## NEW ZEALAND CASE STUDY

## MEASURING FISHERIES MANAGEMENT PERFORMANCE USING A LONG-RUN EQUILIBRIUM MODEL

## Introduction

Reference to a benchmark position of the free-trade of goods and services has assisted the OECD in the analysis of trade issues. The Producer Subsidy Equivalent (PSE), and other measures, have proved useful as pragmatic measures of the deviation of current markets from this benchmark position. Despite their theoretical and other limitations, these measures have encouraged the development of more refined analysis, and provided a useful focus for the discussion of policy initiatives.

When approaching questions of how to manage fisheries resources better, it may be useful to adopt a similar approach. This paper proposes optimal economic exploitation as an analogous benchmark for fisheries management. the paper then attempts to derive a pragmatic measure of the deviation of current management from an optimal management benchmark.

The measure derived, which we have termed the marginal efficiency loss (MEL), may serve as a useful focus for discussion of resource management issues. It is derived from a model based on a prevailing bio-economic paradigm. A relatively small data-set is required. For illustrative purposes, we have calculated the measure for several important New Zealand fisheries.

This report is indicative only and further work is required on conceptual matters, the underlying bio-economic model, and the data used.

## The bio-economic paradigm

The model used in this paper is based on a prevailing paradigm in fisheries economics which describes deterministic equilibrium relationships between catch, effort, revenue and cost (e.g. Clark 1985). Catch has a dome-shaped relationship to effort. Its maximum occurs at a catch called the maximum sustainable yield (MSY). Before any theoretical economic analysis was developed for fisheries science this maximum was an accepted target for sound management of fisheries. It is at present the goal (with qualifications) specified in the New Zealand Fisheries Act (1983).

Economists brought cost and revenue into the picture. Within the paradigm revenue is simply the product of price and catch, and therefore also has a dome-shaped curve in relation to effort. The cost of fishing is proportional to effort. This gives a straight line through the origin which intersects the revenue curve. Three further equilibrium reference points are then defined by these lines. The maximum economic yield (MEY) is the catch at which revenue less cost is greatest. The dynamic maximum economic yield (DMEY) is the yield to which the economically optimum sequence of catches will
converge from any initial stock state. Optimality here refers to the maximisation of net present value of revenue less cost (NPV) and therefore is dependent on a specified discount rate. The open access yield (OAY) is the catch at which revenue equals cost, that is, where the cost and the revenue curves intersect. An example of these reference points is shown for the Chatham Rise orange roughy fishery case study in Figure 1.

Simple economic argument suggests that if a fish stock is a common property resource and there is open access to fishing it, then the catch will tend towards the OAY. The OAY and the MSY always occur at higher effort (and lower stock biomass) than the DMEY which occurs at higher effort than the MEY (for feasible bio-economic parameters). The aim of good management of a fish stock, under the paradigm, is to maximise the NPV and therefore to move the stock towards the DMEY state. Achievement of this aim is not common, with many of the world's most valuable fish stocks being fished either near their OAYs or, at other levels, but with the profits dissipated by costly management regimes.

Considerations not included in the paradigm are the values to society of recreational fishing and of environmental conservation. There are practical difficulties in quantifying these values. It is heuristically clear, however, that both values increase with increasing stock size. A management regime which tended to increase a fish stock size from the vicinity of the OAY to that of the DMEY would be socially beneficial.

In the paradigm a Schaefer production curve of catch against effort is generally used. This has the shape of an inverted parabola. In this report, however, an age-structured model is used which generally gives an asymmetric equilibrium production curve. Because recruitment does not have a strong positive relationship to stock size, the curve is usually very flat on its right-hand limb, reaching its maximum at high effort and declining slowly beyond. The conclusions to be drawn from curves of this shape are essentially the same as those from Schaefer curves.

## Case study -- Chatham Rise orange roughy stock (ORH3B)

In order to explain the general method, we follow through its application to the Chatham Rise orange roughy stock. Appendices 2 and 3 give further examples (east coast North Island snapper, and west coast South Island hoki).

Hypothetical equilibrium states of the Chatham Rise orange roughy stock were simulated on the basis of assumed values for key parameters. All relationships were deterministic. Since only equilibrium results were sought, the present age structure was not a required, even though the model was based on age structured relationships. The following biological data were used. It was obtained from a draft NZFARD (Francis \& Robertson 1991). The data requirements are not great.

| Virgin stock biomass | 393000 tons |
| :--- | :--- |
| Instantaneous natural mortality rate | $0.05 \mathrm{yr}_{-1}$ |
| Age at recruitment | 23 yr |
| Maximum age | 70 yr |
| Mean weight at age vector |  |
| Recruitment function dependent on stock size |  |

Minor details defining precisely when the catch is taken during the season, how growth is modelled, and how the maximum age class is dealt with, were also required (see Appendix 1). These details were all necessarily based on Francis \& Robertson to ensure that the present simulation was
consistent with their virgin stock biomass estimate. A full description of the equations used is given in Appendix 1.

The following economic data was used. The base year (1989/90) catch and stock biomass were also based on Francis \& Robertson. Value was taken to be half the free on board export price. The other parameter values were assumed. Further research is required to establish them more firmly.

| Unit value of landed fish | $1.10 \$ / \mathrm{kg}$ |
| :--- | :--- |
| Discount rate | $10 \%$ |
| Surplus profit in the base year | $10 \%$ |
| Catch in the base year | 37837 tons |
| Stock biomass at the start of the base year | 84000 tons |
| Aggregation parameter | 0.30 |

The economic structure of the model is a simple representation of the cost and revenue which arises from catching and landing fish from a wild stock. Revenue is the (constant price times the weight of the landed catch. Since the model refers only to equilibrium (i.e. long-run) states the cost of fishing is modelled wholly as a variable cost. It includes normal profit so that revenue less cost is the surplus profit.

A unit of fishing effort is defined to produce a unit of cost. We arbitrarily set effort to one in the base year. The aggregation parameter determines the extent to which fishing effort produces disproportionate increases in fishing mortality as stock biomass declines (see Appendix 1). This depends on details of the aggregation behaviour of the stock. The parameter ranges between zero and one. At one extreme (zero), cost is proportional to fishing mortality (the conventional assumption). At the other, cost is proportional to catch.

For any chosen fishing mortality rate the model calculates the equilibrium effort, catch and stock biomass, and the corresponding revenue and cost. Except at values of the aggregation parameter near one, the cost of catching a ton of fish increases as the stock biomass declines because fishing mortality increases. For this reason MEY and DMEY tend to occur at relatively high stock biomass levels.

## Output

By varying fishing effort, the model generates the equilibrium relationships between the variables. Of interest are the standard reference points of MEY, DMEY, OAY, and MSY. Because we are interested in assessing the base year (non-equilibrium) state of the fishery, we need to define corresponding equilibrium points. Two such points are defined. In the first, base year effort is applied continuously to achieve an equilibrium state. In the second, we find the equilibrium effort which would sustain the base year stock levels biomass at equilibrium. We also determine the equilibrium stock biomass that would result from fishing at the base year effort.

Base year effort
Base year stock biomass
Open access yield (OAY)
Maximum sustainable yield (MSY)

The equilibrium yield resulting from the base year effort
The equilibrium yield at the base year stock biomass
The equilibrium yield at which a zero surplus profit is produced
The maximum equilibrium yield

Maximum economic yield (MEY)
Dynamic MEY (DMEY)

The equilibrium yield producing the maximum surplus profit
The equilibrium yield to which the economically optimum sequence of catches will converge from any initial stock state.

Finding these reference points is relatively straightforward (see Appendix 1).
The DMEY will occur at a higher effort (and lower stock biomass) than the MEY. A positive discount rate means that short-term increases in surplus profit can outweigh subsequent reductions caused by the depletion of the stock. DMEY equals MEY when the discount rate is set to zero. Note that DMEY has lower equilibrium profits than the MEY. The DMEY's superiority derives instead from the non-equilibrium profits that can be made during the transition to the DMEY equilibrium.

The DMEY represents the theoretical target yield and stock state for optimal management. Other equilibrium states can be compared in terms of how far the effort, stock biomass, catch, revenue and surplus profit deviate from the DMEY positions.

## Measure of efficiency

It would be desirable to characterise equilibrium states by an economic measure of how far they deviate from the DMEY. Here, we propose a Marginal Efficiency Loss (MEL) whose definition is based on a property of the DMEY. If an equilibrium catch is increased by one ton in one year and then effort is returned to its equilibrium level, the NPV of this catch sequence will differ from that of the equilibrium. This difference, divided by the cost of catching the additional ton is a measure of deviation from the DMEY. We define the MEL as the absolute value of this ratio expressed as a percentage.

It is a property of the DMEY (which we use in searching for it) that this measure will equal zero at the DMEY. At any other point it will measure the percentage loss of productivity per ton at the margin.

The proposed MEL does not give a complete picture of base year fisheries management, because it does not indicate the extent of change required to achieve optimal management. Accordingly, we supplement the MEL with other indicators, such as measures of relative effort and stock size.

## Results - Chatham Rise orange roughy stock (ORH3B)

The equilibrium revenue curve shown in Figure 1 is very flat for effort greater than about 15 per cent of base year effort (the revenue includes 20 per cent overrun, see Francis \& Robertson, 1991). This is largely because recruitment only begins to fall steeply at very low stock biomass (Beverton-Holt recruitment parameter, $\mathrm{D}=0.95$ ). By chance the OAY and the MSY are almost equal. The outstanding feature of this fishery is the extremely high base year (1989/90) effort. Just a decade ago a truly virgin stock began to be fished. The size of the stock and its productivity were quite unknown. A TAC was set which proved to be much higher than could be sustained in the long-term. Evidence that the stock was declining very rapidly and That its productivity is extremely low has become increasing conclusive in the last four years.

Table 1. Orange roughy Chatham Rise (ORH3B)

## Equilibrium states in relation to DMEY

| Reference point | MEY | DMEY | Stock at base <br> year level | OAY | MSY | Effort at base <br> year level |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| Fishing mort. F | 0.056 | 0.106 | 0.160 | 0.228 | 0.230 | 0.618 |
| Effort index | 61 | 100 | 135 | 174 | 175 | 341 |
| Stock index | 158 | 100 | 71 | 52 | 52 | 21 |
| Revenue index | 85 | 100 | 105 | 106 | 106 | 99 |
| Profit index | 123 | 100 | 57 | 0 | -2 | -282 |
| Profit/ton index | 144 | 100 | 54 | 0 | -3 | -285 |
| MEL $(\%)$ | 68 | 0 | 31 | 49 | 49. | 74 |

Figure 1.
Table 1 gives measures of the extent of deviation of the reference points from the DMEY. The equilibrium revenue does not change markedly over the range of fishing mortalities whereas the effort, and therefore the cost does. Base year effort exceeds the optimal effort by a factor of three. Base year fishing mortality exceeds that for the DMEY by a factor of six. The difference is due to the effects of fish aggregation. Base year stock size (1989/90) is 29 per cent below the optimal level.

Turning to the primary measure proposed, the MEL of base year effort is 74 per cent. This means that there is a 74 per cent efficiency loss from catching an extra ton of fish. Before this equilibrium state was reached, it would be likely that effort would be reduced towards the OAY level. At this point, the efficiency loss would be 49 per cent. Even if catches were constrained to maintain the base year stock level, the MEL would still be 31 per cent.

## Conclusions

Following the approaches used to address trade issues, we have endeavoured to construct a measure of the extent current fisheries management deviates from a benchmark of optimal economic management. The bio-economic model used to calculate the measure is derived from a prevailing bio-economic paradigm which compares long-run equilibrium positions. The data set required to produce indicative results is relatively small, and indicative values are likely to be available for most commercially valuable stocks.

The measure, which we have called the marginal efficiency loss (MEL), could serve as a reference point for discussions on resource management issues. It could help identify high priority resource management issues, enable comparisons between different fish stocks, and assess the approximate gains from initiatives towards better management. The measure does not have to be theoretically perfect to fulfil these roles.

As an important qualification, it should be noted that the MEL does not provide a complete picture of optimal management, in a dynamic sense. Since fish stocks are rarely at their optimal equilibrium state, ideal management involves selecting the sequence of catches which will ultimately drive the stock towards the optimal level. In the transition, optimal fishing effort may be above, or
below, the long-run optimum, depending on the initial state of the stock. Comparison of base year effort and stock size equilibriums to the optimal long-run position help place the MEL in an appropriate context.

Further work is still required on a number of fronts, including on conceptual issues. For example, the measure might be better related to the value-added, rather than the costs of harvesting. In cases of stock depletion, the measure could then be interpreted as the price distortion caused by not properly internalising the costs of overfishing. This is analogous to the choice between using a PSE measure as a guideline rather than a value-added measures such as Effective Rate of Assistance (ERA).

Enhancements to the structure of the underlying model are possible. For example, initial parameters for catch and stock size in the base year could be specified by age-class rather than for the stock as a whole. There are a number of other such options for further generalisation of the model.

Analysis of the sensitivity of the model to various parameter assumptions would also be useful.
Finally, there are issues to be worked through concerning the estimation of parameters, and the interpretation of results.

## APPENDIX 1 - MODEL EQUATIONS

A deterministic model of a fish stock is used in which each age class is accounted for separately. A vector represents the numbers of fish in each age class. Equations determine the reduction in the numbers in each age class caused by natural, amateur and fishing mortality on an annual basis (there is no immigration or emigration). The weights of fish in the stock (biomass) and in the catch are determined by a vector of mean weight at age. Recruitment occurs at the start of each year and is only into a single age class.

Let $\quad \mathbf{N}^{\mathbf{a i}}$ be the number of fish of age a at the start of year $\mathbf{i}$,
$\mathbf{r}$ be the recruitment age of fish in the stock,
$\mathbf{m}$ be the maximum age of fish in the stock,
$\mathbf{W}^{\mathbf{a}}$ be the mean weight of a fish of age a at the start of a year,
F be the instantaneous fishing mortality rate per year,
$\mathbf{M}$ be the instantaneous natural mortality rate per year,
A be the instantaneous amateur mortality rate per year,
$\mathbf{R}^{\mathbf{i}}$ be the number of fish recruited into age class $\mathbf{r}$ at the start of year $\mathbf{i}$,
$\mathbf{Y}^{\mathbf{i}}$ be the catch weight in year $\mathbf{i}$,
$\mathbf{B}^{\mathbf{i}}$ be the stock biomass at the start of year $\mathbf{i}$,
$\mathbf{B}^{\mathbf{V}}$ be the virgin stock biomass at the start of a year,
$\Delta$ be the parameter giving the proportion of virgin recruitment that occurs when $\mathbf{B}^{\mathbf{i}}=\mathbf{0 . 2} \mathbf{B} \mathbf{v i}$,
$\mathbf{k}$ be the cost of fishing per unit fishing mortality at virgin stock biomass,
D be aggregation parameter in the cost function,
d be the annual percentage discount rate (the nominal increase in value as a percentage over one year),
p be the value per unit weight of landed fish,
$\mathbf{S}^{\mathbf{i}}$ be the surplus profit in year $\mathbf{i}$.

Then
$\mathrm{N}^{\mathrm{a}+1 \mathrm{i}+1}=\mathrm{Nai}_{\mathrm{e}_{-( }(\mathrm{F}+\mathrm{M}+\mathrm{A})} \quad$ where $\mathrm{r}<\mathrm{a}+1<\mathrm{m}$,
and $\quad \mathrm{N}_{\mathrm{ri}+1} \quad=\mathrm{R}_{\mathrm{i}+1}$

The number of fish in age class $\mathbf{m}$ is modelled in two alternative ways. Either all fish die at the end of their mth year (senile mortality) or fish cease to grow and remain nominally m-year-olds (plus group).
$\mathbf{N}_{\mathbf{m i}+1}$
$=\mathbf{N}_{\mathbf{m}-1} \mathrm{e}^{-(\mathbf{F}+\mathrm{M}+\mathrm{A})}$
(senile mortality)
or $\quad \mathrm{N}_{\mathrm{mi}+1}=\left(\mathrm{N}_{\mathrm{mi}}+\mathrm{N}_{\mathrm{m}-1 \mathrm{i}}\right) \mathrm{e}-(\mathrm{F}+\mathrm{M}+\mathrm{A}) \quad$ (plus group) .
The stock biomass at the start of year $\mathbf{i}$, can be obtained from these numbers at age,

$$
\mathrm{B}_{\mathrm{i}} \quad \sum_{\mathrm{amr}}^{\mathrm{m}} \mathrm{~N}_{\mathrm{ai}} \mathrm{~W}_{\mathrm{a}}
$$

Recruitment is modelled according the Beverton-Holt formula (reparameterised),

$$
\mathrm{R}_{\mathrm{t}}=\frac{4 \Delta \mathrm{Rv}}{\left(\mathrm{~B}_{\mathrm{v}} / \mathrm{B}_{\mathrm{t}-\mathrm{r}}\right)(1-\Delta)+5 \Delta-1}
$$

Notice that when $\Delta=1$ recruitment is constant $\left(R_{v}\right)$.
Natural and amateur mortality are modelled as occurring at constant rates throughout the year. Fishing is modelled in three alternative ways. It may occur at the start of the year (before any natural or amateur mortality), throughout the year (concurrent with natural and amateur mortality) or at the end of the year (after all natural and amateur mortality). The catches by number for each age class are:
or

$$
\mathbf{N}_{\mathbf{a i}}\left(\mathbf{1}-\mathbf{e}^{-\mathbf{F}}\right) \quad \text { (start of year fishing), }
$$

$$
\begin{array}{ll}
\mathbf{N}_{\mathbf{a i}} \underset{\mathbf{F}+\mathbf{M}+\mathbf{A}}{\mathbf{F}}(\mathbf{1}-\mathbf{e}-(\mathbf{F}+\mathbf{M}+\mathbf{A}) & \text { (fishing throughout year) } \\
\mathbf{N}_{\mathbf{a i}}\left(\mathbf{1}-\mathbf{e}^{-\mathbf{F}}\right) \mathbf{e}-(\mathbf{M}+\mathbf{1}) & \text { (end of year fishing). }
\end{array}
$$

It should be noted that fishing in the middle of the year (after half a year of natural and amateur mortality) would give the same catch as fishing throughout the year, up to second order mortality terms.

Catch (weight) can be obtained by introducing the weights at age into the expressions and summing. Growth is modelled in two ways. Firstly, fish of age a have a constant weight $\mathbf{w}_{\mathbf{a}}$ throughout the year, giving:

$$
\begin{array}{llll} 
& Y_{t} & =\sum_{a=r}^{m} N_{a i} W_{a}\left(1-e^{-F}\right) & \text { (start of year fishing), } \\
\text { or } & Y_{t} & =\sum_{a=r}^{m} N_{a i} W_{a} \frac{F}{F+M+A}\left(1-e^{-(F+M+A)}\right. & \text { (fishing throughout year) } \\
\text { or } & Y_{t} & =\sum_{a-r}^{m} N_{a i} W_{a}\left(1-e^{-F}\right) e^{-(M+1)} & \text { (end of year fishing) }
\end{array}
$$

Alternatively, fish of age are modelled to grow from weight $\mathbf{w}_{\mathbf{a}}$ to weight $\mathbf{w}_{\mathbf{a}+\mathbf{1}}$ during a year. This gives the same catch equation for start of year fishing and

$$
\begin{aligned}
& \mathrm{Y}_{\mathrm{i}}=\sum_{\mathrm{a}=\mathrm{r}}^{\mathrm{m}} \mathrm{~N}_{\mathrm{a}} \mathrm{~W}_{\mathrm{a}}+1\left(1-\mathrm{e}^{-\mathrm{F}}\right) \mathrm{e}^{-(\mathrm{M}+1)} \quad \text { (end of year fishing) }
\end{aligned}
$$

Fishing effort is defined to be proportional to the cost of fishing. The cost of fishing is modelled to be a function of the fishing mortality rate and the ratio of the stock biomass to the virgin stock biomass. Since the stock biomass, $\mathbf{B}$ is a variable which changes throughout the year, it is necessary to obtain the annual cost by integration. If $\mathbf{B}$ is the stock biomass during year $\mathbf{i}$,

$$
\mathrm{C}_{\mathrm{i}}=\stackrel{1}{\mathrm{kF} \int} \underset{0}{ }\left(\mathrm{~B} / \mathrm{B}_{\mathrm{v}}\right)^{\mathrm{D}} \mathrm{dt}
$$

The results of the integration depend on when fishing occurs so that,

$$
\begin{aligned}
& \left.C_{i}=\frac{\mathrm{kF}}{\mathrm{~B}_{\mathrm{v}}{ }^{\mathrm{D}}} \sum_{\mathrm{a}=\mathrm{r}}^{\mathrm{m}} \mathrm{~N}_{\mathrm{ai}} \mathrm{~W}_{\mathrm{a}}\right)^{\mathrm{D}} \frac{\left(1-\mathrm{e}^{\mathrm{FD}}\right)}{\mathrm{FD}} \quad \text { (start of year fishing) } \\
& \left.C_{i}=\frac{k F}{B_{v}{ }^{\mathrm{D}}}{ }_{\mathrm{a}=\mathrm{r}}^{\mathrm{m}} \sum_{\mathrm{ai}} \mathrm{~W}_{\mathrm{a}}\right)^{\mathrm{D}} \frac{\left(1-\mathrm{e}^{\mathrm{F}+\mathrm{M} \mathrm{D} \mathrm{D}}\right)}{(\mathrm{F}+\mathrm{M}) \mathrm{D}} \quad \text { (fishing throughout year)) } \\
& \left.C_{i}=\frac{k F}{B_{v}{ }^{D}}{ }_{a=r}^{m} N_{a i} W_{a}\right)^{D} e^{-M D} \frac{\left(1-e^{-\mathrm{FD}}\right)}{F D} \quad \text { (end of fishing year) }
\end{aligned}
$$

when growth is modelled as stepwise. The weight factors change correspondingly when fish are modelled to grow throughout the year. Notice that when $\mathbf{D}=0$ cost is proportional to fishing mortality (the conventional assumption) and when $\mathbf{D}=1$ cost is proportional to catch. This latter case may apply when easily found aggregations of fish can be caught at all stock biomass levels.

The surplus profit in year $\mathbf{i}$ is the revenue less the cost:

$$
S_{i}=p Y_{i}-C_{i}
$$

At equilibrium variables do not change over time so that the index $\dot{\mathbf{i}}$ can be dropped. The net present value of surpluses is given by:

$$
S(1+100 / d)
$$

Hypothetical equilibrium states of the stock are simulated and the values of variables associated with these states are calculated. The model simply generates each equilibrium age structure by a single iteration through the numbers at age vector. The defined equilibrium points are sought by varying fishing mortality. MSY and MEY are sought by successive quadratic approximation and OAY and DMEY are sought by successive linear approximation.

## APPENDIX 2 - NORTH-EAST NORTH ISLAND SNAPPER STOCK (SNAI)

The data for this analysis has been obtained from a draft NZFARD (Gilbert, 1991). The biological data are as follows:

Virgin stock biomass
Instantaneous natural mortality rate
Instantaneous amateur mortality rate
Age at recruitment
Maximum age
Fishing season
Mean weight at age vector (at start of yr)
Fish growth pattern
Maximum age class
Beverton-Holt $\Delta$

The following economic data are assumed:

| Unit value of landed fish | $4.25 \$ / \mathrm{kg}$ |
| :--- | :---: |
| Aggregation parameter | 0.10 |
| Discount rate | $10 \%$ |
| Base year | 1990 |
| Surplus profit in the base year | $10 \%$ |
| Catch in the base year | 5388 t |
| Stock biomass in the middle of base year | 58700 t |

The equilibrium revenue curve shown in Figure 2 is typical of a stock where recruitment is constant. In reality recruitment is known to be positively correlated to temperature during the spawning season. The MSY lies well to the right. The OAY is only slightly lower than the MSY but occurs at a much lower effort. The base year (1990) effort is a good deal below that of the OAY. It has been near the base year level since 1986, the start of the Quota Management System (QMS). Prior to this it was a good deal higher. Effort at the MEY is about half the base year level and that at the DMEY lies between the two values.

Figure 2.

Table 2. Snapper North-east North Island (SNAI) Equilibrium states in relation to DMEY

| Reference point | MEY | DMEY | Stock at base <br> year level | Effort at base <br> year level | OAY | MSY |
| :--- | :---: | :---: | :---: | :---: | ---: | ---: |
| Fishing mort. F | 0.050 | 0.076 | 0.081 | 0.111 | 0.144 | 222 |
| Effort index | 68 | 100 | 106 | 142 | 180 | 267 |
| Stock index | 127 | 100 | 96 | 77 | 62 | 42 |
| Revenue index | 83 | 100 | 102 | 111 | 115 | 118 |
| Profit index | 114 | 100 | 95 | 55 | 0 | -148 |
| Profit/ton index | 133 | 100 | 92 | 50 | 0 | -125 |
| MEL $(\%)$ | 43 | 0 | 6 | 34 | 53. | 74 |

Table 2 gives measures of the extent of deviation of the reference points from the DMEY. Revenue does not change markedly over the range of fishing mortalities. The changes in effort and hence cost are much greater over this range. Base year fishing effort is 42 per cent higher than at the optimum. The MEL of base year effort is 34 per cent, which means a productivity loss of this amount, if the base year level of effort continues.

The base year biomass of the stock is 4 per cent below the optimal level. The analysis is certainly not precise enough to measure differences of this size. The closeness of the base year stock biomass to its optimal size is partly due to good luck and partly due to good management. In the mid-1980s, when the QMS was introduced the stock was somewhat lower than at base year and was perceived to require some rebuilding. The Total Allowable Catch (TAC)was therefore set to allow this to occur. Fortuitously, spawning season temperatures have been well above average for most of the late 1980s. Recruitment has therefore been above average. The effect of lower catches and higher recruitment has resulted in an increasing stock biomass. The stock is thus ins a state which is both healthy biologically and economically. Although detailed data are not available the fishery is believed to be highly profitable. Sports fishermen are also benefiting from an increased stock size in what is a very popular amateur fishery.

The TAC has increased by almost 30 per cent since the inception of the QMS. The equilibrium catch and thus the equilibrium revenue modelled here represent values corresponding to average recruitment. While recruitment can be predicted to remain above average for a few more years (strong juvenile year-classes are still to enter the stock) the base year TAC will begin to reduce the stock to below optimal levels when recruitment returns to normal. Based on this analysis a reduction in the TAC would become desirable when this occurs.

## APPENDIX 3 - WEST COAST SOUTH ISLAND HOKI STOCK (PART OF HOKI)

The data for this analysis has been obtained from a draft NZFARD (Sullivan, 1991). The biological data are as follows:

| Virgin stock biomass | 1373000 t |
| :--- | :--- |
| Instantaneous natural mortality rate (value for female used) | $0.25 \mathrm{yr}^{-1}$ |
| Instantaneous amateur mortality rate | $0 \mathrm{yr}^{-1}$ |
| Age at recruitment (value for females used) | 5 yr |
| Maximum age | 20 yr |
| Fishing season | end of year |
| Mean weight at age vector (at start of yr) | as specified in Sullivan (1991) for |
|  | females |
| Fish growth pattern | stepwise |
| Maximum age class | plus group |
| Beverton-Holt $\Delta$ | 0.95 |

The following economic data are assumed:

| Unit value of landed fish | $0.35 \$ / \mathrm{kg}$ |
| :--- | :---: |
| Aggregation parameter | 0.20 |
| Discount rate | $10 \%$ |
| Base year | 1990 |
| Surplus profit in the base year | $10 \%$ |
| Catch in the base year | 183000 t |
| Stock biomass at the start of the base year | 698000 t |

The equilibrium revenue curve shown in Figure 3 is again similar in shape to that for the previous species although the flat right-hand limb is not shown here. MSY occurs at very high fishing effort (about three time the base year level). The stock assessment for this stock is a good deal less certain than that for the previous two examples because good stock biomass indices have proved difficult to obtain. An extremely large growth in annual catch occurred between 1985 and 1988. According to the stock assessment it is only in the last year (1990) that the stock fell below its DMEY level. Continuing fishing at the base year effort would drive the stock below its OAY biomass.

Figure 3.

Table 2. Hoki West coast South Island (part of hoki) Equilibrium states in relation to DMEY

| Reference point | MEY | DMEY | Stock at base <br> year level | OAY | Effort at base <br> year level | MSY |
| :--- | :---: | :---: | :---: | :---: | :---: | ---: |
| Fishing mort. F | 0.117 | 0.142 | 0.217 | 0.317 | 0.420 | 1620 |
| Effort index | 83 | 100 | 146 | 202 | 257 | 759 |
| Stock index | 108 | 100 | 83 | 68 | 57 | 27 |
| Revenue index | 85 | 100 | 122 | 138 | 148 | 164 |
| Profit index | 103 | 100 | 70 | 0 | -87 | -1130 |
| Profit/ton index | 116 | 100 | 57 | 0 | -59 | -683 |
| MEL $(\%)$ | 14 | 0 | 28 | 49 | 62. | 90 |

Table 3 gives measures of the extent of deviation of the reference points from the DMEY. As before, the equilibrium revenue does not change markedly over the range of fishing effort whereas the cost does. Base year effort is two and a half times that required in the longer-term. The marginal net benefit of reducing the catch by one ton from an equilibrium state corresponding to recent effort is 62 per cent of the marginal cost of catching it. The MEL which would apply if the base year stock were maintained is 28 per cent.

