australia's most valuable wild fishery product. Since the majority of the catch is exported to the Asian market, the beach price of Southern Rock Lobster is highly influenced by the demand specific to Asian culture. For instance, the beach price of Southern Rock Lobster tends to be higher around the Chinese New Year and the Mid-autumn (or Moon) festival. Red colour lobsters are more favoured by Chinese customer than pale colour (called strawberry or brindle) lobsters as red represents happiness or good luck in Chinese culture. It is also believed that smaller "plate size" lobsters are more favoured, but to what extent the size and colour preferences of the consumers affect the beach prices of Southern Rock Lobster in Tasmania is not well understood. Beach price is the price paid for lobsters to fishers at time of landing. Export price is the price received by processors from Chinese buyers.

This chapter aims to improve our understanding of Southern Rock Lobster beach price by size grades and colour. The results can be used to develop plausible assumptions of beach price in the simulations in the bioeconomic management decision making framework. In addition, information about export price is included in this chapter, which can be used in future model analyses.

3.2. Methods

The data on Southern Rock Lobster beach prices containing the trade date, quantity traded, unit price per kg, colour, and size of the animal were obtained from business transaction books from a processor in Tasmania between April 2006 and December 2011. The information on size and colour is not always recorded in the business transaction books. The transactions without size information were excluded in this analysis, while retaining the transactions without colour information. We adopted the size grade categories used by processors (Table 3.1). In total 2,673 transactions were extracted. A large proportion of the transaction records were excluded (roughly 60%) due to missing size information. The unit price differences by size grades and colour were investigated by comparing general statistical properties (mean, quantiles, coefficient of variation).

Table 3.1. Size grade categories of Southern Rock Lobster used by Tasmanian processors.

Size grade	Lobster weight (kg)
SB	0.55-0.60
B	0.60-0.80
C	0.80-1.00
D	1.00-1.50
E-	1.50-2.00
E+	2.00-2.50
F	>2.50

For the purpose of comparison, the export prices of Southern Rock Lobster containing the shipment date, quantity shipped, unit price per kg, and the size of the animal were also obtained from tax invoice records from another processor in Tasmania between July 2010 and April 2011. A total 315 transaction records were obtained.

3.3. Results

3.3.1. Beach prices

Notched boxplots showing mean, median, upper and lower quantiles of unit beach price for different size grades are given in Fig. 3.1. Both mean and median beach prices ($/kg) were the highest for the size grade SB ($62.5; $62.0), followed by D ($62.2; $60.0), C ($61.1; $60.0), B ($59.2; $58.0), E- ($57.9; $57.8), E+ ($49.4; $48.0), and F ($45.9; $44.0). There was no evidence that the median beach price across the grades of lobsters smaller than 2kg (SB to E-) were different. However, the median beach price for larger animals (greater than 2kg, grades E+ and F) was significantly lower than the other grades. The difference in median value between SB and F was $18/kg. A pairwise comparison (Welch t-test) showed no evidence of a difference in mean price between SB and B (p=0.08), C (p=0.47), D (p=0.89). However, there was moderate evidence of a difference between SB and E- (p=0.01), and strong evidence of a difference between SB and E+, F (p<0.01).

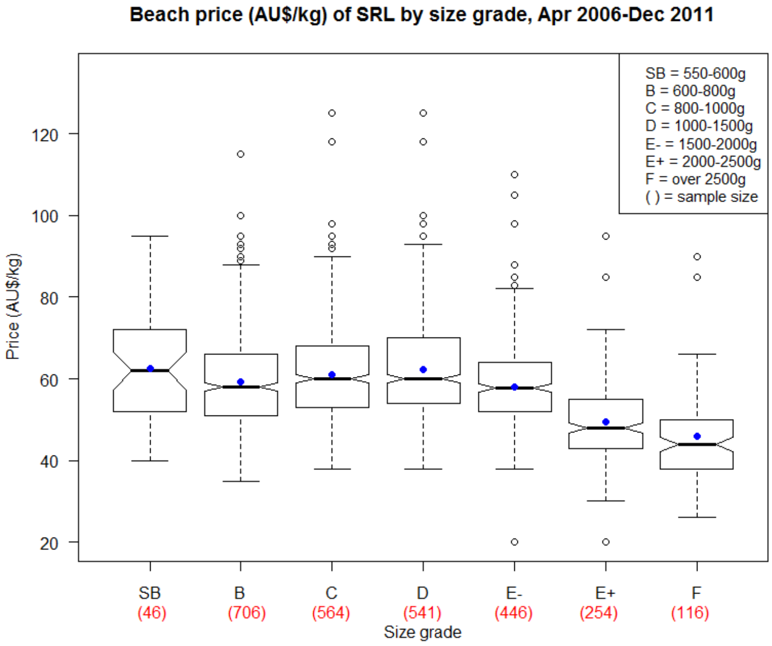

Figure 3.1. Notched boxplot of Southern Rock Lobster beach prices by size grade. The bottom and top of the box are the 25th and 75th percentile, the band near the middle of the box is the 50th percentile (median) and the end of the whiskers represent the minimum and maximum of the data excluding the outliers (>1.5 times the interquartile range). Blue points show mean values. If the notches of two plots do not overlap this is 'strong evidence' that the two medians differ (Chambers *et al.* 1983).

The majority of the transaction records (2,156 or 80%) did not report the colour of the animals. Since the colour was reported only when the catches consist of animals with a colour other than red, it is reasonable to assume that those unspecified animals were red in colour. The mean value of "unspecified" colour lobsters was $60/kg, while mean values for red and strawberry (or brindle) lobsters were $50/kg and $52/kg, respectively (Fig. 3.2). It is counter intuitive that the mean value of red lobster is lower than that of strawberry lobster (see Chandrapavan et al. 2009 for the impacts of colour on lobster prices), but this is largely because 1) a large proportion of red coloured animals were recorded as "unspecified"; and 2) data was confounded with different size animals. For these reasons, simply comparing the mean values of "red" and "strawberry" does not give us useful information. Instead, comparing the prices of the two colour groups with the same size category on the same trading date is more useful. Overall, red colour animals received $0-8/kg higher prices than the strawberry colour animals conditional on the same size and date, with an average difference of $2.56/kg with standard error (SE) ± $0.25/kg.

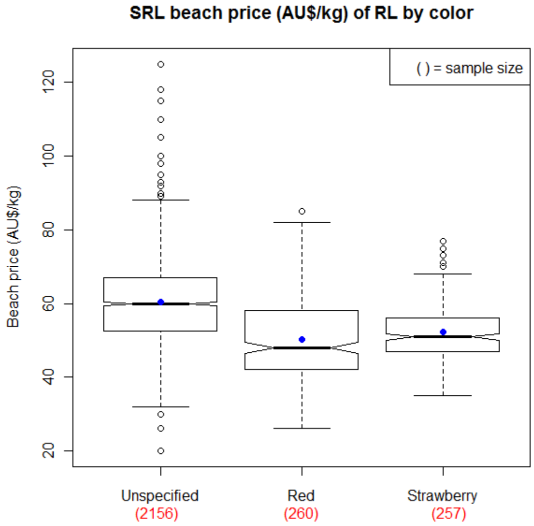

Figure 3.2. Notched boxplot of Southern Rock Lobster beach prices by colour (see Fig. 3.1 for interpretation of boxplot).

Monthly average and median beach prices of Southern Rock Lobster across the sampled years (2006-2011) are given in Fig. 3.3. The beach price was highest in September (median $65/kg), while it was lowest in March and December (both $52/kg). The beach prices during the winter months (Jun-Aug) were higher than the summer months (Dec-Feb), which is consistent with the previous observations (Frusher et al. 2003), although there were limited samples available during these months.

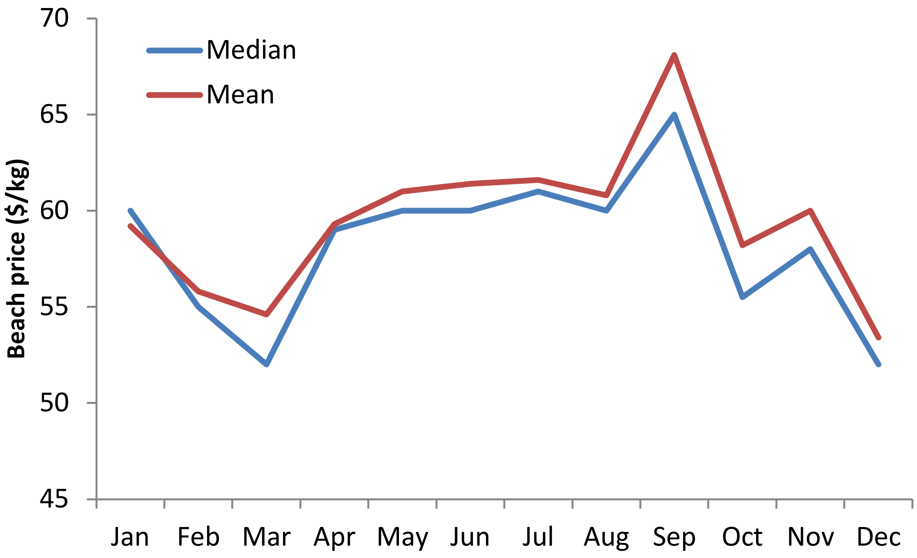

Figure 3.3. Median and mean monthly beach prices of Southern Rock Lobster between April 2006 and December 2011.

Since the above average and median beach prices by month were confounded with different size and colour animals across the sampled years, we fitted a linear regression model of the log of beach price against the season, size grade, colour and year

$$\log \hat{P} = \alpha + \beta_1 Season + \beta_2 Size + \beta_3 Colour + \beta_4 Year\ ,$$

where each predictor was assumed to be a categorical variable. For the purpose of simplicity, size grades were re-classified into three groups: small (less than 1.5kg), medium (1.5-2kg) and large (over 2kg), and months were grouped into four seasons: winter (Jun-Aug), spring (Sep-Nov), summer (Dec-Feb), and autumn (Mar-May). The unspecified colour animals were assumed to be red. Coefficients for season, size, colour and year were all highly significant (Tables 3.3; 3.4), however, the low value adjusted R-squared for the fitted model (0.385) suggests that there are additional sources of variability in beach price. Diagnostic plots from the linear regression model are shown in Fig. 3.4.

Table 3.3. Coefficients, standard errors (SE), t-value and p-values (Pr(>|t|)) from a linear regression model of beach price and covariates season, size, colour and year. The coefficients of all parameter estimates are presented relative to large lobsters of red colour in autumn 2006 and are on the log scale.

Parameter	Coefficient	SE	t-value	Pr (> | t |)
intercept	3.747	0.013	279.9	2.00E-16
spring	0.081	0.012	6.9	8.69E-12
summer	-0.057	0.008	-7.3	3.01E-13
winter	0.083	0.010	8.5	2.00E-16
medium	0.200	0.012	17.2	2.00E-16
small	0.258	0.010	27.2	2.00E-16
strawberry	-0.147	0.011	-13.4	2.00E-16
2007	-0.004	0.012	-0.4	0.708
2008	0.084	0.012	6.9	5.07E-12
2009	0.191	0.013	14.5	2.00E-16
2010	0.204	0.012	17.2	2.00E-16
2011	0.152	0.013	11.7	2.00E-16

Table 3.4. ANOVA results for overall significance of each variable included in the model.

Parameter	DF	Sum of sq	Mean sq	F-value	Pr(>F)
Season	3	4.72	1.57	57.9	2.20E-16
Size	2	17.42	8.71	320.8	2.20E-16
Colour	1	4.64	4.64	170.9	2.20E-16
Year	5	19.02	3.80	140.1	2.20E-16
Residuals	2661	72.25	0.03	-	-

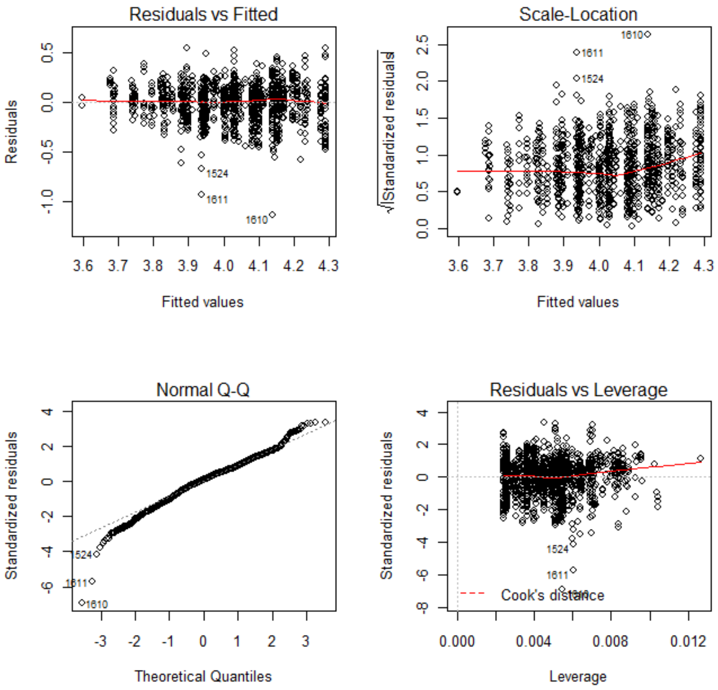

Figure 3.4. Diagnostic plots from linear regression model of beach price and covariates season, size, colour and year.

The predicted beach prices were generally lower in summer, while they were the highest in spring, followed by winter for all size groups (Fig. 3.5). Note that in the linear regression model the coefficients for 2006, large size, red colour and autumn are included in the intercept. One issue is that the SEs of any prediction involving these particular predictor values will be underestimates as their linear coefficient is fixed to zero with zero variance. The normal QQ plot suggests residual errors have fat tails, but the Residuals vs. Fitted plot and the Scale-Location plot suggest there are no obvious trends in the residuals (Fig. 3.4). The Leverage plot suggests there are no overly influential data.

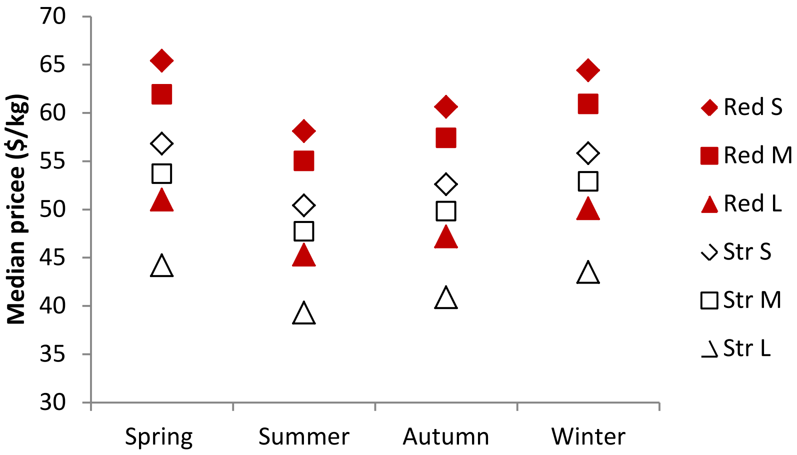

Figure 3.5. Predicted beach price ($/kg) for red and strawberry (Str) Southern Rock Lobster by size class and season for 2011 from the linear regression model.

In the Tasmanian rock lobster stock assessment, time-step is used to model the growth of animals, thus we also used a similar linear regression model that includes time-step instead of season and the predicted price is provided in Table 3.5.

Table 3.5. Predicted beach price ($/kg) by time-step for 2011 from a linear regression model that includes time-step. Note: Time step 1=Jan, 2=Feb, 3=Mar, 4=Apr, 5=May-Jul, 6=Aug-Sep, 7=Nov, 8=Dec. The stock assessment model length classes 11-16 for males and 10-16 for females represent weight class (S, less than 1.5kg), 17-18 represents (M, 1.5-2kg) and 19 and above represent (L, over 2kg).

	Less than 1.5kg (S)	1.5-2kg (M)	Over 2kg (L)
Red			
Time step1	62.713	58.603	47.965
Time step2	60.844	56.857	46.536
Time step3	58.799	54.946	44.972
Time step4	66.089	61.757	50.547
Time step5	69.398	64.850	53.078
Time step6	75.225	70.295	57.534
Time step7	62.253	58.173	47.613
Time step8	58.351	54.527	44.629
Strawberry			
Time step1	53.750	50.227	41.109
Time step2	52.148	48.730	39.884
Time step3	50.395	47.092	38.544
Time step4	56.643	52.930	43.322
Time step5	59.479	55.581	45.491
Time step6	64.473	60.247	49.311
Time step7	53.356	49.859	40.808
Time step8	50.011	46.734	38.250

The variation in beach prices ($/kg) within a month across the years (2006-2011) are shown in Fig. 3.6. Although our data represent only a fraction of the total transactions and the true beach price variation may be different, the data show that price variation was higher in 2009 and 2010. The coefficient of variation (CV) was highest in 2010 (0.259), followed by 2009 (0.246), 2011 (0.179), 2008 (0.174), 2007 (0.140) and 2006 (0.122).

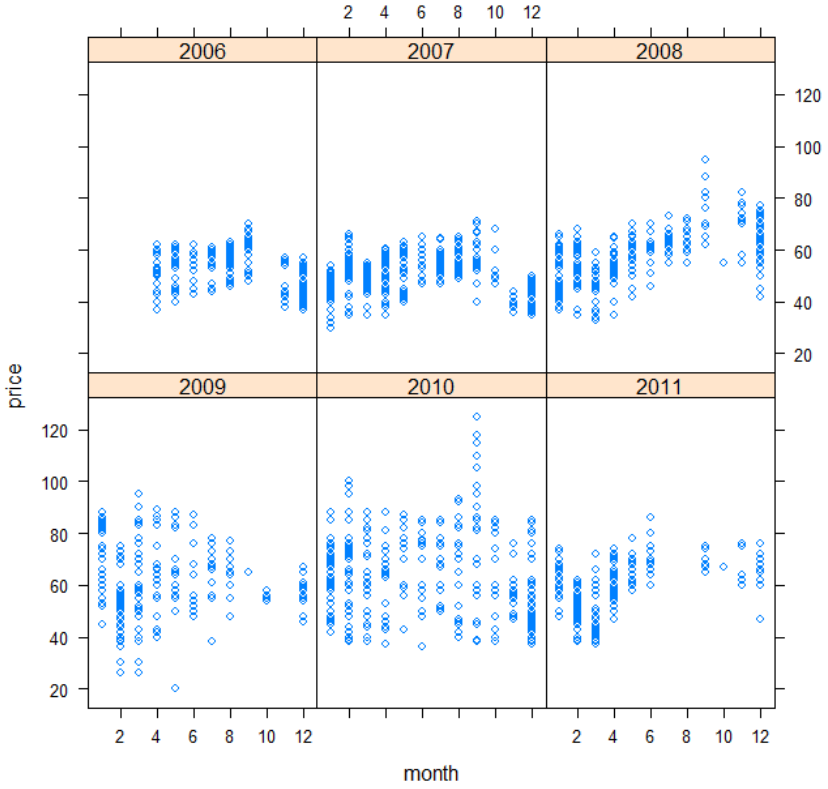

Figure 3.6. Southern Rock Lobster beach prices by month between April 2006 and December 2011.

3.3.2. Export prices

We have limited samples for the Southern Rock Lobster export prices, particularly for size grades E+ and F (only 7 samples). The mean and median values for lobsters above 1.5kg (i.e. grades E-, E+ and F) were considerably higher than those for other grades (Fig. 3.7). This is most likely because larger animals were only exported during periods of high demand in China (e.g. mid-August) and were otherwise sold on the domestic market. Brindle/strawberry colour animals were also exported during the high price months. Therefore the use of the mean/median prices for larger animals (grades E-, E+ and F), and smaller (grade B) with brindle/strawberry colour is misleading. For the rest of the size grades (B-D), there was no statistical difference in mean prices across the grades (F=0.93, p=0.47). This is similar to the analysis of differences in beach prices.

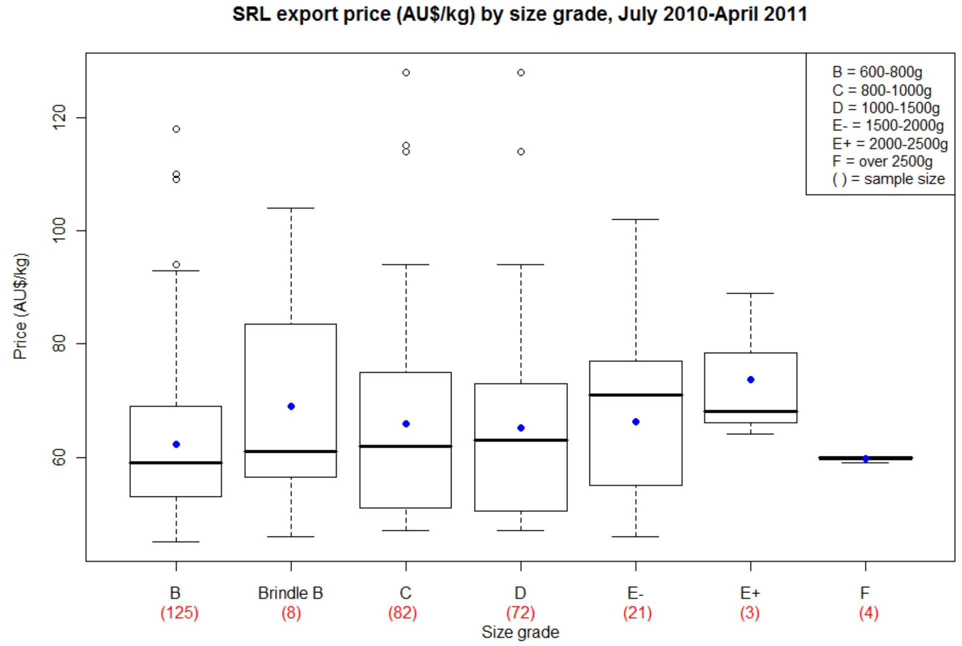

Figure 3.7. Boxplot of Southern Rock Lobster export prices by size grade (see Fig. 3.1 for interpretation of boxplot). Note no lobsters of size grade SB were recorded. Notches are not shown due to small sample sizes for some of the size grades.

3.3.3. Concluding Remarks

There was clear evidence that larger size grade lobster above 2kg receive significantly lower beach prices (up to $18/kg difference in median unit price) than the smaller Southern Rock Lobster below 2kg, while the differences in beach price among the smaller size grades (SB to E-) were marginal. The animals over 2kg represent approximately 8% of the total weight traded, but 6% in revenue due to this unit price difference. The red colour animals on average received a $2.6/kg higher unit beach price than the paler colour animals.

This analysis included only the price data with size information, and a large proportion of the transaction records were consequently disregarded. Even when size information was available, inconsistent recording, such as the use of unclear size categories (e.g. “over 2kg”, or “under 1.5kg”) made it difficult to identify the true size grade. The colour of the animal was not consistently recorded for over 20% of price data. Our analysis suffers from a large degree of uncertainty given the data limited environment. The results should be therefore seen as work-in-progress estimates. For future work, we recommend building a systematic data collection scheme in collaboration with the industry and standardizing the data recording method so that the quality of the data can be improved. This would also allow us to carry out econometric analyses to evaluate the effects of size, colour and year/seasons on Southern Rock Lobster beach prices.

3.4. South Australian Price Inputs for the Bioeconomic Model

In South Australia fishers are paid a lower price for lobsters above a 2kg price differential called the price split (J. Redman pers. comm.). SARDI collects average monthly price data from processors. However, this information does not capture the price split. The monthly average price for small (below 2kg) and large (above 2kg) lobsters was estimated using 2009/10 average monthly prices (Table 3.6) and length-frequency information from commercial catch sampling undertaken between 2006/07 and 2010/11 (Linnane et al. 2013a; b).

Table 3.6. Monthly average beach price/kg from the 2009/10 fishing season in the Southern and Northern Zones of the South Australian lobster fishery. Note the Northern Zone does not commence fishing until November.

Month	Southern Zone	Northern Zone
October	$60.18	-
November	$51.80	$47.99
December	$48.41	$48.25
January	$53.43	$47.56
February	$58.42	$49.44
March	$62.18	$50.36
April	$67.28	$59.45
May	$68.30	$59.30

Lobsters from catch sampling were allocated to 4mm model length bins used by the ROCK projection model based on their carapace length, zone and month of sampling. The weight of lobsters for each bin in each month was estimated by multiplying the number of lobsters by the estimated mid-point weight estimated using length-weight relationships (Linnane et al. 2013a; b). For each month, the price of small (below 2kg) lobsters was calculated using the equation below

$$\text{small price} = \text{average price} * \frac{\text{total kg}}{\text{small kg} + x * \text{large kg}},$$

where *x i*s a scaling factor of 0.8 in the Northern Zone and 0.75 in the Southern Zone. The price of large (above 2kg) lobsters was therefore

$$\text{large price} = x * \text{small price}.$$

For the bioeconomic modeling, we assumed that large lobsters above 2kg attract a price 20% lower than smaller lobsters in the Northern Zone and 25% lower in the Southern Zone. In the Northern Zone we assumed the price split applies for the entire season (Table 3.7) while in the Southern Zone we assumed the price split applies from January onwards (Table 3.8).

Table 3.7. Estimated monthly average price/kg for lobsters in the Northern Zone above and below the 2kg price split.

Month	Small (< 2kg)	Large (2kg+)
November	$48.18	$38.54
December	$49.45	$39.56
January	$49.57	$39.65
February	$51.39	$41.11
March	$52.00	$41.60
April	$62.23	$49.78
May	$63.21	$50.57

Table 3.8. Estimated monthly average price/kg for lobsters in the Southern Zone above and below the 2kg price split. Note the price split applies from January onwards in the Southern Zone.

Month	Small (< 2kg)	Large (2kg+)
October	$60.18	$60.18
November	$51.80	$51.80
December	$48.41	$48.41
January	$55.71	$41.79
February	$61.14	$45.86
March	$64.25	$48.19
April	$70.52	$52.89
May	$72.22	$54.16

In our calculation of the prices of small and large lobsters for the bioeconomic modelling we assume that prices are fixed for all projection years at the values estimated. As with the estimation of fishing costs (Chapter 2) this was done because we have no way of estimating how prices may change over time. We also applied different price reductions for large lobsters in each zone and only applied the price split from January onwards in the Southern Zone. This is consistent with our information on how the price split currently operates in South Australia.

3.5. Acknowledgements

We thank the Red Rock Lobster Pty. Ltd, A.R. (Tony) Garth Fish Processor P/L, Ian Heathorn and Ken Smith for providing us information on prices. We also thank Joel Redman for essential advice on the price split.

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4. Lobster Fishery Management Strategy Assessment Decision Support Model: Stock Assessment and Projections

André E. Punt

4.1. Introduction

The evaluation of harvest strategies depends on two forms of the ROCK fishery model: a sex-, size- and spatially-structured stock assessment model and its directly associated projection model in which different harvest strategies are projected forward in time and their management outcomes reported. The stock assessment model is an estimation model, meaning it is fitted to all available data by maximum likelihood. All parameter values used in the bioeconomic modelling of this project were obtained from the stock assessment estimator. The tool developed to evaluate alternative harvest policies is the projection model. The projection model provides outputs reporting the impacts of tested harvest policies on catches, stock size and the economics of the fishery. The projection model uses the exact same equations describing the population dynamics as the estimation model. The stock assessment model is written in AD Model Builder, and the projection model is written in FORTRAN.

4.2. The stock assessment method

The stock assessment method (“ROCK”; see Appendix 1 for the mathematical specifications of the population dynamics model on which this method is based and Appendix 2 for a user manual) is a general framework which generalises the methods used in the past to conduct assessments for rock lobster off Tasmania (Punt and Kennedy 1997) and Victoria (Hobday and Punt 2001; Hobday et al. 2005). The stock assessment method is an example of an “integrated” method (Maunder and Punt 2013; Punt et al. 2013). Integrated stock assessment methods (see Fournier et al. (1998); Bull et al. (2005); Methot and Wetzel (2013) for examples of integrated stock assessment methods based on age-structured population dynamics models) involve separating the specification of the model of the population dynamics from the way the data are used to estimate “free” parameters of that model.

The population dynamics model allows for multiple spatial areas among which there may be movement of lobsters. The establishment of marine protected areas (MPAs) can be modelled by treating each MPA as a spatial area within the model where there are no removals (but for which there may be monitoring data) (e.g., Hobday et al. 2005). The dynamics of the populations within each spatial area are tracked by sex and length-class, with a time-step which is user-specified. The time-steps within a year need not be of the same length given that catches are lower for some periods during the year than other periods, and pooling over months increases sample size and reduces run times. Growth is modelled using a size-transition matrix (which determines the probability of growing from one size-class to all other size-classes; although the current implementation of the model prohibits “shrinkage”). The number of animals is increased due to recruitment to the population and reduced due to natural mortality and fishery catches. Several fisheries can take place within each spatial area. Current applications include commercial, recreational and illegal fisheries. The model also allows for discarding of undersized lobsters. Fishery and survey selectivity can be modelled using several functional forms, and allowance can be made for female vulnerability to differ from that for males and to vary during the year. The model also allows for a minimum legal size for the commercial and recreational fisheries, and for this size to change over time. Recruitment to the population (the numbers entering the first size-class in the model) can be treated as dependent or independent of egg production, and recruitment can occur to one or many size-classes.

Most of the parameters of the model can be either estimated when it is fit to the available data, or pre-specified using auxiliary data. For example, the size-transition matrix can either be pre-specified based on independent analyses (e.g. McGarvey and Feenstra 2001) or estimated along with the other parameters. The latter is preferred (Punt et al. 2010), but estimating the parameters of a size-transition matrix can slow down run times considerably. The data which can be used to estimate the parameters of the model are catches (assumed to be known without error), commercial and survey catch rates, length-frequency data collected during scientific sampling as well as from the commercial fishery, indices of puerulus, and tag-recapture data. Each data source is assigned a particular likelihood function (e.g. catch-rates are assumed to be log-normally distributed, while the tag recoveries are assumed to be the outcomes of Bernoulli trials). The weight assigned to the likelihood component for each data source can be varied to explore the sensitivity of the results to the emphasis placed on each data type. This allows the analyst to determine whether (and to what extent) the various data sources are in conflict.

4.3. The projection model

The output from the stock assessment method provides the initial conditions for forecasts under alternative (user-specified) harvest policies. Consequently, the model on which projections are based accounts for the information collected during historical monitoring. Appendix 3 provides the mathematical specifications for the projection model and Appendix 4 is the user manual.

The code implementing the projection model is modularised so that users can specify their own harvest control rules. These control rules can range from time-series of catches by each fishery in each area to harvest control rules which change total allowable commercial catches (TACCs) annually based on analyses of monitoring data (Punt et al. 2012a, b). In addition, recreational catches can either be pre-specified or assumed to be related (non-linearly) to available biomass, while illegal catches can be assumed to be a pre-specified proportion of commercial catches. The user can specify maximum and minimum legal sizes for each future year by sex and area.

Catch limits can either be set for all of the spatial areas, by spatial area, or for groups of spatial areas for models with multiple spatial areas. An effort dynamics model is used to assign catches to areas when catch limits apply to multiple spatial areas. The code includes a default effort dynamics model (based on that of Punt and Kennedy (1997)), but the facility exists for users to supply their own effort dynamics models (e.g. Harmon et al. in press).

The projection model includes modules which have been developed to address specific questions related to management of rock lobster populations off Australia. For example, the model allows for translocation of lobsters from one spatial area to another. This module allows translocated lobsters to have different natural mortality and growth rates than lobsters which are not translocated, and to permit a delay in the time translocated lobsters take to contribute to egg production.

The projection model outputs the annual discounted profit, which is the difference between revenue and the sum of fixed and variable costs. The revenue is calculated from the landed catch by size-class, accounting for prices which depend on size, time during the year, and location. The variable costs are assumed to be proportional to the number of pot lifts. The number of pot lifts for a given area during a given time-step is computed by dividing the exploitation rate for that time-step by the estimated catchability coefficient. The projection model allows constraints to be imposed on the number of pot lifts in a given area during each time-step to avoid unrealistic outcomes where fishing effort is unrealistically high so that a catch limit is taken.

Future recruitment is either governed by a stock-recruitment relationship, generated from a pre-specified set of years, or related to environmental covariates. The latter allows scenarios to be explored in which recruitment is impacted by climate change (e.g. Pecl et al. 2009). Finally, the facility exists to force trends in parameters such as growth, natural mortality and catchability to explore the impact of environmental forcing on the performance of harvest control rules (and indeed stock assessments and monitoring schemes; Punt et al. 2012b).

The projections can be deterministic or stochastic, with stochasticity arising from uncertainty about the values for the parameters of the population dynamics model, from variation in future recruitment, and from variation in the data available for setting of future catch limits using harvest control rules. At present, it is not possible for the economic parameters (prices and costs) to vary stochasticity, but scenarios can be explored in which prices and costs exhibit trends with time.

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5. Evaluating the effect of changing minimum size limits for Tasmanian lobster: Spatially appropriate size limits

Caleb Gardner, Klaas Hartmann, André E. Punt and Eriko Hoshino

5.1. Introduction

The Southern Rock Lobster *Jasus edwardsii* (Hutton 1875) is common around coastal regions of southern Australia and New Zealand. The species supports valuable commercial and recreational fisheries across the whole of its range, which covers several management jurisdictions. One consistent management tool is the use of a legal minimum length (LML), which is based on carapace length (CL) in Tasmanian regulations, defined as 'the minimum distance measured from the anterior surface of the median suture to the posterior edge of the dorsal region of the carapace, excluding any attached hairs'.

LMLs vary among jurisdictions in Australia (Frusher et al. 1997; Hobday and Ryan 1997; McGarvey et al. 1999), but are always applied at one set level across the entire zone for which licenses or quotas relate. At the same time, it has long been recognised that these fisheries are spatially heterogeneous, both in terms of the biology and the fishing patterns of the fleet (Hamon et al. 2009; Linnane et al. 2009). The use of a single LML across broad areas of the fishery despite these spatial differences has been a pragmatic approach to management, recognising that enforcement of regional LMLs can be difficult.

Spatial differences in biology and fleet are unusually pronounced in the southern Australian state of Tasmania. For example, average annual growth of 100 mm CL females off western Tasmania varies from around 1 mm in the south to 14 mm in the north (Punt et al. 1997). Likewise, the size at onset of maturity roughly doubles across a similar spatial range from 59 mm CL in the south to 112 mm CL in the north (Gardner et al. 2006). Spatial heterogeneity in the fleet is most pronounced with longitude due to prevailing winds, with fishers willing to tolerate lower catch rates on the more protected and accessible east coast (Hamon et al. 2009). The Tasmanian lobster fishery is thus an ideal case study to examine the interactions between management regulations and spatial heterogeneity. Spatial heterogeneity is common, and almost the rule, for coastal fisheries, which implies that responding to these patterns, while attempting to maintain simple, enforceable management rules has been a common challenge (Punt 2003; Steneck and Wilson 2010).

5.1.1. History of Legal Minimum Lengths In Tasmania

LMLs in Tasmania have a long history characterised by debate stemming from the problem of managing all regions with a single tool. LMLs were considered by a Government Commission in 1882, later supported by William Saville Kent, the Inspector of Fisheries, and approved by the Tasmanian Parliament in the 1885 Act for the Protection of Crayfish (Saville-Kent 1884; Harrison 2013). The initial LML was 10 inches total length for both sexes, but was increased in 1890 to 12 inches total length. The legal size for both sexes was measured as CL from 1947 and initially set at ~108 mm (4 ¼ inches) (Harrison 2013). This was then raised to ~114 mm (4 ½ inches) in 1948 to create consistent enforcement across Tasmania and the adjacent jurisdiction of Victoria. This higher LML reduced production from southern Tasmania so the LML was dropped back to ~108 mm for both sexes in 1956 (4 ¼ inches) following lobbying from fishers. The female legal minimum legal size remained the same as males at ~108 mm (4 ¼ inches) until it was lowered to ~106 mm (4 1/6 inches) in November 1966 (Harrison 1967) and then converted to metric (105mm) in the early 1970s. The conversion to the metric limit raised the male limit slightly to give the current limit of 110mm CL.

The lower size limit for females introduced in 1966 was proposed by scientists as a method to provide higher sustainable yield from slower growth areas in the southern part of the fishery. Harrison (1987) explained that this was entirely driven by economic goals because the spawning stock was considered so well protected by a 105 mm LML that "*it is not necessary to rely on any spawning contribution by animals above the legal size*" (Harrison 2013). The intent at the time was to apply the lower 105 mm LML to the southern area only. However opposition from industry to spatial management resulted in the LML being applied across the entire jurisdiction (Harrison 2013). Debate about these historical changes continues to today, with some fishers lobbying for the female LML to be raised to 110mm CL, as per males.

This study used a spatial bioeconomic model of the Tasmanian rock lobster fishery (Gardner et al. submitted) to explore the impacts of different LMLs over a ten-year projection period. This model which was fitted to data for the Tasmanian rock lobster fishery and parameterized using data from economic surveys, formed the basis for projections under a range of LMLs.

Figure 5.1. History of change in legal minimum length (LML) regulation in the Tasmanian Southern Rock Lobster Fishery. LML was measured as total length (TL) until 1947 and carapace length (CL) thereafter. TL was converted to CL according to CL = 0.393*TL.

5.2. Methods

The bioeconomic model consisted of a population dynamics model, which represented the underlying resource, and an economic model, which calculated annual discounted or net present value (NPV) of profits. The population model was fitted to research and commercial sampling data including length-frequency measurements and compulsory catch and effort data for the commercial sector. Biological parameters used in the model are defined in (Gardner et al. submitted), while economic data were updated to those for the 2010/11 fishing season, based on a more recent survey of the industry (EconSearch 2012).

The population dynamics model was used to represent the sex- and size-structure of the stock in eight sub-zones, to account for spatial heterogeneity in biological traits (Fig. 5.2), and how this structure changes over time owing to the impact of fishing, natural mortality, growth and variation in recruitment. The biological model had eight quasi-monthly time steps, and the lobster population was represented using 5-mm CL size bins; both of these specifications were also required for economic modelling because price varies with time of year and size of lobster (Gardner et al. submitted).

Recruitment of juveniles to the population in future years was through selection of a settlement at random from those estimated from data from 2000 to 2010. This time period was used because it occurred after individual transferable quota management was introduced in the fishery and thus reduced risk of bias from change in fishing and reporting practices. Median trajectories of projections are shown in results, and were based on 1,000 simulations. The projections assumed no relationship between current egg production and future recruitment, which was appropriate given that projections were limited to 10 years. Any effect of the management scenarios examined would not be observed over this period because of several slow processes involved, including the stock response to new management (greater than 1 year), the duration of egg incubation (~ 6 months), larval development (18-24 months), and recruitment to the fishery (minimum of 4 years and more typically 6 years) (Bruce et al. 1999; Linnane et al. in press).

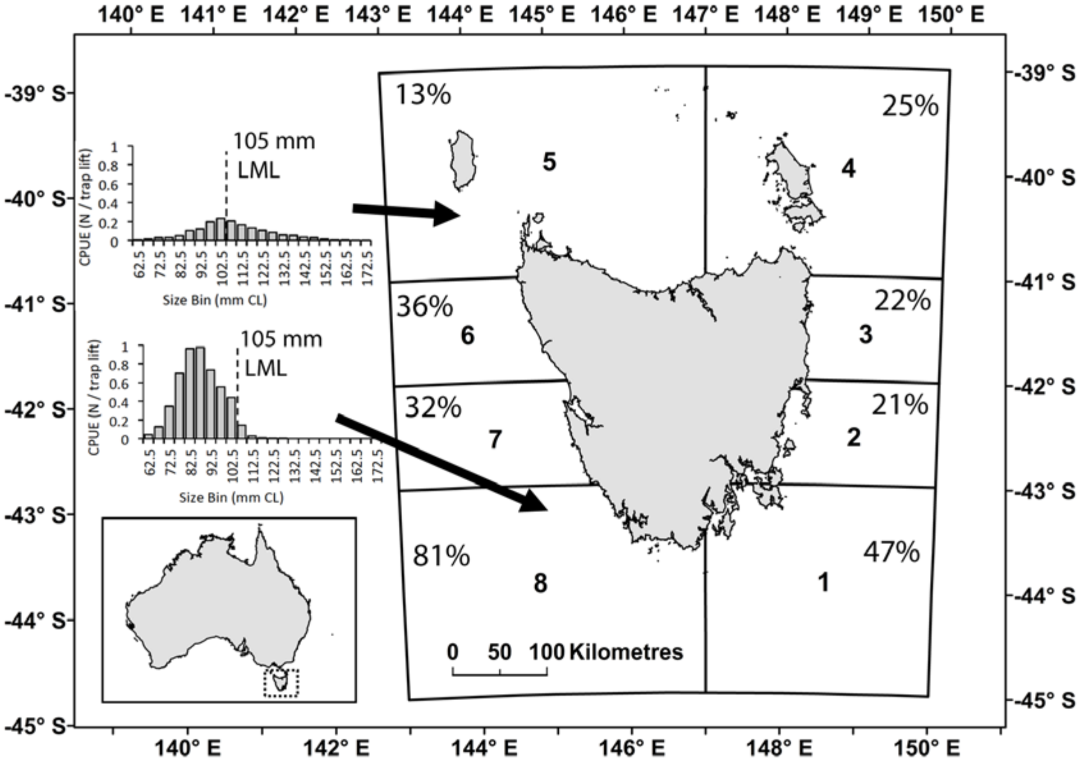

Figure 5.2. Sub-zones used for modelling the Tasmanian rock lobster fishery (1 to 8) and estimates of current egg production as a percentage of that in the unfished state for each subzone (Hartmann et al. 2013). Size structure of catches of female lobsters from research sampling (1987-2011) are shown for sub-zones 5 and 8, relative to the legal minimum length (105 mm CL, dashed vertical line). Numbers of lobsters per size bin are scaled as catch (N) per trap lift (n=12,453 for Area 5; n=21,669 for Area 8).

Scenarios examined assumed current management controls, with the exception of changes to the LML. Most importantly, this involved constraining the catch to 1,100 tonnes by the commercial sector plus a further 130 tonnes of recreational and illegal catch as per the current fishery assessment (Hartmann et al. 2013). The distinction between these sectors was important because the commercial catch was allocated among sub-zones with an effort dynamics model, while the catch from other sectors was spatially fixed. The effort dynamics model first assigned catches to time-step within the year and then used a second model to allocate catches to sub-zone. The proportion of the annual commercial catch taken in each sub-zone and each time period responded to the biomass in each sub-zone and included inertia in the extent to which catch varies (Punt and Kennedy 1997). Values for the effort dynamics model were estimated by fitting to observed data from 1997-2006. The consequence of the effort dynamics model for projections of alternate LMLs was that effort and catch would move between sub-zones as exploitable biomass was affected by changes in LML. This was the only source of movement among sub-zones as each sub-zone is biologically distinct with negligible movement of lobsters, based on observations from tag recapture data (Barrett et al. 2009; Gardner et al. 2003).

The following scenarios were examined as examples of alternate LMLs:

1) 105 mm CL Statewide, which was the basis of current, status quo management
2) 110 mm CL Statewide, as proposed by industry;
3) the 1966 proposal of a female LML in southern areas (sub-zones 1, 7 and 8) of 105 mm CL, and a female LML in remaining areas of 110 mm CL; and
4) a targeted system that had LMLs broadly in line with spatial patterns in growth. This system had three regional LMLs targeting egg production above limit reference points in all areas: 105 mm LML in the southern areas (sub-zones 1-3 and 8), 110 mm LML in midwest coast areas (sub-zones 6 and 7), and a larger LML of 130 mm in northern areas (sub-zones 4 and 5).

Outcomes were compared in terms of changes in egg production, biomass and economic indicators. Scenarios were generally compared using median trajectories, although the stochastic recruitment was used for estimating the probability of meeting the management objective of egg production at or above 25% of unfished levels in each sub-zone. Total biomass is not used in formal reference points for the fishery, but does provide an indicator of ecosystem impact with higher levels relative to the unfished state preferred.

Economic performance of the fishery is indicated by trends in catch rate but also measured directly as economic yield, with scenarios compared using net present value (NPV) applying a real discount rate of 7.5%. This was used as an estimate of the business discount rate based on business borrowing costs and was thus higher than the societal discount rate. We used the business rate because NPV outcomes were mainly of interest for businesses, while fisheries managers were more concerned with egg production outcomes. The price of lobster and cost of fishing was kept constant over the projection as is appropriate with the use of a real discount rate.

5.3. Results

5.3.1. Statewide

The Tasmanian rock lobster fishery uses a limit reference point for statewide egg production of 25% of unfished egg production, which is higher, and thus more conservative, than the 20% reference point used in the national assessment of the stock (Flood et al. 2012). All median trajectories of size limit scenarios stayed well above this reference point and thus management objectives for statewide egg production were met with any of the choices examined (Fig. 5.3). Modest improvements in statewide egg production, ranging 1% to 4% of unfished levels after 10 years, were achieved. The 110 mm CL statewide limit for females and the targeted regional limits achieved the highest increases in egg production.

All alternate size limit scenarios resulted in some loss of NPV relative to the current 105 mm limit (Table 5.1). Greatest decrease was from the 110 mm statewide and the targeted regional limits, which resulted in declines of 27% and 29% in NPV respectively. The 1966 proposal of a 110 mm LML in the north and a 105 mm LML in the south resulted in a far smaller decrease in NPV of 6%.

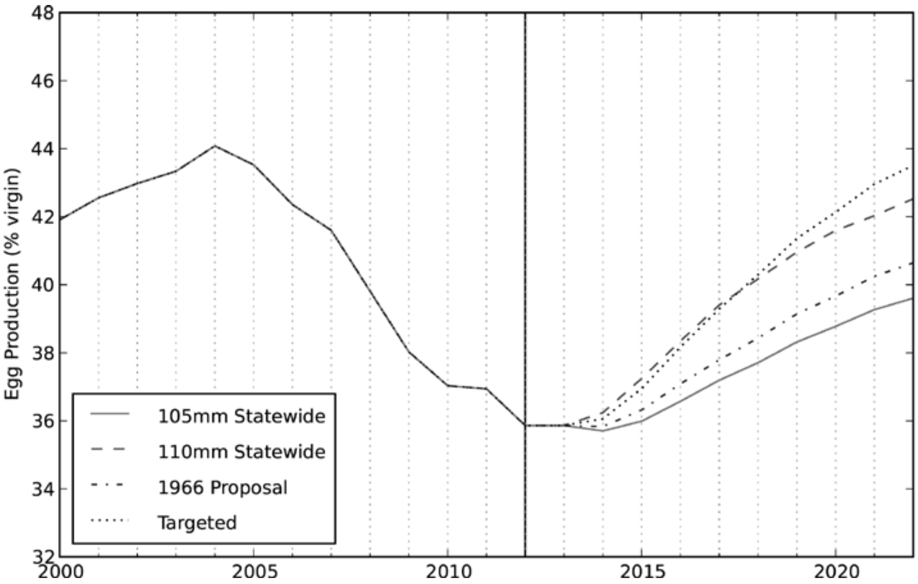

Figure 5.3. Median trajectories of statewide egg production as per cent of unfished levels under different size limit scenarios.

5.3.2. Regional outcomes

Outcomes of the different scenarios were vastly different among regions, with the two extremes of sub-zone 5 (fast growth, north west) and sub-zone 8 (slow growth, south west; Fig. 5.4). Most of the sub-zones were predicted to have a very high probability that egg production will be above the limit reference point of 25% within 10 years with the current 105 mm statewide LML – the exceptions were the northern, fast growth sub-zones 4 and 5 (Table 5.1). Egg production in these sub-zones is thus the main challenge facing management of egg production in the Tasmanian jurisdiction.

The 110 mm statewide scenario compounded the problem of low northern egg production, with the estimated probability of the egg production being above reference point falling by 5% (from 30% to 25%) in sub-zone 4 (Table 5.1). Egg production in southern areas, where it is already very high, was increased further under the 110 mm statewide limit. Total biomass in the north is also of management concern as it is currently very low relative to unfished levels (11%), and the 110 mm LML also led to lower total biomass than the current 105 mm LML (Fig. 5.4).

The 1966 proposal improved egg production and assisted in shifting production towards regional reference points of 25% of unfished levels, but was inadequate to fully address the issue. The probability of exceeding the egg production reference point in sub-zone 4 improved from 30% to 36%, but this is still well below even a 50% probability. Only the targeted strategy of three regional LMLs led to a probability of 60% or more that egg production would be above reference points in all sub-zones (Table 5.1). This was most pronounced in sub-zone 5, where the targeted strategy led to a 63% probability of meeting the reference point, yet all other scenarios resulted in only a 2-3%.

Catch rate declined in all areas for each alternate LML scenario, which would be expected given that catch rate is influenced by exploitable biomass and this depends on the LML. Lower catch rate implies higher cost of fishing for the same TAC, as reflected in lower NPVs relative to the current 105 mm LML. That is, any change in management to rebuild egg production in the fishery will reduce profitability over the time period examined in these scenarios (10 years). It is possible that stock-recruitment effects would result in higher productivity at some point in the future, but if that occurs it would be a longer term outcome. Catch rates declined most in the north with the targeted strategy while they were most reduced in the south by the 110 mm strategy.

Table 5.1. The probability of meeting regional egg production management targets after 10 years (25% of the unfished levels).

Female legal minimum length scenario	Probability of exceeding 25% unfished egg production after 10 years (2022) in sub-zones								NPV $AUD millions
	1	2	3	4	5	6	7	8	
105 mm statewide (status quo)	100	96	98	30	2	93	96	100	379
110 mm statewide (= male LML)	100	98	97	25	2	97	100	100	278
1966 proposal (105 mm Areas 1,7,8; 110 mm elsewhere)	100	99	99	36	3	99	95	100	359
Targeted (105 mm Areas 1-3,8; 110 mm 6-7; 130 mm Areas 4-5)	100	96	98	72	63	97	100	100	269

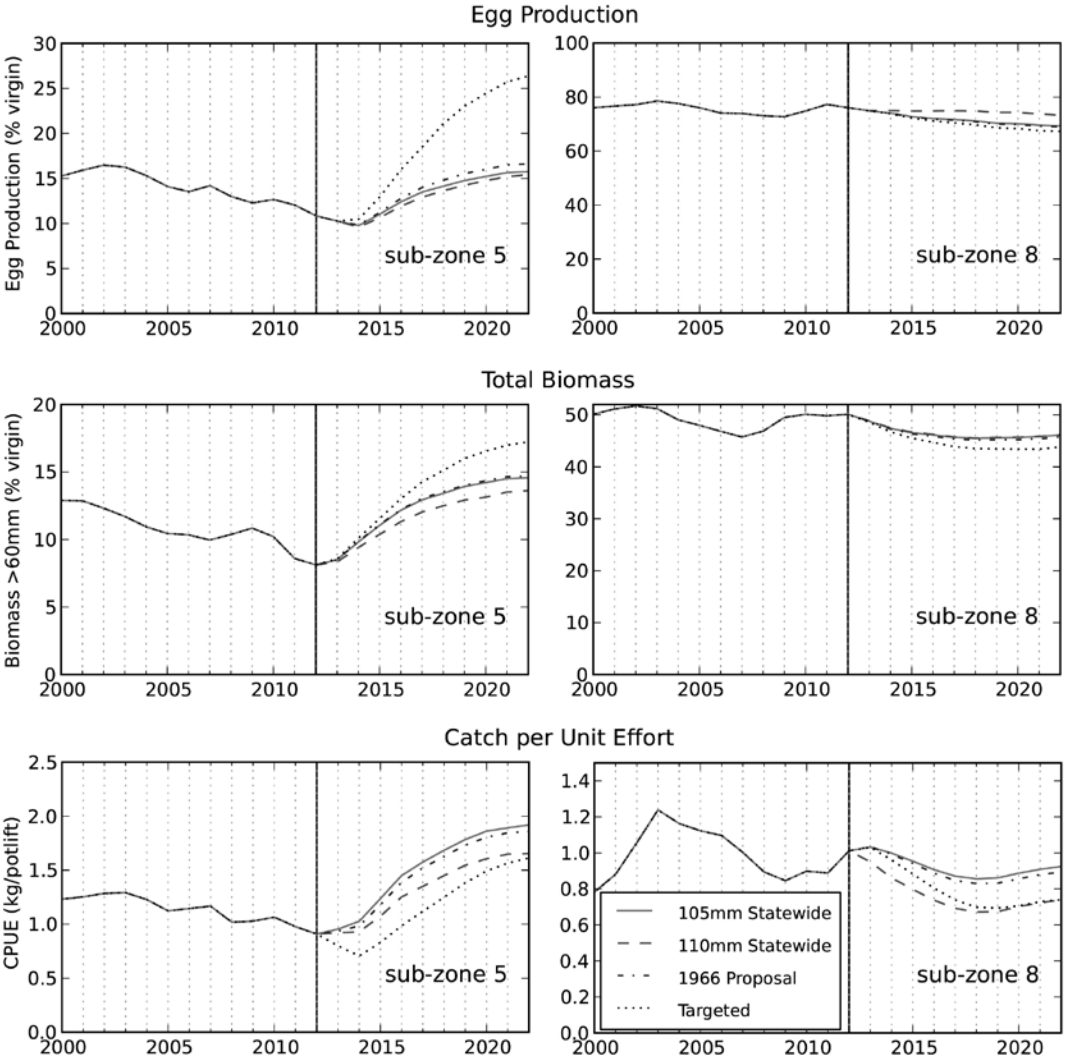

Figure 5.4. Median trajectories of model outputs for two sub-zones: the fast growth north western sub-zone 5, and the slow growth south western sub-zone 8.

5.4. Discussion

Size limits or legal minimum lengths (LMLs) are widely employed in fisheries management because they deal directly with the fundamental objectives of protecting reproductive output and allowing animals to grow to a size where yield is reasonable. They generally also have the advantage of effective enforcement at low cost because landed product from all sectors can be investigated, although there are exceptions where enforcement is difficult, including fisheries for stalked barnacles and other Latin American artisanal fisheries (Salas et al. 2007; Jacinto et al. 2011). LMLs are well entrenched in management of the Tasmanian lobster fishery, having been first established around 130 years ago (Saville-Kent 1884). Management of the fishery has also involved the use of a total allowable catch for 15 years, but LMLs remain important, and tend to be discussed extensively at stakeholder meetings.

Spatial variation in growth and reproduction has long been recognised as an important consideration for management in this fishery, and this variation is common with invertebrate or fish species that have limited movement (Kritzer 2004; Hamilton et al. 2011). Spatial variation in biological traits implies a possible need for spatial management tools such as regional LMLs, although these can be difficult to enforce when vessels and catch transit over boundaries (Appeldoorn 1994), as would be required in Tasmania where there are no ports along large stretches of coast. Implementing regional LMLs thus requires a strong case for improved outcomes that outweigh the problems of increased cost for enforcement.

The benefit-cost of regional LMLs is clear where yield is foregone with a single LML as occurs with molluscan fisheries for conch and abalone (Appeldoorn 1994; Tarbath 1999). In those fisheries, a combination of a single conservative size limit plus spatial variation in growth results in some parts of the fishery becoming excluded from harvest. An analysis of California sheephead (*Semicossyphus pulcher*) quantified the yield lost by a single LML across the entire jurisdiction at around 26% relative to applying different LMLs across nine zones, although most of this yield would be captured by the more pragmatic alternative of two regional LMLs (Hamilton et al. 2011). This trade-off between what is possible and what is pragmatic also influenced the scenarios examined here, with a maximum of three regional limits explored, even though data and modelling capacity existed to explore many more regional LMLs.

Spatial variation in biology interacts with LMLs to not only affect yield, but also egg production. Benefits from managing egg production are ambiguous in Southern Rock Lobster because of the extensive larval dispersal that occurs over the 18-24 month larval life (Bruce et al. 1999). In the case of Tasmania, this means that most recruitment is thought to originate from eggs produced outside the jurisdiction although there is also some degree of self-recruitment with temporal variation in the strength of this (Bruce et al. 1999). Uncertainty regarding the extent of self recruitment versus external recruitment also exists on a smaller scale with management of giant clam fisheries (Yau 2011), and as with rock lobster, the appropriate management response is to assume some reliance on self recruitment and protect local egg production. Managing to account for uncertainty in the source of recruits means not only ensuring adequate egg production within the jurisdiction but also ensuring that this is well distributed around the region, rather than being aggregated in slow growth areas. This is the current state of the Tasmanian fishery where egg production is at acceptable levels overall (Flood et al. 2012), but has a distribution highly impacted by fishing, with production concentrated in the south west (81% of unfished) while other areas such as the north west are highly depleted (13% of unfished).

The modelling conducted here shows that improving the spatial distribution of egg production requires a spatial management solution, and that increases to the statewide female LML actually compound the problem of reduced egg production in the north. The higher statewide female LML championed by industry resulted in greater protection of females in southern areas where egg production is already high, so that catch and effort was displaced northwards. As a result, depletion of egg production in the northern areas became more severe with the presumed conservative management change of a higher LML. Substantial economic yield would also be forgone over the 10-year projection period with a higher LML. In contrast, regional LMLs could be applied effectively to restore egg production in all areas to above limit reference points, with a similar economic impact to the statewide 110 mm CL LML.

We thus have the difficult situation in Tasmania where the commercial fishing industry attempt to be responsible stewards of the resource by lobbying for an increase in the female LML, yet failing to appreciate that this management change would be counter-productive to their goals. This lobbying for a larger LML occurs simultaneously with opposition to the introduction of effective regional size limits. This pattern of lobbying for change to management to increase egg production while opposing spatial management has occurred several times since the 1966 attempt to introduce a 105 LML limit in the south, including through a vote of members of the commercial industry peak body in 2009 following release of a discussion paper and a port meeting tour explaining the issue (Gardner 2009). Most fishers find it counter-intuitive that an increase in the statewide LML is not the best approach to manage egg production.

There are three contributing factors to why fishers find results of these analyses counterintuitive. LMLs tend to be considered in isolation rather than interacting with catch limits. In fisheries such as that for New South Wales spanner crab, the LML is set at such conservative levels that this assumption is reasonable (Kennelly and Scandol 2002). However, there is more typically an interaction between LMLs and catch so that outcomes for egg production are influenced by both (Perry et al. 2002). We see this in the northern region of the Tasmanian fishery where females mainly mature above the LML and thus egg production is more influenced by exploitation rate than LML. Secondly, the population dynamics of fished species with spatial heterogeneity can be complex. Gendron and Savard (2008) reported a similar situation to that of Tasmania where Canadian lobster fishers lobbied for a maximum legal length, assuming that this would be effective in protecting egg production. However, research showed that spatial differences led to poor outcomes including unequal negative economic impact (Gendron and Savard 2008). Finally, the fact that effort and catch tends to be displaced to some other part of the stock when a portion of the stock is excluded from harvest tends to be ignored. Displaced catch is readily quantified in systems such as this where a TAC is applied, but tends to be overlooked. Failure to consider the effect of displaced catch and effort occurs not only in discussion of LMLs but also in debate around many fishery management decisions where catch is shifted from one part of a fishery to another, such as with catch displaced by MPAs or between different species in mixed fisheries (Casey and Wesche 1997; Stump 2005).

In summary, this analysis shows that the Tasmanian rock lobster fishery faces a significant management challenge if the objective of maintaining high levels of egg production in all sub-zones is to be achieved. High spatial variation in growth means that the industry proposal for an increase in a jurisdiction-wide female LML will be counterproductive to the objective of rebuilding stocks and egg production in all sub-zones. This occurs because harvest rates would be increased in northern areas as a result of effort and catch displaced from slower growth areas in the south. The solution to this spatial problem appears to be spatial management, with the example of three regional LMLs examined here resulting in substantially improved egg production and comparable economic yield to the industry proposed LML. Creating operationally feasible regional LMLs would clearly be challenging and different combinations of LMLs to those examined here may be more readily enforced. Ongoing work is being conducted to identify LMLs that achieve egg production and economic goals whilst being acceptable to industry and management.

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6. Robustness of MEY in Tasmania and South Australia: Consistency under recruitment, size limits and TACCs

Klaas Hartmann, Caleb Gardner, André E. Punt, Richard McGarvey, Janet Matthews

6.1. Introduction

The total allowable commercial catch (TACC) is regularly reviewed across all Australian Southern Rock Lobster fisheries. In South Australia a quota-setting decision rule which seeks an approximately constant exploitation rate has been put in place (see Chapter 9). This rule sets the TACC based on the previous season's CPUE. In contrast, in Tasmania several reference points relating to sustainability and economic performance have been established, and a TACC is determined through a consultative process, which meets most or all of these reference points.

Whilst these processes differ substantially, they share common weaknesses that may expose these fisheries to overfishing and inefficiency. The weaknesses we will explore here are: i) the delay from the time changes occur in a fish stock to the time that management can react, and ii) inefficiencies arising from historical input controls.

6.1.1. Delayed management response to changes

There is a substantial delay from the time something changes in the fish stock to the time management can respond to this. In Tasmania, the TACC for the following quota season is set using data collected from the previous quota season. For example in 2013, the TACC for the 2014/2015 season is being set using the commercial logbook data collected up to the end of the 2012/2013 season. Consequently, there is a two year lag from the time changes may become apparent in logbooks through to the time that a management decision is made to respond to these changes.

This problem is exacerbated by the fact that multiple years of data are required to understand aspects of the stock such as the level of recruitment or the abundance of undersize in a given year. Consequently, management strategies that are robust to variations in stock abundance are required. Such strategies would reduce the need for frequently altering management controls.

A recent example of this has been an extended period of below average recruitment in Southern Rock Lobster during the last decade. Management was too late to respond to the recruitment downturn due to the delay in understanding the fluctuating stock, resulting in under-caught TACCs and a dramatic reduction in the value of the fisheries, as evidenced by low quota sale and lease prices. This low recruitment period was unavoidable. However, a robust management strategy could have dampened the impact on the fishery.

Here we explore management strategies that may be robust across a broad range of likely future recruitment scenarios. Such management strategies will produce good outcomes regardless of what future recruitment holds. In this chapter we show that such strategies exist and that the current Tasmanian and South Australian rock lobster fishery TACC setting systems could be made to be robust to future recruitment variation.

6.1.2. Input control inefficiencies

Total allowable commercial catches were introduced to Southern Rock Lobster fisheries following decades of fishing under input controls. As discussed in Chapter 5, these input controls have seen limited revision and in some cases force inefficiencies upon the fisheries with limited benefit. Minimum legal size limits in particular were originally set to provide several years of sexual maturity and egg production prior to animals entering the legal population. This ensured that the stock would remain sustainable regardless of the fishing pressure applied in the fishery. Now that TACCs are in place, the main benefit provided by size limits is to prevent harvesting of animals that are too small, thereby permitting the utility (economic yield) per recruit to be maximised.

Traditionally size limits have been evaluated in the context of maximising the yield per recruit that is determined by the size at which natural growth of the animal begins to be outweighed by natural mortality. Recruitment impacts aside, the largest sustainable harvest would be obtained my harvesting all animals at this size. Things are more complicated in reality--different size classes have different prices, harvesting a narrow size range is more expensive than harvesting a range of sizes, and lobster growth varies dramatically even within a single state. With the advent of the Southern Rock Lobster bioeconomic model it is possible to set size limits in a much more sophisticated manner that considers all of these factors and provides greater economic return and fishery sustainability.

6.2. Methods

6.2.1. Delayed management response

We considered a range of alternative future recruitment scenarios to explore the robustness of a set TACC against delayed management reaction. This is a worst case scenario because it is assumed that recruitment would change and management would not respond during the considered time horizon.

We used the projection model (see Chapter 4) to project the Tasmanian and South Australian fisheries under different harvest levels for a range of future recruitment scenarios. 500 replicates were performed for each combination of harvest level (TACC) and recruitment scenario. All model settings and parameters, apart from the TACC and recruitment, were set to those used in the 2012/2013 stock assessments conducted in each state.

Historical variability in recruitment was used to estimate future potential recruitment reductions. This was achieved by dividing the available recruitment estimates into groups of seven years. This includes groups with years of good recruitment and groups with poor recruitment (e.g. in Tasmania the recent 2000-2006 low). The model was projected for each seven year period that assumed recruitment from 2013 onwards would be as it was during that seven year period.

Fishery projections were then carried out for each seven-year period for a broad range of possible TACCs and the value of the fishery under each management strategy was calculated in terms of the net present value (NPV).

6.2.2. TACC and size limit combinations

We considered size limits that varied across Tasmania due to the spatial variability in growth. Specifically, the size limits could be set for each of the following zones:

- South: Areas 1 and 8

- East: Areas 2 and 3
- West: Areas 6 and 7
- Northern: Areas 4 and 5.

For example, it may be appropriate to set a lower size limit in the South zone given the slower growth in this area.

A broad range of combinations of TACCs and size limits in each of the zones was considered. We restricted the number of possible size limits to reduce the number of scenarios that needed to be considered. This resulted in 48,496 management scenarios. To keep run-times manageable we reduced the number of replicates to 50 for each of these scenarios.

6.3. Results

6.3.1. Delayed Management Response

Fig. 6.1 shows the value of the Tasmanian rock lobster fishery as a function of hypothetical future TACCs. Each line corresponds to a different recruitment scenario. The solid black line corresponds to the assumptions used by the current stock assessment process and indicates that a TACC of 1,000t would maximise the value of the fishery, this point is commonly referred to as the maximum economic yield (MEY). Importantly, TACCs in the range of 800-1,160t lead to 90% of MEY, so a broad range of management options achieve a good economic outcome.

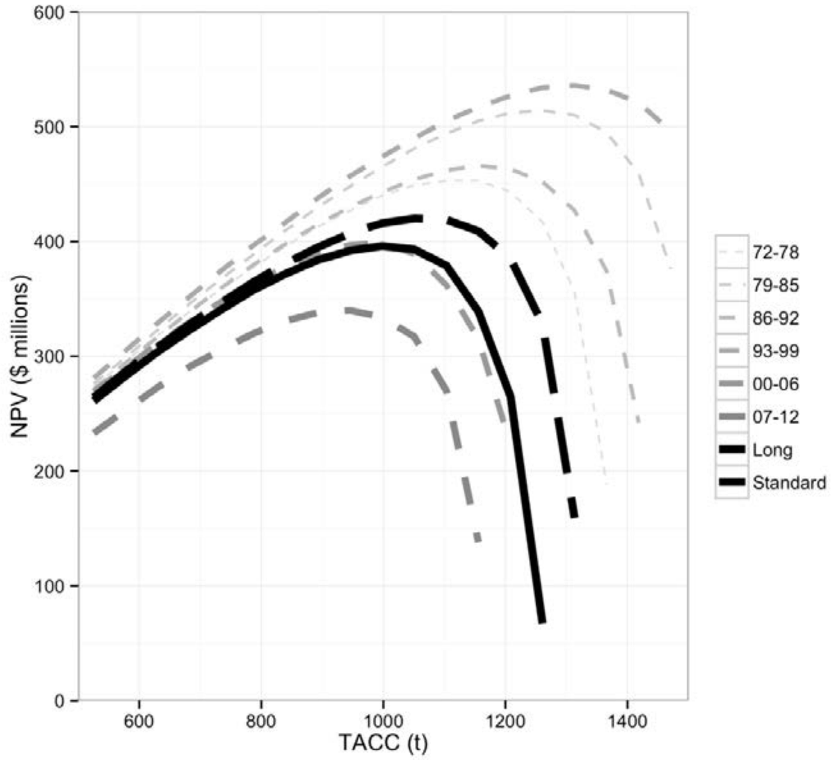


Figure 6.1. The net present value (NPV) of the Tasmanian Southern Rock Lobster fishery (y axis) as a function of the TACC for a range of recruitment assumptions. The “Long” recruitment scenario uses recruitment from 1965-2000, the “Standard” scenario uses 2000-2010 as used in the 2012/2013 stock assessment and the other scenarios use the range of years indicated. Under the standard recruitment scenario (solid line) the value of the fishery is maximized with a TACC of 1,000t. TACCs below 1,050t are robust to recruitment variation over the projection period considered.

The black dashed line in Fig. 6.1 corresponds to the full range of available recruitment estimates. A higher TACC of approximately 1,100t would maximise economic yield in this case. Relative to long-term recruitment, recent recruitment estimates suggest a reduction of 100t in the TACC corresponding to MEY and a 6% reduction in MEY. The other lines in Fig. 6.1 correspond to different historical periods of recruitment. These were considered to explore the sensitivity of optimal management to natural recruitment variability and long-term temporal trends.

The same analysis was conducted for the Southern Zone of South Australia (Fig. 6.2) and shows similar characteristics to the Tasmanian analysis with TACCs below 1,200t providing good economic outcomes that are robust to recruitment variation.

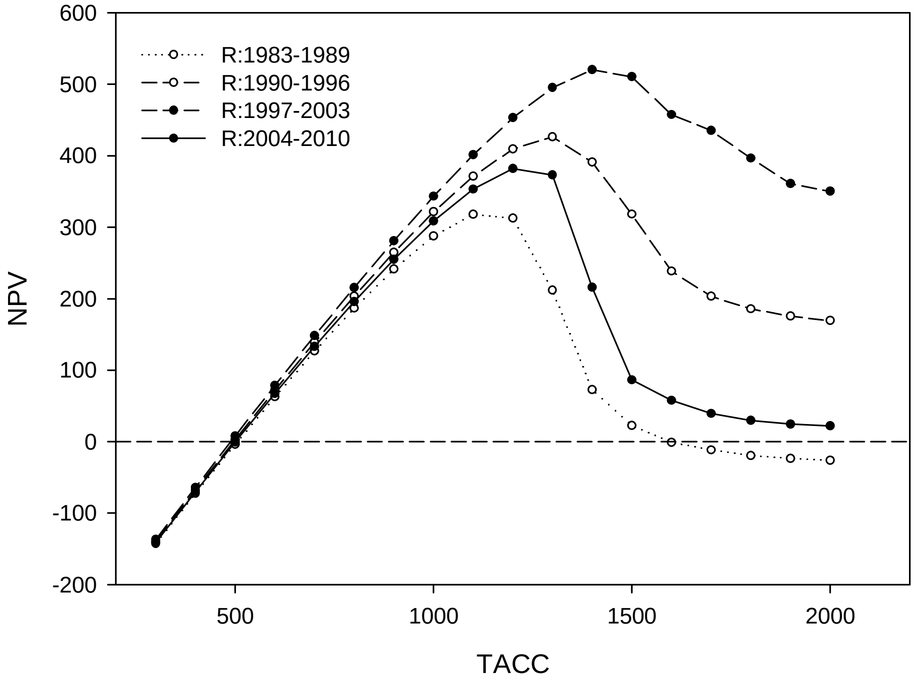


Figure 6.2. The net present value (NPV) of the South Australian Southern Zone Southern Rock Lobster fishery (y axis) as a function of the TACC for a range of recruitment assumptions, as indicated in the legend. TACCs below 1,200t are robust to variation in recruitment over the projection period considered.

6.3.2. TACC and size limit combinations

Figs. 6.3 to 6.5 provide examples of management scenarios and their likely outcomes in terms of the profitability of the fishery (sum of the net present value: NPV, AU$ million at a 7.5% discount rate) and simulated egg production in 2023 for the Tasmania fishery. Fig. 6.3 illustrates that imposing a single, state-wide size limit of 110mm for female lobster (currently 105 mm for females, 110 mm for males) while maintaining the present level of TACC yields a lower NPV and lower egg production than the current management scenario, indicating that such a change in management moves the fishery in the wrong direction. Lowering the levels of TACC will improve the egg production, but has minimal impacts on economic performance (Fig. 6.3) unless combined with a different size limit. For example, Fig. 6.4 shows the management scenarios that were equal to, or lower than, the current size limit (105mm or smaller) for the Southern zone when imposed in combination with TACC changes. Lowering the size limit for the Southern zone will improve both NPV and egg production, except for the case where the TACC is also increased. This indicates that the TACC should be maintained at the present level - and ideally lower than the present level - to improve both profitability and egg production. There are many scenarios that can lead to higher egg production, but poor economic outcomes, and such options were not explored in detail.

Instead, we identified the frontier or boundary curve (Fig. 6.5) that illustrates the various size limit and TACC combinations that lead to the best outcomes. We then explored the characteristics of the management options which sit on the frontier curve, using a regression tree approach with NPV as an independent variable. The aim of the regression tree is to visually show which explanatory variables (TACC or size limit by fishing zone) explain most of the variation in NPV. Similarly, we identified the worst cases where management options yielded the poorest outcomes (far away from the frontier). For the management options that are on the frontier, the regression tree result (Fig. 6.6) shows that if TACC is smaller than 97.5 kg/unit, the variation in NPV can be explained simply by the size of TACC (e.g. the smaller the TACC, the lower the NPV), but if the TACC is larger than 97.5 kg/unit, the variation in NPV is explained not only by the TACC, but also the size limit for male lobster in the Southern zone (south male) and female lobster in the Western zone (west female). If the TACC is larger than 102.5 kg/unit, setting the size limit for south male less than 102.5mm yielded the best NPV. The options that are identified as worst are all in the cases of the highest TACC (110 kg/unit). Among these, setting the size limit for female lobster in the Southern zone (south female) larger than 97.5mm yielded the worst economic outcome with the lowest NPV, but setting the larger size limit for south female (above 97.5mm) as well as west female (above 102.5mm) yielded much better economic outcomes among the TACC 110 kg/unit scenarios (Fig. 6.7).

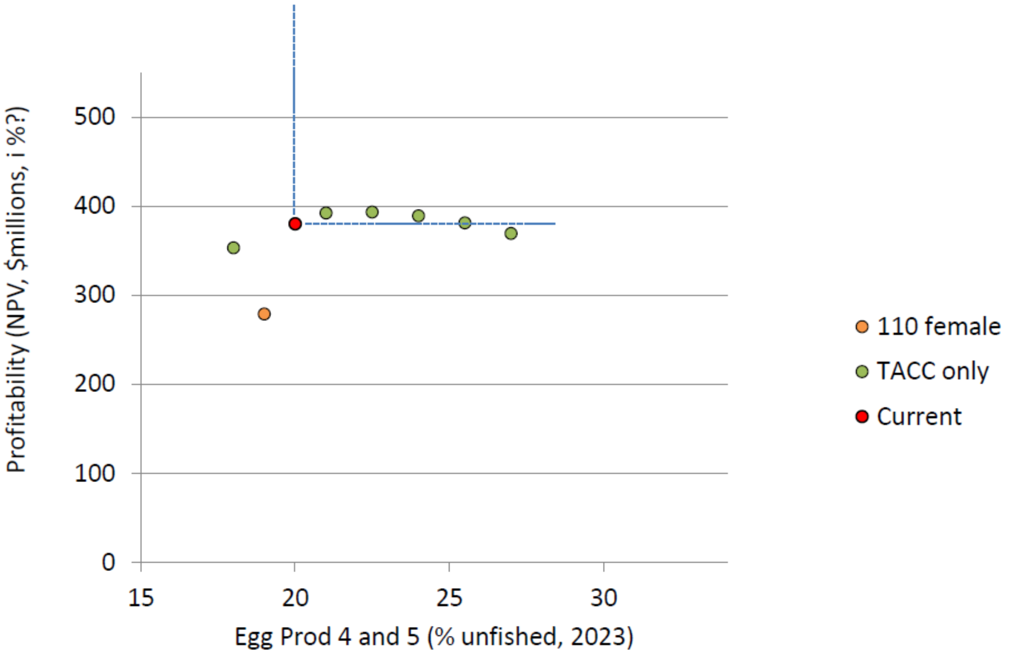
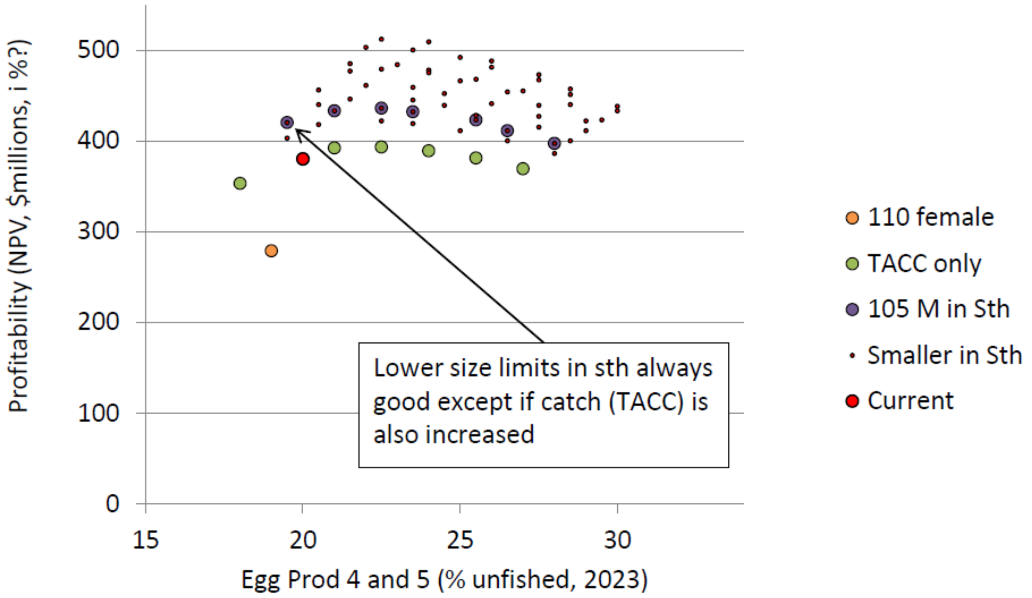
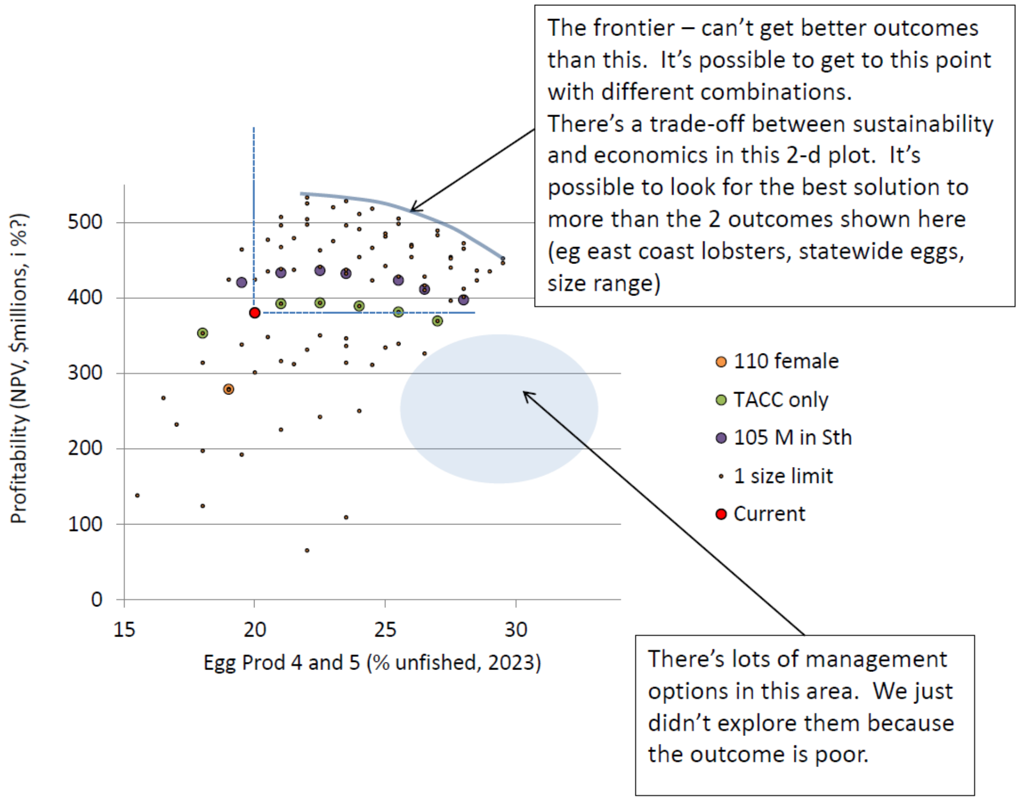


Figure 6.3. Tasmanian management scenarios and their likely outcomes in terms of NPV ($million) and egg production (as % of unfished) for the northern zone (Areas 4 and 5). The TACC only scenarios (green dots) correspond to changing just the TACC. The 110 female scenario corresponds to an increase in the female size to 110mm in the northern zone and the Current scenario corresponds to the current management arrangement. The size limit reduction reduces both profitability and egg production. Decreasing the TACC allows egg production to increase whilst profitability decreases.



Lower size limits in sth always good except if catch (TACC) is also increased

Figure 6.4. Tasmanian management scenarios and their likely outcomes in terms of NPV ($million) and egg production(as % of unfished) for the northern zone (Areas 4 and 5). In addition to the scenarios presented in 6.3, the additional scenarios correspond to lower size limits in the southern zone (Areas 1 and 8). These scenarios permit both egg production and profitability to be increased simultaneously – a win-win scenario.



The frontier – can't get better outcomes than this. It's possible to get to this point with different combinations.
There's a trade-off between sustainability and economics in this 2-d plot. It's possible to look for the best solution to more than the 2 outcomes shown here (eg east coast lobsters, statewide eggs, size range)

There's lots of management options in this area. We just didn't explore them because the outcome is poor.

Figure 6.5. Tasmanian management scenarios and their likely outcomes in terms of NPV ($million) and egg production (as % of unfished) for the northern zone (Areas 4 and 5). In contrast to Figure 6.4, this shows a clear frontier (blue line). Scenarios that provide a better

outcome cannot be produced by changing size limits and/or the TACC. This frontier is the optimal trade-off between profitability and egg production.

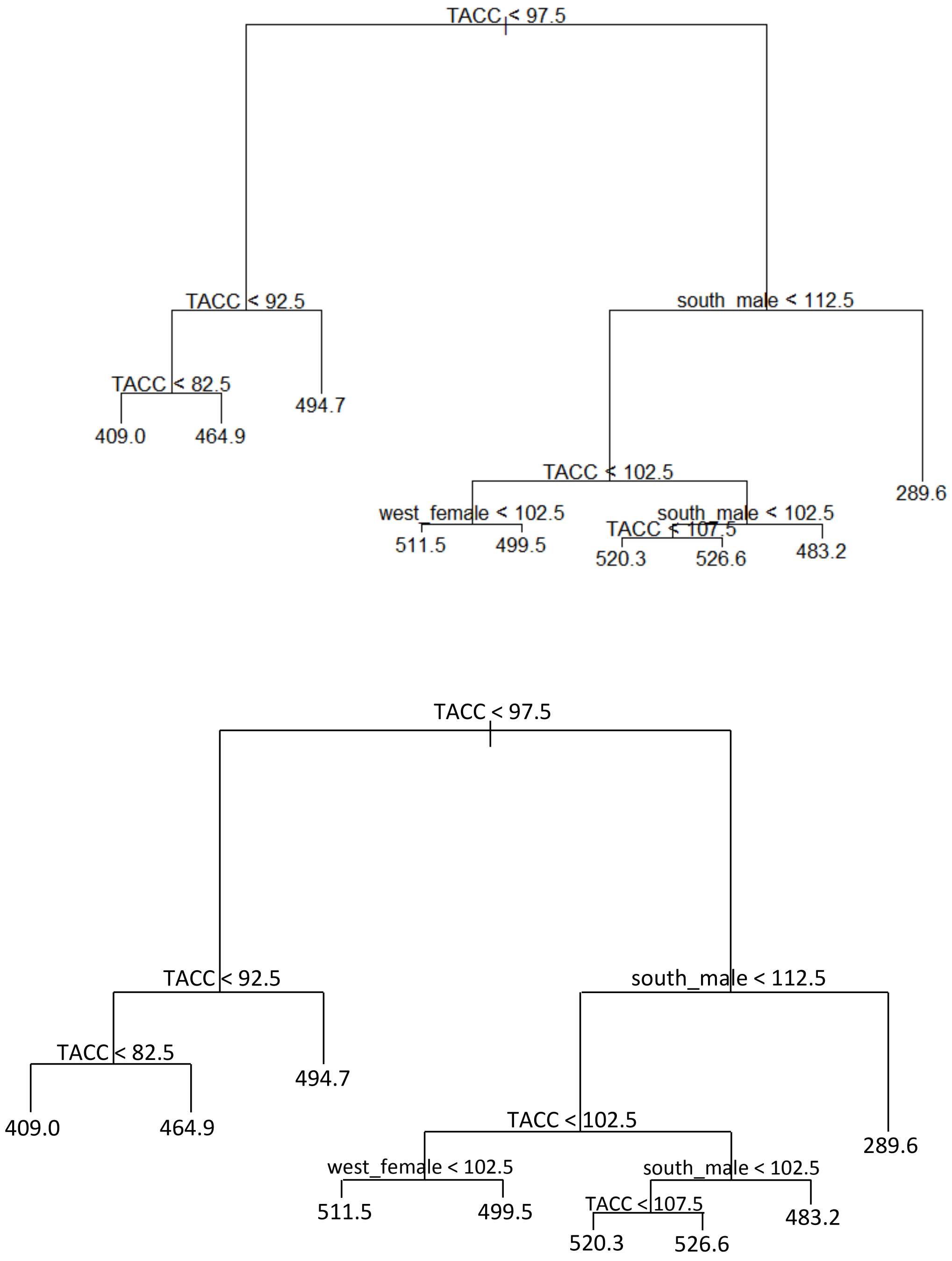


Figure 6.6. Regression tree for the management options that produce the best outcomes (on the frontier curve). The unit for TACC is kg/unit, and the rest of the quantities is in mm. The numerical numbers at the end of the tree branches indicate NPV (AU$ million) from the fishery.

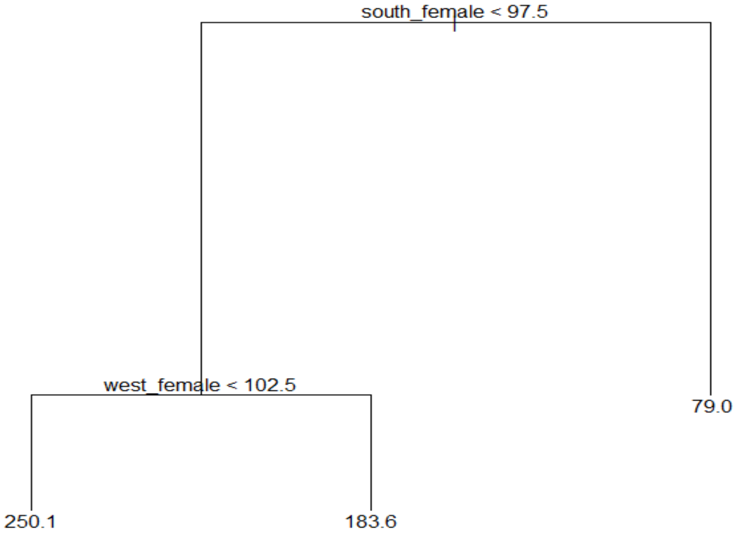


Figure 6.7. Regression tree for the management options with the worst outcomes (far away from the frontier). The unit for TACC is kg/unit, and the rest of the quantities is in mm. The numerical numbers at the end of the tree branches indicate NPV (AU$ million) from the fishery.

6.4. Discussion

From an overall economic perspective, for a given set of assumptions the NPV curve (e.g. Fig. 6.1) has a relatively flat section. There are a broad spectrum of TACCs that will provide a value close to this peak. When alternative assumptions about recruitment are considered there is overlap between the relatively flat peaks of these curves. This allows us to identify robust management strategies that provide economic outcomes within some percentage of the optimum across all alternative assumptions. A TACC set in this would avoid the need to rapidly respond to future recruitment changes as they occur and would substantially reduce the possibility of depleting the population to the levels that recently occurred in Southern Rock Lobster.

In Tasmania the 2012/2013 TACC of 1,103t is robust across most recruitment scenarios except the most pessimistic and most recent scenario (2007-2012). Note that this scenario is incomplete, covering only six years and recruitment estimates for the most recent years (particularly 2011 onwards) are imprecise until further data are collected. Consequently, this may present an overly pessimistic recruitment scenario. However to provide a good outcome under even this scenario would only take a 50t reduction to 1,050t.

A new dynamic harvest control rule was implemented in both South Australian lobster fishery zones, in 2011. This harvest strategy, with four basic components (see Chapter 9 below), is a form of quota-setting strategy that seeks, by its main component—a table of what the TACC will be set to given the previous season's CPUE, to achieve approximately constant exploitation rate (a constant fraction harvested yearly). The strategy testing reported in Chapter 9 shows that these 2011 SA strategies as implemented are very nearly economically optimal, as measured by NPV, if recruitment were to remain at historical levels. However, if recruitment is lower than the historical average going forward in time, these tests of the 2011 South Australian harvest strategies show that lower levels of exploitation are more economically optimal, where lower exploitation levels can be implemented in the harvest strategy by proportionally lowering TAC levels in each TACC-versus-CPUE band. One drawback of a dynamic harvest strategy is higher yearly variation in catch than the constant quota strategies evaluated in this chapter.

The exploration of size limits and TACCs lead to the general conclusion that the minimum legal size limit has little impact on the levels of NPV if the TACC is set low enough (e.g. less than 97.5 kg/unit), but once the TACC becomes higher the minimum legal size limit plays an important role in determining the NPV. The results also suggest that imposing a single, state-wide size limit could lead to poor management outcomes (i.e. lower NPV and egg production with 105mm size limit for female lobster). The key message is that it is vital to investigate size limits and TACC management options simultaneously, as they interact to produce counter-intuitive results.

7. Regional Management in Tasmanian lobster: Managing an over-depleted region for ecosystem benefits

Caleb Gardner, Klaas Hartmann, André E. Punt and Eriko Hoshino

7.1. Introduction

The east coast of Tasmania has been heavily depleted. Fishers (both commercial and recreational) in this region continue to fish at much lower catch rates than the rest of the state due to favourable weather conditions, easy access, lower fishing costs and lifestyle. Consequently, the biomass has been depleted to 16%, 8% and 10% of virgin biomass in sub-zones 1, 2 and 3 respectively. Consequently, catch per unit effort (CPUE) is at a record low in these sub-zones (see Fig. 7.1).

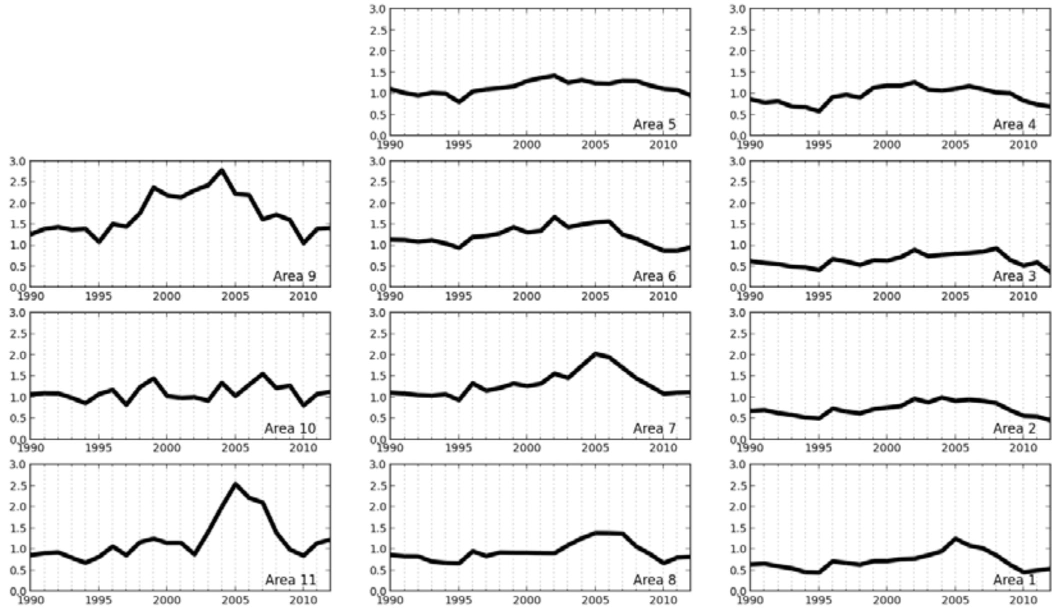


Figure 7.1. CPUE (kg / potlift) for each of the Tasmanian stock assessment areas. The area of concern includes sub-zone 1, 2 and 3, which have the lowest CPUE in the state.

Due to preferential fishing on the East Coast, the state-wide total allowable commercial catch (TACC) is an insufficient long term management measure for meeting East Coast biological and economic targets. A TACC could only achieve these targets if it were set at a level significantly lower than required for the rest of the state.

The low biomass is of particular concern on the East Coast as large lobsters may fulfil an important ecosystem function. A range-extending urchin – *Centrostephanus* – has been causing widespread kelp barrens. Recent studies have shown that large lobsters predate on *Centrostephanus* (Ling and Johnson 2012). Densities of large lobsters that are achievable by pro-active management over the next decade may be sufficient to reduce the extent of the kelp barrens (Ling et al. 2009).

7.2. Methods

The stock assessment model described in Chapter 4 was used to consider the future of the Tasmanian rock lobster fishery under different management options. This chapter focused on determining an appropriate level of catch (combined recreational and commercial) for the East Coast. The mechanism by which this is achieved was debated over several years by industry and management, with scientific advice on specific issues.

Current biomass is at a record low level. A target of 20% of virgin biomass was chosen as a significant improvement over the current stock state that is achievable with substantial fishery intervention, but at minimal economic cost.

Different mechanisms for implementing the catch limit were discussed. These included regional quota, reduced seasons and a catch cap:

1) *Regional quota* was widely discussed as it would allow a fine level of control over the catch. However, it was deemed too expensive to implement and there were concerns about equity when existing TACC units are split into east/west components.
2) *Reduced seasons* were considered and a mechanism for dynamically altering seasons to achieve the target catch was developed. As data are entered up to a year after fishing occurs, there were concerns that this method would not operate in a sufficiently timely manner.
3) A *catch cap* was chosen as this was inexpensive to administer and will effectively limit the catch. The exact details are being finalized and include a range of rules to allow compliance, address practical fishing concerns and avoid excess fishing pressure on regions adjacent to the catch cap.

7.3. Results

An East Coast catch cap of 200t was identified as the highest level of catch (to the nearest 5t) that met the reference points. Fig. 7.2 shows how the total biomass increases with the cap in place and the required level of 20% virgin biomass is achieved by the target year of 2021. The proportional increase for large lobsters under an East Coast cap is much greater as relatively few lobsters grow to this size under current management rules. This is illustrated in Table 7.1, where the total biomass of large lobsters is expected to be ten times higher in 2021 with the East Coast cap than without.

CPUE is anticipated to increase substantially throughout the state due to the recent TACC reduction (Fig. 7.3). The East Coast cap exaggerates this change in sub-zones 1, 2 and 3 with dramatic increases expected, whilst reducing the rate of CPUE increase elsewhere.

The additional pressure placed on the rest of the fishery as a result of the East Coast catch cap indicates that a TACC reduction may be necessary to achieve targets in other areas and for overall profitability. Table 7.2 shows the economic value of the fishery with and without an East Coast cap and with and without a 5kg / unit (4.7%) reduction in the TACC. This shows that the introduction of an East Coast cap combined with a 100kg/unit TACC provides very similar net present value ($386 million; see Table 7.2) to a 105kg/unit TAC applied without an East Coast cap ($389 million). At the same time, it provides substantial increases in the legal biomass and total biomass by 2021. These increases also provide economic benefits not considered here including:

- Reduction in inter-annual variation of catch rates and fisher's profitability
- Improved ecosystem function including predation of invasive *Centrostephanus* urchin with the potential to decrease the extent of kelp barren formation (a substantial emerging problem on the East Coast)
- Increased catch rates and fisher satisfaction in the recreational sector
- Industry resilience to price increases such as fuel shocks through the increased catch rates

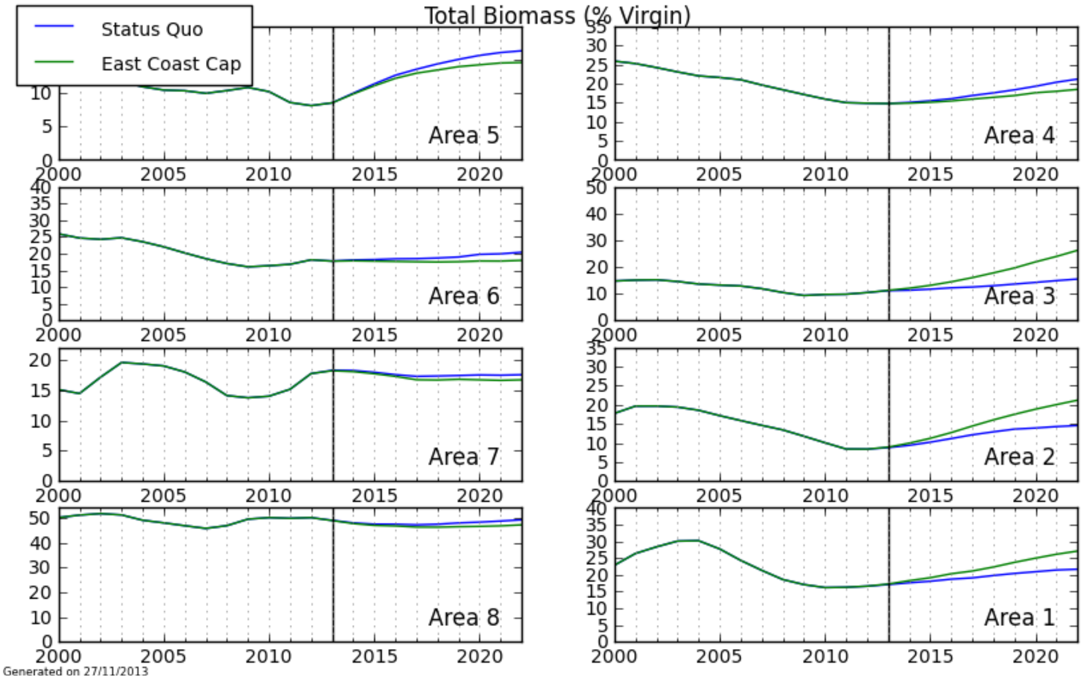


Figure 7.2. Biomass as a percentage of the virgin biomass for each of the stock assessment areas with and without the East Coast cap in place. The capped areas (Areas 1, 2 and 3) experience an additional increase in biomass with the East Coast cap in place, whilst other areas are negatively impacted due to the additional pressure placed on them.

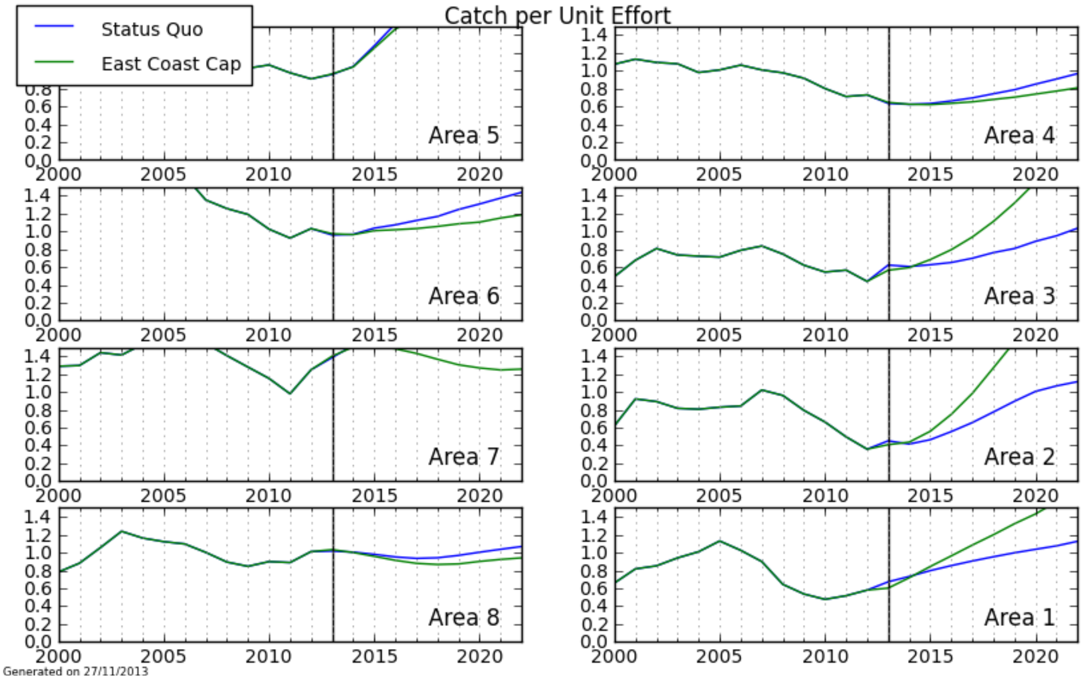


Figure 7.3. CPUE (kg/potlift) for each of the stock assessment areas with and without the East Coast cap in place.

Table 7.1. Large (>145mm carapace length) lobster biomass on the East Coast under three management regimes – no fishing, a 200t catch cap and no catch cap. Biomass is shown in 2012 and 2021 for the East Coast in its entirety and for each of the areas individually.

	Large Lobsters (>145mm; t)							
	East Coast		Area 1		Area 2		Area 3	
	2012	2021	2012	2021	2012	2021	2012	2021
Cease Fishing	26	728	1.6	141	3.3	258	21	329
Cap	26	252	1.6	37	3.3	70	21	145
No Cap	26	72	1.6	10	3.3	15	21	46

Table 7.2. Total biomass as a percentage of the virgin level and fishery net present value (NPV; millions $) for combinations of catch caps and TACCs. The biomass levels are the 70th percentile of the distribution. For example in Area 2, with a 200t cap and 100kg TACC the model predicts that the biomass will exceed 20% of the unfished level with 70% probability.

			Virgin biomass (% in 2021)			
200t Cap	TACC (kg/unit)	NPV (millions $)	Area 1	Area 2	Area 3	Area 4
Yes	100	386	26	20	24	20
No	105	389	21	14	15	20
Yes	105	369	26	20	24	18
No	100	394	22	15	16	22

7.4. Discussion

Catches on the East Coast of Tasmania are presently at low levels due to record low catch rates and the recent reduction of the TACC from 1,524t to 1,103t. Consequently a catch cap of 200t, which is close to the current catch is sufficient to achieve the required target virgin biomass percentage of 20%. The catch cap achieves this target by ensuring that catches do not return to the East Coast as the expected CPUE increases (see Fig. 7.3) occur.

The East Coast is expected to rebuild to healthier levels faster than the rest of the state with the catch cap in place. The East Coast will have higher CPUE than most other areas from the late 2010s onwards. Consequently, maintaining the catch cap puts greater pressure on the rest of the resource. Unsurprisingly, it becomes necessary to reduce the statewide TACC if the catch cap is in place to meet the standard statewide reference points.

The East Coast cap combined with a TACC revision results in a negligible 0.08% decrease in the value of the fishery, whilst providing substantial increases in total biomass of approximately 40% and increasing large lobster biomass ten-fold in 2021 relative to managing the fishery without a cap.

A major challenge facing the East Coast cap is that a limit has been set for recreational and commercial fisheries combined. It is anticipated that recreational catches will increase substantially as CPUE nearly doubles over the next five years. This increase will result from both increased success rates and increased participation as the recreational fishing community becomes aware of the recovering stock. The recreational sector currently takes about 50t in the 200t area. As this increases substantial recreational rule revisions or a reduction in the commercial catch on the east coast will be required to maintain the total catch at 200t.

7.5. References

Ling, S.D., and Johnson, C.R. 2012. Marine reserves reduce risk of climate-driven phase shift by reinstating size- and habitat-specific trophic interactions. Ecological Applications 22(4): 1232-1245.

Ling, S.D., Johnson, C.R., Frusher, S.D., Ridgway, K.R. 2009. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proceedings of the National Academy of Sciences of the United States of America 106(52): 22341-22345.

8. Four lobster fishery management policies: minimum and maximum size limits, constant quota, and a yearly quota-setting harvest control rule targeting constant exploitation rate for the South Australian Southern Zone

Richard McGarvey, André E. Punt, Caleb Gardner, John Feenstra, Klaas Hartmann, Eriko Hoshino, Paul Burch, Stacey Paterson, Janet M. Matthews, Adrian Linnane, Lisa Rippin and Julian Morison

8.1. Introduction

Upon completing the extension of the bioeconomic projection model for use with the South Australian lobster fishery under this project, four broadly different ways to manage the South Australian Southern Zone rock lobster fishery (SZRLF) were tested. This Southern Rock Lobster fishery with the single average largest catch among the three states, the SZRLF currently has catch rates and total catches that are the lowest on record. Recruitment has been low in recent years. Exploitation rates remain high, around 50% per year.

The goal of this chapter's use of the bioeconomic projection model was to see if any general 'rules of thumb' could be identified about how best, and in particular, how most profitably, to manage this renewable resource. If model comparisons could identify management approaches that were, as a class, significantly worse or better overall, that would provide useful guidance to managers and industry about what directions to pursue in enhancing the long-term economic outcomes for this fishery.

The success or failure of fishery management can be assessed by a range of policy outcomes. But both at the outset of fishery science (Gordon 1954; Schaefer 1954) and increasingly in recent years, notably for AFMA-managed fisheries (http://www.afma.gov.au/about-us/functions-and-powers/), including the Northern Prawn Fishery (Dichmont et al. 2010), and for Western Australian lobster, the ability to produce a fishing industry which generates a healthy profit is being recognised as a fundamental objective. Other objectives include enhanced reproductive output (egg production), greater volumes of seafood production (catch), and greater cash flow for regional communities (revenue). Here we employ the ROCK lobster fishery management projection model to test four common fishery management policies: minimum size, maximum size, fixed levels of quota, and a quota set yearly to achieve approximately constant exploitation rate.

Focusing on the economic outcome of profit can help resolve the trade-off between higher quotas (thus higher catch and revenues) in the short term and strategies of lower exploitation rate with the goal of greater catch rates in the longer term. A sustainability objective favours greater biomass which spawns more egg production. However, fishery economics can also favour greater biomass because it permits higher catch rates. Lower catch rates mean less fishing effort, and so lower costs, are expended to take any given catch or quota. In general, net profit can be achieved by either increasing catch (higher revenue) or reducing levels of effort (reducing variable costs). By identifying management policies that optimise average longer term profit, it is plausible to resolve the trade-offs of revenue versus fishing cost, and of sustainability versus catch, in a single measure that fishermen can relate to. Ultimately we seek management strategies that optimise economic return to the fishing industry while also increasing sustainability. These two objectives can potentially be achieved by increasing stock abundance: higher catch rates increase profit by reducing the effort needed to take the quota; and higher abundance means higher egg production. Profit, quantified here by the 20-year future projected net present value, will be a principal performance measure of the fishery management policies evaluated.

In this chapter, we use ROCK, the SZRLF bioeconomic projection model to test these four general ways to manage a fish stock. The SZRLF harvests about AU$70 million of lobsters annually and exports the majority to Asia. The fishery is limited access and has been under individual quota since 1993.

8.2. Methods

8.2.1. Four Management Policies Tested

By ‘policies’ we refer to broadly different categories of regulatory control that are commonly used to manage fish stocks. Four policies are investigated: (1) minimum and (2) maximum size limits, below or above which lobsters are returned to the sea, (3) constant fixed quotas, and (4) quotas that vary under a harvest control rule that seeks a constant exploitation rate.

Three specific ‘strategies’ are tested under each policy. Specific strategies under the minimum legal size (MLS) policy were minimum sizes of 93.5 mm, 98.5 mm (the current regulation) and 103.5 mm carapace length (CL). The three strategies under the maximum-size-limit policy were maximum sizes of 175 mm, 160 mm and 145 mm. Constant quotas were set at test levels of 1,250 t (the current quota for the SZRLF, the lowest it has been since quota was implemented), 1,400 t, and 1,550 t.

The fourth policy was a harvest control rule (HCR) seeking a constant exploitation rate. Quota in each season was set in direct proportion to the previous fishing season’s catch per unit effort (CPUE). This assumes that catch rate is a good measure of relative biomass. This is a good approximation for this lobster fishery, where 1.5 million pot lifts are set yearly across limestone reef which is relatively even and accessible. Biomass is inferred from catch rate by the regression shown in Fig. 8.1. Using the harvest rule, three levels of exploitation rate were tested, 30%, 40% and 50%, meaning the total allowable commercial catch (TACC) was set yearly to take a catch that was 30%, 40% or 50% of the mean biomass from the previous season. The mathematics of this ‘pure linear’ HCR are given by Punt et al. (2011).

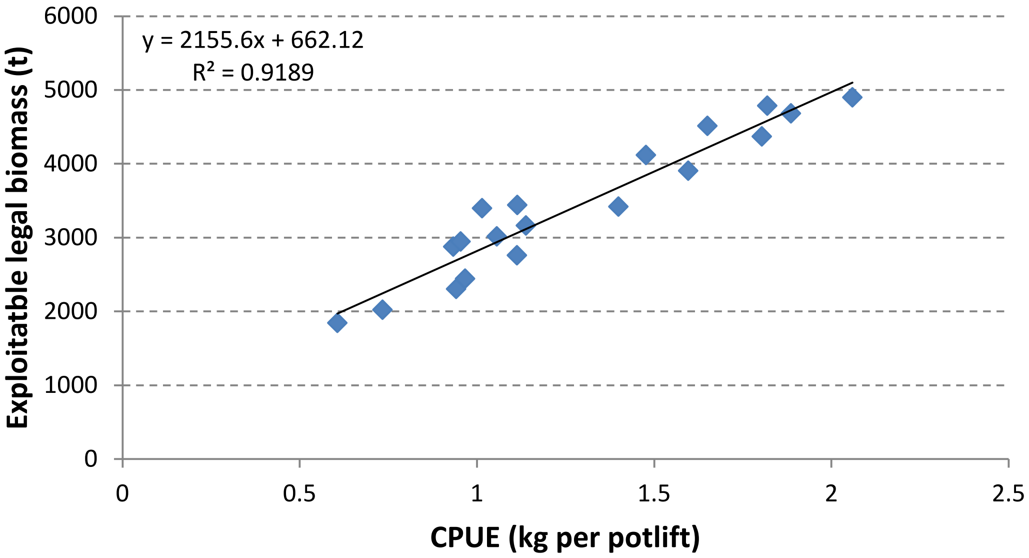


Figure 8.1. Regression fit of ROCK estimation model (1993-2011) legal (available) year-average biomass estimates to yearly average CPUE for the SZRLF.

This regression outcome was used in the HCR algorithm to convert CPUE in each season to estimated legal-size biomass. From this, the quota (as 30%, 40% or 50% of biomass) is specified as the next fishing season's TACC.

8.2.2. ROCK Projection Model

The ROCK lobster management strategy projection model in Chapter 4 has been under development for a number of years, initially for application to Tasmanian rock lobster (Green et al. 2012). The projection model, written in FORTRAN, was further developed and adapted for use in the two South Australian fishery zones under this project. The projection model (whose mathematical specifications are given in Appendix 3, with a User Manual given in Appendix 4), can be used to run simulations testing the performance of a wide range of strategies for managing these lobster fisheries. The underlying dynamics describing how the fisheries respond to varying levels of catch, effort, different size limits, or time closures, is based on a well developed length-based stock assessment estimation model (Punt et al. 1997; McGarvey et al. 2010). Estimation model equations (Appendix 1), and all estimated model parameters (Appendix 1; Appendix 2D) were inferred from fitting the estimation model by maximum likelihood to three principal data sources: (1) commercial and recreational catch and effort data, including monthly total catches by both weight and by number of lobsters landed, and monthly potlifts set, (2) tag recoveries for estimating growth transition matrices (McGarvey and Feenstra 2001), and (3) sampled catch length-frequencies and sex proportions from thousands of commercial fishery potlifts, which includes undersize and spawning lobsters that are returned to the water.

The variable fishing costs per potlift, and the fixed costs per year for the whole SZRLF were estimated using EconSearch interview survey data (Chapter 2). Landed price per kg of lobster, by month and size grade, was summarised in Chapter 3.

8.2.3. Projection method: Recruitment and catch rate variation

It is necessary to forecast 20 years of recruitment to project fishery dynamics 20 years forward in time, and thus predict the effects of different management strategies. In these simulations, recruitment is forecasted by a simple random sample of estimated historical recruitment values. Specifically, we sampled from yearly SZRLF recruitment estimates, outputted by the estimation model, from the years since quota was implemented (1993 to 2010).

In addition, the projection model imposes yearly variation in CPUE, reflecting the assumption that CPUE is a less than perfect index of yearly change in stock biomass. The estimated historical level of deviation between the model predicted CPUE and actual monthly CPUE (the sigma of residuals) over the years since quota was implemented was used to stochastically randomise the future monthly CPUE values, yielding a variation, though smaller, in the yearly CPUE indicator employed in the HCR used for yearly quota setting under the 4th policy tested.

Once yearly recruitment is specified, the projection model projects forward to compute the expected outcomes for selected fishery performance indicators. Multiple test runs of each strategy are obtained by repeatedly sampling for possible future recruitments (and CPUE variation), yielding multiple possible future outcomes of how the fishery evolves over the next 20 years for each strategy tested. Averages by year, and for all 20 years combined, of these multiple future runs are taken to obtain mean expected outcomes under each strategy, and to quantify expected levels of possible variation in future outcomes.

The choice of which years of recruitment to sample from, and more generally what mean level of future recruitment is assumed, can have an important influence on the assessed outcome of management strategy performance comparisons.

8.2.4. Effort Levels for (non-quota) size limit strategies

Catch limits were not imposed with the two pure size-limit policies. Monthly fishing effort was fixed for these policies based on historical levels of effort in years when quota was not reached. For the SZRLF, this occurred in three successive seasons: 2007/08, 2008/09, 2009/10. The average number of potlift numbers set each month over those three fishing seasons were computed. Those average monthly effort levels were assumed for all 20 future projection years, under the minimum and maximum-size-limit strategies.

8.2.5. Model Outputs

Net present value (NPV), as the measure of fishery profitability, will play a principal role as performance measures for each strategy. It is computed as a weighted sum over the future 20 years of each fishery model projection run. We employed a discount rate (r_d) which equalled the (Dec 2012 – Mar 2013) Reserve Bank of Australia cash rate of 3.0%.

$$NPV = \sum_{y=2012}^{2031} \frac{1}{\left(1+r_d\right)^{y-2012}} \cdot Profit_y \, .$$

Model outputs are presented in three stages: First we present profitability, as NPV. NPV will primarily determine which strategies are most successful.

However, in addition to NPV, we consider egg production, total catch, and the year-to-year stability in catch to be principal indicators of fishery performance, since higher egg production, catch (and thus total gross revenue) and a more stable year-to-year variation in catch are additional objectives of fishery management for these lobster stocks.

It would be unrealistic to expect to find a single management strategy that achieved the best outcome for all four of these indicators, so we will plot 20-year time averages of these performance measures against each other in ‘management scatterplots’, seeking the best trade-offs in performance among these quantifiers of success.

Finally, we present yearly time series for 12 important variables, including recruitment, catch rate, variable costs, and yearly profit to interpret these outcomes. These values are presented in two figures, one for biological performance indicators, and another for economic performance indicators. To simplify these 12 time series graphs, we plot only five strategies in each, the baseline strategy and one strategy from each of the four policies.

The baseline strategy, against which other strategies are compared, is the same as the minimum-size-limit strategy, with the size limit set at the current SZRLF MLS of 98.5 mm CL. Recall that for all size-limit strategies, no quota applies, and catch is limited only by a fixed monthly effort which was the historical mean effort by month in years when quota was not reached.

8.3. Results

The profitability for these four policies showed clear winners and losers in bioeconomic model outputs. The three strategies under each policy tested formed groups. There was little overlap between policies in profitability of the grouped strategies of each policy, permitting us to rank each policy in profitability performance achieved. Below we consider the results for each policy in turn.

The principal results are summarised by the average profitability achieved for each strategy quantified by 20-year projected NPV (Fig. 8.2). In Figs. 8.2 to 8.5, for clarity, we present fishery outcomes for the same specific random sample of 20-year forecasted recruitment (Fig. 8.4a) for each strategy tested. In Fig. 8.6, we examine the sensitivity of the NPV outcomes among the 12 strategies tested by assuming 3 different mean level of recruitment, the middle level being the baseline (historical sampled level). We ran multiple (100) 20-year projection runs for each strategy for this recruitment scenario sensitivity testing, by sampling 100 recruitment time series.

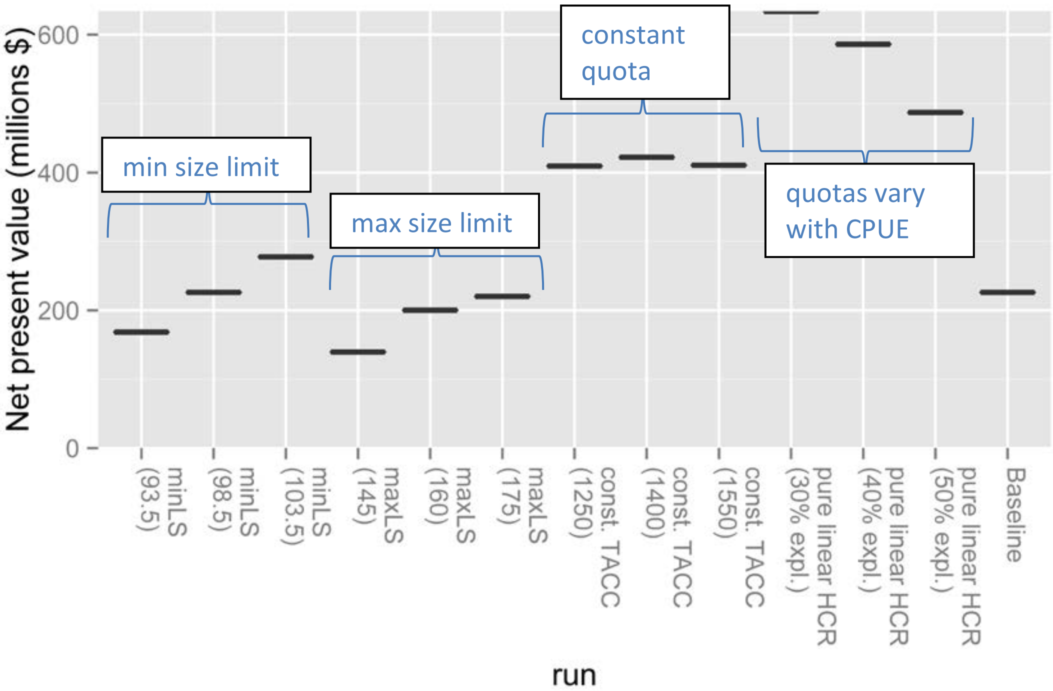


Figure 8.2. Net present value of 12 strategies for managing the SZRLF. Each level represents average yearly discounted profit (NPV) across 20 projection years. Three specific strategies were tested for each of the four management policies evaluated. The four policies are minimum size limits, maximum size limits, constant TACCs set fixed for all 20 future years, and a pure linear harvest control rule (HCR) which seeks constant exploitation rate by dynamically setting each year's catch quota (TACC) in proportion to the previous fishing season's CPUE.

8.3.1. Maximum Size Limits

The three maximum size-limit strategies performed poorly compared with the other strategies tested. Lobsters above a designated maximum size limit are returned to the water and release mortality was assumed to be zero. NPVs for the three maximum size strategies tested (Fig. 8.2, 'max LS' strategies) were all lower than for the baseline strategy.

A maximum size of 175 mm CL (Fig. 8.2, 'maxLS (175)') had little impact, the model predicting an NPV nearly equal to baseline. Tighter maximum sizes of 160 and 145 mm CL led to reductions in future profit. Economic returns are thus consistently reduced under this policy, since large lobsters are returned to the sea with no chance they can be recaptured later. In addition, average egg production was not higher than the baseline when there is a maximum size limit (Fig. 8.3a, ochre diamond marker strategies). Mature females grow much more slowly than males, and rarely reach these maximum sizes, so larger females are not protected by these maximum size limits and negligible enhancement of egg production was achieved (Fig. 8.3a).

8.3.2. Minimum Size Limits

Unlike maximum size, a 5 mm increase, from the current MLS of 98.5 to 103.5 mm CL, is projected to lead to a measurable improvement in profitability (Fig. 8.2, 'minLS (103.5)' versus 'minLS (98.5)'). Examining Fig. 8.3a, along the x-axis, the minimum size strategy of 103.5 mm (red box) is predicted to lead to a 3% increase in average catch compared to baseline.

Given that recruitment is identical for all strategies, the higher average catch for a 103.5 mm MLS compared to the baseline is a reflection of a yield-per-recruit effect. All male lobsters, and some (still immature) female lobsters are growing rapidly in the size range 98.5-103.5 mm CL. When lobsters of these sizes are thrown back, they grow, generally achieving one additional moult, which increases the average landed weight of each recruit. This model-simulated increase in mean weight of an average individual lobster landed (Fig. 8.4b) implies growth of surviving individuals exceeds the counter-balancing negative effect of losses from the population due to natural mortality. The model-predicted balance of those two processes results in the predicted 7% increase in yearly average landed catch weight (Fig. 8.4e). Gross value of production (GVP, revenue to industry) rises directly proportional to this 7% increase in yearly tonnage of catch landed (Fig. 8.5e). Profit equals revenue minus costs. Since variable costs under all size-limit strategies are the same (with effort as numbers of potlifts fixed to the historical monthly average in years of not reaching quota), total costs are also the same for the 98.5 and 103.5 mm CL minimum sizes. The 7% increase in revenue, once the (same) costs are subtracted away, led to a 20% increase in the percentage difference in average yearly profit (Fig. 8.5f).

It took about 6 years for a higher yield–per–recruit to be fully reflected in yearly industry net returns. Looking at the time series of non-discounted profit (Fig. 8.5f), higher profits for a 103.5 mm MLS compared to the baseline (98.5) are consistently achieved only after 2018. Catches under the higher minimum size are lower than under the baseline for the first three years after the size limit is raised (2012-2014; Fig. 8.4e) which leads to lower profits over these years (Fig. 8.5f). In the intervening years (2015-2018), the yearly catch, revenue and profit time series for the 98.5 and 103.5 mm MLS were roughly the same.

For enhancing sustainability, a higher minimum size allows more spawning prior to harvest, increasing yearly egg production. The 20 future-year average egg production is forecast to rise by about 29% relative to baseline under an increase in minimum size to103.5 mm (brown box of Fig. 8.3a and red time series of Fig. 8.4f).

8.3.3. Constant Quotas

While raising the minimum size limit is estimated to yield a measurable economic and sustainability benefit, larger NPV improvements are achieved by imposing a constant quota of 1,250 t (the current SZRLF TACC), or TACCs of 1,400 t, or 1,550 t. Surprisingly, the three fixed TACCs tested all led to about the same level of profitability (NPV in Fig. 8.2, ‘constant TACC’ strategies), suggesting that these quotas span the local maximum economic yield. The lower TACC of 1,250 t has lower revenues but also commensurately lower fishing costs than those of the 1,400 t or 1550 t TACC scenarios, giving each of these quota strategies a roughly equal difference between revenues and costs, and thus similar profitability.

The constant quota policy led to higher profitability than the size-limit policies. All three constant-quota strategies led to considerably higher average yearly profits (NPVs for ‘constant TACC’ Fig. 8.2) than the six size-limit strategies. Many fewer potlifts are needed to take the catch under the constant 1,400 t TACC strategy (blue line in Fig. 8.5a) than under the minimum and maximum size limits shown in Fig. 8.5a. Fewer yearly potlifts lowers the total costs of fishing (Fig. 8.5a). Lower costs under quota arise because much higher long-term catch rates (Fig. 8.5b, blue line for 1400 t quota) imply that the TACC can be taken with fewer potlifts than under the size-limit strategies, increasing profitability (Figs. 8.2; 8.5f).

The three constant quota strategies also led to large increases in 20-year average egg production compared with the baseline (Fig. 8.3a, blue triangles), being 134%, 83%, and 42% higher for constant TACCs of 1,250 t, 1,400 t, and 1,550 t, respectively, compared with the baseline of (effectively maximum) monthly fishing effort and a 98.5 mm CL MLS.

The indicator which shows a decisive advantage for constant quotas is 'catch stability', which we quantified here as the negative variance of the yearly catches, i.e. $Catch\ stability \equiv \frac{-1}{n_y - 1}\sum_{y=2012}^{2031}(C_y - \bar{C})^2$, where the number of years n_y = 2031-2012+1 = 20. Compared with constant quotas all other strategies have much lower levels of catch stability (Fig. 8.3c). The fishing industry has indicated a clear preference for a more stable year-to-year catch, which improves business planning, including bank financing. Processing/tanking/exporting and international air transport facilities can also be run more efficiently when the yearly supply of exported live lobsters is more stable over time.

8.3.4. Harvest Control Rule for Quota Setting: Targeting Constant Exploitation Rate

The fourth policy tested was a HCR designed to re-set the TACC yearly so as to achieve an (approximately) constant exploitation rate. We assume CPUE is a reliable relative index of stock biomass. Under this HCR, if CPUE rises by 10% compared to the previous year, the quota for the following season is likewise set 10% higher. If CPUE drops by 20%, so also does the next year's TACC. In this way, a constant fraction of available biomass is removed each season, achieving constant exploitation rate (constant harvest fraction). If drawn on a graph of TACC versus biomass, this HCR is summarised by a straight line whose slope equals the exploitation rate, hence the name of this policy as the "pure linear HCR". Variations of this constant exploitation rate policy, including the harvest strategy actually implemented in 2011 for the two South Australian fisheries, are discussed in the next chapter. A linear HCR where the TACC only changes if CPUE moves substantially from its current level, with designated upper and lower bounds of CPUE above or below which the quota re-set, was described and examined by Punt et al. (2011).

The pure linear HCR was the best performer among the four policies evaluated, achieving higher or much higher levels of profitability than the other three policies (Fig. 8.2). Comparing the three strategies under this policy, the highest NPV was obtained with the 30% exploitation rate (Fig. 8.2 'pure linear HCR (30% expl.)'). NPVs for all three pure linear HCR strategies were higher than the constant quota strategies.

In the short term, lowering exploitation rates reduced catches, but not profit. The immediate adoption of 30% or 40% constant-exploitation-rate HCR's (compared with the estimated 2011 level of 51%) leads to immediate catch (and thus effort) reductions. Yearly catch (Fig. 8.4e) and thus also revenue (Fig. 8.5e) underwent sharp short-term reductions from 2011 to the first year the HCR is applied (2012) under the 40% 'pure linear' HCR. However, fishing costs also declined by a similar amount (Fig. 8.5d). With revenues and costs declining by a similar amount, (regular yearly non-discounted) profit (Fig. 8.5f, green line, 2013 onward) declined by less than for the size-limit strategies even in the short term. Lower profit for all strategies in those early projection years (2013-2014) reflects lower recruitment in those years (2011-2013).

20-year average egg production for the three pure linear HCR strategies (Fig. 8.3a) is also higher than for the baseline, being about 62% higher for an exploitation rate of 40%, 103% higher for an exploitation rate of 30%, and 34% higher for an exploitation rate of 50%.

The trade-off between higher egg production and higher catch is displayed in Fig. 8.3a. The more optimal strategies are found in the upper right-hand corner of this management scatterplot because we seek strategies that achieve the best outcome for both of these important indicators; similarly, for the trade-off of higher profit as NPV versus higher total landed catch (Fig. 8.3b). The constant-exploitation-rate HCR's (for all 3 levels of exploitation rate) perform best in these two trade-offs, being better positioned in the upper right-hand corners of these two scatterplots.

However, the constant-exploitation-rate (pure linear HCR) strategies were the worst performers for achieving a more stable year-to-year catch. These were far from the upper right-hand corner in the scatterplot of profit versus catch stability (Fig. 8.3c). This results from the TACC being set yearly under this dynamic policy, requiring yearly adjustments in TACC with changes in yearly CPUE, notably due to yearly variation in recruitment.

8.3.5. Testing the sensitivity of policy profitability performance comparisons under different assumed levels of mean yearly recruitment

The NPV comparison of Fig. 8.2 was generalised in two ways: by running multiple sampled 20-year forecasted recruitment, and by testing three recruitment scenarios. Recruitment time-series were created by randomly sampling the historical estimates directly, and then generating high and low recruitment scenarios by adjusting these same 100 recruitment time series uniformly, increasing all yearly recruitment values by 25% and likewise decreasing all values by 25%.

In broad strokes, the policy comparison outcome was not altered by different recruitment scenarios (Fig. 8.6). The constant exploitation rate strategy was consistently the best performer, leading to higher profitability under all three scenarios (Fig. 8.6a-c).

However, the level of recruitment did influence which strategy among each of the two quota policies was best. Perhaps as expected, lowering recruitment improved the relative profitability, as NPV, of lower quota (Fig. 8.6b, constant TACC), and of lower (constant) exploitation rate (Fig. 8.6b, pure linear HCR). This can be interpreted to reflect the need for lower overall levels of fishery exploitation when recruitment is trending downward (as it has since 2003 in all five Australian Southern Rock Lobster fisheries). In particular, this is consistent with the notion that fewer animals should be removed, overall or as a fraction of what is available when recruitment is lower, to maintain catch rates at levels that permit profitable fishing.

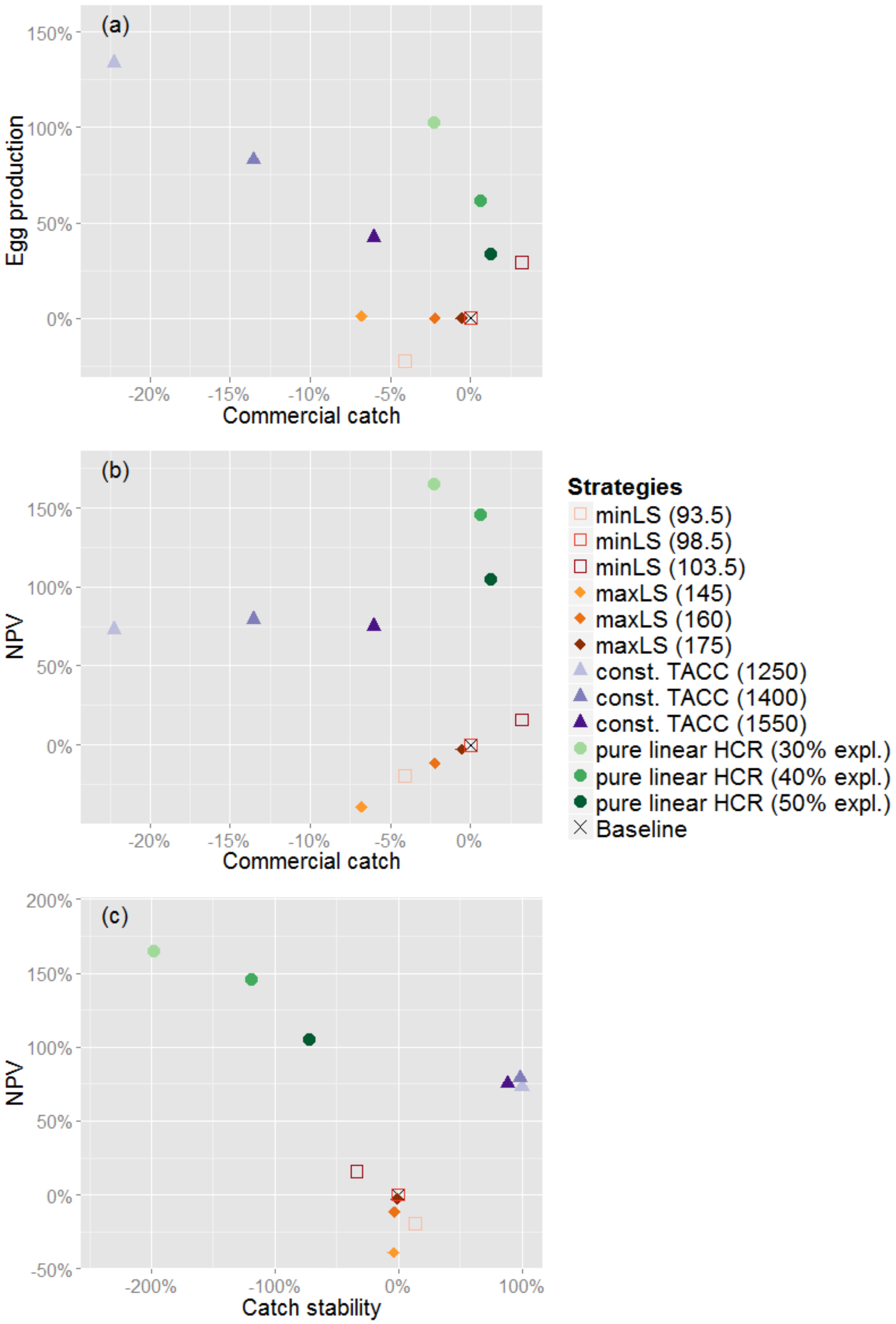


Figure 8.3. Management scatterplots summarise 20-year average outcomes. Each point is a single strategy that was evaluated. The percentages along each axis for each indicator refer to percentage deviations of that strategy relative to the baseline strategy (98.5 mm minimum size, no quota control). The two indicators chosen for each scatterplot graph can involve a trade-off in the search for optimal fishery management: (a) egg production versus commercial catch, (b) profitability (as NPV) versus commercial catch, and (c) NPV versus 'catch stability' (negative variance of commercial catch). For all four indicators plotted, a

higher percentage is the more favourable fishery management outcome: higher egg production, higher catch, higher NPV and higher year-to-year catch stability. Therefore the best performing, more optimal strategies are found as points in the upper right-hand corner of each management scatterplot.

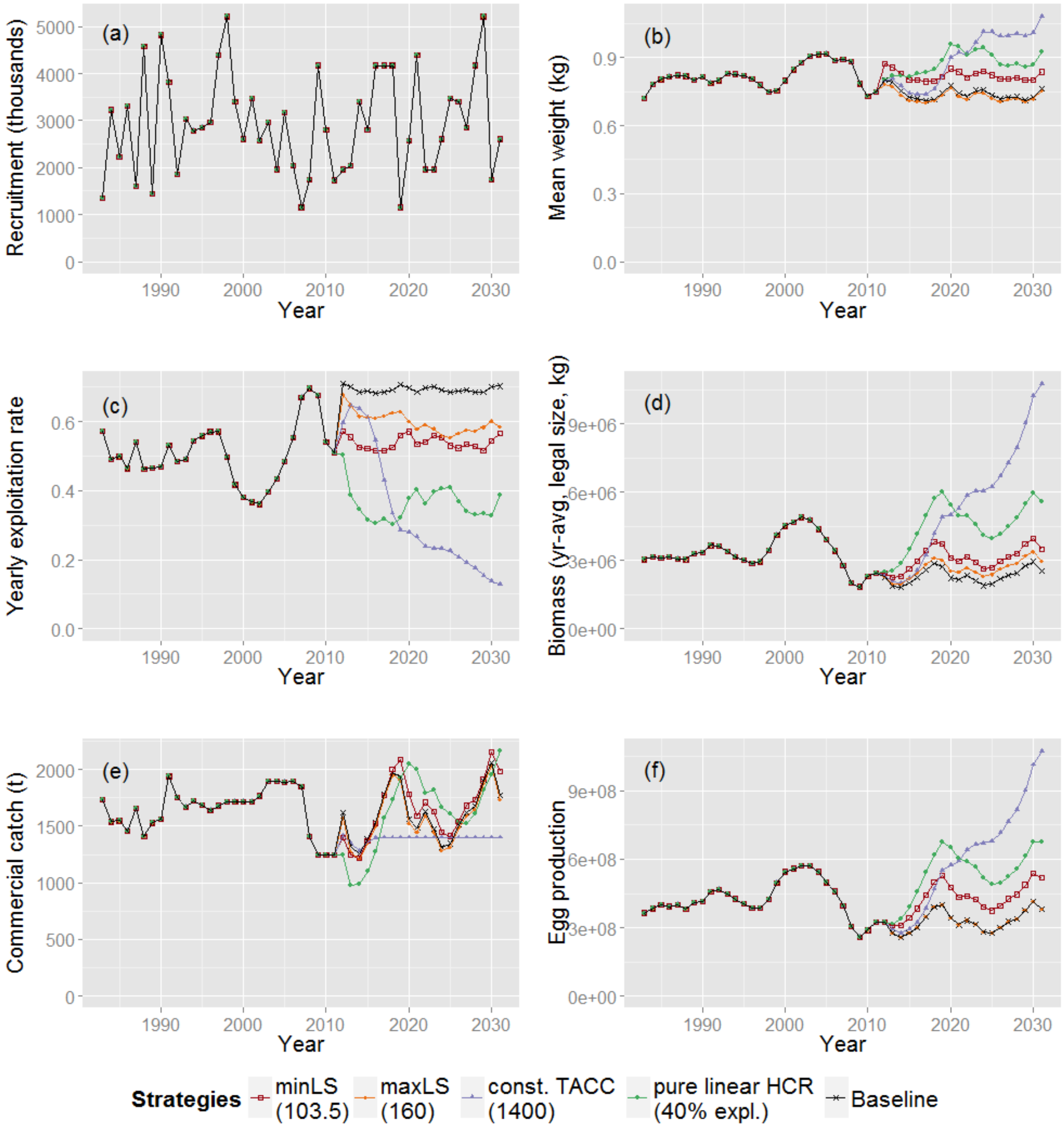


Figure 8.4. Six biological yearly time series model outputs for the SZRLF: (a) recruitment (thousands), (b) mean landed lobster weight (kg), (c) average yearly harvest fraction, (d) year-average legal-size lobster biomass (kg), (e) commercial catch (t), and (f) egg production.

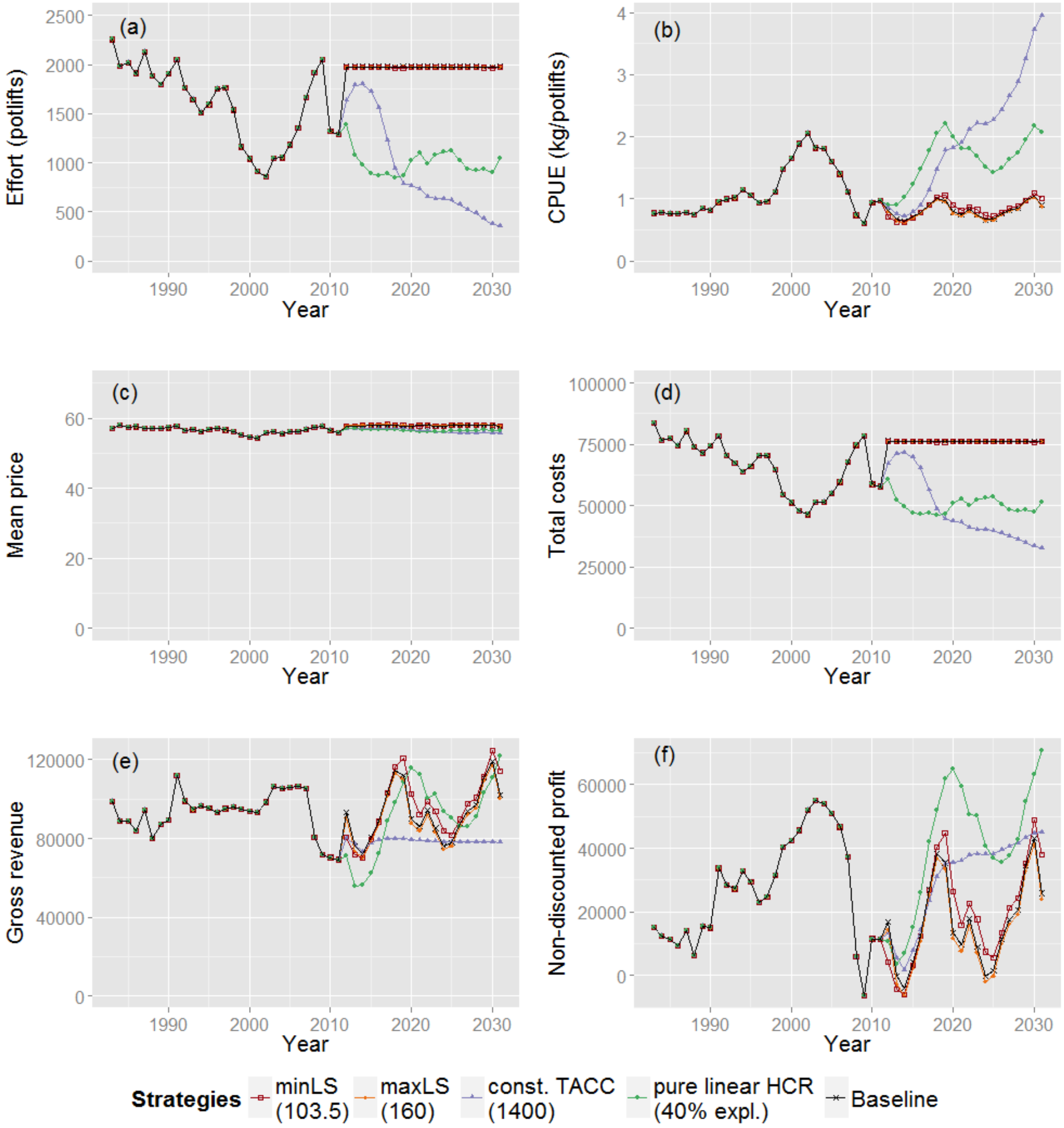


Figure 8.5. Six economic yearly time series model outputs for the SZRLF: (a) effort in yearly potlifts set, (b) catch-per-unit-effort (kg/potlifts), (c) mean price ($), (d) total costs ($thousands), (e) gross revenue ($thousands), and (f) non-discounted industry-total profit ($thousands).

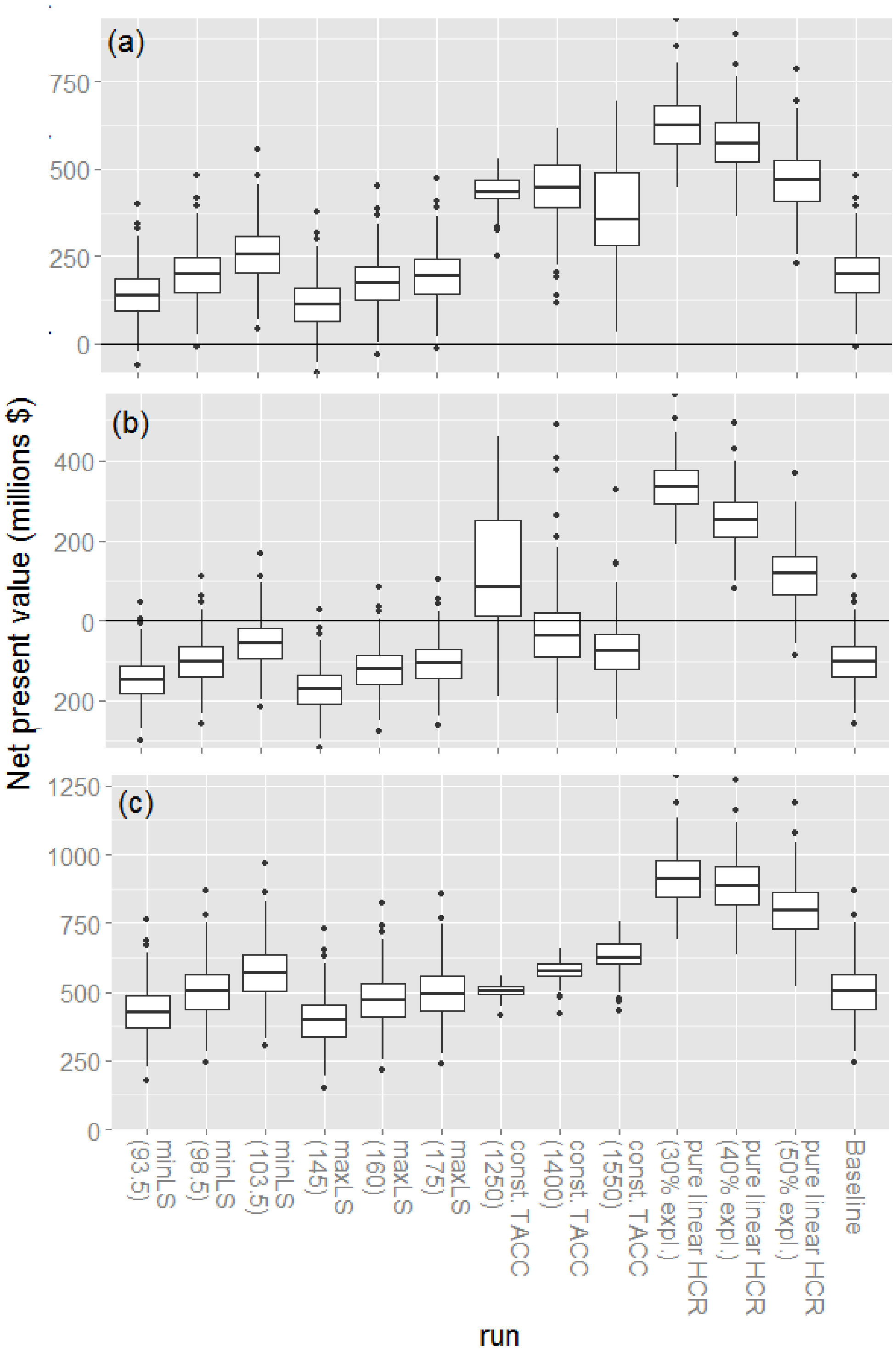


Figure 8.6. Net present value for the SZRLF (average yearly discounted profit across 20 projection years) comparing the four management policies evaluated, with three specific strategies tested for each policy: (a) baseline (i.e. historical recruitment sampled from 1993-2011), (b) recruitment 25% lower than baseline, and (c) recruitment 25% higher than baseline.

8.4. Discussion

The model outcomes showed a clear difference in performance among the four management policies examined.

Maximum size strategies clearly performed worst, and this policy need be considered no further as an option in these *Jasus edwardsii* fisheries. The poor performance of maximum size as a management policy has been observed in other studies, for example for South Australian Snapper (McGarvey 2004). There was negligible enhancement of egg production since females rarely grow to the maximum size limits we examined. However, the landings of larger male lobsters, and so correspondingly revenue, was reduced. Unlike with minimum size limits, lobsters above the maximum size limit will never grow back into a fishable size range.

The outcomes of the minimum size policy differed between the two South Australian zones. The South Australian Northern Zone fishery, with exploitation rates of about 15%, showed no change in outcomes when the minimum size was lowered from 105 to 98.5 mm CL (results not shown). However, NPV and egg production for the Southern Zone fishery which has an exploitation rate of around 50%, was predicted to increase even with a modest 5 mm increase in minimum size. However, the Chinese market favours smaller lobsters in the size range from 98.5 to 103.5 mm CL, sometimes paying a higher price for such lobsters. For this reason, a change to a higher minimum size is not likely to be selected as a high priority strategy in the SZRLF. Nevertheless, raising the minimum size could be reconsidered if enhancing egg production became an important objective, particularly if the change in minimum size was combined with other management actions.

All six output control strategies (constant or dynamically varying quotas) yielded much higher average profits than size-limit strategies.

The most striking outcome from these comparisons was the clear selection of the constant-exploitation-rate policy (compared with size-limit or constant-quota policies). The superior performance of this dynamic decision rule (HCR) for quota setting can provide a general guide for how to better manage the South Australian rock lobster resource. The superior performance of the constant-exploitation-rate policy for three of four indicators (profitability, yearly average catch total, and egg production), with consistently much higher 20-year profits, across a range of potential recruitment levels, and for different possible levels of target exploitation rate, identifies this policy as clearly the best of the four considered.

One surprising outcome was that while catches are markedly lower under the constant-exploitation-rate policies in the shorter term, profits are not lower, even by the first year relative to size limits. Profit was not projected to decline (Fig. 8.5f) even with the imposition of a 30% exploitation rate in the first projection year of 2012, reduced from 51% in the last historically estimated year of 2011, because the savings in reduced fishing costs exceeded or, compared with constant quotas, roughly equalled (Fig. 8.5d and 8.5e), the lower revenue from reduced catch. In the longer term, lower levels of exploitation increase standing stock biomass, raising catch rates. Total catches subsequently rise with higher catch rates, and approximately constant effort as a direct consequence of the constant-exploitation-rate HCR policy. The NPVs (Fig. 8.2 and Fig. 8.5f) and catches (Fig. 8.3b and Fig. 8.4e) were higher under the pure linear constant exploitation rate policy than under constant quotas. The management scatterplots display the favourable trade-off of these two management objectives, identified by the position of the pure linear strategies in the upper right corner ('sweet spot') of the NPV-versus-catch management scatterplot (Fig. 8.3b).

We can assess why the constant-exploitation-rate policy is more economically favourable. Lower fishing costs are part of the reason. A second possible reason is that a constant exploitation rate permits higher catches to be taken when recruitment is favourable. When recruitment is poor and biomass declines, the TACC as a constant proportion of the declining biomass is reduced via the linear HCR. Consequently, this strategy is far more flexible, and direct, in response to the principal source of variation, which is usually that associated with recruitment, in choosing the appropriate level of TACC to set each year.

The principal drawback of this constant exploitation rate policy is the much higher year-to-year variation in catch, quantified by much lower catch stabilities in Fig. 8.3c. Stability is an important management objective, and modifications of this strategy could be proposed to mitigate this high yearly variation in catch. One approach to reducing the yearly variability in the shorter term would be to lower exploitation rates more slowly, rather than all in one year. This would alleviate the large initial-year drop in catch. The large short-term drop in catch is the second principal drawback of the pure linear policy tested here. Bringing in lower exploitation rates over several years would address, at least partly, these two principal drawbacks of this constant exploitation rate policy. This would also reduce concern by industry about the short-term impact of lower TACCs. However, these concerns would also be addressed by the model prediction that profit should not be much affected due to large savings in fishing costs, even in the short term, balancing the reduction in revenue.

Many of these results are specific to the overall higher level of exploitation that characterises the SZRLF, currently above 50% (51% for the 2011/12 season; Linnane et al. 2013a). Nevertheless, dynamic constant-exploitation-rate HCR was still the best policy for the South Australian Northern Zone, with exploitation rates between 14% and 20% (Linnane et al. 2013b).

A management policy which keeps exploitation rate approximately constant is not difficult to implement in practice, as it only requires the catch rate from the previous season. It can, in principle, even be implemented without model estimates of absolute biomass, using CPUE alone. If biomass is not known, this application of the constant-exploitation-rate policy would not be able to specify a target exploitation rate. However, a schedule of TACC versus CPUE could still be chosen by managers and stakeholders, based on chosen target levels of fishing effort, which is all this policy requires to be implemented, as the fishermen did in designing this HCR for the SZRLF (see Chapter 9). Of course modifications, or combination with other regulatory controls such as minimum size, are more common in practice. An HCR using a linear relationship of catch rate in one year to TACC in the next year was implemented in New Zealand lobster fisheries in fishery management zones CRA 8 and CRA 7, and now more recently in CRA 3 (New Zealand National Rock Lobster Management Group 2013).

This general approach, of setting yearly TACCs in rough proportion to the previous year's CPUE, was implemented in the 2011 harvest strategies for both South Australian lobster fisheries (summarised in Linnane et al. 2013a; b). We evaluate the implemented fully-featured 2011 harvest strategies for these two fishery zones in the next chapter of this report, comparing its performance with the best performing policy from this Chapter, namely the pure linear constant-exploitation-rate strategies.

8.5. References

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9. South Australian harvest control rule: Comparing two quota-setting strategies to achieve approximately constant exploitation rate

Richard McGarvey, John Feenstra, André E. Punt, Janet M. Matthews and Paul Burch

9.1. Introduction

In 2011, a new harvest strategy was implemented for South Australian Southern Rock Lobster in the two fishery zones. This plan was developed by industry, initially by Southern Zone fishermen's representatives, including Joel Redman, David Mansur, Simon Peters, Jason Haines and Mark Denton. The crucial element of this strategy, is the quota-setting table of TACC-versus-CPUE (Fig. 9.1). The levels of TACC chosen for each band of CPUE determine the effective exploitation rate that this harvest control rule (HCR) imposes. Fishers chose the levels of quota in this TACC-versus-CPUE table based on a target range of fishing effort, 1.4 to 1.6 million potlifts per year.

The harvest strategy implemented in the two zones had four main features: (1) a table specifying the TACC to be set given CPUE from the previous season (Figs. 9.1; 9.2), (2) a pre-recruit index (PRI) threshold below which the TACC cannot rise in any given year, even when the CPUE has risen sufficiently, (3) a cap on the maximum TACC, where above a given level of catch rate, the TACC rises no further, and (4) a limit reference point (LRP) procedure, which predicates the management response when stock abundance (CPUE) declines to high-risk levels, demarcated by a selected LRP threshold level of CPUE.

In this chapter, we present an evaluation of these South Australian lobster fishery harvest strategies by which TACC has been set yearly since it was implemented in 2011. The details of the four main features differ between the two fishery zones, especially for the LRP procedure, but a similar overall HCR was implemented in each South Australian fishery zone. Chapter 8 compared the economic performance of four broadly-defined policies for managing the Southern Zone. One sensible extension of the relatively definitive results found in the strategy comparisons of Chapter 8 is to compare the best-performing policy of Chapter 8, the pure linear rule version of the constant exploitation rate quota-setting HCR policy, with the actual harvest strategies that were implemented in the two South Australian lobster fishery zones.

The Northern and Southern Zone 2011 harvest strategies are variations on a constant exploitation rate policy. In this chapter, we compare two versions of this policy, the one actually implemented in South Australia lobster fisheries and the 'pure linear' HCR examined in Chapter 8.

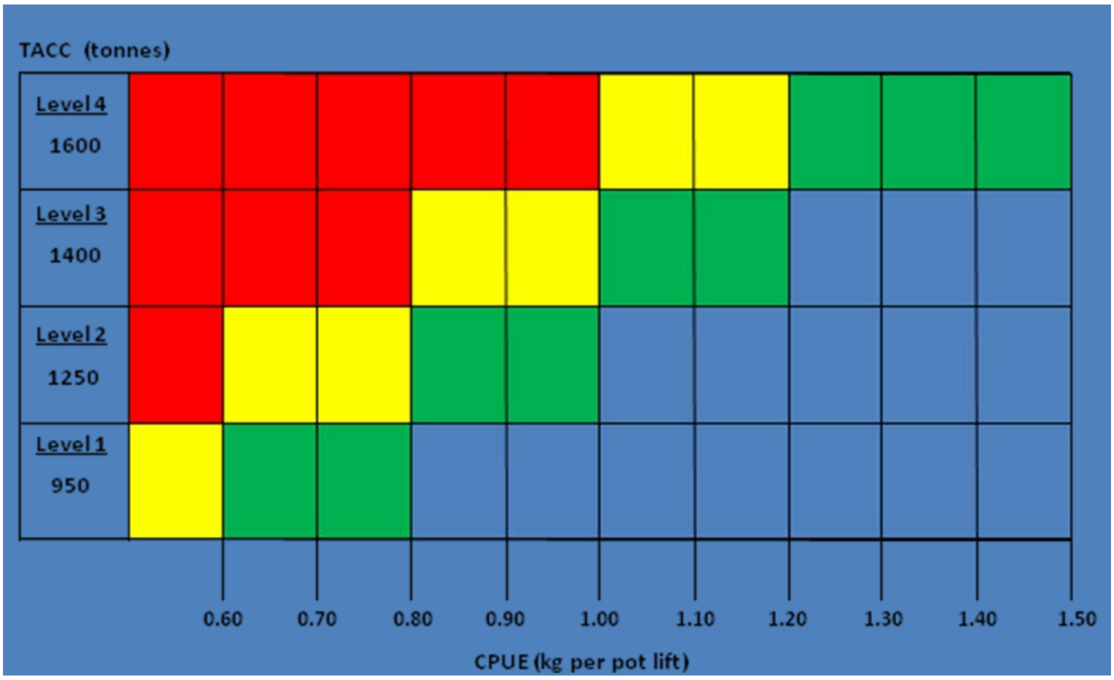
9.2. Methods

The four specific features of the South Australian HCR from the 2011 harvest strategy in each zone (Linnane et al. 2013a; 2013b) were programmed into the bioeconomic projection model. The most important feature, the tables specifying the TACC for the fishing season to come given the previous season's CPUE, are shown in Figs. 9.1 and 9.2 (Linnane et al. 2013a; 2013b):

A second feature of the harvest strategy in both zones requires that the pre-recruit index (PRI) reach a designated minimum threshold before a TACC increase the subsequent season is permitted. The PRI is a yearly measure of the catch rate of undersize lobsters. To model PRI in future years, the historical PRI index data (Linnane et al. 2013a; 2013b) were fitted in the ROCK estimator to the model-predicted undersize catch numbers per potlift, with estimated undersize length selectivity explicit, yielding an estimate of PRI catchability. Model projections used this estimated catchability to project the PRI in future years, given yearly projection model undersize catch numbers.

A third feature of the harvest strategy is the LRP procedure which comes into effect when CPUE declines to levels that signal unsustainably low stock abundance. This was also programmed into the bioeconomic projection model. The LRP procedures in the two zones differ considerably (Linnane et al. 2013a; 2013b).

The fourth South Australian harvest strategy feature is the upper TACC cap, where, with some qualifications in the SZRLF, the TACC would remain at 1,600 t for values of CPUE above 1.2 kg per potlift, and in the NZRLF the TACC remains at 550 t for values of CPUE above 1.3 kg per potlift. This TACC cap can potentially have an important influence on the overall economic and sustainability performance of the South Australian harvest strategies, since catch does not rise, even if CPUE rises above these cap threshold levels of CPUE.



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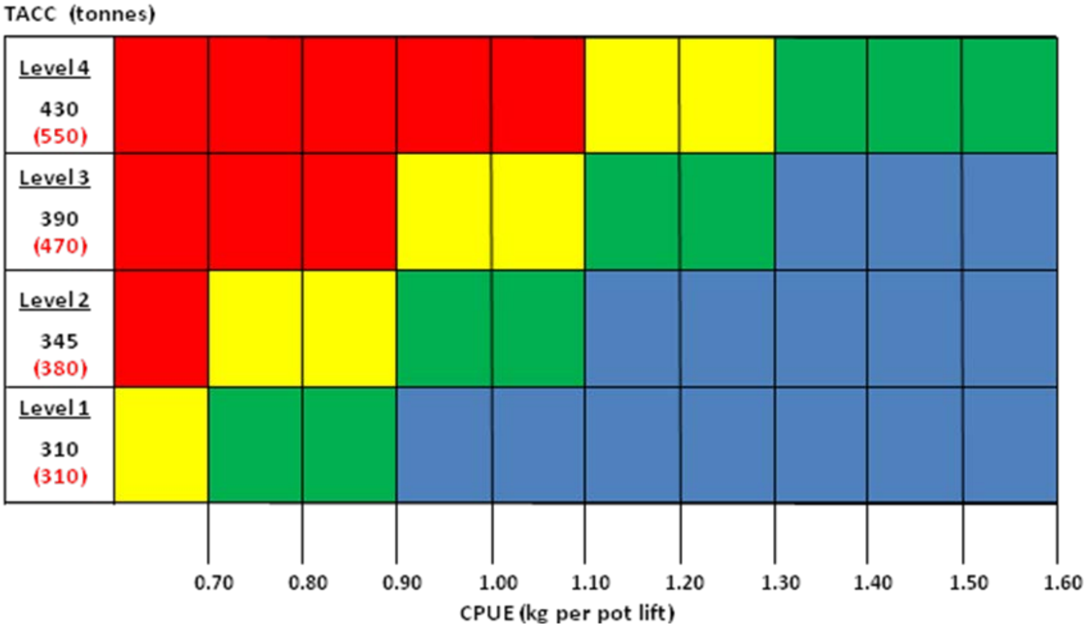
Level 1 950	🟨	🟩	🟩							

Figure 9.1. The TACC-versus-CPUE table from the Southern Zone rock lobster fishery (SZRLF) harvest strategy. For CPUE from any given season (along the horizontal), the next season's TACC is set by the level given by the corresponding green boxes. For CPUE below 0.6 kg per potlift, an LRP sub-rule comes into effect.



Level 4 430 (550)	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩
Level 3 390 (470)	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟦	🟦	🟦
Level 2 345 (380)	🟥	🟨	🟨	🟩	🟩	🟦	🟦	🟦	🟦	🟦
Level 1 310 (310)	🟨	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦

Figure 9.2. The TACC-versus-CPUE table from the Northern Zone rock lobster fishery (NZRLF) harvest strategy (see Fig 9.1 for explanation of TACC decision making process). For CPUE below 0.7 kg per potlift, an LRP sub-rule comes into effect.

9.2.1. Testing for economic performance under assumed lower average recruitment levels

Lower trending recruitment has been observed in all five Southern Rock Lobster fisheries of South Australia, Victoria and Tasmania since about 2003. The results of section 8.3.5. showed that under different assumed mean levels of recruitment, different levels of exploitation rate were economically optimal.

The estimated recruitment levels since 1983 for the SZRLF are shown in Fig. 9.3.

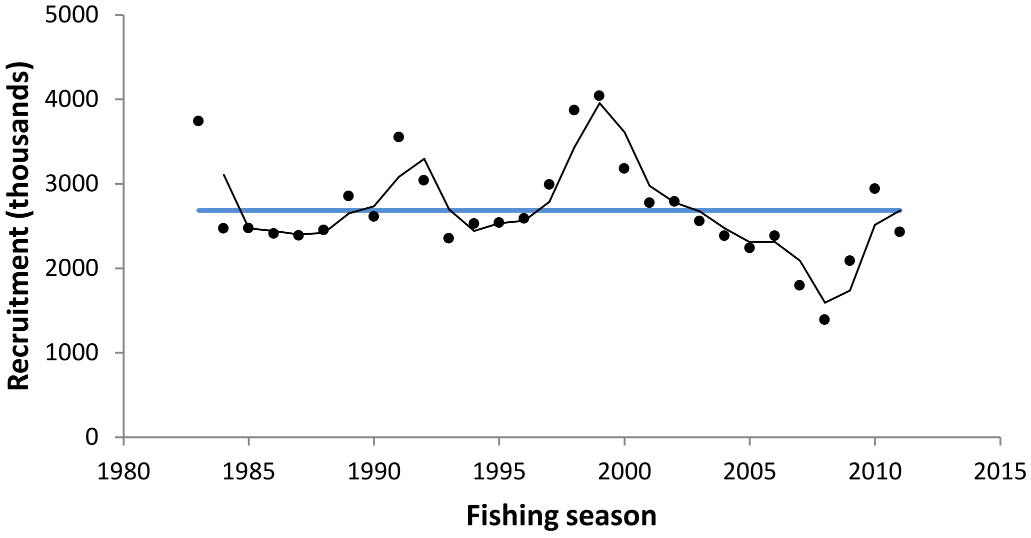


Figure 9.3. Yearly recruitment for the SZRLF, estimated by the ROCK stock assessment model (1983-2011). Mean recruitment over these years is shown by the blue horizontal line. The black line plots the 2-year moving average.

Recruitment is estimated to have been below average for all except one year, since 2003. Several of the lowest recruitment years on record have been recent, notably 2007-2009. This is a major factor in the current all-time low catch rates and TACCs that have characterised the SZRLF in recent years.

In this chapter, we expand the investigation of how lower trending recruitment affects which strategies are optimal, and specifically, which are predicted to yield higher profitability, in the two South Australian zones. We compare the net present value (NPV) outcomes achieved by raising and lowering the levels of TACC by 15% in all CPUE bands of the TACC-versus-CPUE tables for the two current four-feature harvest strategies, under varying recruitment regimes. For both zones, different assumed levels of exploitation rate were tested, quantified by altered levels of TACC, for recruitment set 25% lower than the historical mean levels of previous years.

Information about future recruitment can be obtained from the puerulus settlement index (PSI). If the correlation of lagged PSI with recruitment is sufficiently strong over historical years when the two series overlap, it is more probable that PRI will remain a reasonable forecaster of recruitment in future years. In the NZRLF, the PSI is moderately correlated with model recruitment, providing potential predictive power. Northern Zone puerulus are thought to grow to reach the sizes where cohorts are created in the ROCK model (from 82.5 to 102.5 mm CL) about three years after they settle. The ROCK model estimates recruitment for each cohort as undersize lobsters, about one year prior to them being fully recruited to legal size, where minimum legal size in the NZRLF is 105 mm CL. In the SZRLF, the correlation of PSI with recruitment is not strong.

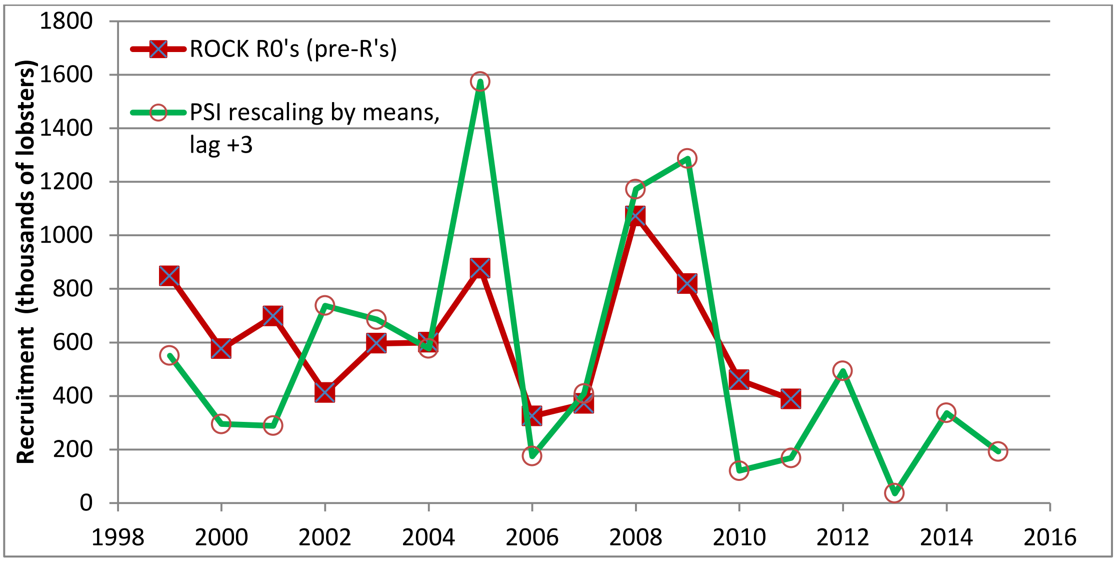


Figure 9.4. The NZRLF puerulus settlement index (PSI), PSI lagged 3 years forward from the year of puerulus settlement to the year when each settled cohort reaches the assumed age of recruitment in the ROCK stock assessment model, 1999-2011 (in green). Estimated ROCK recruitment numbers (defined yearly as a pulse over the lobster size range of 82.5 mm CL – 102.5 mm CL) (in red). The four most recent years of PSI (in green, 2012-2015) are years for which model recruitment is not yet estimated.

The bioeconomic projection model for the NZRLF has been modified to allow recruitment forecasting based on the PSI. We tested two 10-year forecasts based on the PSI. One scenario (Fig. 9.5b) assumed the recent low PSI levels (lagged three years forward to 2012-2015, Fig. 9.4) will persist for another six years, by repeating the four years of 2012-2015 PSI-forecasted recruitment 1.5 times for another six years. A second (less pessimistic) recruitment scenario (Fig. 9.5c) assumed that the next four years of recruitment are forecast by 2012-2015 PSI but that in the subsequent six years recruitment is sampled from the default levels of 2003-2011. The default NZRLF scenario (Fig. 9.5a) is recruitment sampled from 2003-2011 which included the relatively strong peak of ROCK recruitment of 2008 and 2009 (Fig. 9.4).

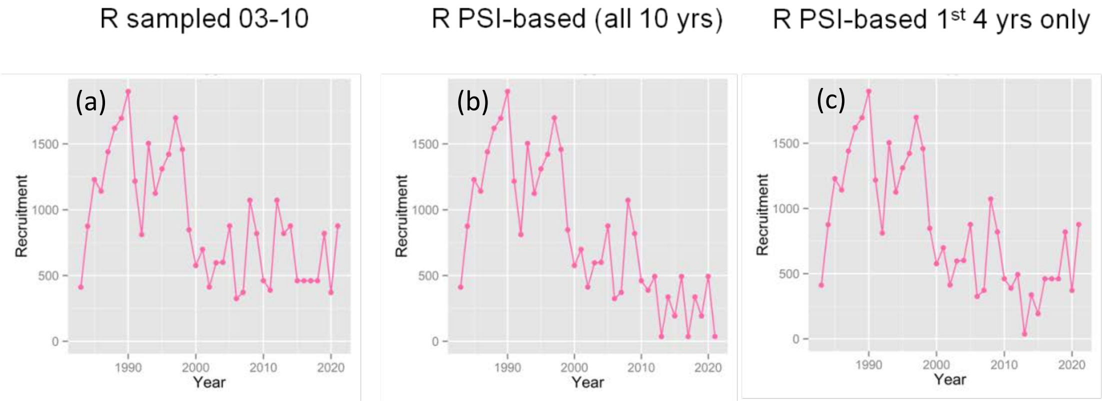


Figure 9.5. Three scenarios of 10-year forecasted recruitment for the NZRLF. See text above.

9.3. Results

The pure linear rule with a 30% exploitation rate performed better than the SZRLF harvest strategy as implemented in 2011 in terms of NPV (Fig. 9.6), with the pure linear rule with a 40% exploitation rate performing next best. However, the SZRLF harvest strategy as implemented also achieved a high NPV (Fig. 9.6). This harvest strategy achieved higher 20-year NPV than the two strategies that used the same HCR but with TACCs increased or decreased by 15% within each CPUE band of the TACC-versus-CPUE table (i.e. with effective exploitation rates increased or decreased by about 15%). This implies that the implemented levels of TACC are approximately optimal under the assumed levels of recruitment for the simulations of Fig. 9.6, namely recruitment sampled uniformly from the years 1993-2011 (Fig. 9.5a).

The SZRLF harvest strategy offers the important additional advantage of more stable catches than the pure linear HCR. Thus the industry-devised HCR strategy performed very well. In particular, the TACCs were very nearly optimal for the historical sampled levels of SZRLF yearly recruitment (1993-2011).

The current implemented HCR is the best performing of all six strategies for the NZRLF, assuming recruitment sampled from 2003-2011, (Fig. 9.7). The pure linear rule with a 20% exploitation rate, the current HCR with all TACCs set 15% lower, and 15% higher, all did nearly as well (Fig. 9.7). The harvest strategies achieved levels of profitability higher than the pure linear rule with a 15% target exploitation rate, and much higher than the pure linear rule with a 10% exploitation rate.

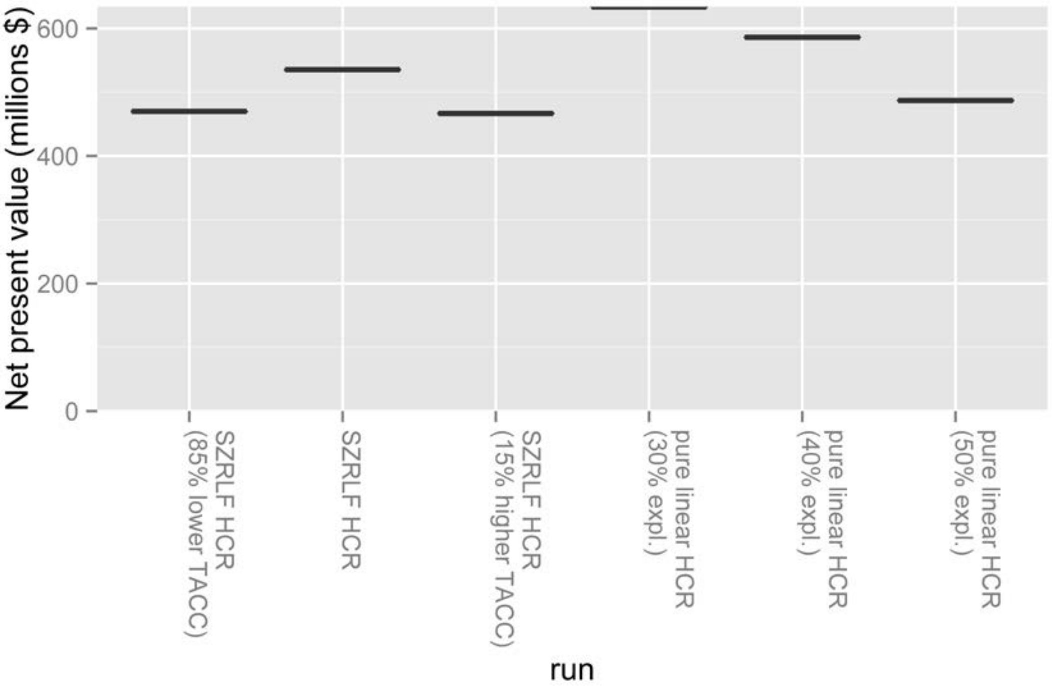


Figure 9.6. Net present value (discounted average profit across a 20-year projection) for the South Australian Southern Zone for the current SZRLF harvest strategy HCR (tested under three TACC levels) and a pure linear rule HCR (tested under three different target exploitation rates).

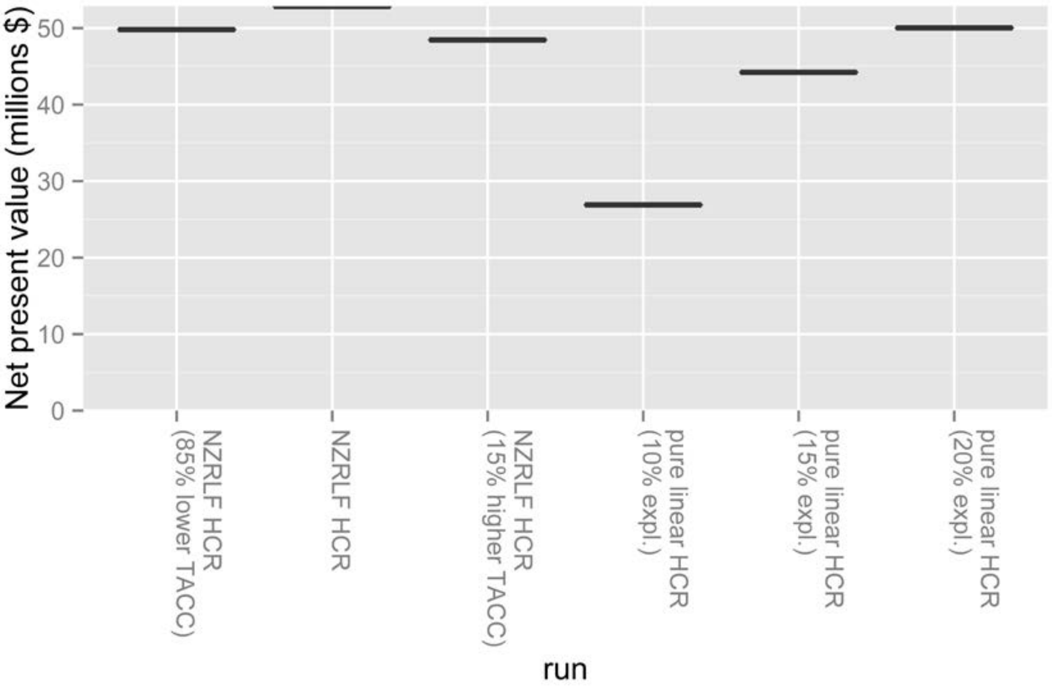


Figure 9.7. Net present value (discounted average profit across a 10-year projection) for the South Australian Northern Zone. for the current NZRLF harvest strategy HCR (tested under three TACC levels) and a pure linear rule HCR (tested under three different target exploitation rates).

9.3.1. Testing economic performance of harvest strategies under assumed lower average recruitment levels

The SZRLF (Fig. 9.8) and the NZRLF (Fig. 9.9) show much higher NPV for strategies with lower exploitation rates when the simulations of Figs. 9.6 and 9.7 are repeated but with recruitment set 25% lower across all years. For the SZRLF HCR's (Fig. 9.8), 20-year NPV's are about 60% higher ($320m versus $200m) for a version of the current SZRLF harvest strategy that sets TACC's 15% lower than those actually implemented in 2011 when recruitment is set 25% lower than the historical average.

The same result is evident for the NZRLF (Fig. 9.9); with recruitment set 25% lower, a reduction in TACC levels by 15% in the 2011 harvest strategy is predicted to lead to better economic performance (Fig. 9.9).

This outcome was also observed when monitored levels of puerulus settlement (Fig. 9.5) were used to forecast recruitment in the NZRLF (Fig. 9.10). As with a uniform 25% reduction of sampled recruitment, 15% lower levels of TACC in the NZRLF HCR are predicted to produce a slightly superior (less negative) profitability outcome using forecasted recruitment based on PSI, either for all ten projected years (Fig. 9.10b), or for only the next four years (Fig. 9.10c). For all PSI-based projections of NZRLF NPV (six strategies shown in Fig. 9.10), overall discounted profit is negative.

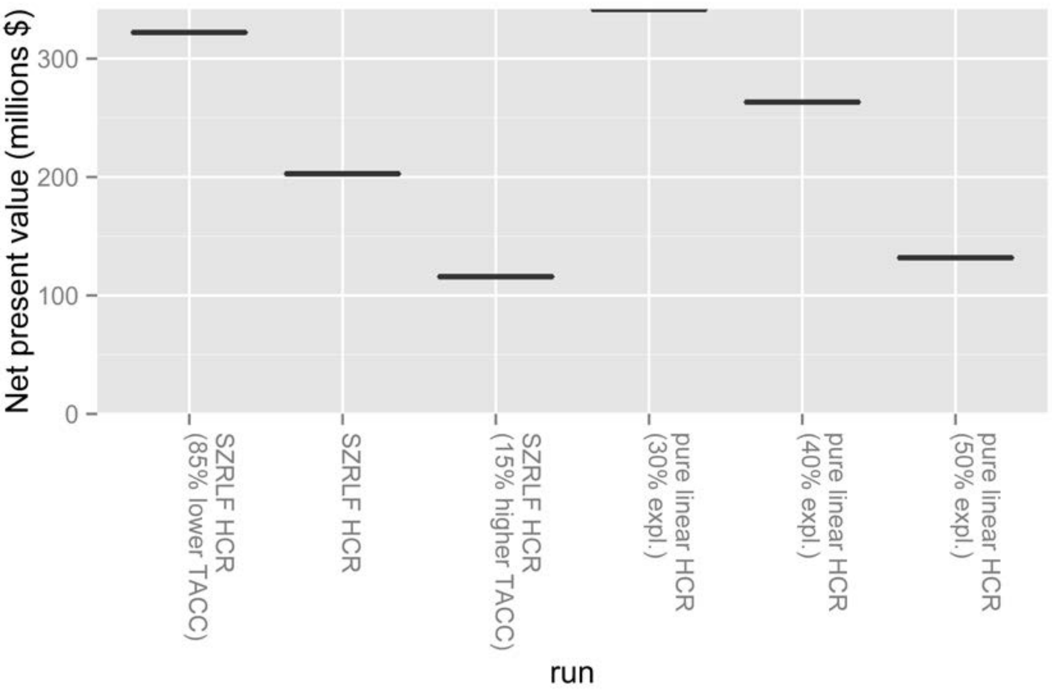


Figure 9.8. SZRLF NPV comparisons assuming 25% lower average recruitment.

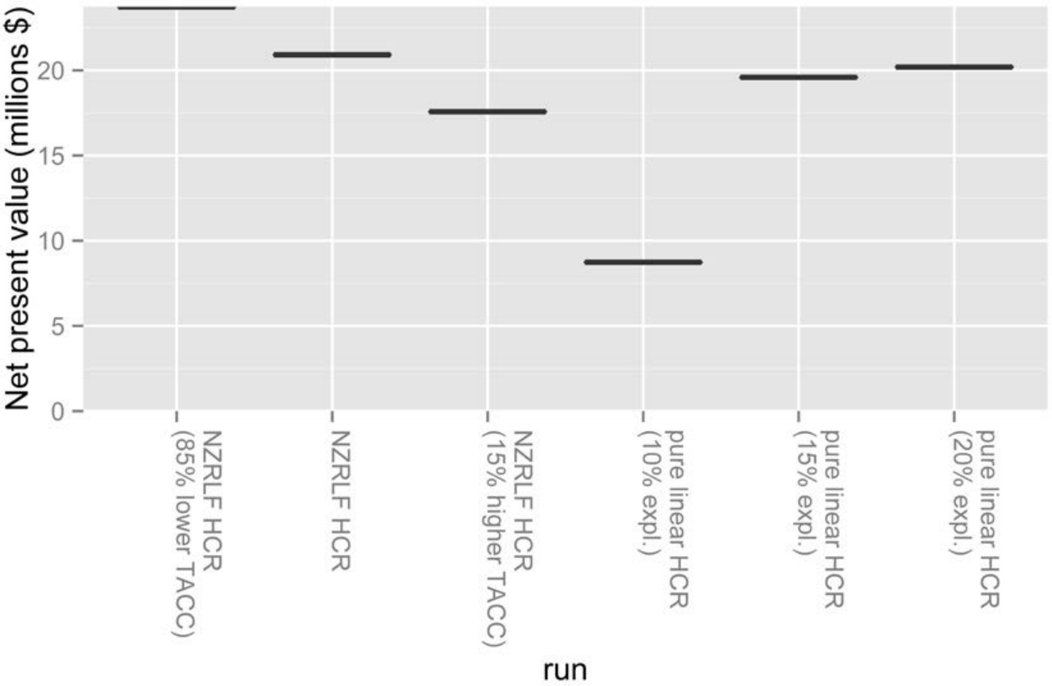


Figure 9.9. NZRLF NPV comparisons assuming 25% lower average recruitment.

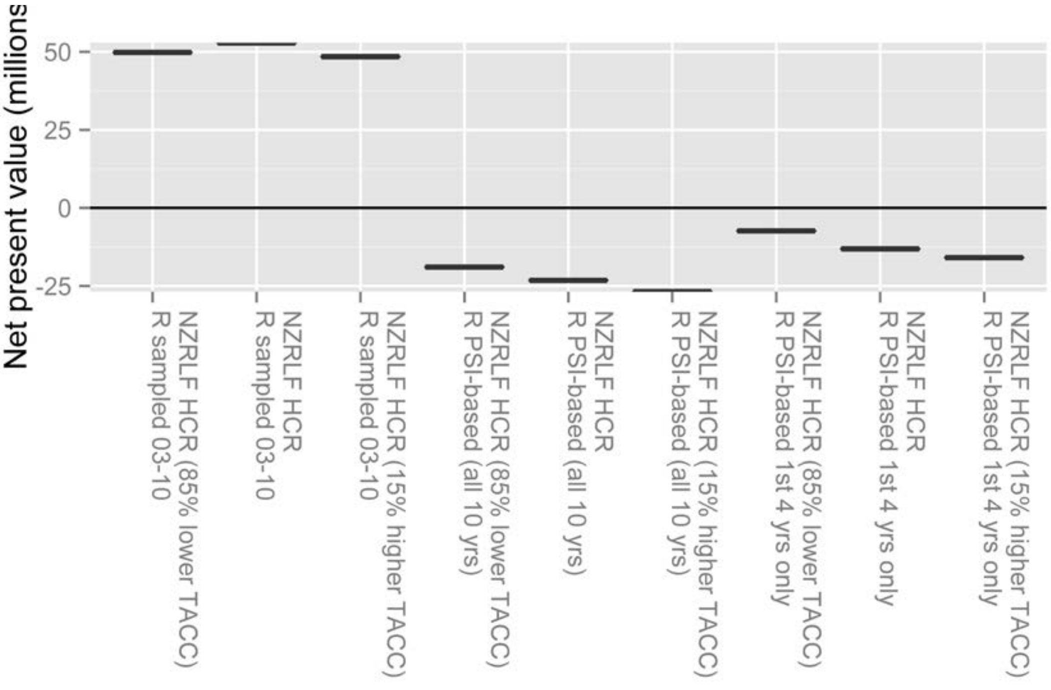


Figure 9.10. NZRLF NPV comparisons assuming PSI-forecasted recruitment. Current 2011 harvest strategy HCR (each under three tested TACC levels) based on three recruitment scenarios: "R sampled 03-10" is the standard recruitment sampling procedure from historical years 2003-2010 (Fig. 9.5a), "R PSI-based (all 10 yrs)" used 4-year PSI (2012-2015) repeated in succession to predict recruitment for all 10 projection years (Fig. 9.5b), and "R PSI-based 1st 4 yrs only" used PSI for the first four projection years and then the standard recruitment sampling procedure was used for the remaining six projection years (Fig. 9.5c).

9.4. Discussion

This chapter sought to identify economically optimal outcomes for the South Australian lobster fisheries. The highest NPVs in both South Australian fishery zones were achieved by the 2011 HCRs as implemented (Figs. 9.5; 9.6). The roughly equally lower NPVs for 15% increases and decreases in TACCs (Figs. 9.5; 9.6) suggests the remarkable outcome that these harvest strategies, as implemented with strong industry guidance, are model projected to approximately achieve MEY under historical levels of recruitment.

However, recruitment in recent years has trended markedly below the historical mean in both South Australian lobster fishery zones, as in other Southern Rock Lobster fisheries of Tasmania and Victoria. For this reason, the management strategy comparisons were re-tested under scenarios of assumed lower-than-average recruitment.

Two principal bioeconomic model outcomes for the management of the two South Australian lobster fisheries were observed:

(1) For both the NZRLF and SZRLF, the harvest strategies implemented in 2011 were found, remarkably, to be very nearly economically optimal. These strategies included the levels of TACC agreed to, and primarily driven by industry, in the TACC-versus-CPUE tables. These 2011 harvest strategies also included a PRI rule, a TACC cap at high CPUE, and an LRP procedure at low CPUE. The current harvest strategies, assuming historical levels of recruitment continue for 20 (SZRLF) and 10 years (NZRLF) into the future, were close to the best pure linear rule strategy, being either slightly lower (SZRLF) or slightly higher (NZRLF). However, the 2011 strategies have the additional advantage over the pure linear rule of considerably greater catch stability.

(2) NPVs were relatively much higher at lower exploitation rates When a scenario of 25% lower recruitment is forecast, and all other factors remain the same, This was true for both the pure linear rule and the 2011 harvest strategies.

For the Northern Zone (only), this model outcome of relatively higher profitability (NPV) for strategies with lower-than-current exploitation rates was also obtained for recruitment forecasted by the only available measurement-based forward indicator of future recruitment, namely the PSI. For the NZRLF, if PSI remains a reliable indicator of average recruitment over the next four years, the bioeconomic model predicts a sharp decline in NPV over the next 10 years, and in particular, forecasts a negative 10-year discounted profit for both PSI-based scenarios tested. This result is inferred from the PSI index showing all-time low levels of puerulus settlement from 2009-2012, which are lobster cohorts reaching ROCK estimation model recruitment in 2012-2015, followed one year later by lower-than-average recruitment to the legal stock in the four Northern Zone fishing seasons of 2013/14 – 2016/17.

A better economic performance for strategies that target a lower effective exploitation rate when yearly supply of new lobsters is reduced is not altogether surprising. One way to explain this outcome is that when recruitment is lower on average, exploitation rate needs to be lower to maintain catch rates high enough to recoup the costs of fishing operations despite a lower supply of new lobsters yearly.

9.5. References

Linnane, A., McGarvey, R., Feenstra, J., and Hawthorne, P. 2013a. Southern Zone Rock Lobster (*Jasus edwardsii*) Fishery 2011/12. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000276-7. SARDI Research Report Series No. 703. 89pp.

Linnane, A., McGarvey, R., Feenstra, J and Hoare, M. 2013b. Northern Zone Rock Lobster (*Jasus edwardsii*) Fishery 2011/12. Fishery assessment report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000320-7. SARDI Research Report Series No. 702. 77pp.

10. Winter fishing

Richard McGarvey, John Feenstra, Paul Burch, Janet M. Matthews, Adrian Linnane, Justin Phillips and Kyriakos Toumazos

10.1. Introduction

One potential way to enhance economic returns to the two lobster fisheries in South Australia is to allow fishing in winter. The Tasmanian lobster fishery has been opened for fishing at varying times, and in recent years this has included many winter fishing months. Currently, the fishing seasons for the two South Australian zones are October-May (SZRLF) and November-May (NZRLF). The principal intended benefit of extending the fishing season into winter is to capture higher prices at this time of lower supply.

At the request of industry members on the South Australian MAC Research Subcommittee (April 2013), we used the bioeconomic model to test the outcomes for a full 12-month open fishing season in the two South Australian lobster zones. Two other changes to the season length were also tested for the Southern Zone.

As in Victoria and Tasmania currently, it was agreed by South Australian industry and fishery managers that no landing of females would be permitted during the open winter fishing season (June-September) because most mature females are egg bearing over winter.

10.2. Methods

There are little or no data in South Australia, on winter fishing since there is no experience of winter fishing for lobster in this state. Initially, we attempted to use Western Zone Victorian estimates for parameters on catchability in winter months when the Victorian fishery is open (through 14 September of each year). However, these parameters appeared to be potentially unrealistic, in particular, suggesting catch rates were double those of normal summer months (for males). Discussions with the Victorian stock assessment scientists (Terry Walker, pers. comm.) confirmed this uncertainty about the realism of Victorian parameter estimates.

Consequently, in the absence of data for South Australia, and uncertainty about Victorian parameter values, we elected to use the average of May and October catchability parameter values in the Southern Zone, and the average of May and November values in the Northern Zone. These values were assumed to be constant through all winter months. We made the same assumptions for prices and fishing costs, using the average of the two nearest months and holding them constant over winter.

In addition to testing whole-of-winter fishing for the Southern Zone, at the request of the research sub-committee, we tested two further changes to the current fishing season: (1) a 7-month fishing season (closing May) and (2) September fishing (males only).

One additional technical modelling adjustment was made. No stochastic variation of catch rate (based on estimated sigmas—see subsection 8.2.4) was included for these winter fishing projections since no estimated sigmas are available for these months.

10.3. Results

We summarise the model outcomes for economic performance (as NPV) under winter fishing in the two zones. As noted, data for winter fishing were absent, and assumptions were made that winter fishing was not different than the average of the first and last months of the regular fishing season, assumptions which must certainly oversimplify the true economic performance of winter fishing in South Australia.

All strategies run assumed the current harvest strategy (Chapter 9) remained in effect for each zone, including quotas set by the TACC-versus-CPUE table and the PRI threshold.

10.3.1. Southern Zone

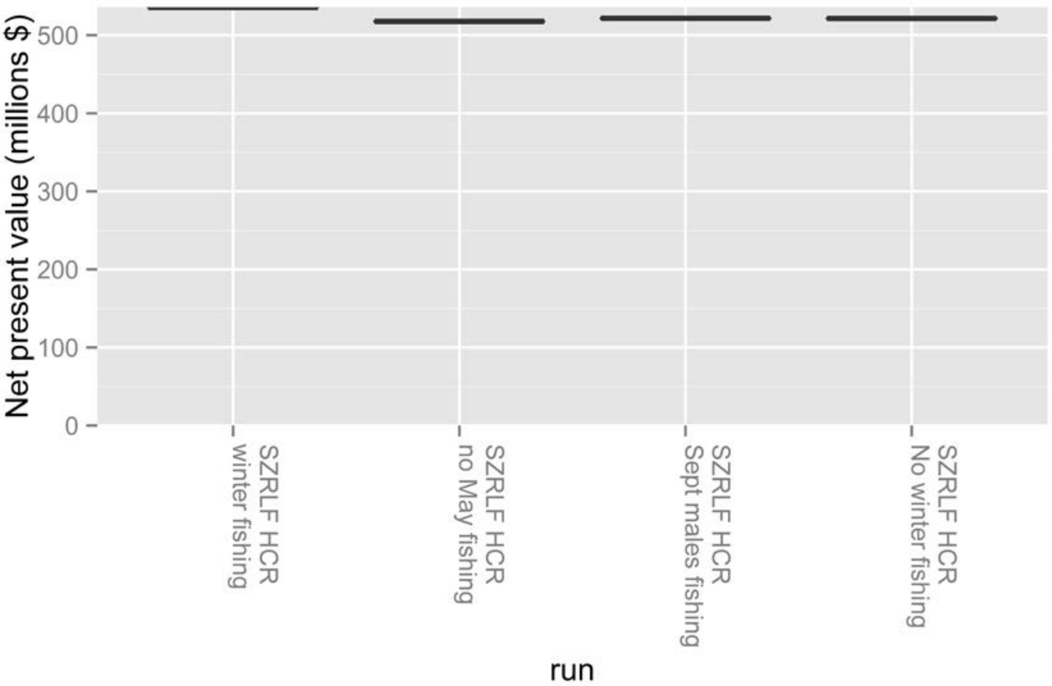


Figure 10.1. NPV plot for different choices of fishing season length, including winter fishing (a full 12-month season) in the Southern Zone. Results show summed discounted profit (NPV) for simulations run under 20-year projection time frames.

Differences among the four season length options (Fig. 10.1), including a 12-month season (Fig. 10.1, 'winter fishing') and the baseline (Fig. 10.1, 'No winter fishing') show little impact of extending the fishing season on average yearly profit. Thus, perhaps unsurprisingly, the model, making assumptions that winter fishing is like the two months before and after the winter closure, projected no meaningful change on NPV. The slightly higher NPV under winter fishing (Fig. 10.1) probably reflects higher observed prices in May and October for Southern Zone lobsters, which would be reflected in a higher assumed price for winter fishing lobsters in these projections.

The same very modest change in NPV was also the outcome for a strategy that reduced the season by one month by closing May, and for a strategy that extended the existing fishing season by one month, opening one month earlier in September.

10.3.2. Northern Zone

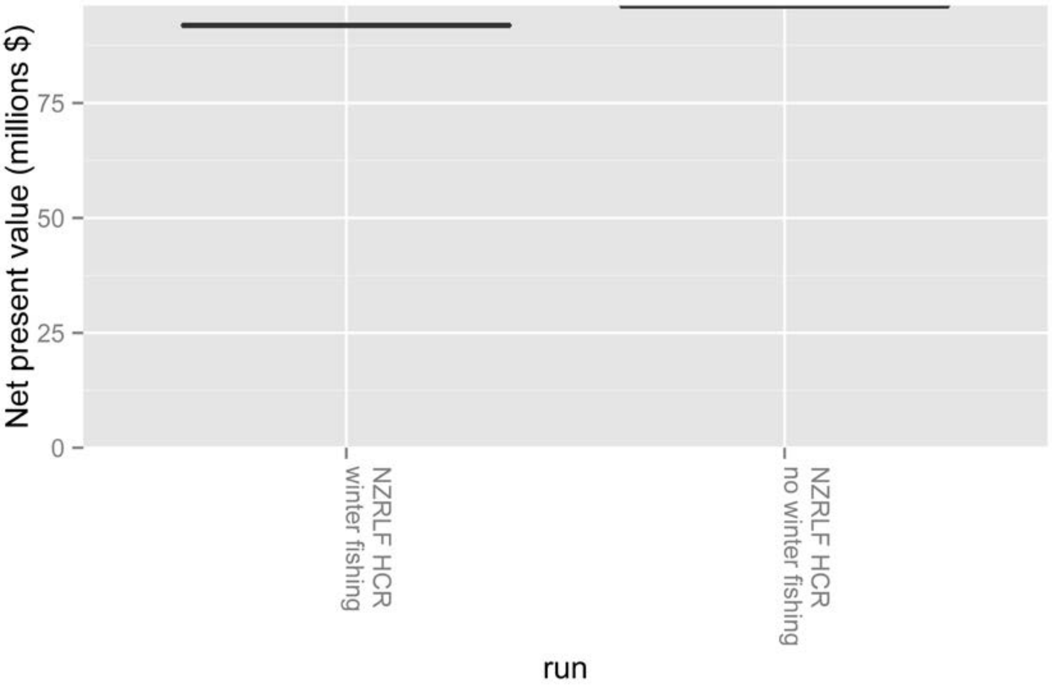


Figure 10.2. NPV plot for winter fishing in the Northern Zone. Results show average profit (NPV) for simulations run under 20-year projection time frames.

For the Northern Zone, only a 12-month season was tested, as requested by Northern Zone members of the Research Subcommittee. As for the Southern Zone, the impact of change in economic outcomes of a 12-month season in the Northern Zone (Fig. 10.2) was very small, and given the uncertainty in projection outputs, effectively negligible.

In summary, for both zones no meaningful change in economic performance could be discerned, given the absence of data, and the need to assume constant average values of catchability, price and fishing costs based on the months before and after the current seasonal closures.

10.4. Discussion

While this analysis shows small impact of opening the fishery for all 12 months, this analysis is only preliminary and is greatly limited by the lack of any data for winter fishing in South Australia since these two zones have been closed to winter fishing to date. In particular, we do not know what catch rates (of males only) will be, what the price might be, or how fishing costs might change.

The analysis of Hoshino of the seasonal variation in Tasmania lobster price (Table 3.2) showed a relatively modest increase in average price over the winter season, except for September, where the average price was $65 compared to an overall (unweighted) monthly average of $59.45, a roughly $5 higher September price per kg.

However, more strategic price gains may be possible. In particular, lobsters in the far west of the Northern Zone often bring a much lower price than the average over the current 7-month fishing season, principally due to their larger size which is less favoured by the Chinese market in normal high supply months. It may be possible to achieve larger gains in landed price, compared to what far west lobsters typically bring by targeting winter fishing to this outlying region.

Pursuing strategic economic benefits is of particular value in the current fishery where average recruitment levels are trending lower, so profit levels are lower than in earlier years. Gaining a higher price, when possible, will of course directly increase revenues and thus industry profitability. One drawback of fishing in the far west of the Northern Zone is that costs are higher, due to longer steaming times from the main ports of Port Lincoln and Kangaroo Island, and the need for processors to drive up to far west landing sites (e.g. Ceduna) to collect landed lobsters.

The Northern Zone industry (Kyri Toumazos, Executive Officer NZRLFA, pers. comm.) have also noted that the transport of lobsters from the far west by truck in very hot summer months risks stress or mortality for far west lobsters landed in summer. Winter temperatures are far more favourable for far west lobster product quality and survival.

To pursue this potential economic enhancement for the Northern Zone fishery, research is soon to commence to undertake experimental opening of the fishing season into winter while at the same time combining this with investigation of benefits of extending the spatial range of exploitation in the Northern Zone. The bioeconomic model developed for South Australia in this project would be extended and utilised to estimate potential economic gains, in particular, accounting for the trade-off of higher fishing costs against potentially better price of winter fishing in the Northern Zone far west.

11. Benefits and Adoption

In this section, examples are listed of uses of the bioeconomic modelling tools for management decision making in Tasmanian and South Australian rock lobster.

1. In Tasmania, some fishers requested an increase in the minimum size of lobsters to better protect spawning females. The bioeconomic model examined variations on this objective. Results found that because females grow slowly in that region, the reduction in numbers harvested would mean that fishers would need to move to other, faster growth, regions of Tasmania, to catch their quotas, increasing exploitation there. This displaced effort would reduce catch rates overall and reduce egg production in those target regions such that (1) economically the fishery would be worse off, and (2) gains in egg production would be small. **Accordingly, it was decided not to raise the minimum size limit in Tasmanian lobster.** (See Chapter 5)

2. In northeast Tasmania, populations of urchins have exploded, in part due to southward extensions of the warm urchin-favourable waters of the East Australian Current. Overgrazing by urchins has devastated some kelp forests in this region of the Tasmanian coastal shelf. Because (only) large lobsters predate on these species of urchins, one solution proposed to reduce urchin numbers was to increase the population density of larger Southern Rock Lobster. Environmental lobby groups were strongly endorsing a maximum size limit for harvested lobsters. The bioeconomic model was utilised to evaluate this strategy, and it was found that a maximum size limit would severely reduce profitability. An alternative strategy of reducing overall levels of exploitation in this region, using a catch cap, essentially a spatially-restricted TACC, would increase number of larger lobsters even more than a maximum size limit, without the attendant severe economic sacrifice. **This strategy identified by the bioeconomic model was adopted, preserving important economic benefit to the fishing industry and regional Tasmanian communities, while still achieving stated ecological management objectives.**

3. In South Australia, the existing harvest strategy implemented in 2011 underwent formal review. At November 2013 meetings of the Management Advisory Committee (MAC) Harvest Strategy Review Working Groups (Northern Zone and Southern Zone), **the harvest strategy review committees requested the bioeconomic testing of a range of management strategy options for implementation in the two SA lobster fisheries**. Strategies evaluated with the bioeconomic modelling tools developed in this project were selected by representatives of industry, PIRSA fishery managers, and SARDI stock assessment scientists. These results were reported to industry in February and to the two Harvest Strategy Review Working Groups in early March 2014. The Working Groups refined this to a set of final strategies that were evaluated by the bioeconomic model and presented to the two Working Groups on 14 April 2014.

4. In the South Australian Southern Zone, harvest strategy modifications were recommended, which await approval by wider industry, the PIRSA Director, and the Minister. **Three modifications found to be economically optimal or to enhance catch stability in model testing were recommended by the Southern Zone Harvest Strategy Review Working Group: (1) a revised procedure for quota setting when the fishery falls below the limit reference point CPUE of 0.6 kg/potlift, (2) narrowing the width of CPUE bands into**

which yearly TACCs under the harvest control rule are assigned, and (3) a revised set of hybrid TACC levels for yearly quota setting.

5. Future application: In the South Australian Northern Zone, industry are advocating a new management regime, combining spatial management to access outlying fishing grounds and opening winter fishing to capture a higher export price. Winter fishing was examined under this project (Chapter 10) but insufficient information was available to assess its likely future performance. A new FRDC/Seafood CRC project is now approved to gather information on winter fishing in the Northern Zone. **In a projected second stage of this upcoming project, the bioeconomic modelling tools will be used to assess the economic performance of this industry-led Northern Zone strategy of winter fishing and spatial management**.

12. Further Development

As an immediate follow-up to the project, the bioeconomic model was used to test different South Australian harvest strategy options. The harvest strategies implemented in 2011, in both the Southern and Northern Zones, were under review by the MAC Harvest Strategy Review Working Groups. In the first meetings of the Working Groups on 19 and 20 November 2013, it was agreed that different scenarios and modifications of the 2011 harvest strategies would be proposed by industry and the chair of the Research Sub-Committee (Cathy Dichmont) in consultation with the SARDI team who will undertake this work. Harvest strategy performance comparison outcomes were reported back to the South Australian rock lobster MAC Harvest Strategy Review Working Groups on the 2nd and 3rd March 2014, and the final set of narrowed down strategies were reported on 14 April 2014.

The South Australian Northern Zone has expressed strong industry support for research focused on the combination of a 12-month fishing season and spatial management. Currently June to October are closed to fishing in the Northern Zone, and most catch is taken in areas closer to port. The first stage of this research has now been approved and will commence on 1 June 2014. Industry will lead the experimental winter fishing, and SARDI will estimate biomass by region. Experimental fishing will run during all five winter months and in all four regions of the Northern Zone, including in two more outlying regions of the far west on the Great Australian Bight, and in deep water near the Shelf edge. These areas have been relatively lightly fished in recent years due to higher fuel costs, a lower price for larger lobsters, lower quality for deep water fish for export, and a lower Northern Zone quota. The bioeconomic modelling tools developed in this project are proposed for use in a planned second stage of this research to examine modifications to the management regime. Winter fishing, in particular, is intended to obtain a higher price for larger lobsters in those months of lower global supply, when prices have been reported to be higher in recent years. Data from this exploratory fishing will be used in the bioeconomic modelling tools in the planned second stage of the project, which will be considered following the outcomes to be reported in the first stage of this project.

13. Planned Outcomes

The following Planned Outcomes and Benefits were included in the original project proposal:

1. A comprehensive database of fishery-aggregated economic information, including variable and fixed fishing costs and price, will be gathered and summarised for the Southern Rock Lobster fishery in the three states.
2. A suite of management strategies for these lobster fisheries, novel and conventional, will be proposed by industry and managers for model evaluation.
3. Dynamic maximum-likelihood-parameterised bioeconomic management strategy evaluation modelling tools will be developed and extended for evaluating the lobster fishery management strategies proposed.
4. The net present value of each strategy, along with other economic and biological outputs, will be communicated to industry and managers. A brochure will be distributed. Workshops with industry and managers will permit close engagement of stakeholders with the relative economic benefits of each management strategy proposed. The most economically favourable management strategies will be highlighted in publication and workshops, and how these increases in profit are expected to be achieved will be considered and discussed.

With the project now complete, the Planned Outcomes include any further bioeconomic analysis of harvest strategies for Tasmania and South Australia.

In Tasmania, the bioeconomic model is used regularly to assess proposed changes to the harvest strategy used to set quota, and to directly inform yearly quota decision making, identifying levels of TACC that will optimise economic return (Chapter 6). Recent examples of the use of the bioeconomic model in specific Tasmanian applications are given in Chapters 5 and 7.

In South Australia, the bioeconomic model has been used this past year (2013/14) extensively to support a comprehensive review of the existing Harvest Strategy. The bioeconomic modelling tools will be used in the Northern Zone to assess the likely impact of a 12-month fishing season. See point 5 in Chapter 11, Benefits and Outcomes, above.

14. Conclusion

The profitability of different strategies for managing these lobster fisheries can vary greatly. Some strategies generate a much higher expected profit, and some much lower, averaging 10 or 20 years into the future.

Some general lessons for Southern Rock Lobster fishery management were apparent in these model outcomes. For example, among four broadly different policies tested, (1) maximum size led to the lowest profit, and the lowest increase in egg production. A first lesson learned was that maximum size strategies will not be profitable or even assist sustainability for these lobster stocks. This poor performance for maximum size limit strategies was observed in both the South Australian Southern Zone bioeconomic analysis, and in northeast Tasmania, where it is a management objective to increase numbers of large lobsters. Maximum size limits result in an economically poor fishery outcome. (2) An increase in the minimum size limit can be economically beneficial, yielding higher profit through higher yield-per-recruit, when growth rates were faster and mortality rates higher, notably in the SA Southern Zone. However, a higher minimum size yielded no net impact in the SA Northern Zone. In SE Tasmania, where growth rates are very slow and many lobsters, especially females, never reach legal size, the reverse outcome from the SA Southern Zone was predicted, and profitability is predicted to be lowered by raising the minimum size. (3) A third policy tested, of constant quotas (TACC's that remained constant in future years) yielded considerably higher average profit than any of the size limit strategies. (4) However, a fourth policy for the SA Southern Zone was clearly the best performer, being the most profitable of all four policies tested, and also yields a higher predicted volume of catch, and relatively high egg production. This best policy was a yearly quota-setting harvest control rule designed to seek an approximately constant yearly harvest fraction (a constant exploitation rate). By setting the TACC yearly to remove an approximately constant fraction of the available lobster biomass, three of four important management objectives were optimised, including measurably higher profitability. However, it was the worst performer for achieving a stable yearly catch.

A more stable version of this policy was implemented in the two South Australian zones in 2011. Model testing suggested the strategies implemented in the two zones were economically optimal if historical levels of recruitment were assumed. However, at these historical levels of recruitment, catch rates are predicted to recover and in reality, catch rates, in the last two years, have not. The reason for slow or no recovery is that lobster recruitment, in recent years, in all five Southern Rock Lobster fishery zones, Tasmania, South Australia, and Victoria, has trended lower than average. Consequently, a scenario of less-than-average future recruitment was tested. Under lower recruitment, strategies with lower average levels of exploitation led to higher profitability. One way to interpret this outcome is that, when recruitment is lower on average, removing fewer lobsters yearly maintains lobster abundance and thus catch rates at economically viable levels, namely at levels that cover fishing costs.

The bioeconomic model has now been used to advise the current formal review of the two SA harvest strategies. Variations of the existing harvest strategies selected by industry, managers and scientists were tested and strategies among those were identified to enhance industry profitability. Two important issues were also addressed for managing Tasmanian rock lobster. See Chapter 11, Benefits and Adoption.

Appendices

Appendix 1: Model specification for the ROCK stock assessment estimation model

André E. Punt and John Feenstra

Specifications for a Generalized Spatial Rock Lobster Model

The population dynamics model is spatially-structured, and operates on a user-specified set of time-steps (which need not all be of the same duration). The spatial strata in the model are referred to as “sub-zones” (indexed by “z”) and the number of time-steps each year is *T*. The duration of the *i*th time-step (*i*=0,1,..,*T*-1) is denoted t_i and, by definition, $\sum_{i=0}^{T-1} t_i = 1$. The time-steps are such that the model can be run with any definition of “year” (e.g. “calendar year” or “quota year”). Growth, fishing, movement, establishment of a MPA, and settlement (number of animals entering the model; not the same as recruitment to the exploitable biomass) can occur during any of the time-steps.

A. The population dynamics model

A.1. Basic dynamics

The equation that specifies the number of animals of sex *s* in size-class *l* in sub-zone *z* at the start of time-step *i* of year *y* takes account of natural mortality, fishing mortality, movement, growth, and settlement. Assuming that harvest occurs before growth and settlement, after which movement occurs:

$$N^{s,z}_{y,i+1,l} = \sum_{z'} Y_i^{s,z,z'} \left[\sum_{l'} X^{s,z'}_{l',l,y,i} \, N^{s,z'}_{y,i,l'} \, e^{-Mt_i} \, \{1-\tilde{H}^{s,z'}_{y,i,l'}\} + \Omega_i^{s,z'} \Phi_l^s \, R_y^{z'} \right] \qquad \text{(A.1)}$$

where $N^{s,z}_{y,i,l}$ is the number of animals of sex *s* in size-class *l* in sub-zone *z* at the start of time-step *i* of year *y* (the size-classes range from 1 to n_L^s), $X^{s,z}_{l',l,y,i}$ is the fraction of the animals of sex *s* in size-class *l’* in sub-zone *z* that grow into size-class *l* during time-step *i* of year *y* (the possibility of shrinkage is ignored), $Y_i^{s,z,z'}$ is the fraction of the animals of sex *s* that move from sub-zone *z*’ to sub-zone *z* at the end of time-step *i*, *M* is the instantaneous rate of natural mortality (assumed to be independent of sex, size, sub-zone, and time), $\tilde{H}^{s,z}_{y,i,l'}$ is the exploitation rate on animals of sex *s* in size-class *l* and sub-zone *z* at the start of time-step *i* of year *y*:

$$\tilde{H}^{s,z}_{y,i,l} = \sum_{f \in f_z} \tilde{S}^{s,f}_{y,i,l}(1-\tilde{p}^{s,z}_{i,l})(1-H^{s,f}_{y,i,l})V_i^s \, F^f_{y,i} \qquad \text{(A.2)}$$

V_i^s is the relative vulnerability of males to females during time-step *i* (V_i^s=1 for males), $\tilde{p}^{s,z}_{i,l}$ is the proportion of animals of sex *s* in sub-area *z* in length-class *l* which are returned live during time-step *i* because they are spawning, $H^{s,f}_{y,i,l}$ is the proportion of animals of sex *s* in length-class *l* which are returned live during time-step *i* of year *y* by fleet *f* because of high-grading, $\tilde{S}^{s,f}_{y,i,l}$ is the vulnerability of the gear used by fleet *f* on animals of sex *s* in size-class *l* during time-step *i* of year *y* given the implications of the legal minimum size:

$$\tilde{S}^{s,f}_{y,i,l} = \begin{cases} 0 & \text{if } L^s_l + \Delta L^s_l \le \mathrm{LML}^{s,f}_y \\ S^{s,f}_{y,i,l} & \text{if } L^s_l \ge \mathrm{LML}^{s,f}_y \\ S^{s,f}_{y,i,l}(L^s_l + \Delta L^s_l - \mathrm{LML}^{s,f}_y)/\Delta L^s_l & \text{otherwise} \end{cases} \tag{A.3}$$

f_z is the set of fleets which are found in sub-zone *z*, L^s_l is the lower limit of size-class *l* for sex *s*, ΔL^s_l is the width of a size-class *l* for sex *s*, $\mathrm{LML}^{s,f}_y$ is the legal minimum size for sex *s* and fleet *f* during year *y*, $S^{s,f}_{y,i,l}$ is the vulnerability of the gear used by fleet *f* on animals of sex *s* in size-class *l* during time-step *i* of year *y*, $F^f_{y,i}$ is the exploitation rate on fully-selected (i.e. $\tilde{S}^{s,f}_{y,i,l} = 1$) animals by fleet *f* during time-step *i* of year *y*, $\Omega^{s,z}_i$ is the fraction of the settlement to sub-zone *z* that occurs to sex *s* during time-step *i* ($\sum_s \sum_i \Omega^{s,z}_i = 1$), Φ^s_l is the proportion of the settlement of animals of sex *s* that occurs to size-class *l* ($\sum_l \Phi^s_l = 1$), and R^z_y is the settlement of animals to sub-zone *z* during year *y*.

Allowance is made for vulnerability to differ among years to implement possible past and future changes in vulnerability due to changes to legal minimum sizes, gear configurations and where fishing occurs within sub-zones. Vulnerability can also account for discarding (live), as well as high-grading by fishers.

Allowance is also made for settlement to occur to any size-class, during any time-step and in different ratios for males and females. However, by pre-specifying the values for the $\Omega^{s,z}_i$ and Φ^s_l, it is possible implement simpler models such as that the sex-ratio of settlement is 50:50, occurs to one size-class only, and only happens during one time-step. For ease of parameter estimation, the annual settlements are parameterized as follows:

$$R^z_y = \bar{R}^z_y \, e^{\varepsilon^z_y - (\sigma_{R,y})^2/2} \tag{A.4}$$

where $\bar{R}^z_y$ is mean settlement to sub-zone *z* during year *y*, ε^z_y is the "settlement residual" for year *y* and sub-zone *z*, $\sigma_{R,y}$ is the standard deviation of the random fluctuations in settlement for year *y*:

$$\sigma^2_{R,y} = \begin{cases} \tilde{\sigma}^2_R \, \tilde{\tau}^{(y_{\text{start}} - y)} & \text{if } y \le y_{start} \\ \tilde{\sigma}^2_R & \text{otherwise} \end{cases} \tag{A.5}$$

$\tilde{\sigma}_R$ is the extent of variation in settlement for years after y_{start}, and $\tilde{\tau}$ determines the extent to which σ_R changes with time. $\tilde{\tau} < 1$ means that for earlier years before y_{start} the settlement will be closer to the mean settlement.

Mean settlement is either an estimated constant or related to egg production by means of the Beverton-Holt stock-recruitment relationship, i.e.:

$$\bar{R}^z_y = \frac{4hR^z_0 \tilde{B}^z_{y-\tilde{L}} / \tilde{B}^z_0}{(1-h)+(5h-1)\tilde{B}^z_{y-\tilde{L}} / \tilde{B}^z_0} \tag{A.6}$$

where *h* is the steepness of the stock-recruitment relationship, $\tilde{B}^z_y$ is the egg production in sub-zone *z* during year *y*, $\tilde{L}$ is the lag between spawning and settlement. Egg production is given by the following equation for the case in which spawning is assumed to occur at the start of time-step i_m:

$$\tilde{B}^z_y = \sum_l Q^z_l \, N^{\mathrm{f},z}_{y,i_m,l} \tag{A.7}$$

where Q^z_l is the expected number of eggs produced by a female in size-class *l* in sub-zone *z*, and i_m is the time-step in which spawning occurs. $\tilde{B}^z_0$ is computed from the value for the parameter R^z_0 and the unfished egg production-per-recruit. The annual recruitment to the fishable population during a time-step is the number of animals that reach the legal minimum size during that time-step plus any animals that settle during that time-step at sizes larger than the legal minimum size.

A.2. Catches

The fully-selected exploitation rate for fleet *f* during time-step *i* of year *y*, $F^f_{y,i}$, is calculated by using Equation A.8a if catches are specified in mass and using Equation A.8b if they are specified in numbers:

$$F^f_{y,i} = \frac{C^f_{y,i}}{\sum_l \sum_s \tilde{S}^{s,f}_{y,i,l}(1-\tilde{p}^{s,z_f}_{i,l})(1-H^{s,f}_{y,i,l})V^s_l \, W^{s,z_f}_l \, \tilde{N}^{s,z_f}_{y,i,l}} \tag{A.8a}$$

$$F^f_{y,i} = \frac{C^f_{y,i}}{\sum_l \sum_s \tilde{S}^{s,f}_{y,i,l}(1-\tilde{p}^{s,z_f}_{i,l})(1-H^{s,f}_{y,i,l})V^s_l \, \tilde{N}^{s,z_f}_{y,i,l}} \tag{A.8b}$$

where $C^f_{y,i}$ is the catch by fleet *f* during time-step *i* of year *y* (equal to the landed catch multiplied by one plus the ratio of numbers landed to discards which die), $\tilde{N}^{s,z}_{y,i,l}$ is the number of animals of sex *s* in size-class *l* in sub-zone *z* when the catch during time-step *i* of year *y* is removed, z_f is the sub-zone in which fleet *f* operates, and $W^{s,z}_l$ is the mass of an animal of sex *s* in size-class *l* and sub-zone *z*. Equation (A.8) implies the assumption that discard mortality is negligible compared with fishing mortality.

A.3. Initial conditions

It is impossible to project this model from unexploited equilibrium owing to a lack of historical catch records for the entire period of exploitation. Instead, it is assumed that the population was in equilibrium with respect to the average catch over the first ω years for which catches are available in year $y_{start}-\chi$. This approach to specifying the initial state of the stock differs from that traditionally adopted for assessments of rock lobster off Tasmania and Victoria (Punt and Kennedy, 1997; Hobday and Punt, 2001) in that no attempt is made to estimate an initial exploitation rate. The settlements for years $y_{start}-\chi$ to $y_{start}-1$ can be treated as estimable so that the model is not in equilibrium at the start of year y_{start}. The exploitation rate for the years $y_{start}-\chi$ to $y_{start}-1$ are set to the value used to calculate the size structure between years y_{start} and $y_{start}+\omega$ where both ω and χ are pre-specified constants.

A.4. Allowing for Marine Protected Areas

The approach to allow for Marine Protected Areas (MPAs) follows Hobday *et al.* (2005). Each MPA is assigned to a "home" sub-zone and its dynamics follow Equation A.1, including movement between the MPA and the sub-zone in which it is located. The settlement for each sub-zone is allocated to the areas open and closed to fishing within the sub-zone based on the size of the MPA relative to the total area of the sub-zone (i.e. the "area" of an MPA is the proportion of the total settlement to the sub-zone in which it located which settles in the MPA).

B. The objective function

The objective function summarises the information collected from the fishery and contains contributions from five data sources:

(a) commercial catch rates,
(b) length-frequency data,
(c) commercial catches in number,
(d) an index of settlement (based, for example, on puerulus data), and
(e) tagging data (separately to estimate movement rates and growth).

It is not necessary to have all these types of data to estimate the values for the parameters of the model (see Table A1.1).

B.1. Catch-rate data

The contribution of the catch-rate data for the commercial and recreational fleets to the likelihood function is given by:

$$L_1=\prod_f\prod_y\prod_i\frac{1}{I^f_{y,i}\sqrt{2\pi}\,\sigma^f_{q,y,i}}\exp\left(-\frac{(\ell\mathrm{n}I^f_{y,i}-\ell\mathrm{n}(q^f_i\,\overleftrightarrow{q}^f_{y,i}B^{e,f}_{y,i}))^2}{2(\sigma^f_{q,y,i})^2}\right)\qquad\text{(B.1a)}$$

while the contribution of fisheries independent index (FIMS) data to the likelihood function is given by:

$$L_1=\prod_f\prod_y\prod_i\frac{1}{K^f_{y,i}\sqrt{2\pi}\,\tilde{\tilde{\sigma}}^f_{q,y,i}}\exp\left(-\frac{(\ell\mathrm{n}K^f_{y,i}-\ell\mathrm{n}(q^f_i\overleftrightarrow{q}^f_{y,i}\tilde{\tilde{q}}^{f_{z,f}}\,B^{e,f}_{y,i}))^2}{2(\tilde{\tilde{\sigma}}^f_{q,y,i})^2}\right)\qquad\text{(B.1b)}$$

where $\sigma^f_{q,y,i}$ is the standard deviation of the random fluctuations in catchability for log-catch-rate for commercial/recreational fleet *f*, year *y*, and time-step *i*, $\tilde{\tilde{\sigma}}^f_{q,y,i}$ is the standard deviation of the random fluctuations in catchability for FIMS fleet *f* during time-step *i* of year *y*, q^f_i is the catchability coefficient for commercial/recreational fleet *f* and time-step *i*, $\tilde{\tilde{q}}^f$ is the FIMS catchability coefficient FIMS series *f*, $\vec{q}^f_{y,i}$ is the trend in catchability due to environmental or fishery factors, i.e. $\vec{q}^f_{y,i} = \exp\left(\sum_j \theta^{f,j}_i E^j_y\right)$, $f_{z,f}$ is the commercial fleet which operates in the same sub-zone as FIMS fleet *f*, $I^f_{y,i}$ is the catch-rate index for commercial/recreational fleet *f*, year *y*, and time-step *i*, E^j_y is the value for the jth environmental / fishery index for year *y*, $\theta^{f,j}_i$ is the parameter which links catchability for fleet *f* during time-step *i* and environmental variable *j*, $K^f_{y,i}$ is the catch-rate index for FIMS fleet *f*, during time-step *i* of year *y*, and $B^{e,f}_{y,i}$ is the exploitable biomass available to fleet *f* during time-step *i* of year *y* (the biomass available to the fleet less half of the catch time-step *i* of year *y*) if the catch-rate index relates to catch-rate (commercial fishery or a survey):

$$B^{e,f}_{y,i} = \sum_s \sum_l V^s_l \, \tilde{S}^{s,f}_{y,i,l} \, W^{s,z}_l \, (\tilde{N}^{s,z_f}_{y,i,l} - C^{s,z_f}_{y,i,l} / 2) \tag{B.2a}$$

while it is

$$B^{e,f}_{y,i} = \sum_s \sum_l V^s_l \, \tilde{S}^{s,f}_{y,i,l} \, \tilde{N}^{s,z_f}_{y,i,l} \tag{B.2b}$$

if the catch-rate is a pre-recruit index.

$C^{s,z}_{y,i,l}$ is the catch of animals of sex *s* in size-class *l* in sub-zone *z* during time-step *i* of year *y*:

$$C^{s,z}_{y,i,l} = \sum_{f \in z} V^s_i \tilde{S}^{s,f}_{y,i,l} (1 - \tilde{p}^{s,z}_{i,l})(1 - H^{s,f}_{y,i,l}) W^{s,z}_i \tilde{N}^{s,z}_{y,i,l} F^f_{y,i} \tag{B.3}$$

The maximum likelihood estimate for q^f_i can be obtained analytically (the values for the $\tilde{\tilde{q}}^f$ are estimated as part of the non-linear search procedure):

$$\hat{q}^f_i = \exp\left(\sum_y \ell\text{n}(I^f_{y,i} / \vec{q}^f_{y,i} B^{e,f}_{y,i}) / (\sigma^f_{q,y,i})^2 / \sum_y 1 / (\sigma^f_{q,y,i})^2 \right) \tag{B.3a}$$

$$\hat{q}^f_i = \exp\left(\frac{\sum_y \ell\,\text{n}(I^f_{y,i} / \vec{q}^f_{y,i} B^{e,f}_{y,i}) / (\sigma^f_{q,y,i})^2 + \sum_y \ell\,\text{n}(K^f_{y,i} / (\tilde{\tilde{q}}^f \vec{q}^f_{y,i} B^{e,f}_{y,i})) / (\tilde{\tilde{\sigma}}^f_{q,y,i})^2}{\sum_y 1 / (\sigma^f_{q.y,i})^2 + \sum_y 1 / (\tilde{\tilde{\sigma}}^f_{q,y,i})^2} \right) \tag{B.3b}$$

Allowance is made for the possible changes in catchability between groups of years by treating each period in which catchability is constant as a separate catch-rate index. The values for the residual standard deviations can also be estimated analytically.

B.2. Length-frequency data

Length-frequency data are available for the commercial/recreational catch and from research sampling. The commercial length-frequency data provide information on the proportion of the (landed) catch of each sex in each size-class above the legal minimum size, while the research length-frequency data also provide information on the number of animals of legal minimum size and smaller. The observed fraction of the landed catch of animals of sex *s* in number during time-step *i* of year *y* by fleet *f* that are in size-class *l* is denoted $\rho^{s,f}_{y,i,l}$. The model-estimate of this quantity, $\hat{\rho}^{s,f}_{y,i,l}$, takes account of the vulnerability of the gear and the numbers in each size-class:

$$\hat{\rho}^{s,f}_{y,i,l} = \tilde{S}^{s,f}_{y,i,l}(1-\tilde{p}^{s,z_f}_{i,l})(1-H^{s,f}_{y,i,l})\tilde{N}^{s,z_f}_{y,i,l} / \sum_{l'} \tilde{S}^{s,f}_{y,i,l'}(1-\tilde{p}^{s,z_f}_{i,l})(1-H^{s,f}_{y,i,l})\tilde{N}^{s,z_f}_{y,i,l'} \qquad \text{(B.4)}$$

The observed value of $\rho^{s,f}_{y,i,l}$ is assumed to be multinomially distributed, which leads to the following likelihood function (ignoring constants independent of the model parameters) for each of the two sources of length-frequency data:

$$L_2 = \prod_f \prod_s \prod_y \prod_i \prod_l (\hat{\rho}^{s,f}_{y,i,l})^{\omega^{s,f} Z^{s,f}_{y,i} \rho^{s,f}_{y,i,l}} \qquad \text{(B.5)}$$

where $\omega^{s,f} Z^{s,f}_{y,i}$ is a factor to weight the length-frequency data relative to the other data for sex *s*, fleet *f* and time-step *i* of year *y* (the "effective sample size" for sex *s*, fleet *f* and time-step *i* of year *y*) where $Z^{s,f}_{y,i}$ is the number of animals of sex *s* caught by fleet *f* during time-step *i* of year *y* which were sized. The quantity $\omega^{s,f}$ is needed because the likelihood (Equation B.5) is based on the assumption that the length-frequency data are collected by means of a simple random sample from the catch. Unfortunately, using the raw data (i.e. setting $\omega^{s,f} = 1$ in Equation B.5) assigns too much emphasis to the length-frequency data because the sampling for length-frequency is not random and because the assumption that vulnerability is time-invariant will be violated to some extent. Down weighting the data corrects to some extent for this.

The effective sample sizes for each category of data implied by the model fit to the data can be calculated using the approach of McAllister and Ianelli (1997). The value for quantity $\omega^{s,f}$ can be adjusted so that the average value of $\omega^{s,f} Z^{s,f}_{y,i}$ equals the model-calculated effective sample size so that the input weighting for the data is consistent with the fit of the model to the data. However, care should be taken when doing this when the data types (catch-rate, catch-in-numbers, catch length-frequency) are in conflict and ω should never be set > 1.

Equations B.4 and B.5 are based on assumption that the model is fitted separately to the data by sex. However, this approach ignores any information that may be contained in the sex-ratio of the length-frequency data. Therefore, rather than fitting to the data by sex, the model can be fitted to the sex-length data, i.e.:

$$\hat{\rho}^{s,f}_{y,i,l} = \tilde{S}^{s,f}_{y,i,l} V^s_i (1-\tilde{p}^{s,z_f}_{i,l})(1-H^{s,f}_{y,i,l})\tilde{N}^{s,z_f}_{y,i,l} / \sum_{s'} \sum_{l'} V^s_i \tilde{S}^{s',f}_{y,i,l'}(1-\tilde{p}^{s,z_f}_{i,l})(1-H^{s,f}_{y,i,l})\tilde{N}^{s',z_f}_{y,i,l'} \qquad \text{(B.6)}$$

and

$$L_2 = \prod_f \prod_s \prod_y \prod_i \prod_l (\hat{\rho}^{s,f}_{y,i,l})^{\omega^{s,f} Z^f_{y,i} \rho^{s,f}_{y,i,l}} \qquad \text{(B.7)}$$

The summations in Equations B.4 and B.6 are taken over fleet when the length-frequency data are provided for multiple fleets combined.

The length-frequency for high-graded animals along with spawners is included in the likelihood function analogously to the length-frequency data for the landings (Equations B.4-B.7), except the model predictions are computed to match the data type. Undersize length-frequencies can also be fit as part of full length frequencies for data from research sampling. The model-predicted number of animals of sex *s* in sub-zone *z* and length-class *l* during time-step *i* of year *y* which are undersized for fleet *f* is:

$$S^{s,f}_{y,i,l} V^s_i (1-\tilde{p}^{s,z_f}_{i,l}) \tilde{N}^{s,z_f}_{y,i,l} \tag{B.8a}$$

while the model-predicted number of live spawners of sex *s* in sub-zone *z* and length-class l during time-step i of year y is:

$$S^{s,f}_{y,i,l} V^s_i \tilde{p}^{s,z_f}_{i,l} \tilde{N}^{s,z_f}_{y,i,l} \tag{B.8b}$$

B.3. Catch-in-number

The commercial catches in number, $C^{N,f}_{y,i}$, are assumed to be lognormally distributed. The contribution of these data to the likelihood function is therefore given by:

$$L_3 = \prod_f \prod_y \prod_i \frac{1}{C^{N,f}_{y,i}\sqrt{2\pi}\sigma^f_N} \exp\left(-\frac{(\ell n C^{N,f}_{y,i} - \ell n \hat{C}^{N,f}_{y,i})^2}{2(\sigma^f_N)^2} \right) \tag{B.9}$$

where $\hat{C}^{N,f}_{y,i} = \sum_s \sum_l V^s_l \tilde{S}^{s,f}_{y,i,l} \tilde{N}^{s,z_f}_{y,i,l} F^f_{y,i}$.

In addition, analogous to the landed commercial catches, data series of discards of spawners and of undersize are also fit (if provided).

B.4. Indices of settlement

The puerulus data are assumed to provide a relative index of settlement which is normally or lognormally distributed, i.e.:

$$L_4 = \prod_z \prod_y \frac{1}{\sqrt{2\pi}\sigma^z_{J,y}} \exp\left(-\frac{(J^z_y - \tilde{q}^z R^z_{y+L_R})^2}{2(\sigma^z_{J,y})^2} \right) \tag{B.10a}$$

$$L_4 = \prod_z \prod_y \frac{1}{J^z_y \sqrt{2\pi}\tilde{\sigma}^z_{J,y}} \exp\left(-\frac{(\ell n J^z_y - \ell n(\tilde{q}^z R^z_{y+L^z_R}))^2}{2(\tilde{\sigma}^z_{J,y})^2} \right) \tag{B.10b}$$

where J^z_y is the puerulus-based index of settlement for sub-zone *z* and year *y*, $\sigma^z_{J,y}$ is the standard deviation of J^z_y, $\tilde{\sigma}^z_{J,y}$ is the standard deviation of the logarithm of J^z_y, $\tilde{q}^z$ is the constant of proportionality between the puerulus-based indices of settlement for sub-zone *z* and settlement for sub-zone *z*, and L^z_R is the lag (in years) for sub-zone *z* between the puerulus stage and settlement to the first size-class considered in the model.

The maximum likelihood estimate for $\tilde{q}^z$ can be obtained analytically:

$$\hat{\tilde{q}}^z = \sum_y \tfrac{1}{(\sigma^z_{J,y})^2} J^z_y R^z_{y+L^z_R} / \sum_{y'} \tfrac{1}{(\sigma^z_{J,y'})^2} (J^z_y)^2 \qquad \text{(B.11a)}$$

$$\hat{\tilde{q}}^z = \exp\left(\sum_y \tfrac{1}{(\tilde{\sigma}^z_{J,y})^2} \ell n(J^z_y / R^z_{y+L^z_R}) / \sum_{y'} \tfrac{1}{(\tilde{\sigma}^z_{J,y'})^2} \right) \qquad \text{(B.12b)}$$

where $\tilde{n}^z$ is the number of years for which puerulus-based indices of settlement are available for sub-zone *z*.

B.5. Tag-recapture

Tag-recapture data provide a basis to estimate movement, growth and exploitation rates. However, within this model (and owing to uncertainty regarding, for example, reporting rates), the tag-recapture data are used only to determine growth and movement rates.

B.5.1. Using tagging data to estimate movement

Tagging data are used to estimate movement following the recapture conditional framework of McGarvey and Feenstra (2002). Specifically, the likelihood for the tag-recapture data is the product over recaptures of the probability of recapturing a tag in the sub-zone in which it was recaptured given its sub-zone of release, its time of release and the time that it was at liberty for. The recapture-conditioned recapture probability for tagged lobsters at large for just one movement time is:

$$f(z_\mathrm{r} \mid z_\mathrm{t}, t_\mathrm{t}, t_\mathrm{r}, s) = \frac{Y^{z_\mathrm{t},z_\mathrm{r}}_{t_*} \left[\prod_{t=t_*}^{t_\mathrm{r}-1} (1-\tilde{H}^{s,z_r}_{t,l}) e^{-Mt_t} \right] \tilde{H}^{s,z_\mathrm{r}}_{t_\mathrm{r},l}}{\sum_{z'_\mathrm{r}=1}^{n_\mathrm{z}} Y^{z_\mathrm{t},z'_\mathrm{r}}_{t_*} \left[\prod_{t=t_*}^{t_\mathrm{r}-1} (1-\tilde{H}^{s,z'_r}_{t,l}) e^{-Mt_t} \right] \tilde{H}^{s,z'_\mathrm{r}}_{t_\mathrm{r},l}} \qquad \text{(B.13)}$$

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

For computational ease, the dependence of $\tilde{H}$ on size is dropped when evaluating Equation B.13 (i.e. vulnerability is assumed to be 1 for all tagged animals). Equation B.13 can be extended to animals that were at liberty for more than one movement time. For example, the extension to two movement times is:

$$f(z_\mathrm{r} \mid z_\mathrm{t}, t_\mathrm{t}, t_\mathrm{r}, s) = \frac{\left(\sum_{z=1}^{n_z} Y_{t_1}^{z_\mathrm{t},z} \left[\prod_{t=t_1}^{t_2} (1-\tilde{H}_{t,l}^{s,z}) e^{-Mt_t}\right] Y_{t_2}^{z,z_\mathrm{r}}\right) \left[\prod_{t=t_2}^{t_\mathrm{r}-1} (1-\tilde{H}_{t,l}^{s,z_r}) e^{-Mt_t}\right] \tilde{H}_{t_\mathrm{r},l}^{s,z_\mathrm{r}}}{\sum_{z'_\mathrm{r}=1}^{n_z} \left(\sum_{z=1}^{n_z} Y_{t_1}^{z_\mathrm{t},z} \left[\prod_{t=t_1}^{t_2} (1-\tilde{H}_{t,l}^{s,z}) e^{-Mt_t}\right] Y_{t_2}^{z,z'_\mathrm{r}}\right) \left[\prod_{t=t_2}^{t_\mathrm{r}-1} (1-\tilde{H}_{t,l}^{s,z'_r}) e^{-Mt_t}\right] \tilde{H}_{t_\mathrm{r},l}^{s,z'_\mathrm{r}}}$$

where t_1 is the time when movement first occurs after tagging, and t_2 is the time when movement occurs before recapture.

Generalization to tagged animals which were at liberty for more than two movement periods is straightforward and involves accounting for all possible paths between the sub-zone of release and that of recapture.

B.5.2. Using tagging data to estimate growth

After assigning the tagging data to sub-zone, sex, size-class and time-step of release, the tag-recapture data can be summarized by the vectors l_1, t_1, *t* and l_2, where l_1 is the size-class-at-release, t_1 is the time-step at release. *t* is the time-at-liberty [in model time-steps], and l_2 is the size-class-at-recapture. The contribution of the tag-recapture data for one animal to the likelihood function is the probability of observing that an animal tagged at the start of time-step t_1 when it was in size-class l_1 and at liberty for *t* time-steps, was recaptured when it was in size-class l_2 (McGarvey and Feenstra, 2001; Punt *et al.*, 2009). This probability is the (l_1, l_2) entry of the matrix given by $L_4 = \prod_{i=t_1}^{t_1+t-1} \mathbf{X}_i^{s,z}$. The contribution of the data on growth to the likelihood function is then the product of L_4 over all of recaptured animals. The data used to estimate growth are restricted to animals which did not change sub-zones between release and recapture so that the growth estimates pertain to a single sub-zone. The likelihood function for the growth data allows for random sizing error (i.e. the recapture size-class is incorrect with probability α).

C. Parameter estimation

Table A1.2 lists the parameters of the population dynamics model and the objective function, and highlights those parameters assumed to be known exactly and those parameters whose values are estimated by fitting the model to the data (many parameters can either be estimated or pre-specified).

C.1. Movement

The parameters that determine movement can either be pre-specified or estimated. The movement parameters are specified in logit-space, i.e. for two regions:

$$Y_i^{s,z,z'} = e^{\tau_i^{s,z,z'}}; \quad Y_i^{s,z',z} = 1/(1+e^{\tau_i^{s,z,z'}}) \tag{C.1}$$

where $\tau_i^{s,z,z'}$ the parameter which determines the movement rate among sub-zones. $\tau_i^{s,z,z'}$ may be sex-specific or independent of sex.

C.2. Modelling growth

The size-transition matrix **X** for a given year can either be pre-specified or computed using the equation:

$$X^{s,z}_{l',l,i} = \begin{cases} \displaystyle\int_{-\infty}^{L_1+\Delta L^s/2} \frac{1}{\sqrt{2\pi}} e^{-(L-E(L_{l'})_i^{s,z})/(2(\sigma(L)_i^{s,z})^2)} dL & \text{if } l=1 \\ \displaystyle\int_{L_l+\Delta L^s/2}^{L_l+\Delta L^s/2} \frac{1}{\sqrt{2\pi}} e^{-(L-E(L_{l'})_i^{s,z})/(2(\sigma(L)_i^{s,z})^2)} dL & \text{if } 2 \le l \le n_L^s - 1 \\ 1 - \displaystyle\int_{-\infty}^{L_n-\Delta L^s/2} \frac{1}{\sqrt{2\pi}} e^{-(L-E(L_{l'})_i^{s,z})/(2(\sigma(L)_i^{s,z})^2)} dL & \text{if } l = n_L^s \end{cases} \tag{C.2}$$

where $E(L)_i^{s,z}$ is the expected length of an animal of sex *s* and length *L* in sub-zone *z* after growth occurs during time-step *i*, and $\sigma(L)_i^{s,z}$ is the standard deviation of the length of an animal of sex *s* and length *L* in sub-zone *z* after growth occurs during time-step *i*.

Two options exist to parameterize $E(L)_i^{s,z}$ and $\sigma(L)_i^{s,z}$.

A. The von Bertalanffy parameterization assumes that the growth increment follows a von Bertalanffy growth curve, i.e. $E(L)_i^{s,z} = L - (\ell_\infty^{s,z} - L)(1 - e^{-\kappa_i^{s,z}})$, while the standard deviation of the growth increment, $\sigma(L)_i^{s,z}$, depends on time-step, sex, and sub-zone but not size, i.e. $\sigma(L)_i^{s,z} = \sigma_i^{s,z}$.
B. The polynomial parameterization is based on setting $E(L)_i^{s,z}$ and $\sigma(L)_i^{s,z}$ using polynomial functions, i.e.:

$$E(L)_i^{s,z} = \sum_{j=0}^{m_i^{s,z}} L^j \delta_{i,j}^{s,z}\,; \qquad \sigma(L)_i^{s,z} = \sum_{j=0}^{\tilde{m}_i^{s,z}} L^j \tilde{\delta}_{i,j}^{s,z} \tag{C.3}$$

where $\ell_\infty^{s,z}$, $\kappa_i^{s,z}$, and $\sigma_i^{s,z}$ (von Bertalanffy parameterization), and $\delta_{i,j}^{s,z}$ and $\tilde{\delta}_{i,j}^{s,z}$ (polynomial parameterization) are the parameters which determine the size-transition matrix. The number of terms in the polynomial model are defined by the quantities $m_i^{s,z}$ and $\tilde{m}_i^{s,z}$.

The values for the parameters $\ell_\infty^{s,z}$, $\kappa_i^{s,z}$, and $\sigma_i^{s,z}$ may change over time (separate estimated parameters for blocks of years) or change as a function of a covariate, e.g. $\ell_{\infty,y}^{s,z} = \overline{\ell}_\infty^{s,z} e^{\phi_y^{s,z} E_y}$ where $\overline{\ell}_\infty^{s,z}$ is a reference value for $\ell_\infty^{s,z}$, E_y is the value of the covariate, and $\phi_y^{s,z}$ is the parameter which relates changes in the covariate to changes in $\ell_\infty^{s,z}$.

C.3. Vulnerability

Vulnerability-at-length for each fleet can either be pre-specified or estimated. When vulnerability is estimated, each vulnerability-at-length within a pre-specified range of lengths can be treated as an estimable parameter, or vulnerability can be treated as an (estimable) logistic function of length. Vulnerability for a fleet can be sex-specific or independent of sex, and vulnerability for one fleet can be assumed to be same as that for another fleet. Vulnerability can change over time in “blocks”.

C.4. Bayesian considerations

It is necessary to specify prior distributions for all of the estimable parameters of the model (Table A1.2) if Bayesian methods are to be used to represent uncertainty. The prior assumed for the logarithm of mean settlement is $U(-\infty,\infty)$, with the intention that this prior is “uninformative”. It should be noted, however, that no prior can be truly “uninformative” because a prior that is uninformative for one quantity in a model will be informative about some other quantity in that model (Punt and Hilborn, 1997). The prior for each of the settlement residuals is $N(0;\sigma_R^2)$, i.e. the contributions of the settlement residuals to the objective function is:

$$P = 0.5\sum_z \sum_y (\varepsilon_y^z)^2 / (\sigma_{R,y}^2) \tag{C.4}$$

It is also possible to impose a penalty which relates the settlement residuals to environmental variables, i.e.:

$$P = 0.5\sum_z \sum_y (\hat{q}^z \varepsilon_y^z - E_y^z)^2 / \sigma_{E,z}^2 \tag{C.5}$$

where $\hat{q}^z$ is a parameter which relates the settlement residuals for sub-zone *z* with the environmental index for that zone, and $\sigma_{E,z}$ determines the strength of the relationship between the environmental index and the settlement residuals.

The Markov Chain Monte Carlo method (Hastings, 1970; Gelman et al., 1995) is used to develop the posterior distributions. The MCMC method was chosen over alternative methods such as the Sample-Importance-Resample method (Rubin, 1987) because it works well with the complicated posterior surfaces commonly encountered when applying size-structured models (Punt and Hilborn, 1997). A major problem associated with the application of Bayesian methods to complex problems is how to assess whether convergence to the posterior has occurred (Punt and Hilborn, 1997). Four ways of doing this are:

a) Visually examining the traces for several of the key model outputs.
b) Computing the diagnostic statistics developed by Raftery and Lewis (1992), Geweke (1992), and Heidelberger and Welsh (1983).
c) Computing the so-called “single chain Gelman statistic”. This statistic involves comparing the variability of the means in 50 segments of the chain with the variability within each such segment.
d) Examining the partial auto-correlation function to assess whether the amount of thinning is sufficient to ensure that sequential points are essentially uncorrelated.

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Table A1.1. The data inputs for the model. Data for the “required” data sources are not needed for all combinations of year, time-step and sub-zone.

Quantity	Description	Required / Optional
C_t^f	catch by fleet *f* during time-step *i* of year *y* (in mass)	Required *
$LML_y^{s,z}$	The legal minimum size for sex *s* and sub-zone *z* during year *y*	Required *
$I_{y,i}^f$	Catch-rate index for time-step *i* of year *y* and fleet *f*	Required [&]
$\rho_{y,i,l}^{s,f}$	Fraction of the catch of animals of sex *s* in number during time-step *i* of year *y* fleet *f* that are in size-class *l*	Required [&]
$\omega_{y,i}^{s,f}$	“Effective sample size” for sex *s*, fleet *f*, and time-step *i* of year *y*	Required [$]
$K_{y,i}^f$	Catch-rate index for FIMS fleet *f*, for time-step *i* year *y*	Optional
$C_{y,i}^{N,f}$	Catch by fleet *f* during time-step *i* of year *y* (in numbers)	Optional
J_y^z	The puerulus-based index of settlement for sub-zone *z* and year *y*	Optional
L_R^z	The lag (in years) between the puerulus stage and settlement to the first size-class considered in the model for sub-zone *z*	Optional
$T_{y,i,l}^{s,z}$	The number of tagged animals of sex *s* in size-class *l* released in sub-zone *z* during time-step *i* of year *y*	Optional
$\tilde{T}_{y,i,l}^{s,z}$	The number of tagged animals of sex *s* in size-class *l* recaptured in sub-zone *z* during time-step *i* of year *y*	Optional
E_y^j	jth Environmental covariate	Optional

* Required for all years, time-steps and sub-zones.
& Not required for all years and time-steps but performance increases with additional data.
$ Required for the years and time-steps for which size-composition data are provided.

Table A1.2. Parameters of the model and their prior distributions. Parameter values fixed using auxiliary information are denoted as “User-specified”.

Parameter	Description	Prior distribution
ε_y^z	The settlement residuals	$N(0;\sigma_R^2)$
$\ell\mathrm{n}(\overline{R}^z)$	Mean settlement	U(-∞, ∞)
$\ell\mathrm{n}(R_0^z)$	Unfished settlement	U(-∞, ∞)
h	Steepness	U[0.2, 1]
$\tilde{\sigma}_R$	The extent of variation in settlement for years after y_{start}	User-specified
$\tilde{\tau}$	The extent to which σ_R changes with time	User-specified
$X_{l',l,y,i}^{s,z}$	Fraction of the animals of sex *s* in size-class *l’* in sub-zone *z* that grow into size-class *l* at the end of time-step *i* and year *y*	User-specified *
$\tau_i^{s,z,z'}$	Parameter which determines the fraction of the animals of sex *s* that move from sub-zone *z*’ to sub-zone *z* at the end of time-step *i*,	User-specified *
M	Natural mortality	User-specified
$S_{y,i,l}^{s,f}$	Vulnerability as a function of sex and length	User-specified *
$P_{i,l}^s$	The proportion of animals of sex *s* in size-class *l* which are spawning during time-step *i*	User-specified
$\tilde{H}_l^{s,f}$	The relative vulnerability of an animal of sex *s* in size-class *l* to be being high-graded by fleet *f*	User-specified
$\tilde{H}_y^f$	the impact of high-grading by fleet *f* during year *y*	Calculated
$\Omega_i^{s,z}$	Fraction of the settlement by time-step, sex and sub-zone	User-specified *
Φ_l^s	Proportion of the settlement of animals of sex *s* that occurs to size-class *l*	User-specified
Q_l^z	Egg production as a function of size and sub-zone	User-specified
$W_l^{s,z}$	Mass as a function of size, sex, and sub-zone	User-specified
i_{m}	The time-step in which spawning occurs	User-specified

L_l^s	The lower limit of size-class *l* for sex *s*	User-specified
$\ell_\infty^{s,z}, \kappa_i^{s,z}, \sigma_i^{s,z}$	Von Bertalanffy growth parameters	User-specified *
$\delta_{i,j}^{s,z}, \tilde{\delta}_{i,j}^{s,z}$	Polynomial growth parameters	User-specified *
$\phi_y^{s,z}$	Link between growth parameters and environmental data	User-specified *
α	Probability is incorrectly assigning a recaptured animal to a size-class	User-specified *
χ, ω	Parameters which define the initial state	User-specified
$\tilde{\tilde{q}}^f$, q_i^f	Catchability	U(-∞, ∞)
$\theta_i^{f,j}$	Parameters linking environmental variables and catchability	User-specified *
$\sigma_{q,y,i}^z$ / $\tilde{\tilde{\sigma}}_{q,y,i}^z$	Standard deviation of the random fluctuations in catchability for sub-zone *z* and time-step *i* of year *y*	User-specified * &
σ_N	Standard deviation of the random fluctuations in mean mass	User-specified *
$\sigma_{J,y}^z$ / $\tilde{\sigma}_{J,y}^z$	The standard deviation / *CV* of J_y^z	User-specified * &

* Indicates parameters that could be estimated or pre-specified.
& If estimated, only a single value can be estimated for each index. Also, the same value can be estimated for multiple catch-rate series.

Appendix 2: User Manual for the ROCK stock assessment estimation model

André E. Punt and John Feenstra

This appendix outlines how to specify the values included in the input files for ROCK23A (GENERAL.ROC, NORTH.DAT, NORTH.CTL and ROCK23A.PIN)[1]. It does not detail the mathematical specifications for the model or for the method used for parameter estimation. These are available in Appendix 1. Similarly, the mathematical specifications and user manual for the projection software are described in Appendices 3 and 4. The appendix provides a glossary of key terms.

A. Specification of the data

The data are specified in the file "NORTH.DAT".

A.1. Stock and dimensions

The inputs in this section are:

(a) the first and last years of the assessment period (these are the years for which data are available – the modelled period will be longer than this, depending on options for the initial state model),

(b) the number of years the model is "burnt-in" to set up the initial size-structure (this should be approximately the number of age-classes in the population),

(c) the number of years for which fishing mortality should be set to zero before the start of the burn-in (this value should be 1 if there is only one area and larger than this (10-15 years) if there are multiple areas or "settlement" is computed from a stock-recruitment relationship; see Section B.4c for specifying a stock-recruitment relationship),

(d) the number of time-steps during each year (1 for an annual model; 2+ for a model with multiple periods during the year; note that each time-step can be of a different duration),

(e) the total number of sub-zones for which data are supplied (this number needs to be as large as the number of sub-zones that are to be assessed; giving data for more sub-zones than are to be assessed simplifies model specification and running of sensitivity tests),

(f) the number of sub-zones actually assessed (this number must be at least 1),

(g) the number of marine protected areas (MPAs) (zero if there are no MPAs; 1+ otherwise; if this input is specified it is necessary to indicate when the MPAs were established (Section A.3), the size of the MPA relative to the sub-zone in which it is located (Section B.5) and movement between the fished areas and the MPAs; (Section B.6b)),

(h) the number of fishery fleets (at least 1),

(i) the number of survey fleets (0 if there are no survey fleets),

(j) a list of indices for the data sub-zones to indicate which are the actual sub-zones on which the assessment is to be based (there should be one value for each sub-zone for which data are available; the value should be zero or negative if the sub-zone concerned is to be ignored and a number from 1 to the number of assessed sub-zones otherwise; this determines which sub-zones are to be used in the analysis under consideration),

---

[1] To run the model, ROCK23A.TPL must be compiled to an .EXE file using AD Model Builder. To run the ROCK23A.EXE, open a windows command prompt (cmd.exe) in the folder in which the input files are located, type ROCK23A and press enter

(k) a list of indices for each fishery fleet (each value should be the number of the area in which the fleet operates; there must be one value for each fishery fleet),

(l) a list of indices for each survey fleet (the value should the number of the area in which the fleet operates; there must be one value for each survey fleet; blank if there are no survey fleets),

(m) a value for each fishery fleet indicating whether the catch is reported in weight (1) or in numbers (2) (fishery fleets only; the catches by the survey fleets are assumed to be negligible), and

(n) a value for each sub-zone indicating the major commercial fleet in the sub-zone.

Note that each of the items a-n must have at least one value associated with it. The example below involves eight fleets (five fishery fleets and three survey fleets) and three sub-zones, only two of which (the first and third) are actually being assessed.

```
1983                    # First year of the assessment
2006                    # Last year of the assessment
20                      # Number of burn-in years
10                      # Years for which F is zero
9                       # Time steps per year
3                       # Number of sub-zones with data
2                       # Total number of sub-zones to be assessed
0                       # Number of MPAs
5                       # Number of fishery fleets
3                       # Number of survey fleets
1 -1 2                  # Indexes between data and actual areas
1 1 2 2 3               # Indexes between fishery fleets and sub-
zones
1 2 3                   # Indexes between survey fleets and sub-zones
1 1 2 1 1               # Are the catches in weight (1) or numbers
(2)
1 3 5                   # The major commercial fleets by sub-zone
```

A.2. Biological processes

The model is flexible in terms of which biological processes are to be modelled. The biological processes currently included in the model (and their codes) are listed below. The model executes the specified biological process in the order input for each time-step (note that it is not necessary to include all of the biological processes in every application of the model; for example, analyses based on a single sub-zone and no MPAs won't need processes 1 and 2).

1. Move animals among sub-zones (if movement is specified to occur during the current time-step)
2. Create new MPAs (if any new MPAs are specified to occur during the current time-step)
3. Compute the egg production.
4. Apply half of natural mortality.
5. Compute the exploitation rate.
6. Compute the reference biomass.
7. Remove the catch.
8. Implement growth among size-classes (only used if growth occurs during the current time-step).
9. Add "settlement" to the modelled population (reminder: the term "recruitment" is used in this manual when referring to growth larger than the minimum legal size and entering the exploitable biomass, and "settlement" when referring to

entering the modelled population, which will include animals smaller than the minimum legal size).

10. Compute the total legal biomass.

The order of some of the processes should not be changed. For example, the exploitation rate must be calculated before the catch is removed. However, depending on the order of inputs, growth can, for example, be specified to occur before or after the catch is removed. An example case is given below. Note that the first input is the number of processes that may occur in each time-step and that not mentioning a process will lead to it being ignored (all models should minimally include natural mortality and catch, compute exploitation rates, and allow for growth and settlement).

```
11 # Number of biological processes
1 # Move animals among sub-zones
2 # Create new MPAs
3 # Compute egg production
4 # Remove half of mortality
5 # Compute exploitation rates
6 # Compute reference biomass
10 # Compute total-legal biomass
7 # Remove catch
4 # Remove half of mortality
8 # Allow for growth
9 # Allow for settlement
```

The final inputs in this section are: (a) the time-step when egg production should be computed, and (b) the first time-step for which “settlement” for a given year relates to (for example, if there are 9 time-steps and this input is 8, then “settlement” for time-steps 1-7 is based on the “settlement” for year *y* while “settlement” for time-steps 8-9 is based on the settlement for year *y*+1).

```
1                # Time-step in which spawning occurs
8                # Time-step for calculating settlement
```

Note that if the model only has one time-step both of these inputs must be set to 1.

A.3. Specifications for MPAs

The specifications for when each MPA was implemented and in which assessed sub-zone each MPA falls is specified as follows:

```
1990 2 1           # Year started, Time started, MPA Home
```

This line implies that an MPA was started in 1990 in the second time-step and is located in assessed sub-zone 1 (iii). Note that no values should be supplied for this input (the line is to be left blank) if no MPAs are specified (see Section A.1g above).

A.4 Specifications for size-classes

A.4a Number of sizes size-classes

The lower limit of the first size-class (assumed to be the same for both sexes) is entered (i), followed the number of size-classes for males (ii) and females (iii), i.e. for the example below the first size-class starts at 82.5mm, there are 29 size-classes for males and 21 for females.

```
82.5                   # Start of lowest size-class
29 21                  # Number of size-classes (males then females)
```

A.4b Size-class widths

"1" is entered to indicate that the width of each size-class is the same and "2" for variable-length size-classes. If the width of each size-class is the same then the specification for the value of the size-class is given as males (4 mm in this example) and then females (5 mm in this example):

```
1                       # Set to 1 for fixed size-classes
4 5                     # Widths of length-classes (males then
female)
```

Alternatively, the entire sequence of size-limits (upper values) must be provided for males (one row) and females (next row) if the size-class width differs among size-classes:

```
2                       # Set to 2 for variable-length size-classes
90 100 120 130 …        # Males
90 105 110 120 …        # Females
```

A.5. Specifications for reference size and recruitment

The software outputs a variety of biomasses. The "reference" biomass is the total biomass (males+females) above the "reference size" and is useful for comparisons among, for example, different states. The "reference size" is entered here (one value for each assessed area). Next is entered the time-step during which recruitment to the fishery is calculated (if there are 9 time-steps and this input is 8, then the reported recruitment for year *y* is the number of animals growing to above the minimum legal size during time-steps 8-9 of year *y*-1 and during time-steps 1-7 during year *y*). The time-step for defining recruitment should be "1" for an annual model. Note that this input does not specify when animals are added to the model (see Section B.7b for this).

```
# Output statistics
80 80          # Reference size (one value for each assessed area)
8              # Time-step for calculating recruitment to the LML
```

Note that the time-steps which define when recruitment is calculated (this input) and when "settlement" occurs (see Section A.2) need not be the same. Setting these inputs to different values will lead to recruitment consisting of animals which grow to size-classes above the LML based on two values for the annual "settlement".

A.6. Catch data

The catch data for each time-step are provided in rows. There must be a row for each time-step between the first time-step of the first year to the last time-step of the last year (even if the catch was zero for the entire time step).

A.6a Landings

The first catch input is the landings (although it can be the total catch if landings and discards are not to be modelled separately). The values in each row are the year, the time-step, and the catches for each fishery fleet. For example, the catch data for a model with two annual time-steps and four fleets would be entered as:

```
# Catch data
# ==========
# Year Time-step Fleet-1 Fleet-2 Fleet-3 Fleet 4
  1978         1     100     200       0     100
  1978         2     110     190       0     100
  1979         1     120     180     100     100
```

A.6b Dead discards

"1" is specified if there are data on "dead discards" (i.e. assuming the catches entered above are live animals) ["0" otherwise]. This input is then followed by the proportion of the landed [live] catch which is discarded dead if "1" was entered (no input is provided if there are no "dead discards"). Note that discard rates must be specified for all years and time-steps within the year. For example, if there are two fleets and fleet 1 has dead discards but fleet 2 does not, the input would be

```
# Discard rates
# =============
1             # Set to 1 if there are dead discards; 0 otherwise
# Year Time-step Fleet-1 Fleet-2
  1978         1     0.1     0.0
  1978         2     0.1     0.0
  1979         1     0.1     0.0
```

A.6c High-grading

The next input is "1" if there are data on the fraction of the legal catch which is released live (i.e. high-grading) ["0" otherwise]. This input is then followed by the proportion of the landed [live] catch which is discarded live if "1" was entered (no input is provided if there are no discards). Note that high-grade rates must be specified for all years and time-steps within the year. It is necessary to indicate that high-grading is occurring when specifying vulnerability patterns (see Section B.8a) if "1" is entered at this input. For example, if there are two fleets and fleet 1 high grades but fleet 2 does not, the input would be

```
# High-grade fractions
# ====================
1             # Set to 1 if there is high-grading; 0 otherwise
# Year Time-step Fleet-1 Fleet-2
  1978         1     0.1     0.0
  1978         2     0.1     0.0
  1979         1     0.1     0.0
```

A.7. Catch-rate data

A.7a General specifications

Catch-rate data pertain to fleets (and hence sub-zones because each fleet is linked to a single sub-zone). The inputs in this section are:

(i) the number of catch-rate series that will be used (this will be less than the number of catch-rate series entered if data are specified for fleets which are found in sub-zones which are not to be assessed during the current model run).

(ii) how many residual standard deviations are to be estimated and how many are to be shared. There are 29 catch-rate series in the case below, but only 15 residual standard deviations ("sigmas") are estimated because some are shared (e.g., the same residual standard deviation applies to catch-rate series 1 and 8). If the value at this input for a catch-rate series is set to 0, the assessment assumes that the residual standard deviation (by year) for that catch-rate series is known *a priori*, and is set to the values entered in the final set of inputs in this section.

(iii) How many catchability parameters should be assumed to be the same? In the example below catchability is assumed to be the same for series 1, 2 and 3 .

```
# Catch rate data
# ===============
29                                      # Number of CPUE series
```

```
# Treatment of Sigma (0 pre-specify; otherwise CPUE group number of
estimated sigma)
1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 9 10 11 12 13 14 15
# Treatment of catchability
1 1 1 4 5 6 7 8 9 10 11 12 13 14 15 16 …
```

A.7b Relating catchability to environmental variables

This set of inputs specifies how (if at all) catchability is related to an environmental index [or a forcing function in general]. The inputs are (i) the number of environmental time-series catchability is related to (0 means none), followed by (ii) specifications for which environmental indices are related to catchability. The latter input consists first of the index of the environmental variable concerned (see Section B.2 for how to input environmental variables), and then a number to indicate the parameter that will be used to link catchability to the variable concerned. Note that the index of the catch-rate series must be entered before specifying the indices for environmental variable purposes. In the example below there are two catch-rate series, the first series is not related to any environmental indices and the second (hence the “2” at the start of the second line) is related to three such indices (numbers 5, 7 and 9), and the value of the parameter linking catchability to the environmental variables is the same for environmental variables 7 and 9 (it is both parameter 2).

```
0 3               # Number of environmental indices by CPUE series
2 5 1 7 2 9 2     # Cpue Series No; environmental series numbers
```

Note that if you want to specify that catchability is increasing exponentially at 5% per annum, you should create an “environmental index” with values 0, 0.04879, 0.09531, 0.139762, etc. These are the logged values for catchabilities of 1, 1.05, 1.10, ... The parameter associated with this index (see Sections B.9 and D.k) would be set to 1 and not estimated.

A.7c Further inputs

(i) the minimum residual standard deviation (often referred to as “sigma”) (this value should be set to a value larger than zero to avoid overweighting a short catch-rate series; although the same objective can often be achieved by assuming that the residual standard deviation for a short catch-rate series equals that for another catch-rate series),
(ii) the number of types of catch-rate series (“1” if there are commercial catch-rate data only, or “2” if there are commercial catch-rate data and FIMS data),
(iii) the phase in which the FIMS catchability coefficients should be estimated (only provide a value if “2” was entered at the previous input),
(iv) the number of data points to be entered, and
(v) the number of data points that will be used (this number and that at the previous input will differ if data are provided for more fleets than are to be included in the assessment).

The value for this last input determines the amount of storage for the catch-rate data. Its value need not be identical to the number of data points to be used in the assessment, but must be no less than this (setting the number of “used” data points to a value higher than necessary will increase the storage requirements of the analysis somewhat).

```
0.04                                    # Minimum sigma
2                                       # Number of CPUE types
2                                       # Phase for FIMS q
342                                     # Number of data points
219                                     # Number that will be used
```

A.7d The data

The final inputs for this section are the data themselves (ordered by (i) CPUE series, (ii) fleet, (iv) year and (v) time-step). The “Type” (vi) is “1” for commercial catch-rate data and “2” for FIMS data, while the “Source” (iii) is “1” for catch-rate data and “2” for pre-recruitment indices. Note that allowance can also be made for (pre-specified) rates of change in catchability (See Section B.7). Multiple series can be supplied for each fleet-time-step combination to allow different values for catchability to be estimated to different time-periods (e.g. due to changes in regulations such as introduction of a TACC from a given year onwards).

```
# Series Fleet Source Year Time-step Type   CPUE CV
   1      1         1 1983         1    1  0.768  1
   1      1         1 1984         1    1  0.801  1
   1      1         1 1983         1    1  0.768  1
   1      2         1 1985         1    1  5.978  1
```

The CV entered here (vii) is treated as a relative CV if a residual standard deviation is estimated for the catch-rate series (if a value of 1 or larger is entered at the “treatment of sigma” input for that series; see Section A.7a-ii above) or as the actual CV if a value of 0 is entered at the “treatment of sigma” input for that series).

A.8. Catches-in-numbers data

A.8a General specifications

The inputs for catch-in-numbers data are essentially identical to those for catch-rate data (except that there is no FIMS analogy for catch-in-numbers and there is no catchability so no link to environmental variables):

(i) the number of catch-in-numbers series that will be used.
(ii) how many residual standard deviations are to be estimated and how many are to be shared. If the value for a catch-in-numbers series is set to 0, the assessment assumes that the residual standard deviations (by year) for that catch-in-numbers series are known *a priori*, and are set to the values entered in the final set of inputs in this section. A residual standard error is estimated for numbers 1 and larger.
(iii) the minimum residual standard deviation (this value should be set to a value larger than zero to avoid overweighting a short catch-in-numbers series),
(iv) the number of data points (rows of data) to be entered, and
(v) the number of data points that will be used (these two numbers will differ if data are provided for more sub-zones than are to be assessed).

```
# Catch-in-numbers data
# ====================
2         # Number of catch-in-number series
1 2       # Treatment of Sigma (0 pre-specify; otherwise catch-in-
numbers group number of estimated sigma)
0.04                                # Minimum sigma
342       # Number of data points
342       # Number that will be used
```

A.8b The data

The final inputs for this section are the data themselves (ordered by type (category) (i), fleet (ii)):

```
# Category Fleet   Year Time-step Catch-in-numbers CV
         1     1   1983         1             1200  1
         1     1   1984         1             1100  1
         1     1   1985         1             1260  1
         1     1   1986         1             1400  1
```

The category determines type of data. Available categories are: 1 – the landed catch; 2 – the discards of spawners; and 3 – the catch of under-sized animals.

A.9. Length-frequency data

Length frequency data can be supplied by fleet or for two fleets combined (fleet-combined length-frequency data would arise if a fleet fished in two sub-zones, but where some of the catches which were sized were within the sub-zones is unknown – this can occur if catch sampling data are based on factory sampling).

The inputs that determine the length-frequency information for each type of length-frequency data (by fleet or two fleets combined) include two rows of six values that specify the number of vectors of length-frequency samples. The six values listed are the numbers of length-frequency samples for: (I) male-commercial, (II) female-commercial, (III) male+female-commercial, (IV) male-research, (V) female-research, and (VI) male+female-research. The two rows list respectively (i) the number of samples for which data are provided and (ii) the number of samples which will be actually be used. The values for this last input determine the amount of storage for the length-frequency data. These values need not be identical to the number of data points to be used in the assessment, but must be no less than this.

```
# sample sizes
0 0 0 0 0 227             # Number of data points
0 0 0 0 0 227             # Number that will be used
```

A.9a Minimum length-frequency sample size

This input indicates the minimum sample size for inclusion in the analyses. If the sample size for a sample’s length-frequency data is less than this value, the data for that sample are ignored.

```
50 # Minimum sample size
```

A.9b Data for individual fleets

Each line of length-frequency data includes data type (category), fleet, time-step and year, and sample size (the total number of sized animals, and the data for each size class specified for males and then females).

```
# Males+Females -- Research (Pot sampling)
# Category Fleet Time-step Year Sample Size The data
         1     1         2  1978        120   72  89  90  100 …
         1     1         3  1978        200  172 819  91  100 …
         1     1         4  1978        200  272 890  90  102 …
```

The category column specifies the type of length-frequency (1=landed catch; 2=released spawners; 3=high-graded animals). Note that the vulnerability pattern for a fleet (see Section B.8a) needs to allow for release of spawners and high-grading if data for spawners and high-graded animals are to be fit to for that fleet.

A.9c Combined fleets

There are two additional inputs for fleet-combined length frequency data which are provided before the combined-fleet length-frequency data themselves (which are formatted as in Section A.9b). These are the number of combinations of fleets (“3” in the example below) and then a line for each fleet combination which lists the code for the fleet combination (in this case 26, 27, and 28) for which data will be specified and the original model fleets (i.e. fleet “26” relates to the fleet-combined length-frequency data for fleets 6 and 9 combined).

```
# Length-frequency data (fleet combined)
# ======================================
3 # number of fleet-combinations
26 6 9
27 7 10
28 8 11
```

This is followed by a block of sample sizes as above (two rows, six columns), which must be provided, even if no combined-fleets are used. For example

```
# sample sizes
0 0 0 0 0 227             # Number of data points
0 0 0 0 0 227             # Number that will be used
```

or if no combined fleets are used:

```
# sample sizes
0 0 0 0 0 0             # Number of data points
0 0 0 0 0 0             # Number that will be used
```

If any data are provided in this section (i.e. fleet combinations exist and the previous sample sizes were non-zero) the data are then provided in the same format as for the length-frequency data for a single fleet.

```
# Males+Females -- Research (Pot sampling)
# Category Fleet Time-step Year Sample Size The data
         1    26         2  1978        120   72  89  90  100 …
         1    26         3  1978        200  172 819  91  100 …
         1    26         4  1978        200  272 890  90  102 …
```

A.10. Puerulus settlement indices

The inputs for the puerulus indices are:

(a) the form of the likelihood to be assumed for the puerulus index data (0 for log-normal; 1 for normal),
(b) the number of years between the puerulus stage and entry into the lowest size-class considered in the model,
(c) the number of data points (a value of 0 here means there is no puerulus index data), and
(d) the data themselves (if 0 was not entered at the previous input). The form of the data for each year are: (i) year, (ii) puerulus index, and (iii) the standard deviation of the puerulus index

```
0                        # Likelihood component for puerulus data
3                        # Delay to entry to the model
2                        # Number of data points
# Data (Year, puerulus index, SD)
1988   21 1.23
1989   22 2.33
```

A.11. Projection phase

The inputs provided at this input provide the basis for the projections into the future. These inputs are the series for which catchability coefficients are to be output (there must be one for each time-step) – these catchability coefficients will be used to calculate effort in the future given catch and population size. One catchability coefficient needs to be entered for each time-step and sub-zone even if there is no CPUE index for some time-step/sub-zone combinations. In the example below there is no CPUE index for time-step 8 but “23” has been entered to match the specification for time-step 7. The value specified for missing CPUE series will be inconsequential if there are no future catches during the time-step for CPUE series that are missing.

```
# Catchability coefficients for the future
17 18 19 20 21 22 23 23  # Catchability coefficients for the future
```

A.12. Mark-recapture data (movement)

The specifications for the mark-recapture data which are intended to inform movement are:

(a) the number of mark-recapture records (a 0 here indicates there are no mark-recapture data),
(b) the minimum time-at-liberty (in years) – a value must be provided even if there no mark-recapture data (records are ignored if the time-at-liberty is less than the minimum time-at-liberty), and
(c) the data themselves. The data for each recapture is the tag ID (not used) (i), sex (ii), year and time-step of release (iii), year and time-step of recapture (iv), sub-zone of release (v) and sub-zone of recapture (vi).

```
2939                          # Number of records:
1.0                                                   # Minimum time-
                              at-liberty (years)
#              Release        Recapture     Release Recapture
#Tag No Sex Year Time-step  Year Time-step Sub-zone  Sub-zone
      1   2 1992         9  1995         1        1         1
      9   1 1992         9  1994         1        1         1
     14   1 1992         9  1994         1        1         1
     24   1 1992         9  1994         3        1         2
```

A.13. Mark-recapture data (growth)

The specifications for the mark-recapture data which are intended to inform growth are:

(a) the number of mark-recapture records,
(b) the maximum time-at-liberty (in time-steps), – a value must be provided even if there no mark-recapture data (records are ignored if the time-at-liberty is larger than the maximum time-at-liberty), and
(c) the data themselves. The data for each recapture are: sub-zone of release (and recapture) (i), sex (ii), period of release (iii), number of periods at liberty (iv), size-class of released animals (v), size-class of recaptured animals (iv), and number of animals with this set of values (vii). It is not recommended that animals which were recaptured in different sub-areas from where they were released be included in this data set (unless growth is assumed to be the same in both sub-areas).

```
29                           # Number of records:
7.0                          # Maximum time-at-liberty (time-steps)
# Sub-zone Sex RelPer PerOut RelLen RecLen   No
         1   1      1      1      1      1    5
         1   1      1      2      1      2    1
         1   1      1      1      1      2    2
```

A.14. Concluding input

The final input is a test number. This input is used to check that the input has been correctly specified. This is extremely important because an error in the input file could result in large portions of the input data being interpreted incorrectly.

```
# Test Number
123456
```

The input is echoed to two output files (CHECK.OUT and SOUTH.DAT). These files should be examined to ensure that the input has been entered correctly.

B. Specification of the control (estimation) parameters

The specifications for the estimable parameters and the likelihood function are given in the file NORTH.CTL.

B.1. Time-blocks

The first input in the CTL file specifies which time-blocks will be used in the analyses (time-blocks are one way for vulnerability and growth to change over time; see Sections B.7 and B.8). The time-blocking in the model is defined by:

(a) the number of time-block options that are to be used,

(b) the number of time-blocks for each option (in the example below there are three time-block options, two of which consist of two time-blocks [1+ number specified], and one of which consists of three time-blocks), and

(c) the years which define each of the time-blocks.

```
3                          # Number of time-block options
1 2 1                      # No of time-blocks per time-block options
1990 2000                  # Time block 1
1990 2000 2001 2003        # Time Block 2-3
1990 2001                  # Time Block 4
```

B.2. Environmental time-series

It is possible to relate some of the parameters of the model to an environmental variable such as temperature (currently only catchability and growth; see Sections A.7b and B.7b). Environmental variables are specified by (a) the number of environmental indices (0 if none), (b) the ranges of years for each environmental variable, and (c) the values for each environmental variable. The following example illustrates how to specify that there are two environmental variables, one of which applies to 2005 to 2008 and the other 2000 to 2005. The values for the first environmental variable are 1, 1, 2, 2 for 2005, 2006, 2007 and 2008:

```
2                        # Number of environmental variables
2005 2008                # range of years (series 1)
2000 2005                # range of years (series 2)
1 1 2 2                  # values for the environmental variable 1
1 1 2 2 2 3              # values for the environmental variable 2
```

B.3. Time-step lengths

This input provides the duration of each time-step (the number of values entered must match the number of time-steps selected in Section A.1d). These durations need not be the same, but they must sum to 1.

```
0.1          # Length of step 1
0.7          # Length of step 2
0.2          # Length of step 3
```

B.4. Settlement specifications

There are several inputs related to “settlement”.

B.4a Bounds and phase for average settlement

The values for this input are (i) the lower and upper limits for the logarithm of the average “settlement” ($\bar{R}^z$), (ii) an initial value for this parameter (which may not be used if the initial value is taken from the PIN file; see Section D.1a), and (iii) the phase in which this parameter (by sub-zone) is estimated [setting the phase for a parameter to -1 means that it is not estimated and setting it to a value larger than 1 means that it is not estimated in the first phase]. One row of values must be specified for each sub-zone for which data are provided (even if the data are not used in the assessment). The following specifications (for an assessment with two sub-zones) indicate that average “settlement” should only be estimated for the first of two sub-zones (the phase is -1 for the second sub-zone):

```
-100 100 14 1    # Virgin settlement (sub-zone 1)
-100 100 14 -1   # Virgin settlement (sub-zone 2)
```

B.4b The range of years for which “settlement” is estimated

This range can extend back beyond the assessment period (See Section A.1a) to allow the size-structure at the start of the first year of the assessment period to be estimated. The second year entered is the last year of the assessment plus 1. This input must also specify the lower and upper bounds for the “settlement residuals” (ε_y^z) and the phase in which these parameters are estimated for each sub-zone for which data were provided (not just the sub-zones which are included in the actual assessment). The initial values for the “settlement residuals” that are actually estimated are specified in the PIN file (see section D.a) or set to zero if the PIN file is to be ignored.

```
# Settlement deviations (first and last years, limits, phase)
1963 2011
-5 5 2                     # Sub-zone 1
-5 5 2                     # Sub-zone 2
```

B.4c The stock-recruitment relationship

Three lines of input values specify the stock-recruitment relationship. The first line lists the minimum and maximum, initial value (see Section D.b for how an initial value is specified using a PIN file), and phase for the steepness of the stock-recruitment relationship (i), the second line lists the lag between egg production and entering the first size-class in the model (i.e. “settlement”) (ii), and the third line specifies the stock-recruitment relationship (0=none, which will mean that inputs “i” and “ii” will be ignored), and 1=Beverton-Holt stock-recruitment relationship) (iii). The example below is for a case in which “settlement” is related to egg production according a Beverton-Holt stock-recruitment relationship, but steepness is pre-specified rather than being estimated.

```
# Steepness parameters
0.2 1.0 0.5 -3                       # Steepness parameter
7                                    # Lag to settlement
1                                    # Stock-recruitment relationship
```

B.4d Standard deviation of the “settlement” residuals

The standard deviation of the “settlement” residuals by year, $\sigma_{R,y}$, is defined according to the formula:

$$\sigma_{R,y}^2 = \begin{cases} \tilde{\sigma}_R^2 \, \tilde{\tau}^{y_{\text{start}} - y} & \text{if } y \le y_{\text{start}} \\ \tilde{\sigma}_R^2 & \text{otherwise} \end{cases}$$

where $\tilde{\sigma}_R$ is the standard deviation of the “settlement” residuals for the assessment period, and $\tilde{\tau}$ is the rate at which σ_R changes over time for the years before year

y_{start} (the taper weight). Setting the taper weight to a number less than 1 will force the model to estimate "settlement" for the years before catches are supplied to be closer to mean "settlement" the earlier the year < y_{start}.

```
0.5          # Settlement CV (sigma-R)
0.9          # Taper weight for SigmaR (tau)
```

B.4e Relationship between settlement deviations and environmental variables

Two inputs indicate whether the deviations about the stock-recruitment relationship are related to an environmental variable. The inputs for each area (for which data are provided) are the number of the environmental index concerned [0 if there is no relationship between the settlement deviations and an environmental variable; see Section B.2 for how environmental variables are specified] (i) and the standard deviation of the relationship between the environmental index and the "settlement" deviation (ii). If there is no relationship between the settlement deviations and an environmental variable, the value at (ii) is ignored. There are five areas in the example below, "settlement" for two of these areas is assumed to be linked to an environmental index:

```
# Link between settlement and environmental variables
  1   0   3   0   0
0.5 0.5 0.5 0.5 0.5
```

B.4f Timing of settlement

The inputs are how many times "settlement" occurs each year (i), and the time-steps during which "settlement" occurs each year, one value for each time "settlement" occurs during the year (ii). Note that when "recruitment" occurs during the year will depend on when growth is assumed to occur and is not necessarily closely related to when "settlement" occurs. The two inputs should be "1" for an annual model.

```
2              # Number of settlement events each year
3 8            # When settlement occurs each year
```

B.4g Split of settlement to sex

The next set of inputs relates to the split of the annual "settlement" to sex and time-step. Again, the inputs are the lower, upper, and initial values for these parameters and the phases in which they are to be estimated (the initial value is set in the PIN file – see Section D.e – if a PIN file is used). One line of input must be provided for one less than the product of two times the number of times "settlement" occurs during the year. Consequently, for two time-steps and two sexes, there would be three lines of input.

```
0 10000 1 2    # Split of settlement to sex and time-step
0 10000 1 2    # Split of settlement to sex and time-step
0 10000 1 2    # Split of settlement to sex and time-step
```

B.4h Proportion of settlement by size-class

The fraction of total "settlement" which occurs to each size-class (assumed to be the same for each time-step during which "settlement" occurs) must be specified first for males (i) and then for females (ii), for each sub-zone in turn.

```
# Fraction settlement by size-class (males then females)
# males (sub-zone 1)
0.35  0.20  0.15  0.15  0.10  0.05  0     0     0     0     0     0
# females (sub-zone 1)
0.45  0.25  0.15  0.10  0.05  0     0     0     0     0     0     0
# males (sub-zone 2)
0.35  0.20  0.15  0.15  0.10  0.05  0     0     0     0     0     0
# females (sub-zone 2)
0.45  0.25  0.15  0.10  0.05  0     0     0     0     0     0     0
```

B.5. MPA specifications

The fraction which a new MPA (see Section A.1g for where MPAs are specified) constitutes of the open area when it is first implemented is specified here. One value should be entered per MPA. As a result, if there are two MPAs in the same sub-zone and the values for this input are 0.1 and 0.1 for each MPA, it implies that the first MPA constitutes 10% of the open area and the second MPA 9% (10% of 90%). A blank line should be provided if no MPAs are to be modelled.

```
# MPA specifications (ignore if MPAs are not included in the model)
0.1  0.1               # Fraction of the remaining OPEN area in the
MPA
```

B.6. Movement parameters

B.6a Between which sub-zones does movement occur?

The purpose of this section is to specify between which sub-zones (which can include MPAs) movement occurs. The inputs are:

(a) the number of sub-zones to which each sub-zone is connected to (note that the sub-zones for which input is specified need to include both the original (assessed) sub-zones and any MPAs; the first set of sub-zones are the original and the remaining sub-zones are the MPAs; i.e. if there are 3 assessed sub-zones and 2 MPAs; sub-zones 1-3 are the assessed (original) sub-zones and sub-zones 4 and 5 are the two MPAs); a value of “0” should mean there is no movement from sub-zone under consideration, a value of “2” means that animals from this sub-zone move to two other sub-zones, etc.,
(b) whether the movement rates differ among the sexes (“1” means no and “2” yes), and
(c) the sub-zones to which movement is to occur.

The input below is interpreted as follows: (I) there are two sub-zones and each is connected to one sub-zone by movement, (II) movement is not sex-specific, and (III) sub-zone 1 is connected to sub-zone 2, and sub-zone 2 is connected to sub-zone 1.

```
# Movement specifications
# =====================
1 1         # Number of sub-zone to which each sub-zone is connected
1           # Sex-specific movement (estimated; set to 2 for “yes”)
2           # Destination sub-zone (sub-zone 1)
1           # Destination sub-zone (sub-zone 2)
```

B.6b Specification of movement rates

This set of inputs indicates whether the movement rates should be estimated and, the bounds on the movement rates (after logistic transformation). One line of input must be provided for each movement rate. The four values which must be supplied for each movement rate are (i) the lower and upper bounds (in logit-space), (ii) an initial value (only used if the PIN file is ignored; see Section D.g for how to specify movement rates using a PIN file), and (iii) the phase in which the parameter concerned is to be estimated (setting the phase to a negative value fixes the movement rate at its initial value).

```
-100 100 -2 2   # Movement parameter estimated in phase 2
-100 100 -2 -2  # Movement parameter fixed
```

B.6c Timing of movement

How often movement occurs each year and the time-step(s) during which movement takes place is specified here (the second input must not be specified if no movement is modelled, i.e. the number of movements entered is “0”). Note that when during the specified time-steps movement occurs is specified at input A.2. For an annual model both inputs should be set to “1”.

```
1                # Number of movements each year
9                # Timing of movement
```

B.7. Biological parameters

Several of the inputs in NORTH.CTL relate to the biological parameters on which the population dynamics model is based. Note that specifications for growth, weight-at-length and egg production must be provided for all sub-zones and not just those which will be assessed.

B.7a Natural mortality

Natural mortality is assumed to be independent of sub-zone, sex, size, and time.

```
# Natural mortality
# =================
0.1          # Natural mortality (M)
```

B.7b The size-transition matrices

The size-transition matrices can either be provided directly or calculated from growth parameters under the assumptions that growth is either governed by (I) a von Bertalanffy growth equation, or (II) polynomial functions (McGarvey and Feenstra, 2001). The first three growth-related inputs (needed irrespective of how growth will be modelled) are:

(i) whether growth is specified directly in the form of matrices of transition probabilities or as growth parameters (1=matrices; 2=von Bertalanffy parameters; 3=polynomial parameters),
(ii) the number of time-steps each year during which growth occurs, and
(iii) the time-steps during the year when growth occurs.

The following input would imply that there are four size-transition matrices (two for each sex) and that the size-transition matrices are specified directly rather than being calculated from parameters. Growth in this case occurs during time-steps 3 and 8.

```
# Size-transition
# ===============

1           # Is growth pre-specified or calculated from parameters
2           # Number of time growth occurs each year
3 8         # Timing of growth (end of time-step)
```

The total number of growth matrices is twice the number of times growth occurs (times areas) during the year, minus any pair of matrices set equal (see below). The next input is a look-up table for each combination of sex and sub-zone, including those sub-zones which are not being assessed in the current application (note that a look-up table is not provided for MPAs because the growth within an MPA is assumed to be the same as that for the sub-zone in which the MPA is located). Four values are specified in the order: hierarchy of sub-zone – sex combinations (males then females) in the look-up table. The first two numbers indicate the indices for the growth matrices for the sub-zone – sex combination which are to be averaged, the next number indicates whether growth is time-blocked (i.e. growth is specified for a periods of "blocks" of years) by specifying the value for the time-block (see Section B.1), and the final number indicates whether the growth parameters are a (linear) function of some environmental covariate by specifying the index of the environmental variable (See Section B.2). It is possible to make growth for two sub-zones the same by setting the index in the first column to the index for the growth matrix which is to be used for this sub-zone – sex combination multiplied by minus one.

In the following example, the growth matrices for males in sub-zones 1 and 2 are the same while growth of females in sub-zone 1 is time-blocked and growth of females in sub-zone 2 is related to environmental variable 2. Note that growth for a sex-sub-zone combination cannot be simultaneously time-blocked and related to an environmental variable.

```
 1 0 0 0                # Growth matrices for males in sub-zone 1
 2 0 1 0                # Growth matrices for females in sub-zone 1
-1 0 0 0                # Growth matrices for males in sub-zone 2
 4 0 0 2                # Growth matrices for females in sub-zone 2
```

Pre-specified size-transition matrices

The next inputs are the size-transition matrices if "1" was entered at the "`Is growth pre-specified or calculated from parameters`" input above. The order hierarchy of size-transition matrices should be sex (male then female), sub-zone, and time-step.

Growth specified as polynomial functions

If growth is to be specified in the form of polynomial functions, the next input is the maximum number of size-classes an animal can grow, including the current size-class, (e.g. "2" at this input means that an animal either stays in its current size-class or grows (i.e. "jumps") one size-class) and the number of parameters defining the mean and standard deviation. In the following example, the maximum number of size-classes an animal can grow through is 5, while the growth function for males in sub-zone 1 is linear in expectation (2 parameters) with a constant standard deviation (1 parameter) and that for females in sub-zone 1 is linear in expectation and standard deviation (two 2s for each type of parameter).

```
6                                 # Number of jumps
2 1 2 2                           # Means and SDs (sub-zone 1)
2 2 1 1                           # Means and SDs (sub-zone 2)
```

The next input specifies the lower and upper bounds, initial values (only used if the PIN file is ignored; see Section D.i for how to set initial values if a PIN file is used), and phases for each estimated parameter. If growth is modelled using polynomial functions, the number of parameters can be calculated from the table above by summing the entries. For each sub-zone-time-step-sex combination, the parameters are in the order:

1) Mean constant term
2) Standard deviation constant term
3) Mean linear term
4) Mean quadratic term
5) …

6) Standard deviation linear term
7) Standard deviation quadratic term

```
# Growth parameters
 0   5   3 2                          # The mean parameters
 0 0.5 0.2 2                          # The constant sd
-1   1   0 3                          # The linear term for the mean
```

The linear, quadratic, etc. parameters compute the mean and standard deviation of the growth increment as a function of the size class index + 0.5. These parameters are ordered by sub-zone, sex, and time-step (i.e. sub-zone 1 is first, within sub-zone 1 the parameters for males are listed before those for females, and within males, the growth parameters are listed for each time-step). If growth is time-blocked or growth depends on environmental covariates, the parameters for the 2nd and subsequent time-blocks / environmental parameters are provided *after* those for the default set of growth parameters. The order is again sub-zone, sex, and time-step. Note that bounds, initial values, and phases need to be specified for all parameters within each time-step even if the intent is that not all of these parameters are to be estimated (setting the phase to a negative number can be used to avoid treating a parameter as estimable).

Growth specified as a von Bertalanffy growth curve

If growth is to be modelled by the von Bertalanffy growth curve, the next input is the maximum number of size-classes an animal can grow (e.g. “2” at this input means that an animal either stays in its current size-class or grows one size-class). The number of parameters is 1 (for L_∞) plus twice the number of times growth occurs each year (one parameter for each of κ and σ). Note that the parameter count needs to take account of whether growth is time-blocked or related to an environmental variable. The order of the parameters is as specified above for polynomial growth functions.

```
6                                     # Number of jumps
# Growth parameters
80 300 200 4                          # An example of an Linf parameter
 0 0.5 0.1 2                          # An example of an k parameter
 0  40  10 6                          # An example of a sigma parameter
```

Measurement error

The bounds, initial value (only used if the PIN file is ignored; see Section D.j), and phase for the parameter which quantifies the rate of measurement error for the tag-recapture data (the number is the probability of an animal in size-class *j* being measured to be in size-class *j*-1 or *j*+1) should be provided here. The phase for this parameter should be negative if there are no tagging data.

```
# Alpha parameter
0.001 0.499 0.3 7                     # Specs for the alpha parameters
```

B.7c Weight-at-length

Weight-at-length can either be specified for each size-class in turn (“2”) or computed from the standard weight-length relationship (“1”):

$$W_i = a(\overline{L}_i)^b$$

where W_i is the weight of an animal in size-class *i*, $\bar{L}_i$ is the mid-point of size-class *i*, and *a* and *b* are the parameters of the relationship. The first option is specified by providing the estimates of $\ell n a$ and *b*, as follows:

```
# Weight-at-length (males then females)
1
 -15.07077 3.114                                 # Males (sub-zone 1)
 -15.12115 3.135                               # Females (sub-zone 1)
 -15.07077 3.114                                 # Males (sub-zone 2)
 -15.12115 3.135                               # Females (sub-zone 2)
```

The second option is specified as follows:

```
# Weight-at-length (males then females)
2
19.0 21.0 …
19.0 21.0 …
19.0 21.0 …
19.0 21.0 …
```

As for growth, specifications for weight-at-length must be provided for all sub-zones for which data are provided and not just those that will be assessed.

B.7d Egg production versus size

The next biological parameter is the relationship between size and egg production. Three options are available. The first option (3) is to enter egg production-at-length for each size-class while the other options (1 and 2) are respectively:

$$Q_i = \begin{cases} 0 & \text{if } L_i < L_{\text{mat}} \\ (1+e^{-\ell n 19(\bar{L}_i - L^m_{50})/(L^m_{95}-L^m_{50})})^{-1}(\tilde{a}+\tilde{b}W_i) & \text{otherwise} \end{cases}$$

or

$$Q_i = \begin{cases} 0 & \text{if } L_i < L_{\text{mat}} \\ (1+e^{-\ell n 19(\bar{L}_i - L^m_{50})/(L^m_{95}-L^m_{50})})^{-1}\tilde{a}W_i^{\tilde{b}_i} & \text{otherwise} \end{cases}$$

where Q_i is egg production for animals in size-class *i*, L_{mat} is the lowest length-at-maturity, L^m_{50} is the size-at-50%-maturity, L^m_{95} is the size-at-95%-maturity, and $\tilde{a}$ and $\tilde{b}$ are the parameters of the relationship between weight and egg production for mature females. The “mature biomass” output from the software is “egg production” when $\tilde{a}$ and $\tilde{b}$ relate to the relationship between weight and egg production, and the biomass of mature animals when $\tilde{a}$=0/$\tilde{b}$=1 (option 1) or $\tilde{a}$=1/$\tilde{b}$=1 (option 2). When $\tilde{a}$=1/$\tilde{b}$=0, the “mature biomass” output is the number of mature individuals.

Options 1 and 2 are entered as follows (the first input for each sub-zone is L_{mat}, the next two inputs are L^m_{50} and L^m_{95}, and final two inputs are $\tilde{a}$ and $\tilde{b}$).

```
# Egg production versus length
1                      # Specified pars (1 or 2) or raw data (3)
```

```
64  80.09 81.745 0.181 2.969       (sub-zone 1)
64  80.09 81.745 0.181 2.969       (sub-zone 2)
```

or

```
# Egg production versus length
2                      # Specified pars (1 or 2) or raw data
64   76.251   84.392     .000000181409    2.969 (sub-zone 1)
64   80.088   94.458     .000000181409    2.969
```

Option 3 involves providing the (relative) number of eggs for each size-class

```
# Egg production versus length
3
0 0.01 0.02 …
1.e+6 1.e+6 1.e+6 …
0 0.01 0.02 …
1.e+6 1.e+6 1.e+6 …
```

B.7e Proportion of females which spawn in each time-step

One value indicating the proportion of females which spawn in each time-step must be provided here, and for each subzone. For example, the below input assigns the same proportions across time-steps for each of two sub-zones.

```
# Proportion spawning
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1
```

B.8. Selectivity and vulnerability

The exposure of an animal to harvest depends on its size and sex and this exposure can change over time owing to the impact of changes over time in vulnerability[2]. Some fleets (e.g. commercial and recreational catches) are also impacted by the Legal Minimum Length (LML), which can also change over time. The vulnerability of an animal of a given size and sex is the product of size-specific vulnerability and sex-specific vulnerability.

B.8a General vulnerability parameters

The parameters related to vulnerability must be specified for each sub-zone for which data are provided and not just for the sub-zones that will be assessed. Vulnerability is specified separately for each fleet (fishery and survey). The nine numbers which define vulnerability are:

- (i) the vulnerability type (0=pre-specified; 1=logistic function of length; 2=estimate size-class-specific values; the vulnerability for a fleet can be made equal to that for another fleet by setting this input to the negative of the index for the fleet to which vulnerability should be set),
- (ii) whether vulnerability is sex-specific (1=No; 2=Yes),
- (iii) the number of vulnerability parameters which are to be estimated if vulnerability is estimated for a subset of the size-classes (see above at input “(i)”),
- (iv) whether this fleet is subject to an LML (0=No; >1=Yes),
- (v) a pointer to the number of the time-blocks which determines how the LML is time-blocked (0=No time-blocks, 1+=the time-block concerned; see Section B.1),

---

[2] “Selectivity” in this model is not gear selectivity, but rather the combined effects of selectivity and availability – hence the term “vulnerability”

(vi) whether vulnerability for the fleet is time-blocked (which allows vulnerability to change over time) (0=No; 1=Yes),

(vii) the type of high-grading function (0=no high-grading; 1=high-grading is a logistic function of length; 2=high-grading is a knife-edged function of length),

(viii) does the fleet return spawners live (1=Yes; >1 no), and

(ix) is this fleet subject to high-grading of live animals(1=Yes; >1 no).

The following example shows (I) specifications for a fleet (fleet 1) which has sex-specific logistic vulnerability and is subject to an LML, (II) a fleet (fleet 2) the vulnerability for which mimics that for fleet 1, (III) a fleet (fleet 3) which has time-blocked vulnerability, and (IV) a [survey] fleet (fleet 4) which has the same vulnerability pattern as fleet 1, is not subject to the LML and which reports (live) spawners, (live) high-graded animals, and legal animals separately.

```
# Type Sex Est Par MLS?  MLS blks Selex Blks HG Spn HG
     1   2       0    1         0          0  0   0  0   # Fleet 1
    -1   2       0    1         0          0  0   0  0   # Fleet 2
     1   2       0    1         0          1  0   0  0   # Fleet 3
    -1   2       0    0         0          0  0   1  1   # Fleet 4
```

Note that if vulnerability is to be mirrored, the row for the fleet for which vulnerability is estimated must be provided before the rows for any fleets for which mirror vulnerability is to be set, i.e. the following input will not work because vulnerability for fleet 2 is not defined when the input for fleet 1 is being analysed.

```
# Type Sex Est Par MLS?  MLS blks Selex Blks HG Spn HG
    -2   2       0    1         0          0  0   0  0   # Fleet 1
     1   2       0    1         0          0  0   0  0   # Fleet 2
```

B.8b Vulnerability check parameter

This input is a check to ensure that the user and the program agree on how many vulnerability parameters should be estimated. Note that if high-grading is estimated (a value other than “1” in the first HG column above), the count of vulnerability parameters includes the parameters needed to define high-grading as a function of length (2 for an increasing logistic function, 1 for a knife-edged function, and 3 for a declining logistic function). A warning is output (and the program stops) if there is no agreement on the number of estimated parameters!

```
# Vulnerability parameters (used only)
16
```

B.8c Bounds, initial values and phase for estimated parameters

This set of inputs specifies the bounds, initial values (only used if the PIN file is ignored), and phases for each of the vulnerability parameters (this is only for those fleets which are included in the sub-zones included in the assessment). For example, for two sexes and logistic length selectivity the input would be as below.

```
# Fleet 1 (Sex 1; Fishery Area 1)
-5 10 1 -8
-5 10 1 -8
# Fleet 1 (Sex 2; Fishery Area 1)
-5 10 1 -8
-5 10 1 -8
```

B.8d Pre-specified vulnerability

NOTE: This section is not currently implemented by the code (rock 23) and should be ignored.

If vulnerability is pre-specified (a value of 0 in Section B.8a-i) rather than being estimated (a value of 1 or 2 in B.8a-i) for some of the fleets which are included in the assessment (fleets which are not included in the assessment can be ignored) the next input needs to list the values for vulnerability. This input should be blank if vulnerability is not pre-specified for any fleet.

```
# Vulnerability
# =-=-=-=-=-===
1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00
```

B.8e Legal Minimum Limits

The next set of inputs provides specifications for each LML. These scenarios are linked to fleets using the "`With MLS`" and "`MLS blocks`" options above (see Section B.8a, items "iv" and "v"). The order of the inputs is that of fleet and LML scenario. Thus, the input would be as follows if there are two fleets and fleet 1 has time-blocked LMLs:

```
110 105      # Default LMLs for fleet #1
110 110      # LMLs for fleet #1 in the second block
110 110      # Default LMLs for fleet #2
```

B.8f Relative vulnerability of females

This input specifies the relative vulnerability of females to males. The values input here are the lower and upper bounds, initial values (only used if the PIN file is ignored; see Section D.f for how to specify the relative vulnerability parameters using a PIN file) and phases for each parameter. There must be one relative vulnerability parameter for each time-step.

```
# Female vulnerability
0 1 0.5 -1    # Bounds, initial value, phase for time-step 1
0 1 0.5 -1    # Bounds, initial value, phase for time-step 2
```

B.9. Environmental variables related to catchability

It is necessary to specify the bounds, initial values (not used unless the PIN file is ignored; See Section D.k for how to specify initial values for these catchability parameters using a PIN file) and phases for the parameter which links catchability to environmental variables if catchability is related to an environmental variable (see Section A.7b). For example, the input here is as follows if there are two linkages, and the value of the second parameter is known:

```
# Environmental parameters
-1 1  0.1  1
-1 1  0.0 -1
```

This input should be blank if there are no environmental variables that are linked to catchability.

B.10. Specifications related to fitting

These specifications relate to the weight assigned to:

(a) the fishery length-frequency data (see Section A,9),
(b) the survey length-frequency data (see Section A.9),
(c) the catch-rate data (see Section A.7),
(d) the catch-in-numbers data (see Section A.8),

(e) the tagging data related to movement (see Section A.11),
(f) the tagging data related to growth (see Section A.12), and
(g) the puerulus data (see Section A.10).

```
# Weights and likelihoods
# =-=-=-=-=-=-=-=-=-=-=-=
0.001       # Weight (Fishery fleet Length-frequency)
0.001       # Weight (Survey fleet Length-frequency)
2.0         # Weight (CPUE data)
1.0         # Weight (catch-numbers data)
0.1         # Weight (tagging data (movement))
0.1         # Weight (tagging data (growth))
0           # Weight (Puerulus)
```

Weights can also be specified by fleet within a data type. This involves setting the following input to “1” (setting it to zero means that all fleets should be weighted equally).

```
# Detailed weights (1=Yes)
# ======================
1
```

If this input is set to “1”, the weights are entered next (no further input is required if “0” was entered). The weights are entered in the order of cpue, catch, and male and female length samples, with an example as follows for the case of 10 catch-rate series (the 2nd of which is to be down-weighted by 0.5), two catch series, and three fleets for each of males and females:

```
# Now provide the weights
1 0.5 1 1 1 1 1 1 1 1                             # Cpue
1 1                                               # Numbers
1 1 1                                             # Length (male)
1 1 1                                             # Length (female)
```

B.11. Initial conditions

This section provides the inputs related to how the initial conditions are specified. The two inputs:

(a) determine how many times the iterative procedure used to calculate the vector of numbers-at-length at the start of the first year for which catches are available is applied (higher leads to more accurate results, but can slow the calculations down substantially), and
(b) the length of time over which the initial fishing mortality is averaged.

```
# Initial conditions
# =-=-=-=-=-=-=-=-=-
10              # Loop counter for initial conditions
5               # Years over which to tune
```

B.12. Concluding input

The final input is a test number. This input is used to check that the input has been correctly specified.

```
# Test Number
123456
```

The input is echoed to output files (CHECK.OUT and SOUTH.CTL). These files should be examined to ensure that the input has been entered correctly.

C. The GENERAL file

The file GENERAL.ROC provides various control parameters.

(a) Whether parameter estimation should occur (values of 1+) or whether the model should simply be projected forward using the values in the PIN file (or the values specified at the initial parameters fields if the PIN file is ignored) (value of -1 and less). Setting this parameter to “-1” is useful when checking that the input files are correctly specified.

```
1           # estimate or project
```

(b) the level of diagnostics to be produced. Values of 1 and 2 are normal, but higher values (which can produce enormous amounts of output) should be selected if problems with input files are to be diagnosed

```
2             # 1 basic diagns; 2 additional diags; 3 ??
```

(c) specifications for MCMC sampling. These two inputs are currently ignored.

```
1000         # Burn-in form MCMC
1            # Thinning rate for MCMC
```

(d) The next input should be set to 1 to check that the model is correctly calculating the initial state. It should not be changed by the user.

```
-1           # Check the initial state
```

(e) The next input in this file allows the user to ignore the PIN file (value=1) and base estimation on the values specified in the CTL file. This option should be selected if many runs are to be done and the user wishes to ensure that she/he can replicate the results.

```
0            # Set this to "1" to ignore the PIN file
```

(f) The next input in this file is a flag which indicates that a control rule should be applied. It was created for a different project and the value associated with this parameter should generally be set to 0.

```
0            # Number of projection years
```

(g) The next three input specify the current TACC, the minimum TACC and the maximum TACC. These inputs are only used if the number of projection years is non-zero.

```
250000                  # last TAC
100000                  # Minimum TAC
500000                  # Maximum TAC
```

(h) The next five inputs in this file are (i) the year which is specified to the reference year for the projections, (ii) the year a recovery plan started, (ii) the year a rebuilding plan started, (iv) the amount by which the TACC can be reduced, and (v) the amount by which the TACC can be increased. These inputs are only used if the number of projection years is non-zero.

```
1951                    # Reference year
2010                    # Start of recovery plan
2010                    # Start of rebuilding plan
0.5                     # Amount by which TACC can be reduced
```

```
1.1                    # Amount by which TACC can be increased
```

D. The PIN file

The file ROCK23A.PIN file contains the initial values for the parameters of the model (used if the PIN file is not ignored; see Section C.e). The performance of the non-linear minimization method used to estimate the values for the parameters depends critically on how close the initial values are to the best estimates for the model parameters. AD Model Builder reads the PIN file ignoring any comment lines (lines which start with “#”). Therefore, the program may actually run (but not give sensible results) even if the wrong number of initial values is provided. The PIN file can be checked by setting the value for input “e” in “GENERAL.ROC” file to “-1” and examining the file ROCK23A.PAR. It should match ROCK23A.PIN. The file CHECK.OUT also lists the number of parameters of each type which need to be specified.

The general structure of the PIN file is as follows (the specifications are provided for an assessment with two sub-zones and 10 “settlement” residuals – the number of “settlement” residuals is calculated by the program depending on the number sub-zones and start-end settlement years (see Section B.4b*)*; the PAR file should be checked to ensure that the correct number of “settlement” residuals are specified).

(a) The parameter values relate to the logarithms of the average “settlement”s, $\overline{R}_0^z$ (see Section B.4a); for the case in which there are two sub-zones:

```
# log_R0
10 12
```

(b) The steepness of the stock-recruitment relationship (see Section B.4c):

```
# Steepness
1.000
```

(c) The vulnerability parameters (see Section B.8c). Number of vulnerability parameters depends on how vulnerability is specified. For the case in which there are two commercial vulnerability blocks, the number of parameters is 4 (2 parameters of the logistic curve x 2 blocks); note that the parameters are in log-space

```
# SelPars
4 3
4 3
```

Note that parameter values need to be provided (and the number depends on the options specified when defining vulnerability) even if vulnerability is not estimated (phase < 1).

(d) The parameters related to the “settlement” residuals (see Section B.4b). One initial value needs to be provided for each “settlement” year’s residual

```
# Eps (one value for each 1965, 1996, etc.)
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

(e) The parameters related to the split of the annual “settlement” between sexes and “settlement” events (see Section B.4g). Therefore, three values need to be provided if “settlement” occurs twice a year and there are two sexes (there are actually four parameters, but the fourth is simply the difference between the first three and unity):

```
# PrSxSn0
1 1 1
```

(f) The relative vulnerability of females to males for each time-step (see Section B.8f); one initial value should be provided for each time-step. These parameters need to be provided even if the relative vulnerability is not estimated. For example, for 7 time-steps:

```
# VulnEst
1 1 1 1 1 1 1
```

(g) The movement rates (see Section B.6b). The number of values should be equal to the number of movement parameters (twice this if movement is sex-specific). There will be a total of four movement parameters (sub-zone 1 to sub-zone 2 for males (i); sub-zone 1 to sub-zone 2 for females (ii), sub-zone 2 to sub-zone 1 for males (iii); sub-zone 2 to sub-zone 1 for females (iv)) if there are two sub-zones and movement is sex-specific (note that the parameters are in logit space).

```
# EstMovePars
0.1 0.1
0.2 0.1
```

(h) The parameters related to the catchability for FIMS surveys relative to catch-rate series (see Section A.7c). One parameter is needed for each of the FIMS series (which is one less than the number of CPUE Types – see Section A.7).

```
# qF
0.3
```

(i) The parameters related to growth. The number of growth parameters depends on how many sub-zones have growth estimated (rather than being pre-specified or mimicked), the number of time-blocks and whether growth relates to an environmental variable (see Section B.7b). The following example shows how von Bertalanffy growth parameters (i.e. option "2" in Section B.7b) would be specified if (i) there are two growth events each year (so the growth matrix for each year depends on five parameters), (ii) there are two areas, (iii) growth for males in sub-zone 2 mimics that in sub-zone 1, (iv) growth for males in sub-zone 1 is time-blocked (by a blocking structure with 2 blocks), and (v) growth for females in sub-zone 1 is related to an environmental variable.

```
# Growth parameters
200 0.1 10 0.1 10    # Males in sub-area 1 (reference values)
150 0.1 10 0.1 10    # Females in sub-area 1 (reference values)
150 0.1 10 0.1 10    # Females in sub-area 2 (reference values)
200 01 10 0.1 10     # Block 1 values for males in sub-area 1
200 01 10 0.1 10     # Block 2 values for males in sub-area 1
0 0 0 0 0            # Environmental links for females in sub-zone
2
```

The initial values are set so that time-varying growth is not present (although it could be estimated to be once the program is complete; whether parameters are changed from their initial values depends in the phases set when setting the bounds for the vulnerability parameters). Note also that because the growth parameters are linked to the environmental covariates by an exponential transform, “0” corresponds to no effect of an environmental covariate on the parameter.

If the growth matrices are pre-specified (option “1” in Section B.7b) then a single input parameter is needed.

```
# Growth parameters
1
```

(j) The probability of incorrectly measuring an animal when it is recaptured (see Section B.7b).

```
# Alpha:
0.248432
```

(k) The parameters related to the parameters which link catchability to environmental indices (see Section B.9). The example input below would be entered if three environmental variables were linked to catchability.

```
# Q pars
0 0 0
```

The final entry in the PIN file must be:

```
# Dummy
0
```

E. Outputs

The main output files are ROCK23A.REP and DIAGFILE. The files CHECK.OUT, SOUTH.DAT and SOUTH.CTL echo the input and should be checked to ensure that the data have been entered correctly. A file AEPOUTPUT.OUT is created if the projection options are used. SAOutput.Out contains outputs tailored to South Australian analyses.

E.1. ROCK23A.REP

The file ROCK23A.REP lists the detailed population dynamic outputs:

(1) The harvest rates by year, time-step and sub-zone (note that the output starts at the start of burn-in period)
(2) The exploitable biomass by year, time-step and sub-zone (note that the output starts at the start of burn-in period)
(3) The time trajectory of egg production by sub-zone (separate sub-zones in each column).
(4) The time trajectory of “settlement” by sub-zone (separate sub-zones in each column).
(5) The fits to catch-rate data.
(6) The fits to the catch-in-numbers data.
(7) The fits to the length-frequency data.
(8) The fits to the larval data
(9) The midpoints of each size-class, weight-at-length, maturity-at-length, egg production-at-length.
(10) Vulnerability, relative female vulnerability, the size-breakdown of the “settlement”.
(11) The size-transition matrices
(12) The numbers-at-length by year, time-step and sub-zone

(13) The vulnerability (total, landed and discarded), and relative probability of high-grading.

E.2. DIAGFILE

The file DIAGFILE summarizes the fits to the data further. The data in this file are less formatted that those in ROCK23A.REP to make graphical summarises of the data easier to construct. The specific information provided in DIAGFILE is:

(1) The fits to catch-rate data.
(2) The fits to the catch-in-numbers data.
(3) The fits to tagging data (note that the fit to the tagging data is aggregated by numbers released and recaptured by sub-zone and time of release/recapture).
(4) The fits to the length-frequency data.

References

McGarvey, R., Feenstra, J.E., 2001. Estimating length-transition probabilities as polynomial functions of premoult length. Marine and Freshwater Research 52, 1517-1526.

Glossary of terms

FIMS: Fisheries Independent Monitoring Survey

Fishery Fleet: A fleet for which the removals are sufficiently large that they should be taken into account; fishery fleets reflect commercial, recreational or illegal removals.

Fleets. Fleets are either fisheries or surveys. The key difference between fishery and survey fleets are that the catch by a fishery fleet is removed from the population while that by a survey fleet is not. Fleets are associated with a sub-zone[3] (although there is an exception to this for size-composition information). There may be (usually will be) several fleets in each sub-zone.

MPA: Marine Protected Area.

Phase: The phase assigned to a parameter indicates when (and if) it should be estimated. The value of a parameter with a phase of -1 (or less) is not estimated, but set to its initial value. The value of a parameter with a phase of 1 is estimated in the first round of minimizations (and in all subsequent rounds) whereas a parameter with a phase of 2 is estimated in the second and all subsequent rounds of minimizations.

Recruitment: The number of animals growing to be larger than minimum legal size (i.e. becoming available to fishery).

Settlement: The number of animals entering the model.

Sub-zone: Sub-zones are areas within the model; each “sub-zone” is associated with a local population.

Survey fleet: A fleet for which the removals are negligible.

---

[3] The terms “sub-zone” and “area” are used interchangeably in this document.

Time-step: 1 for an annual model or 2+ for a monthly or weekly model.

Vulnerability: The combined impact of gear selectivity (the relative probability among size- and sex-classes of being captured) and of availability (the relative probability among size- and sex classes of being located in the fishery).

Appendix 3: Model specification for the ROCK projection model for testing future management strategies

André E. Punt and John Feenstra

A. Introduction

The population dynamics model on which the projections are based is identical to that on which the stock assessment is based. However, this model is extended to implement future removals and translocation, as well as to calculate the output statistics related to costs, revenues and profits. The parameters of the growth transition matrix, natural mortality, and settlement may also change over time in response to changes in environmental covariates.

This technical description does not outline how changes in minimum legal sizes (MLS) are implemented because this is identical to how MLSs are implemented in the assessment model.

B. Catches and effort dynamics

The catches by year, time-step, and sub-zone are supplied by the user when conducting the assessment or are calculated by applying a stock assessment model to simulated data and then applying some form of harvest control rule to the output form of the stock assessment. However, the projections are based on specifying annual catches by the recreational fishery as well as by "catch limit area"[4] (for the commercial fishery). It is therefore necessary to calculate the catches by year, time-step and sub-zone (by the commercial, recreational and illegal fisheries) to project the model forward.

The total recreational catch during year *y*, $C_y^{\rm rec}$, is either specified by the user or calculated using an exploitation rate strategy where the exploitation rate may be a function of the relative exploitable biomass, i.e.

$$C_y^{\rm rec} = \bar{F}^{rec} (\bar{B}_{y,1}^{e,rec} / \bar{B}_{y*,1}^{e,rec})^{\varpi} \bar{B}_{y,1}^{e,rec} \tag{B.1}$$

where $\bar{F}^{\rm rec}$ is the average exploitation rate over the last three years of the assessment period, $\bar{B}_{y,1}^{e,rec}$ is the exploitable biomass available to the recreational fleet during time-step 1 of year *y* (the biomass available to the fleet at the start of the time-step), *y** is the second to last year before the end of the assessment, and ϖ is a parameter to allow recreational effort to increase when biomass is high and vice versa. The split of the catch for the recreational fleet (f_{rec}) by time-step and sub-zone is assumed to be static so that the catch during time-step *i* of year *y* in sub-zone *z* by the recreational fishery, $C_{y,i}^{f_{rec}}$, is given by:

$$C_{y,i}^{f_{rec}} = C_y^{\rm rec} \phi_i^{{\rm rec},z} \tag{B.2}$$

where $\phi_i^{{\rm rec},z}$ is the proportion of the recreational catch which is taken from sub-zone *z* during time-step *i* ($\sum_i \sum_z \phi_i^{{\rm rec},z} = 1$).

---

[4] A catch limit area is a set of sub-zones (although it could be the entire region modelled) for which a catch limit is set. There may be several catch limit areas to implement, for example, regional TACs.

The catch by the illegal fleet (f_{ill}) associated with the commercial fleet (f) during time-step *i* of year *y* in sub-zone *z*, $C_{y,i}^{f_{ill}}$, is assumed to be a (sub-zone- and time-step-specific) proportion of the (landed) commercial catch during time-step *i* of year *y* in sub-zone *z*, i.e.:

$$C_{y,i}^{f_{ill}} = \eta_i^z \, C_{y,i}^f \tag{B.3}$$

where $C_{y,i}^f$ is the commercial catch in sub-zone *z* during time-step *i* of year *y*, and η_i^z is the proportion of the commercial catch in sub-zone *z* during time-step *i* which is taken illegally.

The value of $C_{y,i}^f$ depends on the catch limit for the catch limit area in which sub-zone *z* is found, as well as the effort dynamics model. The default effort dynamics model operates by first assigning catches to time-step within the year and then using a second model to allocate catches to sub-zone. Letting $C_{y,i}^{\mathrm{Comm},Z}$ denote the commercial catch during time-step *i* of year *y* for the catch limit area in which sub-zone *z* is found, Z:

$$C_{y,i}^{\mathrm{Comm},Z} = \lambda_i \, C_y^{\mathrm{Comm},Z} \tag{B.4}$$

where λ_i is the (pre-specified) proportion of the catch limit for the catch limit area in which sub-zone *z* is found which is taken during time-step *i*, and $C_y^{\mathrm{Comm},Z}$ is the catch limit for year *y* for the catch limit area in which sub-zone *z* is found.

$C_{y,i}^f$ is then allocated to sub-zone *z* using the formula:

$$C_{y,i}^f = \tilde{\lambda}_{y,i}^z \, C_{y,i}^{\mathrm{Comm},Z} \tag{B.5}$$

where $\tilde{\lambda}_{y,i}^z$ is the proportion of $C_{y,i}^{\mathrm{Comm},Z}$ for year *y,* time-step *i,* and sub-zone *z*:

$$\tilde{\lambda}_{y,i}^z = \Omega_{y,i}^z \, / \sum_{z' \in Z} \Omega_{y,i}^{z'} \tag{B.6a}$$

$$\ell n \Omega_{y,i}^z = a_i^z + b_i^z \, B_{y,i}^{e,f} + c_i^z \tilde{\lambda}_{y,i-1}^z + d_i^z \tilde{\lambda}_{y-1,i}^z \tag{B.6b}$$

where *a*, *b*, *c*, *d* are coefficients[5], and $B_{y,i}^{e,f}$ is the exploitable biomass available to fleet *f* during time-step *i* of year *y* (mid-time-step *i* of year *y*).

---

[5] The values for parameters of Equation B.6b are estimated for the application to Tasmania by fitting it to the proportion of the catch by sub-zone from 1997-2006 (data for 1994-96 are ignored because there was a month in 1995 in which the catch from all sub-zones was zero). The likelihood function is assumed to be multinomial, but this is largely arbitrary because the model is not being fit to data for which the precision is known. In any case, the reason for this model is projection and not inference. Note that Equation B.6b depends on the predicted (rather than observed) proportions in the previous period (same year) and previous year (same period). For the first year used to calibrate the model (1997), the observed rather than predicted proportions are assumed.

Equation B.6b allows the split of the catch among sub-zones (within a catch limit area) to respond to the biomass in each sub-zone as well as the split of the catch among sub-zones in the previous time-step and in the current time-step in the previous year. The constant (*a*) reflects inertia in the extent to which catch varies spatially.

Equation B.6 can lead to catches which exceed the exploitable biomass in a sub-zone. In this case, the catch for the sub-zone concerned is set to the exploitable biomass and the catch which cannot be taken from the designated sub-zone is allocated to the remaining sub-zones in proportion to the catch limits allocated using Equation B.6a. Alternatively the effort (number of pot-lifts) required to take the catch for a sub-area in a given time-step may exceed the pre-specified maximum. In this case, the catch is carried forward into the next time-step.

C. Generation of future settlement

There are four main ways to generate future settlement:

- Select a settlement at random from those for a pre-specified series of years.
- Generate settlement as a log-normal variate with a default value for mean and coefficient of variation from the assessment parameters.
- Generate settlement as a log-normal variate with a pre-specified coefficient of variation, and mean given by the Beverton-Holt stock-recruitment relationship.
- Read in a single settlement array of values (one for each future year) from an input file, which is deterministic and identical for each simulation.

The mean recruitment may be adjusted to account for changes over time of mean recruitment.

D. Translocation

The dynamics of translocated animals generally follow those of non-translocated animals (for example translocated animals contribute to spawning and can be caught during fishing[6]). Translocated animals are selected at random (within a pre-specified range of size-classes) from the sub-zone in which they were taken and become indistinguishable from the animals in the sub-zone to which they are translocated after a pre-specified time. Between translocation and being indistinguishable from other animals, the biological parameters for translocated animals may differ from those for the animals in the sub-zones from which they were taken and to which they were relocated. The following options are available.

- Natural mortality for a translocated animal can exceed the nominal rate before the animal becomes indistinguishable.
- The animal may not produce eggs (even if it is mature) for a pre-specified time after being located.
- Egg production as a function of length can change smoothly between that for the sub-zone from which the animal was taken and that to which it was relocated:

$$Q_l = (\chi^{\rm mat})^t Q_l^{\rm From} + (1-\chi^{\rm mat})^t Q_l^{\rm To} \qquad \text{(D.1)}$$

  where $Q_l^{\rm From/To}$ is egg production for animals in size-class *l* in the sub-zone from which the animal was taken (From) and to which it has been relocated (To), *t* is the time since the relocation occurred, and $\chi^{\rm mat}$ is a parameter

---

[6] However, translocated animals cannot change sub-zones until they become indistinguishable from the animals in the sub-zone to which they were translocated.

which determines how quickly egg production changes from the original to the new sub-zone.

- Growth as a function of length can change smoothly between that for the sub-zone from which the animal was taken and that to which it was relocated:

$$\mathbf{X}_i^s = (\chi^{\text{grow}})^t \mathbf{X}_i^{s,\text{From}} + (1-\chi^{\text{mat}})^t \mathbf{X}_i^{s,\text{To}} \qquad \text{(D.2)}$$

where $X_i^{s,\text{From/To}}$ is the size-transition matrix for animals of sex *s* during time-step *t* in the sub-zone from which the animal was taken (From) and to which it has been relocated (To), and χ^{grow} is a parameter which determines how quickly egg production changes from the original to the new sub-zone.

E. Costs, revenue and profit

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

$$P_y = \frac{1}{(1+\beta)^{y-y_S}} \left[\sum_z \sum_i (R^z_{y,i} - \tilde{C}^z_{y,i}) - \tilde{F}_y \right] \qquad \text{(E.1)}$$

where P_y is the (discounted) profit during year *y*, β is the discount rate, y_S is the first year of the projection period, $R^z_{y,i}$ is the revenue generated from commercial fishing in sub-zone *z* during time-step *i* of year *y*, $\tilde{F}_y$ is the fixed cost during year y, and $\tilde{C}^z_{y,i}$ is the (variable) cost of commercial fishing in sub-zone *z* during time-step *i* of year *y*.

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

$$R^z_{y,i} = \sum_l \sum_s p^{s,z}_{y,i,l} W^{s,z}_l \tilde{H}^{s,z}_{y,i,l} N^{s,z}_{y,i,l} e^{-Mt_i/2} \qquad \text{(E.2)}$$ [7]

where $N^{s,z}_{y,i,l}$ is the number of animals of sex *s* in size-class *l* in sub-zone *z* at the start of time-step *i* of year *y*, $\tilde{H}^{s,z}_{y,i,l}$ is the exploitation rate on animals of sex *s* in size-class *l* and sub-zone *z* at the start of time-step *i* of year *y, M* is instantaneous rate of natural mortality (assumed to be independent of sex, size, sub-zone, and time), t_i is the duration of time-step *i*, $p^{s,z}_{y,i,l}$ is the (pre-specified) price of a lobster of sex *s* in size-class *l* and sub-zone *z* during time-step *i* of year *y,* and $W_l^{s,z}$ is the mass of an animal of sex *s* in size-class *l* and sub-zone *z*.

The default model for the (variable) costs of commercial fishing in sub-zone *z* during time-step *i* of year *y* is given by:

$$\tilde{C}^z_{y,i} = c^z_i \, C^f_{y,i} / (q^f_i B^{e,f}_{y,i}) \qquad \text{(E.2)}$$

---

[7] The natural mortality term is adjusted for animals which have been relocated, but are not yet indistinguishable for the animals in the sub-zone to which they have been relocated.

where c_i^z is the cost for a single potlift during time-step *i* in sub-zone *z*, and q_i^f is the catchability coefficient for time-step *i* and commercial fleet *f*.

The default model for the (fixed) costs of commercial fishing during year y is given by:

$$\tilde{F}_y = \kappa \Omega_y \qquad \text{(E.3)}$$

where Ω_y is the number of boats during year y, and κ is the annual fixed cost for each boat.

Appendix 4: User manual for the ROCK projection model for testing future management strategies

André E. Punt and John Feenstra

This document outlines how to specify the values included in the input files for PROJECT.FOR. It does not detail the mathematical specifications for how the projections are conducted. These are available in Appendix 3.

A. SOUTH2.GEN, SOUTH2.DAT AND SOUTH2.CTL

These three files contain the inputs on which the stock assessment was based. They are created automatically using the program ROCK23A.TPL (although they are named SOUTH.GEN, SOUTH.DAT and SOUTH.CTL). However, if there are several sub-zones and the assessment program was run for each sub-zone in turn (for example because the amount of data is such that it is impossible computationally to assess all sub-zones simultaneously), it may be necessary to run the assessment program for all sub-zones at once (but stop it quickly) to obtain the SOUTH.DAT and SOUTH.CTL files which are then correctly specified for a multi-sub-zone analysis. It should never be necessary to directly modify the values in these files. The files SOUTH.GEN, SOUTH.DAT and SOUTH.CTL should be renamed SOUTH2.GEN, SOUTH2.DAT and SOUTH2.CTL.

B. PROJ2.DAT

This file contains most of the specifications needed to conduct a set of projections (other main inputs are provided in the files MLS.DAT, ECO.DAT, TRANS.DAT, FORCING.TXT, GENDATA.DAT, and a HCR.IMP.* file). The contents of PROJ2.DAT are as follows. Note that the format of this file (and all of the other files which provide input for PROJECT.FOR) ***must*** follow the outline below (including comment and blank lines). Failure to do this will result in program crashes.

Specify the years for which catch and effort data are to be output (to the file “EFFORT.IMP”) to allow the effort dynamics model (currently (September 2013) not used, but two values are required) to be fitted:

```
# Effort years
1994 2007
```

Specify the first year and time-step for the projection (these values must be considered in relation to the last year of the assessment period). The results of the assessment for any time-steps beyond the time specified here are overridden during the projection.

```
# First projection year
2008
# First period for quota year
3
```

Specify for how many years the projections should be undertaken:

```
# Number of projection years
50
```

Specify the number of parameter vectors (“0” for the MLE and a number larger than 0 to conduct projections for multiple parameter vectors), the number of projections to be conducted for each parameter vector (100 – 1,000 is recommended if projections are based on the MLEs and 1-10 if they are based on multiple parameter vectors), and whether the projections involve stochastic recruitment (“1”) or not (“0”).

```
# Number of parameter vectors (0=MLE)
0
# Number of replicates for each parameter vector
100
# Projections are stochastic (1=Yes)
1
```

The set of parameter vectors is produced automatically by the stock assessment model (using the “-mceval” option in ADMB) and this set of vectors should be stored in the file MCMC.INP.

The next input allows the user to change the random number seed from the default value.

```
# Random number seed
-989010
```

The next input allows the user to reduce the number of output files to only the major output files by entering “0”.

```
# Produce all output files (1=Yes)
0
```

The next input is used to define the period of time-steps for defining the pre-recruitment index (which may be used if a harvest strategy is employed), consisting of the first time-step and the last time-step.

```
# First and last periods for calculating the pre recruitment index
2 6
```

The next input indicates which user-defined harvest control strategy is employed. -1 results in no harvest control rule being applied and instead requires yearly catches to be input from a file, 1 means the South Australian rule involving a fixed Cpue-TACC schedule table will be applied, 4 will employ the constant exploitation rate HCR rule (SARDI). Options 1 and 4 read from input files HCR.IMP.SA and HCR.IMP.CER respectively. For details on the harvest control rules see the fishery management and stock assessment reports, and also sections on input for files HCR.IMP.SA and HCR.IMP.CER.

```
# Harvest control rule (-1 for none).
1
```

The next input allows users the ability to consider runs in which the default catch limits (TACs) are multiplied by a constant (this avoids having to retype all of the catches):

```
# Catch multiplier
1.00
```

The next set of inputs relate to the generation of settlement (all inputs must be provided even if they are not going to be used) for each sub-zone in the model. The first input specifies which settlement model to use. The available options are: “0”: select a future settlement from the settlements from a pre-specified series of historical years, “1”: generate future settlement from a log-normal distribution based on the mean and coefficient of variation from the assessment results, “2”: generate settlement as a log-normal variate with a pre-specified coefficient of variation, and mean given by the Beverton-Holt stock-recruitment relationship., “3”: Values read in a single settlement array of values (one for each future year) from an input file (“SettlRs.CSV” containing a line for start-finish future years followed by a line per year for each settlement value), which is deterministic and identical for each simulation. Note that trends in settlement can also be specified using the forcing functions built into the projection program (see the discussion of the input for the file “FORCING.TXT”) below. The second set of inputs is the ranges of years to be used when applying methods 1 and 2, each column corresponding to an area. The final input in this section determines for how many past years (negative values) of the assessment model-estimated settlement values should be replaced by generated values (this will be necessary if the data available to the assessment do not provide information regarding some of most recent settlements):

```
# Option defining recruitment
1         # How to generate future settlement (1=Normal)
 1998 1998 1998 1998 1998 1998 1998 1998 1998 1998 1998
 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007
   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
```

The projection program outputs reference biomass using the reference length specified in the file NORTH.DAT. It also outputs reference biomass using a second reference length (one value for each sub-zone):

```
# Reference selectivity (alternative)
   60   60   60   60   60   60   60   60   60   60   60
```

The next set of inputs allows the user to specify that growth is temperature-dependent (“1). Use of this option is not generally recommended. If the first option below is not equal to 1 then the second option value is of no consequence, and the third option relates to temperature modelling in case recruitment option 2 was chosen above.

```
# Option defining growth
0
# Maximum fraction of increase in growth that is possible
1
# Option for Temp-rec (1=off)
1
```

The next input is the economic discount rate, β. A blank line needs to follow the discount rate.

```
# Discount rate (per annum)
0.075
```

The following input specifies how catch limits are to be set. The example below involves setting two catch limits set each year (for different sets of sub-zones). The first catch limit will apply to sub-zones 1-5 and the second catch limit will apply to sub-zones 6-8. The list of sub-zones is followed by a blank line.

```
# Number of catch limit areas
2
```

```
# Regions per catch limit area
5 3
# Sub-zones
1  2  3  4  5
6  7  8
```

The next input indicates for each zone [row] which fleets relate to the commercial catch, the recreational catch and the illegal catch. There are two sub-areas in the example below. There is a commercial, recreational and illegal fleet in the first sub-area but only a commercial fleet in the second sub-area. The last line of input must be followed by a blank line. Note that fleets must be specified for MPAs (although the input for MPAs is logically “-1 -1 -1”).

```
# Fleet pointer (comm, rec, illegal)
1  2  4
3 -1 -1
```

The next input specifies how future recreational catches are to be specified. The options are 0 to provide a time-series of catches in mass, -1 to set the month 1 exploitation rate of the recreational fleet to the average month 1 exploitation rate by this fleet over the last three years of the assessment period, and -2 same as option -1 but involving an extra factor of a power function of the ratio of the current exploitable biomass available to the recreational fleet (month 1) to the exploitable biomass available to the recreational fleet in the second-to-last year of the assessment. The power of this relationship is the second of the two sets of inputs.

```
# Rec catch (0=Pre-specified;1=Dynamic; 2= Dynamics with power
0      # option
5.0    # Power parameter
```

The next input specifies the effort allocation algorithm to employ. This algorithm is used to allocate catches among time-steps and sub-zones. The effort allocation algorithms are user-written, although there is a default algorithm (#1). Currently (September 2013) only an option value of 1 is expected.

```
# Which effort allocation option
1
```

The next two inputs should not be changed from the defaults below (unless you know the code). Note the empty line between first and second inputs.

```
# runtype options
1

0
```

The next input provides a limit on the number of pot-lifts in each time-step. If the model-predicted number of pot-lifts exceeds the maximum, the catch is re-set (reduced). The first value input determines which of two options is used to re-set the catch, 0 if maximum catch is sought that can be caught with less than stipulated maximum effort, or 1 if catch is to correspond to that exactly obtainable by the maximum effort. The effort for each time-step can be set to a very large number to remove this effect from the analysis.

```
# Maximum effort by period
1
 1   10000000
```

```
 2   10000000
 3   10000000
```

The next input specifies the fraction of the total recreational catch which occurs in each sub-area [columns] and time-step within year [rows]. This input is also followed by a blank line. Note that the numbers in the block of input must add to 1 (although the program will rescale the input anyway).

```
# Time-step  RecreationCatch_as _prop_TARC
#    1   2   3   4   5
1     0.07039     0.01856     0.0223      0.02869     0.01898
2     0.04873     0.01285     0.01544     0.01986     0.01314
3     0.0195      0.00514     0.00618     0.00795     0.00526
4     0.03621     0.00955     0.01147     0.01475     0.00976
5     0.01538     0.00405     0.00487     0.00627     0.00414
```

The next input specifies the ratio of the illegal catch to the commercial catch (by sub-zone [columns] and time-step within the year [rows]). This input is followed by a blank line.

```
#        1     2     3     4     5
1     0.02  0.02  0.02  0.02  0.02
2     0.02  0.02  0.02  0.02  0.02
3     0.02  0.02  0.02  0.02  0.02
```

The next input lists the annual catch limits. The input is in the form: year, recreational catch, and commercial catch (one column for each catch limit area). There should be one line for each year of the projection period. For example, if catch limits are to be set for two catch limit areas, the input will be of the form:

```
#Projected catches (Recreational, Commercial-1 Commercial-2)
2008     150000 1523000 100000
2009     150000 1470000 100000
2010     150000 1470000 100000
```

The inputted commercial catches will be ignored if the projections are based on a harvest strategy which involves conducting a future stock assessment (or applying a harvest control rule).

The final input in PROJ2.DAT is the dead discard rate, one per fishing fleet.

```
# Future dead discard rate (per fleet).
0.083 0
```

C. MLS.DAT

This file lists the values for minimum and maximum legal size limits (by sex and fishing fleet). The first line is a comment line and each subsequent line (one line for each year of the projection period), lists the year followed by, for each fleet, the minimum legal length for males, the maximum legal length for males, the minimum legal length for females, and the maximum legal length for females, with the same four columns repeated on each line for additional fishing fleets (such as recreational catch).

```
# Label line
2011  98.5  1000  98.5  1000  98.5  1000  98.5  1000
2012  98.5  1000  98.5  1000  98.5  1000  98.5  1000
```

D. ECO.DAT

This file lists the data on prices and costs that are used to compute net profit and hence net present value. Blank lines must separate each of the input sections.

The format for the price data is a row for each combination of sex, time-step, length-class, each of which is a column, with prices listed for each sub-zone. Note that data must be provided for all length-classes even those which are below the MLS.

```
# Prices by Sex, time-step, size-class, and sub-zone
  1  1  1   .00000   .00000   .00000
  1  1  2   .00000   .00000   .00000
  1  1  3   .00000   .00000   .00000
….
  1  1 12 70.00000 70.00000 70.00000
  1  1 13 70.00000 70.00000 70.00000
```

Variable cost data are supplied as a matrix with rows for sub-zones (data should not be supplied for MPAs) and columns for time-steps (and a header line), e.g. for a case with three time-steps and two sub-zones:

```
# costs by sub-zone (row) and time-step (column)
34.18853955 34.18853955 34.18853955
34.18853955 34.18853955 34.18853955
```

The next input specifies how variable costs are to be calculated. Entering “0” at this input results in the cost per pot being constant and equal to the values given at the previous input. Entering a value other than 0 will lead to a user-specified variable cost function being used (the routine which implements variable costs `VariableCostSpec` is found in the file USESPECFNS.FOR; currently (September 2013) not specified).

```
# Option for variable costs (0)
0
```

The next two inputs specify how fixed costs are calculated. The first input is the fixed cost and the second is the specification for the model of fixed costs. Entering “0” at the second input results in fixed costs being assumed to be zero, entering “1” at the second input results in the fixed costs being assumed to be equal to the first input multiplied by the number of boats, and entering a value of “2” for the second input is the same as input option of “1” but with the number of boats component in the cost formula replaced by a user-specified fixed cost function (`FixedCostSpec`, found in the file USESPECFNS.FOR).

```
# Default fixed costs
10
# Option for fixed costs (0=None; 1=Fixed; 2=User defined)
1
```

The final input in ECO.DAT is information on the rate at which prices and costs will change in the future and the number of boats in each future year. The three columns for each year are: year, trend in prices and costs, and annual number of boats. The second and third column values multiply the prices and variable costs respectively.

```
# Trends in prices, costs, and boats
2008    1    1   1
2009    1    1   1
```

E. TRANS.DAT

This file contains the specifications needed to conduct projections in which translocations occur. The first input in this file is a flag. If it is set to 2, translocations do not occur and no further input is required, else if it is 1 translocation is assumed.

```
# Are there translocations (1=Yes,2=No)
1
```

The next two inputs specify when in the sequence of events during the year (e.g. growth, natural mortality, survival, etc.) translocation occurs and the number of years between an animal being translocated and having the same natural mortality rate, growth transition matrix and egg production as animals of the same size (and sex) in the sub-zone into which it was translocated.

```
# When do translocations occur (in the sequence of processes)
5
# Number of years before complete immersion
2
```

The next four inputs specify how the biological processes of egg production, growth and natural mortality change between an animal being translocated and becoming identical to an animal of the same size (and sex) in the sub-zone into which it was translocated (full details of the meaning of these three parameters are given in the technical description of the projection model).

```
# Proportion of SOM after one year (chi-mat)
0.5
# Years without spawning
1
# Proportion of Growth after one year (chi-grow)
0.5
# Extra mortality (expressed as survival)
0.95
```

Although the last input above allows growth (i.e. the entries of the size-transition matrix) to change smoothly between that for the sub-zone from which an animal was taken and the sub-zone to which it was translocated, growth may not behave that way. Therefore, it is possible to specify a number of additional growth transition matrices and have growth for translocated animals change smoothly from the additional growth transition matrix to the growth transition matrix for the sub-zone to which the animals were translocated. At present, the only way to specify such “transitional” matrices using is using option “3” (see Section B.7 of the user manual for the assessment program). Note that these additional matrices are numbered immediately beyond those specified for the assessment program (i.e. 22 size-transition matrices were supplied to the assessment program in the example below) and to an sub-zone numbered one higher than the number of sub-zones in the assessment (e.g. 12 if there were 11 sub-zones in the original model).

```
# Number of growth matrices (same format as main)
2
# Specific parameter values
  .00002520  -.48180200   .00000000   .00000000
  .45395000  -.02118710   .00000000   .00000000
 2.25602000  -.12205900   .00000000   .00000000
….
  .05241170   .00000000   .00000000   .00000000
  .02066320   .00000000   .00000000   .00000000
  .22005900   .00000000   .00000000   .00000000
```

```
# Number of extra sub-zones
1
# Look up table
23 24 0 0
```

The final set of inputs specifies the details of the translocations. The input for each translocation is the year and period in which the translocation occurred, the sex of the animals translocated (separate lines of input must be provided for each sex), the sub-zone from which the animals were taken and the sub-zone to which they were translocated, the number of animals which were translocated, the range of size-classes from which the translocated animals were taken (assumed to be random within that range), and the growth transition matrix to use when computing growth immediately after translocation).

```
# Number of translocations
8
# Translocation data (Year period sex removal-sub-zone release-sub-
zone N Min-size Max-size Source growth matrix)
2008 3 1 11 5 200000 1 5 11
2008 3 2 11 5 200000 1 5 11
```

F. FORCING.TXT

This file provides the specifications for how growth, settlement, natural mortality, and catchability change over time. The first input in this file indicates whether any of these quantities change over time. The remaining inputs in this section are only needed if “1” is entered at this first input.

```
# Should anything change over time (1=Yes)
0
```

The first set of specifications in this file relate to changes over time in growth. The first input in this set specifies whether growth changes over time (first option greater than 0). The rest of the input for time-varying growth needs to be provided even if growth does not change over time. The second input is the amount by which the initial population is scaled (so 1 means no scaling). The third set of inputs are the reference values for ℓ_∞, κ, and σ (see Section 3.2 of the model specifications) by sub-area and sex, while the final set of inputs are the factors which multiply these reference values for each year of the projection period (one row for each year of the projection period, with the order for the multipliers the same as for the reference values for the growth parameters). This input needs to be followed by a blank line.

```
# Should growth change over time (1=Yes)
1
# Multiplier for initial size-structure
1
# Base parameters
 102.4 3.5 12.4 97.4 3.5 9.1 102.5 3.5 28.6 85.7 3.5 17.8
# Parameter adjustment
2009 1.000 1.000 1.000   …
2010 1.000 1.500 1.000   …
2011 1.000 2.000 1.000   …
```

The next set of specifications in this file relate to changes over time in mean settlement. There is one row of input for each year from the start of the assessment period which lists the year followed the multiplier on mean settlement, one for each sub-zone. This input must be followed by a blank line.

```
# Multiplier on settlement
2009 1.000 1.000
2010 1.000 1.000
```

The third set of specifications in this file relate to changes over time in natural mortality. There is one row of input for each year, since the start of the initialisation year of the assessment model, which lists the year followed by the multiplier on natural mortality. This input must be followed by a blank line.

```
# Multiplier on natural mortality
2009 1.000
2010 1.000
```

The final set of specifications in this file relate to changes over time in catchability for each catch rate series. There is one line of input for each year of the projection period, which lists the year followed by the multiplier on the reference catchability (which is provided to the projection model using the file 'Input.par').

```
# Multiplier on catchabilty
2009 1.000 1.000
2010 1.000 1.000
```

G. GENDATA.DAT

This file specifies how future data are to be generated. The values in this file are used if a feedback control management strategy will be used to set the catch limits for the future.

The first input is an indicator for whether the data will be deterministic (no observation error, "1") or stochastic (with observation error, any other value). This value should be set to "1" when attempting to assess the deterministic behaviour of a management strategy. This input must be followed by a blank line.

```
# Are data deterministic (set to 1 for deterministic data)
1
```

The second block of inputs relate to future catch-rate data. The inputs for future catch rate data are: (a) the number of catch-rate series in the future, (b) the catch-rate series identifier for each of these series, and (c) what is the extent of (log-normal) observation error about the future catch-rate. This input must be followed by a blank line.

```
# CPUE data
# =========
# Number of series
2
# Fleets for series
1 2
# Sigmas
0.1 0.1
```

The third set of inputs relates to future catch-in-numbers data, and may be of interest if catch number data is fit as part of simulations (currently (September 2013) this is not enabled in the code for the harvest strategies considered in this project). The inputs for future catch-in-numbers data are: (a) the number of catch-in-numbers series in the future, (b) series identifiers, and (c) what is the extent of (log-normal) observation error about the future catches-in-number. This input must be followed by a blank line.

```
# Catch in numbers
# ==================
# number of series
2
# Fleets for series
1 3
# Sigmas
0.1 0.1
```

The next input may be ignored (unless you know the code), except a value is required to be entered.

```
# Frequency of future Growth data
1
```

The final set of inputs in this file relate to future data on the length composition of the fish and survey (research) catches, and may be of interest if length data is fit as part of simulations (currently (September 2013) this is not enabled in the code for the harvest strategies considered in this project). The first input in this section is the number of future sets of length-frequency data, the second set of inputs indicates the fleet, the type of length-frequency data (1-male-commercial, 2-female-commercial, 3-male+female-commercial, 4-male-research, 5-female-research, and 6-male+female-research), and the type of length-frequency (1=landed; 2=released spawners; 3=high-graded animals). In the example below, there will be four sets of future length-frequency data, two of these sets relate to samples from the commercial catch and two to samples from survey catches (fleets 1 and 3 are fishing fleets while fleets 4 and 5 are survey fleets). The final set of inputs is a row for each future year indicating the effective sample size (in this case 100 for each fleet x year) and the weight assigned to the data when applying the stock assessment model (in this case 1).

```
# Length-frequency data
# =====================
# Number of series
4
# Fleet and type
1 3 1
3 3 1
4 6 1
5 6 1
# Specification (Year, EffN, Assumed N)
2009 100 100 100 100 1 1 1 1
2010 100 100 100 100 1 1 1 1
2011 100 100 100 100 1 1 1 1
```

H. INPUT.PAR

The file INPUT.PAR contains the estimates for the parameters. This file is required to have values that match that of ROCK23A.PAR (which is automatically produced by the assessment program), and additionally (past the dummy value) is expected to contain catchabilities (obtained from the assessment output). First catchabilities are read corresponding to catch rates proportional to legal-size abundance, one line for each fishing fleet and one column for each time-step (use a value of 0 if no catch rate series applies for a time-step). Next is input for catchabilities corresponding to catch rates proportional to under-size abundance (which may be used as a proxy for pre-recruitment index used in some harvest strategies), and these follow the same format as for the previous input matrix. However, if there are multiple sub-zones, and each is assessed separately, it is necessary to combine each INPUT.PAR file into a single file.

I. EFFORTA.DAT

The values in this file are used in effort dynamics model to apportion yearly catch among time-steps. The first line is a comment (i.e. non-data line), followed by a single line of data containing a value for each time-step and which should sum to 1 (though the code does automatic normalisation to ensure a sum of 1). An empty line follows next, followed by a group of four pairs of lines each for a comment and a row of input (one column per time-step). These inputs correspond to coefficient constants “a”, “b”, “c”, and “d” in equation B.6b in Appendix 3, and may be set to values of 0 if a single whole zone is the subject of the projection.

J. HCR input files

If either option 1 or 4 was provided as input for the HCR option value in PROJ2.DAT, then either HCR.IMP.SA or HCR.IMP.CER respectively needs to exist and have values as outlined below.

J.1. HCR.IMP.SA

The first input is an option to indicate if the full HCR should apply from the start year for the first Cpue-TACC (C-T) schedule (note: “cpue” = catch rate): “0” means use the TACC value provided in PROJ2.DAT, “1” means use the HCR.

```
#
#
0
```

The next input is the value of the PRI (pre-recruit index) threshold. If the PRI fell below this value then no increase in TACC will be allowed by the HCR.

```
#
1.3
```

The next inputs are the maximum number of cpue bin increases and the maximum number of cpue bin decreases for the HCR. So for the input illustrated below the new TACC determined by this HCR may be based on up to 10 cpue rule categories lower than the current categories, but only one above the current category.

```
#
1 10
```

The next input is the number of C-T schedules to be implemented over the projection period.

```
#
1
```

The next input is the starting years for each of the C-T schedules.

```
#
2012
```

The next input is the number of cpue bins for each C-T schedule.

```
#
6
```

The next input is the cpue bin in the table chosen to reflect the fixed Cpue-TACC schedule table situation just prior to the first HCR implementation.

```
#
4
```

The next input are the C-T schedules, one table at a time with a blank line between each table.

```
#
0       950
0.5     950
0.6     950
0.8     1250
1.0     1400
1.2     1600
#
#
```

The next input is an indicator to flag which South Australian zone is involved, 1 for SZ and 2 for NZ.

```
#
1
```

The next input indicates whether to engage special treatment for the case of very low cpue, “1” means engage this, and any other value results in no such treatment. The next few inputs pertain specifically to this treatment option, and applies only for the SZ.

```
#
1
```

The next input is the threshold cpue value.

```
#
0.5
```

The next value is the number of years before which the TACC will be set to 0 (prior to which TACC is determined via the exploitation levels given two inputs down).

```
#
3
#
#
```

The next input is a vector of constant yearly exploitation rate levels (first year of treatment, second year,…,0,0). Note: Two extra inputs of “0” need to be appended.

```
#
0.5 0.4 0.3 0 0
```

The next input is the intercept coefficient parameter value to derive a value for cpue when no fishing took place (due to closures, i.e. TACC set to 0 as noted above).

```
#
1070.4
```

The next input is the corresponding (to intercept above) value for the slope coefficient parameter value.

```
#
2579.4
```

The next set of inputs relate to the special treatment to be implemented if the TACC has remained at the upper level for a given (see the inputs below) number of years and cpue remains above a given high level (see the inputs below), and applies only to the SZ. The first input is to indicate whether to engage the treatment, “1” meaning to engage and any other value means not to engage.

```
#
```

```
0
```

The next input is the number of years back to check.

```
#
3
```

The next input is the threshold cpue value.

```
#
1.8
```

The next input is the new TACC value (if conditions are met set by above inputs).

```
#
1760
```

The next set of inputs relate to a special treatment regime to implement when cpue has been low in the NZ. The next input indicates whether to engage this treatment, “1” meaning to engage and any other value means not to engage.

```
#
0
```

The next input provides the number of different cpue (and TACC) values that may be applied according to the treatment.

```
#
0
```

The next input provides the vector, of length equal to the above input value, of sliding-scale cpue values, in descending order. These values are cpue limits defining cpue bins for which fixed TACC values are set (next input).

```
-1
```

The next input provides the vector of corresponding TACC values.

```
-1
```

J.2. HCR.IMP.CER

The first input in this file is an option to indicate if the full HCR should apply from the start year indicated in the next input below this one: “0” means use the TACC value provided in PROJ2.DAT, “1” means use the HCR.

```
#
#
0
```

The next input is the starting year.

```
#
2012
```

The next input vector is the A (intercept) and B (slope) linear relationship coefficients used to determine the cpue limits for the rule.

```
#
564.98 1945
```

The next input is the vector holding the minimum, target, and maximum exploitation rate values.

```
#
0.35 0.40 0.45
```

The next input is the maximum permitted TACC value. (set this very high to effectively not use this restraint.)

```
#
100000
```

The next input is the PRI limit control value; i.e. don't increase TACC if PRI is too low.

```
#
1.3
```

The remaining inputs relate to the special treatment for the case of very low cpue. These are identical to the values input as described for the input file HCR.IMP.SA.

K. Output files

The projection program produces several output files. Three of these DATA.ALL, FITS.ALL and SUM.ALL are used for debugging purposes and can be ignored. The two main types of output files are PROJECT.OUT and a series of CSV files which all provide summaries of the projections. There are also JUNK.OUT and HCR.OUT, the former of which contains user-defined harvest control strategy diagnostics and the latter is another general summary file with much overlap with the PROJECT.OUT and CSV files (and includes some South-Australian definitions for indices).

K.1. PROJECT.OUT

This file contains output for each simulation and year. The first line contains broad column header labels only, and the three numbers on the next line being respectively the total number of simulations, the number of parameter vectors and the number of simulations for each parameter vector (the total number of simulations is the product of the number of parameter vectors and the number of simulations for each parameter vector).

The output line for each simulation includes a column for the parameter vector number (0 for the MLE), the replicate for that parameter vector, and the year (starting in the first year of the assessment period). The remaining columns are described below:

- Exploitable biomass in the middle of the fishing season during the first time-step (by area and in total).
- Exploitable biomass just before the fishery in the first time-step (by area and in total).
- Settlement (by area).
- The expected settlement (by area).
- The expected temperature (by area).
- Egg production, or mature biomass (depending on maturity settings from SOUTH2.CTL) at the time of spawning (by area and in total).
- The reference biomass based on the reference length in SOUTH2.DAT (by area and in total). Total biomass in mid month 1 above the reference size given in assessment run (per area and total).
- The reference biomass based on the reference length in SOUTH2.DAT (by area and in total) before the fishery. Total biomass in start month 1 above the reference size given in assessment run (per area and total).
- Revenue from commercial fishing (by area and in total).
- Variable cost from commercial fishing (by area).
- Fixed cost (non-area specific).
- Total variable cost.
- Total profit from commercial fishing (after discounting).
- The annual catch (commercial, recreational and illegal) by area and the total commercial catch.
- Total costs (inclusive of variable and fixed).

K.2. CSV output files

The CSV output files are listed below, along with the quantities they contain and short description. These files contain output for each simulation and year.

K.2.a. PROJECTA.CSV

- **Exploitable biomass**
  Exploitable (commercial) biomass at middle of month 1 (per area and total).
- **Exploitable biomass 2**
  Exploitable (commercial) biomass at start (pre-fishing) of month 1 (per area and total).
- **Exploitable biomass (M)**
  Exploitable (commercial) male biomass at middle of month 1 (per area and total).
- **Exploitable biomass (F)**
  Exploitable (commercial) female biomass at middle of month 1 (per area and total).

K.2.b. PROJECTB.CSV

- **Egg production**
  Egg production, or mature biomass, depending on assessment run inputs (per area and total).

K.2.c. PROJECTC.CSV

- **Recruitment**
  Settlement (per area and total).
- **Mean recruitment**
  Trend recruitment (per area and total).
- **Mean temperature**
  Mean temperature (per area and mean over areas).

K.2.d. PROJECTD.CSV

- **Reference biomass (mid month 1)**
  Total biomass in month 1 above the reference size given in the assessment run (per area and total).
- **Reference biomass 2 (mid month 7)**
  Total biomass in month 7 above the reference size given in projection input (per area and total).
- **Total reference2 biomass month 1**
  Total biomass at start month 1 in area 1 above the reference size given in projection input.
- **Total reference2 numbers month 1**
  Total population at start month 1 in area 1 above the reference size given in projection input.
- **Harvest fraction month 1 reference2**
  Yearly fraction harvested as total commercial catch (area 1) divided by total biomass at start month 1 in area 1 above the reference size given in projection input.
- **Total reference2 biomass average yearly**
  Average total biomass across months in area 1 above the reference size given in projection input.
- **Harvest fraction average yearly reference2**

Yearly fraction harvested as total commercial catch (area 1) divided by average total biomass across months in area 1 above the reference size given in projection input.

K.2.e. PROJECTE.CSV

- **Commercial catch**
  Yearly commercial catch (per area and total).
- **Recreational catch**
  Yearly recreational catch (per area and total).
- **Illegal catch**
  Yearly illegal catch (per area and total)
- **Total catch**
  Total yearly catch across areas and the three types.

K.2.f. PROJECTF.CSV

- **Revenue**
  Yearly revenue from commercial fishing (by area and in total).
- **Pots**
  Yearly commercial fishing effort as no-error potlifts (by area and in total).
- **Variable costs**
  Yearly variable cost from commercial fishing (by area and in total).
- **Non-discounted profit**
  Yearly total profit from commercial fishing (before discounting).
- **Fixed costs**
  Yearly fixed costs (non-area specific).
- **Discounted profit**
  Yearly total profit from commercial fishing (after discounting).
- **Discount factor**
  The discount rate (start year of projection as reference year).
- **Total costs**
  Yearly total commercial costs (inclusive of variable and fixed).
- **Mean price**
  Yearly total commercial revenue divided by total commercial catch weight.

K.2.g. PROJECTH.CSV

- **Catch-per-unit-effort**
  Yearly commercial catch rate, based on no-error potlifts (by area and in total).
- **Revenue-per-unit-effort**
  Yearly revenue divided by no-error potlifts (by area and in total).
- **Non-discounted profit-per-unit-effort**
  Yearly total non-discounted profit divided by no-error potlifts.

K.2.h. PROJECTI.CSV

- **PRIy**
  Yearly commercial (for area 1) inferred pre recruit numbers catch rate (“pre recruitment index”) based on both errors in potlifts and in the inferred pre recruit numbers.
- **PRIyv2**
  Yearly commercial (for area 1) inferred pre recruit numbers catch rate (“pre recruitment index”) based on both no-errors in potlifts and in the inferred pre recruit numbers.
- **PRIvy3**

Yearly commercial (for area 1) inferred pre recruit numbers catch rate (“pre recruitment index”) based on errors in potlifts and no-errors in the inferred pre recruit numbers.

K.2.i. PROJECTJ.CSV

- **ExploitB Month1**
  Exploitable (commercial) biomass at start of month 1 (for area 1).
- **Catch in numbers**
  Yearly total commercial catch in numbers (for area 1).
- **Number exploitable month 1**
  Exploitable (commercial) population at start of month 1 (for area 1).
- **Mean weight**
  Yearly total commercial catch weight divided by catch number (area 1).
- **Number CPUE**
  Yearly total commercial catch rate by numbers (area 1).
- **Total legal biomass month 1 SA def**
  Total biomass at start month 1 in area 1 above the legal size.
- **Total legal numbers month 1 SA def**
  Total population at start month 1 in area 1 above the legal size.
- **Harvest fraction month 1 SA def**
  Ratio of total commercial catch weight to total biomass at start month 1 in area 1 above the legal size.
- **Effort proj with error data in past**
  Total yearly commercial effort (with errors, area 1).
- **Effort proj without error data in past**
  Yearly total commercial effort as potlifts (no errors, area 1).
- **Recruits above LML**
  Yearly total number of legal size recruits (area 1).
- **Reference2 biomass (start month 7)**
  Total biomass at start month 7 above the reference size given in projection input (area 1).
- **Total legal biomass average yearly SA def**
  Yearly average biomass over start of month in area 1 above the legal size.
- **Harvest fraction average yearly SA def**
  Total yearly commercial catch weight divided by yearly average biomass over start of months in area 1 above the legal size.

Appendix 5: EconSearch report for Tasmania, based on the 2012 survey

Economic Indicators
for the Tasmanian
Rock Lobster Fishery
2010/11

A report prepared for

Seafood Cooperative Research Centre

Prepared by

econsearch

7 November 2012

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Contents

Tables

Figures

Abbreviations

CFAC	Commercial Fisheries of Australia Council
CRC	Cooperative Research Centre
GOS	gross operating surplus
GVP	gross value of production
HKD	Hong Kong dollar
RBA	Reserve Bank of Australia
RecFAC	Recreational Fishers of Australia Council
R&M	repairs and maintenance
SA	South Australia
SARDI	South Australian Research and Development Institute
SARLAC	South Australian Rock Lobster Advisory Council
Seafood CRC	Seafood Cooperative Research Centre
TACC	total allowable commercial catch
TBCC	Total Boat Cash Costs
TBI	Total Boat income
TRLFA	Tasmanian Rock Lobster Fishers Association
USD	United States dollar
UTAS	University of Tasmania

Executive Summary

Catch and Gross Value of Production…

Total catch in the fishery followed was consistent (constrained by quota) between 1998/99 and 2006/07 but declined in subsequent years. In 2010/11 total catch (1,225 tonnes) was 17 per cent below that in 1998/99 (1,485 tonnes).

The value of catch in the Tasmanian Rock Lobster fishery has fluctuated between years but has generally followed an increasing trend since 1999/00. The total value of catch in 2010/11 ($63.6 million) was 50 per cent higher than the value of catch in 1997/98 ($42.3 million). The increase in value is wholly attributable to an overall increase in price and despite a 17 per cent decline in catch.

Between 1999/00 and 2010/11 the 82 per cent increase in nominal average price of Southern Zone Rock Lobster was equivalent to a 31 per cent rise in real price.

The relationship between (USD) exchange rates, and the price of Rock Lobster over the period 1997/98 and 2010/11 is similar to the relationship between (HKD) exchange rates and the price of Rock Lobster over the same period. The coefficient of correlation is moderately positive in both cases (0.49 for USD and 0.29 for HKD), which is counter to expectations. Other factors influencing demand, such as the increasing wealth and size of the middle class in Asia, are likely to be responsible for the overall increasing trend in price of Rock Lobster.

Financial Performance Indicators…

Between 1999/00 and 2010/11, the total number of active vessels in the fishery declined from 291 to 236. The average income per boat followed a slight increasing trend, despite some year-to-year fluctuations. In 2010/11 average income was around $270,000 (in nominal terms).

Profit…

Gross operating surplus (GOS) was calculated excluding imputed wages for operator and family members. The average GOS of all boats in 2010/11 was estimated to be almost $37,000 (Table 3.4).

Profit at full equity is a measure of the profitability of an individual licence holder, assuming the licence holder has full equity in the operation. It is a useful absolute measure of the economic performance of fishing firms. Average profit at full equity in 2010/11 was approximately $58,000. Profit at full equity was highly variable within the fishery, around -$37,000 in the lowest quartile and almost $118,000 in the highest quartile[8].

Rate of return to capital…

The rate of return to boat capital (i.e. fishing gear and equipment) for all boats is relatively high (15.3 per cent), however the rate of return to total capital (including the licence value) is much lower, estimated to average 3.9 per cent in 2010/11. The rate of return to fishing gear and equipment is -6.1 per cent in the first quartile and 47.5 per cent in the fourth quartile. Rate of return on total boat capital is -1.7 per cent in the first quartile and 27.1 per cent in the fourth.

---

[8] The sample of survey participants was ranked by return on total fishing capital and divided into quartiles.

Economic Rent…

When an economic rent is generated in a fishery and there are transferable licences, the rent represents a return to the value of the licences. The 2010/11 aggregate value of licences was estimated to be $258.6 million (236 licences with an average value of $1.1 million per licence or $23,000 per pot). An annual economic rent of -$10.1 million represents a return of -3.9 per cent to the capital value of the fishery.

1. Introduction

EconSearch was included in a consortium of research organisations (including CSIRO, Department of Primary Industries Victoria, SARDI, SARLAC, Southern Rock Lobster Ltd and University of Tasmania) to undertake a CRC Seafood funded project to develop bioeconomic models for the Southern Rock Lobster fisheries. This project is part of a series of projects within the CRC on decision support tools for fisheries, with the other projects directed to Western Rock Lobster, Prawns and Abalone. In each case, biological and economic data are combined to enable stakeholders to make decisions about their fishery with the goal of enhancing profitability.

In this project EconSearch were responsible for the collection of economic information from licence holders. This report presents the data collected from licence holders in the Tasmanian Rock Lobster Fishery in the form of economic indicators.

The economic indicators detailed in this report include:

- gross value of production (catch and price);
- financial performance indicators (income, costs, profit, and return on investment);
- economic rent; and
- external factors influencing the economic condition of the fishery.

2. Method of Analysis and Definition of Terms

2.1 Survey of Licence Holders in the Fishery

The questionnaire for the survey of licences holders was based on previous economic indicator surveys conducted in South Australia. The questionnaire was drafted by the consultants and subsequently modified after consultation with the other project participants at the University of Tasmania.

In May 2012, a presentation was made about the project and survey at the annual Tasmanian Rock Lobster Fishers Association (TRLFA) meeting in Launceston. Copies of the survey were handed out to interested fishers and contact details were obtained. A list of names of licence holders who had indicated their willingness to participate in the survey was also provided by the University of Tasmania. These two groups made up the sampling frame for the survey, which included a total of thirty licence holders in the Tasmanian Rock Lobster Fishery. The time period for which information was sought was the 2010/11 financial year.

In June 2012, licence holders were contacted by telephone. The purpose of the initial call was to remind and inform licence holders about the survey, and to ascertain their willingness to participate. A total of 20 responses were received which represented 8 per cent of the total active vessels in the fishery.[9]

Of the 33 licence holders who initially indicated that they might be willing to participate, 13 did not provide a response to the survey for the following reasons:

- could not be contacted (following initial contact);
- too busy; and
- concerns about how the data would be used.

2.2 Definition of Terms[10]

Total Boat Income (TBI): refers to the cash receipts received by an individual firm and is expressed in dollar terms. Total boat income is calculated as catch (kg) multiplied by ‘beach price’ ($/kg). Total boat income is the contribution of an individual licence holder to the GVP of a fishing sector or fishery.

Total Boat Variable Costs: are costs which are dependent upon the level of catch or, more commonly, the amount of time spent fishing. As catch or fishing time increases, variable costs also increase. Variable costs are measured in current dollar terms and include the following individual cost items:

- fuel, oil and grease for the boat (net of diesel fuel rebate)
- bait
- ice
- provisions
- crew payments
- fishing equipment, purchase and repairs (nets, pots, lines, etc)

---

[9] A vessel is considered ‘active’ if it reports catch in the 2010/11 fishing season (Hartman et al. 2012).

[10] Where possible definitions have been kept consistent with those used by Brown (1997) in ABARE’s *Australian Fisheries Surveys Report*.

- repairs & maintenance: ongoing (slipping, painting, overhaul motor)

Boat Gross Margin: is defined as *Total Boat Income* less *Total Boat Variable Costs*. This is a basic measure of profit which assumes that capital has no alternative use and that as fishing activity (days fished) varies there is no change in capital or fixed costs.

Total Boat Fixed Costs: are costs that remain fixed regardless of the level of catch or the amount of time spent fishing. As such these costs, measured in current dollar terms, are likely to remain relatively constant from one year to the next. Examples of fixed cost include:

- insurance
- licence and industry fees
- office & business administration (communication, stationery, accountancy fees)
- interest on loan repayments and overdraft
- leasing

Total Boat Cash Costs (TBCC): defined as *Total Boat Variable Costs* plus *Total Boat Fixed Costs*

Gross Operating Surplus: (GOS) is defined as *Total Boat Income* less *Total Boat Cash Costs* and is expressed in current dollar terms. GOS may be used interchangeably with the term Gross Boat Profit. A GOS value of zero represents a breakeven position for the business, where TBCC equals TBCR. If GOS is a negative value the firm is operating at a cash loss and if positive the firm is making a cash profit. GOS does not include a value for owner/operator wages, unpaid family work, or depreciation.

Owner-operator and Unpaid Family Labour: in many fishing businesses there is a component of labour that does not draw a direct wage or salary from the business. This will generally include owner/operator labour and often also include some unpaid family labour. The value of this labour needs to be accounted for which involves imputing a labour cost based on the amount of time and equivalent wages rate. In the above calculations this labour cost can be included simply as another cost so that Gross Operating Surplus takes account of this cost. Alternatively, it can be deducted from GOS to give a separate indicator called Boat Cash Income. Owner-operator and unpaid family labour is separated into variable labour (fishing and repairs and maintenance) and overhead labour (management and administration).

Boat Cash Income: is defined as *Gross Operating Surplus* less *imputed wages for owner- operator and unpaid family labour*.

Boat Capital: includes capital items that are required by the licence holder to earn the boat income. It includes boat hull, engine, electronics and other permanent fixtures and tender boats. Other capital items such as motor vehicles, sheds, cold-rooms, and jetty/moorings can be included to the extent that they are used in the fishing business. The fishing licence/permit value is included in total boat capital.

Depreciation: Depreciation refers to the annual reduction in the value of boat capital due to general wear and tear or the reduction in value of an item over time.

Boat Business Profit: is defined as *GOS* less *Depreciation* less *Owner-operator and Unpaid Family Labour*. Boat Business Profit represents a more complete picture of the actual financial status of an individual firm, compared with GOS, which represents the cash in-cash out situation only.

Profit at Full Equity: is calculated as *Boat Business Profit* plus *rent, interest and lease* payments. Profit at Full Equity represents the profitability of an individual licence holder, assuming the licence holder has full equity in the operation, i.e. there is no outstanding debt associated with the investment in boat capital. Profit at Full Equity is a useful absolute measure of the economic performance of fishing firms.

Rate of Return to Capital: is calculated as *Profit at Full Equity* divided by *Boat Capital* multiplied by *100*. This measure is expressed in percentage terms and is calculated for an individual licence holder. It refers to the economic return to the total investment in capital items, and is a useful relative measure of the performance of individual firms. Rate of return to capital is useful to compare the performance of various licence holders, and to compare the performance of other types of operators, and with other industries.

Gross value of production (GVP): refers to the value of the total annual catch for individual fisheries, fishing sectors or the fishing industry as a whole, and is measured in dollar terms. GVP, generally reported on an annual basis, is the quantity of catch for the year multiplied by the average monthly landed beach prices.

Beach price: refers to the price received by commercial fishers at the "port level" for their catch, and is generally expressed in terms of $/kg. Processing costs are not included in the beach price, as processing operations are assumed to occur further along the value chain. The use of beach prices also removes the effect of transfer pricing by the firm if it is vertically integrated into the value chain.

Cost of management services: in a commercial fishery management services will generally include biological monitoring and reporting; policy, regulation and legislation development; compliance and enforcement services; licensing services; and research.

3. Economic Indicators for the Tasmanian Rock Lobster Fishery

3.1. Catch and Gross Value of Production

The data shown in Table 3.1 indicate that following the introduction of a total allowable commercial catch (TACC) in 1998, catch remained relatively stable for a number of years. Between 1998/99 and 2007/08, at least 98% of TACC was caught (Hartmann et al. 2012). However, from 2008/09 to 2010/11 declining catch rates meant that catch was not constrained by quota, with 3.3 per cent, 7.8 per cent and 7.6 per cent of TACC going uncaught in each respective year. This declining trend in catch prompted a series of cuts to quota, with a three per cent cut between 2008/09 and 2009/10 and a 10 per cent reduction in quota between 2009/10 and 2010/11 both failing to constrain catch. A further 17 per cent cut in quota between 2010/11 and 2011/12, resulted in catch being constrained.

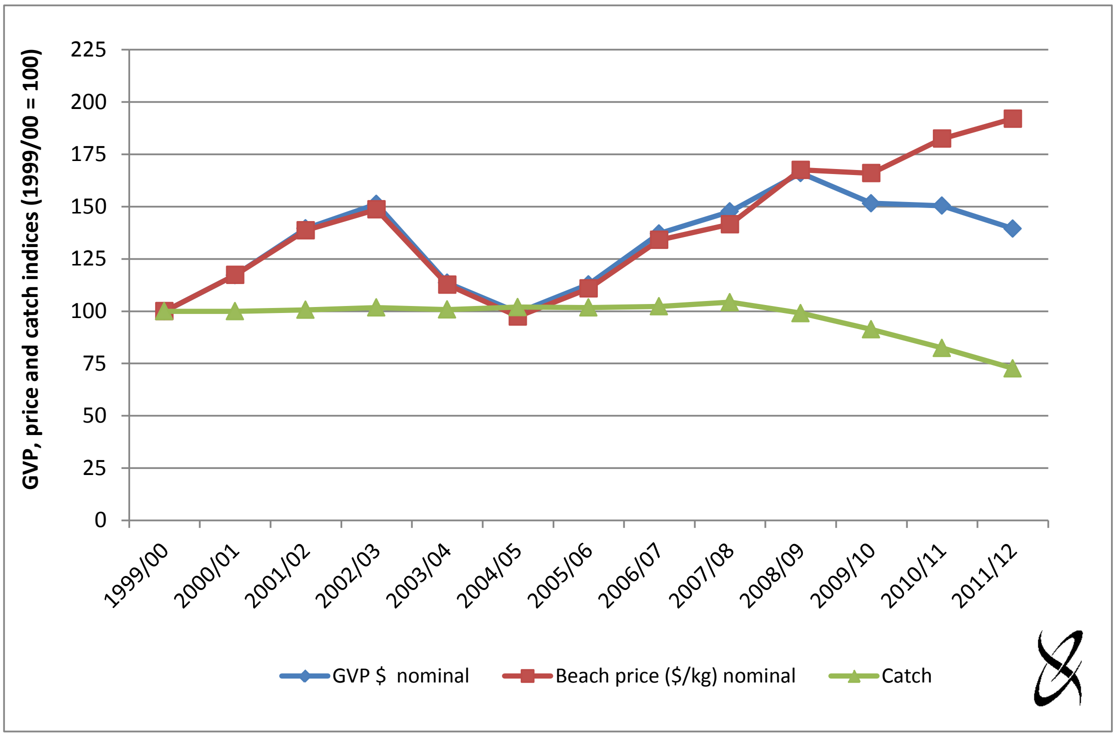
Table 3.1 Tasmanian Rock Lobster catch, value of catch and TACC, 1999/00 to 2011/12

Year	Catch (tonnes)	Value of Catch ($m)	TACC (tonnes)
1999/00	1,486	42	1,503
2000/01	1,485	50	1,503
2001/02	1,495	59	1,503
2002/03	1,512	64	1,524
2003/04	1,497	48	1,524
2004/05	1,515	42	1,524
2005/06	1,512	48	1,524
2006/07	1,520	58	1,524
2007/08	1,550	62	1,524
2008/09	1,472	70	1,524
2009/10	1,357	64	1,471
2010/11	1,225	64	1,324
2011/12	1,079	59	1,103

Source: UTAS, Hartman et al. (2012)

Table 3.1 and Figure 3.1 illustrate how the value of the fishery has changed over the 13 years, 1999/00 to 2010/11. The nominal value of the Tasmanian catch in 2011/12 of $59.0 million was 39 per cent above that in 1999/00. Despite the relatively constant catch between 1999/00 to 2007/08 the value of fishery has increased significantly due mainly to an increase in price. From 2008/09, falls in catch resulted in a slight decrease in nominal gross value of production (GVP) despite continued increases in nominal beach price. Despite the fall in GVP between 2008/09 and 2011/12, fishery GVP still remains well above 1999/00 levels.

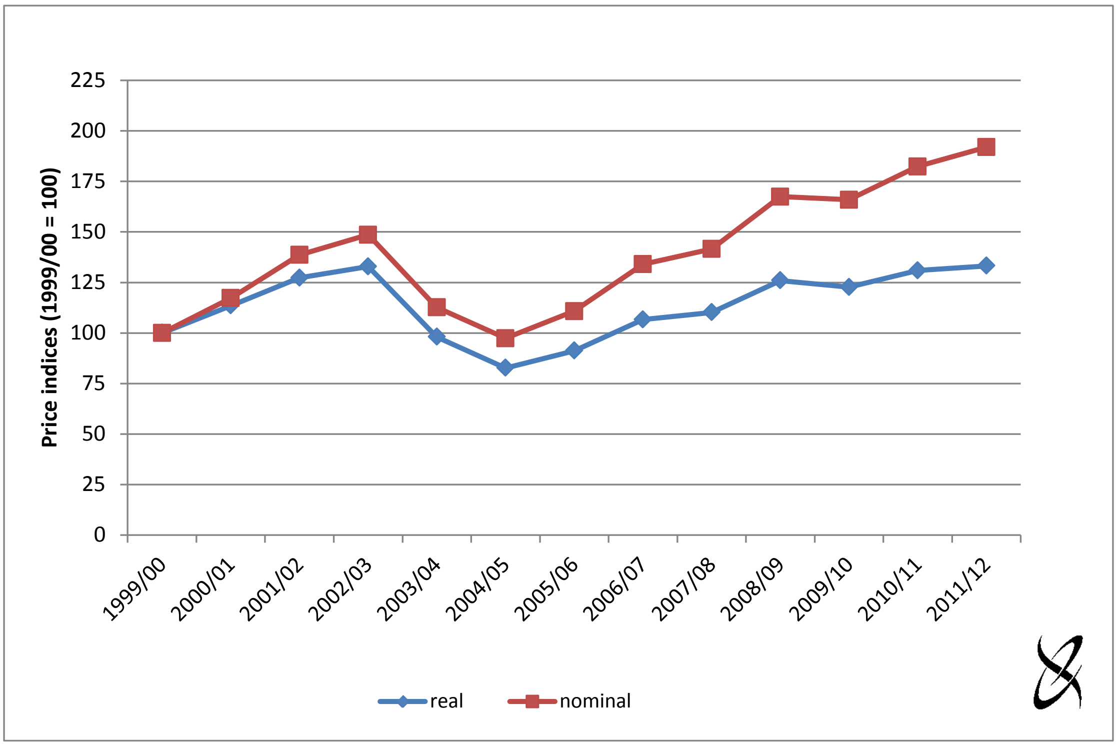
Figure 3.1 GVP, price and catch indices for the Tasmanian Rock Lobster fishery (1999/00=100)



Source: UTAS and Econsearch analysis

The price of Tasmanian Rock Lobster followed an increasing trend between 1999/00 and 2002/03. In the following two years there was a sharp decline in price primarily due to the SARS outbreak which affected demand for Rock Lobster from Hong Kong and other Asian export destinations. Since 2003/04 there has been a constant growth in beach price which reached $54.65/kg in 2010/11. Figure 3.2 shows that the nominal price in 2011/12 was 92 per cent above that in 1999/00, which was equivalent to a 33 per cent real price increase. Due to the fall in catch between 2007/08 and 2011/12, the value of the Tasmanian catch in 2011/12 was actually 3 per cent lower in real terms than it was in 1999/00 (39 per cent higher in nominal terms as noted above).

Figure 3.2 Price index for the Tasmanian Rock Lobster fishery (1999/00=100)



Source: UTAS, ABS (2011) and Econsearch analysis

3.2 Financial Performance Indicators

The major measures of the financial performance of the surveyed boats in the Tasmanian Rock Lobster fishery for 2010/11 are shown in Table 3.2. Estimates are based on the licence holder survey conducted over the period August to September 2012.

It was possible to divide the 2010/11 survey responses into four groups (quartiles) according to rate of return to capital. The first quartile comprises the 25 per cent of boats with the lowest rate of return and fourth quartile includes the 25 per cent with the highest rate of return to capital. The financial performance measures for return to capital quartiles for 2010/11 are provided in Table 3.3.

In addition, the survey responses were divided into two groups according to the average number of pots carried on board for the 2010/11 season. The first group includes those licence holders with 47 pots or fewer (approximately 25 per cent of survey respondents), the second group includes licence holders with more than 47 pots (approximately 75 per cent of survey respondents)[11] The financial performance estimates for the pot groups for 2010/11 are provided in Table 3.4 as an average per boat and in Table 3.5 as an average per pot.

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[11] Number of pots was based on average number of pots carried by the licence holders who participated in the 2012 survey of licence holders.

Income…

The average income per boat for the fishery as a whole was approximately $296,000 in 2010/11 (Table 3.2).

In 2010/11, the average gross income for boats in the first quartile (around $237,000) was approximately 20 per cent below the average ($296,000), while in the fourth quartile, average gross income ($305,000) was 3 per cent above the average recorded for all surveyed boats (Table 3.3).

As expected, the average gross income per boat was positively correlated with the number of pots per boat (Table 3.4). Boats with more than 47 pots, had on average double the income of boat with less than 47 pots. The gross income per pot was also significantly higher for boats with more than 47 pots (Table 3.5).

Costs…

Table 3.2 to Table 3.5 show total costs separated into variable and fixed costs. Variable costs (60 per cent of total boat cash costs in 2010/11) represented a significantly greater proportion of total boat cash costs than fixed costs (40 per cent). This is consistent with other fisheries where the variable costs are generally in the range of 60 to 80 per cent and fixed costs in the range of 20 to 40 per cent.

In 2010/11, for the fishery as a whole, approximately 31 per cent of total boat cash costs were attributable to labour costs (just under $86,000 per boat including imputed unpaid labour), by far the largest individual cost item. The labour costs reported in Table 3.4 are comprised of payments to licence owners and crew as well as an imputed wage to those licence owners and other family members who are not paid a wage directly by the business. Imputed unpaid labour (just over $13,000 per boat for 2010/11) was divided into variable (fishing and repairs and maintenance) and fixed (management and administration) components based on the 2010/11 licence holder survey.

The other significant cash costs were leasing (20 per cent), repairs and maintenance (13 per cent), fuel (8 per cent), and licence fees (5 per cent) (Table 3.2).

Total boat cash costs are lowest for boats in the first (least profitable) quartile, and highest for boats in the second quartile. Depreciation costs are significantly higher for boats in the first quartile than for any other quartile, indicating recent investment in boats and equipment (Table 3.3).

Boats with less than 47 pots have, on average, much lower total boat cash costs than boats with more than 47 pots (47 per cent below, and 16 per cent above the average respectively). Depreciation costs are also much lower for licence holders with less than 47 pots (57 per cent below the average) compared to licence holders with more than 47 pots (19 per cent above the average) (Table 3.4).

Table 3.2 Financial performance in the Tasmanian Rock Lobster fishery, 2010/11 (average per boat) [a]

		2010/11	
		Average per Licence	Share of TBCC[b]
(1)	**Total Boat Gross Income**	**$296,353**	
	Variable Costs		
	Fuel	$21,049	8%
	Repairs & Maintenance [c]	$36,658	13%
	Bait/Ice	$9,963	4%
	Provisions	$5,080	2%
	Labour - paid	$72,239	26%
(2)	- unpaid [d]	$9,017	3%
	Other	$10,811	4%
(3)	**Total Variable Costs**	**$164,817**	**60%**
	Fixed Costs		
	Licence Fee	$14,220	5%
	Insurance	$8,580	3%
(4)	Interest	$12,282	4%
(5)	Labour - unpaid [d]	$4,278	2%
(6)	Leasing	$54,659	20%
	Legal & Accounting	$2,839	1%
	Telephone etc.	$2,763	1%
	Slipping & Mooring	$3,877	1%
	Travel	$1,760	1%
	Office & Admin	$2,990	1%
(7)	**Total Fixed Costs**	**$108,246**	**40%**
(8)	**Total Boat Cash Costs (3 + 7)**	**$273,063**	**100%**
	Boat Gross Margin (1 - 3)	**$131,536**	
(9)	**Total Unpaid Labour (2 + 5)**	**$13,295**	
	Gross Operating Surplus (1 - 8 + 9)	**$36,585**	
(10)	**Boat Cash Income (1 - 8)**	**$23,290**	
(11)	**Depreciation**	**$32,113**	
(12)	**Boat Business Profit (10 - 11)**	**-$8,823**	
(13)	**Profit at Full Equity (12 + 4 + 6)**	**$58,117**	
	Boat Capital		
(14)	Fishing Gear & Equip	$380,745	
	Licence Value	$1,095,725	
(15)	**Total Boat Capital**	**$1,476,470**	
	Rate of Return on Fishing Gear & Equip (13 / 14 * 100)	**15.3%**	
	Rate of Return on Total Boat Capital (13 / 15 * 100)	**3.9%**	

[a] Financial performance estimates for 2010/11 are based on the 2012 licence holders survey.

[b] Total boat cash costs.

[c] Repairs and maintenance costs have been classified as a variable cost although it is noted that some of these costs may be fixed (e.g. regulated maintenance).

[d] Unpaid labour was divided between variable (time spent fishing and on repairs and maintenance) and fixed (management and administrative duties) based on survey responses.

Source: 2010/11 Tasmanian Rock Lobster Fishery survey and EconSearch analysis

Table 3.3 Financial performance in the Tasmanian Rock Lobster fishery by return to capital quartile, 2010/11 (average per boat)

		Average per boat				
		Lowest 25%	Second quartile	Third quartile	Highest 25%	All Boats
(1)	**Total Boat Gross Income**	**$236,760**	**$308,043**	**$335,325**	**$305,283**	**$296,353**
	Variable Costs					
	Fuel	$18,556	$23,100	$24,922	$17,617	$21,049
	Repairs & Maintenance [a]	$27,238	$79,307	$20,394	$19,694	$36,658
	Bait/Ice	$8,916	$8,873	$14,720	$7,343	$9,963
	Provisions	$4,648	$1,163	$7,577	$6,933	$5,080
	Labour - paid	$77,556	$75,021	$65,107	$71,271	$72,239
(2)	- unpaid [b]	$12,344	$9,617	$8,006	$6,101	$9,017
	Other	$11,055	$6,998	$19,418	$5,771	$10,811
(3)	**Total Variable Costs**	**$160,314**	**$204,079**	**$160,144**	**$134,731**	**$164,817**
	Fixed Costs					
	Licence Fee	$23,518	$6,335	$20,429	$6,596	$14,220
	Insurance	$9,445	$6,655	$10,579	$7,639	$8,580
(4)	Interest	$5,155	$25,126	$7,880	$10,964	$12,282
(5)	Labour - unpaid [b]	$5,856	$4,563	$3,798	$2,895	$4,278
(6)	Leasing	$1,580	$56,999	$62,704	$97,351	$54,659
	Legal & Accounting	$4,845	$1,837	$2,640	$2,032	$2,839
	Telephone etc.	$2,614	$2,108	$4,686	$1,644	$2,763
	Slipping & Mooring	$4,420	$3,745	$3,626	$3,716	$3,877
	Travel	$1,060	$101	$2,649	$3,231	$1,760
	Office & Admin	$2,411	$4,602	$1,288	$3,660	$2,990
(7)	**Total Fixed Costs**	**$60,905**	**$112,071**	**$120,280**	**$139,727**	**$108,246**
(8)	**Total Boat Cash Costs (3 + 7)**	**$221,219**	**$316,150**	**$280,424**	**$274,458**	**$273,063**
	Boat Gross Margin (1 - 3)	**$76,446**	**$103,964**	**$175,181**	**$170,552**	**$131,536**
(9)	**Total Unpaid Labour (2 + 5)**	**$18,200**	**$14,180**	**$11,804**	**$8,996**	**$13,295**
	Gross Operating Surplus (1 - 8 + 9)	**$33,741**	**$6,073**	**$66,705**	**$39,821**	**$36,585**
(10)	**Boat Cash Income (1 - 8)**	**$15,541**	**-$8,107**	**$54,901**	**$30,825**	**$23,290**
(11)	**Depreciation**	**$59,143**	**$25,130**	**$22,825**	**$21,352**	**$32,113**
(12)	**Boat Business Profit (10 - 11)**	**-$43,602**	**-$33,238**	**$32,076**	**$9,473**	**-$8,823**
(13)	**Profit at Full Equity (12 + 4+ 6)**	**-$36,867**	**$48,887**	**$102,660**	**$117,788**	**$58,117**
	Boat Capital					
(14)	Fishing Gear & Equip	$605,680	$338,320	$331,120	$247,860	$380,745
	Licence Value	$1,565,700	$1,396,800	$1,233,400	$187,000	$1,095,725
(15)	**Total Boat Capital**	**$2,171,380**	**$1,735,120**	**$1,564,520**	**$434,860**	**$1,476,470**
	Rate of Return on Fishing Gear & Equip (13 / 14 * 100)	**-6.09%**	**14.45%**	**31.00%**	**47.52%**	**15.26%**
	Rate of Return on Total Boat Capital (13 / 15 * 100)	**-1.70%**	**2.82%**	**6.56%**	**27.09%**	**3.94%**

[a] Repairs and maintenance costs have been classified as a variable cost although it is noted that some of these costs may be fixed (e.g. regulated maintenance).

[b] Unpaid labour was divided between variable (time spent fishing and on repairs and maintenance) and fixed (management and administrative duties) based on survey responses.

[c] Average number of pots owned and leased by licence holders in each quartile.

Source: 2010/11 Tasmanian Rock Lobster Fishery survey and EconSearch analysis

Table 3.4 Financial performance in the Tasmanian fishery by number of pots, 2010/11 (average per boat)

		Average per boat		
		Less than 47 pots	More than 47 pots	All Boats
(1)	**Total Boat Gross Income**	**$160,822**	**$341,530**	**$296,353**
	Variable Costs			
	Fuel	$11,249	$24,316	$21,049
	Repairs & Maintenance [a]	$9,879	$45,585	$36,658
	Bait/Ice	$6,187	$11,222	$9,963
	Provisions	$2,844	$5,825	$5,080
	Labour - paid	$41,008	$82,649	$72,239
(2)	- unpaid [b]	$7,142	$9,642	$9,017
	Other	$1,494	$13,916	$10,811
(3)	**Total Variable Costs**	**$79,802**	**$193,155**	**$164,817**
	Fixed Costs			
	Licence Fee	$15,944	$13,645	**$14,220**
	Insurance	$6,162	$9,386	$8,580
(4)	Interest	$4,322	$14,935	$12,282
(5)	Labour - unpaid [b]	$3,388	$4,574	$4,278
(6)	Leasing	$29,554	$63,027	$54,659
	Legal & Accounting	$1,428	$3,309	$2,839
	Telephone etc.	$1,520	$3,177	$2,763
	Slipping & Mooring	$2,190	$4,439	$3,877
	Travel	$110	$2,311	$1,760
	Office & Admin	$555	$3,802	$2,990
(7)	**Total Fixed Costs**	**$65,173**	**$122,604**	**$108,246**
(8)	**Total Boat Cash Costs (3 + 7)**	**$144,975**	**$315,759**	**$273,063**
	Boat Gross Margin (1 - 3)	**$81,020**	**$148,375**	**$131,536**
(9)	**Total Unpaid Labour (2 + 5)**	**$10,530**	**$14,217**	**$13,295**
	Gross Operating Surplus (1 - 8 + 9)	**$26,377**	**$39,988**	**$36,585**
(10)	**Boat Cash Income (1 - 8)**	**$15,847**	**$25,771**	**$23,290**
(11)	**Depreciation**	$13,667	$38,261	**$32,113**
(12)	**Boat Business Profit (10 - 11)**	**$2,180**	**-$12,490**	**-$8,823**
(13)	**Profit at Full Equity (12 + 4+ 6)**	**$36,056**	**$65,471**	**$58,117**
	Boat Capital			
(14)	Fishing Gear & Equip	$153,460	$456,507	$380,745
	Licence Value	$295,800	$1,362,367	$1,095,725
(15)	**Total Boat Capital**	**$449,260**	**$1,818,873**	**$1,476,470**
	Rate of Return on Fishing Gear & Equip (13 / 14 * 100)	**23.5%**	**14.3%**	**15.3%**
	Rate of Return on Total Boat Capital (13 / 15 * 100)	**8.0%**	**3.6%**	**3.9%**
	No. of pots owned	14	47	39
	No. of pots leased[c]	-25	-2	-8
	Average Number of Pots [d]	**39**	**50**	**47**

[a] Repairs and maintenance costs have been classified as a variable cost although it is noted that some of these costs may be fixed (e.g. regulated maintenance).

[b] Unpaid labour was divided between variable (time spent fishing and on repairs and maintenance) and fixed (management and administrative duties) based on survey responses.

[c] As reported in survey, or where average number of pots on board exceeds pots owned, calculated as the difference between them.

[d] Average number of pots on boat for each licence holder (may be less than number of pots owned and leased).

Source: 2010/11 Tasmanian Rock Lobster Fishery survey and EconSearch analysis

Table 3.5 Financial performance in the Tasmanian Rock Lobster fishery by number of pots, 2010/11 (average per pot)

		Average per pot		
		Less than 47 pots	More than 47 pots	All Boats
(1)	**Total Boat Gross Income**	**$4,145**	**$6,876**	**$6,312**
	Variable Costs			
	Fuel	$290	$490	$448
	Repairs & Maintenance [a]	$255	$918	$781
	Bait/Ice	$159	$226	$212
	Provisions	$73	$117	$108
	Labour - paid	$1,057	$1,664	$1,539
(2)	- unpaid [b]	$184	$194	$192
	Other	$39	$280	$230
(3)	**Total Variable Costs**	**$2,057**	**$3,889**	**$3,510**
	Fixed Costs			
	Licence Fee	$411	$275	**$303**
	Insurance	$159	$189	$183
(4)	Interest	$111	$301	$262
(5)	Labour - unpaid [b]	$87	$92	$91
(6)	Leasing	$762	$1,269	$1,164
	Legal & Accounting	$37	$67	$60
	Telephone etc.	$39	$64	$59
	Slipping & Mooring	$56	$89	$83
	Travel	$3	$47	$37
	Office & Admin	$14	$77	$64
(7)	**Total Fixed Costs**	**$1,680**	**$2,469**	**$2,306**
(8)	**Total Boat Cash Costs (3 + 7)**	**$3,736**	**$6,358**	**$5,816**
	Boat Gross Margin (1 - 3)	**$2,088**	**$2,987**	**$2,802**
(9)	**Total Unpaid Labour (2 + 5)**	**$271**	**$286**	**$283**
	Gross Operating Surplus (1 - 8 + 9)	**$680**	**$805**	**$779**
(10)	**Boat Cash Income (1 - 8)**	**$408**	**$519**	**$496**
(11)	**Depreciation**	$352	$770	**$684**
(12)	**Boat Business Profit (10 - 11)**	**$56**	**-$251**	**-$188**
(13)	**Profit at Full Equity (12 + 4+ 6)**	**$929**	**$1,318**	**$1,238**
	Boat Capital			
(14)	Fishing Gear & Equip	$3,955	$9,191	$8,110
	Licence Value	$7,624	$27,430	$23,338
(15)	**Total Boat Capital**	**$11,579**	**$36,622**	**$31,448**
	Rate of Return on Fishing Gear & Equip (13 / 14 * 100)	**23.5%**	**14.3%**	**15.3%**
	Rate of Return on Total Boat Capital (13 / 15 * 100)	**8.0%**	**3.6%**	**3.9%**

[a] Repairs and maintenance costs have been classified as a variable cost although it is noted that some of these costs may be fixed (e.g. regulated maintenance).

[b] Unpaid labour was divided between variable (time spent fishing and on repairs and maintenance) and fixed (management and administrative duties) based on survey responses.

Source: 2010/11 Tasmanian Rock Lobster Fishery survey and EconSearch analysis

Cash Income and Profit…

The separation of variable and fixed costs from total cash costs enables the calculation of boat gross margin (total boat income less total boat variable costs) as a basic measure of profit (assuming that capital has no alternative use and that as fishing activity varies there is no change in capital or fixed costs).

Gross operating surplus (GOS) was calculated excluding imputed wages for operator and family members. The average GOS of all boats in 2010/11 was estimated to be almost $37,000 (Table 3.2).

Boat cash income is measured as gross operating surplus with imputed wages (unpaid labour) included as cash costs. The estimated average boat cash income in 2010/11 was around $23,000 per boat (Table 3.2).

Gross operating surplus and boat business profit give an indication of the capacity of the operator to remain in the fishery in the short to medium term. Average boat business profit was estimated to be a loss of around $9,000 per boat in 2010/11.

Profit at full equity is a measure of the profitability of an individual licence holder, assuming the licence holder has full equity in the operation. It is a useful absolute measure of the economic performance of fishing firms. Average profit at full equity in 2010/11 was approximately $58,000 (Table 3.2).

In 2010/11, the average boat business profit for boats in the first quartile was a loss of $44,000. Boats in the third and fourth quartile made a profit, just over $32,000 and $9,000 respectively (Table 3.3). Profit at full equity was positive for the second, third and fourth quartiles ($49,000, $103,000 and $118,000 respectively. The first quartile makes a significant loss by this measure (approximately $37,000).

Whether boats with more than 47 pots were less or more profitable than boats with less than 47 pots depends upon the measure of profit used. Boat gross margin was much higher for boats with more than 47 pots (13 per cent above the average compared to 38 per cent below for boats with 47 pots or less). However, boat business profit (which includes depreciation costs) was higher for boat businesses which carry 47 pots or less (approximately $2,000) than for businesses which carry more than 47 pots (a loss of over $12,000). Profit at full equity was almost double the value for boats that carried more than 47 pots ($65,000), than for boats that carried 47 pots or less ($36,000) (Table 3.4).

Return on Investment…

There are a number of interpretations of the concept of return on investment. For the purpose of this analysis it is appropriate to consider the investment as the capital employed by an average licence holder in the fishery. Capital includes boats, licence/quota, fishing gear, sheds, vehicles and other capital items used as part of the fishing enterprise. It does not include working capital or capital associated with other businesses operated by the licence holder. The rate of return to total capital has been calculated using the profit at full equity as a percentage of the average investment in all capital (i.e. fishing gear and equipment and licence value).

While the rate of return to boat capital (i.e. fishing gear and equipment) for all boats is relatively high (15.3 per cent), the rate of return to total capital (including the licence value) was estimated to average 3.9 per cent in 2010/11 (Table 3.2).

The average profit at full equity per boat in the first quartile was approximately -$36,000, compared to $118,000 in the fourth quartile. This significant difference is due to lower average gross income in the first quartile compared to the fourth quartile. The average investment in fishing gear and equipment was higher in the first quartile (approximately $606,000 in 2010/11) compared to the fourth quartile ($248,000). Similarly, the licence value in the first quartile was significantly higher than the average licence value in the fourth quartile ($1,567,000 and $187,000 respectively). Accordingly, in 2010/11, the average rate of return to total capital was -1.7 per cent in the first quartile and 27.1 per cent in the fourth quartile (Table 3.5). Both the second and third quartiles have higher investment (total boat capital) than the fourth quartile, but lower investment than the first. Values of profit at full equity for the second and third quartile, also fell between the first and fourth quartiles.

In 2010/11, licence holders with 47 pots or less had a significantly higher average rate of return to total capital of (8.0 per cent) than licence holders with more than 47 pots (3.6 per cent). This is despite having a lower value for profit at full equity, and due to having a much lower total boat capital investment than licence holders who carried more than 47 pots.

Licence values…

The value of licences represents a significant proportion of the capital used by each licence holder in the fishery. The reported average licence value of $1.1 million per boat (approximately $32,000 per pot) for 2010/11 represents the licence holders' estimate of the value of their licence, based on the 2012 survey responses.

Licence values are determined by both current earning capacity and expectations about future earnings. There was a large degree of variability in the licence holders estimates of licence value. Survey respondents estimates of licence value ranged from approximately $2.7 million to $0.6 million, however this wide variation primarily reflects the differences in ownersip of licences within the fishery. Estimates of the value of the entitlement (without quota) ranged from $40,000 to $100,000. Estimates of the value of a single pot ranged from $15,000 to $30,000. These highly variable estimates of value are reflected in variation in sale price. Survey participants were aware of actual sales of pots for as little as $18,000 and as much as $32,000 between mid 2010 and the time the survey was conducted.

A sensitivity analysis was undertaken to estimate the rate of return to capital for a range of licence values. The results are presented in Table 3.6. Based on the costs and returns shown for the year 2010/11 in Table 3.6, a licence value of approximately $0.8 million (25 per cent below the licence value estimated for 2010/11) would mean an annual return to the total asset of 4.8 per cent, while a licence value of around $1.4 million (25 per cent above the licence value estimated for 2010/11) would mean an annual return to the total asset of 3.3 per cent (Table 3.6).

Table 3.6 Sensitivity of rate of return to changes in licence value, 2010/11 [a]

Licence Value	$821,794	$1,095,725	$1,369,656
Rate of Return to Total Capital (%)	4.8%	3.9%	3.3%

[a] Based on the licence value estimated for 2010/11 and values 25 per cent above and below this estimate.

Source: EconSearch analysis

3.3 Economic Rent

Economic rent[12] is defined as the difference between the price of a good produced using a natural resource and the unit costs of turning that natural resource into the good. In this case the natural resource is the Tasmanian Rock Lobster fishery and the good produced is the landed lobster.

The long term costs all need to be covered if the licence holder is to remain in the fishery. These long-term costs include direct operating costs such as fuel, labour (including the opportunity cost of a self employed fisher's own labour), bait, overheads such as administration and licences and the cost of capital invested in the boat and gear (excluding licence). Capital cost includes depreciation and the opportunity cost of the capital applied to the fishery. The opportunity cost is equivalent to what the fisher's investment could have earned in the next best alternative use.

Determining the opportunity cost of capital involves an assessment of the degree of financial risk involved in the activity. For a risk-free operation, an appropriate opportunity cost of capital might be the long-term real rate of return on government bonds. The greater the risks involved, the greater is the necessary return on capital to justify the investment in that particular activity. For this analysis the long term (10 year) real rate of return on government (treasury) bonds of 5 per cent has been used and a risk premium of 5 per cent has been applied.

Given the relatively high-risk nature of the industry (weak property rights therefore short time horizons, exposure to exchange rate fluctuations, general price volatility, problems of resource sustainability and political risk in export countries) an argument could be made for a higher required rate of return.

What remains after the value of these inputs (labour, capital, materials, services) has been netted out is the value of the natural resource itself. The economic rent generated in the Tasmanian Rock Lobster fishery in 2010/11 was estimated to be approximately -$10.1 million (Table 3.7)

When an economic rent is generated in a fishery and there are transferable licences, the rent represents a return to the value of the licences. The 2010/11 aggregate value of licences was estimated to be $258.6 million (236 licences with an average value of $1.1 million per licence or $23,000 per pot). An annual economic rent of -$10.1 million represents a return of -3.9 per cent to the capital value of the fishery.

---

[12] Economic rent is comprised of three types of rent: entrepreneurial rent, quasi-rent and resource rent. As in any business some operators are more skilful than others and will therefore earn more profit. These profits, which are one component of economic rent, are *entrepreneurial rents*. In the short-term fishers may earn large surpluses over costs, which may provide prima facie evidence of substantial resource rents. However, there are some circumstances where such surpluses can occur but they are not true rents. These are referred to as *quasi-rents*. One example is where a fishery is developing or recovering and there may be under-investment in the fishery. Another example is where there is a short-term but unsustainable increase in price due to, for example, exchange rate fluctuations. However, some profits will be obtained because the natural resource being used (i.e. the fishery) has a value. These profits are described as *resource rents* and are also a component of economic rent.

Table 3.7 Economic rent[a] in the Tasmanian Rock Lobster fishery, 2010/11 ($'000)

	2010/11
Gross Income	$63,624
Less Labour	$4,790
Less Cash Costs	$53,834
Less Depreciation	$6,894
Less Opportunity Cost of Capital (@10%)	$8,174
Economic Rent	**-$10,068**

[a] Adjusted for sample bias. For example, based on the 2012 survey of licence holders gross income in the fishery for 2010/11 was estimated to be $69.9 million.

Source: EconSearch analysis

4. Other Indicators

4.1 Factors Influencing the Economic Condition of the Fishery

There are a number of factors in 2010/11 that have impacted on the economic performance of the fishery. Most of these are likely to continue to affect economic outcomes in the future.

Stock status…

In 2012, UTAS published a report on the current biological status of commercial fishery in Tasmania (Hartman et al. 2012). It was stated in this report that there was clear evidence of a decline in exploitable biomass between 2008 and 2012. In most areas, the number of pre-recruits has been below average for several years, suggesting continued poor recruitment since 2007. Peurulus settlement off Tasmania improved during 2010, although the effects of this improvement will not be felt in the short term.

Stock assessment…

Reference points for the Tasmanian Rock Lobster Fishery were developed in 2009 and 2010 through the Commercial Fisheries of Australia Council (CFAC) and the Recreational Fishers of Australia Council (RecFAC). Limit reference points exist for biological sustainability measures, and both limit and target reference points exist for economic benefit from the fishery. No reference points exist for biological interactions, although data are collected on this.

Decisions about fishery management are made in order to satisfy the reference points. There must be a 90 per cent probability that limit reference points will be met, and a 70 per cent probability that target reference points will be met. Reference points exist in relation to egg production, exploitable biomass, catch per unit effort. Recent cuts to quota to close to 100kg per pot were necessary to meet the acceptable reference point probabilities (Hartman et al. 2012).

Export markets…

Factors that will continue to impact exports include the higher Australian dollar (see detail below), economic growth in China, import tariffs and competition from lower-cost product (Southern Rock Lobster from South Africa and Tropical Rock Lobster from Cuba and Vietnam). Exposure to currency and market risks, makes diversification of export markets important. Southern Rock Lobster (a collaboration between the South Australian, Tasmanian and Victorian Rock Lobster industries) carried out marketing activities between 2005 and 2011 targeting the US super premium fine dining sector. These marketing activities resulted in development of new enterprises serving that market, although market growth in the sector has been low. In the period between 2011 and 2016 Southern Rock Lobster will continue to work to identify explore and develop alternative markets, but will not be directly involved in marketing activities.

Exchange Rate…

A significant proportion of the Tasmanian Rock Lobster catch is exported overseas. Accordingly, the value of the Australian dollar can have a significant impact on the economic performance of the fishery. The value of the Australian dollar influences the price of Australian exports overseas. Significant changes in the value of the Australian dollar have the potential to influence the demand for Australian Rock

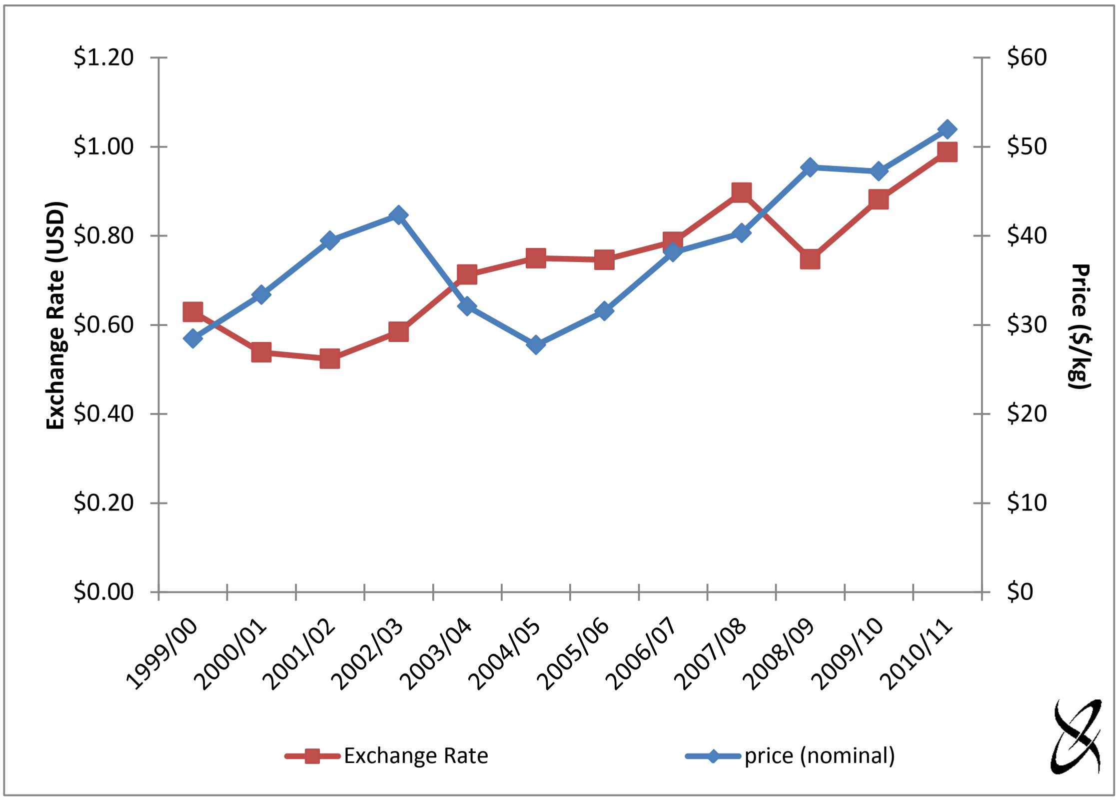
Lobster exports. The Australian dollar generally followed an increasing trend throughout 2010/11 rising from US87 cents in July 2010 to US106 cents in June 2011.

The average exchange rate in 2010/11 was US 98 cents, an increase of 12 per cent compared to the average for the previous year (Figure 4.1). Other things held equal, a rise in the value of the currency would have the effect of decreasing the price of Rock Lobster received by Australian exporters between 2009/10 and 2010/11.

A widely used measure of the relationship between two variables, such as price and exchange rate, is the coefficient of correlation. The coefficient of correlation can range in value from 1.0 for a perfect positive correlation to –1.0 for a perfect inverse correlation. The coefficient of correlation between the exchange rate (USD) and the average price in the Tasmanian Rock Lobster fishery for the period 1999/00 to 2010/11 is 0.49. This runs counter to expectations, and is likely due to the effect of other factors, such as an increase in the wealth and size of the middle class in China, on the Rock Lobster price.

The relationship between the average price in the Tasmanian Rock Lobster fishery and the exchange rate (USD) between 1999/00 and 2010/11 can be observed in Figure 4.1. This figure shows that both exchange rate and Rock Lobster Price trend upwards over the period.

Figure 4.1 Exchange rate (USD) and average beach price for Tasmanian Rock Lobster, 1999/00 to 2010/11

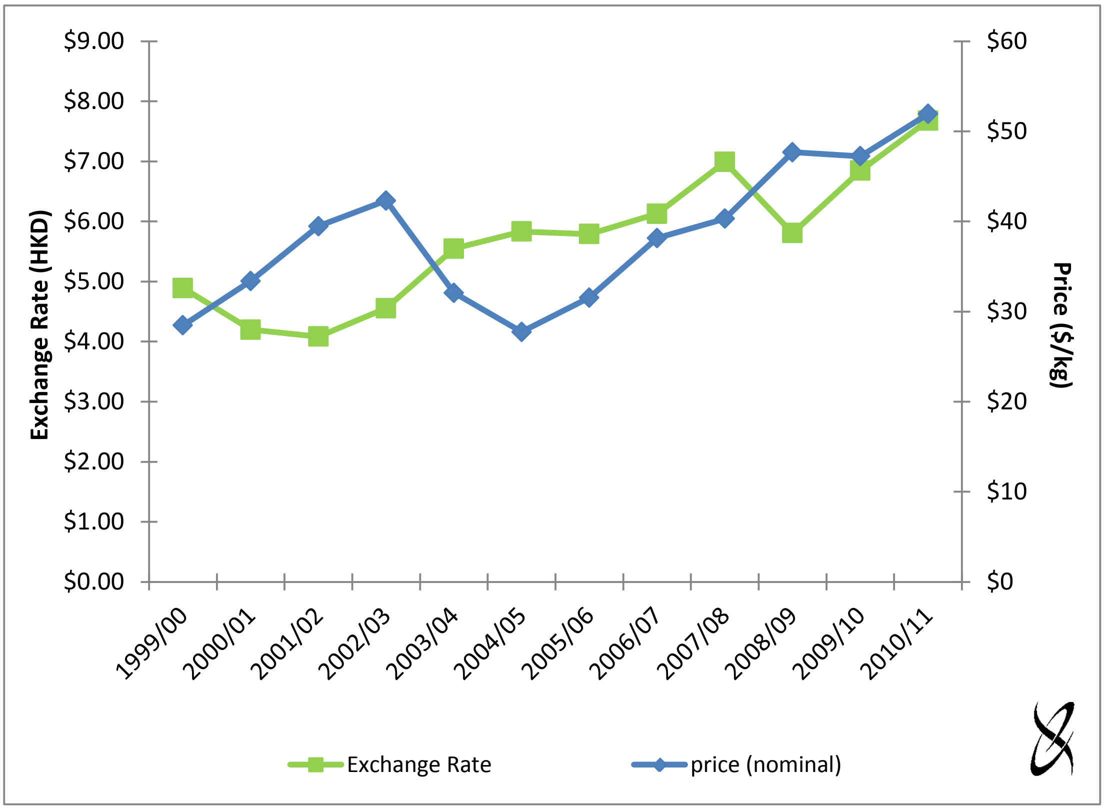


Source: UTAS, RBA (2011) and previous issues, and EconSearch Analysis

Historically, the most significant export destination for Tasmanian Rock Lobster exports has been Hong Kong. Thus it may be useful to compare the value of the Australian dollar with the Hong Kong dollar (HKD). The relationship between the price of Rock Lobster and the exchange rate over the past 14 years can be readily observed in Figure 4.1 and Figure 4.2. Similar to the USD, the long term upward trend in Rock Lobster Price and exchange rates creates a positive coefficient of correlation (0.29).

The average rate of exchange in 2009/10 was 6.85 HKD increasing to 7.68 (HKD) in 2010/11.

Figure 4.2 Exchange rate (HKD) and price for Tasmanian Rock Lobster, 1999/00 to 2010/11



Source: UTAS, RBA (2011) and previous issues, and EconSearch Analysis

4.2 Licence Holder Comments

During the 2012 survey licence holders raised several key issues that have potential to affect the economic performance of the fishery. Of the 20 licence holders who participated in the survey, 14 made some comment on management issues.

Management…

A few fishers commented on the fact that the fishery could be better managed. It was suggested by one licence holder that as the government employees in charge of managing the fishery did not rely on the long term health of the fishery for their ‘bread and butter’, they did not have the same incentives as licence holders and fishermen to look after the fishery. They suggested that management needs of the fishery would be better served by a private charter operating in conjunction with the fishers’ association.

Biological and Financial sustainability…

Several fishers commented that there were currently more boats in the fishery than could be sustained. One licence holder commented that when the quota was cut, one third of the quota was lost, but no boats exited the industry. Other fishermen commented that it was a difficult business to enter or exit due to the high levels of capital involved in running an operation.

It was commonly felt that the high number of fishers in the industry put pressure on both the fishing operations (as more fishers meant lower catch rates), and on financial operations (as the high number of fishers in the industry made it difficult to obtain quota at a ‘fair price’).

It was also suggested that, low catch rates reduced the ability of fishers to invest in repairs and maintenance. A few fishers mentioned the biological sustainability of the quota levels. One fisher suggested that the current levels did not restrain quota enough, however another fisher said that it was too hard on fishers when the quota was reduced.

Deckhands…

Two licence holders mentioned that they had stopped employing deckhands in the last few years. One had stopped fishing because it had become unprofitable which was, in turn, because catch rates were too low. The other had continued to fish, but stopped employing deckies in order to keep costs down. Another fisher commented that the salary for deckhands has become extremely unreliable. Lower catch rates and fluctuating prices have reduced the average income that deckhands can rely on.

Prices for catch…

Several fishers commented on the high variability in the prices for catch and the difficulty this was causing fishers. In particular, the fishers who completed the survey later in the second half of August commented on the dramatic drop in prices for Rock Lobster in China. They highlighted how dependent Rock Lobster fishers were on exporting to China and how the lack of a trade agreement, combined with price volatility in this market, made the industry extremely volatile.

The quota lease market…

The quota lease market was a matter of concern for many of the participants in the survey. A few fishermen commented that the use of rock lobster licences as part of an investment portfolio for overseas investors had driven up the price of fishing licences. It was remarked that increasing prices for licences, increased the pressure on licence holders to charge high lease prices and cover rising interest rate payments. It was also remarked that there was an oversupply of vessels and pots relative to the volume of quota available which was also acting to drive up the price of quota.

A few fishermen commented that the fishery operations were better when the fishery was dominated by owner operators and suggested that the fishery should return to this model of operations.

Many fishermen commented on the difficulty of setting a price for leasing quota at the start of the season, when the beach price could vary drastically within a season. Several fishermen felt that one third of the beach price was the fairest price for leasing quota as this shared the risk between the licence holder and the fisher. However, most of these fishers remarked that they were unable to obtain this arrangement for quota that they leased.

Succession…

Some fishers in family businesses remarked that they would already be retired, or working in other jobs, except that they were in the process of handing the business on to their sons. Income from their licence(s) and fishing business was the primary source of income for several family members, often including several generations and extended family. This suggests a high level of dependence on the ongoing sustainability of the resource and the ability to continue to use the resource.

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Disclaimer

We have prepared the above report exclusively for the use and benefit of our client. Neither the firm nor any employee of the firm undertakes responsibility in any way whatsoever to any person (other than to the above mentioned client) in respect of the report including any errors or omissions therein however caused.

Appendix 6: Economic survey questionnaire

Below is a copy of the Southern Zone EconSearch questionnaire used for the economic survey in 2012. The survey questionnaire was identical for the Northern Zone and very similar for Tasmania.

EconSearch Pty Ltd
214 Kensington Road
Marryatville SA 5068
Tel: 08 8431 5533
Fax: 08 8431 2210
Contact: Stacey Paterson or
Lisa Rippin

Southern Zone Rock Lobster Economic Indicators Study 2010/11

Please read this first:

- Please only include the amounts that can be attributed to your Southern Zone Rock Lobster fishing business for the 2010/11 financial year
- If exact figures are not available, please provide careful estimates.

PART A CAPITAL

1. What is the length of your boat? ____________________

2. What is the engine capacity of your boat? ___________________

3. In the following table, please include a list of all fishing gear and equipment that you use for fishing in the Southern Zone Rock Lobster fishery, including electronic equipment, sheds, trailers and motor vehicles (please give values *exclusive* of GST).

Item	**Age (yrs)**	**Current value $**	**Replacement cost $**
Boat engine			
Boat (without engine)			
Electronic Equipment			
Fishing Gear (specify)			
Sheds/buildings			
Motor vehicles			
Trailers			
Other equipment (specify)			

4. If this capital is not solely used for the Southern Zone Rock Lobster fishery, what is the percentage of your capital used for the Southern Zone Rock Lobster fishery?___________%

5. If your capital has other uses, what are these uses?

____

6. How many pots did you own during the 2010/11 financial year? _____________

Leasing to…

7. How many pots did you **lease to** other licence holders during the 2010/11 financial year?

____

8. If you did lease pots to other licence holders during 2010/11, how much did you receive per pot?

____

9. How many kilograms of quota did you **lease to** other licence holders during the 2010/11 financial year?

____

10. If you did lease quota to other licence holders during 2010/11, how much did you receive per kilogram of quota?

____

Leasing from…

11. How many pots did you **lease from** other licence holders during the 2010/11 financial year?

____

12. If you did lease pots from other licence holders during 2010/11, how much did you pay per pot?

____

13. How many kilograms of quota did you **lease from** other licence holders during the 2010/11 financial year?

____

14. If you did lease quota from other licence holders during 2010/11, how much did you pay per kilogram of quota?

____

Licence value…

15. What is your estimation of the current market value of your fishing licence (meaning what is the value of the pots you own)?

$_____________________/pot or $_________________total value of fishing licence

PART B EXPENDITURE

1. Are skipper wages charged as a percentage share of landed value? **Yes / No**
2. If so, what's the skippers percentage share of landed value in 2010/11? ________
3. How many crew (deckies) do you normally have? __________________________
4. Are crew wages charged as a percentage share of landed value? **Yes / No**
5. If so, what's the crew percentage share of landed value in 2010/11? ___________

6. Please provide estimates of your direct costs and administrative costs associated with fishing in the Southern Zone Rock Lobster fishery for the whole of the 2010/11 financial year. For your administrative costs, only include the amount that can be attributed to Rock Lobster fishing (please provide values *exclusive* of GST).

Direct Fishing Costs (2010/11)	**$ (excl. GST)**
Boat Fuel & Lubricants	
Ice, Bait	
Skipper Fees	
Crew Wages	
Provisions	
Fishing licence fees	
Repairs and maintenance to boat and equipment	
Slipping/mooring/boat survey	
Protective Clothing	
Freight and Marketing	
Other fishing costs (provide details)	
Administrative Costs (2010/11)	
Insurances – vessels	
Insurances – other	
Legal & Accounting	
Communication –telephone, fax, email	
Power	
Repairs and maintenance to Buildings/Plant	
Repairs and maintenance to Motor Vehicles	
Rates and Rents	
Leasing Charges and Fees	
Interest and borrowing costs	
Travel, accommodation	
Membership, association expenses	
Other expenses (specify)	

PART C EMPLOYMENT

1. How many people are employed in your Southern Zone Rock Lobster fishing activity (including yourself, paid employees and unpaid family helpers involved in running the fishing business, whether they are involved in actual fishing time, maintenance of fishing equipment, or the management (eg bookkeeping, negotiating with processors, attending meetings) of the fishing operations)?

Year	**Full-Time**	**Part Time**	
		No of Persons	**Full Time Equivalent**
Actual 2010/11			
Estimated 2011/12			

2. Please estimate the number of days in 2010/11 that were spent on these activities by people who were not paid a wage (assuming an average of 8 hours per day).

	Fishing (boat time) (days)	**Repairs & Maintenance (days)**	**Management & Administration (days)**
You (licence holder)			
Family (unpaid)			
Other unpaid labour			

PART D SALES

1. Estimate the net value of the fish that you caught and sold during **2010/11**, that is, the income you received from fish sales **after** marketing costs (commission, freight, packing etc) were deducted.

Species	**Sales ($)**	**Weight (tonnes)**
	`	

2. Number of fishing days for 2010/11 ____________

3. Average number of shots per day for 2010/11 ________________

NOTE(for this final report): PART E – PART J of this questionnaire have been removed from this Appendix 6 (information collected not used in this project).

PART K FURTHER COMMENTS

Please provide any additional comments that could assist in preparing the report.

Thank you for completing this survey

Appendix 7: Communications with Stakeholders: Fishers, Peak Bodies, Managers and Management Committees

Richard McGarvey and Caleb Gardner

An important component of this project, stated in Objective 4, was to communicate project outcomes to industry and fishery managers. In this appendix we describe project communication, including bioeconomic modelling results and their implications for enhancing overall fishery profitability, to industry and managers.

The management structures in place to communicate bioeconomic modelling outcomes from testing various proposed management strategies differed in the two states. In Tasmania, a steering committee had been established under the previous Tasmanian bioeconomic modelling project (Australian Seafood CRC Project No. 2006/220) to facilitate the communication of modelling outcomes, and to suggest strategies for testing using the bioeconomic modelling tools. Strategies proposed for evaluation could originate with industry or fishery managers. In South Australia, the main fishery management bodies, on which both industry and managers sit, acted in the role of steering committee for this project.

We now summarise the extent and nature of communications by project scientists with industry and managers of the Southern Rock Lobster fisheries in Tasmania and South Australia.

7.1. Tasmania

Project co-investigators Caleb Gardner, Eriko Hoshino and Klaas Hartmann met with industry and government extensively during the project. These meetings will continue to take place beyond the life of this project to ensure uptake of results obtained during this project.

Meetings took place through the Department of Primary Industries, Parks, Water and Environment (DPIPWE) and the Tasmanian Rock Lobster Fisherman's Association (TRLFA). Meetings with DPIPWE consisted of regular discussions with fisheries managers regarding practical issues related arising from different proposed management options and to identify particular issues concerning the fishery. DPIPWE arranges regular Crustacean Fisheries Advisor Committee (CFAC) meetings which consist of fishing industry, processing industry, environmental, governmental and scientific representatives. Work arising from this project was presented at eight CFAC meetings and directly informed a number of management decisions including TACC decisions and the formation of a East Coast management zone.

Meetings with the TRLFA took place through the Sustainability and Profit Options Committee (SPOC), TRLFA general meetings and port visits. The SPOC committee liaised with researchers to produce practical proposals based on the management options that were identified by the project as being profitable. The SPOC committee also actively sought economic advice on particular management issues that the tools developed by this project were able to investigate. The proposals produced through this process were then presented to fishers in port visits before being presented formally at the TRLFA general meetings where members comments were sought and members voted whether to trial specific options or investigate them further. During the course of the project work was presented at five TRLFA meetings, dozens of port visits and numerous SPOC meetings preceding each of the TRLFA meetings.

Progressing the management options identified in this process is an ongoing process with a number of lines of enquiry being actively pursued by TRLFA, DPIPWE and IMAS.

7.2. South Australia

The project Principal Investigator (PI, R. McGarvey, SARDI) and the SA rock lobster assessment scientist (A. Linnane, SARDI) met with industry bodies and PIRSA state government fishery managers to explain the project objectives, and the bioeconomic modelling tools that were being developed under this project to assist management decision making.

These meetings included:

(1) Presentations by Caleb Gardner (Seafood CRC representative from TAFI) and Rick McGarvey (project PI) to the two lobster fishery industry-led management bodies at that time, the Southern Zone and Northern Zone Harvest Strategy Review Working Groups (November 2010, at Robe and Port Lincoln), chaired by Richard Stevens with industry and PIRSA managers attending. The two Working Groups unanimously supported the project and agreed to act as steering committees for the South Australian component. South Australian management was re-structured in 2011 and 2012, with the creation of the new MAC as the principal management group and establishing also a Research Sub-Committee.

(2) Results of early South Australian bioeconomic model runs were presented to the industry peak body for South Australian lobster, SARLAC (the SA Rock Lobster Advisory Council Inc.). Gary Morgan and Adrian Linnane also attended. The goal was to seek support from industry for this project, and request advice for how to re-constitute the project Steering Committee. SARLAC members attending expressed unanimous support and the Research Sub-Committee of the MAC was recommended as the new Steering Committee. SARDI Waite PRC, 6 September 2012.

(3) In February 2012 R. McGarvey and A Linnane met with the recently appointed PIRSA lobster fishery manager to summarise the decision-assist bioeconomic tools made available under this project, which can test proposed management strategies for both economic and sustainability outcomes.

(4) In April 2013, R. McGarvey presented a detailed presentation of the project capabilities to the South Australian MAC Research Sub-Committee, offering them for use in upcoming review of the South Australian harvest strategies. Industry requested analysis of the potential bioeconomic outcomes from two strategies: a 12-month fishing season (Chapter 10) for both zones, and of a lowered minimum size limit in the Northern Zone, from 105 mm CL to 98.5 mm CL, which is the minimum length currently applying to lobster harvest in the Southern Zone.

(5) In May 2013, R, McGarvey presented a detailed summary of project objectives, methods and outcomes in an Economic Performance Enhancement workshop in Melbourne (28-29 May 2013), chaired by Tim Ward for a linked Seafood CRC project. C. Gardner also presented. Attending were managers, industry representatives, processors, industry peak body leaders, and scientists and modellers from Tasmania, South Australia, Victoria, NSW and New Zealand. Based on this presentation, McGarvey invited to present at the Lobster Congress.

(6) On 1-2 September 2013, R. McGarvey and C. Gardner presented the outcomes of project research, and explained the objective of bioeconomic modelling for enhancing economic outcomes, at the Trans-Tasman Lobster Industry Conference 2013 in Sydney. Industry, managers, scientists,

processors, industry peak body leaders, representatives from FRDC and the Seafood CRC, and other participants in the rock lobster fishing industry in New Zealand and Australia attended. Considerable time outside formal sessions permitted discussions with industry, managers and scientists, and granting body representatives from around Australasia.

(7) R. McGarvey presented project results at the Australian Society of Fish Biology Conference in Hamilton, New Zealand in August 2013.

(8) Industry workshops, where all active lobster fishers and licence holders, could attend were held for the two South Australian lobster fishery zones, in September 2012, in Millicent for the Southern Zone, and Adelaide (SARDI Aquatics) for the Northern Zone. These industry workshops were to explain the potential value of using all available data to advise on which management policies present the best economic performance was a specific milestone task of the project proposal. Attendance was strong and discussion vigorous and relatively supportive at Millicent in the Southern Zone. Industry is still suspicious of these mathematical and statistical tools but are gradually becoming more accepting of their value. The Northern Zone meeting was less strongly attended, in part due to disappointment with MPA fishing exclusion zones being established currently in the Northern Zone region. Discussions with the Northern Zone included industry support for research focused on the combination of a 12-month fishing season and spatial management. These meetings with wider industry were facilitated by Ian Cartwright, with the fishery managers (A. Jones), the stock assessment scientist (A. Linnane), and industry peak body representatives (J. Phillips and K. Toumazos) also attending.

(9) The PI (R. McGarvey) and the stock assessment scientist (A. Linnane) attended meetings, with the PIRSA lobster fishery manager (A. Jones), on 19 and 20 November 2013 to begin the process of evaluating the existing harvest strategy in each zone. At these meetings, the MAC formally requested outputs from the bioeconomic modelling tools developed in this project, to assist the evaluation of the existing harvest strategy.

(10) A series of meetings were held in December 2013 and January 2014 with PIRSA fishery managers (A. Jones and A. Fistr) and industry peak body representatives (K. Toumazos and R. Rowe for the Northern Zone, and J. Phillips for the Southern Zone) to select the range of harvest strategies to be evaluated by these bioeconomic modelling tools.

(11) These results were presented to the MAC Harvest Strategy Review Working Groups for the Southern Zone (Robe SA, 3 March 2014) and the Northern Zone (Port Lincoln SA, 4 March 2014). These results were considered in the choice of whether to continue with the existing 2011 harvest strategy, or to modify that strategy. The modelled economic performance of each strategy tested was an important decision making criterion in the decision to make three major changes to the existing harvest strategy in the SA Southern Zone. (See Chapter 11, Benefits and Adoption.)

(12) Prior to these South Australian Harvest Strategy Review Working Group meetings, the PI of this project presented these results in meetings with the Northern Zone peak body executive committee (Port Lincoln, 13 February 2014) and with wider industry (all invited) for the Southern Zone (in Millicent, 28 February 2014).

(13) The bioeconomic modelling tools developed in this project are proposed for use in this Northern Zone evaluation of spatial management and winter fishing as requested by the Northern Zone peak body (NZRLFA, Executive Officer, Kyri Toumazos). A research proposal (FRDC and Seafood CRC) to gather data on winter fishing and to estimate abundance in outlying regions, with SARDI, has now been approved. The bieconomic modelling

tools would be used to assess economic performance of strategies that may be proposed in a projected second stage of this work.

In addition to communications with industry or managers, the modellers and economic researchers working together on the project from the two states met at SARDI Aquatic Sciences in August of each year, 2011, 2012 and 2013. These meetings were productive for coordinating research activities, partitioning the programming tasks and model development and data analysis tasks among researchers on the project team.