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A BIOECONOMIC MODEL OF THE TASMANIAN ROCK LOBSTER FISHERY

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The rock lobster fishery is an important industry for Tasmania, generating a gross value of production of $~~52~~13m in 1983-84. Entry into this fishery has been limited since 1967 to protect the resource from biological overexploitation.

A bioeconomic model was used to calculate the maximum sustainable yield and maximum (sustainable) economic yield in the Tasmanian rock lobster fishery. The results of this analysis were used to quantify the levels of fishing effort and catch that can be justified on economic grounds in this fishery.

It was found that to have achieved the maximum economic yield in 1982 would have required, on average, a reduction in catch of around 50 per cent and a reduction in effort of about 70 per cent. These results are consistent with findings of studies elsewhere.

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Introduction

Current fisheries policy in Australia is largely concerned with economic efficiency and structural rationalisation within the industry (Sturgess and Meany 1982). An important issue that has emerged is the degree to which a fishery can be managed so as to avoid biological overexploitation while permitting economic efficiency. In 1967 the Tasmanian Government introduced legislation to restrict the number of boats in its rock lobster fishery. In this study a bioeconomic analysis is undertaken to determine the present overall performance of the fishery.

Governments impose fisheries management policies because of the common-property nature of the resource (Anderson 1977). First, because a fishery lacks clearly delineated property rights, there is no incentive for fishermen to conserve the resource. Second, economic theory suggests that, even if the resource is conserved at some level, if a commercial fishery is left unregulated fishermen will tend to maximise their income by equalising returns and costs at the margin (Gordon 1954; Scott 1955). As a result the resource rent would be completely dissipated. Therefore, maximum profits would not accrue to the fishery as a whole. A society that allows its fishery to operate at an open-access level wastes its resources if there are more productive uses of the inputs, such as capital and labour, elsewhere in the economy. Government intervention in a fishery is therefore necessary (providing it results in a net social benefit), to conserve the resource, to correct the open-access market failure, and to produce an efficient allocation of society's resources. Limited entry is one form of government regulation used for these purposes.

The effects of a management policy for a fishery can be analysed using a bioeconomic model (Bell 1970, 1972; O'Rourke 1971; Gulland 1974; Anderson 1977; Hall 1977; Copes 1978; Clark and Kirkwood 1979; Ottesen 1980). Within such a model, the biological data on a fish population are combined with the economic data on the exploitation of a particular fishery to determine an optimal production level which economists generally term the maximum economic yield. A bioeconomic model, therefore, accommodates the two basic concerns of a fishery management policy, namely, resource conservation and economic efficiency.

Overall, the objectives of this study are:

(a) to develop a bioeconomic model of the rock lobster fishery of Tasmania;

(b) to use this model to calculate the maximum sustainable yield and the maximum economic yield of this fishery; and

(c) to use the results of (b) to quantify the optimal level of effort and catch for the fishery and compare these with actual levels.

The Tasmanian Rock Lobster Fishery

The rock lobster fishery is an important industry for Tasmania. In 1983-84 this fishery produced 2.045 kt of rock lobster, generating a gross value of production of $~~52~~ 13m and an export value of $~~34~~ 12m. About 70 per cent of production is exported, mainly to the United States and Japan. The remainder is marketed mainly in Tasmania, Victoria and New South Wales.

The fishery has had a long history of development. It was first commercially exploited in 1804 (Hall 1984; McDermott 1984) and even in the early years some management controls were imposed - for example, minimum legal lengths of lobsters and catching restrictions on berried (egg-bearing) females. By 1872, lobsters were being exported to mainland areas.

In response to an influx of capital to the fishery, limited entry was introduced in 1967, limiting the initial fleet to 442 boats (Department of Primary Industry 1979; BAE 1985). Later, further controls were imposed, including a restriction on the number of pots a vessel could carry. Thus, throughout its history, government-imposed management controls have had some bearing on the economic performance of this fishery.

The rock lobster (<u>Jasus novaehollandiae</u>) is the principal rock lobster species of southern Australia. It is highly fecund, the female being capable of producing 600 000 to a million eggs during the spawning season in September and October (Winstanley 1973, 1977; CSIRO 1982). The fishing season is largely determined by the lobster's physiology (moulting) and the state of the sea environment (water temperature and food availability). In Tasmania the main fishing season is from November to February, but lower catches are made throughout the season which ends in August. Tasmanian rock lobsters generally reach minimum legal catch size at four years of age.

The Bioeconomic Model

The bioeconomic model of the Tasmanian rock lobster fishery developed here is a variant of a surplus yield model developed by Schaefer (1954), which has been used in several studies of commercial fisheries (Smith 1969; Bell 1970, 1972; O'Rourke 1971; Silliman 1971; Ricker 1975; Tomkins and Butlin 1975; Gulland 1977; Scott 1979; Morgan 1980; Sissenwine 1984). The Schaefer model allows estimation of the sustainable yield curve of a fishery based on data on catch and fishing effort. This yield curve is then used to derive the points of maximum sustainable and maximum economic yield, the latter being defined as the yield obtained when the fishery is being operated (sustainably) at maximum profit.

The Schaefer model uses a specific population growth function known as the Verhulst-Pearl logistic:

$$(1) \quad \frac{dN}{N_t dt} = a(N^* - N_t)$$

where N is the population size (by weight); N* is the natural equilibrium population in the absence of fishing; and a is a constant. The equation describes a symmetrical quadratic function which has zero growth rate at zero population and at the natural equilibrium population, and maximum growth rate at N*/2. Figure 1 depicts this relationship. The maximum growth rate, G_m, is the maximum sustainable yield: the maximum level of catch or yield that may be taken from the fishery on an indefinite basis.

To maintain the population at maximum sustainable yield level (N*/2) requires a specific level of fishing effort. Alternatively, the population might be maintained at some level other than N*/2, requiring a different level of fishing effort. The relation between sustainable yield and effort required is referred to here as a yield curve.

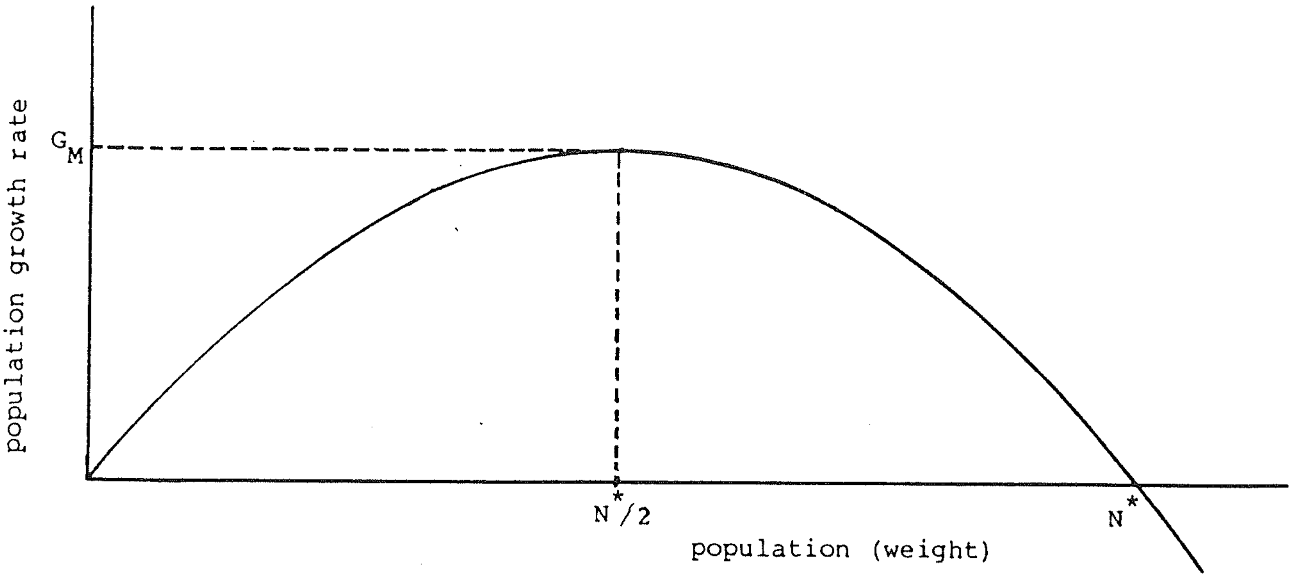


FIGURE 1 - Growth Curve for a Fish Population in a Constant Environment

Although the Schaefer model is an accepted model for estimating the maximum sustainable yield in a commercial fishery, some authors have used other functional forms. The Fox model (Fox 1970) results in an exponential relationship between population size and fishing effort, and an asymmetrical yield curve. It is argued, as noted by Copes (1978) and Ottesen (1980), that the number of rock lobsters reaching maturity is dependent less on the size of spawning stock than on environmental factors (Schaefer 1957). The above authors suggest, therefore, on theoretical grounds, that the Fox model is superior to the Schaefer model. For a specific fishery, however, the selection of the appropriate functional form of the yield curve is an empirical question (O'Rourke 1971). The Fox model was initially tried in this investigation, but the Schaefer model had better explanatory power and no serial correlation.

Whenever a fishery is exploited, the rate of population change becomes the natural growth rate minus the mortality attributed to fishing (Bell 1972):

$$(2) \qquad \frac{dN}{N_t dt} = a(N^* - N_t) - F(E) + U_t$$

where

$F(E)$ is the proportionate rate of loss from the fish population due to fishing effort (E, signifying production inputs, primarily capital and labour); and

U_t is a random disturbance (a 'catch-all' variable for environmental factors that influence catch per unit effort).

If it is assumed that F(E) is proportional to fishing effort (E),

(3) $F(E) = kE_t,$

then in the steady state, when $\frac{dN}{N_t dt} = 0,$

(4) $0 = a(N^* - N_t) - kE_t + U_t.$

Catch (Y), for a given effort, is considered to be proportional to the population size, and since it has already been assumed proportional also to effort (E), then:

(5) $Y_t = kE_t N_t.$

Substituting Y/kE for N in equation (4) gives the following production function:

(6) $$\frac{Y_t}{E_t} = kN^* - \frac{k^2 E_t}{a} + \frac{k}{a} U_t.$$

Bell (1972) and O'Rourke (1971) explicitly endeavoured to model environmental factors in their analysis by adding the explanatory variable water temperature into equation (6). Hall (1977) was critical of the ad hoc modelling of the environmental factors in Bell's and O'Rourke's analyses and suggested that the correct treatment of environmental variables lay in Gordon's seminal article (Gordon 1954, p.141): 'All natural factors, such as water temperature, food supplies, natural predators etc., which affect the population are, for purposes of the system analysed, locked up in' N*. Hall therefore argued that environmental factors should be modelled in the following manner:

$$(7) \qquad N_t^* = N(Z) = \beta_o + \sum_{j=1}^{J} \beta_j Z_{tj}$$

where N(Z) is the domain of J environmental variables, Z, that affect the natural equilibrium population. Controlled biological experiments upon the western rock lobster (Panulirus cygnus) suggest that the lobster's growth rates are positively correlated with water temperature up to 26°C, and that growth and survival rates decline at higher temperatures (Chittleborough 1975). Since temperature is the only environmental variable for which a time series exists, the applicable form of equation (7) collapses into:

$$(8) \qquad N_t^* = \beta_o + \beta_1 T_t$$

where T_t is surface sea water temperature in degrees Celsius. There was insufficient biological information to determine how water temperature in conjunction with other uncontrolled environmental factors affects the rock lobster through its various physiological stages; hence a lagged term in water temperature is not justified. Substituting equation (8) into equation (6) gives the following production function for the Tasmanian fishery:

$$(9) \qquad \frac{Y_t}{E_t} = k\beta_o - \frac{k^2}{a} E_t + k\beta_1 T_t + \frac{k}{a} U_t.$$

Empirical Results

In this study, annual time series data were used to estimate equation (9) using ordinary least squares. Initially effort, E, was measured in potlifts (the number of pots used by a boat in fishing, multiplied by the number of times a year they are used) but this measure was discarded because the available time series data from 1961 to 1983 were insufficient and lacked the variation needed for robust analysis. Instead, effort was measured using potdays (the number of pots used by a boat in fishing multiplied by the number of days a year spent fishing) for which a longer time series, from 1947 to 1983, was available. Water temperature data collected at the CSIRO offshore monitoring station at Maria Island were used.

The model's sustainable yield curve is the fishery's long-run production function; each point on the yield curve depicts the level of catch after the fishery has fully adjusted to a constant level of effort. However, over the period examined, fishing effort was not constant and the observed catch and effort data are unlikely to correspond exactly with long-run equilibrium. Catch, and catch per unit of effort, therefore reflect levels of effort previously applied to the fishery. Accordingly, a method outlined by Gulland (1969) was used to approximate the equilibrium relation between effort and catch per unit of effort.

Gulland's approach relates catch per unit effort in year i to fishing effort averaged over the mean fishable duration of a year class (the average period during which the year class of year i has previously been exposed to fishing) rounded to the nearest whole year (Fox 1975). The Tasmanian rock lobster catch generally consists of 4-7-year old fish, hence the average fishable duration of the rock lobster year class is three years. Consequently, catch per unit effort in year i is related to the average of E_i, E_{i-1} and E_{i-2}. As a result of this data manipulation the sample period became 1949 to 1983.

The initial results in estimating equation (9) indicated sea water temperature to be an insignificant variable, and it was therefore dropped from the model. The model was then re-estimated, with the following results (standard errors in parentheses):

$$(10) \qquad \frac{Y_t}{E_t} = \underset{(0.332)}{4.909} - \underset{(0.199)}{3.463}\, E_t$$

$$\bar{R}^2 = 0.76 \qquad DW = 1.54$$

where Y = annual landings of Tasmanian rock lobster (kt), and E = million potdays a year.

The estimated parameters are significant and have the signs expected *a priori*. The results are in accord with the hypothesis, implicitly incorporated in the model, that in the long-run equilibrium solution, the average productivity of a unit of effort is an inverse function of the aggregate effort applied to the fishery (Bell 1972). The Durbin-Watson statistic suggests that serial correlation is not a problem at the 5 per cent level of significance, while the corrected $\bar{R}^2$ indicates that the model has a fairly high explanatory power.

Maximum sustainable yield

The sustainable yield curve for the fishery is obtained by cross-multiplying through equation (10) by E:

$$(11) \quad Y = 4.909\ E - 3.463\ E^2.$$

The level of effort (E) associated with the maximum sustainable yield (Y) is that at which

$$(12) \quad \frac{dY}{dE} = 4.909 - 6.926\ E = 0,$$

that is, 0.709 million potdays (with the appropriate error); hence, from equation (11), maximum sustainable yield is 1.738 kt, with 95 per cent confidence bounds of 1.837 kt and 1.639 kt.

The actual catch for 1982 was 1.903 kt, whilst the actual effort was 0.933 million potdays. It follows that, on the basis of the results reported here, the Tasmanian rock lobster fishery may have been slightly biologically overexploited in 1982.

Maximum economic yield

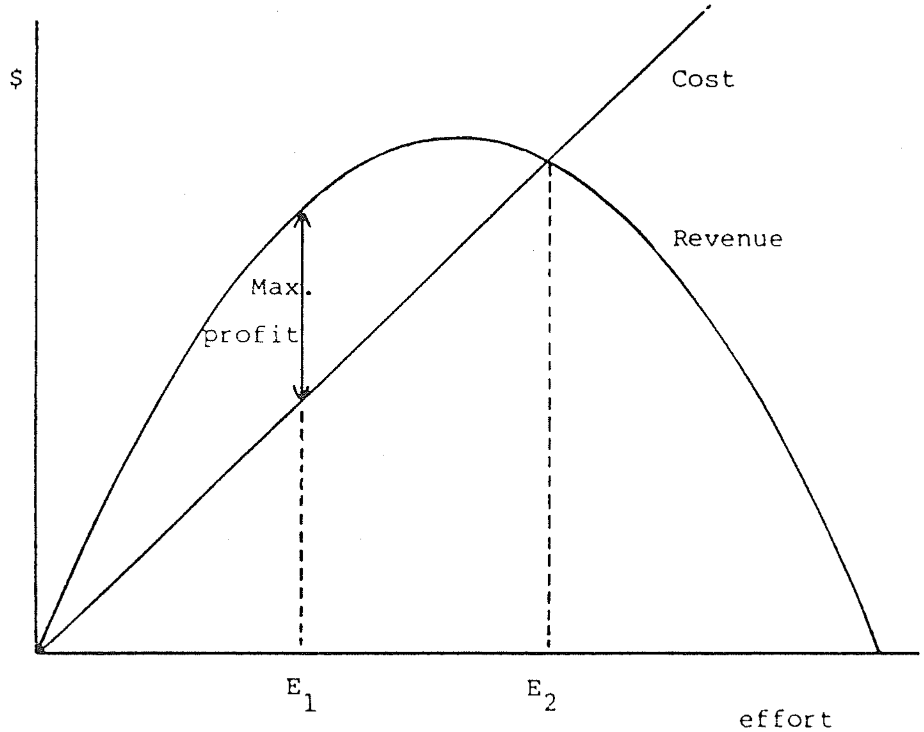
Maximum economic yield is defined as that level of output at which the resources of a society are being applied at the optimal level within the fishery. Theoretically, this occurs when the marginal cost of fishing equals the price of the catch. Since the price is readily accessible, the problem becomes that of calculating at what yield the marginal cost has that value.

Gordon (1954) assumed that a fishery's total cost, C, is a linear function of effort:

$$(13) \quad C = bE$$

where b is the average opportunity cost of a potday. Using recent BAE survey data (BAE 1985) and unpublished data from the Tasmanian Department of Sea Fisheries, b can be calculated as follows: The total annual cost of a boat in 1982 consists of total cash costs, owner-operator allowance, capital depreciation and the user cost of capital. (A real rate of interest of 10 per cent, as used by Treasury in its appraisal of public investment projects, was used to calculate the user cost of capital. The value of the licence entitlement is not included because it is endogenously determined by the fishery's profitability.) This annual cost is then divided by the ratio of total number of potdays to the total number of boats. For 1982, the result is $19.89 per potday.

In Figure 2, the sustainable yield curve is shown schematically with yield expressed in money terms. Also shown is the linear relation between cost and effort. Their intersection dictates the equilibrium level of effort, E_2, which will be adopted if there is open access to the fishery. The maximum economic yield is that at E_1, where marginal cost and revenue are equal, and profit (the difference between total cost and revenue) is maximised.



E_1: Effort maximising difference between total benefit and total cost
E_2: Effort adopted under open access

FIGURE 2 - Cost of Fishing, and Revenue from Yield

To obtain an expression for the effort, E, in terms of yield, equation (11) is solved:

(14) $E = [4.909 \pm (24.098 - 13.852Y)^{1/2}] / 6.926.$

Substituting the above estimate of b in (13):

(15) $C = 19.89 \times E.$

The fishery's marginal cost, C_M, defined as the derivative of the total cost, C, with respect to yield, Y,

(16) $C_M = dC/dY,$

can now be expressed:

(17) $C_M = \pm 19.89 / [24.098 - 13.852Y]^{1/2}.$

The average price fishermen received for Tasmanian rock lobster in 1982 was $5.93/kg (BAE 1983, 1984). If we assume that price is independent of yield (since most rock lobster is exported), the maximum economic yield is theoretically the value of Y at which the marginal cost is $5.93/kg. Equating equation (17) with $5.93 (price per kg of rock lobster) gives a maximum economic yield of 0.928 kt, with 95 per cent confidence limits of 0.973 kt and 0.885 kt.

Substituting this result into equation (14) gives two levels of effort in equilibrium with this output, of which the lower must be the optimum: 0.255 million potdays.

As mentioned previously, the actual level of effort applied to the Tasmanian rock lobster fishery in 1982 was 0.933 million potdays and the catch was 1.903 kt. To have achieved maximum economic yield in the Tasmanian rock lobster fishery in 1982 would have required, on average, around a 50 per cent reduction in catch and a 70 per cent reduction in effort. Although these figures may seem rather large they are comparable to results obtained in a similar study (Hall 1984) and studies undertaken in the United States (O'Rourke 1971; Bell 1972).

Nevertheless, the above results are dependent on the assumption that short-term prices and costs fully reflect long-term prices and costs. If the cost per unit effort used in the calculations underestimates the long-term cost per unit effort, then the prescribed reduction in effort is overestimated. It appears that the 1982 input-output price ratio generally reflected the long-term input-output price ratio. A caveat about input prices must be noted: these costs would have been distorted by management regimes.

Implicit throughout the analysis is the assumption that regulation itself is costless (Anderson and Lee 1984). Reducing effort from the open-access equilibrium level, E_2, is clearly beneficial, in itself, down to the maximum-profit equilibrium level, E_1, but further reduction is not. If regulation is costless, economic efficiency is maximised at E_1. If, however, regulation is not costless (see Figure 3), the optimal level of effort is some level E_3 which is greater than E_1. Thus the model's prescribed degree of reduction in effort to achieve an optimal allocation of resources within the fishery should be treated as an upper bound.

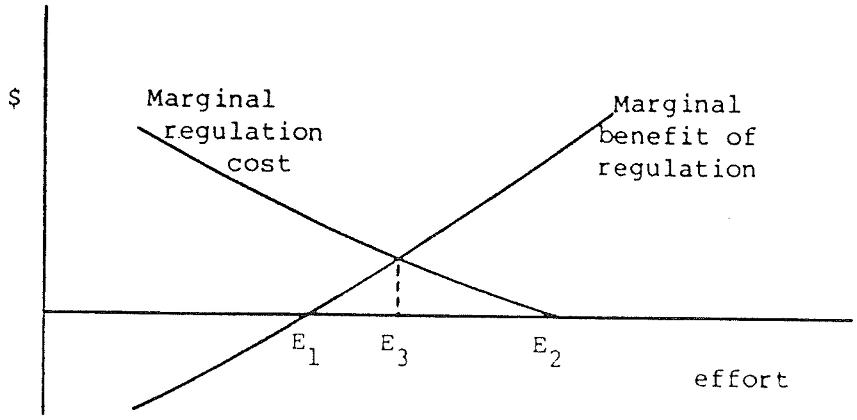


FIGURE 3 - Regulation Costs and Benefits Associated with Management

The prescribed reduction in catch and effort levels should not be seen as a one-off adjustment. Management should be flexible in order to respond to changes in biological conditions and rock lobster demand. An increase in the price of rock lobster in an unmanaged fishery would be associated with an increase in effort and higher input costs, if the open-access equilibrium is to be maintained. Similarly, under management, changes in demand or other conditions would necessitate changes in effort if maximum economic yield is to be attained.

Conclusions

According to the results reported in this paper, the actual catch from the Tasmanian rock lobster fishery in 1982 probably exceeded the maximum sustainable yield. Based on the assumptions of the model, this indicates that there was probably biological overexploitation which may result in reduced catches in the longer term.

Further, limited entry has not resulted in economic efficiency in resource allocation within the fishery. The magnitude of the required reduction in fishing effort suggests further restrictions on effort. It is noted that Anderson (1976) stated for any limited entry regime to be successful it must also have output controls associated with it to attain maximum economic yield.

This study has addressed only the economic efficiency issues in the Tasmanian rock lobster fishery; the social welfare issues arising from a reduction in catch and effort levels are beyond the scope of this investigation. It may be that in the remote fishing areas of Tasmania, where employment and the opportunity cost of labour are relatively low, the cost of the excess labour inputs is lower than any alternative providing the fishermen with a minimum standard of living. Further, the study has not established the net benefits, to society, if management simply tries to reallocate fishing effort from this fishery to another.

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