MANAGEMENT OPTIONS IN THE WESTERN ROCK LOBSTER FISHERY

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INTRODUCTION

The West Australian Government has initiated a review of management methods in the Western Rock Lobster Fishery with the aim of determining the method which will maximise the economic, social and other benefits derived in the long run by the West Australian community. Since 1965, the Western Rock Lobster Fishery has been managed by what is essentially a license limitation scheme involving restricted entry for boats, and strict controls on the aggregate number of pots which can be used by the commercial fishing sector. These core policy instruments have been supported by a range of other regulations designed, at least in part, to reinforce the effectiveness of the license limitation scheme.

By most measures, management of this fishery has been highly successful. Biological over-exploitation of the fish stock has been prevented, at least until recently. The level of compliance with fishery regulations has also improved significantly over the past twenty-five years, and has been achieved without excessively high levels of enforcement costs. However, by far the most significant achievement, and one which is still quite rare in the management of fisheries around the world, has been the generation and preservation of significant resource rents in the fishery. This rent generation has been driven primarily by increases in the price of the product from levels where rock lobster was regarded as a basic, if not subsistence, food to levels to where rock lobster is now clearly in the luxury category. Nevertheless, the management of the fishery has ensured that most of the potential rent has not been dissipated. The tangible evidence of this rent generation is the prices paid for pot licenses, which are freely tradeable. On this basis, the aggregate capitalised value of resource rent in the fishery now exceeds $900 million, which, at a discount rate of five per cent, implies that over $45 million in resource rent is generated annually.

Notwithstanding these achievements, there is widespread concern that the future profitability, and even the viability of the industry is under threat unless the current management practices are reformed. For a number of years, there has been continuing increases in nominal fishing effort, and even greater increases in effective fishing effort, despite continuing attempts to tighten regulations governing the level of use and effectiveness of fishing gear in the industry. This increasing effort is linked to higher exploitation rates which in turn has led to marked decreases in the estimated size of the breeding stock. In particular, it is concern over the level of the breeding stock that has been the primary motivating force behind the initiation of the investigation into long term management methods for the Western Rock Lobster Fishery.

In evaluating alternative management methods, governments understandably have broadly defined objectives. The focus in this paper will be narrower, and concentrate exclusively on the impact of alternative management methods on economic efficiency. Other considerations, such as social equity and conservation of the marine environment, will not be considered even though they may be important determinants of community welfare. To further reduce the scope of the analysis, only two management options are considered below. One is to continue to rely on a modified version of the current management scheme, the essence of which is a license limitation scheme involving restricted use of key inputs (ie pots) in order to limit the amount of fishing effort applied to the resource stock, and thereby control the level of catch and the exploitation rate. The alternative is to abandon this input control based method of management for one based on controlling output, or level of catch.

The most commonly used method of managing a fishery by controlling output is to rely on a variable closed season, whereby the season is closed as soon as the total allowable catch (TAC) is reached, but in which no attempt is made to limit level of catch by individual fishing firms. It is widely recognised that such a management scheme leads to significant, if not total rent dissipation, and for that reason this alternative will not be considered further below. Instead, the alternative management system to be discussed will be one based on individual transferable (catch) quotas (ITQ's) which in theory should foster generation of the maximum potential resource rent from the fishery.

A wide range of possible advantages and disadvantages for each of these two alternative management methods have been identified in the literature, but the discussion below will be restricted to three key issues. The first issue, and the one which will be discussed in most detail, is the degree to which a license limitation based management system results in dissipation of potential rent. In particular, estimates are made of the magnitude of rent dissipation associated with current regulations in the Western Rock Lobster Fishery, as well as the impact on future levels of rent dissipation consequential on further reductions in the level of license inputs needed to reduce the exploitation rate to levels required to protect the breeding stock.

A second issue which needs to be considered is the potential to increase the net return per unit of catch by switching from a management system based on ITE's to one based on ITQ's, and in particular by relaxing some the of regulations currently used to support the license limitation scheme. While there may be a number of potential avenues for increasing the returns from a given catch by deregulating the way in which the Western Rock Lobster is harvested, the only one to be considered below is the scope to add value by altering the time at which the catch is taken.

Finally, there is the issue of compliance, and in particular the costs of enforcing regulations necessary to ensure that the chosen management system achieves its objectives in terms of reducing the exploitation rate, and protecting the breeding stock so that the fishery can be exploited on a sustainable basis. Expert opinion suggests that enforcement costs for a given level of compliance are likely to be significantly higher under an ITQ-based management system than under an input control management system which limits exploitation rate to the same levels. Some of the possible extra enforcement costs involved in an ITQ-based management system will be discussed below.

ESTIMATION OF RENT DISSIPATION FROM LICENSE LIMITATION

Anderson (1985) has demonstrated that fishery regulation by means of licence limitation may generate rents in a commercial fishery. While restricting the amount of a major input used in the production of effort may increase the unit cost of effort, the reduction in the total amount of effort devoted to the fishery will yield a benefit through a shift of resources to higher value uses elsewhere.

Rent dissipation is defined in this paper as the difference between the level of resource rent actually generated under a license limitation scheme and that for the benchmark case of a sole owner generating maximum potential rent. Dupont (1990) describes the sources of such rent dissipation as:

- capital stuffing, or input substitution, which results when fishermen attempt to increase their catches by using more unrestricted inputs in place of the restricted input,

- fleet redundancy, or excessive effort, due to the fact that the regulator permits more than the optimal number of restricted inputs to be employed in the fishery,

- heterogeneous vessels and/or catching technology which allows less efficient firms to continue to operate in the fishery.

As there is a high degree of homogeneity of vessel type in the Western Rock Lobster Fishery, the judgement was made that the third source of rent dissipation was unlikely to be important, and it is ignored in the rest of this paper. The other two types of rent dissipation were estimated from the following analytical model, which is based on that in Campbell and Lindner (1990).

The basic model for the analysis is illustrated in Figure 1 of the present paper. Note that this model is a static model, but that conclusions drawn from it about the optimal level of effort are good approximations if the intrinsic growth rate for rock lobster is large relative to the discount rate. Figure 1 shows a linear schedule for the average revenue of effort, AR_e, such as that which can be derived from the Schaefer model (Schaefer 1967), and a perfectly elastic long-run supply curve of effort, S_e. It should be noted that the Schaefer model is based on a logistic growth function for biomass, and on the assumption that catch per unit of effort is always a constant proportion of stock. In the absence of regulation, long-run steady-state equilibrium is at the effort level E_0 at which the value of average product of effort equals the long-run average cost of effort, C_0. Because inputs are combined in the least cost manner at all points on S_e, it will be referred to below as the efficient average marginal cost curve.

When one or a range of inputs is restricted in supply by licence limitation to a level significantly less than that which would prevail in an open access fishery, the marginal cost curve for the industry is coincident with S_e up to level of effort E_r, defined as the level of effort at which the limited supply of the restricted input becomes binding. Beyond E_r, the industry marginal cost curve diverges from the most efficient cost path because increases in effort beyond E_r can only be achieved by substituting unrestricted inputs for the restricted input. This somewhat inelastic section of the industry's marginal cost curve is labelled MC'_e. Note that it is equivalent to the short-run marginal cost curve for an industry which can only increase the use of some factors in the short-run.

Equilibrium effort in such an industry will be determined by the intersection of the MC'_e curve with the average revenue of effort curve (AR_e). This point of intersection is labelled G in Figure 1, and determines both the actual level of effort (E_a) and the actual value of average revenue of effort. Because E_a of effort could have been generated at total cost of $OCHE_a$, the efficiency loss from excessively costly effort (ie rent dissipation due to input substitution, or capital stuffing) is measured by the area of the triangle FGH.

Optimal effort in Figure 1 is depicted by E^*, as this level of effort equates efficient marginal cost with the marginal revenue of effort (MR_e), thus maximising potential rent which is represented by area ABC in Figure 1. As actual effort exceeds optimal effort, there is a further amount of rent dissipation due to excessive effort, or fleet redundancy, which is represented by the area of the triangle BDH.

Given that the fishery is to be managed by a license limitation scheme, the second best solution is to minimise the combined value of rent dissipation due to input substitution and to fleet redundancy. This is equivalent to maximising the realised rent, represented by the area $CFGJ$. Campbell and Lindner (1990) have derived an analytical result for this second best solution given particular assumptions about the form of the key relationships, and the derivation is reproduced as an Appendix.

The key determinant of the degree of rent dissipation is the form and slope of the industry marginal cost curve, MC'_e. A license limitation scheme will be successful in minimising rent dissipation if this marginal cost curve is highly inelastic. Campbell and Lindner (1990) show that the necessary conditions are

1. The elasticity of substitution between restricted and unrestricted inputs should be very low so that there is very limited scope to increase effort indefinitely by using more and more unrestricted inputs.

2. The restricted input(s) should be a major component of total factor costs.

On the face of it, the Western Rock Lobster fishery meets the critical conditions for successful management by an appropriately designed license limitation scheme. While level of usage of both boats and pots is restricted to the number of licenses issued, it is clear that the restriction on the number of pots that can be used is the effective policy instrument for controlling level of effort and generating rent. Because of the biology of the Western Rock

Lobster, lifting pots more than once every 24 hours is subject to severe diminishing returns. Consequently, the absolute limit on the number of pot lifts is simply the product of the number of licensed pots in the fishery multiplied by the potential number of fishing days in the fishing season. Since most other types of fishing gear and methods are banned by regulation, it should be difficult to substitute other inputs for pots. On the other hand, the cost of boats and pots do not represent a major part of catching costs, so the marginal cost curve will be less than completely inelastic.

This is born out by the history of the fishery. Fishermen have shown remarkable ingenuity in finding ways to work their pots harder. For most of the duration of the license limitation scheme, there has been a steady increase in the ratio of the actual number of pot lifts to potential number of pot lifts. Fishermen also have devised means to increase the catchability per pot lift, mainly by more careful pot placement. New technologies such as colour depth sounders, GPS, mechanised pot lifters (and even remote controlled mini-submarines with video cameras and transmitters until they were banned by regulation) materially assisted fishermen to increase "effective pot lifts" without increasing nominal pot lifts.

Despite a degree of input substitution, tangible evidence of rent generation in this fishery is provided by the prices at which pot licenses are traded. For the past two years, advertisements asking $14,000 or more per pot license have not been uncommon. Of course, prices actually paid may be lower than asking prices, but even at a price of $12,000 per pot license, the total capital value of the fishery exceeds $800 million. It is not easy to decide on an appropriate discount rate to amortise these capital values to obtain an estimate of annual rent generated in the fishery. In a study of the market for ITQ's in New Zealand where data was available on prices paid both for annual lease of quota as well as for quota in perpetuity, a figure of 3% was suggested as a reasonable average. This figure is not inconsistent with the long term real rate of return on farm land, although it may be too low if the industry believes that there is a significant degree of sovereign risk associated with holding pot licenses. Because the regulations governing this fishery have been changed fairly frequently in recent years, discount rates of 3%, 5% and 7% could be justified, yielding estimates of current annual fishery rent ranging from $24 million to $56 million.

The data necessary to estimate the magnitude of the two types of rent dissipation identified above differs in the extent to which it is "available" by way of direct observation. For example, the actual level of effort in the fishery in any given year (E_a) is directly observable, because the Fisheries Department collects detailed data on both catch and effort (as measured by number of pot lifts). Currently there are approximately 12 million pot lifts per annum of effort being applied in the Western Rock Lobster fishery. Average priced paid to the fishermen per kilogram of catch is also fairly easy to obtain, although it does fluctuate markedly, both intra-seasonally, and between fishing seasons. Some judgement is required in choosing a value likely to prevail in the future. In the analysis below, a value of $22 per kilogram was used, which reflects a view that the real price of rock lobster is likely to continue to rise in the near future.

Catch per unit of effort is also quite volatile on a year to year basis due to significant annual fluctuations in the level of recruitment to the fishery. For the purpose of estimating the average level of rent dissipation under alternative management regimes, what is really required is the relationship between level of effort and the sustainable catch per unit of effort. To derive this relationship, a simple simulation model was constructed which could be used to predict a time series of annual catches based on data on the actual annual levels of effort applied in the fishery from 1945 to 1992. The parameters of this model are the three coefficients of the logistic growth curve, namely the intrinsic growth rate (r), ceiling stock size (K), and a catchability co-efficient (A). Values for these parameters were obtained by visually fitting the predicted time series of catches derived from the simulation model to the actual series of catches in the fishery for the period from 1945 to 1992. The plot of these two time series of annual catches is illustrated in Figure 2. There are significant differences between the predicted and actual catch in many years, largely due to year to year fluctuations in recruitment to the fishery which could not be taken account of in the simulation model. Estimated parameter values derived by this method were:

- unexploited stock size (K) = 50 million kg
- catchability co-efficient (A) = 03
- intrinsic growth rate (r) = 0 8

These parameter values were then used in the logistic growth function to predict sustainable catch per unit of effort for various levels of effort required in the analysis below.

The actual level of rent currently being generated in the fishery also needs to be estimated. In Figure 1, the amount of annual rent being generated from E_a of effort is depicted by the area C_aFGJ. As noted above, this annual amount of rent cannot be observed directly, but it can be estimated from the prices paid by fishermen for pot licenses, which are freely tradeable. The current selling price for pot licenses is about $14,000, so with 69,000 licensed pots in the fishery, the capitalised value of the industry's expectations about future rent total $966 million. Using a discount rate of five per cent to amortise this value, yields an estimate of annual resource rent being generated in the fishery of $48 3 million. If the prices being paid by fishermen for pot licenses are based on expectations about continuing increases in product prices, and/or efficiency gains in catching rock lobster, then this value might over-estimate the annual resource rent currently being generated in the fishery, but will still approximate the average annual resource rent expected for the foreseeable future.

The other three values required to estimate the level of rent dissipation in the fishery are

- the average cost of effort using minimum cost combinations of inputs (ie C_m)

- the efficient level of restricted effort (ie the point at which the actual marginal cost curve for the industry diverges from the efficient marginal cost curve - depicted by E_r in Figure 1)

- the slope of the restricted marginal cost curve (g)

Only one of the above values is needed in order to estimate the other two given that all of the more directly observable information is available. Campbell (1991) in an analysis of the Tasmanian Rock Lobster Fishery has estimated that the elasticity of substitution is less than unity, and has an expected value 0.75. The biology of the Southern Rock Lobster in Tasmanian waters differs in some respects from that of the Western Rock Lobster, and there are also some differences between the Tasmanian and West Australian fisheries in terms of regulations and catching technology. Nevertheless, the degree of substitution between pots and other inputs is likely to be similar in both fisheries

In order to carry out the analysis, it was assumed that the restricted marginal cost curve is linear, and that it shifts in a parallel manner when fishery managers alter the number of licensed pots in the fishery. Because of uncertainty about the slope of the restricted marginal cost curve (g), and about trading prices for pot licenses, Monte Carlo risky simulation analysis was carried out using the following distributions

- an uniform distribution of the restricted level of effort, E_r, over the range from 65% to 95% of E_a (as a proxy for the slope of the restricted marginal cost curve (g)
- a triangular distribution of pot license trading prices over the range from $12,000 to $16,000 and with a mean value of $14,000 per pot

The relationships set out in the Appendix 2 were used to generate a distribution of estimates for:

- the minimal average cost, C_m,
- the optimal level of effort, E^* and
- the maximum potential rent which could be generated under sole ownership

The results are set out in Table 1. "Minimum" average cost (ie based on least cost input combinations) was estimated to range from $12.62 up to $14.48. The corresponding range of values for optimal effort is 7.5 to 8.2 million pot lifts, and $69.3 million to $84 million for maximum potential annual resource rent. An associated plot of the computed frequency distribution of estimates for C_m is presented in Figure 3

Measures of rent dissipation are sensitive to the degree of license limitation, so scenarios ranging from a reduction in actual effort to only 8 million pot lifts (ie a 33% reduction) up to the *status quo* of 12 million pot lifts (ie no reduction in effort due to retirement of licensed pots) were used as basis for estimation of the following measures of rent dissipation plus associated measures.

- rent dissipation due to input substitution (FGH)

- rent dissipation due to fleet redundancy or excess effort (BDH)

- total rent dissipation (DWL)

- required percentage reduction in number of licensed pots relative to status quo to achieve assumed level of effort

- percentage change in realised aggregate annual resource rent relative to the best guess estimate of current annual resource rent

Results are presented in Table 2, and supplemented with plots of the frequency distributions of total rent dissipation for the scenarios of 8, 10, and 12 million pot lifts of equilibrium effort. Among the various scenarios presented, reducing effort to 10 million pot lifts comes closest to maximising the mean value of realised annual resource rent, and minimising mean aggregate annual rent dissipation. To achieve this level of reduction in equilibrium effort in the long run is likely to require a 35% reduction in the number of licensed pots in the fishery. Politically, this will be difficult to achieve, to say the least. Even if it could be achieved, it would only raise annual resource rents by about 17%, and would still involve rent dissipation totalling somewhere between $9.4 million and $29.2 million, with a deadweight loss of about $19 million being most likely. Another notable feature of the results is the fact that while reductions in the number of licensed pots might achieve substantial reductions in rent dissipation due to fleet redundancy by reducing equilibrium effort by a sizeable margin, such gains will be more or less offset by large increase in rent dissipation due to input substitution.

POTENTIAL MARKETING BENEFITS OF ITQ'S

Catching Western Rock Lobster in a less costly and more efficient manner is not the only source of potential gain which might flow from an input based management system to one based on controlling output via ITQ's. Wilen (1988) noted that where there is a tendency to race to fish, and/or where regulators have shortened the fishing season to contain effort, the efficiency gains to be made by switching to ITQ's may arise largely out of the marketing rather than the product side.

The current management system results in a highly seasonal pattern of catch, with forty to fifty per cent of the catch being caught during the period from mid November to end of January. The problem is exacerbated by the fact that the majority of lobsters caught during this period are "white" (ie. freshly moulted), and widely regarded in the market place as inferior in quality to "red" lobsters which predominate in the catch for the rest of the season (February to June). This problem of seasonality of catch is further exacerbated by a closed fishing season from the first of July to mid November.

Because of the size of the Western Rock Lobster Fishery relative to other suppliers of rock lobster onto the world market, changes to the duration of the fishing season in Western Australia can have significant effects on the seasonal variation in prices in world markets. Prices in the world market, and in particular prices for live lobster in the prime markets of Japan and Taiwan during our closed season are much higher than at other times of the year. Under an ITQ-based management system, there are no in-principle reasons why fishing effort should be restricted to part of the year so long as there are necessary supplementary controls to ensure that the breeding stock is not excessively exploited for a given total allowable catch. Issues involved in the estimation of the potential to increase aggregate revenue from a given size of catch of Western Rock Lobster by altering the seasonal distribution of the catch are discussed below.

Net returns to the fishing industry from catching, processing, and marketing rock lobster depends, *inter alia*, on the following considerations:

a) The price received per kilogram of catch

If the processing sector is competitive, the so called "beach" price will be an indicator of the net return per unit of catch attributable to catching operations. Because there are indications of co-operative behaviour and price pooling in the processing sector for Western Rock Lobster, an imputed measure of net return per unit of catch will be used rather than beach prices to estimate potential marketing benefits.

This net return per unit of catch will depend on the level of the catch, the seasonal distribution of the catch, the composition of the catch, and how the catch is processed and sold. Of particular importance in determining net return per unit of catch are the following characteristics of the catch:

- the size grades of the rock lobster that make up the catch.
- the colour of the lobster (lobsters caught during December and January after the November moult are generally paler in colour than lobsters caught in the rest of the year, and are referred to as "whites" as opposed to "reds").
- the time of the year when the catch is taken and/or marketed;
- the fitness of the catch for processing into various forms of final product.

Rock lobster is marketed as live rock lobster, as whole, boiled rock lobster (which may be either frozen or chilled), as frozen, whole, raw rock lobster, or as frozen tails. Almost all of the catch is exported, with Japan, Taiwan, and the USA being the principal end markets. Most live rock lobster exports go to Japan or Taiwan, and typically command a sizeable premium over other forms of product. Only a limited proportion of the catch is suitable for marketing as live rock lobster, although improvements in handling rock lobster when caught are increasing this proportion.

Frozen, boiled rock lobster also go mainly to the Japanese and Taiwanese markets, but in contrast to live rock lobster which are destined mainly for the restaurant market, boiled rock lobster are used mainly in the function market (ie weddings, banquets, etc). In Japan, small size, red rock lobster command a considerable premium over white or larger rock lobster in the function market. The premium for red rock lobster in the restaurant market in Japan, and in Taiwan is much smaller than in the function market. The Taiwanese market also does not pay any significant premium for small size *vis a vis* large size rock lobsters.

Frozen, whole, raw rock lobster also are exported mainly to Japan and Taiwan, and tend to serve as a backup to the market for live rock lobster. By contrast, frozen tails go almost exclusively to the US market, where they are used in the restaurant trade. There is no significant premium for small size, or for red versus white rock lobster in this market.

b) Average catching cost per kilogram of catch

Note that for any given level of catching capacity, average catching cost will depend mainly on the catch per unit of effort, which varies seasonally. In particular, catch per unit of effort tends to be very high in December, and again in March-April. It is significantly lower at other times during the fishing season. Evidence from the early history fishery pre-dating a closed season indicates that catch per unit of effort would be even lower still during the period of the current closed season.

c) Processing cost per kilogram of catch

For a given product type (see above), processing costs depend almost entirely on utilisation of processing capacity. Hence the seasonal pattern of catch levels is an important determinant of processing costs, as is the length of the fishing season. In common with other industries, inter-year variation in the level of production and/or demand also will have an impact on capacity utilisation, and hence on processing costs. Processing costs will also vary between product type. For instance, live rock lobster exports need to be air freighted to their destination, and need to be held before and after transport in holding tanks.

Management is likely to influence marketing returns, mainly via its impact on the duration of the fishing season, and on the seasonal pattern of catch within the season. As mentioned above, exploitation rates in the rest of the rock lobster fishery are very high, with approximately 80% of the annual recruits to the fishery being harvested during the fishing season. Hence, even though effort is controlled in the fishery, there is a rush to fish during the early part of the season when catch rates are high because fishing becomes progressively less profitable during the fishing season as catch rates decline, due at least in part to a declining level of the available stock to be caught. Thus the current management method tends to exacerbate, rather than ameliorate the intrinsic biologically determined seasonal pattern of the catch that would prevail even if effort were constant throughout the year. By contrast, with an ITQ-based management system, fishermen should be able to fish at any time of the year so long as the breeding stock is protected, and they will choose to allocate more effort to those times of the year when the net return to catching is greatest. As mentioned above, catching costs will be lowest during December, and during March-April when catch per unit of effort is highest.

At the current time, net returns per unit of catch in the world market are highest during the closed season, and generally tend to be inversely related to average catching costs during the fishing season. In part this seasonal pattern of marketing returns simply reflects the impact of changing supply in overseas markets with somewhat inelastic demand. On top of these normal supply and demand considerations, the quality of the catch during the peak harvest period of December-January is lower than at other times of the year because most of the product caught is freshly moulted (ie. white) and as a result is both less suitable for processing into high value product such as live lobster exports, and also discounted in the Japanese market due to the preference for red rock lobster for the function market.

In order to gain some appreciation of the potential marketing benefits from a switch to ITQ's, an analysis is underway of the impact of reducing the catch in December by 2 million kg (about twenty per cent of the catch), and instead catching this same quantity of rock lobster during the current closed season when net returns from marketing are higher. Preliminary findings indicate that the revenue gained to the industry from this intra-seasonal reallocation of catch could add as much as $24 million (ie about ten per cent) to aggregate industry revenue (Monaghan, 1994, pers comm.). Some of this potential benefit to the industry would be offset by increased catching costs due to a reduction in the average catch per unit of effort across the whole year. The magnitude of this additional catching cost will depend on the management method in place in the fishery. Estimation of these extra catching costs, both for the current license limitation scheme as well as for an ITQ-based management scheme, have not yet been completed.

COMPLIANCE COSTS FOR LICENSE LIMITATION AND FOR ITQ'S

Under the current license limitation management scheme, compliance costs are devoted mainly to

- Inspection of the commercial catch of about 12 million kg. to ensure that regulations concerning catching undersized animals, oversize breeding stock females, and/or spawning or setose females are being observed.

- Pot monitoring to ensure that unlicensed pots are not being used, and that licensed pots are being legally. This aspect is becoming more difficult vessels become faster and better equipped with navigation aids such as GPS and plotters.

- Enforcement of limited entry to ensure that unlicensed fishermen do not operate on a commercial basis.

The estimated cost to the WA Department of Fisheries of current enforcement arrangements for the Western Rock Lobster fishery is about $2.1 million (McLaughlan, 1994, pers. comm.). This includes enforcement of both the commercial and the recreational sectors.

Additional enforcement requirements to monitor compliance with ITQ regulations would include

- registration of quota allocations and transfers

- documentation of catch receivals at approved landing points

- maintenance of computer based quota records

- licensing rock lobster receivers

- monitoring landing points other than those approved for catch receivals, as well as other methods to detect illegal catching or sales

- miscellaneous (eg specification of containers to avoid falsification of catch weights)

The cost of these additional requirements has been estimated at nearly $1 million in the first year, with ongoing extra costs of about $560 million per annum (McLaughlan, 1994, pers. comm.). Even if these extra costs prove to be grossly under-estimated, they would seem to be very much smaller than the potential benefits likely to follow from changing to an ITQ based management system in the Western Rock Lobster fishery.

APPENDIX 1 **A Model of Rent Dissipation and Second Best Effort Under License Limitation (from Campbell and Lindner (1990))**

We need to specify functional forms for the average product of effort schedule and the supply or marginal cost of effort schedule consistent with the assumptions we have made so far

$AR_e = a - bE$ subject to $a, b > 0$. [1]

$MC_e = C_0 + C_1(E - E_B)$ subject to $C_0, C_1 > 0, E \geq E_B$. [2]

The equilibrium condition for the fishery is $AR_e = MC_e$, and so it follows that

$E_B = [(C_1 + b)E - (a - C_0)]C_1^{-1}$ [3]

The fishery rent can be defined as

$\pi_E = (a - C_0 - bE)E$ [4]

and the level of effort which gives a first-best optimum can be calculated as

$E^* = 0.5(a - C_0)b^{-1}$ [5]

The efficiency loss resulting from the input restriction can be expressed as

$L = 0.5(MC_e - C_0)(E - E_B)$. [6]

which, on substituting for MC_e and E_B, simplifies to

$L = 0.5[(a - C_0) - bE]^2 C_1^{-1}$ [7]

The second-best optimum level of effort, $\hat{E}$, is obtained by choosing E to maximise $W = \pi_E - L$. The solution value is

$$\hat{E} = 0.5(a - C_0)b^{-1}[(C_1 + b)/(C_1 + b/2)] = E^*[(C_1 + b)/(C_1 + b/2)]$$ [8]

Given our assumptions about the production of effort, the proportion of the restricted input excluded from the fishery by the limitation program is defined as $B = 1 - (E_B/E_0)$. Substituting for E_B and E_0 and setting E and $\hat{E}$ gives the level of the second-best optimum licence limitation program

$\hat{B} = 0.5[(C_1 + b)/(C_1 + b/2)]$

APPENDIX 2 Derivation of Formulae to Estimate Key Parameter Values and Measures of Rent Dissipation Under License Limitation

In Figure 1, CFGJ depicts realised aggregate annual resource rent from E_a of effort and associated average revenue of effort, $ARtE_{at}$

$$CFGJ = CHGJ - FGH$$
$$= (ARtE_{at} - C_a) * (E_a - E_r)$$
$$= (g/2) * (E_a^2 - E_r^2)$$

where $g = (ARtE_{at} - C_a)/(E_a - E_r)$

Hence

$$E_r = (E_a^2 - (CFGJ/2))^{0.5}$$

$$C_a = ARtE_{at} - g * (E_a - E_r)$$

Rent dissipation due to input substitution

$$FGH = (ARtE_{at} - C_a) * (E_a - E_r)/2$$
$$= (g/2) * (E_a - E_r)^2$$

In the Schaefer model, sustainable average revenue of effort

$$AR_s = P * A * K * (1 - (2 * E * A/r))$$

where P = price of catch
A = catchability coefficient
K = unexploited stock size
E = sustained level of effort
r = intrinsic growth rate
A =

Optimal effort, $Eopt = (1 - C_a/(P * A * K)) * (r/(2 * A))$ and corresponding

Maximum potential sustainable annual resource rent

$$Opt\ rent = (P * A * K * (1 - Eopt * A/r) - C_a) * Eopt$$

Rent dissipation due to fleet redundancy

$$BDH = (E_a - Eopt) * (C_a - ARtE_{at})$$

FIGURE 1: RENT DISSIPATION FROM LICENSE LIMITATION

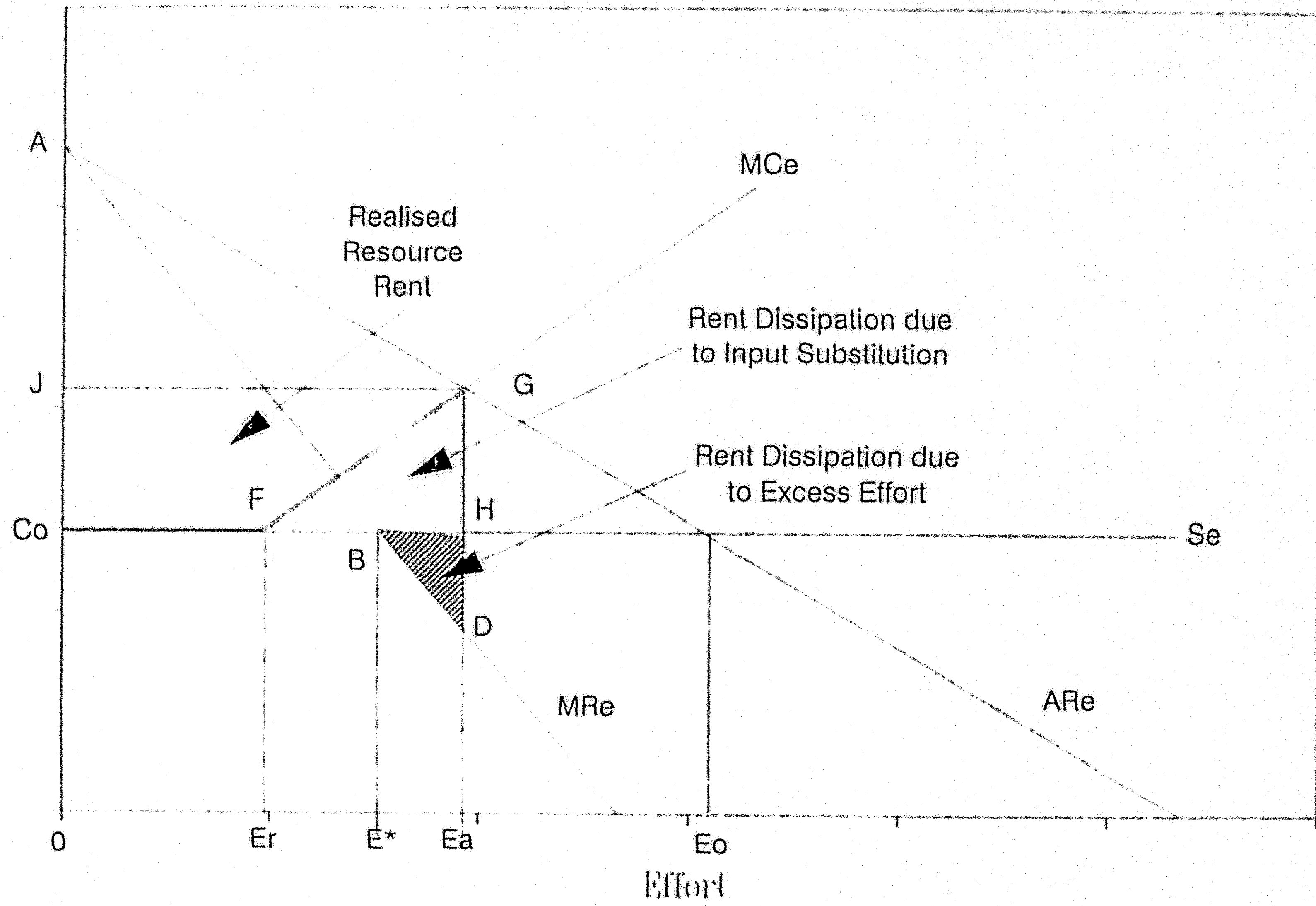
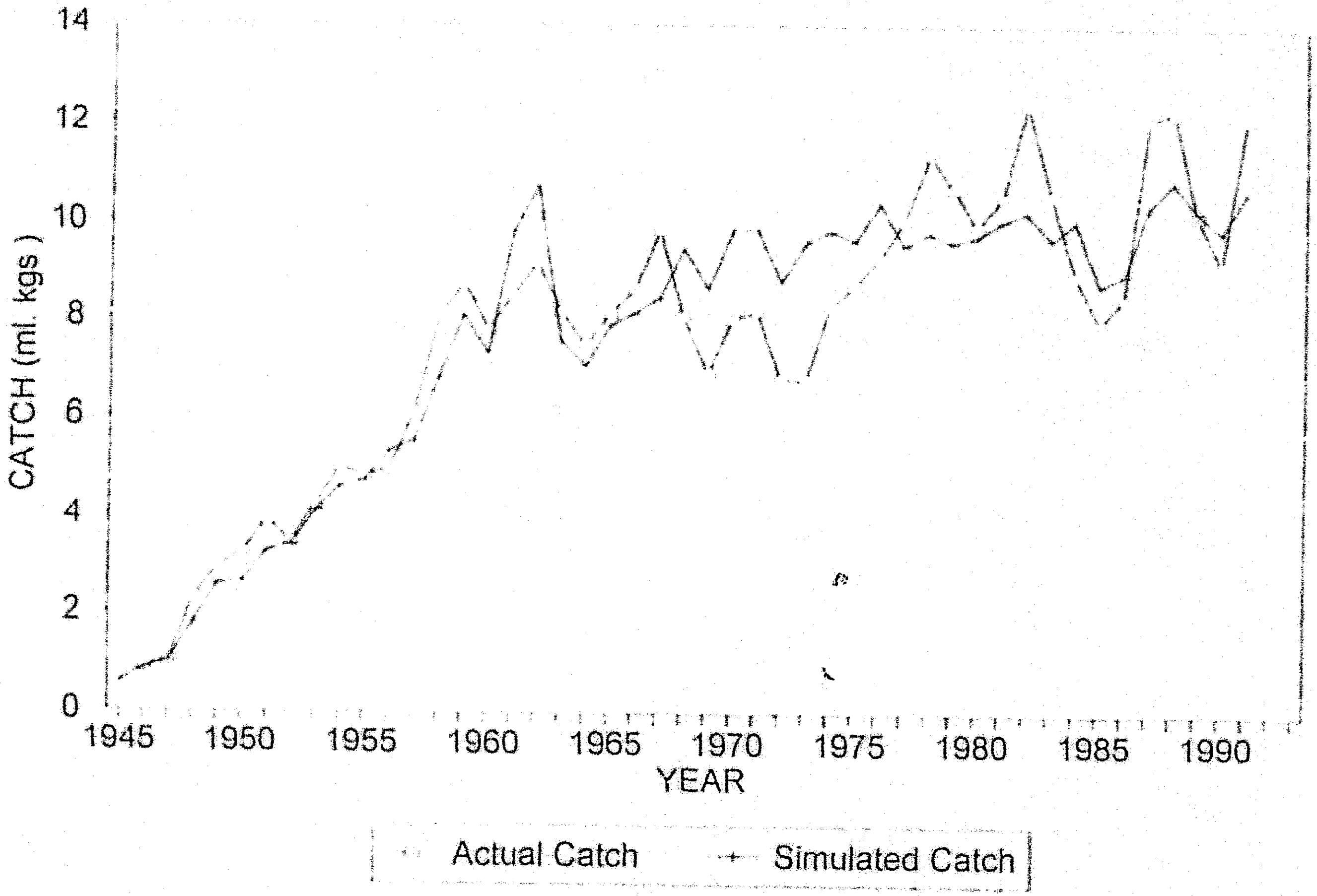


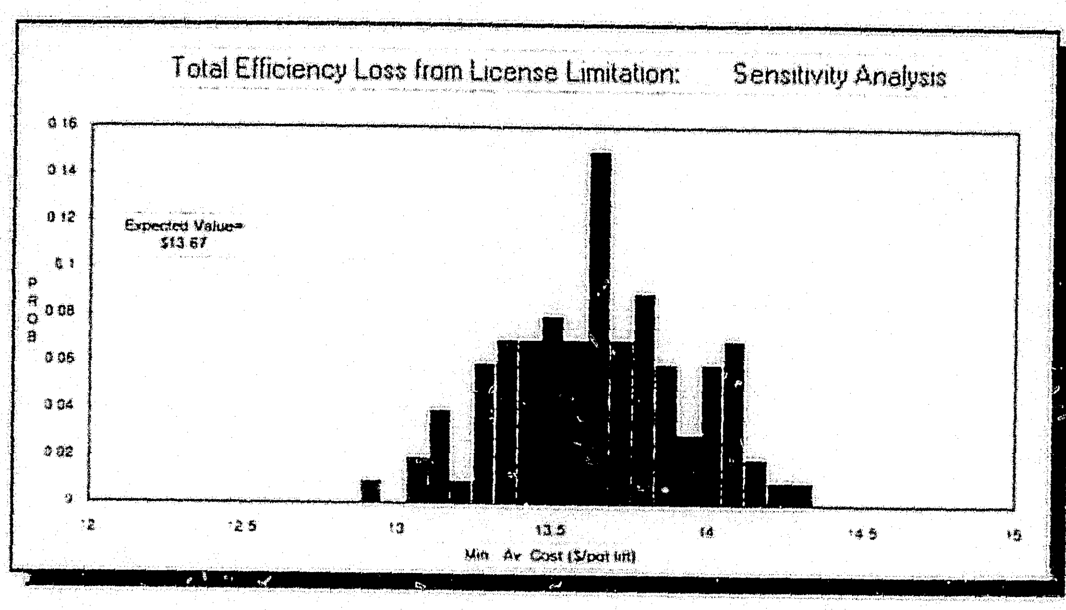
FIGURE 2: WRL ANNUAL CATCH

Simulated vs Actual Catch History



PARAMETER VALUES USED IN SENSITIVITY ANALYSIS FOR LICENSE LIMITATION SCHEME

	Observed Parameter Values						Estimated Parameter Values		
	r/i=	Price	License	#pots	CPUE	Effic. Effort	Min.AC	Eopt	Opt. Rent
Output Range:		($/kg.)	$/pot		(kg/lift)	(% Ea)	($/lift)	(m. lifts)	($ m.)
Minimum=	5%	$22	$12,000	69,000	0.83	65%	$12.62	7.484	$69.30
10Perc=							$13.21	7.632	$72.08
Mean=	5%	$22	$14,000	69,000	0.83	80%	$13.67	7.811	$75.53
90Perc=							$14.07	7.990	$79.00
Maximum=	5%	$22	$16,000	69,000	0.83	95%	$14.48	8.236	$83.95


Total Efficiency Loss from License Limitation: Sensitivity Analysis
Expected Value=
$13.67
PROB
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
12
12.5
13
13.5
14
14.5
15
Min. Av. Cost ($/pot lift)

IMPACT OF LICENSE LIMITATION SCHEMES

Sensitivity Analysis for Various Equilibrium Effort Levels

Parameter	r =	Price	License	#pots	CPUE	Effic Effort
Values		($/kg)	$/pot		(kg/lift)	(% Ea)
Min	5%	$22	$12,000	69,000	0.83	65%
Median	5%	$22	$14,000	69,000	0.83	80%
Max	5%	$22	$16,000	69,000	0.83	95%

Effort = 8 m. pot lifts	FGH ($ m.)	BDH ($ m.)	DWL ($ m.)	DWL (% Opt. Rent)	% pot redn.	% rent incr.
Output Range:						
Minimum=	$5.87	$0.00	$5.96	8%	22%	-36%
10Perc=	$9.56	$0.00	$9.69	12%	38%	-26%
Mean=	$24.59	$0.07	$24.65	33%	71%	6%
90Perc=	$39.49	$0.15	$39.50	52%	103%	34%
Maximum=	$43.51	$0.33	$43.54	57%	114%	55%
Effort = 9 m. pot lifts						
Minimum=	$4.43	$0.72	$6.44	9%	8%	-19%
10Perc=	$7.17	$1.25	$8.97	12%	25%	-8%
Mean=	$18.49	$1.77	$20.26	27%	53%	15%
90Perc=	$29.78	$2.27	$31.24	42%	80%	36%
Maximum=	$32.73	$2.85	$34.36	45%	89%	54%
Effort = 10 m. pot lifts						
Minimum=	$3.19	$3.85	$9.41	12%	-7%	-9%
10Perc=	$5.13	$4.97	$11.22	15%	11%	1%
Mean=	$13.27	$5.95	$19.22	25%	35%	17%
90Perc=	$21.36	$6.85	$27.11	36%	58%	31%
Maximum=	$23.50	$7.84	$29.19	39%	69%	48%
Effort = 11 m. pot lifts						
Minimum=	$2.16	$9.45	$13.91	17%	-22%	-8%
10Perc=	$3.43	$11.16	$16.30	22%	-4%	1%
Mean=	$8.90	$12.61	$21.51	29%	17%	12%
90Perc=	$14.33	$13.91	$26.92	35%	35%	23%
Maximum=	$15.93	$15.30	$28.03	38%	49%	34%
Effort = 12 m. pot lifts						
Minimum=	$1.32	$17.53	$21.09	26%	-36%	-14%
10Perc=	$2.14	$19.83	$23.77	30%	-22%	-8%
Mean=	$5.41	$21.74	$27.14	36%	0%	0%
90Perc=	$8.69	$23.45	$30.15	41%	15%	9%
Maximum=	$9.82	$25.24	$31.42	43%	29%	15%

Total Efficiency Loss from License Limitation: Sensitivity Analysis