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Production model for the FMA 1 scampi fishery, 1989–91

M. Vignaux and D. Gilbert
MAF Fisheries Greta Point
P.O. Box 297
Wellington

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MAF Fisheries, N.Z. Ministry of Agriculture and Fisheries

1 Executive summary

The FMA 1 scampi fishery began in the 1986-87 fishing year. There are sufficient data since 1989 to estimate a year effect from a regression model of catch per unit effort (CPUE). This gives a possible stock size index of three values, which show a 40% decline. When a plausible production curve is fitted to this index it produces an estimate of present surplus production well below the present quota of 120 tonnes per year. The stock is estimated to be somewhat above the size that would produce maximum sustainable yield. These results are considered to be highly uncertain because of the shortness of the CPUE time series, the uncertainty as to how stock size affects CPUE, and the uncertainty in the height of the production curve for scampi.

2 Introduction

The scampi fishery in FMA 1 began in the 1986-87 fishing year, but it is only since 1989 that substantial catches have been taken. The fishery is conducted principally by vessels 20–30 m long using multiple rigs of two or three nets with very low headline height, mostly in waters 300–450 m deep.

Because the fishery is so new, there are few data on stock size, productivity, or even the biology of the species (a description of our current state of knowledge was given by Cryer (1992)). This paper uses the best information available on the scampi fishery in FMA 1 to model the stock and produce an estimate of its present state.

3 Data

To model a stock using the method described by Gilbert (1992), we require: the complete history of catches taken from the stock since the start of the fishery; a stock index which shows relative changes in stock size over a period of time; and a model relating the surplus production to the stock size.

3.1 Catches

The catches from this fishery are solely commercial and are given by Cryer (1992), see Table 1 below. The fishery essentially began in 1986–87 with a small catch of about 5 t. Very few vessels were involved before 1989.

Table 1: Catch(t) for scampi in FMA 1

Fishing year	Catch (t)
1986-87	5
1987-88	15
1988-89	60
1989-90	103
1990-91	179
1991-92	120†

†for the 1991-92 year a projected catch equal to the quota was assumed

3.2 CPUE analysis

A possible index of stock size for scampi in FMA 1 was calculated from commercial catch and effort data using a multiple regression approach. There were insufficient catch and effort data to calculate an index for the other areas.

Since the CPUE index is the only index available, it has been used as an index of stock size in the production model. It has been assumed that the index is proportional to the total stock biomass at the start of the corresponding fishing year. If there are significant quantities of scampi in areas which have not been fished and these fish do not move between areas, then they will not be included in the biomass estimate.

3.2.1 Commercial catch and effort data

Data were obtained for every recorded tow targetting scampi in FMA 1 in 1989, 1990, and 1991. Fishing did not start until March in 1989 and was almost completely finished by November in 1991. For each tow, the vessel identity, the date of the tow, the location of the tow, the depth of the tow, the time at which the tow started and finished, and the catch of scampi were extracted from the database. No specific information on gear was available.

For all vessels owned by one particular company, it was possible to examine all the records in which the catch was zero to see whether the tow could have caught scampi (in which case a zero is a legitimate catch) or whether it could never have caught scampi. Where the TCEPR form or the vessel's log indicated that the tow was a gear test, or for some reason the gear was lifted before it hit the bottom, the record was removed. About 90% of the records were from this particular company, and could be checked in this way. The remaining 10% were from other companies, and some non-legitimate zero catches may remain. Since a logarithmic model was to be used, the remaining zero catches were adjusted to a catch of 1 kg. This is one way to allow for zero catches; the alternative is to leave these records out (Doonan 1991). The effect of

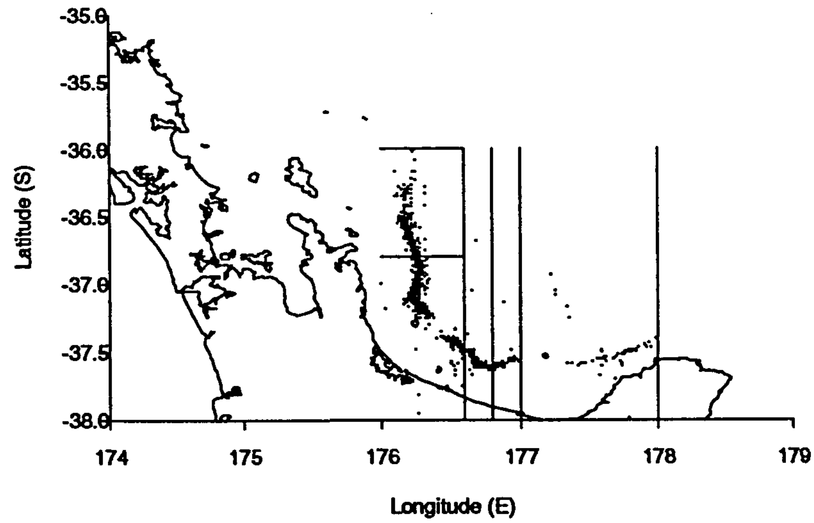

Figure 1: Area boundaries used for CPUE analysis of scampi in FMA 1

replacing the zero catches with other small catches, such as 10^{-3} and 10^{-6} kg, was investigated, but the results were not substantially different.

The location of each tow was coded with one of eight area codes, drawn using 0.2 degree lines of latitude and longitude. These areas cut across the "ribbon" of the commercially fished areas, and cover approximately the same depth range. After preliminary analysis, these areas were combined into 5 larger areas by combining neighbouring areas with similar catch rates (Figure 1). The length of the tow in hours was calculated from the start time and end time of the tow. The start time of the tow was used to estimate the effect of daily cycles on catch rates. The start times were divided into 12 two-hour segments. Incomplete records, for example if the start or end time was not available, were not used.

3.2.2 Investigation of vessel crowding

It has been suggested that crowding of vessels in the fishing area has caused a decrease in catch rates unrelated to any change in stock size. The finest scale of location data that we have is the length of a tow, which is (using the data) about 4 h, or (at 2.7 knots) about 20 km, or 0.2 degrees of latitude or longitude. The scampi fishing area was therefore broken up into areas 0.2 degrees wide (each approximately equal in width) (Figure 2).

For each day in 1990, the number of vessels fishing in each of these areas was calculated. Of the 2618 tows used, 1536 were in areas in which only one vessel fished on that day, 589 were in areas with two vessels, 372 with three vessels, 107 with four vessels, and 14 with five vessels (Table 2). There were never more than five vessels recorded on one area in one day, and less than 5% of tows were done with more than three vessels in the area on the day. This alone makes it unlikely that crowding could be affecting the overall catch rates.

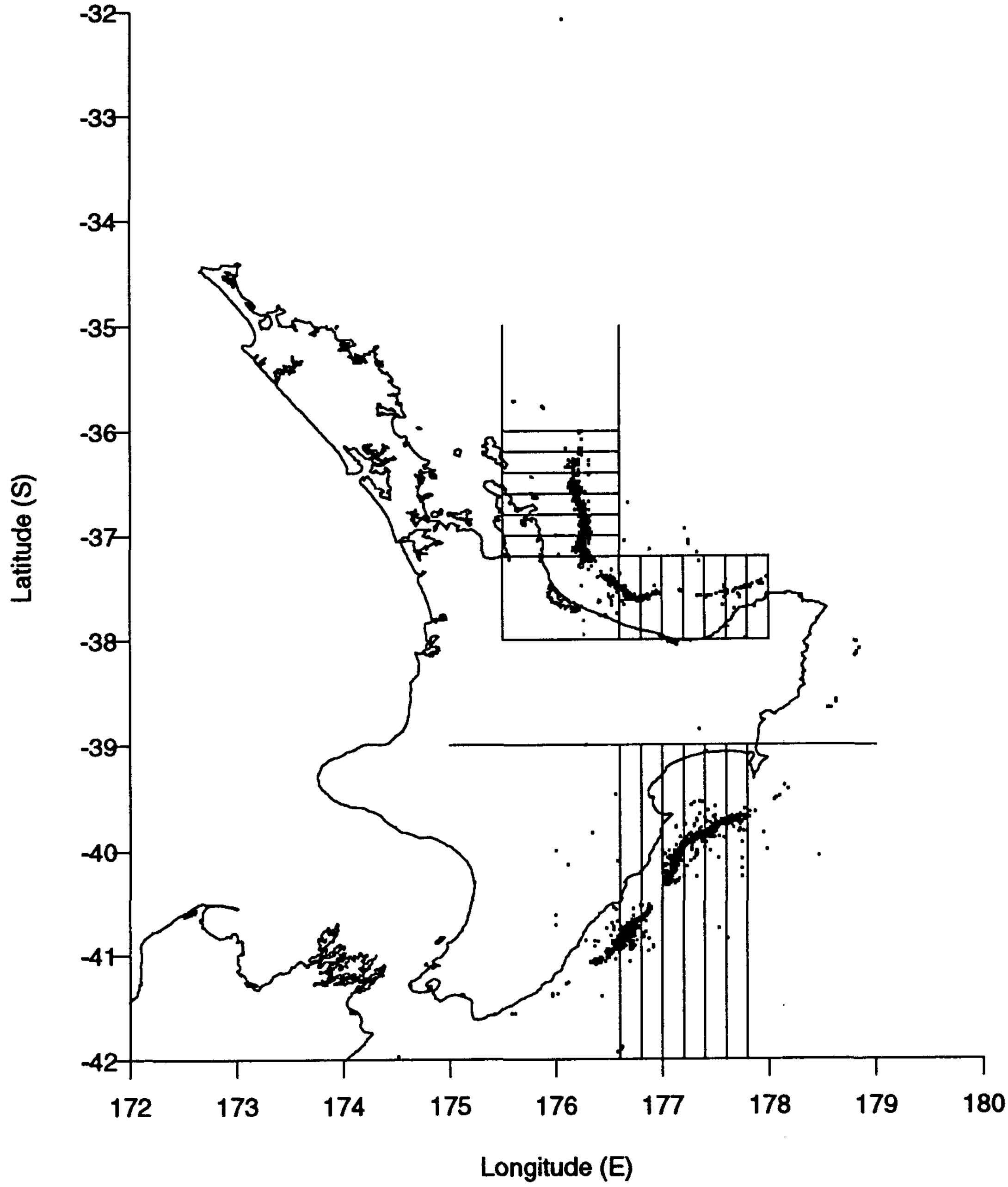

Figure 2: Fine scale areas used in investigation of vessel crowding

Table 2: The effects of the number of vessels fishing in an area on a day on scampi catch rates and other parameters. Numbers in brackets are standard errors, asterisks note values significantly different from overall mean (using a t test at the 5% level)

Vessels	1	2	3	4	5	Any
Number of tows	1536	589	372	107	14	2618
Mean catch(kg)	118.7 (2)	116.6 (3)	113.6 (3)	117.5(7)	120(17)	117.5(1.4)
Length of tow(h)	3.9(0.03)	4.0(0.04)	*4.2(0.05)	*4.4(0.08)	*4.1(0.26)	4.0(0.02)
Catch rate(kgh^{-1})	31.3 (0.6)	30.9(1.4)	29.5(2.2)	27.4(2.2)	29.1(3.6)	30.8(0.6)
Depth (m)	363.6(1.1)	358.8(1.9)	*354.5(1.5)	358(2.2)	373(5.6)	361.1(0.8)
Proportion at night	0.19	0.17	0.22	0.28	0.14	0.19

Table 3: The effects of the number of vessels fishing in an area on a day on scampi catch rates and other parameters (daytime tows only). Numbers in brackets are standard errors, asterisks note values significantly different from overall mean (using a t test at the 5% significance level)

Vessels	1	2	3	4	5	Any
Number of tows	1276	491	271	67	12	2117
Mean catch(kg)	121.8 (2)	119.8 (4)	121.7 (4)	140.0(9)	126.7(19)	122.0(2)
Length of tow (h)	*3.86(0.03)	3.98(0.05)	*4.11(0.06)	*4.50(0.08)	4.24(0.3)	3.94(0.02)
Catch rate (kgh^{-1})	32.5 (0.7)	31.8(2)	32.8(3)	30.6(2)	29.4(4)	32.3(0.7)
Depth (m)	*367(1)	359(2)	*354(2)	*356(3)	374(6)	363.2(0.9)

The mean catch, the mean length of tow, the depth, the proportion of tows at night, and the catch rate were tabulated by the numbers of vessels in the area (Table 2). This suggests that a tow in an area with many vessels fishing that day is likely to be longer than average, but that the catch rate is not significantly affected. There is some suggestion that a tow done in an area with many vessels fishing is more likely to be a night tow, so a similar analysis was done for daytime tows only to remove any possible effect of night tows being longer (Table 3). Again the mean length of tow is significantly greater in the crowded areas, and the depth appears to be shallower, but mean catch rates are not significantly affected by the number of vessels fishing in an area.

As there are very few vessels fishing in crowded conditions, the values of some means are poorly estimated. This may mean that a true crowding effect in the scampi fishery is just not detectable from this data.

There may also be competing effects of vessels being attracted to areas of high catch rate (causing a positive correlation between crowding and catch rate) and of vessels being unable to do the tows they want (because of crowding) and getting lower catches. This would cause a negative correlation between crowding and catch rate. However, no significant crowding effect can be determined from the data.

3.2.3 Regression model

Catch per hour was chosen as the measure of catch per unit effort (CPUE) most likely to index stock size. Catch per tow and catch per day were not used because the mean length of tow and the mean number of hours fished per day increased during the period 1989–91. Catch per nautical mile was not used because towing speed was not available for some shots. Catch per unit area fished was not used because no information was available on wing spread or door spread.

The logarithm of catch per hour was regressed against each of the possible predictor variables (such as year, vessel, start time of tow) to find the variable which explained the most variability in log(CPUE). This variable was then included in the model, and log(CPUE) regressed against the selected variable and each of the other predictor variables to find the next most useful variable. This stepwise regression procedure was continued until no extra explaining power came from adding an extra variable to the model.

Using the logarithm means that the model is multiplicative, that is, that the effect of each variable is to multiply the expected CPUE by a factor whose value depends on the value of the variable. The model was of the form

$$C_t = M + Y_{i_t} + P_{j_t} + Q_{k_t} + R_{l_t} + \ldots \qquad (1)$$

or, equivalently

$$\exp(C_t) = \exp(M) * \exp(Y_{i_t}) * \exp(P_{j_t}) * \exp(Q_{k_t}) * \exp(R_{l_t}) + \ldots \qquad (2)$$

where C_t is the logarithm of catch per unit effort for a particular tow t, M is an overall mean for C_t, Y_{i_t} is the effect on C_t of tow t being in the i_tth year, P_{j_t} is the effect of variable P having value j_t, Q_{k_t} is the effect of variable Q having value k_t, R_{l_t} is the effect of variable R having value l_t, and so on. The method of including categorical variables in the regression analysis was described by Vignaux (1992).

At each iteration the categorical variable with the most explaining power for the CPUE was chosen, using the sum of squares for regression (SSR) as the measure of the amount of the variability in the data explained by the variables included in the model (Brook & Arnold 1985).

$$SSR = \sum_t (\hat{C}_t - M)^2 \tag{3}$$

where $\hat{C}_t$ is the value of C_t predicted from the predictor variables using the results of the regression, and M is the mean of C_t. The total variability in the data is the total sum of squares (SST)

$$SST = \sum_t (C_t - M)^2 \tag{4}$$

The amount of variability not explained by the model is the sum of squares of the error or residual (SSE)

$$SSE = \sum_t (\hat{C}_t - C_t)^2 = SST - SSR \tag{5}$$

The ratio of SSR to SST is the proportion of the variability explained by the model, often called R^2. R^2 was not adjusted for the number of degrees of freedom, as the large data set makes the adjustment trivial.

The iterations stopped when the increase in SSR from an extra variable was trivial. An F test was done to test the significance of each extra variable, testing

$$F_{1,N-k} = \frac{\Delta SSR}{SSE/(N-k-1)} \tag{6}$$

where N is the number of records in the sample, k is the number of variables already used in the regression, ΔSSR is the increase in SSR due to the addition of the extra variable and SSE is the SSE after adding the extra variable. However, because of the large number of degrees of freedom $N - k - 1$ (about 2000), even if ΔSSR is as small as 10, the F test will still be significant at the 1% level (F at least 6.6). It was decided not to carry the procedure on until the addition of another variable became statistically insignificant because the effect of the extra variables is marginal well before this point. An arbitrary cut off of 5% was chosen, that is, if the extra variable did not improve SSR by 5% it was not included.

A possible index of stock size can be estimated from the regression coefficients for the years as (Doonan 1991)

$$\hat{A}_i = \exp(\hat{Y}_i - \hat{Y}_{1989}) \tag{7}$$

where $\hat{Y}_i$ is the regression coefficient for year i, $\hat{Y}_{1989}$ is the regression coefficient for 1989, and $\hat{A}_i$ is the year effect in year i relative to the year effect in 1989. The variance of this estimate is

$$s^2_{\hat{A}_i} = \hat{A}_i^2 \exp(\sigma^2)(\exp(\sigma^2) - 1) \tag{8}$$

where

$$\sigma^2 = \text{Var}(\hat{Y}_i) + \text{Var}(\hat{Y}_{1989}) - 2\text{Cov}(\hat{Y}_i, \hat{Y}_{1989}) \quad (9)$$

The variables tested for inclusion in the model were month, vessel, time of day, area, depth, and year. The month effect was a 12-value categorical variable, that is, each tow must have been done in one of the 12 months of the year. The relative month effect is a measure of the relative power of 1 hour's fishing in each of the 12 months of the year. Similarly the vessel effect is a nine-value categorical variable, and measures the relative power of an hour's fishing by each of the nine vessels. Time of day at start of tow was investigated as a twelve value variable, in 2 hour segments within a 24 hour day. Area was used as a 5-value variable as shown in Figure 1. Depth was investigated as a 10-value categorical variable. The divisions, chosen so that there were nearly the same number of tows in each division, were at: 360, 375, 380, 389, 394, 400, 407, 414, and 429m. No interaction effects were examined.

Finally, year was used as a three-value categorical variable. This variable measures the relative power of an hour's fishing in each of the different years. If the year effect explains changes in CPUE, in a way that is not explained by any of the other variables, then it may be measuring changes in stock size.

3.2.4 Results of the regression

The results of the regression are shown in Table 4. This shows the multiple regression coefficient $R^2 = SSR/SST$ for each combination of variables included. For example, with the vessel effect alone, the R^2 was 11%, with month effect alone the R^2 was 7.7%. The vessel effect had the largest R^2 so it was chosen to include in the model. Having included the vessel effect in the model, the month effect was the most important variable with an R^2 of 15.7% (for the model including both a vessel effect and a month effect), so month was selected as the second variable.

The most important variable was the vessel (Table 4). This means that some of the vessels had higher catch rates on average than others, possibly because of characteristics such as size of vessel, or type of gear, or efficiency of crew or skipper. The vessel effect was weakly correlated with the length of the vessel ($R^2 = 0.58$), but many other things would contribute to the vessel effect as well. The effect of month, the second predictor variable is shown in Figure 3. Catch rates are lowest in September and rise to a maximum in January.

The third most important variable was year. A possible index of stock size can be calculated from the regression coefficients as described above (Table 5). These yearly indices are shown in Figure 5.

The effect of time of day, the fourth predictor variable is shown in Figure 4. Catch rates are highest in the morning and fall off in the afternoon and evening. The fifth predictor variable selected was area. Since the five areas used in the analysis had been chosen on the basis of catch rate stratification, it is not surprising that the area variable was significant. Depth was also a significant variable, but its additional power to explain variance was so small that it was

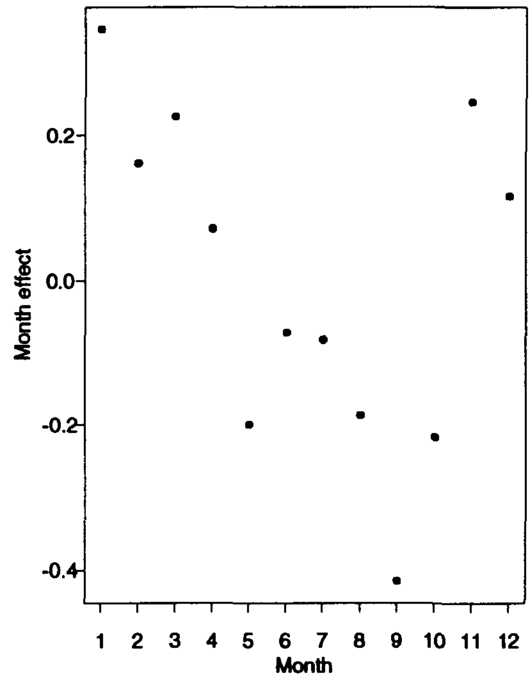

Figure 3: The effect of month on scampi catch rates (month effect is the regression coefficient of month in the regression model, and is logarithmic).

not included. As can be seen from Table 4, using the five most significant variables, 26% of the variability in log(catch per hour) could be explained.

These seasonal and diurnal changes in catch rates are reasonably smooth, have a plausible periodicity, and are consistent with experience in the fishery. The existence of such effects in this commercial CPUE data suggests that the data contain real information on factors affecting catch rates. It is therefore not unreasonable to assume that the year effect measures changes in stock size.

3.3 Production model

The age structured model often used in New Zealand stock assessments requires von Bertalanffy growth parameters, and length-weight, age at recruitment, and natural mortality rate parameters. These are not available for New Zealand scampi. Here a production model is used which requires fewer parameters.

The production model assumes that yield (surplus production) during a year is determined solely by the recruited stock biomass at the start of the year. The age structure of the stock, and the extent to which it can change production for a fixed stock biomass, is ignored in a

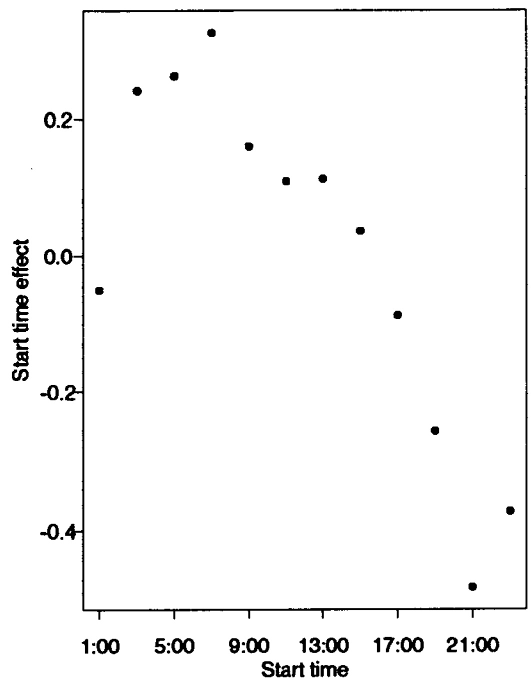

Figure 4: The effect of time of day on scampi catch rates. (time of day effect is the regression coefficient of the hour in the regression model, and is logarithmic)

Table 4: Multiple regression coefficient ($R^2 = SSR/SST$) of log(catch per hour) using stepwise choice of variables

Step Variable chosen	1	2	3	4	5	6
Vessel	11.0					
Month	7.7	15.7				
Year	6.2	14.3	19.7			
Time of day	4.7	14.2	19.4	23.2		
Area	7.4	13.9	18.0	21.1	24.7	
Depth	4.0	12.1	16.6	21.0	24.7	25.9
Improvement(of R^2)		4.7	4.0	3.5	1.5	1.2

Table 5: Relative year effects ($\hat{A}_j$) for regression against log(catch per hour)

Year	No. tows	Reg. coeff.	Var	Cov	$\hat{A}_j$	$s_{\hat{A}_j}$
1989	612	0.2865	0.038	0.038	1.00	0
1990	778	-0.0707	0.038	0.037	0.70	0.03
1991	1301	-0.2159	0.038	0.037	0.61	0.02

production model. In practice, the age structure effect is relatively small.

The change in the stock biomass during a year is the amount by which the catch exceeds or falls below the yield for that year. Necessarily, the yield is zero at virgin stock biomass, B_0. A yield versus stock biomass curve typically rises to a maximum between 0 and 1/2 B_0 as biomass declines from B_0. The location of the maximum depends mainly on the relationship between stock size and recruitment. If recruitment is strongly positively related to stock size, then the maximum will be near 1/2 B_0. If recruitment is nearly constant, then the maximum will be near 0. Scampi fecundity of a few hundred eggs per female suggests that there may be a strong positive relationship between stock size and recruitment. We have therefore assumed in the baseline model that the maximum production occurs at pB_0, where $p = 0.4$.

The productivity rate of a stock is correlated with and of a similar size to, its natural mortality rate. See the "Guide to Biological Reference Points" (in Annala 1992) for a discussion of the relationship between productivity and natural mortality. We define a parameter r as the productivity rate of the stock at its maximum production. Here we assume as a baseline case that $r = 0.3$ per year, the natural mortality rate quoted by Cryer (1992). This gives,

$$\begin{aligned} MSY &= prB_0 \\ &= 0.12B_0 \end{aligned}$$

We assume the production curve to be parabolic. This assumption was made by Schaefer (1954), but he assumed the maximum production to be at $1/2B_0$. In fact, model estimates are not very sensitive to the shape assumption (Gilbert 1992).

Our parabola is constrained to pass through (B_0,0) and to pass through its maximum at (pB_0,prB_0). This completely determines the coefficients of the quadratic production function. Simple algebra gives

$$Y_i = \frac{rp}{(1-p)^2}\left\{-\frac{1}{B_0}B_i^2 + 2pB_i + (1-2p)B_0\right\}$$

and stock biomass is updated by

$$B_{i+1} = B_i + Y_i - C_i$$

where Y_i is production for year i,
p is the proportion of B_0 where production is at the maximum,
r is the productivity where production is at the maximum,
B_i is the stock biomass at the start of year i,
C_i is the catch during year i.

In the baseline case this gives

$$Y_i = -\frac{0.33}{B_0}B_i^2 + 0.27B_i + 0.067B_0$$

The model was fitted assuming the relative year effects (Table 5) were proportional to stock biomass, using the maximum likelihood method, (*see* Gilbert 1992). This method is essentially identical to that commonly used for age structured models.

The baseline assumptions (A) and four other assumptions are given in Table 6. In models B and C the annual productivity at MSY is taken to be 0.1 and 0.8, respectively. In model D the MSY is assumed to occur at $0.2B_0$ ($r = 0.3$). The same assumptions as in the baseline case are made in model E, except that the shape of the production function is that of Pella & Tomlinson (1969) rather than a parabola.

4 Results

Estimates of virgin stock biomass, B_0, current stock biomass (at the start of the 1992–93 fishing year), B_{92}, current surplus production, CSP_{92}, and maximum sustainable yield, MSY, are given in Table 6.

Figure 5 shows the estimated stock biomass fitted to the CPUE indices for FMA 1 (for the baseline assumptions). Figure 6 shows the annual catches in relation to the concurrent surplus production. Figure 7 shows the production models for the five alternative assumptions.

5 Discussion

From the baseline assumptions, the scampi stock in FMA 1 has fallen fairly rapidly since the start of the fishery to somewhat above the size that will produce MSY. The present quota of

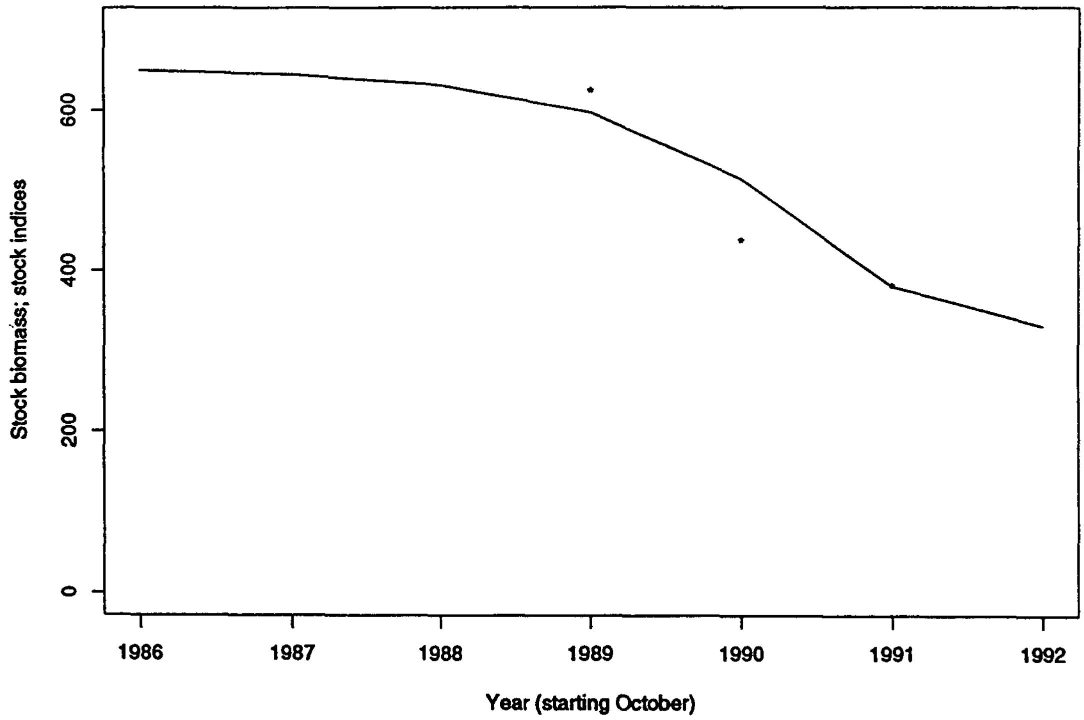

Figure 5: Estimated stock biomass (t) fitted to the CPUE indices (asterisks) for FMA 1 (for the baseline assumptions)

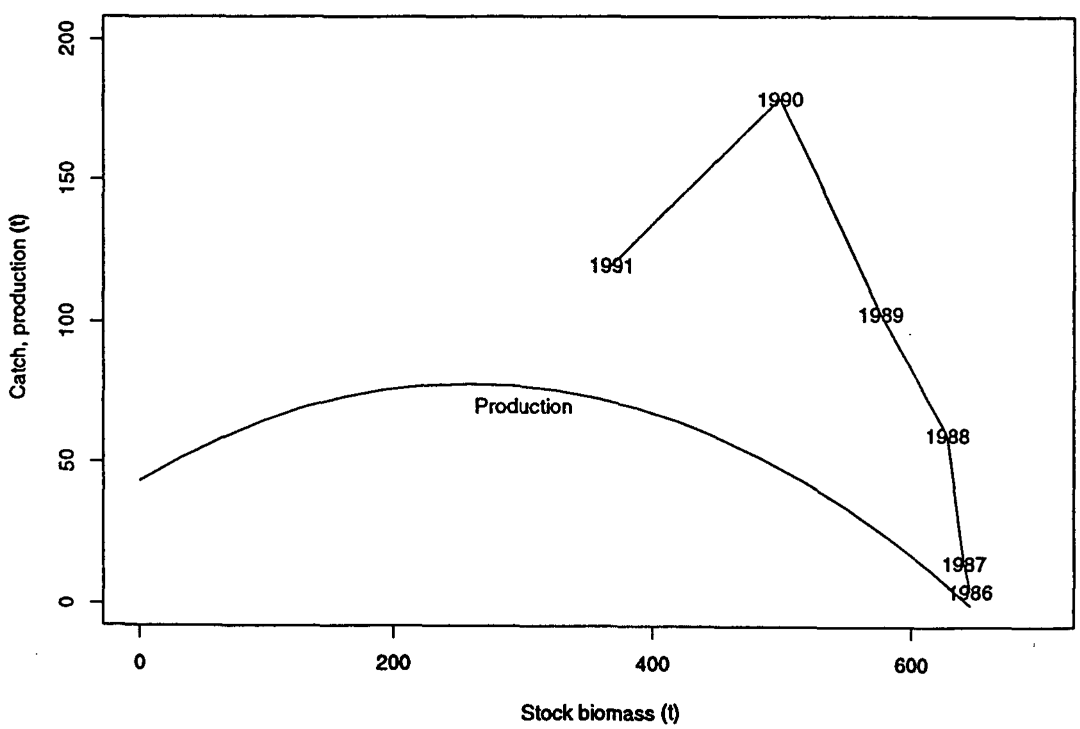

Figure 6: Annual catches in relation to the concurrent surplus production

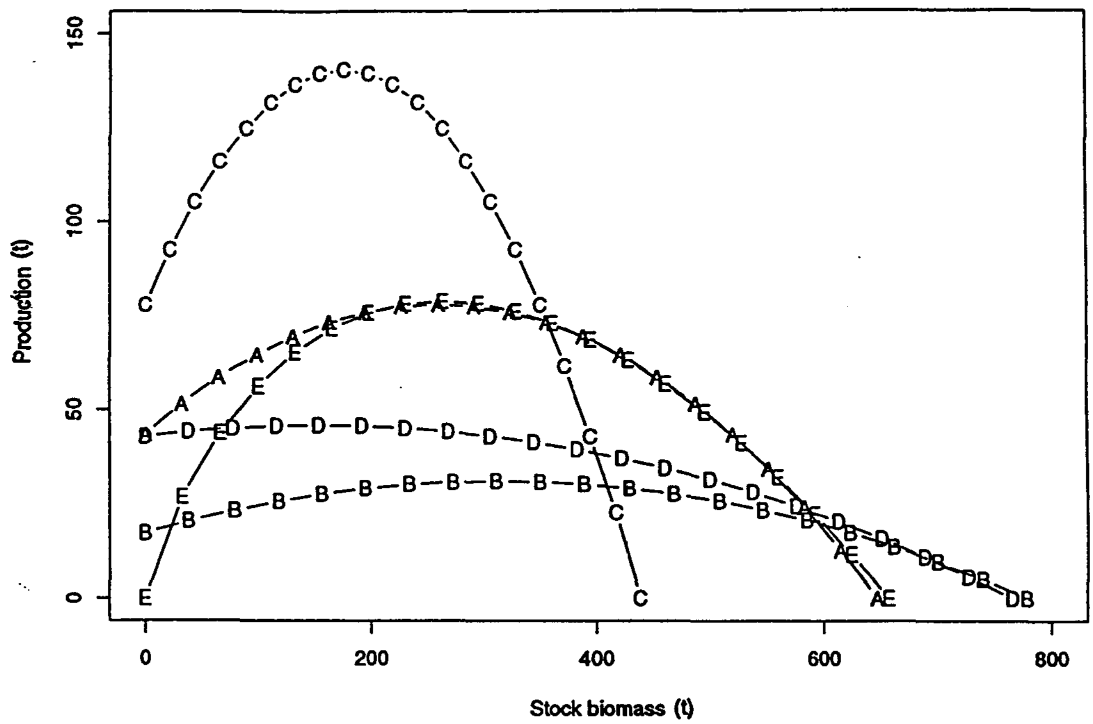

Figure 7: Production models for the five alternative assumptions, (see Table 6 for the letter designations).

120 t is a good deal higher than the estimated present surplus production and will therefore lead to continuing decline of the stock.

These analyses give somewhat lower estimates of virgin stock biomass than those obtained by Cryer (1992) for two reasons. Firstly, the CPUE indices obtained as year effects by the multivariate analysis show a steeper decline than the raw catch per hour data. Secondly, in a Leslie model the annual biomass decline is equal to the catch, whereas here it is the difference between catch and production. This produces a lesser absolute decline from the same virgin biomass. Hence, a lower virgin biomass will be estimated than in the Leslie model to fit the same relative steepness in the stock indices.

The true value of productivity at MSY is likely to be well inside the range of values assumed for models B and C. It should be noted that estimates of absolute production do not change in proportion to changes in productivity at MSY, particularly to increases in productivity. Nevertheless these alternative model assumptions give yields between 40% and 180% of the baseline estimates. Model D gives reduced production because the MSY is assumed to occur at $0.2B_0$ (i.e., it is assumed that recruitment declines less as stock biomass declines). Model E gives almost identical results to the baseline case because the production curves are almost concurrent except at low stock biomass.

The results of these analyses depend on the crucial assumption that the CPUE indices are proportional to stock biomass. Any factor not included in the model which has changed

Table 6: Estimates of stock biomass (t) and yield (t) for scampi (FMA 1) based on various production model assumptions fitted to CPUE indices. B_{92} is the stock biomass at the start of the 1992-93 fishing year. CSP_{92} is the production corresponding to B_{92}.

	Assumptions			Estimates			
Model	Location of maximum pB_0	Productivity at MSY r	MSY prB_0	B_0	B_{92}	CSP_{92}	MSY
Parabola (A) (baseline)	**$0.4B_0$**	**0.3**	**$0.12B_0$**	**647**	**$0.49B_0$**	**76**	**78**
Parabola (B)	$0.4B_0$	0.1	$0.04B_0$	779	$0.46B_0$	31	31
Parabola (C)	$0.4B_0$	0.8	$0.32B_0$	438	$0.58B_0$	127	140
Parabola (D)	$0.2B_0$	0.3	$0.06B_0$	794	$0.46B_0$	41	46
Pella & Tomlinson (E)	$0.4B_0$	0.3	$0.12B_0$	657	$0.49B_0$	77	79

systematically over the years could affect the indices. For example, the vessels may be more effective than in previous years because of improvements in gear, or skipper skill, and this might allow them to maintain catch rates while stock size was falling. Alternatively, any changes in procedure intended to improve quality at the expense of quantity (for example aiming for larger fish) could cause catch rates to fall faster than stock size.

Because scampi are relatively dispersed, the fishers are not able to search for and target concentrations of fish (as they can in orange roughy and hoki fisheries, for example). This means that catch rates will depend to a greater extent on the density of scampi over larger areas of their habitat than in more targeted fisheries. This makes it more likely that CPUE reflects stock size.

However, although there are no dense schools of scampi, there are likely to be patches of higher density. Movement may be too slow to maintain these patches as they are fished down, so that as vessels finish fishing the most desirable patches and move to less dense patches, catchability declines. This serial depletion would be difficult to detect in the data (despite the use of an area effect) if the good and bad patches were on scales comparable with the length of a tow. This would mean that the CPUE index was influenced by the frequency and density of patches as well as by stock size.

Catchability has been shown to change diurnally, seasonally and by area and it probably also changes from year to year. If this occurs then the estimated year effect from the regression will include not only the stock size index but also a catchability effect. The two would be inseparable.

If we had a long time series, any fluctuations in catchability from year to year would not affect the overall trend. However, a time series of only 3 years may show a trend which is simply a result of random variation. It is not until a longer series is obtained that we can assume that random variation will average itself out.

6 Acknowledgments

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