Modelling the South Australian Lobster Fishery

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Abstract: The modelling of the rock lobster (*Jasus edwardsii*) fishery in South Australia has been the subject of a three-year data gathering program. In collaboration with fishers, a tool for assisting in the sustainable management of the resource was developed. The goal was to test management policies that allow increases in reproductive output while enhancing economic yield. The model's user interface was developed to an ease of use comparable to commercial software for use by fishers in co-management of the resource. This paper describes the modelling framework and user interface that was developed, and the results for management strategies being considered at present. The framework is essentially divided into five principle submodels: catch, effort, growth, economics, and population reproduction, with the lobster population being broken into 8 mm length classes divided by sex and spatial cell. Mortality of lobsters occurs by commercial harvest, natural mortality, incidental release mortality, predation inside pots before retrieval, illegal harvesting, and recreational catch. Five categories of management control scenario are simulated: quota, effort regulation (as total pot retrievals), size regulations (allowing minimum, maximum and mid-range slice length protection) and seasonal and area closures. Results indicate that size strategies have limited potential compared with effort limitations and quota.

1. INTRODUCTION

The South Australian Rock Lobster Fishery Management Model (SARLMOD) is a dynamic spatial simulation. The two principal objectives of regulatory strategies are to enhance earnings, usually via higher catches but also by lowering variable costs of fishing, and to increase total South Australian egg production, to ensure long-term sustainability.

This paper considers three categories of management strategies; size limits, effort controls, and quota. These are the principal forms of regulation in the South Australian lobster fishery. The model's predicted effects of these strategies are discussed in turn below. Throughout this paper the term 'baseline' refers to the model reconstruction of the historical time series indicators for management decision making: total catch, CPUE (catch per commercial lobster trap retrieval, i.e. 'pot lift'), net earnings per pot license held, and total egg production. These decision-making (management) variables are presented for both the northern and southern South Australian lobster fishery zones. The term 'Overlay' refers to the model outputs for user-chosen regulatory modification to baseline. Comparing overlay to baseline illustrates the model's predicted effect for each strategy tested.

2. THE MODEL

The lobster population is broken down into 8 mm length categories, by sex, and by spatial cell. The data to which the model is fitted are principally threefold: total catch by weight, catch per unit effort, and length-frequency samples from the commercial catch. As a consequence the lobster population is subdivided by length rather than age. Growth is represented by discrete transition probabilities from one length class to the next and is derived by fit to mark-recapture data (Punt and Kennedy, in press). A 'fortnightly' (semi-monthly) time step is employed. The model follows change in stock and effort in each model cell and quarter-areas of 1° squares of latitude-longitude.

Of the nine submodels (see, Figure 1) two submodels, principally describing spatial allocation of fishing effort and yearly settled lobster puerulus among model cells are of fundamental importance to the model structure[1]. New submodels including mortality, catch, stock-recruitment, initialisation, fishing cost, size limit regulation, quota regulation, and the addition of environmental yearly recruitment variability 1983-1996 when catch data by weight and numbers permitted recruitment time series reconstruction. The new user interface required rewriting the model in a Windows-based programming language.

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[1] These submodels are taken directly from Walters et al., (1997).

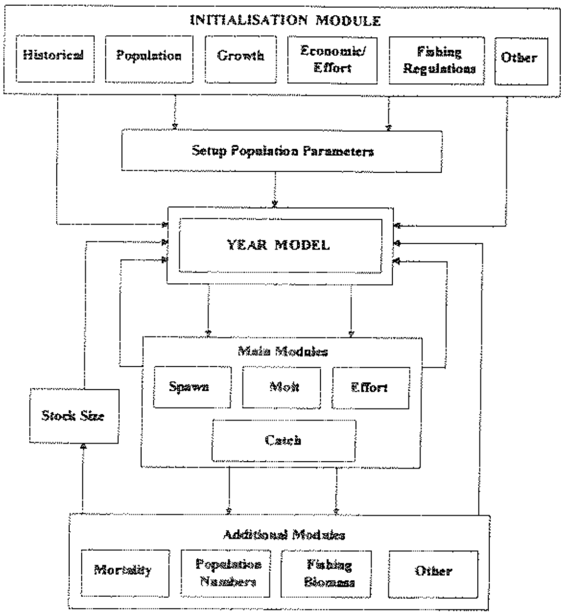

Figure 1. Structure of the South Australian Lobster Fishery Management Model.

2.1 Historical Information

The simulation of the rock lobster population began in October 1968 with the commencement of the Southern Zone fishing season. From 1968 the model simulates changes due to given management strategies in the rock lobster population until the year 2003. Time series graphs generated by the software reflect this period from 1968 when the fishery became limited entry and a regular system for collecting catch and effort data was established. The model generates data for up to five years prior to 1968 to allow the catches and lobster populations to equilibrate.

2.2 The User Interface

The graphical user interface (Figure 2), was developed using the Delphi programming language permitting easy control of the model and the analysis/display of its results. Mouse-driven menus allow users to perform tasks such as: opening and saving results of individual management strategies, generating text summaries i.e. reports of input variables or models predictions, and the ability export data to either word processing or spreadsheet packages.

2.3 Model Parameters

Catch Vulnerabilities: The capture efficiency of commercial lobster gear varies depending on time of year and lobster size.

Economic and Effort Dynamics: Parameters include fortnightly price, price elasticity, fishing effort response parameters, and fixed and variable costs.

Growth and Fecundity Parameters: Modify parameters describing growth of lobsters by proportion moulting each season, and the fecundity of females of different lengths.

Mapped Parameter Information: Mapped information can be edited for five mapped cell values: regulation zone, growth region, puerulus settlement index, habitat size index, closed refuge areas, management strategies fishing regulations.

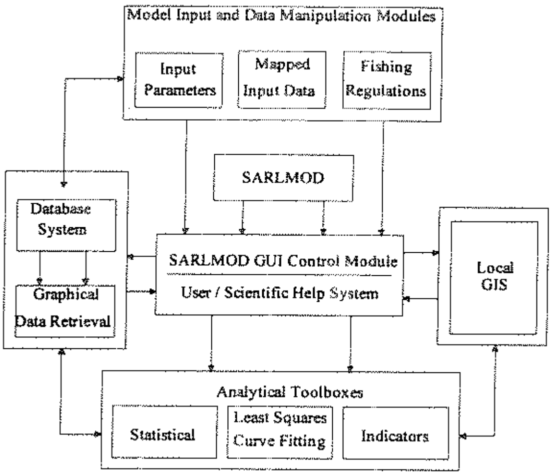

Figure 2. Flow structure of the Lobster Fishery Management Model's User Interface

2.4 Model Output

The model interface displays three categories of outputs: maps, length frequency graphs of the catch, and time plots of the critical variables for management.

2.4.1 Maps

The model produces density maps for both the Adult and Juvenile lobster population. The Juvenile density maps represent the numbers per unit area of lobsters below legal harvestable length (sublegals in the 82 - 98 mm carapace length range), in each cell of the model. The Adult density maps present the number of adult lobsters that are 98 mm or greater in carapace length. Each cell on the maps covers one fourth of a full one-degree-square Marine Fishing Area (MFA).

2.4.2 Catch Length Frequencies

The *Catch Length Frequencies* (see, Figure 4) illustrate the proportion of the lobster catches in each 8 mm carapace length class for males and females in each zone. Model and data (fishery-sampled) catch frequencies for 1994 (Figure 4) allow comparison of the simulated frequencies against the displayed historical trend, to assess how the model represents the changes in lobster population size structure over time and by sex and zone.

2.4.3 Time Plots

While length frequencies serve primarily as model validation, the principal model outputs for testing fishery management strategies are the time plots (time series graphs). The following describes each of these graphs and how each result is calculated.

Catch per Potlift: This panel shows the annual average simulated and historical catch per potlift for each zone in kilograms from 1968 to 2003.

Total catch by zone: This panel shows the total annual commercial catch (in thousands of tons) for each zone, showing both model output and historical data, from 1968 to 2003.

Egg production: This screen panel displays the total number of eggs released by females in each simulation year from 1968 to 2003 for each zone. In addition, the Northern and Southern Zones contributions are added to show total lobster egg production for the state. Egg production does not depend on male abundance, i.e. all females eggs are assumed to be successfully fertilised on release.

Earnings per pot per year: This panel presents approximate average yearly earnings in thousands of dollars per licensed pot from 1968 to 2003. Earnings are calculated as revenue minus the costs of fishing. Costs are calculated by adding fixed cost and variable cost per potlift, and crew and skipper shares, as percentages. In the Northern Zone, fixed cost is modelled to increase with the rising trend in overall effort from 1968 to 1995. In the Southern Zone, fixed costs are assumed constant for all simulation years.

Price variation through the season is reflected in the model but for all model years the same prices are used. The *Economics and Effort Dynamics* parameters assume prices for each fortnight as well as the cost parameters, all of which you can change as described above.

3. MODELLING EXPERIMENTS

3.1 Strategy One: Size Limits

The first strategy to be tested is an increase in the legal minimum length (LML) at which lobsters can be retained. Those which are smaller must be returned to the water. This regulation change is under consideration in the Northern Zone. An increase of LML to 110 mm in both zones (and for both sexes of lobster) was tested in the simulation fishery beginning in 1980. The limit was 98.5 mm in both zones at that time.

The yearly levels of four critical variables for the managing of the lobster resource before (as baseline plot) and after (as overlay plot) the imposition of the increased LML (Figures 3 and 4) illustrate the effect of the strategy we chose to test. Both the historical data and the model baseline result are always displayed. Following the run of a management strategy, the additional overlay plot is added.

The length distribution of harvested lobsters, illustrated in the "Catch Length Frequencies" (Figure 4) displays the direct effect of the 110 mm size regulation. The baseline run allows harvest in the length class of 98-106 mm (starting at 98.5 mm in the Southern Zone), while for the overlay (i.e. under increased LML) lobsters are only fully exploited at the length class of 114-122 mm.

The four principal time series output variables (Figure 3) indicate a relatively small change with the exception of egg production, which increased substantially due to the ability of females to spawn roughly one additional season before becoming susceptible to legal capture. The Southern Zone increase in egg production was greater due to the smaller mean length at harvest, in turn due to generally higher levels of exploitation. Annual catches, catch-per-unit-effort (CPUE), and revenues all experienced a substantial decline in the two or three years immediately following the imposition of an LML increase. Subsequently these were not noticeably altered in the Southern Zone compared to the baseline simulation outputs.

In the Northern Zone, where the dominant dynamic feature is a peak in yields centred around 1991, the length strategy yielded a lower level of catch, CPUE and earnings in the rising years and an improvement over the baseline in the years following the peak.

A second size regulation strategy was one which protected lobsters in a mid-range segment of lengths, in the test case simulated, from 130 to 140 mm. The idea was to demonstrate a compromise between a maximum and minimum length, in particular, to achieve higher egg production. The result was that the catches, catch rates, and earnings were substantially lower. Egg production increased less than with a minimum length increase of comparable magnitude. This strategy under-performed an increase in LML, and resulted in lower yields from the resource than the unaltered (baseline) size limits.

A third size strategy was tested, namely a maximum size limit for females in the Northern Zone, where substantial numbers of larger females are still harvested. Choosing a limit of 138 mm, the result was a reduction in yields, by 50 percent, and a greater increase in egg production than the mid-length slice.

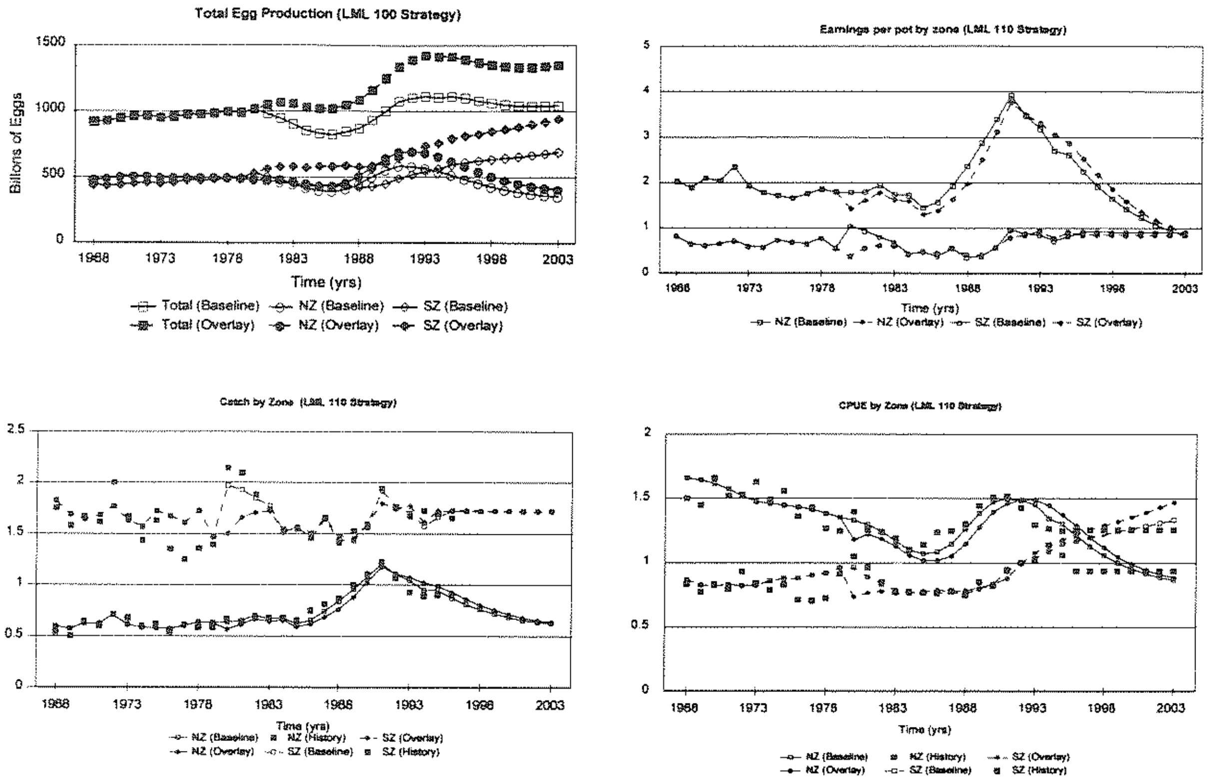

Figure 3. Time plots for the size strategy of raising legal minimum length to 110 mm in both fishery zones.

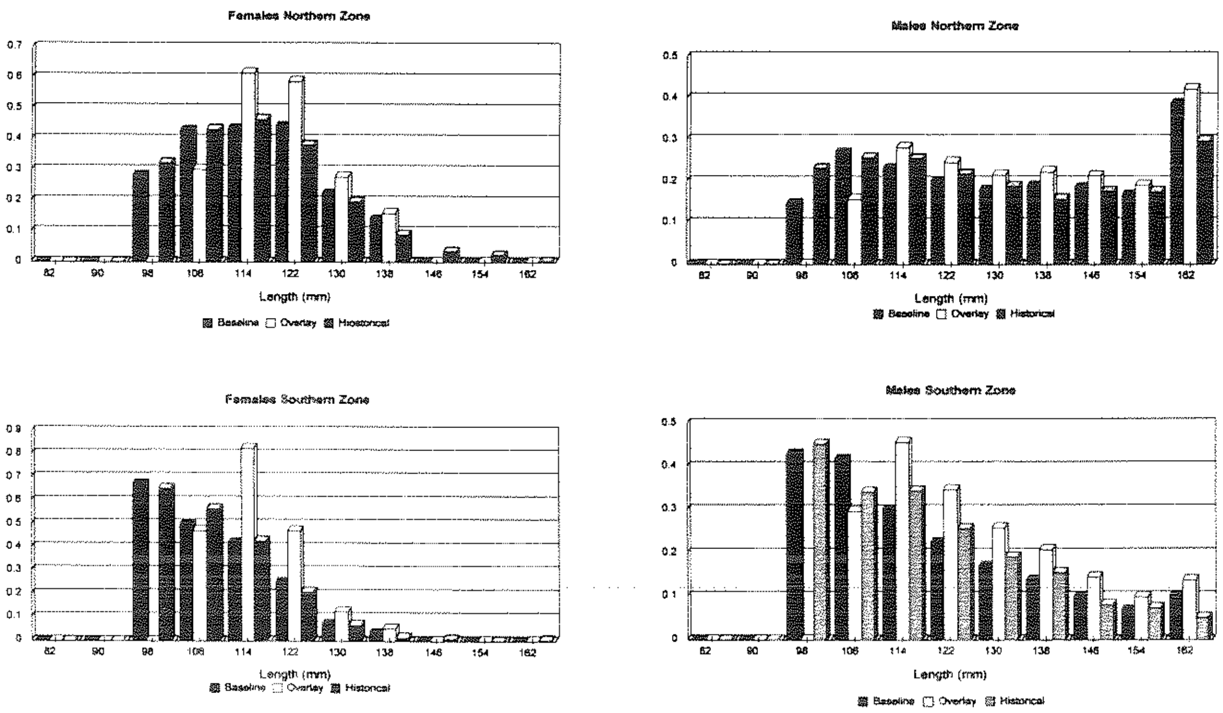

Figure 4. Proportions of lobsters captured in different length classes, before (baseline) and after (overlay) imposition of an increase in legal minimum length to 110 mm.

3.2 Strategy 2: Effort reduction in the Northern Zone

The Northern Zone is managed effectively by effort controls and no quotas are in place. Two management strategies were tested to investigate optimal effort limitation. First, a minimal reduction policy, set to take effect in 1989, two years before the catch peak, reduced yearly pot lifts by factors of 0.975, 0.95, 0.925, 0.9 in 1989-92, and maintained a level of 0.9 times baseline level of effort in subsequent years. The second strategy, requiring a large short-term sacrifice to achieve a long-term revenue stream substantially greater than at present, reduced effort by factors of 0.95, 0.9, 0.85, 0.8, 0.75, 0.7, 0.65, 0.6 for 1980-87, and maintained a level of 0.6 baseline level of effort for five more years. In 1993, effort was allowed to return to 0.9 of baseline.

The modest effort reduction (not plotted) beginning in 1989 produced roughly equal benefit and sacrifice. Catches were slightly lower following 1989 and rose gently to their unregulated levels over 7-8 years. CPUE was higher throughout, due to lower effort. Earnings were slightly lower in the first 7-8 years and when catches rose to roughly reach former unregulated levels, earnings were higher due to cost savings of less fishing to bring in that catch. Egg production is increased by approximately 3%.

The large effort reduction strategy (NZ, Figure 5) appeared to yield a long-term benefit, but required a substantial short-term loss. Catches were, on average, unchanged, with the short-term lower yields in the years leading up to the 1991 peak, followed by years of higher-than-baseline landings.

Averaged over the years, 1980 to 2003, the total earnings were about 3% higher under the reduced effort strategy, due to cost savings of fewer days at sea. Egg production is more strongly enhanced by this reduction in total human exploitation, yielding a rise of 20% over those years. Thus it offers the potential for a win-win strategy, benefiting both the human predators, by higher earnings and more days at port with family, and by enhanced probability of long-term sustainability. The one important drawback of this outcome is the less stable dynamic trend of Northern Zone catch (NZ, Figure 5) over those years, where the low point catches are a bit lower, and the peak catches a bit higher under the reduced effort strategy.

3.3 Strategy 3: Quota reduction in the Southern Zone

The Southern Zone is managed by quotas. As with the Northern Zone effort reduction, two strategies, modest and ambitious, were tested. The first imposed a constant quota at the present level but beginning in 1989 rather than 1993. The second quota strategy, imposed the present quota of 1720 t in 1980, followed by reductions to 1680, 1640, 1600, 1560, 1520, 1480, 1440 t over the years 1980 to 1987. The 1440 t quota was maintained for five more years. In 1993, quota was raised to a level well above baseline of 1900 t.

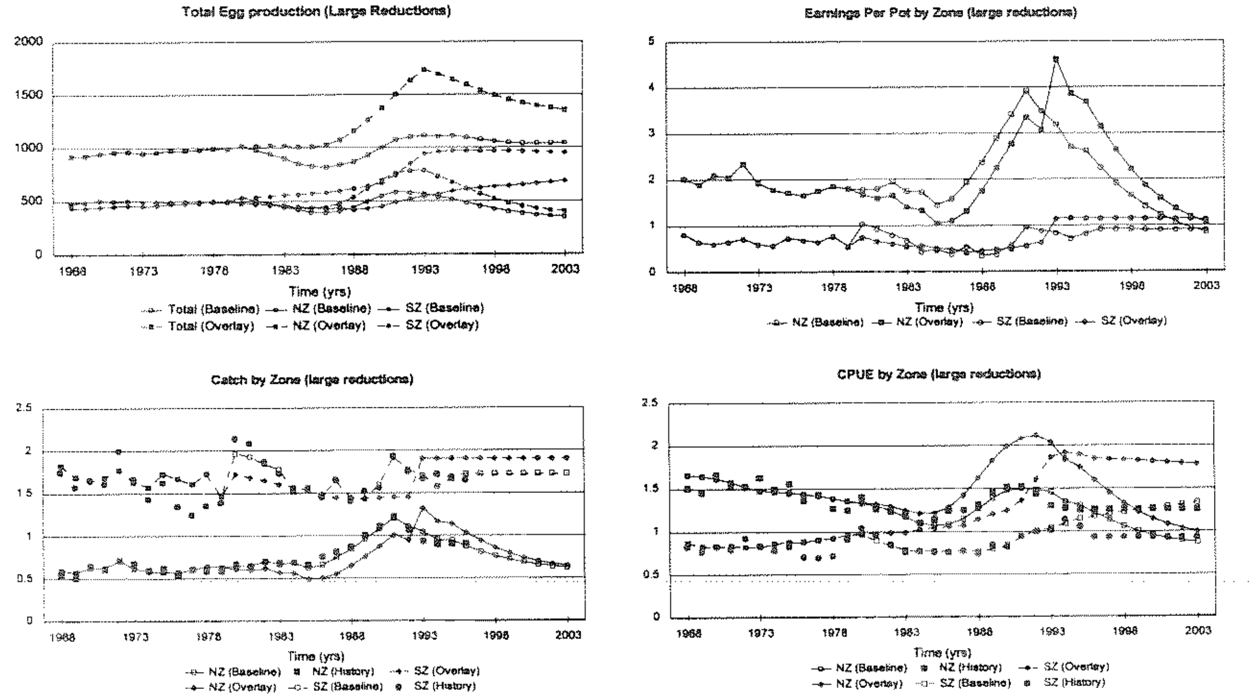

Figure 5. Time plots for the high impact strategies. In the Northern Zone, effort was reduced between 1980 and 1987, held fixed at 60 % of historical levels, and allowed to return to 90% historical levels in 1993. In the Southern Zone, quota was reduced steadily from its present level of 1720 t in 1980 to 1440 t in 1987, held fixed, and raised to 1900 t in 1990.

Under the (modest) strategy of the 1720 t quota imposed a few years earlier (not plotted), average catches are unchanged. The benefits of the quota system in higher stability of annual landings were evident. The slightly lower long-term catch is not a highly robust prediction, but depends on the long-term estimate of recruitment versus the choice of 1720 t as the quota. It suggest that 1720 is slightly below MSY, but an estimate of average recruitment to this level of accuracy is not likely to be established with a high degree of confidence. Thus, quota at its present level is a stabilising strategy erring if at all, slightly on the side of caution.

The ambitious quota strategy (SZ, Figure 5) is also successful in achieving its aim of long-term higher catches and earnings. Because of the timing, in 1980, when effort rose above the level that this 1720 t quota would allow, the reductions in catch did not go much below the lower levels over those years from 1980 to 1993. Average earnings over that time, due to lower fishing costs, were approximately unchanged, and generally more stable. Egg production rose steadily over that time, and more rapidly following the recruitment peak of the late 1980's and early 1990's. When the quota was then raised to a much higher level than at present, to 1900 t, earnings rose accordingly. Egg production and CPUE after 1993 decline only very slowly, indicating that this level of population density and thus of catch, are sustainable over times long with respect to those that the present management regime can be expected to influence (and this model predict).

4. DISCUSSION

In all of the enhanced conservation strategies tested, an increase in egg production is obtained. Less fishing means a denser and more numerous parent stock on the bottom at annual spawning. The Beverton-Holt stock-recruitment relationship employed in this model, as in most lobster fishery models of which we are aware (Punt et al., in press; Starr et al., in press) makes very conservative assumptions about the relationship between eggs produced and recruits surviving to size of legal harvest, to the extent that recruitment, apart from the environmental variation (independent of parent stock), is constant. Data permits no further inference. If, however, medium increases in eggs did result in slightly higher recruit numbers on average, then the benefits of regulation would be substantially strengthened towards both economic and ecological objectives.

On the other hand, the highly stable nature of lobster catches, over four decades in the Southern Zone, and the other evidence that shows no dependence of recruitment on egg production, suggests the action of strong density dependence, such that bottom densities, and thus catches per year, appear effectively independent of the rates of adult removal.

If strong territoriality on the limited stretches of rocky bottom, or any other form of density dependent regulation were acting, then it may be that leaving a few more lobsters on the bottom will not enhance, but possibly limit recruitment of adults to those habitats, and thus, (modestly) reduced long term catches could conceivably ensue. The dynamics of population reproduction are a principal subject of future study in the South Australian rock lobster fishery.

The quota system thus appears to yield the most apparent long-term success. Several practicalities of quota may erode that outcome in practice. The first is unreported catch, a problem that may be growing since quota was imposed in 1993. Second the costs of enforcement, of recording each kg landed, and of research where catch and catch per unit effort no longer reflect population density, mean greater costs to establish this system and lower levels of reliability of catch data for stock assessment. However, fishers in the Southern Zone, originally of two (strong) minds about this management regime at its outset, are now largely in consensus that it improved the fishery, and equally, their lifestyles, since many fewer days of fishing were required to harvest their share, and fishing on days of bad weather was no longer necessary. However, in the fishery season that ended in April 1997, catches and particularly catch rates declined, a response not predicted by the model.

5. ACKNOWLEDGEMENTS

This work is the culmination of the project conceived and initiated by the late Philip Sluczanowski. We thank the fishers of the South Australian lobster industry and C. J. Walters, J. H. Prescott, G. Ferguson, M. Lorkin, S. Slegers, A. Peso, D. Maynard and J. M. Matthews. This work was supported by the Fisheries Research and Development Corporation 93/086 and 93/087.

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