Recruitment of Population Dynamacist

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Costs associated with the management of the rock lobster and abalone share-management fisheries are recovered (or partially recovered) from shareholders through management charges levied on share-holdings. Consequently, shareholders in these fisheries contributed to this project through their contributions to the salaries of the fisheries scientists involved with the modelling and assessment of the rock lobster and abalone resources.

Significant contributions were made to the development of models, training of staff and the discussion of assessment methodologies by visiting experts Mr Norm Hall (Fisheries WA) and Professor Cynthia Jones (Old Dominion University, North Carolina).

The Director of the Centre for the Ecological Impacts of Coastal Cities (University of Sydney), Professor Tony Underwood, and staff of this centre (chiefly Dr James Scandol during his period of employment at this centre) contributed to this project through the contracted services that this centre provided to NSW Fisheries during 2001 and 2002.

A contribution from the FRDC project "Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery" (FRDC project No. 96/135) is also acknowledged.

NON-TECHNICAL SUMMARY

1993/214.05	**Recruitment of Population Dynamacist**

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OBJECTIVES:

(1) From existing staff, select individuals with at least some of the appropriate skills relevant to utilising population dynamics training.

(2) Provide appropriate training to identified staff such that they can develop population models of major NSW Fisheries.

(3) Begin to develop population models, fishery assessments and management options for the major fishery sectors of NSW.

NON-TECHNICAL SUMMARY:

Outcomes Achieved:

Formation of a group of staff within NSW Fisheries capable of the independent development of population models and fishery assessments

One of the fundamental objectives of fisheries management is to ensure the sustainability of the exploited resource. To determine if the resource is being maintained at a level that is both biologically and economically acceptable, requires a quantitative assessment of the stock. The number of people with the skills necessary to develop quantitative models of fish populations and use these to perform stock assessments are relatively few in Australia and there is high demand for their services. The Fisheries Research and Development Corporation (FRDC) established a program, in partnership with most Fisheries departments in Australia to assist in raising this standard. Under this program, funding was allocated by NSW Fisheries and FRDC to develop appropriate skills in existing staff members at NSW Fisheries.

Training of NSW Fisheries staff involved a combination of courses (in particular, those courses run by the Quantitative Training Unit for Fisheries at the University of Sydney) and interaction with recognised experts in the fields of population modelling and quantitative assessment. Assisted by this training and interaction with experts, several population models and methodologies for quantitative fishery assessment were developed.

Models for the eastern rock lobster population (biomass dynamics and length-structured models) were developed and used in subsequent resource assessments for the fishery and incorporated risk

assessments of the likely consequences of alternative total allowable commercial catches (TACCs) for the stock. An age-structured model for the snapper population and a general version of this model with potential application to other finfish species were also developed. In association with another FRDC project, a biomass dynamics model for spanner crabs was developed and used to provide recommendations for management. Various models for finfish species taken by the NSW Estuary General Fishery were developed through a contract and collaboration with the Centre for Research on Ecological Impacts of Coast Cities.

Beneficiaries of these developments include fishery managers within NSW Fisheries and external stakeholders including management advisory committees, the TACC committee and of course, the commercial, recreational and traditional fishing sectors. The immediate benefits to these groups concern improved quantitative models and fishery assessments leading to improved management of resources for the species and fisheries for which the models were developed. In the longer term, however, improvement in the skills of staff and the formation of a group within NSW Fisheries that is capable of independent development of population models and quantitative assessments will benefit all fisheries in the longer term.

It is concluded that, through the fulfillment of the project's objectives, this project has significantly enhanced the ability of NSW Fisheries to develop quantitative assessments of the status of exploited fisheries resources in NSW.

KEYWORDS: training, population models, population dynamics, fishery assessment.

1. BACKGROUND & NEED

The fundamental objective of most fisheries management plans relates to ensuring the sustainability of the exploited resource. To determine if the resource is being maintained at an acceptable level, both biologically and economically, usually requires a quantitatively based assessment of the stock. This process has now become an integral and critical part of the annual cycle of management for many fisheries. To complete these assessments, computer based simulations of the populations, mostly utilising fishery-related information on catch and effort and sometimes using auxiliary data collected by directed research programs, are used. Consequently, effort in the field of population dynamics has increased markedly over the past 15 years, both as a result of the large increase in computing power available and from the greater level of scrutiny and accountability now required to support fisheries management decisions.

The number of people with the skills necessary to develop these models is relatively small and therefore there is high demand for their services. Within NSW, the need for these types of assessments increased greatly following the introduction of share management and restricted fisheries in the 1990's. Subsequently, the current requirement to produce fisheries management strategies and environmental impact statements for each fishery, has increased the need for such assessments. Consequently, there has been and will be a need to provide quantitative assessment of the performance of fisheries against specific management objectives on an annual (or periodic) basis. For example, specific advice on the likely consequences of alternative harvesting levels (TACs) is required annually for rock lobster and abalone fisheries in NSW.

The FRDC recognised the general deficiency in the quantitative skills base within most fisheries organisations in Australia some 10 years ago and developed a program to assist raising the standard. The original application provided by NSW Fisheries to address the skills shortage in this state involved a request for money to employ a recent graduate with population modelling skills already well developed. This proposal was approved by the FRDC Board (93/214.05) in June 1995. Unfortunately, despite a number of advertising campaigns (Nov 95, Jun 96, Dec 96 and Nov 97), NSW Fisheries was unsuccessful in obtaining a suitable candidate for the position. From discussions with other institutions, such a failure is not uncommon. Consequently, a change in the methodology to achieve our aims of increasing the expertise in population dynamics was proposed.

In the revised proposal, it was the intention to develop the appropriate skills in one or two existing staff members such that they could begin to undertake independent research within this area. This was to be achieved by a combination of training provided by visiting experts brought to Cronulla and attendance of staff at specialised courses. The ultimate objective was the formation of a core group of staff within NSW Fisheries capable of the independent development of population models and fishery assessments.

If this approach was successful, the ability of NSW Fisheries to develop quantitative assessments of the status of exploited fisheries resources in NSW would be enhanced significantly.

2. OBJECTIVES

(1) From existing staff, select individuals with at least some of the appropriate skills relevant to utilising population dynamics training.

(2) Provide appropriate training to identified staff such that they can develop population models of major NSW Fisheries.

(3) Begin to develop population models, fishery assessments and management options for the major fishery sectors of NSW.

3. METHODS

The general methodology described for this project in the funding application is summarised below. However, subsequent movements of staff (into and out of NSW Fisheries) resulted in several iterations of list of tasks outlined here. Nevertheless, each of the steps outlined here was applicable to the development of individual staff and individual population models. The general methodology comprised:

During the first 6 months of the project (July 1998 – Dec 1998):

(i) identify staff members with appropriate skills base and ascertain enthusiasm from those identified staff.

(ii) conduct skills analyses to identify any deficiencies.

(iii) determine a list of suitable and available experts for short term visits to Cronulla Fisheries Centre.

(iv) determine what courses, both within Australia and overseas, would be useful to staff.

Following the completion of these tasks:

(v) assign staff to specified projects and arrange expert supervision (internal or external).

(vi) trainees complete appropriate courses as identified above.

(vii) organise short-term visits of experts (identified above) to Cronulla Fisheries Centre.

In conjunction with and following completion of these tasks:

(viii) develop new population models and assessments for several species / fisheries.

4. RESULTS & DISCUSSION

4.1. Identification of staff, skills analysis & training

During the initial 6 months of the project (1/7/98 – 31/12/98), 2 members of staff were identified for key roles in this project. Dr James Scandol had been recently recruited to the part-time (40%) position of "Fisheries modeller" with NSW Fisheries and possessed experience in both fisheries science and computer programming. Dr Scandol also worked part-time (60%) in the "Quantitative Training Unit for Fisheries" (QTUF) at the University of Sydney. Dr Geoff Liggins had worked as a fisheries biologist with NSW Fisheries for the previous 6 years and had experience in fisheries science and also computer programming. Both these staff were transferred into the newly created "Data" section within the research division. This section included biometrics, data-base and fisheries modeller positions. Dr Liggins remained associated with this project for its duration. Dr Scandol left NSW Fisheries in October 2000 to work at The Centre for Research on Ecological Impacts of Coastal Cities (University of Sydney), where he subsequently completed several modelling and assessment contracts for NSW Fisheries. Dr Scandol subsequently re-commenced employment with NSW Fisheries in late 2002, in the position of Resource Assessment Scientist.

Mr Geoff Gordon, a biometrician with extensive experience in statistics and some experience in population modelling and programming was identified as an additional member of staff for training and skills development in January 2000. Mr Gordon was involved with this project until March 2001 when he resigned from NSW Fisheries.

In addition to Dr Scandol, Dr Liggins and Mr Gordon, several other NSW Fisheries staff were involved with modelling population dynamics, fisheries assessment and this project. Mr Doug Ferrell (Fisheries Scientist) collaborated with Dr Scandol in the development of an age-structured model of the snapper fishery. Dr Duncan Worthington (fisheries scientist) continued his development of a length-structured Bayesian model of the abalone resource. Initially, Dr Rick Fletcher was Principal Investigator for this project until his departure from NSW Fisheries in September 2000. Dr Steve Kennelly subsequently took on the role of Principal Investigator.

Training of staff in aspects of model specification, implementation and assessment methodologies involved consultation and tuition with experts (sections 4.2 & 4.3). To upgrade programming skills, one member of staff (Mr Gordon) attended a course in the "C" programming language. Staff associated with this project and many other staff from NSW Fisheries attended courses in the statistical software package "S-Plus" and fisheries population dynamics courses run by the Quantitative Training Unit for Fisheries at the University of Sydney. Staff from NSW Fisheries made up the majority of participants (about 80%) for the courses "Introduction to Fisheries Modelling", Methods for Fisheries Modelling" and "Applications of Fisheries Modelling" run by QTUF at the University of Sydney (Underwood *et al.,* 2001).

4.2. Visiting experts to Cronulla Fisheries Centre

4.2.1. Associate Professor Norm Hall (Fisheries WA), 6 September – 6 October 1998

Mr Norm Hall, from Fisheries WA, is an internationally recognised expert in the population dynamics and modelling of fisheries. Mr Hall visited the Cronulla Fisheries Centre for one month between 6 September and 6 October 1998. During this visit, Mr Hall worked extensively with, and provided training to, Dr Scandol and Dr Liggins. The first 2 weeks of Mr Hall's visit was devoted to conducting an extensive review of the existing rock lobster biomass dynamics model and recommendation for future model development (report provided in Appendix 3). During the third week, the process of re-engineering and re-coding a version of this model in the programming language "C" was begun. Mr Hall also developed a framework for the development of a length-structured model for the lobster population and provided guidelines and advice for the progression of model development by Dr Scandol and Dr Liggins. During the final week of his visit, Mr Hall commenced development of a prototype age- and length-structured model for the snapper fishery with Mr Ferrell and Dr Scandol.

4.2.2. Professor Cynthia Jones (Old Dominion University, North Carolina), September 1999 – January 2000.

Professor Cynthia Jones is a well-known expert in population dynamics and a member of Fishery Assessment boards in the USA. During her stay as visiting fellow at Cronulla, Dr Jones conducted short courses and provided general assistance and discussions with respect to the fisheries models (rock lobster and snapper) under development.

4.3. Visits by NSW Fisheries staff to experts off-site

Dr Scandol spent 2 weeks with Mr Norm Hall at Fisheries WA in late 1999. During this time they completed an extensive review of developments to the length-structured models for rock lobsters and the age-structured model for snapper.

4.4. Development of population models and assessments

4.4.1. Re-engineering and re-write of a biomass dynamics model for rock lobster

During late 1998 and early 1999, a previously existing biomass dynamics model for the rock lobster fishery was re-engineered and rewritten in "C" by Dr Scandol and Dr Liggins following training and guidelines provided by Norm Hall (see section 4.2.1 and Appendix 3) in September 1998. This represented the first significant modelling project within the scope of this FRDC project. This model was subsequently used in resource assessment for the rock lobster fishery in May 1999 (Liggins *et al.,* 1999). As for previous assessments (e.g. Montgomery *et al.,* 1998), the biomass dynamics model was used to fit a time series of catch and CPUE data from fishery-dependent sources and provided a risk assessment of alternative harvest strategies (different TACs) for future years. Several important details concerning the model and the data with which it was fit differed from the previous implementation of the model. The structure of the model and the first assessment in which it was used are detailed in the resource assessment document (Liggins *et al.,*1999) and a copy of the executive summary from this document is included in Appendix 4.

Use of this model has continued in subsequent annual assessments of the rock lobster fishery (Liggins *et al.,* 2000, 2001).

4.4.2. Development of a length-structured model for rock lobster

Following the identification and description of a strategy for the development of a length-structured model for the rock lobster fishery (see section 4.2.1), Dr Scandol and Dr Liggins developed a proto-type length-structured model during early 1999. This model was included in the fishery assessment in May 1999 (Liggins *et al.,* 1999) even though the necessary information to provide a realistic representation of the stock and fishery was not yet available. It was included to: (i) demonstrate current progress and present the model structure; (ii) demonstrate model capabilities and (iii) present results of a preliminary study of model sensitivity to values of key parameters. Feedback from fishery managers and the TAC committee was positive. Compared to the more simplistic biomass dynamics model, the length-structured model: (i) addressed the need to represent the spawning biomass (or more generally, individual length-classes of lobsters) in addition to exploited biomass; (ii) provided the ability to account for the relative vulnerability to capture of different sizes of lobsters during different periods of fishery development; (iii) accounted for the probability of retention or discard of different sizes of lobster during different periods of fishery development.

Development of this model continued during 1999 and 2000 and was presented in the resource assessment in 2000 (Liggins *et al.*, 2000). In this assessment the model was used to provide a "preliminary" assessment for comparison with results derived from the biomass dynamics model. In addition, a preliminary analysis of the contribution of the maximum size-limit for lobsters (200mm carapace length, introduced in 1993-94) to the subsequent rebuilding of the stock was provided. A risk assessment module was added to the model in early 2001. Based on estimates of model parameters, a risk assessment of the consequences of a range of constant harvest strategies for the period 2001-02 to 2006-07 was provided in this assessment (Liggins *et al.,* 2001, copy of the executive summary from this assessment included here in Appendix 5). With increasing availability of the data necessary to use this model in a realistic way, increasing emphasis is being placed on this model in annual assessments and subsequently, by the TAC committee in their deliberations.

4.4.3. Development of an age-structured population model for NSW finfish species

Following on from the preliminary development work and guidelines provided by Norm Hall in 1998 (section 4.2.1) and further consultation with Mr Hall in 1999 (section 4.3.1), a synthetic age-structured population model for the NSW snapper fishery was developed by Mr Ferrell and Dr Scandol during 1999-2000. Using maximum likelihood methods this model can be fit to catch rate data, catch-at-age data and catch-at-length data. Over the past couple of years, this model has/is being used by Mr Ferrell in a component of the PhD he is currently completing.

During 1999-2000 this model was developed such that it could also be applied to other species of finfish. Its actual use for studying the population dynamics of species such as bream and mullet has been limited by issues associated with data quality and data contrast (rather than by problems associated with model development). It is notable that the underlying algorithm for this model was central to the later work completed by Scandol (2003b).

4.4.4. Development of a biomass dynamics model for Spanner crabs

Associated with the FRDC project 96/135 *"Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery",* Dr Kennelly and Dr Scandol developed a biomass dynamics model. This model was conditioned on catch and fitted to the results of fishery-independent surveys and/or commercial CPUE using non-linear optimisation. A description of this model and details of the analyses undertaken are provided in Kennelly & Scandol (1999, 2002). The key output of this work was the recommendation of a total allowable commercial catch to fishery managers and the Spanner Crab Management Advisory Sub-committee in 1999. A copy of the non-technical summary from the FRDC report (Kennelly & Scandol, 1999) is provided in Appendix 6.

4.4.5. Continued development of the length-structured Bayesian model for Abalone

Bayesian stock assessment and decision analysis using a stochastic, length-structured, dynamic model provides the basis of the annual resource assessment for the NSW abalone fishery. Whilst this model existed prior to this project (e.g. Worthington *et al.*, 1998), on-going development and use of this model (Worthington *et al.*, 1999, 2000) has occurred in parallel with this FRDC project. It also contributes to the current breadth of modelling approaches and expertise within NSW Fisheries.

4.4.6. Modelling services for the NSW Estuary General Fishery

A suite of modelling services were provided for major species caught in the NSW Estuary General Fishery via a contract to Dr Scandol at the *"Centre for Research on Ecological Impacts of Coastal Cities*" at the University of Sydney. Analyses based on age, length and catch data were completed for the 5 principal species in the fishery: dusky flathead, luderick, yellowfin bream, sand whiting and sea mullet. This project included: (i) fitting of growth models; (ii) calculation of $F_{max}/F_{0.1}$, fishing mortalities and age and length at first capture for optimal yield per recruit; (iii) estimation of total mortalities; (iv) construction of biomass dynamics models; (v) identification of appropriate trigger points for total catch performance indicators using simulated biomass data (Scandol & Forrest, 2001). The executive summary from the final report to NSW Fisheries (Scandol & Forrest, 2001) is included here in Appendix 7.

4.4.7. Landed catch as an indicator for the management of fisheries

Due to the paucity of information about many fish stocks in NSW, NSW Fisheries has elected to use landed catch as a temporary performance indicator within Fisheries Management Strategies until other indicators can be developed. Dr Scandol at the *"Centre for Research on Ecological Impacts of Coastal Cities*" at the University of Sydney was contracted to design a monitoring system that could detect transient and persistent trends in time-series of commercial landings. The scope of this project included: (i) design of a numerical algorithm (based upon cumulative sum control charts, "CUSUM") that used landed catch as an input and provided a simple Boolean output to indicate whether the most recent year's data on landed catch should trigger a review of the fishery; (ii) tests on the algorithm using simulated catch data to estimate sensitivity and specificity of the scheme; and (iii) application of the algorithm to several examples of landed catches from NSW Fisheries.

The executive summary from the final report to NSW Fisheries (Scandol, 2003a) is included here in Appendix 8.

4.4.8. Stock status indicators for the management of fisheries in NSW

A project that extended the work of Scandol (2003a) (see section 4.4.7) was contracted to Dr Scandol at the *"Centre for Research on Ecological Impacts of Coastal Cities*" at the University of Sydney. This project: (i) extended the rationale for using the CUSUM quality control algorithm for 8 more robust indicators of stock status; (ii) tested the algorithm using simulated CPUE, age- and length-structured data; (iii) examined sensitivity and specificity of the algorithm for detecting impacts, for each indicator and (iv) provided example analyses for several species important to NSW Fisheries.

The executive summary from the final report to NSW Fisheries (Scandol, 2003b) is included here in Appendix 9.

4.5. Formation of a group within NSW fisheries capable of independent development of population models and assessments

Despite the departure of one member of staff (Mr Geoff Gordon) during this project, a substantial increase in skills associated with fisheries modelling and assessment has accrued to 5 members of staff that currently work for NSW Fisheries (Dr J. Scandol, Dr G. Liggins, Dr S. Kennelly, Dr D. Worthington and Mr D. Ferrell). Over the course of this project, the range of population models and assessment methodologies developed (section 4.4) provides evidence of the enhanced capacity of this group within NSW Fisheries to independently develop fisheries models and assessment methodologies.

5. BENEFITS

Benefits accrue from this project to commercial, recreational and traditional fishing sectors within NSW. Because each of these sectors harvest fish from shared stocks, any improvements in population models, the accuracy of fishery assessments or the development of improved assessment methodologies provides benefits to each sector. The original funding application to FRDC for this project suggested that the flow of benefits across these sectors would be approximately: 70% of benefits to the commercial sector, 25% to the recreational sector and 5% to the traditional fishing sector.

Specific benefits related to development of population models and/or fishery assessment methodologies have been provided to the commercial, recreational and traditional components of fisheries for: rock lobsters (sections 4.4.1 & 4.4.2), spanner crabs (section 4.4.4), abalone (section 4.4.5) and species taken by the estuary general fishery (dusky flathead, luderick, yellowfin bream, sand whiting and sea mullet; sections 4.4.3 and 4.4.6).

Specific client-groups of NSW Fisheries associated with individual fisheries have directly benefited from this project. The TAC committee (independent of NSW Fisheries) which sets the TAC for quota-based fisheries (the commercial fisheries for lobster and abalone) has acknowledged the improvement of models and resource assessments since 1998. Management advisory committees are also beneficiaries. Just as the Lobster Management Advisory Committee (LOBMAC) and the Abalone Management Advisory Committee (ABMAC) have benefited from the development of improved population models and assessment methodologies that include risk assessment, other management advisory committees will receive similar benefits in the longer term.

More generally, client-groups associated with each of the fisheries for which NSW Fisheries is responsible will derive benefits from this project in the future. The research associated with developing indicators of stock status for the management of fisheries in NSW (sections 4.4.7 & 4.4.8) has general application across all fisheries. Moreover, future benefits to each sector of each fishery will accrue from the improved skills-base of NSW Fisheries personnel and the establishment of a group within NSW Fisheries capable of independent population modelling and resource assessment.

Most generally, the community has and will benefit from the better resource management that should ensue from the improved information available upon which to base decisions and policy.

6. FURTHER DEVELOPMENT

This project has demonstrated the benefits of a staff development program (in the areas of population modelling and fisheries assessment) to individual staff, NSW Fisheries and client groups of NSW Fisheries. It is recommended that this development program is continued. This is considered crucial because of the inevitability of staff turnover and the need to maintain a group within NSW fisheries that can continue to facilitate the development of population models and assessment methodologies.

Training of staff in the basics of population modelling by attendance at courses (run internally or externally) is recommended. Moreover, the interaction of staff with modelling and assessment experts from outside NSW Fisheries is likely to have similar benefits to those realised during this project. Short-term visits (or sabbaticals) of experts to the Cronulla Fisheries Centre would be ideal. One such relationship has recently been established.

A 3-year co-operative research project between NSW Fisheries and Professor Tony Pitcher (Fisheries Centre, University of British Columbia) titled *"Towards ecosystem-based fishery management in NSW using spatial ecosystem simulation"* commenced in November 2002. This project is exploring the potential of whole-ecosystem simulations based on Ecospace, a spatially explicit modelling technique, to forecast the results of alternative policy options for the marine and estuarine fisheries in NSW. Data is being gathered and models will be developed in a partnership between New South Wales Fisheries scientists and the world leaders in the field at the Fisheries Centre, University of British Columbia. Several visits from Professor Pitcher and his PhD student (Robyn Forrest) to NSW Fisheries are scheduled over the course of the project.

The substantial improvements to population models and assessments for rock lobster, abalone, spanner crabs and for several species of finfish and the subsequent flow-on benefits to NSW Fisheries and client-groups could also be realised for other species and fisheries under NSW management. Improved data collection programs and the application of modelling and assessment methodologies similar to those outlined in this project are recommended. Indeed, one of the immediate priorities of the current "Resource Assessment Scientist" (Dr James Scandol) is to complete a "Resource Assessment Strategy for NSW Fisheries". This strategy is in draft form at present and draws on the various results from this project.

7. CONCLUSIONS

The methodology involving the selection and training of appropriate members of staff has facilitated the formation of a core group of staff within NSW Fisheries capable of the independent development of population models and fishery assessments. Moreover, in addition to significantly expanding the skills of several individuals in the organisation, one of the staff that underwent targeted skills development (Dr James Scandol) now occupies the full-time position of "Resource Assessment Scientist" with NSW Fisheries. Thus, in addition to fulfilling the objectives of this FRDC project, the aim of the original project in 1995 (see section 1.0) of employing an individual with well-developed modelling skills has also been realised.

The first 2 objectives of the project involved the identification, selection and subsequent training of existing staff such that they could develop population models for major NSW Fisheries. Training was provided by a combination of courses and interaction with experts in the field of modelling population dynamics. Five members of staff (Dr James Scandol, Dr Geoff Liggins, Mr Geoff Gordon, Dr Duncan Worthington and Mr Geoff Gordon) were involved in this training and consultation to varying degrees (section 4.1-4.3).

Fulfillment of the first 2 objectives then facilitated the third objective: "Begin to develop population models, fishery assessments and management options for the major fishery sectors of NSW." The successful development of population models for rock lobster, spanner crab and several estuarine finfish species and the ongoing development of the abalone model demonstrate significant advances in the development of population models within NSW Fisheries. Moreover, the use of the lobster and abalone models as the basis of annual resource assessments and the risk assessments of alternative harvest strategies therein, demonstrates the utility of these models in contributing to fishery management via the process of annual resource assessment.

Through fulfillment of these objectives, this project has significantly enhanced the ability of NSW Fisheries to develop quantitative assessments of the status of exploited fisheries resources in NSW. In addition, the research concerning the development of indicators of the status of stocks for the management of fisheries in NSW (sections 4.4.7 and 4.4.8) is directly contributing to the formulation of objectives, performance indicators and triggers in Fisheries Management Strategies currently being developed for fisheries in NSW.

Conclusions have also been made in the form of recommendations for further developments (section 6.0). Specifically: ongoing training of staff; establishment and maintenance of co-operative relationships with recognised experts in the field of modelling and assessment; improvements in the modelling and assessment of other stocks in NSW; and the development of a formal strategy for the resource assessment of all fisheries in NSW.

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9. APPENDICES

Appendix 1: Intellectual Property

There are no issues concerning intellectual property associated with the work done in this project.

Appendix 2: Staff

Dr Rick Fletcher	(former Director, Research Division) - Principal Investigator for project, July 1998 - September 2000.
Dr Steve Kennelly	(Chief Scientist) - Principal Investigator for project, since September 2000.
Dr Geoff Liggins	(Fisheries Scientist)
Dr James Scandol	(Resource Assessment Scientist)
Mr Geoff Gordon	(Biometrician), resigned March 2001.
Dr D. Worthington	(Fisheries Scientist)
Mr D. Ferrell	(Fisheries Scientist)

Appendix 3: Review of the 1998-99 assessment of the fishery for eastern rock lobster (*Jasus verreauxi*), N.G. Hall, September 15, 1998.

Review of the 1998-99 Assessment of the fishery for Eastern Rock Lobster (*Jasus verreauxi*)

N. G. Hall

September 15, 1998

Summary

A brief review of the recent stock assessment for *Jasus verreauxi*, and information required for assessment of the TAC for the eastern rock lobster fishery was carried out. Several issues of concern were raised with respect to the biomass dynamics model which is currently used. These issues relate to the form of the objective function for the least squares algorithm, the difficulty of fitting the least median squared error model and obtaining consistent parameter estimates, and the need to incorporate the uncertainty of both parameter estimates and of unreported data into the assessment of the response of the system to alternative TACs. These issues should be referred to the original authors, as they may already have considered and resolved the questions raised. Simple delay-difference and age structured models are described, but it is concluded that there is little advantage in attempting to meet the TAC Committee's needs by developing a delay-difference form of model. The age structured model has been implemented in Excel and provides an example of the implementation of such a model. The AD Model Builder implementation of the spatial length structured model has been annotated and corrected, but there are still difficulties in applying this model to the fishery data. It is suggested that future model development follow the developmental sequence of, in order, a single area age structured model, a single area length structured model, a spatial age structured model, and a spatial length structured model; this would allow a gradual increase in complexity and the development of an understanding of the uncertainties and limitations of each model before the more complex model is initiated.

Introduction

The recent stock assessment of the fishery for *Jasus verreauxi* by Montgomery *et al*. (1998) was considered by the eastern rock lobster TAC Committee before setting the Total Allowable Catch for the 1998/99 fishing season. The Committee found that some aspects of the assessment were inadequate for their needs. In particular, they noted that:

1. The risk of stock collapse is more closely associated with the spawning biomass rather then the exploited biomass;
2. The rock lobsters above the legal maximum size make a contribution to the spawning potential of the stock, yet are not represented within the biomass dynamics model;
3. The reduced number of pots being used within the fishery have a higher efficiency due to competition between pots being reduced (the use of the VP model's assumption of cpue being proportional to a power of the applied fishing effort needs to be explored as an alternative, in addition to the current approach being used in the biomass dynamics model);
4. There is a need to assess the progress of the 1993 management measures in achieving the objective of rebuilding the stock in terms of objective observations from the fishery;
5. An assessment of the current status of the exploited stock and of the spawning stock relative to the virgin state needs to be an output of the model;
6. The progress of the Fisheries Research Institute in developing the new length structured model needs to be reported;
7. The research advice needs to provide information on the level of catch that could be taken without reducing the current stock size;

Initial impressions that I gained on reading the Montgomery *et al*. (1998) document were that:

1. The uncertainties associated with parameter estimates do not appear to be represented in the subsequent assessment of the likely risk associated with alternative levels of TAC;
2. The uncertainties associated with environmental fluctuations do not appear to be represented in the assessment of the likely risk associated with alternative levels of TAC.

In reviewing the modeling work for the eastern rock lobster fishery, the objectives were to (a) identify possible improvements that might be made to the biomass dynamics models; (b) to describe the spatial length structured model developed by David Fournier, Steve Montgomery and Dennis Reid in AD Model Builder in late 1997, and to resolve the array subscript bounding error that was believed to exist in this code which was an impediment to further model development; (c) to identify an appropriate model structure which might extend the existing modeling approaches and address the issues raised by the TAC Committee; and (d) to set up an example of such a model within Excel, as a guide to developing the new model.

Critical Appraisal of Assessment for 1998/99

A brief review of the assessment for 1998/99 carried out by Montgomery *et al.* (1998) was undertaken to identify improvements that might possibly be made.

Problem with Objective Function for Least Squares Algorithm

A fundamental problem was identified in the objective functions used in fitting the biomass dynamics model to the data for the least squares (LS) algorithm. In the current form presented by Montgomery *et al.* (1998), the fitting procedure will ensure that the mean is zero for the least squares fit but is likely to fail to identify the best fitting curve.

The objective function as specified (in summary form) for the least squared observation error model is Equation 3 from Montgomery *et al*. (1998, p23):

$$L = W_1 \sum_{t1=1903}^{1957-58} \left(\frac{\hat{\upsilon}_{t1}}{\hat{\sigma}_{\upsilon_1}} \right)^2 + W_2 \sum_{t2=1969-70}^{1992-93} \left(\frac{\hat{\upsilon}_{t2}}{\hat{\sigma}_{\upsilon_2}} \right)^2 + W_3 \sum_{t3=1993-94}^{1996-97} \left(\frac{\hat{\upsilon}_{t3}}{\hat{\sigma}_{\upsilon_3}} \right)^2 + W_4 \sum_{t4=1969-70}^{1996-97} \left(\frac{\hat{\upsilon}_{t4}}{\hat{\sigma}_{\upsilon_4}} \right)^2 .$$

Montgomery *et al*. (*op. cit.*) define the variables of this equation as

$$\hat{\upsilon}_{t1} = \ln(I_{t1}) - \ln(q_1 B_{t1}) = \ln\left(\frac{I_{t1}}{B_{t1}} \right) - \ln(q_1)$$

and

$$\hat{\sigma}^2_{\upsilon 1} = \frac{\sum_{t1=1903}^{1957-58} \left(\hat{\upsilon}_{t1} - \sum_{t1} \frac{\hat{\upsilon}_{t1}}{n_1} \right)^2}{n_1 - 1},$$

and similarly for the other terms, where these are the residuals of the logarithms of the indices of abundance and the estimated residual variance for each of the data sets.

For any arbitrary but specific set of *r, K_1* and *K_2*, it may be shown that the optimal solution for q is the value for which

$$\sum_{t1} \frac{\hat{\upsilon}_{t1}}{n_1} = 0$$

and similarly for each of the data sets, where

$$\hat{\sigma}_{\upsilon 1}^2 = \frac{\sum_{t1=1903}^{1957-58} \left(\hat{\upsilon}_{t1}\right)^2}{n_1 - 1},$$

and similarly for each of the other variances. The resulting sum of squares is then

$$L = W_1(n_1 - 1) + W_2(n_2 - 1) + W_3(n_3 - 1) + W_4(n_4 - 1).$$

The weights are simply numeric constants, and the number of observations in each data set is fixed.

The optimum value for the objective function may be obtained by simply varying the catchability parameters of the model till the mean of the residuals for each data set becomes zero. That is,

$$\sum_{t1} \frac{\hat{\upsilon}_{t1}}{n_1} = 0 = \sum_{t1} \frac{\left\{ \ln\left(\frac{I_{t1}}{B_{t1}}\right) - \ln(q_1) \right\}}{n_1} = \left\{ \sum_{t1} \frac{\ln\left(\frac{I_{t1}}{B_{t1}}\right)}{n_1} \right\} - \ln(q_1)$$

or, simply

$$q_1 = \exp\left\{ \sum_{t1} \frac{\ln\left(\frac{I_{t1}}{B_{t1}}\right)}{n_1} \right\},$$

for whatever values of exploited biomasses have been generated given any arbitrary *r*, K_1, and K_2.

The same solution will be obtained for any set of *r*, K_1, and K_2. The objective function is therefore independent of the parameters that determine the biomass dynamics, and is only dependent on the values of the catchabilities. Similarly, the parameter estimate for each catchability is independent of the weights applied.

A more appropriate approach to fit the data in a traditional statistical manner is to use the log likelihood method. Here the log likelihood is to be calculated for k sets of data, where each set is to be weighted by W_k. This is equivalent to transforming the observed and expected values of the variables by multiplying each by the square root of the weight that is applied to the data set. The variance of the transformed values is then equal to the product of the weight and the original variance. The log likelihood of each data set is then calculated as

$$LL_k = -n_k \log\left(\sqrt{2\pi}\right) - n_k \log\left(\sqrt{W_k}\sigma_k\right) - 0.5\sum_j \left\{ \frac{W_k\left(Y_{k,j} - \hat{Y}_{k,j}\right)^2}{W_k \sigma_k^2} \right\}$$

where σ_k is the standard deviation of the untransformed residuals. This becomes

$$LL_k = -n_k \log\left(\sqrt{2\pi}\right) - n_k \log\left(\sqrt{W_k}\right) - n_k \log\left(\sigma_k\right) - 0.5\sum_j \left\{ \frac{\left(Y_{k,j} - \hat{Y}_{k,j}\right)^2}{\sigma_k^2} \right\}.$$

This model was applied within the Excel version of the biomass dynamics model that was set up to test the current version of the biomass dynamics model, and was found to produce acceptable results for the fit of the model.

Difficulty in Parameter Estimation for LMSE using Excel's Solver

As the objective function for the least median squared error is of a similar form to the objective function for the least squared errors algorithm, the question is raised as to whether the function is independent of the paramater values for *r*, K_1, and K_2. A very brief investigation of this within a spreadsheet suggests that the function does depend on the values of these parameters, but there appears to be a very flat surface, as the Solver routine within Excel was sensitive to starting values with a wide range of resulting values of the objective function and a range of resulting parameter estimates; whether the Solver routine is appropriate given the potential for discontinuities in the function with respect to the values of the parameters must also be reviewed.

Yong Chen applies the amoeba or simplex method to estimate parameters in his implementation of the model, however, whether this algorithm overcomes the problem is a question that must still be posed. A more robust optimization method such as simulated annealing may be required. I understand that a number of simulations were applied using synthetic data, and it may be that this problem has already been addressed and the ability of the routine to recover the "true" parameter estimates may be beyond doubt.

Examination of the adequacy of assumptions

In traditional least squares model fitting (or maximum likelihood), a fundamental aspect of the study is to examine the residuals to determine whether the model structure is appropriate and whether assumptions regarding the distribution of residuals is correct … both the independence of consecutive residuals and the form of the distribution. This aspect has received little attention. The pattern of residuals in the first set of cpue data suggests that there are other factors involved. These may be biological (e.g. A slow moving random walk of the parameter estimates of the carrying capacity and the rate of increase), or reflect inadequacy of the assumptions such as the relationship between the total exploited biomass and the catch rate, possibly influenced by factors such as international conflict. The adequacy of the early years of data for the standard fishers needs to be considered critically, and there is a need to ensure that the standard fishers are removed from the values used to calculate the commercial catch rates, such that these two series are independent.

Uncertainty of parameter estimates

The uncertainty associated with the estimates of the parameters must be investigated. It is clear from a quick examination of the surface of the objective function, that this surface is relatively flat suggesting considerable uncertainty in the values of the parameter estimates. These parameter estimates determine the current status of the fishery, the target biomass, and the future trajectory of biomass under the various TAC regimes that are examined. It is important that the uncertainty associated with the parameter estimates should be examined when assessing the risk and potential merits of the alternative harvest strategies.

The usual approaches when dealing with a maximum likelihood or least squares estimation of the parameters is to use the information relating to the shape of the surface to estimate the Hessian and estimate the variance-covariance matrix using a linear approximation around the minimum. Alternatively, provided the model structure is adequate, bootstrapping may be used to estimate the uncertainty of the parameter estimates (and to determine alternative samples of these parameters for use in harvest strategy assessment).

Uncertainty of future environment

While the usual approach is to apply a deterministic model and observation error for the historical data set, projections of the future response of the system usually apply environmental perturbations to the biological processes determining the future system state. While implementation error (error in catch applied given a specified TAC) is considered, process error should also be included in the assessment.

Uncertainty in unrecorded data

While considerable effort has been applied to estimating the uncertainty of parameters associated with alternative selections of the correction factors for the unrecorded catch, it appears that this uncertainty has not been incorporated within the assessments of the future performance of the fishery under the alternative harvest strategies. This needs to be included.

Future Assessment

Biomass Dynamics Model

While past assessments have made extensive use of the biomass dynamics models, and there is value that still may be obtained from further study of the fishery using these models, the TAC Committee is requesting advice regarding the spawning biomass of the stock and the impact of the maximum legal length in protecting a portion of the spawning stock. The structure of the biomass dynamics model is not suited to examination of these aspects of the system.

The biomass dynamics model should continue to be applied to the fishery, as it provides an alternative representation of the fishery, and considerable experience has been gained in applying this model. It provides a useful safeguard to the management advice that is offered, as the response of the system to alternative TAC quotas under alternative models should be consistent with those of the biomass dynamics model.

Age Structured Model

This model structure appears to be the most appropriate for use in the immediate future for fishery assessment. The data requirements are not demanding, and the current cpue data may be used to provide the initial information required. The von Bertalanffy parameters that are still to be determined can be estimated (with associated estimates of uncertainty) from the cpue data. The model allows separation of males and females, and estimation of the changes that have occurred within the spawning stock. The model also permits examination of the benefits of the 200 mm maximum legal length.

With a level of complexity that matches current information needs, but does not attempt to introduce unnecessary complexity where insufficient research data exist, this is the most appropriate model for use in the next assessment. The complexity is appropriate given the resources and the time schedule that must be met to deliver the assessment document.

An example of the format and the calculations has been set up as an Excel spreadsheet in order to assist the development of this model.

Length Structured Model

While it is possible to set up a length structured model, this is probably inappropriate at this time. Certainly data collection needs to be commenced to allow development of this form of model, but the immediate needs for management advice may be satisfied by a simpler form of model. However, prior to developing a spatial version of a length structured model, it would be useful to develop a simple single area length structured model. For this it will be necessary to combine the length frequency information from the different regions into a single representative sample for each year.

The model form that might be used as a guide is the Tasmanian model developed by Punt and Kennedy. It is possible that Paul Breen may now have developed an AD Model Builder version of this for use in New Zealand (Neil Andrew, pers. comm.), and it is likely that this may be available on request.

Spatial Age Structured Model

Development of an age structured model would be appropriate as the first extension of the single area age structured model to a spatial framework. It would be relatively simple to modify the AD Model Builder version of the spatial length structured model for the eastern rock lobster fishery that was developed by David Fournier, Steve Montgomery, and Dennis Reid, to reduce it to an age structured spatial model. This would be a useful development, but again is likely to be of greater complexity than is needed to provide the immediate advice required by the TAC Committee.

Spatial Length Structured Model

The AD Model Builder code prepared by David Fournier, Steve Montgomery, and Dennis Reid has been annotated to provide a clear understanding of the function of the various code segments and functions. A small problem has been corrected and the model now runs, but the Hessian that is produced is not positive definite and accordingly estimates of the variance-covariance matrix can not be obtained.

The length structured model represented in this code is spatial in nature, attempting to fit both the cpue data for the most recent period and the 3 samples of length frequency obtained for each of 4 spatial regions. The model estimates the frequency within each length class by multiplying the proportion of fish within each length class at each age by the proportion at age and the total sample size for the area, year, and sex. The model is essentially an extension of a spatial age structured model, as fishing mortality and migration is age dependent, not length dependent.

Little information on migration is available, and parameters must be estimated from the available data. The model is complex and a considerable number of parameters must be estimated.

Modeling Tools

It appears that AD Model Builder is becoming a valuable tool for the development of fishery models. In its simplest form, the code generated by AD Model Builder is sufficient to produce estimates of the parameters for the model, and estimates of the variance-covariance matrix for the parameters.

For management advice, there is a need to modify the C++ code produced by AD Model Builder to allow for the evaluation of alternative harvest strategies by projecting the fishery a number of years into the future, and to combine the results from a number of runs to produce estimates of risk. In order to produce graphic output, and to summarise the results, it appears probable that the AD Model Builder code will need to be coupled with other software packages and routines.

Terry Quinn has expressed some reservations that the estimated variance-covariance matrix produced by AD Model Builder may be inaccurate in some cases. It is probably appropriate that the AD Model Builder code developed for a fishery model should be backed up by an alternative implementation of the code in an alternative software package or language, allowing exploration and confirmation of the resulting model outputs.

With the need for a considerable number of Monte Carlo runs to evaluate risk, and with the number of age and length classes involved, it appears that use of a procedural language should be considered in preference to use of Excel.

Discussion

The benefits of the robust regression paradigm and use of the least median squared errors estimator need to be evaluated carefully, as a consequence of this paradigm is that it becomes inappropriate to apply the tools available in statistics for models developed in a maximum likelihood or least squares environment. For example, the benefits of adding an additional parameter to explain the improvement in cpues from 1993/94 may be assessed using a likelihood ratio test. The robust regression paradigm appears to encourage the acceptance of residuals that have occurred and acceptance of current model structure, while the more traditional approach encourages the assessment of adequacy of model structure and distribution of residuals.

Uncertainty associated with the LMSE approach needs to be explored. While statistical estimates of the variance-covariance matrix may not be possible, the use of bootstrapping approaches (randomly sampling from the deviations from the model observed in historical cpues) appears to offer the potential to incorporate estimates of model uncertainty in the projections of the future behaviour of the system under alternative harvest strategies.

This review is an informal evaluation of the assessment by Montgomery *et al.* (1998), but it has been conducted without reference to the authors, and without sufficient time for a detailed analysis of the data. Comments made in this discussion should therefore be treated as informal in nature, and should be referred back to the authors for their consideration, and (if they consider appropriate) possible inclusion in further analysis. The issues raised are intended as positive criticism, and it is hoped that they may result in further improvement in the assessment and management of the eastern rock lobster fishery.

Acknowledgements

It is appropriate to acknowledge the considerable input and support provided by Geoff Liggins, Dennis Reid and Geoff Gordon, which was invaluable in undertaking this brief review. Thanks are also offered to Dr Rick Fletcher for making my visit to NSW possible.

References

Montgomery, S., Y. Chen, J. Craig, and L. Diver. 1998. An assessment of the NSW eastern rock lobster resource for 1998/99. NSW Fisheries, Fisheries Research Institute Fishery Resource Assessment Series, 4:1-65.

Appendix 4: Executive summary from: "An assessment of the NSW eastern rock lobster resource for 1999-2000", Liggins *et al.* (1999).

EXECUTIVE SUMMARY

Liggins G.W., Scandol J.P., Montgomery S., Craig J., and Macbeth W. 1999. An assessment of the NSW eastern rock lobster resource for 1999-2000*. NSW Fish. Res. Assess. Ser. 7.*

This report presents the assessment of the NSW eastern rock lobster resource for 1999-2000.

The current objective for the management of the eastern rock lobster resource, as stated in the draft management plan for the fishery, is to increase the biomass of the stock. It is, however, recognised by NSW Fisheries and the management advisory committee for the fishery, that a more appropriate long term objective for the fishery concerns the maintenance of the spawning biomass above some reference level (e.g. 25% of the pre-exploitation level). Such an objective will be adopted once the information necessary to assess the status of the fishery with respect to this objective is available.

This assessment is based upon fishery-dependent catch and effort data: catch data from the commercial fishery for the period 1884-85 to 1997-98; estimates of unreported commercial catches and recreational catches over the period 1969-70 to 1997-98; and catch per unit effort data from the commercial fishery for the periods 1903-04 to 1957-58 and 1969-70 to 1997-98. It should be noted that assessments based upon such fishery-dependent data are susceptible to bias caused by changes in fishing practices, catchability and unpredictable relationships between abundance, fishing effort and catch rate.

The available CPUE information shows some cyclical fluctuations with an overall downward trend over the period 1903-04 to 1958-59 (the first CPUE data series) and from 1971-72 until 1988-89 (part of the second CPUE series). However, patterns in CPUE since 1992-93 suggest that the long-term decline in relative abundance of eastern rock lobsters has been halted and moreover, that the abundance of eastern rock lobsters has been increasing in recent years.

A biomass dynamics model and a range of scenarios that varied the weight given to individual time series of data was fitted to fishery-dependent catch and CPUE data. This model is a revised version of the biomass dynamics model presented in the previous assessment and: (i) takes into account changes in the efficiency of fishing effort by making CPUE proportional to some power of effort and estimating this parameter; (ii) uses a “least squares” estimator rather than “least median of squares estimator”, (iii) assumes a constant carrying capacity, and (iv) the risk assessment analysis (based on the model) has been modified to include the uncertainties associated with estimates of model parameters. In addition to including catch and effort information from the most recent year,1997-98, revisions have been made to the historical data sets and to the range of scenarios (combinations of various CPUE series) to which the model is fit.

Overall, the pattern in annual estimates of biomass (from the biomass dynamics model for both scenarios II and III) is one of long-term decline from the late 1880’s through to 1991-92. This long-term decline was interrupted by short-term increases during the periods 1917-18 to 1920-21 and 1940-41 to 1947-48, periods associated with the 2 world wars. The decline in biomass was accelerated during the 1980’s with biomass reaching its lowest point in the early 1990’s. In response to concerns about the status of eastern rock lobster stock, NSW Fisheries implemented several severe management initiatives (restricting entry to the fishery, implementing a total allowable catch and quota management system, and further restrictions on the commercial and recreational fisheries) between 1992 and 1994. Since 1994-95, against a background of increasing TACC, increasing commercial catch and increasing value of the catch, biomass has increased. Scenario II of the biomass dynamics model (model fit to 1969-70 to 1997-98 CPUE series)

estimates that biomass at the commencement of 1998-99 was 0.48 (90%C.I: 0.37 -0.65) of the pre-exploitation level, that biomass had increased over the period 1994-95 to 1998-89 by 12% (90% C.I.: 2 - 27%) and that the maximum sustainable yield for the fishery is 218 t (90% C.I.: 177 - 260 t). Scenario III, the more conservative scenario of the biomass dynamics model (model fit with "50/50" weighting on the two CPUE time series), estimates that biomass at the commencement of 1998-99 was 0.44 (90%C.I: 0.34 -0.57) of the pre-exploitation level, that biomass had increased over the period 1994-95 to 1998-89 by 7% (90% C.I.: 0 - 18%) and that the maximum sustainable yield for the fishery is 204 t (90% C.I.: 152 - 238 t).

Based on the current (1998-99) TACC of 125 t, and assuming an unreported commercial catch of 25 t (17% of total commercial catch) and a recreational catch of 25 t, the current TAC is approximately 175 t. Assuming a total catch of 175 t during 1998-99, a risk assessment of alternative constant harvest strategies for the period 1999-2000 to 2003-04, based on the biomass dynamics model, predicts that biomass in 2004-05 will exceed the biomass at the commencement of 1998-99:

with 95% probability, for TACs up to 167 t (using scenario II) and 126 t (using scenario III)
with 90% probability, for TACs up to 191 t (using scenario II) and 157 t (using scenario III)
with 75% probability, for TACs up to 218 t (using scenario II) and 190 t (using scenario III)

Allowances must be made within the TAC for the reported commercial catch (i.e. the TACC), the unreported commercial catch and the recreational catch.

The inclusion of an age-structured model in the current assessment document represents the first stage of a development sequence related to age- and length-structured models of the eastern rock lobster resource. However, it is premature to use this model for any strict assessment purpose because the information required for this model is not yet available. Rather, we present the model in this document to demonstrate current progress, model capabilities and present results of a preliminary study of model sensitivity to values of key parameters. The model is presently being used to fine tune the direction of research. This model will be used in the future to assess status of the stock with respect to both the exploited and spawning biomasses.

Current research sub-programs are collecting the information that will support the ongoing development of age- and length-based models of the eastern rock lobster population. Substantial progress has been made over the last year with respect to: (i) the development of an observer-based survey of the size-composition of commercial catches; (ii) ongoing development of the tagging study of growth and movements of lobsters and a preliminary analysis of growth rates and (iii) a pilot fishery-independent survey of abundances of spawning and oversize lobsters. Improvements have been made to the log-book program (collection of catch and effort data from the commercial fishery) and the 4th year of the survey of recruitment to the lobster population (settlement of pueruli) was successfully completed.

We recommend that the TAC committee adopt caution when setting the TAC for the following reasons: (i) the accuracy of the data upon which the biomass dynamics model is based is questionable, particularly the estimates of recreational catch and unreported commercial catch; (ii) assessments based upon fishery-dependent data are susceptible to bias caused by changes in fishing practices, catchability and unpredictable relationships between abundance, fishing effort and catch rate and (iii) we currently have little knowledge of important aspects of the biology of the eastern rock lobster - in particular, the size of the spawning stock.

Appendix 5: Executive summary from: "An assessment of the NSW eastern rock lobster resource for 2001/02", Liggins *et al.* (2001).

EXECUTIVE SUMMARY

Liggins G.W., Scandol J.P., Montgomery S., Craig J., and Macbeth W. 2001. An assessment of the NSW eastern rock lobster resource for 2001-2002. *NSW Fish. Res. Assess. Ser. 14.*

This report presents the assessment of the NSW eastern rock lobster resource for 2001-2002. It is principally based on data collected from the fishery up to the end of the 1999-2000 quota year but with reference to some research data collected during the current year, 2000-2001.

With the introduction of a formal management plan for the fishery in 2000, objectives and performance indicators are now specified for the fishery. Performance against 3 of the 6 objectives of the management plan is assessed here. These objectives are: to increase the biomass of the stock; promote commercial fishing practices for rock lobster that do not have an adverse environmental impact on the broader ecosystem; to ensure appropriate research and monitoring in relation to the fishery. With respect to the first objective, it is recognised by NSW Fisheries and the management advisory committee for the fishery, that a more appropriate long term objective for the fishery concerns the maintenance of the spawning biomass above some reference level (e.g. 15%, 20% or 25% of the pre-exploitation level). In the future, consideration will be given to incorporating such an objective (and associated performance indicators and trigger points) into the management plan for the fishery.

The current assessment is principally based upon fishery-dependent catch and effort data: reported catch data from the commercial fishery for the period 1884-85 to 1999-00; estimates of unreported commercial catches and recreational catches over the period 1969-70 to 1999-00; and catch per unit effort data (based on reported catch and effort and adjusted for unreported catch) from the commercial fishery for the periods 1903-04 to 1957-58 and 1969-70 to 1999-00. It should be noted that assessments based upon such fishery-dependent data are susceptible to bias caused by changes in fishing practices, catchability and unpredictable relationships between abundance, fishing effort and catch rate.

The available CPUE information shows some cyclical fluctuations with an overall downward trend over the period 1903-04 to 1958-59 (the first CPUE data series) and from 1971-72 until 1988-89 (part of the second CPUE series). However, patterns in CPUE since 1992-93 suggest that the long-term decline in relative abundance of eastern rock lobsters has been halted and moreover, that the abundance of eastern rock lobsters has been increasing in recent years.

A biomass dynamics model and a range of scenarios that varied the weight given to individual time series of data (scenario II based on CPUE data from 1969-present and scenario III based on this and an earlier time series of CPUE data) was fitted to fishery-dependent catch and CPUE data. This model is essentially the same as that used in the previous assessment but has been updated with the addition of catch and CPUE data from 1999-00. The length-structured model used in this assessment represents a significant development in the assessment methodology. Compared to the biomass dynamics model, the more complex length-structured model incorporates many more aspects of the biology of lobsters, and the interactions between the fishery and various sizes of lobsters in the stock.

Overall, the pattern in annual estimates of biomass (from the biomass dynamics model for scenarios II and III) is one of long-term decline from the late 1880's through to 1991-92. This long-term decline was interrupted by short-term increases during the periods 1917-18 to 1920-21 and 1940-41 to 1947-48, periods associated with the 2 world wars. The decline in biomass was accelerated during the 1980's with biomass reaching its lowest point in the early 1990's. In response to concerns about the status of eastern rock lobster stock, NSW Fisheries implemented several severe management initiatives (restricting entry to the fishery, implementing a total allowable catch and quota management system, and further restrictions on the commercial and recreational fisheries) between 1992 and 1994. Since 1994-95, against a background of increasing TACC, commercial catch has increased gradually but has not increased in proportion to recent increases in the TACC (3% below 106 t in 1996-97, 8% below 117 t in 1997-98 and 12 % below 125 t in 1998-99 and 17% below in 1999-00). CPUE has increased over the period 1994-95 to 1998-99 with a slight decrease in 1999-2000. Two scenarios examined with the biomass dynamics model provide estimates that biomass at the commencement of 2000-01 was within the range 34% to 64% (90% C.I's depending on scenario) of the pre-exploitation level and that biomass had increased over the period 1994-95 to 2000-01 by between 2% and 43% (90% C.I's depending on scenario). Maximum sustainable yield was estimated to be in the range 172 to 256 t (90% C.I's depending on scenario). Using the base case scenario of the length-structured model (LS-Base), total biomass was estimated to be between 27% and 40% (90% C.I.) of the pre-exploitation level and that it had increased by between 23% and 56% (90% C.I.) since 1994-95. Spawning biomass at the commencement of 2000-01 was estimated to be between 18% and 30% (90% C.I.) of the pre-exploitation level and had increased by between 38% and 91% (90% C.I.) since 1994-95.

The risk assessment of alternative harvest strategies, based on the biomass dynamics model, predicts that biomass at the commencement of 2006-07 will exceed the biomass at the commencement of 2000-01:

- with 95% probability, for total catches up to 156 t (using scenario II) and 155 t (using scenario III)
- with 90% probability, for total catches up to 178 t (using scenario II) and 171 t (using scenario III)
- with 75% probability, for total catches up to 204 t (using scenario II) and 198 t (using scenario III)
- with 50% probability, for total catches up to 222 t (using scenario II) and 214 t (using scenario III)

The risk assessment of alternative harvest strategies, based on the length-structured model (and the base scenario LS-Base) provided estimates of changes in biomass over the period 2000-01 to 2006-07 for the various harvest strategies for total biomass, exploitable biomass (104-200 mmCL) and spawning biomass. Confidence intervals associated with these estimates were wider than for the biomass dynamics model because this risk analysis allows for variations in annual recruitment to the fishery as well as variation in the estimated model parameters. According to the risk analysis based on this model, biomass at the commencement of 2006-07 will exceed biomass at the commencement of 2000-01:

- for total biomass: with 50% probability, for total catches up to 200 t
- for exploitable biomass (104 - 200 mmCL): with 50% probability, for total catches up to 166 t
- for spawning biomass: with 50% probability, for total catches up to 225 t

The total catches described above include components for unreported commercial catch and recreational catch as well as the allocated TACC (for the commercial fishery).

Current research sub-programs are collecting the information that will support the ongoing development of the length-structured model of the eastern rock lobster population: (i) collection and analyses of logbook catch and effort data; (ii) an observer-based survey of the size-composition of commercial catches; (iii) tagging program to study of growth and movements of lobsters; (iv) fishery-independent survey of abundances of mature lobsters; (v) survey of recruitment to the lobster population (settlement of pueruli).

Appendix 6: Non-technical summary from: "Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery", Kennelly & Scandol (1999).

NON TECHNICAL SUMMARY

96/135	Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery.

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OBJECTIVES:

1. Provide fishery-independent estimates of the relative abundances of spanner crabs in NSW;
2. Use the estimates obtained in (1) with similar estimates obtained in 1988-89 to analyse trends in relative abundances;
3. Incorporate the information collected in (2) with existing data on the biology and fishery of spanner crabs to develop a population model for this fishery; and
4. Use the model developed in (3) to provide appropriate advice to fisheries managers and industry on various input and output controls including the TACC.

KEYWORDS:

Spanner crabs, fishery-independent survey, biomass dynamics model, TACC

NON-TECHNICAL SUMMARY:

In 1988-89, a multifactorial, stratified, randomized survey was done in the spanner crab (Ranina ranina) fishing grounds off the coast of New South Wales, Australia to determine fluctuations in relative distributions and abundances across a variety of spatial and temporal scales. This survey was repeated in 1997-98 to provide a new assessment of this stock and to provide fishery-independent data to develop a population model and TACC for the fishery.

The results from these surveys showed the marked sexual dimorphism of this species with males generally attaining larger sizes than females and a sex ratio that was slightly biased towards females. These results, in combination with the 93 mm minimum size limit, meant that: (i) 71-73% of the population was undersize; (ii) male crabs comprised most of the portion of the population that was targeted by fishers; and (iii) approx. 96% of females were protected. These results imply that this fishery should be in a relatively sound position, ensuring long-term viability through the maintenance of a large spawning population.

Comparing catch rates from the two surveys revealed large variabilities in abundances across several of the spatial and temporal scales investigated. A consistent result was that catches of crabs (especially females) decreased during October and December each year in both repeats of

the survey, co-inciding with the spawning period. In one location (Tallows Beach), however, such decreases did not occur, possibly indicating this site as the focus of a spawning migration at this time.

There were some results from the surveys that provide some evidence of the impact of fishing activity, including a significant 6% decrease in the relative abundances of all crabs over the 11 year period of the study, a 11% decline in the numbers of small male crabs (<93mm C.L.) and a 55% decline.

The fishery was modelled from 1984 to 1998 using an observation-error biomass dynamic model conditioned on catch and fitted to the survey results using non-linear optimisation. Confidence intervals for the parameter estimates were determined using bootstrap methods. The results suggested that the median exploitable biomass (with 10% and 90% quantiles) of the NSW stock had been reduced from 1,500 (760, 5,800) tonnes in April 1984 to 940 (400, 4,000) tonnes by December 1998. A risk analysis was completed to predict the effects of various harvest strategies on reference points of the fishery. This analysis indicated that an annual TACC of 290t should not cause any further reduction in the exploitable biomass of the NSW stock (with ? 90% confidence). A TACC of 300 t was recommended to the Spanner Crab Management Advisory Sub-Committee in 1999.

A preliminary analysis of the combined NSW and Queensland fisheries was also completed under the unlikely assumption that the data from the NSW survey also reflected relative abundances throughout Queensland. This indicated that a combined harvest of 2,300 tonnes will cause the exploitable biomass in five years to be similar to that now (with ≥ 50% confidence).

We conclude that the continued use of the fishery-independent survey described in this report will provide a powerful tool to monitor fluctuations in the population after changes in management - thus providing new information and, consequently, modified recommendations to management like adjustments to the TACC. Further, we also recommend that the geographic range of the survey be expanded to include the Queensland fishing grounds so that modelling and management of this fishery can incorporate the entire east coast stock.

Appendix 7: Executive summary from: "Modelling services for the NSW Estuary general Fishery – Final report for NSW Fisheries", J.P. Scandol & R.E. Forrest (2001).

EXECUTIVE SUMMARY

This report was commissioned by NSW Fisheries to provide modelling support for the Estuary General finfish fishery. Analyses based on age, length and catch data (supplied by NSW Fisheries) were completed for the five principal species in the fishery: dusky flathead (*Platycephalus fuscus*), luderick (*Girella tricuspidata*), yellowfin bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*) and sea mullet (*Mugil cephalus*).

The specific aims of the project were as follows:

1. Fit appropriate growth models to age-at-length data.
2. Calculate yield-isopleths, $F_{max}/F_{0.1}$ fishing mortalities and $t_{c\ max}$ (age/length at first capture for optimal yield-per-recruit) for species where appropriate information is available and/or assumptions can be made.
3. Estimate the total mortalities (Z values) for NSW estuarine finfish species where information on the age-structure of the exploitable stock is available.
4. Construct biomass dynamic models to estimate the exploitable biomass for single species, or groups of species, where an appropriate index of abundance (such as catch-per-unit-effort) is available.
5. Identify appropriate trigger points for total catch performance indicators for each species, using simulated biomass data.
6. Identify limitations in the above analyses and make suggestions to NSW Fisheries about how future stock assessments could be improved.

Growth curves were fitted to age-length data. Bootstrapping procedures were used to estimate the errors associated with the fitted growth curves, with results indicating that the growth fitting process was robust for all species except for sand whiting. For all species, Schnute growth models provided a better fit than the standard von Bertalanffy model. This is probably because the data did not contain sufficient information about small fish to enable a statistically stable fit of the von Bertalanffy model.

Optimal growth curves were used in yield-per-recruit analyses. The target reference point, $F_{0.1}$ (recommended safe fishing mortality), was calculated for all species as a function of age-at-first-capture and also as a function of length-at-first-capture. The latter case is much easier to interpret in fisheries where length-at-age is variable, as it relates fishing mortality directly to minimum legal length. For all species, levels of safe fishing mortality increased as length-at-first capture increased. $F_{0.1}$ analyses were very sensitive to changes in the estimate of natural mortality (M). As our estimates of M were highly uncertain, we recommend that our findings be interpreted with care. We do not recommend that our calculated values of F_{01} be used for management or decision making as there are too many limitations with these initial estimates.

Values of $F_{0.1}$ are not in themselves useful for management unless they can be contrasted with current fishing mortality. Fishing mortality can be approximated from estimates of total mortality and natural mortality. Total mortality (Z) was calculated for all species using catch-curve analysis, although confidence in our estimates is compromised by a lack of understanding of recruitment. This is because variable recruitment will confound changes to Z (if pseudo-cohorts are used).

Approximate estimates of current fishing mortality (~*F*) were calculated by subtracting an estimate of natural mortality (*M*) from that of total mortality (*Z*). Our results indicated that no conclusions about current levels of fishing mortality for luderick, yellowfin bream, sand whiting, dusky flathead or sea mullet should be made. We are simply not confident in our estimates of natural mortality. Extensions to these analyses should use a greater range of strategies for dealing with the issue of natural mortality. These analyses have also been compromised by the lack of data about recruitment. As it is unlikely that data to estimate natural mortality will become available in the near future, we recommend that NSW Fisheries continue to explore strategies for managing these stocks that are not dependent upon accurate estimates of fishing mortality. One of these strategies will be to set minimum legal lengths so that harvesting has the least practicable impact on the reproductive output of target species.

There are important issues concerning the use of commercial catch-per-unit-effort as an indicator of abundance. It was therefore decided, after discussions with NSW Fisheries, that attempts to construct biomass dynamic models would be unlikely to yield useful outcomes. Issues associated with standardising commercial CPUE data from the fishery are discussed.

NSW Fisheries has elected to use commercial catch as an indicator of the state of stocks within the Estuary General fishery. Trigger points for changes in landed catch have been defined for principal species. Analyses were completed that examined the sensitivity of different trigger points to known changes in status of simulated catch data. Probabilities of obtaining false negative and false positive detection of recruitment failure or survival failure were obtained for a range of trigger points for each species. Results suggest that if NSW Fisheries uses trigger points of around 25%-40%, they should be able to detect both recruitment failure and survival failure. There will however be a high rate of false positive outcomes. Analyses of this type require subjective judgements to define 1) reference points; 2) the magnitude of change that represents a problem; and 3) acceptable probabilities of false positive and negative outcomes. Stakeholders should be involved in making these judgements.

We strongly urge NSW Fisheries to continue the annual collection of data that measures the age-structure of finfish stocks. This will be the most reliable evidence for recruitment failure and, with time, enable a better understanding of stock dynamics. Although collection of age-structured data is more costly than that of length-structured data, length-based assessments will always be confounded by variability in length-at-age. Collection of age-length data for pre-recruited fish will yield a better understanding of growth and recruitment. Estimates of recreational harvests will be required if assessments of stock biomass are required.

All data used in this study has come from commercial catches and is thus unrepresentative of the population of smaller fish and, to a lesser extent, unrepresentative of the population harvested by the recreational sector. This has, and will continue to, compromise our understanding of individual growth and fishing mortality. Consideration needs to be given to the costs and benefits of fishery independent sampling for these species.

The NSW Estuary General finfish fishery is likely to remain "data-deficient" in the foreseeable future. Sustainable management of this fishery will require development of strategies that are robust to uncertainty in estimates of biomass, natural mortality, commercial and recreational fishing mortality. We urge NSW Fisheries to identify the immediate threats that face the stocks and the patterns in observable data that would result if such impacts occurred. Appropriate managerial responses to such scenarios must be clearly defined and implementation strategies designed. These responses and strategies should be tested with simulated data to explore their effectiveness and practicality.

Appendix 8: Executive summary from: "Landed catch as an indicator for the management of fisheries – Final report for NSW Fisheries", J.P. Scandol (2003a).

EXECUTIVE SUMMARY

NSW Fisheries has elected to use landed catch as a temporary indicator within Fisheries Management Strategies until other indicators can be developed. A monitoring system has been designed to detect transient and persistent trends in time-series of commercial landings. The scheme was based upon cumulative sum control charts (CUSUM) and tested using simulated data from delay-difference models. The models were parameterised to represent a prawn fishery, a finfish fishery and an elasmobranch fishery. Control parameters were determined by seeking values corresponding to a precautionary approach where the rate of false negative signals of fishery impacts was minimised and the rate of false positive signals was specified at 20%.

On the basis of simulations, the scheme managed to detect acute (20% per year) changes to recruitment, survival or fishing with a reliability of 80-90%. Chronic changes (5% per year) were detected with little reliability or consistency. Sensitivity analyses of the assumptions within the analysis were also completed and examples of how the scheme could be applied to, and interpreted for, species within NSW are included. Landed catch appears to be an effective indicator for acute changes in fishery processes but is not an effective indicator of chronic changes. The proximate cause of changes to landed catch will always be difficult to interpret without a detailed evaluation of the fishery. This analysis did not attempt to determine the status of a fish stock nor the seriousness of a trigger point being breached. There were many assumptions required in this analysis and caution should be taken with any interpretation of this study.

NSW Fisheries is planning to undertake a review of a fishery when trigger points based upon landings or other indicators have been breached. The scope, form and effectiveness of this review process will be a critical component of the managerial system for these fisheries. Landed catch is a not a particularly sensitive or specific indicator for a fish stock and there are likely to be many interpretations of what has been observed. The review process must be sufficiently resourced and empowered to thoroughly investigate these interpretations. Precautionary management of these resources will be reflected in consequential reviews and, where appropriate, risk-averse decision-making for these fisheries.

Appendix 9: Executive summary from: "Stock status indicators for the management of fisheries in NSW – Final report for NSW Fisheries" J.P. Scandol (2003b).

EXECUTIVE SUMMARY

This project extended the CUSUM fisheries monitoring system developed in Scandol (2003) to nine stock status indicators. Indicators included: landed catch, fishery-dependant catch-per-unit-effort; a survey of exploitable biomass; as well as age- and length-based indicators such as total mortality, mean age/length and the recruiting fraction of age/length distributions. An operating model was calibrated for yellowfin bream (*Acanthopagrus australis*) but the interpretation will be similar for any finfish species with an analogous life-history. Ten pre-defined impacts on the fishery including "acute recruitment failure now" and "chronic natural mortality increase and chronic recruitment failure" were simulated and the CUSUM fisheries monitoring system used to identify these impacts. Performance was defined as the weighted sum of false positive and false negative errors of detection, where the weight reflected the degree of "precaution" or "risk aversion" of the decision-maker.

Performance of indicators varied according to the type of impact. For example, the indicators landed catch and biomass surveys were best for detecting the impact "acute fishing increase now" (an acute increase in fishing mortality). In contrast, the age and length-based indicators performed very well for the impact of "chronic fishing increase historically and now". An important conclusion of this study is that the length-based indicators had similar performance to age-based indicators.

Sensitivity analyses were completed for some of the components of the model system, including the number of fish that were aged or measured. The scheme was also applied to some example datasets from NSW Fisheries. This analysis did not attempt to determine the status of a fish stock nor the seriousness of a trigger point being breached. There were many assumptions required in this analysis and any interpretation should be cautious. This report should also be read in conjunction with "Landed Catch as an Indicator for the Management of Fisheries".

Different assessment approaches, some simple and others complex, will suit various fisheries for a range of reasons. The methods developed in this report explored approaches somewhere in between population models with quantitative risk assessment and simply "eye-balling" the data. Such methods are required in contemporary fisheries management.

NSW Fisheries is planning to undertake a review of a fishery when trigger reference points have been breached. The scope, form and effectiveness of this review process will be a critical component of the managerial system for these fisheries. The review process must be sufficiently resourced and empowered to thoroughly investigate the likely causes of these trigger point breaches. Precautionary management of these resources will be reflected in consequential reviews and, where appropriate, risk-averse decision-making for these fisheries.

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