Fleet Structures Model Biological Feedback Phase

MAFF Commission
Technical Report No.304
February 1985

MAFF R&D Commission 1984/85
© Crown Copyright 1985

SEA FISH INDUSTRY AUTHORITY
Industrial Development Unit

FLEET STRUCTURES MODEL
BIOLOGICAL FEEDBACK PHASE

Crown Copyright 1985

Technical Report No. 263
MAFF Ref. JAA 16

February 1985

J. Shalliker
C. E. Tucker
J. A. Upfield

SEA FISH INDUSTRY AUTHORITY

Industrial Development Unit

Technical Report No. 263 February 1985

FLEET STRUCTURES MODEL BIOLOGICAL FEEDBACK PHASE

SUMMARY

The Fleet Structures Model* (FSM) is a predictive model under development by the Sea Fish Industry Authority. Its purpose is to simulate aspects of the structure and performance of the United Kingdom sea fishing fleet in order to make comparative assessments of fleet management policy scenarios.

Because of the inherent complexity of the model it has been developed in separate sections. The first of these to reach completion as a stand-alone computer model is the Biological Feedback phase. This predicts the effects of catch levels on fish stocks, and the consequent effect on catch rates as stocks rise or fall.

---

*Note:
The model is now to be called Fleet Structures Model. Various alternative titles have been used in the past such as Fleet Restructuring Model or Fleet Policy Management Appraisal Model. Occasionally in the text and figures these terms are used together with their abbreviations FRM and FPM respectively.

The Biological Feedback Phase is described in terms of its logical structure, its implementation in UCSD Pascal programs, and the definition and evaluation of parameters.

SEA FISH INDUSTRY AUTHORITY

Industrial Development Unit

Technical Report No. 263 February 1985

J. Shalliker
C. E. Tucker
J. A. Upfield

FLEET STRUCTURES MODEL

BIOLOGICAL FEEDBACK PHASE

Contents

Contents Contd.

SEA FISH INDUSTRY AUTHORITY
Industrial Development Unit

Technical Report No. 263 February 1985

FLEET STRUCTURES MODEL
BIOLOGICAL FEEDBACK PHASE

1 INTRODUCTION

This report describes one phase of the Fleet Structures Model (FSM), a computer model developed under MAFF Commission Reference JAA 16. The model simulates aspects of the structure and behaviour of the UK fishing fleet, to obtain as authentic as possible a prediction of the expected response of these to changes in economic parameters and various proposed fleet management policy scenarios.

Development of the model, previously referred to as the Fleet Restructuring Model (FRM) is described in

(i) SFIA Technical Report No. 192: UK Fleet Restructuring Model. Mathematical Aspects - September 1982. (Reference 11).

(ii) SFIA Technical Report No. 197: UK Fleet Restructuring Model. Progress Report - March 1983. (Reference 12)

(iii) SFIA Internal Report No. 1113: UK Fleet Restructuring Model. Vessel Group Structure - September 1983. (Reference 9)

(iv) SFIA Technical Memoranda JS1 - JS15:- May 1984 - January 1985. (Restricted circulation)

Thirteen regional implementations of FSM are required to investigate the whole fleet in detail, having the same logical structure, but differing in quantitative detail and data input. The regions are shown in Figure 4, Appendix I.

Each implementation incorporates a detailed simulation of the regional fleet, together with a less detailed simulation of the whole UK fleet to predict total UK landings. These in turn affect fish stocks and prices, having a feedback effect on the performance of the regional, as well as the UK, fleet.

Because of the complexity of FSM, sections of it have been developed separately, in manageable units which can be validated separately before integrating into the composite model.

The outline structure of FSM, described in detail in SFIA Technical Report 197 , is shown schematically below:

PII - Policy Input and Initialisation Phase		
Main Model	ALE phase	ACT - Activity section LND - Landings section ERN - Earnings section
	VGS	Vessel Group Structure Phase
	BF	Biological Feedback Phase
EFS - Expected Fleet Structure Phase		

The Policy Input and Initialisation phase (PII) is a "once and for all" input phase, to input values of parameters which:

(i) quantify the effects of fleet management policies (Policy Input)

(ii) are otherwise relevant to predictions of the fleet performance (Initialisation - i.e. parameters which are not affected by management policies)

The main model operates over a seven year predictive period, using one-year incremental steps to successively update the fleet structure, the state of fish stocks, etc.

The Expected Fleet Structure Phase (EFS) will output the predicted fleet structure after the seven year period, and transfer other pertinent data to a data file for interactive interrogation using a computer based statistics package.

The Biological Feedback (BF) phase is identical in each of the regional implementations of FSM, not only in its logical structure, but also in the values of parameters. It is the first phase to be fully defined, coded in UCSD Pascal, and validated by test running on the IDU Apple IIe system.

Minor modifications have been made to enable BF to run as a stand-alone computer model and produce a verifiable printed output.

2 BIOLOGICAL FEEDBACK PHASE

2.1 Function of the Biological Feedback Phase

BF determines the effect of each year's predicted catches on expected catch rates in successive years. The input information required by BF is:

(i) Initialisation values to describe the state of fish stocks, base year catches by UK and other countries, and parameters relevant to the behaviour of stocks of each species (from PII).

(ii) A quantification of expected changes in effort and/or catches by other countries (as a policy input in PII).

(iii) The total predicted UK catch of each stock of each species from each ground, for each predictive year, as an output from the Activity Landings and Earnings (ALE) phase.

The output information produced by BF in each predictive year is:

(i) The updated biomass estimate for each stock of each species (required by BF in the next predictive year).

(ii) The updated values of catch rate parameters, in response to change in biomasses, to be utilised in the ALE phase in the next predictive year.

2.2 Definition of Indices

The term "index" is used in FSM to denote a variable used to control repeated calculations. Predictive year, for example, is an index controlling calculations which are performed "... for each predictive year ...". The other primary indices in BF are ground, species and stock.

a) Grounds

Fishing effort and stock location are defined in terms of the grounds illustrated in Figure 5, Appendix II. These grounds are coded 1 to 15 (the FSM ground codes). The names, ICES division codes, and corresponding FSM codes are listed in Table 1, Appendix II.

b) Species

The codes for twenty six designated species, and the list of main constituents in the categories "other fin fish" and "other shellfish" are defined in Tables 2.1, 2.2, 2.3 in Appendix III. It is assumed that, in practice, small landings of species named in Table 2.1 will frequently be assigned to the "miscellaneous and unsorted" catches in landings data.

c) Stocks

The fish of each species in FSM are subdivided into separate and distinct units of population referred to as stocks. Each stock occupies one or more grounds, and not more than one stock of a species occupies each given ground. A general guiding principle in defining FSM stocks is that exploitation patterns for one stock should not significantly affect catch rates of other stocks of the same species in the medium term; however heavy exploitation in one part of a stock will be compensated by redistribution of the remainder in the short term. It should however be noted that FSM does not rigidly adhere to the biologist's concept of a stock, either because of the necessary concurrence of stock and ICES division boundaries, or because the combining of apparently separate stocks would improve the run-time efficiency without loss of discriminatory performance of the BF phase.

Table 3, Appendix IV contains:

(i) The Stock Identification Element array which indicates for each species whether FSM defines a stock on each ground, and, if so, identifying it with a stock code number.

(ii) The Number of defined stocks for each species.

The criteria employed, the information sources used and the summarised stock definition decisions are also listed in Appendix IV.

2.3 <u>Biological Feedback Phase - Outline Structure</u>

The outline algorithm for BF is presented below:

In each predictive year:

<table>
<tr><td rowspan="5">for each species</td><td colspan="2">Input the total UK catch from each ground (calculated in ALE phase) and calculate the total UK catch from each stock by summing over the appropriate grounds</td></tr>
<tr><td rowspan="3">for each stock of each species</td><td>Calculate the "global" (UK + other countries') catch, taking account of the policy input governing other countries' catches</td></tr>
<tr><td>Calculate the expected recruitment as a function of end-of-previous/start -of-current year biomass</td></tr>
<tr><td>Use start-of-year biomass, global catch and recruitment to obtain next start-of-year biomass</td></tr>
<tr><td>for each ground</td><td>Update catch rate multiplier (to be used in next year's ALE phase) by taking account of change in total biomass of appropriate stock</td></tr>
</table>

The detailed BF algorithm is included with the program documentation in Appendix VII.

2.4 Other Countries' Catches Policy

The total catch of each stock from each ground must be controlled by a policy input, since it cannot be predicted within FSM. It is quantified in an interactive policy input routine OCP in the PII phase, which offers four "status quo" scenarios, as follows:

(i) The ratio of other countries' catch from each stock to the corresponding UK catch is kept constant ("fair shares" on our major stocks but possibly at the expense of the stocks), unless the UK catch is low, in which case other countries' catch changes in response to change in biomass so as to simulate constant effort.

(ii) Other countries' catch from each stock changes in response to change in biomass so as to simulate constant effort (no expansion/contraction of other fleets, as UK fleet changes).

(iii) The sum of other countries' catch from each stock plus corresponding UK catch is maintained at constant global catch (other countries gain if UK fleet sector declines, but our expansion is at others' expense).

(iv) Other countries' catch from each stock is kept constant (other countries adjust effort in response to changes in catch rates to match existing quotas).

Instead of accepting default values for a status quo option, the appropriate ratios (in (i)), quantification of effort (in (i) and (ii)) and catches (in (iii) and (iv)) for each stock can be adjusted as a policy input.

Examples of these adjustments are increases of 10% on the expected global catches for selected stocks, under option (iii), and 5% reduction in other countries' catch as a proportion of selected biomasses to reduce effort by other countries' fleets, under option (ii).

The algorithm for OCP is included with the program documentation in Appendix VII.

3 CALCULATIONS IN THE BIOLOGICAL FEEDBACK PHASE

3.1 Data Input

In the full implementation of FSM the transfer of data quantifying the Other Countries' Catch Policy and the values of other parameters relevant to BF should occur in the PII phase. These procedures are included in BF for development, testing and demonstration purposes.

3.2 Total UK Catches from Stocks

In each predictive year and for each stock of each species BF sums the total expected UK catch in tonnes live weight, over each ground holding that stock, in order to determine the total UK catch from that stock, thus:

$$TCK_{fk} = \sum_{g} TCFG_{gf} \qquad \ldots(1)$$

with $k = KIE_{gf}$, subject to $k \neq o$

where:

TCK_{fk} is total UK catch from stock k of species f, for each year,

$TCFG_{gf}$ is total UK catch of species f from ground g, for each year,

KIE_{gf} is the stock identification element for species f on ground g.

In the full FSM implementation $TCFG_{gf}$ is calculated in the ALE phase.

An illustrative example is provided below:

$$KIE_{g3} = 2 \text{ for } g = 4,5,6 \qquad \ldots(2)$$

indicates that saithe (species 3) on grounds 4,5 and 6 (North Sea) are assigned to the 2nd stock of that species.

$$TCK_{32} = TCFG_{43} + TCFG_{53} + TCFG_{63} \qquad \ldots(3)$$

indicates that the total UK catch of stock 2 of species 3 (North Sea Saithe) is obtained by summing the UK catches of saithe from grounds 4,5 and 6.

3.3 Global Catches from Stocks

After calculating the expected UK catch from each stock, the global catch (total mortality due to fishing effort) is obtained by adding the corresponding catch by other countries, determined by policy input.

The selected option and the appropriate ratios or catches are held in the variable OPT and the Other Countries' Catch Policy Array, $OCPA_{fk}$, (calculated in PII).

If Option 1 is selected, then those stocks for which base year UK catches are low are identified in the Boolean array LOW_{fk}, again as part of the policy input routine, thus:

$$LOW_{fk} = \text{TRUE if (and only if)} \begin{cases} ITCK_{fk} < IOCK_{fk} \times LTR \\ \text{or } ITCK_{fk} = 0 \end{cases} \qquad \ldots(4)$$

where

$ITCK_{fk}$ is initial (base year) total UK catch from stock,

$IOCK_{fk}$ is corresponding other countries' catch in base year,

LTR is "low-catch test" ratio, arbitrarily assigned the value 0.1.

The $OCPA_{fk}$ array values are calculated in the policy input routine as follows:

If OPT = 1, then

$$OCPA_{fk} = \frac{100+PCCfk}{100} \times \frac{IOCKfk}{ITCKfk} \quad \text{when } LOW_{fk} = \text{FALSE}$$

$$OCPA_{fk} = \frac{100+PCCfk}{100} \times IOCKfk \quad \text{when } LOW_{fk} = \text{TRUE} \qquad ...(5)$$

If OPT = 2, then

$$OCPA_{fk} = \frac{100+PCCfk}{100} \times \frac{IOCKfk}{IBIOfk} \qquad ...(6)$$

If OPT = 3, then

$$OCPA_{fk} = \frac{100+PCCfk}{100} \times (lTCK_{fk} + IOCK_{fk}) \qquad ...(7)$$

If OPT = 4, then

$$OCPA_{fk} = \frac{100+PCCfk}{100} \times IOCK_{fk} \qquad ...(8)$$

where:

PCC_{fk} is percentage change imposed by policy input on the status quo value of $OCPA_{fk}$,
$IOCK_{fk}$ is initial other countries' catch from stock,
$ITCK_{fk}$ is initial total UK catch from stock,
$IBIO_{fk}$ is initial exploited biomass estimate for stock.

In each predictive year, BF determines the array of other countries' catches from each stock, OCK_{fk}, thus:

If OPT = 1, then

$$\begin{cases} OCK_{fk} = OCPA_{fk} \times TCK_{fk} & \text{if } LOW_{fk} = \text{FALSE} \\ OCK_{fk} = OCPA_{fk} \times CRM_{fk} & \text{if } LOW_{fk} = \text{TRUE} \end{cases} \quad \ldots(9)$$

If OPT = 2, then

$$OCK_{fk} = OCPA_{fk} \times CRM_{fk} \quad \ldots(10)$$

If OPT = 3, then

$$OCK_{fk} = OCPA_{fk} - TCK_{fk} \quad \ldots(11)$$

If OPT = 4, then

$$OCK_{fk} = OCPA_{fk} \quad \ldots(12)$$

where:

TCK_{fk} is expected total UK catch from stock in each year,

OCK_{fk} is corresponding other countries' catch in each year,

BIO_{fk} is exploited biomass estimate at the start of each year.

CRM_{FK} is the catch rate multiplier for a stock, which compares expected daily catch rate with base year daily catch rates as biomass changes.

The global catch from each stock of each species, GCK_{fk}, is then obtained by adding the corresponding UK and other countries' catches, thus:

$$GCK_{fk} = TCK_{fk} + OCK_{fk} \quad \ldots(13)$$

3.4 Nett Production

The increase in exploited biomass of a stock during a year can be expressed as:

$$B_{i+1} - B_i = P_i - F_i \qquad \ldots(14)$$

where:

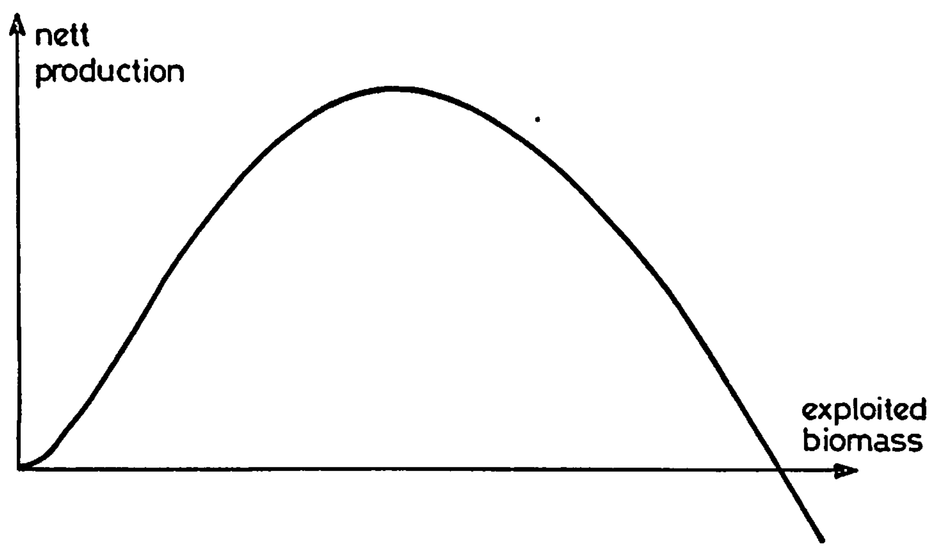
B_i is exploited biomass at start of year i

F_i is mortality due to fishing effort

P_i is nett production in year i, subsuming recruitment to, and growth and natural mortality of, the exploited biomass

The shape of the nett production function is assumed to be roughly parabolic, but with zero gradient instantaneously at the origin, as illustrated below:

Figure 1



This is implemented in BF as follows:

$$PRD_{fk} = 2.244 \times PRP_{fk} \times (1.444\ L^2 - L^3)$$

$$\text{with } L = \ln(1 + 1.618 \times BIO_{fk}/PRQ_{fk}) \qquad \ldots(15)$$

where,

PRD_{fk} is nett production in stock k of species f in each year,

BIO_{fk} is exploited biomass of stock k of species f at the start of each year,

PRP_{fk} and PRQ_{fk} are production rate parameters for stock k of species f.

The function is chosen to describe features of the behaviour of stocks observed in data analysis, while conforming to the concepts of maximum sustainable yield (at the maximum point) and virgin biomass (where expected nett production returns to zero).

The production rate parameters correspond to the coordinates of the maximum point on the production curve. However the values should not be seen as prescriptive; they ensure that for each stock a "sensibly shaped" curve passes through the point representing time-weighted mean biomass and production, with an appropriate gradient at that point.

Knife-edge recruitment is assumed (with no age-structure or stochastic recruitment in the model). A further simplifying assumption is that nett production is a function of start of year biomass, but recruitment occurs after depletion of the biomass through the main fishing effort.

A fuller discussion of the choice of nett production function, its mathematical development and the determination of parameters is found in Appendix V.

3.5 Updating the Biomass

Biomass estimates for each stock are updated for each predictive year as follows:

$$\text{new } BIO_{fk} = BIO_{fk} - GCK_{fk} + PRD_{fk} \qquad ...(16)$$

where:

BIO_{fk} is start of year exploited biomass of stock k of species f

GCK_{fk} is global catch (in live-weight tonnes)

PRD_{fk} is nett production

A non-negativity condition is imposed:

$$\text{If new } BIO_{fk} < 0 \text{ then new } BIO_{fk} = 0 \qquad ...(17)$$

If the adjusted global catches exceeds exploited biomass, but recruitment is sufficient to make the new biomass estimate positive, then this can be interpreted as a significant immature fish content in the year's catch. This appears to be an authentic interpretation of the prosecution of an over-exploited fishery.

e.g. If exploited biomass, catch and production are predicted to be 10, 12, and 5 units respectively then the catch is assumed to contain at least 2 units from the immature stock to make up the shortfall (12 minus 10). The exploited stock, with recruitment correspondingly reduced, will have a new biomass equal to 3 units.

If predicted catches exceed the sum of biomass plus production, then the catch level is accepted for that predictive year, but the stock assumed driven to extinction for successive years.

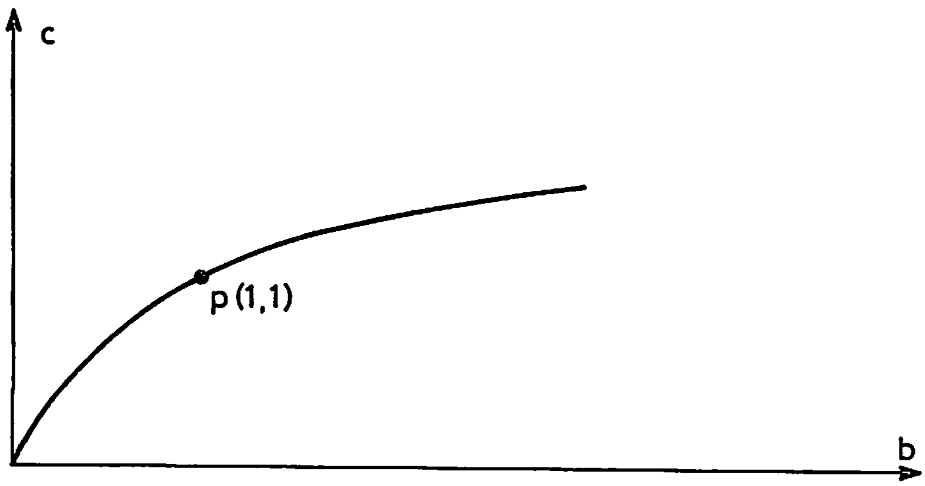
e.g. If biomass, catch and production are predicted to be 10, 17 and 5 units respectively, then FSM will have accepted the 17 units computed in the ALE phase prior to updating the biomass. However the biomass, and hence catch rate, will be zero in subsequent predictive years.

3.6 Updating the Catch Rates

Catch rates (per unit of fishing effort) for each species on each ground are adjusted in the ALE phase using a catch rate multiplier array CRM_{gf}. This latter is updated in BF in response to change in biomass.

The variation of catch rate with biomass is assumed to be a compromise between constant catch rate and density proportionate catch rate, with a characteristic shape as illustrated in Fig. 2 below.

Figure 2



If catch rate ratio, c =
(catch rate)/(base year catch rate)

and biomass ratio, b =
(biomass)/(base year biomass)

then the function should pass through both the origin and the point P(b,c) = (1,1), which represents base year conditions. Also there should be a theoretical horizontal asymptote as biomass increases without limit, representing physical limitations on catch rates (e.g. hold size).

The gradient at P should be species/stock dependent. Typically many demersal species would have catch rates close to density-proportionate, whereas pelagic species would typically have catch rates closer to constant than density-proportionate. The curves for the former would therefore be steeper than for the latter at point P. In the case of a collapsing pelagic fish stock however, the status quo position, P, would have moved into a more density-proportionate section of the appropriate curve, towards the origin.

The catch rate function is implemented in BF as:

$$CRM_{gf} = \frac{(BIOfk/IBIOfk)}{CRPfk + (1-CRPfk)x(BIOfk/IBIOfk)} \quad ...(18)$$

with k = KIEgf

where:

CRM_{gf} is catch rate multiplier for species f on ground g in each year,

BIO_{fk} is exploited biomass of stock k of species f in each year,

$IBIO_{fk}$ is initial (base year) biomass,

CRP_{fk} is catch rate parameter appropriate to stock k of species f,

KIE_{gf} is stock identification element for species f on ground g.

This function has the desirable properties listed above, with the catch rate parameter representing the slope of the curve at point p.

A further discussion of the catch rate function and the list of catch rate parameter values are found in Appendix VI.

3.7 Updating Catches (Assuming Constant UK Effort)

In the full FSM implementation, BF requires, as an input, the expected total UK catch from each species on each ground, calculated in ALE. A procedure has been inserted in the current version of BF which assumes that UK fishing effort is constant, and enables UK catches in subsequent years to be updated using the revised catch rate multiplier, thus:

$$\text{new } TCFG_{gf} = ITCFG_{gf} \times CRM_{gf} \qquad \ldots(19)$$

where:

$TCFG_{gf}$ is total UK catch of species f from ground g in each year

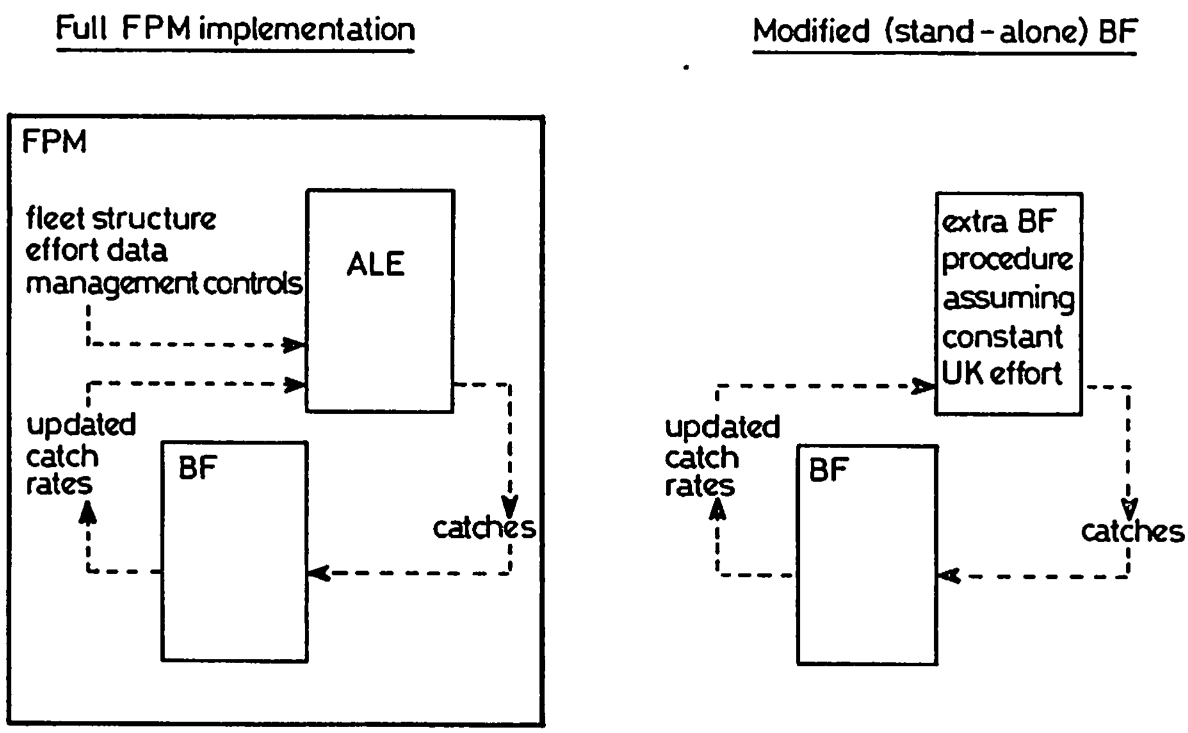
$ITCFG_{gf}$ is initial (base year) total UK catch,

CRM_{gf} is the catch rate multiplier, for each year.

This modification of BF enables the model to operate independently of other phases of FSM, for test and demonstration purposes.

Schematically this aspect of the full FSM implementation, and the modified form of BF are shown below.

Figure 3


Full FPM implementation
Modified (stand-alone) BF
FPM
fleet structure
effort data
management controls
ALE
updated
catch
rates
BF
catches
extra BF
procedure
assuming
constant
UK effort
updated
catch
rates
BF
catches

4 FURTHER DEVELOPMENT OF THE BIOLOGICAL FEEDBACK PHASE

a) Stand-alone BF Development

BF can be developed as an independent model specifically to assess the effects of input-specified changes in future UK fishing effort (e.g. by quota control or encouraging fleet growth) on stocks. The consequent feedback effect on catch rates can then be used as an index of profitability.

b) Catch Rate Model

Further work on the catch rate model, which currently uses subjectively assessed parameters,offers potential improved authenticity of response in this area of the model.

c) Other Countries' Catch Policy

The current proposed structure offers four policy input options to specify the method of estimating other countries' catches. One option is then applied to all stocks of all species. An expansion of the OCP input routine and concommitant modification of the BF structure would permit the independent selection of policy option for each species, or even each stock of each species.

An alternative modification of the OCP/BF structure could be employed to allow the changes in other countries' catches from stocks of each species to vary with predictive year.

d) Interspecies Effects

The current proposed structure comprises a number of independent single-species models running in parallel. There is scope for improving BF by incorporating the expected change in recruitment to the stock of each species on a ground as a result of changes in biomass of other species on the ground (thus allowing for interspecies predation and competition for food).

e) Age-structured Production Model

The current proposed structure assumes knife-edge recruitment and nett production varies only with start of year biomass. An investigation of the dependance of nett production on earlier-year biomasses (using time-series analysis) may indicate potential improvements, to be made by storing the arrays of biomasses for years i, i-1, i-2,... to be used in calculating nett production in year i. Other (cohort-structured) approaches to this modelling may offer valuable improvement.

f) Discard Rates

There is insufficient data to model discard rates although it is likely that the difference between nominal catch and mortality due to fishing effort is significant for some species, especially mackerel. A notional discard rate could be subsumed in the live weight adjustment factor which converts nett landed weight from the ALE phase to live weight. The imposition of quotas may induce higher discard rates, especially in a mixed fishery, but this effect would have to be modelled in the ALE phase.

5 REFERENCES

(in alphabetic order by author)

1 Beverton R J H and Holt S J 1957
On the dynamics of exploited fish popuations.
Fish. Invest., MAFF.

2 Cushing D H 1981
Fisheries biology: a study in population dynamics.
Univ. Winsconsin Press.

3 ICES Bulletin Statistiques 1977,....1982

4 Kimura D K, Balsinger J W and Ito D H 1981
Generalised stock reduction analysis,
Can. Journ. Fish. Aquat. Sci. Vol. 41, pp

5 MAFF Atlas of the seas around the British Isles 1981

6 Pella J J and Tomlinson P K 1969
A generalised stock production model.
Bull. Inter-Am. Tropical Tuna Commission.
Vol. 13, pp 421-458.

7 Ricker W E 1954
Stock and recruitment.
Journ. Fish. Res. Bd. Canada. Vol 11(5).

8 Schaefer M B 1954
Some aspects of the dynamics of populations important to the commercial marine fisheries.
Bull. Inter-Am. Tropical Tuna Comm. Vol 1, pp 27-56.

9 Shalliker J A 1983
Fleet Restructuring Model: Vessel Group Structure.
SFIA Internal Report 1113.

10 Shepherd J G 1982
A family of general production curves for exploited populations.
Math. Bio-Sci. Mag. Vol 59, pp 77-93.

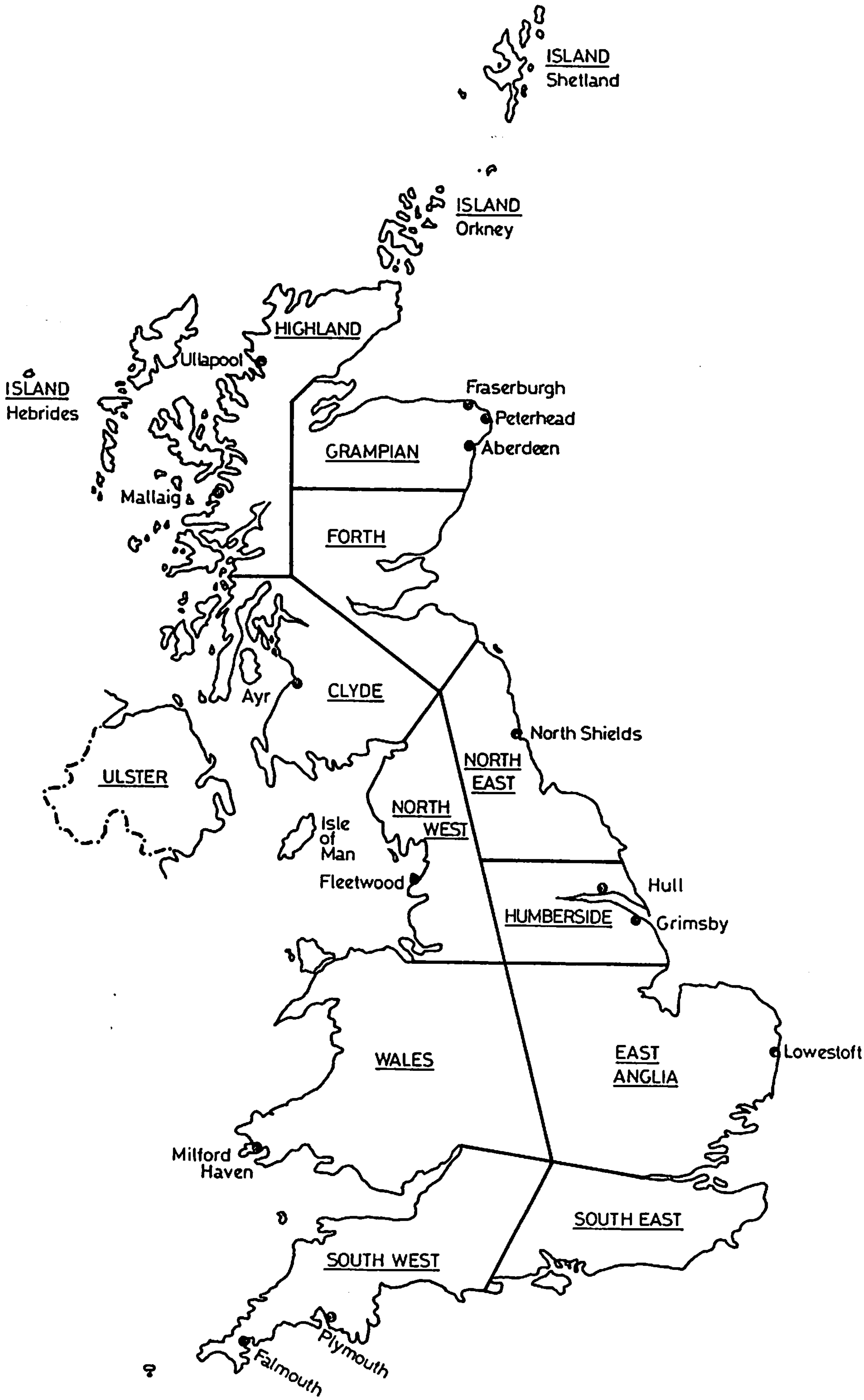
11 Tucker C E and Brugge W J
Fleet Restructuring Model: Mathematical Aspects.
SFIA Technical Report 192.

12 Tucker C E and Brugge W J
Fleet Restructuring Model: Progress Report.
SFIA Technical Report 197.

13 Wheeler A 1969
The fishes of the British Isles and North-West Europe. MacMillan.

14 Wheeler A 1978
Key to the fishes of Northern Europe. Clowes.

APPENDIX 1



FLEET MANAGEMENT POLICY APPRAISAL MODEL REGIONS
Showing Sub-Regions and Major Ports

Fig.4 Appendix I

APPENDIX II

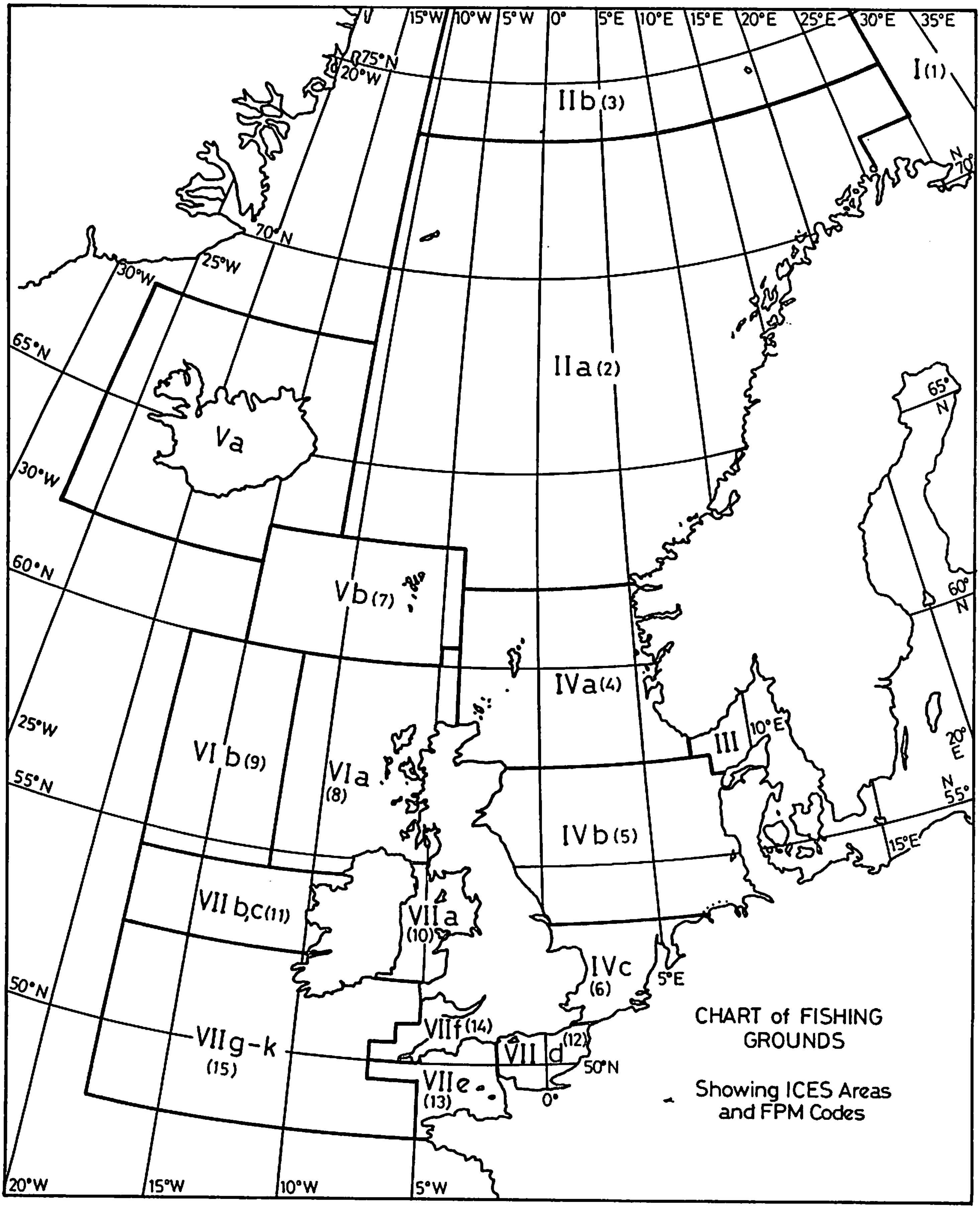


CHART of FISHING GROUNDS
Showing ICES Areas and FPM Codes
I (1)
IIb (3)
IIa (2)
Va
Vb (7)
IVa (4)
III
VI b (9)
VIa (8)
IVb (5)
VII b,c (11)
VIIa (10)
IVc (6)
VIIf (14)
VII d (12)
VIIg-k (15)
VIIe (13)
15°W
10°W
5°W
0°
5°E
10°E
15°E
20°E
25°E
30°E
35°E
75°N
20°W
70°N
25°W
30°W
65°N
60°N
55°N
50°N
65° N
60° N
N 55°
N 70°
10°E
20° E
15°E
5°E
50°N
0°
20°W
15°W
10°W
5°W

TABLE 1

LIST OF GROUNDS AND FRM CODES

Ground	ICES Division	FRM Code
Barents Sea	I	1
Norway Coast	IIa	2
Spitzbergen	IIb	3
Northern North Sea	IVa	4
Middle North Sea	IVb	5
Southern North Sea	IVc	6
Faroe	Vb	7
West of Scotland	VIa	8
Rockall	VIb	9
Irish Sea	VIa	10
West of Ireland }	VIIb }	11*
Porcupine Bank }	VIIc }	
English Channel East	VIId	12
English Channel West	VIIe	13
Bristol Channel	VIIf	14
South East of Ireland }	VIIg }	
Little Sole Bank }	VIIh }	15*
Great Sole Bank }	VIIj }	
West of Great Sole Bank }	VIIk }	
Ground(s) not elsewhere included	-	16**

* ICES "Bulletins Statistiques" give combined catch statistics for (VIIb+VIIc) and (VIIg+VIIh+VIIj+VIIk)

** Enables model to include catches from the Iceland Ground (ICES division Va), Skaggerat-Kattegat (IIIa) or Bay of Biscay (VIII) as may be appropriate for particular regional implementations.

APPENDIX III

TABLE 2.1

LIST OF SPECIES, LABELS AND FRM CODES

Species	Species Label	FRM Species Code
Cod	cod	1
Haddock	had	2
Saithe	sth	3
Whiting	wtg	4
Hake	hke	5
Blue Whiting	blw	6
Norway Pout	npt	7
Sandeels	sde	8
Monkfish	mnk	9
Plaice	plc	10
Lemon Sole	lsl	11
Dover Sole	sol	12
Spur Dog	dog	13
Skates & Rays	ray	14
Herring	her	15
Sprat	spt	16
Mackerel	mac	17
Scad	scd	18
Pilchard	pil	19
Other Finfish	off	20
Shrimp	shr	21
Nephrop	nph	22
Lobster	lob	23
Crab	crb	24
Scallop	scl	25
Queen	qun	26
Squid	sqd	27
Other Shellfish	osh	28

TABLE 2.2

LIST OF MAIN SPECIES INCLUDED IN THE CLASSIFICATION "OTHER FINFISH" CODE = 20, WITH 1982 UK LANDING IN K TONNES

Species	Landings
Ling	4.0
Megrim	2.4
Dab	1.6
Witch	1.6
Dogfish (N.E.I.)	1.6
Catfish	1.2
Conger	1.0
Gurnard	0.9
Turbot	0.6
Flounder	0.4
Redfish	0.4
Remnants	4.0
TOTAL	**19.7**

TABLE 2.3

LIST OF MAIN SPECIES INCLUDED IN THE CLASSIFICATION "OTHER SHELLFISH" CODE = 28, WITH 1982 UK LANDINGS IN K TONNES

Cockle	8.0
Mussel	4.4
Periwinkle	2.7
Whelk	1.6
Oyster	0.5
Remnants	2.6
TOTAL	19.8

APPENDIX IV

Table 3

Stock Identification Element, KIE(g,f)=k
and Number of Stocks, NKF(f)

ICES div		I	II a	II b	IV a	IV b	IV c	V b	VI a	VI b	VII a	VII bc	VII d	VII e	VII f	VII gk	NEI	
	g=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NKF(f)
	f=																	
cod	1	1	1	1	2	2	2	3	4	5	6	7	8	8	7	7	0	8
had	2	1	1	1	2	2	2	3	4	5	6	7	8	8	7	7	0	8
sth	3	1	1	1	2	2	2	3	4	5	6	7	7	7	7	7	0	7
wtg	4	1	1	1	2	2	2	1	3	4	5	4	6	6	4	4	0	6
hke	5	0	0	0	1	1	0	0	1	1	1	1	1	1	1	1	1*	1
blw	6	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0	1
npt	7	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1
sdl	8	0	0	0	1	1	0	0	2	0	0	0	0	0	0	0	0	2
mnk	9	0	0	0	1	1	1	0	2	0	2	2	3	3	3	3	0	3
plc	10	0	0	0	1	1	1	0	2	0	3	0	4	4	5	5	0	5
lsl	11	0	0	0	1	1	1	0	2	0	3	0	4	4	3	3	0	4
sol	12	0	0	0	0	1	1	0	2	0	2	0	0	3	4	5	0	5
dog	13	0	0	0	1	1	1	0	2	0	2	3	3	3	3	3	0	3
ray	14	0	0	0	1	1	2	0	3	3	4	4	3	3	4	4	0	4
her	15	0	0	0	1	1	2	0	3	0	4	3	2	2	5	5	0	5
spt	16	0	0	0	1	1	1	0	2	0	3	3	4	4	5	5	0	5
mac	17	0	1	0	1	1	2	2	2	0	2	2	2	2	2	2	2*	2
scd	18	0	0	0	1	1	1	0	1	0	1	1	1	1	1	1	0	1
pil	19	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1
off	20	1	1	1	2	2	2	3	3	3	4	5	6	6	6	5	0	6
shr	21	0	0	0	1	2	0	0	0	0	3	0	4	0	0	5	0	5
nph	22	0	0	0	1	2	0	0	3	0	4	0	0	0	0	0	0	4
lob	23	0	0	0	1	2	3	0	4	0	5	0	6	7	8	9	0	9
crb	24	0	0	0	1	2	3	0	4	0	5	0	6	7	8	9	0	9
scl	25	0	0	0	1	1	0	0	2	0	3	0	4	5	6	7	0	7
qun	26	0	0	0	1	0	0	0	2	0	3	0	0	4	0	0	0	4
sqd	27	0	0	0	1	1	1	2	2	2	3	0	4	4	3	3	0	4
osh	28	0	0	0	1	2	3	0	4	0	5	0	6	7	8	0	0	8

* significant catch from VIII

The following preconditions apply, in defining stocks within FPM:

(i) **Boundaries** - these must all coincide with the ICES division boundaries used to define ground in FPM.

(ii) **Exclusivity** - the catch of a species from each ground is considered by FPM to have come from one stock only.

(iii) **Contiguity** - grounds occupied by a common stock are always adjacent (relevant to migratory species).

The list of information sources used in deciding stock definitions is presented below:

TABLE 4

Source	Description	Comment
1	"MAFF times series". For major stocks these include catch, total biomass and spawning stock biomass over varying periods. For other stocks catch data only are available (Table 4 below)	Supplied by MAFF abstracts from ICES Working Groups (unpublished) Recruitment estimates can be inferred from full times series data
2	European Commission CFP list of unit stocks for quota management, etc. as of February 1985 (Table 4.2 below)	Do not necessarily coincide with ICES division/FPM ground boundaries
3	ICES "Bulletin Statistique" landings data 1977-82 Table 5 giving breakdown of catches by captor nation, species and grounds (3)	
4	MAFF Atlas of the Seas around the British Isles (1981) (5)	esp. bathimetric chart, and charts of major fisheries
5	Alwyne Wheeler: Key to the Fishes of Northern Europe (W. Clowes Ltd. 1978) (14)	Finfish only
6.	Alwyne Wheeler: Fishes of the British Isles and N.W. Europe (MacMillan 1968) (13)	Incl. Habits, spawning grounds, etc.
7	D. H. Cushing: Fisheries Biology (Univ Winsconsin Press 1981) (2)	esp Ch2 - The Idea of a Unit Stock

TABLE 4.1

STOCKS DEFINED IN MAFF ABSTRACTS FROM

ICES WORKING GROUP TIME SERIES DATA (SOURCE 1)

Type 1 Biomass estimates and catches available
Type 1* Biomass estimates only (catch data can be found elsewhere)
Type 2 Catches only available

Type	Stock	
1	North East Arctic	Cod
1	North Sea	Cod
1	Faroe Plateau	Cod
1	West Scotland	Cod
2	Rockall	Cod
1	Irish Sea	Cod
2	W.Ireland and Sole Bank	Cod
2	English Channel	Cod
1	Celtic Sea	Cod
1	North East Arctic	Haddock
1	North Sea	Haddock
1	Faroe	Haddock
1	West Scotland	Haddock
2	Rockall	Haddock
2	W.Ireland and Sole Bank	Haddock
2	English Channel	Haddock
1	North East Arctic	Saithe
1	North Sea	Saithe
1	Faroe	Saithe
1	West Scotland	Saithe
1	North Sea	Whiting
1	West Scotland	Whiting
2	Rockall	Whiting
1	Irish Sea	Whiting
2	N.Ireland and Sole Bank	Whiting
2	English Channel	Whiting
2	Celtic Sea	Whiting
1	North Sea	Plaice
1	Irish Sea	Plaice
1*	Irish Sea	Plaice (Males)
1*	Irish Sea	Plaice (Females)
1*	Celtic Sea	Plaice (Males)
1*	Celtic Sea	Plaice (Females)
1	North Sea	Sole
1	Irish Sea	Sole
1*	Irish Sea	Sole (Females)
1	Eastern English Channel	Sole

TABLE 4.1 CONTD.

Type	Stock	
1	Western English Channel	Sole
1	Celtic Sea	Sole
1	Celtic Sea	Sole (Males)
1	Celtic Sea	Sole (Females)
1	North Sea	Mackerel
1	Western	Mackerel
1	North Sea	Sprat
2	(IV, VI)	Scad
1	(IVa, VI, VII, VIIIa)	Hake
1	(Danish Areas 1-4, 5ab, 6)	Norway Pout
1	Northern	Blue Whiting
1	Total North Sea	Sandeel
1	Shetland	Sandeel
1	Northern North Sea	Sandeel
1	Southern North Sea	Sandeel
1	Total North Sea	Herring
1	Northern North Sea	Herring
1	Central North Sea	Herring
1	Southern North Sea	Herring
1	West Scotland (i)	Herring
1	West Scotland (ii)	Herring
1	North Irish Sea (Manx)	Herring
1	North Irish Sea (Mourne)	Herring
1	Celtic Sea (i)	Herring
1	Celtic Sea (ii)	Herring
1	(Division VIIj)	Herring

Comment:
The above stock definitions are used in preference to criterion B (in Table 5 below) in order to maximise biological data in producing a viable model.

APPENDIX IV

TABLE 4.2

STOCKS FOR WHICH THE UK HAS A NON-EC QUOTA

(EXCL. CANADIAN WATERS) OR FISHES TO AN EC ALLOCATION

Species	EC and Joint Stocks	Non-EC Waters
Cod	IV+IIa(EC) VI+Vb(EC) VIIa VII(Ex VIIa)+VIII(EC)	I(Nor)+II(Nor) Vb(excl.EC) V(Gre)+XIV(Gre) NAFO 1 (Gre)
Haddock	IV+IIa(EC) VI+Vb(EC) VII+VII(EC)	I(Nor)+IIa(Nor) Vb(Far)
Saithe	IV+IIa(EC)+IIIa+IIIbdc (EC) VI+Vb(EC) VII+VIII(EC)	I(Nor)+II(Nor) Vb(Far)
Whiting	IV+IIa(EC) VI+Vb(EC) VILa VII(Ex VIIa)	
Plaice	IV+IIa(EC) VI+Vb(EC) VLLa VLLde VIIfg VIIhjk	
Sole	IV+IIa(EC) VI+Vb(EC) VIIa VIId VIIe VIIfg VIIhjk	

TABLE 4.2 CONTD.

Species	EC and Joint Stocks	Non-EC Waters
Mackerel	IV+IIa(EC)+IIIa+IIIbcd(EC) VI+Vb(EC)+II(ex EC)+VII +VIII(EC)+XII	
Hake	IV+IIa(EC) VI+Vb(EC)+VII	
Herring	IIa(EC)+IVb(EC)+IIa(EC) IVc(excld Blackwater)+VIId VIa(North)+BIb+Vb(EC) VIa(Clyde) VIIa(Manx) VIIa(Mourne) VIIef VIIghik	
Sprat	IV+IIa(EC) VIIde	
Blue Whiting	IV+IIa(EC) VI+Vb(EC)+VII VIII(EC)	Vb(Far)
Scad	IV(EC)+IIa(EC) VI+Vb(EC)+VII VIII(EC)	
Megrim	VI+Vb(EC) VII	
Monk	VI+Vb(EC) VII	
Norway Pout	IV(EC)+IIa(EC)+IIIa	IV(ex EC)
Sandeel		IV(ex EC)
Redfish		I(Nor)+II(Nor)
Greenland Halibut		I(Nor)+(II(Nor) V(Gre)+(XIV(Gre) NAFO 1 (Gre)
Ling		Vb(Nor)
Blue Ling		Vb(Nor)
Tusk		Vb(Nor)

TABLE 5

LIST OF CRITERIA FOR DEFINITION OF STOCK

Criterion	Description	Comment
A	The stock is defined in MAFF time series data (source 1)	Regarded as a sufficient condition unless there are strong contra-indications
B	The stock is defined as a European Commission CFP stock management unit (source 2)	Boundaries do not always coincide with FPM grounds/ICES division boundaries
C	Biological definition of subspecies or "races"	Multiple stocks on one ground are amalgamated in FPM as one stock
D	Exclusivity: When two larger stocks, occupying a number of grounds have a ground in common, only one is assigned on that ground	All FPM predicted catches from the ambiguous ground assumed from that one stock
E	Inferential indications of common or separate breeding stocks provided by common or separate spawning areas	Separate spawning areas imply separate (biological) stocks
F	Inferential indications from preferred depths/ habitats	e.g. for species found in shallow waters Faroe-Shetland Channel will separate stocks
G	Mobility	e.g. for shellfish stocks defined on as small an area as possible

Criterion	Description	Comment
H	Shoaling/Migration	
I	Commonality of exploitation pattern (with respect to relative catches by UK and other countries)	e.g. if UK has low catches from adjacent stocks, these can be regarded as one common stock in FPM without loss of authenticity in response since the model controls other countries' catches only by policy input
J	Catch levels - low catch on ground adjacent to ground with high catch: FPM can regard as single stock	

The table of stock definitions and summary of decisions is presented below:

TABLE 6

Summary of stock definition decisions

species (f)	stock code	grounds (g)		data available	criteria	comments
cod (1)	1	I IIab	(1) (2,3)	catch 46-83 biom 46-82	A	
	2	IVabc	(4-6)	catch 63-82 biom 66-82	A	
	3	Vb	(7)	catch 61-82 biom 67-82	A	
	4	VIa	(8)	catch 67-82 biom 67-82	A	
	5	VIb	(9)	catch 46-82	A	
	6	VIIa	(10)	catch 67-82 biom 67-82	A,B	
	7	VIIbc VIIf-k	(11) (14,15)	catch 46-82	A,D	Distinct stocks on VIIbc,g-k & VIIfg in t-series but low catches from each. Combine to satisfy exclusivity on VIIg
	8	VIIde	(11)	catch 46-82	A	
had (2)	1	I IIab	(1) (2,3)	catch 50-82 biom 50-83	A	
	2	IVabc	(4-6)	catch 60-82 biom 61-82	A	
	3	Vb	(7)	catch 61-82 biom 67-82	A	
	4	VIa	(8)	catch 65-82 biom 65-82	A	
	5	VIb	(9)	catch 46-82	A	
	6	VIIa	(10)	catch 77-82	A	only grnd not in time series
	7	VIIbc VIIf-k	(11) (14,15)	catch 46-82	A,I,J	
	8	VIIde	(12,13)	catch 45-82	A	

species (f)	stock code	grounds (g)		data available	criteria	comments
sth (3)	1	I IIab	(1) (2,3)	catch 61-82 biom 67-82	A	
	2	IVabc	(4-6)	catch 60-82 biom 60-82	A	
	3	Vb	(7)	catch 60-82 biom 67-82	A	
	4	VIa	(8)	catch 60-82 biom 67-82	A	
	5	VIb	(9)	catch 77-82	I	
	6	VIIa	(10)	catch 77-82	I	
	7	VIIb-k	(11-15)	catch 77-82	I	
wtg (4)	1	I IIab Vb	(1) (2,3) (7)	catch 77-82	I	
	2	IVabc	(4-6)	catch 60-82 biom 61-82	A,E	
	3	VIa	(8)	catch 63-82 biom 63-82	A	
	4	VIb VIIbc VIIf-k	(9) (11) (14,15)	catch 46-81	I	
	5	VIIa	(10)	catch 68-82 biom 72-82	A,B	
	6	VIIde	(12,13)	catch 46-82	A,E	
hke (5)	1	IVab VIab VIIa-k VIII	(4,5) (8,9) (10-15) (16)	catch 77-82 biom 77-82	A,E,H	catch/biom time series includes VIII and IX
blw (6)	1	IIa IVab Vb VIa VIIbc	(2) (4,5) (7) (8) (11)	catch 73-82	A,E	no UK catch from I,IIb
npt (7)	1	IVab VIa	(4,5) (8)	catch 59-82 biom 74-82	A,E	

species (f)	stock code	grounds (g)		data available	criteria	comments
sdl (8)	1	IVab	(4,5)	catch 52-82	A,C,E	
				biom 72-82		
	2	VIa	(8)	catch 77-82	C,E	
				biom 60-82		
mnk (9)	1	IVa-c	(4-6)	catch 77-82	I	
	2	VIa	(8)	catch 77-82	I	
	3	VIIab	(10,11)	catch 77-82	I,F,B	
		VIId-k	(12-15)			
plc (10)	1	IVa-c	(4-6)	catch 51-82	A	
				biom 51-82		
	2	VIa	(8)	catch 77-82	I	
	3	VIIa	(10)	catch 67-82	A	
				biom 73-82		
	4	VIIde	(12,13)	catch 77-82	I	
	5	VIIf-k	(14,15)	catch 77-82	A,F	biom estimates but no catch in MAFF time series data
				biom 70-82		
lsl (11)	1	IVa-c	(4-6)	catch 77-82	I	
	2	VIa	(8)	catch 77-82	I	
	3	VIIa	(10)	catch 77-82	I,F	
		VIIf-k	(14,15)			
	4	VIIde	(12,13)	catch 77-82	I	
sol (12)	1	IVbc	(5,6)	catch 57-82	A,E	IVa incl in t-series but no signif catch
				biom 57-82		
	2	VIa	(8)	catch 67-82	A,J	t-series for VIIa only but small VIa catch: include with VIIa stock for FPM
		VIIa	(10)			
	3	VIId	(12)	catch 71-82	A	
				biom 71-82		
	4	VIIe	(13)	catch 69-82	A	
				biom 69-82		
	5	VIIf-k	(14,15)	catch 70-82	A,F	
				biom 70-82		

species (f)	stock code	grounds (g)		data available	criteria	comments
dog (13)	1	IVabc	(4-6)	catch 77-82	I,G,H	
	2	VIa	(8)	catch 77-82	I,G,H	
		VIIa	(10)			
	3	VIbc	(11)	catch 77-82	I,G,H	
		VIId-k	(12-15)			
ray (14)	1	IVab	(4,5)	catch 77-82	C,D,E	
	2	IVc	(6)	catch 77-82	C,D,E	
		VIIde	(12,13)			
	3	VIab	(8,9)	catch 77-82	C,D,E	
	4	VIIab	(10,11)	catch 77-82	C,D,E	
		VIIf-k	(14,15)			
her (15)	1	IVab	(4,5)	catch 47-82 biom 72-82	A,I	
	2	IVc	(6)	catch 47-82	A,I	
		VIIde	(12,13)	biom 72-82		
	3	VIa	(8)	catch 70-82	A,C,I	2 stks in catch/biom t-series but not sep by ICES div boundary
		VIIbc	(11)	biom 73-82		
	4	VIIa	(10)	catch 69-82 biom 70-82	A,C,E	2 Irish Sea stks in t-series Manx+Mourne
	5	VIIf-k	(14,15)	catch 58-82 biom 58-82	A,C,E	small catch on VIIf but no spawning grds =inc with VIIg-k stk
spt (16)	1	IVabc	(4-6)	catch 65-82 biom 67-82	A	
	2	VIa	(8)	catch 77-82		
	3	VIIab	(10,11)	catch 77-82		
		VIIf-k	(14,15)	catch 77-82		
	4	VIIde	(12,13)	catch 77-82		

species (f)	stock code	grounds (g)		data available	criteria	comments
mac (17)	1	IIa	(2)	catch 69-82	A,C,D	exclude from VIa in FPM by stock 2
		IVab	(4,5)	biom 69-82		
	2	IVc	(6)	catch 72-82	A,C,D	stocks 1&2 on VIa in t-series data
		Vb	(7)	biom 72-82		
		VIa	(8)			
		VIIa-k	(10-15)			
		VIII	(16)			
scd (18)	1	IVabc	(4-5)	catch 74-82	A,J	
		VIa	(8)			
		VIIa-k	(10-15)			
pil (19)	1	VIId-k	(12-15)	catch 77-82	E,I	
off (20)	1	I	(1)	catch 77-82	C	mainly redfish
		IIab	(2,3)			
	2	IVabc	(4-6)	catch 77-82		(composite
	3	Vb	(7)	catch 77-82		(catches
		VIab	(8,9)			(from
	4	VIIa	(10)	catch 77-82		(ICES
	5	VIIbc	(11)	catch 77-82		(separate
		VIIg-k	(15)	catch 77-82		(species
	6	VIId-f	(12-14)	catch 77-82		(data
shr (21)	1	IVa	(4)	catch 77-82	E,G	p borealis
	2	IVb	(5)	catch 77-82	E,G	p bor/p montagui
	3	VIIa	(10)	catch 77-82	E,G	crangon crangon
	4	VIId	(12)	catch 77-82	E,G	palaemonid shrimp?
	5	VIIg	(15)	catch 77-82	E,G,F	p montagui-assume all UK VIIg-k catch from VIIg
nph (22)	1	IVa	(4)	catch 77-82	E,G	
	2	IVb	(5)	catch 77-82	E,G	
	3	VIa	(8)	catch 77-82	E,G	
	4	VIIa	(10)	catch 77-82	E,G	

species (f)	stock code	grounds (g)		data available	criteria	comments
lob (23)	1	IVa	(4)	catch 77-82	E	
	2	IVb	(5)	catch 77-82	E	
	3	IVc	(6)	catch 77-82	E	
	4	VIa	(8)	catch 77-82	E	
	5	VIIa	(10)	catch 77-82	E	
	6	VIId	(12)	catch 77-82	E	
	7	VIIe	(13)	catch 77-82	E	
	8	VIIf	(14)	catch 77-82	E	
	9	VIIg-k	(15)	catch 77-82	E,F	UK VIIg-k catch assumed from VIIg
crb (24)	1	IVa	(4)	catch 77-82	E/J	
	2	IVb	(5)	catch 77-82	E	
	3	IVc	(6)	catch 77-82	E	
	4	VIa	(8)	catch 77-82	E	
	5	VIIa	(10)	catch 77-82	E	
	6	VIId	(12)	catch 77-82	E	
	7	VIIe	(13)	catch 77-82	E	
	8	VIIf	(14)	catch 77-82	E	
	9	VIIg-k	(15)	catch 77-82	E,F	UK VIIg-k catch assumed from VIIg
scl (25)	1	IVab	(4,5)	catch 77-82	E/J	small IVb catch ass from IVa sock
	2	VIa	(8)	catch 77-82	E	
	3	VIIa	(10)	catch 77-82	E	
	4	VIId	(12)	catch 77-82	E	
	5	VIIe	(13)	catch 77-82	E	
	6	VIIf	(14)	catch 77-82	E	
	7	VIIg	(15)	catch 77-82	E	
qun (26)	1	IVab	(4)	catch 77-82	E/J	small IVb catch
	2	VIa	(8)	catch 77-82	E	
	3	VIIa	(10)	catch 77-82	E	
	4	VIIe	(13)	catch 77-82	E	

species (f)	stock code	grounds (g)		data available	criteria	comments
sqd (27)	1	IVabc	(4-6)	catch 77-82	G,H	mobility-
	2	Vb VIab	(7) (8,9)	catch 77-82	G,H	general shellfish criterion
	3	VIIa VIIf-k	(10) (14,15)	catch 77-82	G,H	does not apply
	4	VIIde	(12,13)	catch 77-82	G,H	
osh (28)	1	IVa	(4)	catch 77-82	E	
	2	IVb	(5)	catch 77-82	E	
	3	IVc	(6)	catch 77-88	E	
	4	VIa	(8)	catch 77-82	E	
	5	VIIa	(10)	catch 77-82	E	
	6	VIId	(12)	catch 77-82	E	
	7	VIIe	(13)	catch 77-82	E	
	8	VIIf	(14)	catch 77-82	E	

APPENDIX V

THE NETT PRODUCTION FUNCTION

a) **Time-weighting of historical data for statistical analysis**

Because catch and (where available) biomass data are for varying numbers of years according to the stock, determination of means and linear regressions are performed using weighted data points. The weighting factor is:

$$W_t = 1.35 \times 2^{(-t/10)^2}$$

where t is the number of years from data value occurrence to base year (assumed in these analyses to be 1982).

This weighting has the properties:

(i) $W_o = 1.35$

(ii) $W_{10} = W_o/2$

(iii) $\sum_{t=0}^{12} W_t = 13$ (mean over most recent 13 data points is approximately 1)

(iv) If $t > 12$, $W_t < W_o/3$

(v) $\sum_{t=13}^{\infty} W_t \simeq 3$

After a "plateau" of about 5 data points the weighting starts to decrease fairly rapidly, with little weight attached to data points more than 12 years before the base year.

b) **Exploited biomass for type 1 stocks**

The MAFF extracts from ICES Working Group time series data include, for type 1 stocks, catches, total biomass and spawning stock biomass estimates over varying periods of time. There are 37 such stocks which coincide with the FPM stock definitions.

An estimate of exploited biomass is required for BF and in general this lies at some intermediate value between the two biomass figures. The best estimator is taken to be the weighted mean of the two biomasses (total and spawning) where the weighting factors are provided by the values of the time-weighted linear regression slopes for catch with total and spawning biomass respectively. A non-negativity condition is imposed on the weighting factors.

$$b = (1-q).b^{(t)} + q.b^{(s)} \qquad \ldots(19)$$

where

- b = exploited biomass estimate
- $b^{(t)}$ = total biomass
- $b^{(s)}$ = spawning biomass
- $(1-q)$ and q are the weighting factors subject to $o \leq q \leq 1$

Also

$$\begin{cases} 1-q = m^{(t)}/(m^{(t)}+m^{(s)}) \\ q = m^{(s)}/(m^{(t)}+m^{(s)}) \end{cases} \qquad \ldots(20)$$

where $m^{(t)}$ and $m^{(s)}$ are the respective regression coefficients obtained from the multiple regression analysis of catch with total biomass and spawning biomass, using time-weighted data points:

but subject to

$$\begin{cases} \text{if } m^{(t)} < 0 \text{ then } q = 1 \\ \text{if } m^{(s)} < 0 \text{ then } q = 0 \end{cases} \qquad \ldots(21)$$

Summary results of analysis to determine q-values for type 1 stocks are shown in Table 7 below. These values are used to generate time series of exploited biomass estimates as defined in equation (19).

c) **Nett production time series**

For each type 1 stock, nett production in year i is estimated from:

$$p_i = c_i + b_{i+1} - b_i \qquad \ldots(22)$$

where

p_i is nett production in year i

c_i is catch in year i

b_i is exploited biomass in year i

This relationship is used to generate nett production time series from exploited biomass and catch data.

d) **Analysis of nett production and exploited biomass time series data**

For each type 1 stock, mean values are obtained for biomass and production, and linear regressions performed for production with biomass, production with year and biomass with year, using time-weighted data points.

In general nett production in year i is a function not only of biomass at the start of year i, but also years (i-1), (i-2),... There are also random variations in production which are not attributable to change in biomass. It is therefore advantageous to "de-couple" the corresponding p_i and b_i values in certain cases where biomass is tracking strongly in one direction and compare the respective trends in biomass and production. In such cases, where biomass is strongly correlated with year, the best estimator for the local rate of change of production with biomass is taken to be as follows:

If slope of biomass with year is db/dy
and slope of production with year is dp/dy
(from time-weighted regression analyses)
then the local rate of change of production with biomass is

$$G_{pb} = (db/dy) / (dp/dy) \qquad \ldots(23)$$

It is emphasised that this can only be used when biomass is strongly correlated with year, arbitrarily defined as

$$\text{mod (correlation)} \geqslant 0.7 \qquad \ldots(24)$$

In other cases the best estimator is taken to be the time-weighted regression slope of production with biomass.

The mean values, slopes and correlation coefficients are listed for type 1 stocks in summary table 8, below.

Table 8

Stocks	Mean Catch in ktonnes (Cbar)	sd Catch (sdC)	Mean Total Biomass (B1bar)	sd Total Biomass (sdB1)	Mean Spawning Biomass (B2bar)	sd Spawning Biomass (sdB2)
cod*1	760	260	2100	800	210	68
cod*2	250	50	510	90	280	72
cod*3	27	7.8	130	28	75	20
cod*4	17	4.3	42	8.9	25	4.8
cod*6	10	2.6	20	5.5	9.6	2.4
had*1	130	72	480	260	170	75
had*2	200	140	660	360	430	330
had*3	17	5.3	93	18	71	14
had*4	22	9.2	72	36	58	37
sth*1	193	41	750	250	270	180
sth*2	180	77	740	210	320	120
sth*3	23	9	190	44	130	23
sth*4	26	7.8	290	41	220	45
wtg*2	150	37	530	130	320	82
wtg*3	16	3.4	47	11	31	8.4
wtg*5	13	3.1	42	8.6	16	3.8
hke*1	62	4	290	12	140	7.3
blw*1	530	380	8800	2000	5100	1400
npt*1	400	140	580	190	140	47
sdl*1	580	150	1500	290	790	170
plc*1	130	17	530	60	360	34
plc*3	3.6	0.56	7.9	1.1	4.9	1.1
plc*5	1.4	0.31	3.5	1	1.4	0.48
sol*1	2	4.6	64	14	48	17
sol*2	1.5	0.28	6.9	0.73	5.8	0.86
sol*3	1.5	0.6	0.74	0.94	5.9	1.1
sol*4	.83	0.39	4.9	0.94	4.3	0.85
sol*5	1.2	0.29	6.6	1.3	5.4	1.2
her*1	150	150	236	108	157	59
her*2	27	23	91	78	54	56
her*3	97	71	460	150	275	120
her*4	16	12	46	24	22	10
her*5	18	10	55	27	44	25
spt*1	290	180	480	290	340	200
mac*1	140	130	820	490	630	370
mac*2	480	150	4200	540	3000	460

Stocks	Catch with Total Biom rCB1	Catch with Spawn Biom rCB2	Catch with Year rCY	Total Biom with Year rB1Y	Spawn Biom with Year rB2Y
cod*1	0.79	-0.20	-0.51	-0.73	0.15
cod*2	0.62	0.003	0.2	-0.25	-0.68
cod*3	0.67	0.81	-0.19	-0.15	-0.24
cod*4	0.83	0.84	0.35	0.69	0.18
cod*6	0.93	0.80	0.51	0.30	0.25
had*1	0.95	0.38	-0.46	-0.61	0.07
had*2	0.73	0.91	-0.43	-0.67	-0.43
had*3	0.68	0.70	-0.46	-0.17	-0.43
had*4	0.70	0.80	-0.46	-0.66	0.17
sth*1	0.49	0.60	-0.39	-0.88	-0.51
sth*2	0.76	0.70	-0.02	0.04	0.08
sth*3	0.58	0.76	-0.26	-0.86	-0.47
sth*4	0.66	0.82	0.009	-0.03	0.16
wtg*2	0.58	0.73	-0.04	-0.51	0.09
wtg*3	0.47	0.45	-0.07	-0.49	-0.32
wtg*5	-0.46	0.28	0.80	-0.34	0.09
hke*1	0.49	0.57	0.03	0.85	0.10
blw*1	-0.61	0.39	0.77	0.84	0.16
npt*1	0.86	-0.49	-0.68	-0.42	0.28
sdl*1	0.88	0.49	0.58	0.44	0.09
plc*1	0.64	-0.03	0.76	0.44	-0.41
plc*3	0.82	0.88	-0.42	-0.23	-0.45
plc*5	0.78	0.76	0.73	0.97	0.99
sol*1	0.69	0.82	-0.47	-0.73	-0.80
sol*2	0.13	0.29	0.10	-0.54	-0.70
sol*3	0.16	0.28	0.91	0.16	0.005
sol*4	0.58	0.72	0.93	0.65	0.74
sol*5	0.71	0.67	-0.47	-0.85	-0.86
her*1	0.89	0.30	-0.78	-0.51	0.22
her*2	0.88	0.78	0.57	0.69	0.79
her*3	0.62	0.32	-0.68	0.02	0.38
her*4	0.91	0.73	-0.89	-0.92	-0.84
her*5	0.79	0.78	-0.64	-0.72	-0.77
spt*1	-0.02	0.14	0.19	-0.94	-0.79
mac*1	0.57	0.50	-0.63	-0.98	-0.88
mac*2	-0.82	-0.85	0.87	-0.96	-0.95

Stocks	R squared adj for d.f. (aR2)	Coeff Total Biomass (m1)	S.E. for m1 (SE1)	Coeff Spawn Biomass (m2)	S.E. for m2 (S.E.2)	Wt Factor for Expl Biom m2/(m1+m2) (Q)
cod*1	0.57	0.2702	0.061	0.3618	0.72	0.572
cod*2	0.47	0.4869	0.13	-0.3298	0.17	0.000
cod*3	0.77	0.1621	0.056	0.1378	0.08	0.459
cod*4	0.78	0.2279	0.092	0.4423	0.17	0.660
cod*6	0.86	0.3592	0.076	0.2553	0.17	0.415
had*1	0.90	0.2692	0.026	-0.4487	0.091	0.000
had*2	0.82	0.02401	0.068	0.3685	0.075	0.939
had*3	0.55	0.1272	0.068	0.1831	0.087	0.590
had*4	0.58	0.00764	0.097	0.2056	0.094	0.964
sth*1	0.30	-0.1027	0.11	0.2703	0.15	1.000
sth*2	0.51	0.2157	0.13	0.1171	0.23	0.352
sth*3	0.50	0.02002	0.057	0.2773	0.11	0.933
sth*4	0.51	-0.00236	0.055	0.1427	0.051	1.000
wtg*2	0.52	0.07621	0.062	0.2637	0.098	0.776
wtg*3	0.19	0.1064	0.079	0.1268	0.11	0.544
wtg*5	0.56	-0.3213	0.056	0.6309	0.19	1.000
hke*1	0.32	0.1392	0.10	0.2503	0.17	0.667
blw*1	0.74	-0.1608	0.033	0.1942	0.049	1.000
npt*1	0.66	0.6436	0.18	-0.1210	0.70	0.000
sdl*1	0.74	0.5250	0.11	-0.1413	0.18	0.000
plc*1	0.42	0.2119	0.06	-0.1640	0.11	0.000
plc*3	0.71	0.0699	0.20	0.3857	0.21	0.847
plc*5	0.35	0.1857	0.91	0.3689	0.77	0.665
sol*1	0.62	-0.00275	0.10	0.2290	0.84	1.000
sol*2	-0.12	0.01565	0.13	0.09038	0.11	0.852
sol*3	-0.11	0.0058	0.23	0.1417	0.19	0.961
sol*4	0.67	-0.7167	0.26	1.0950	0.29	1.000
sol*5	0.43	0.3750	0.29	-0.2360	0.31	0.000
her*1	0.96	0.7600	0.12	-1.4050	0.22	0.000
her*2	0.82	0.5975	0.16	-0.4842	0.22	0.000
her*3	0.57	0.8013	0.22	-0.6851	0.27	0.000
her*4	0.82	0.5226	0.11	-0.3525	0.26	0.000
her*5	0.57	0.3584	0.40	-0.0693	0.42	0.000
spt*1	0.01	-0.6105	0.45	0.9465	0.65	0.000
mac*1	0.21	0.2215	0.19	-0.1039	0.26	0.000
mac*2	0.65	0.0563	0.24	-0.3455	0.28	0.000

Stocks	Mean (Expl) Biomass (Bbar)	Slope Biom with Year (dB/dY)	mod Corr Bio w Year (mod rBY)	Mean Production (Pbar)	Slope Prod w Year (dP/dY)	mod Corr Prod w Yr (mod rPB)	Slope Prod with Biom (dP/dB)	mod Corr Prod w Bio (mod rPB)
cod*1	1049	-43.4	0.72	628	-26.2	0.62	0.462	0.43
cod*2	508	-9.44	0.43	248	6.88	0.37	-0.059	0.01
cod*3	106	-0.565	0.10	26.1	-0.960	0.24	-0.017	0.02
cod*4	29.5	0.228	0.20	17.5	0.631	0.44	0.851	0.66
cod*6	18.4	0.098	0.10	10.3	0.448	0.55	0.394	0.46
had*1	492	-27.5	0.59	95.7	-9.41	0.34	0.0079	0.13
had*2	464	-30.6	0.44	186	-13.5	0.24	-0.169	0.21
had*3	80.7	398	0.12	17.9	-1.02	0.44	-0.003	0.00
had*4	60.2	-6.04	0.57	19.9	-0.46	0.09	-0.133	0.22
sth*1	295	-40.4	0.91	165	-4.85	0.51	0.098	0.46
sth*2	584	3.22	0.89	186	-1.30	0.11	0.146	0.48
sth*3	140	-1.9	0.36	30.3	-2.20	0.63	0.329	0.490
sth*4	215	2.82	0.23	29.7	-2.11	0.43	-0.105	0.26
wtg*2	383	2.41	0.17	146	-2.81	0.18	-0.265	0.24
wtg*3	39.8	-0.523	0.34	14.6	-0.319	0.20	-0.124	0.12
wtg*5	16.2	0.476	0.39	11	0.258	0.17	-0.701	0.55
hke*1	189	3.48	0.74	62	0.869	0.19	-0.461	0.49
blw*1	5320	266	0.52	517	-182	0.93	-0.177	0.46
npt*1	574	-48.2	0.57	372	-1.78	0.02	-0.559	0.65
sdl*1	1510	61	0.58	604	5.05	0.06	-0.137	0.15
plc*1	517	1.81	0.23	137	5.29	0.48	-0.022	0.02
plc*3	5.42	-0.225	0.51	3.49	0.103	0.45	0.050	0.10
plc*5	2.11	0.272	0.99	1.59	0.100	0.58	0.416	0.66
sol*1	48.8	-2.92	0.84	19.2	-0.079	0.04	-0.072	0.12
sol*2	5.99	-0.168	0.74	1.25	-0.010	0.05	-0.464	0.47
sol*3	5.72	-0.128	0.42	1.55	0.278	0.46	-1.51	0.76
sol*4	4.25	0.226	0.92	0.788	0.027	0.22	0.127	0.25
sol*5	6.62	-0.331	0.86	0.839	0.027	0.18	-0.114	0.31
her*1	278	-31.7	0.83	158	-27.7	0.58	1.09	0.86
her*2	71.2	10.4	0.52	42.3	11.7	0.70	0.448	0.54
her*3	445	11.9	0.21	92.4	6.32	0.27	-0.114	0.27
her*4	48.6	-6.76	0.92	13.6	-2.79	0.82	0.290	0.62
her*5	56	-4.45	-0.79	18.3	-0.46	-0.27	0.152	0.51
spt*1	370	-33.2	0.73	270	13.2	0.24	-0.219	0.18
mac*1	901	-126	0.97	47.4	-23.1	0.62	0.141	0.49
mac*2	4264	-159	0.94	307.1	32.2	0.43	-0.260	0.58

Stocks	Grad from Slopes w Year (Gpb on Y)	Grad direct calc (Gpb drct)	Gradient chosen Gpb	Prod-Biom ratio (Pbar/Bbar)
cod*1	0.604	0.462	0.604	0.599
cod*2	-0.729	-0.059	-0.059	0.488
cod*3	1.699	-0.017	-0.017	0.246
cod*4	2.768	0.851	0.851	0.593
cod*6	4.571	0.394	0.394	0.560
had*1	0.342	0.079	0.079	0.195
had*2	0.441	-0.169	-0.169	0.401
had*3	-2.563	-0.003	-0.003	0.222
had*4	0.076	-0.133	-0.133	0.331
sth*1	0.120	0.098	0.120	0.559
sth*2	-0.404	0.146	-0.404	0.318
sth*3	1.158	0.329	0.329	0.216
sth*4	-0.748	-0.105	-0.105	0.138
wtg*2	-1.166	-0.265	-0.265	0.381
wtg*3	0.610	-0.124	-0.124	0.367
wtg*5	0.542	-0.701	-0.701	0.679
hke*1	0.250	-0.461	0.250	0.328
blw*1	-0.684	-0.177	-0.177	0.097
npt*1	0.037	-0.559	-0.559	0.648
sdl*1	0.083	-0.137	-0.137	0.400
plc*1	2.923	-0.022	-0.022	0.265
plc*3	-0.458	-0.050	-0.050	0.644
plc*5	0.368	0.416	0.368	0.754
sol*1	0.027	-0.072	0.027	0.393
sol*2	0.062	-0.464	0.062	0.209
sol*3	-2.172	-1.510	-1.510	0.271
sol*4	0.119	0.127	0.119	0.185
sol*5	-0.082	-0.114	-0.082	0.127
her*1	0.874	1.090	0.874	0.568
her*2	1.125	0.448	0.448	0.594
her*3	-0.531	-0.114	-0.114	0.208
her*4	0.413	0.290	0.413	0.280
her*5	0.244	0.152	0.244	0.326
spt*1	-0.398	-0.219	-0.398	0.730
mac*1	0.183	0.141	0.183	0.053
mac*2	-0.203	-0.260	-0.203	0.072

e) **Required characteristics for nett production function**

In searching for a model to describe the behaviour of each stock in terms of the relation between expected nett production and start-of-year exploited biomass, the first priorities are:

(i) When biomass is zero, production is zero.

(ii) The time-weighted mean values of biomass and production ($\bar{b}$ and $\bar{p}$) for type 1 stocks should also satisfy the function.

Other desirable features are:

(iii) There should be one maximum point ($\hat{b}$,$\hat{p}$), corresponding to maximum sustainable yield (MSY) in the steady state.

(iv) There should be a point, other than the origin, for which expected production falls to zero, representing virgin biomass (unexploited fishery).

(v) The local rate of change of production with biomass at ($\bar{b}$, $\bar{p}$) should concur with best estimators obtained from data analysis for type 1 stocks.

f) Investigation of the quadratic production function

Consider the quadratic function:

$$p = 4Hb(L-b)/L^2 \qquad \ldots(25)$$

Differentiating:

$$dp/db = 4H\ (L-2b)/L^2 \qquad \ldots(26)$$

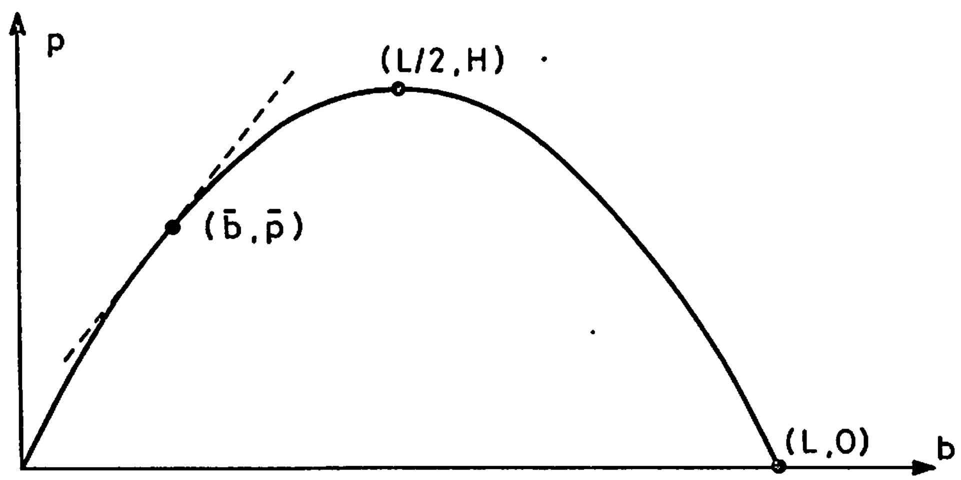
When $b = 0$ $\quad p = 0$

When $b = L/2$, $dp/db = 0$ and $p = H$

When $b = L$, $\quad p = 0$

This is a formulation of the Schaefer steady-state production function (8) and is illustrated below:

Figure 6



We define the "standardised gradient" as:

$$m = (dp/db) / (p/b) \qquad \ldots(27)$$

For the Schaefer curve, m is uniquely defined as a monotonic decreasing function of b for $0 < b < k$, with a hypothetical maximum value of 1 if $b = 0$.

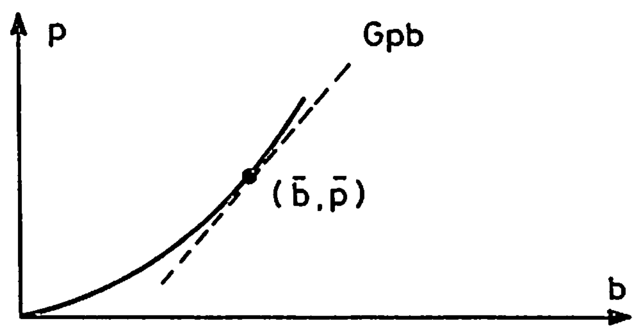
Thus the computed m-value for each type 1 stock using:

$$m_{\bar{b}} = (G_{pb}) / (\bar{p}/\bar{b}) \qquad \ldots(28)$$

can be used to locate the point $(\bar{b}, \bar{p})$ on the Schaefer curve, and hence determine values for parameters H and L.

However the fitting procedure breaks down where m is greater than 1, as illustrated below.

Figure 7



This occurs in 7 of the 16 cases with positive gradient (out of 37 type 1 stocks).

Other documented production models were considered, such as described by Beverton and Holt (1), Kimura (4), Pella and Tomlinson (6), Ricker (7) and Shepherd (10), but none of these appeared to offer a better approach in this context.

A function with roughly the same shape as the Schaefer curve, but with a concave section (increasing gradient) for small values of biomass would appear to be the most satisfactory utilisation of best estimators obtained from analysis of time series data. An appropriate function is proposed below.

g) **Development of the cubelog nett production function**

The following function satisfies the requirements of being "locally sensible" by concurring with the data pair $(\bar{b},\bar{p})$ and having suitable gradient, and also being "asymptotically sensible" by preserving the concepts of MSY and virgin biomass.

Let the general form of the nett production function be:

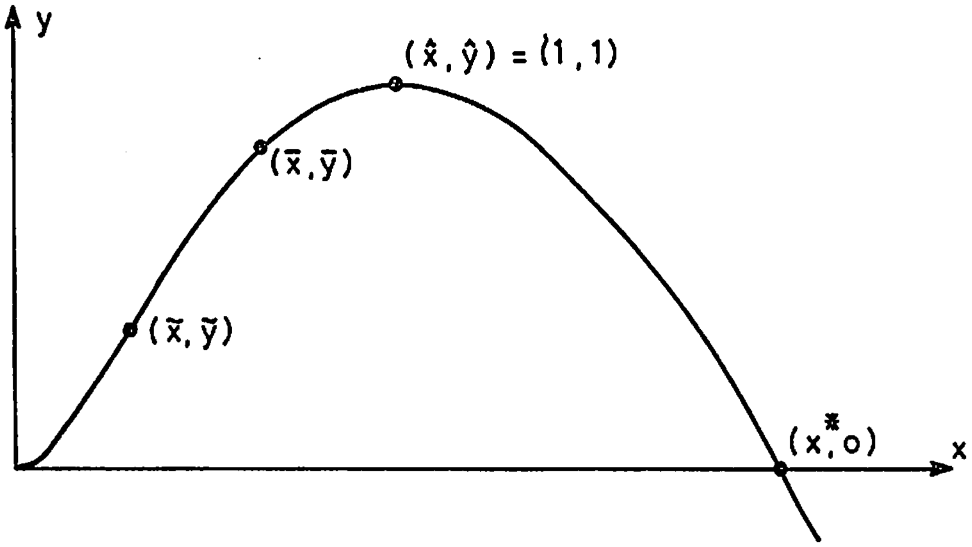
$$y = B\left[\ln(1+kx)\right]^2 - A\left[\ln(1+kx)\right]^3 \qquad \ldots(30)$$

where

- $x = b/\hat{b}$, the normalised biomass
- $y = p/\hat{p}$, the normalised production
- b is exploited biomass,
- p is nett production,
- $\hat{b}$ and $\hat{p}$ are the coordinates of the maximum point.

The characteristic shape is shown below:

<u>**Figure 8**</u>



The gradient increases initially from zero at the origin then decreases after some point of inflexion $(\tilde{x}, \tilde{y})$. The points $(\hat{x}, \hat{y})$ and (x^*, o) represent MSY and virgin biomass respectively.

The point $(\bar{x}, \bar{y})$, representing time weighted mean biomass and production from historical data, should also be on the curve.

Differentiating equation (30) we get

$$\frac{dy}{dx} = \frac{k}{1+kx}\left\{ 2B\left[\ln(1+kx)\right] - 3A\left[\ln(1+kx)\right]^2 \right\} \quad \ldots(31)$$

From equation (30):

$$y = 0 \Rightarrow \ln(1+kx) = 0, 0, B/A$$

$$\Rightarrow \quad x^* = \left[\exp(B/A) - 1\right]/k \quad \ldots(32)$$

(ignoring coincident roots at the origin)

From equation (31):

$$dy/dx = 0 \Rightarrow \ln(1+kx) = 0,\ 2B/3A$$

$$\Rightarrow \quad \hat{x} = \left[\exp(2B/3A) - 1\right]/k \quad \ldots(33)$$

(ignoring zero gradient at the origin)

If we specify that $x^* = 2\hat{x}$ (as with the Schaefer model) then, putting

$$E = \exp(B/3A)$$

in equations (32) and (33) we get:

$$E^3 - 1 = 2(E^2 - 1) \quad \ldots(34)$$

$$\Rightarrow E^3 - 2E^2 + 1 = 0$$

$$\Rightarrow (E-1)(E^2 - E - 1) = 0$$

$$\Rightarrow E = (0.5 - 0.5\sqrt{5}),\ 1,\ (0.5 + 0.5\sqrt{5})$$

The first root yields a complex solution in B/A, and the second is trivial with $\hat{x}$ and x^* both zero.

Thus

$$\exp(B/3A) = 0.5 + 0.5\sqrt{5}$$

$$B/A = 1.444 \text{ to 4 sig.fig.} \quad \ldots(35)$$

Substituting this value in equation (32) and putting $x^*=2$:

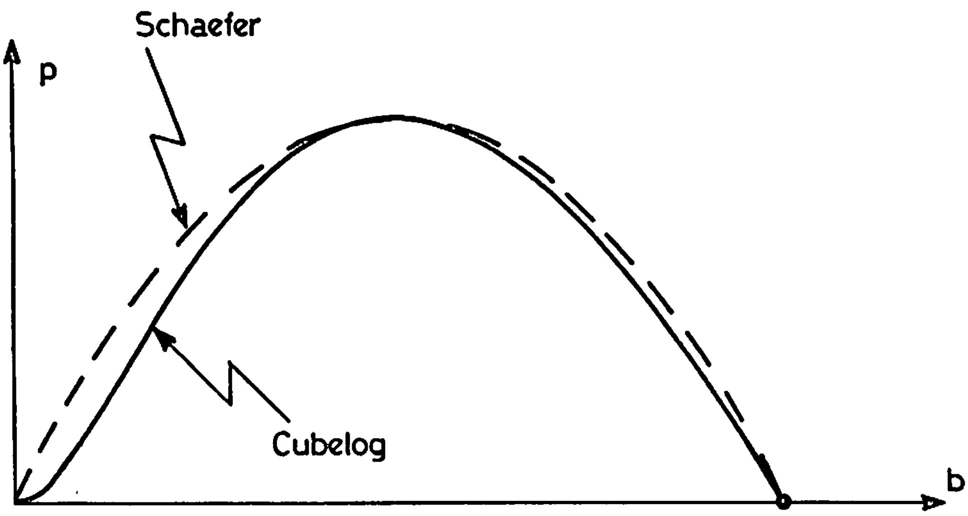
$$2 = [\exp(1.444)-1]/k$$
$$\Rightarrow \quad k = 1.618 \text{ to 4 sig.fig.} \qquad \ldots(36)$$

substituting for A/B and k, and putting x = 1, y = 1 in equation (30):

$$1 = A\{1.444\,[\ln 2.618]^2 - [\ln 2.618]^3\}$$
$$A = 2.244 \text{ to 4 sig.fig.} \qquad \ldots(37)$$
$$B = 3.238 \text{ to 4 sig.fig.} \qquad \ldots(38)$$

This particular case of the cubelong function is close to the Schaefer function as illustrated below.

Figure 9



h) **Estimating the parameters of the cube log model for type 1 stocks**

(i) The point $(\hat{x},\hat{y}) = (1,1)$ lies on the curve

(ii) At $(\bar{x},\bar{y})$ the gradient is the standardised gradient, m, as defined in equation (27).

From equations (30) and (31)

$$\bar{y} = B\left[\ln(1+k\bar{x})\right]^2 - A\left[\ln(1+k\bar{x})\right]^3$$

$$(dy/dx)_{\bar{x}} = \frac{k}{1+k\bar{x}}\left\{2B\left[\ln(1+k\bar{x})\right] - 3A\left[\ln(1+k\bar{x})\right]^2\right\}$$

Also

$$b = x\,\hat{b} \Rightarrow db/dx = \hat{b}$$
$$p = y\,\hat{p} \Rightarrow dp/dy = \hat{p}$$

From equation (27):

$$m = (dp/db)/(p/b)$$

$$= \left(\frac{dp}{dy}\cdot\frac{dy}{dx}\cdot\frac{dx}{db}\right)\Big/\left(\frac{y.\hat{p}}{x.\hat{b}}\right)$$

$$= \left(\hat{p}\cdot\frac{dy}{dx}\cdot\frac{1}{\hat{b}}\right)\Big/\left(\frac{y.\hat{p}}{x.\hat{b}}\right)$$

$$= (dy/dx)\,/\,(y/x) \qquad \ldots(39)$$

(i.e. replacing biomass and production by normalised biomass and production)

So when b = b, x = x, etc.

$$m = \frac{k\bar{x}\left[2B - 3A\ln(1+k\bar{x})\right]}{(1+kx)\left[B - A.\ln(1+k\bar{x})\right].\ln(1+k\bar{x})} \qquad \ldots(40)$$

A, B and k are known, and estimates for m at $x=\bar{x}$ are available for type 1 stocks. However $\bar{x}$ cannot be determined analytically and an iterative search is used. The corresponding value $\bar{y}$ is then calculated from equation (30).

The values of $\hat{b}$ and $\hat{p}$ are then calculated using

$$\hat{b} = \bar{b}/\bar{x}; \quad \hat{p} = \bar{p}/\bar{x} \qquad \ldots(41()$$

These are required as parameters for the production functions for type 1 stocks.

Where parameters for the Schaefer model can be determined from the results of regression analyses for only 30 of the 37 type of stocks (i.e. 80% of cases), this can be done for the cubelog model with all except North Sea mackerel. In this exceptional case, where the production-biomass ratio has fallen to a low level in recent years, apparently anomalous parameters are obtained from the results of analysis. However these provide a feasible model as discussed in section (j) below.

Summary results for determination of cubelog parameters for type 1 stocks are shown in Table 9 below:

Table 9

Stocks	Standardised Gradient (m)	Standardised Mean Biomass (Xbar)	Standardised Mean Prod (Ybar)	Prod ftn Parameter (Bhat) (=PRQ)	Prod ftn Parameter (Phat) (=PRP)
cod*1	1.008	0.485	0.651	2162	964.7
cod*2	-0.121	1.046	0.997	465.5	246.7
cod*3	-0.069	1.027	0.999	103.3	26.12
cod*4	1.435	0.248	0.282	119.1	62.06
cod*6	0.704	0.656	0.846	28.04	12.18
had*1	0.406	0.815	0.956	603.7	100.1
had*2	-0.422	1.152	0.972	402.6	191.3
had*3	-0.014	1.004	1.000	80.39	17.9
had*4	-0.402	1.142	0.976	52.71	20.4
sth*1	0.215	0.909	0.989	324.5	166.8
sth*2	-1.268	1.360	0.851	429.5	218.5
sth*3	1.520	0.207	0.217	675.7	139.9
sth*4	-0.760	1.248	0.928	172.3	32.01
wtg*2	-0.695	1.228	0.938	311.8	155.6
wtg*3	-0.338	1.122	0.982	35.48	14.87
wtg*5	-1.032	1.310	0.888	12.36	12.39
hke*1	0.761	0.626	0.816	302.2	75.94
blw*1	-1.821	1.453	0.769	3661	672.7
npt*1	-0.863	1.272	0.913	451.3	407.3
sdl*1	-0.343	1.124	0.981	1343	615.5
plc*1	-0.083	1.035	0.999	499.7	137.2
plc*3	-0.078	1.030	0.999	5.262	3.494
plc*5	0.488	0.775	0.935	2.723	1.701
sol*1	0.069	0.970	0.999	50.32	19.22
sol*2	0.297	0.871	0.979	6.879	1.277
sol*3	-5.572	1.724	0.444	3.318	3.492
sol*4	0.644	0.692	0.876	6.146	0.8992
sol*5	-0.644	1.215	0.945	5.447	0.8877
her*1	1.537	0.197	0.200	1413	790.4
her*2	0.754	0.629	0.820	113.2	51.59
her*3	-0.549	1.191	0.957	373.7	96.59
her*4	1.475	0.228	0.250	212.9	54.31
her*5	0.749	0.633	0.824	88.48	22.22
spt*1	-0.545	1.188	0.958	311.5	281.9
mac*1	3.485	-0.323	2.683	-2788	17.67
mac*2	-2.812	1.567	0.648	2722	474.1

j) **Anomalous result for North Sea Mackerel**

The maximum theoretical value for the standardised gradient in the cubelog model is exceeded by the value obtained in analysis of time series data for North Sea mackerel (species 17, stock 1) and the model breaks down from that stock.

The anomalous parameters thus obtained, with a hypothetical negative MSY biomass, produce a "locally sensible" model with a production curve satisfying the following:

(i) passes through origin. i.e. zero production for zero biomass

(ii) passes through (1,1) i.e. satisfying mean biomass and production

(iii) has appropriate gradient at (1,1) i.e. satisfying local rate of change from data analysis.

There is no maximum point corresponding to MSY, and the gradient increases indefinitely with biomass, which is not "asymptotically sensible". However the current (initial) biomass is so low that even if there is maximum increase in biomass, with no catch from the stock, the expected biomass will not rise beyond the "locally sensible" range in the seven-year predictive period.

k) **Estimating the Parameters of the cubelog model for type 2 stocks**

Type 2 stocks are those for which only catch data are available. For 75 of these, only 6-year time series are available, extracted from ICES Bulletins Statistiques 1977-82, Table 5, which includes annual total catches of species from grounds. From these short time series unweighted mean annual catches are calculated, and linear regression coefficients determined to give a measure of trend in annual catches with time. These values are given in Table 9 below.

For the eight type 2 stocks defined by MAFF time series and adopted by FPM, there are longer time series, of varying lengths. To take advantage of these data, as in the analysis of type 1 stocks, weighted means and regression coefficients are obtained.

The mean annual catch from a stock offers a first approximation for mean nett production, without a correction for changing biomass. Thus:

$$\bar{p} \simeq \bar{c}$$

$$\text{(mean production)} \simeq \text{(mean catch)} \qquad \ldots(42)$$

However nett production in year i is defined as:

$$p_i = c_i + b_{i+1} - b_i \qquad \ldots(43)$$

where p_i is nett production to a stock in year i

c_i is catch from a stock in year i

b_i is exploited biomass at start of year i

Summing over a period of n years and dividing by n:

$$\frac{1}{n}. \sum_{i=1}^{n} p_i = \frac{1}{n}. \sum_{i=1}^{n} c_i + \frac{1}{n}. \sum_{i=1}^{n} (b_{i+1} - b_i) \quad \ldots(44)$$

$$\Rightarrow \quad \bar{p} = \bar{c} + \frac{1}{n} (b_{n+1} - b_1)$$

$$\Rightarrow \quad \bar{p} = \bar{c} + \Delta\bar{b} \quad \ldots(45)$$

where

$\Delta\bar{b}$ is the mean annual change in biomass over n-year period

In considering the correction term, $\Delta\bar{b}$, the "least unlikely" assumption regarding fishing effort is that effort remains constant.

$$\text{Now } \Delta\bar{b} = \Delta\bar{c} \times \frac{\Delta\bar{b}}{\Delta\bar{c}}$$

$$= \Delta\bar{c} \times \left\{\frac{\bar{b}}{\bar{c}}\right\} / \left\{\frac{\Delta\bar{c}}{c} . \frac{\Delta\bar{b}}{b}\right\}$$

$$= \Delta\bar{c} \times \left\{\frac{\bar{b}}{\bar{c}}\right\} / M \text{-} \Delta\bar{c} \times (\bar{b}/\bar{c})/M \quad \ldots(46)$$

Where $\Delta\bar{c}$ is mean annual change in catch over n-year period

M is the local rate of change of the catch rate function (i.e. catch rate ratio with biomass ratio) as described in Appendix VI).

The overestimate M=1 for all stocks provides an underestimate for the correction term $\Delta\bar{b}$ under the constant effort assumption but gives an improved estimate for $\bar{p}$:

$$\bar{p} = \bar{c} + \Delta\bar{c}/(\bar{c}/\bar{b}) \qquad \ldots(47)$$

Tentative estimates for yield-biomass ratios, $(\bar{c}/\bar{b})$, are provided by MAFF Laboratories, Lowestoft, and these are used to obtain estimates for $\bar{p}$ as shown in Table 9.

In some cases the constant effort assumption is clearly incorrect (eg when catches fall to zero), and a condition is made that the correction term should not be more than 10% of the mean catch.

It should be noted that the correction term does not imply that production is changing, only that production and catch are not balanced.

The yield-biomass estimates are also used to obtain biomass estimates:

$$\bar{b} = \bar{c}/(\bar{c}/\bar{b}) \qquad \ldots(48)$$

Tentative estimates for the ratio of current biomass to MSY biomass are also provided by MAFF Laboratories, Lowestoft, and these are taken to be the best estimators for $\bar{x} = \bar{b}/\hat{b}$

thus $\hat{b}$ is estimated from

$$\hat{b} = \bar{b}/(\bar{b}/\hat{b}) \qquad \ldots(49)$$

Stocks	Est Biomass-MSYbio ratio (Xbar)	Est Prodtn-MSYprod ratio (Ybar) (=fln(Xbar))	MSYbiom Est Bbar/Xbar (Bhat) (=PRQ)	MSYprod Est Pbar/Ybar (Phat) (=PRP)	Phat/Bhat
shr*1	1	1.00E+00	6.80E+03	2.24E+03	0.330001
shr*2	1	1.00E+00	3.37E+03	9.09E+02	0.270001
shr*3	1	1.00E+00	5.10E+02	1.38E+02	0.270001
shr*4	1	1.00E+00	5.40E+01	1.78E+01	0.330001
shr*5	1	1.00E+00	5.43E+01	1.47E+01	0.270001
nph*1	1	1.00E+00	4.13E+03	1.78E+03	0.43194
nph*2	1	1.00E+00	8.05E+03	3.42E+03	0.424597
nph*3	1	1.00E+00	2.10E+04	9.24E+03	0.440001
nph*4	1	1.00E+00	2.03E+04	8.87E+03	0.437239
nph*5	1	1.00E+00	1.77E+03	7.79E+02	0.440001
nhp*6	1	1.00E+00	1.63E+04	7.15E+03	0.440001
lob*1	1	1.00E+00	3.24E+02	1.46E+02	0.450001
lob*2	1	1.00E+00	4.90E+02	2.70E+02	0.550001
lob*3	1	1.00E+00	3.16E+01	1.74E+01	0.550001
lob*4	1	1.00E+00	5.68E+02	2.56E+02	0.450001
lob*5	1	1.00E+00	2.10E+02	1.16E+02	0.550001
lob*6	1	1.00E+00	2.10E+02	1.13E+02	0.537144
lob*7	1	1.00E+00	6.40E+02	3.52E+02	0.550001
lob*8	1	1.00E+00	9.00E+01	4.95E+01	0.550001
lob*9	1	1.00E+00	2.02E+02	1.01E+02	0.49812
crb*1	1	1.00E+00	3.66E+03	1.80E+03	0.490711
crb*2	1	1.00E+00	3.88E+03	2.01E+03	0.5183
crb*3	1	1.00E+00	1.25E+03	5.95E+02	0.474921
crb*4	1	1.00E+00	2.54E+03	1.40E+03	0.550001
crb*5	1	1.00E+00	3.52E+02	1.71E+02	0.485797
crb*6	1	1.00E+00	1.79E+03	8.95E+02	0.499644
crb*7	1	1.00E+00	2.04E+04	1.02E+04	0.49998
crb*8	1	1.00E+00	1.43E+03	7.18E+02	0.500559
crb*9	1	1.00E+00	4.52E+02	2.26E+02	0.49978
scl*1	1	1.00E+00	2.32E+03	1.16E+03	0.500579
scl*2	1	1.00E+00	1.62E+04	8.08E+03	0.499962
scl*3	1	1.00E+00	6.30E+03	3.15E+03	0.500274
scl*4	1	1.00E+00	5.06E+03	2.53E+03	0.500072
scl*5	1	1.00E+00	1.62E+04	8.11E+03	0.499886
scl*6	1	1.00E+00	7.40E+01	3.59E+01	0.485406
scl*7	1	1.00E+00	5.26E+02	2.37E+02	0.450001
gun*1	1	1.00E+00	6.82E+02	3.64E+02	0.533432
gun*2	1	1.00E+00	1.84E+03	8.29E+02	0.450001
gun*3	1	1.00E+00	1.38E+04	7.57E+03	0.550001
gun*4	1	1.00E+00	1.66E+02	4.68E+01	0.281928
sqd*1	1	1.00E+00	1.21E+03	4.61E+02	0.381631
sqd*2	1	1.00E+00	3.28E+03	1.00E+03	0.305787
sqd*3	1	1.00E+00	6.33E+02	5.70E+01	0.09
sqd*4	1	1.00E+00	4.43E+03	1.35E+03	0.303948
osh*1	1	1.00E+00	1.75E+03	1.75E+02	0.1
osh*2	1	1.00E+00	7.41E+03	7.41E+02	0.1
osh*3	1	1.00E+00	1.12E+05	1.12E+04	0.1
osh*4	1	1.00E+00	1.53E+04	1.53E+03	0.1
osh*5	1	1.00E+00	1.07E+05	1.07E+04	0.1
osh*6	1	1.00E+00	1.15E+04	1.15E+03	0.1
osh*7	1	1.00E+00	8.05E+03	8.05E+02	0.1
osh*8	1	1.00E+00	2.06E+04	2.06E+03	0.1

Stocks	Calcd change in Biomass	Catch* 10%	Chosen change in Biomass (dB/dY)	Est Mean Production (Pbar)
shr*1	8.27E+02	204	2.04E+02	2.24E+03
shr*2	-1.87E+02	101	-1.01E+02	9.09E+02
shr*3	-2.73E+02	15.3	-1.53E+01	1.38E+02
shr*4	1.30E+01	1.62	1.62E+00	1.78E+01
shr*5	-1.53E+01	1.63	-1.63E+00	1.47E+01
nph*1	1.32E+02	165	1.32E+02	1.78E+03
nph*2	1.98E+02	322	1.98E+02	3.42E+03
nph*3	9.35E+02	840	8.40E+02	9.24E+03
nph*4	7.55E+02	811	7.55E+02	8.87E+03
nph*5	2.60E+02	70.8	7.08E+01	7.79E+02
nhp*6	1.10E+03	650	6.50E+02	7.15E+03
lob*1	-1.62E+01	16.2	-1.62E+01	1.46E+02
lob*2	2.54E+01	24.5	2.45E+01	2.70E+02
lob*3	3.20E+00	1.58	1.58E+00	1.74E+01
lob*4	-3.56E+01	28.4	-2.84E+01	2.56E+02
lob*5	1.44E+01	10.5	1.05E+01	1.16E+02
lob*6	7.80E+00	10.5	7.80E+00	1.13E+02
lob*7	5.08E+01	32	3.20E+01	3.52E+02
lob*8	1.24E+01	4.5	4.50E+00	4.95E+01
lob*9	-3.80E-01	10.1	-3.80E-01	1.01E+02
crb*1	-3.40E+01	183	-3.40E+01	1.80E+03
crb*2	7.10E+01	194	7.10E+01	2.01E+03
crb*3	-3.14E+01	62.6	-3.14E+01	5.95E+02
crb*4	3.68E+02	127	1.27E+02	1.40E+03
crb*5	-5.00E+00	17.6	-5.00E+00	1.71E+02
crb*6	-6.40E-01	89.6	-6.40E-01	8.95E+02
crb*7	-4.40E-01	1018	-4.40E-01	1.02E+04
crb*8	8.00E-01	71.7	8.00E-01	7.18E+02
crb*9	-1.00E-01	22.6	-1.00E-01	2.26E+02
scl*1	1.34E+00	116	1.34E+00	1.16E+03
scl*2	-6.40E-01	808	-6.40E-01	8.08E+03
scl*3	1.72E+00	315	1.72E+00	3.15E+03
scl*4	3.60E-01	253	3.60E-01	2.53E+03
scl*5	-1.86E+00	811	-1.86E+00	8.11E+03
scl*6	-1.08E+00	3.7	-1.08E+00	3.59E+01
scl*7	-1.07E+02	26.3	-2.63E+01	2.37E+02
qun*1	2.28E+01	34.1	2.28E+01	3.64E+02
qun*2	-1.94E+02	92.1	-9.21E+01	8.29E+02
qun*3	1.41E+03	688	6.88E+02	7.57E+03
qun*4	-1.01E+03	36.2	-3.62E+01	4.68E+01
sqd*1	4.60E+02	98.5	9.85E+01	4.61E+02
sqd*2	6.63E+02	19	1.90E+01	1.00E+03
sqd*3	-2.77E+02	133	-1.33E+02	5.70E+01
sqd*4	4.33E+02	17.5	1.75E+01	1.35E+03
osh*1	0.00E+00	74.1	0.00E+00	1.75E+02
osh*2	0.00E+00	1118	0.00E+00	7.41E+02
osh*3	0.00E+00	152.7	0.00E+00	1.12E+04
osh*4	0.00E+00	1069.3	0.00E+00	1.53E+03
osh*5	0.00E+00	115.3	0.00E+00	1.07E+04
osh*6	0.00E+00	80.5	0.00E+00	1.15E+03
osh*7	0.00E+00	206.4	0.00E+00	8.05E+02
osh*8	0.00E+00	0	0.00E+00	2.06E+03

Stocks	Mean Catch (Cbar)	Yield-Biom estimate (C/B)	Biom Est (=Cbr/(C/B)) Bbar	Corr. Catch with Year (rCY)	Slope Catch with Year (dC/dY)
shr*1	2040	0.3	6.80E+03	-0.52	248
shr*2	1010	0.3	3.37E+03	-0.15	-56.2
shr*3	153	0.3	5.10E+02	-0.81	-82
shr*4	16.2	0.3	5.40E+01	0.82	3.9
shr*5	16.3	0.3	5.43E+01	-0.40	-4.6
nph*1	1650	0.4	4.13E+03	0.36	52.7
nph*2	3220	0.4	8.05E+03	0.19	79.2
nph*3	8400	0.4	2.10E+04	0.61	374
nph*4	8110	0.4	2.03E+04	0.31	302
nph*5	708	0.4	1.77E+03	0.11	104
nhp*6	6500	0.4	1.63E+04	0.37	438
lob*1	162	0.5	3.24E+02	-0.75	-8.1
lob*2	245	0.5	4.90E+02	-0.61	12.7
lob*3	15.8	0.5	3.16E+01	0.66	1.6
lob*4	284	0.5	5.68E+02	-0.74	-17.8
lob*5	105	0.5	2.10E+02	0.50	7.2
lob*6	105	0.5	2.10E+02	.34	3.9
lob*7	320	0.5	6.40E+02	0.79	25.4
lob*8	45	0.5	9.00E+01	0.54	6.2
lob*9	101	0.5	2.02E+02	-0.02	-0.19
crb*1	1830	0.5	3.66E+03	-0.16	-17
crb*2	1940	0.5	3.88E+03	0.30	35.5
crb*3	626	0.5	1.25E+03	-0.25	-15.7
crb*4	1270	0.5	2.54E+03	0.83	184
crb*5	176	0.5	3.52E+02	-0.10	-2.5
crb*6	896	0.5	1.79E+03	-0.32	-0.32
crb*7	10180	0.5	2.04E+04	-0.22	-0.22
crb*8	717	0.5	1.43E+03	0.40	0.4
crb*9	226	0.5	4.52E+02	-0.05	-0.05
scl*1	1160	0.5	2.32E+03	0.67	0.67
scl*2	8080	0.5	1.62E+04	-0.32	-0.32
scl*3	3150	0.5	6.30E+03	0.86	0.86
scl*4	2530	0.5	5.06E+03	0.18	0.18
scl*5	8110	0.5	1.62E+04	-0.93	-0.93
scl*6	37	0.5	7.40E+01	-0.54	-0.54
scl*7	263	0.5	5.26E+02	-0.78	-53.4
gun*1	341	0.5	6.82E+02	0.17	11.4
gun*2	921	0.5	1.84E+03	-0.68	-97
gun*3	6880	0.5	1.38E+04	0.73	704
gun*4	83	0.5	1.66E+02	-0.74	-504
sqd*1	362	0.3	1.21E+03	0.68	138
sqd*2	985	0.3	3.28E+03	0.44	199
sqd*3	190	0.3	6.33E+02	-0.21	-83
sqd*4	1330	0.3	4.43E+03	0.35	130
osh*1	175	0.1	1.75E+03	0.00	0
osh*2	741	0.1	7.41E+03	0.00	0
osh*3	11180	0.1	1.12E+05	0.00	0
osh*4	1527	0.1	1.53E+04	0.00	0
osh*5	10693	0.1	1.07E+05	0.00	0
osh*6	1153	0.1	1.15E+04	0.00	0
osh*7	805	0.1	8.05E+03	0.00	0
osh*8	2064	0.1	2.06E+04	0.00	0

Stocks	Est Biomass-MSYbio ratio (Xbar)	Est Prodtn-MSYprod ratio (Ybar) (=ftn(Xbar))	MSYbiom Est Bbar/Xbar (Bhat) (=PRQ)	MSYprod Est Pbar/Ybar (Phat) (=PRP)	Phat/Bhat
cod*5	0.25	2.86E-01	6.52E+03	2.57E+03	0.393668
cod*7	0.25	2.86E-01	7.41E+04	3.57E+04	0.48115
cod*8	0.25	2.86E-01	3.95E+04	1.90E+04	0.48115
had*5	0.25	2.86E-01	7.26E+03	4.89E+03	0.67361
had*6	0.25	2.86E-01	1.54E+03	1.04E+03	0.67361
had*7	0.25	2.86E-01	2.44E+04	1.35E+04	0.554803
had*8	0.25	2.86E-01	2.41E+03	1.51E+03	0.628996
sth*5	0.1	6.53E-02	7.10E+03	2.94E+03	0.413621
sth*6	0.1	6.53E-02	5.13E+04	2.60E+04	0.505537
sth*7	0.1	6.53E-02	1.39E+05	7.01E+04	0.505537
wtg*1	0.25	2.86E-01	1.45E+04	6.97E+03	0.48115
wtg*4	0.25	2.86E-01	8.40E+04	4.04E+04	0.48115
wtg*6	0.25	2.86E-01	5.91E+04	2.82E+04	0.477776
sdl*2	1	1.00E+00	5.74E+03	3.16E+03	0.550001
mnk*1	1	1.00E+00	1.46E+04	3.95E+03	0.270001
mnk*2	1	1.00E+00	9.87E+03	2.66E+03	0.270001
mnk*3	1	1.00E+00	5.60E+04	1.85E+04	0.330001
plc*2	0.5	6.71E-01	1.48E+04	2.42E+03	0.163691
plc*4	0.5	6.71E-01	4.60E+04	7.54E+03	0.163994
lsl*1	1	1.00E+00	3.15E+04	6.92E+03	0.22
lsl*2	1	1.00E+00	1.77E+03	3.18E+02	0.18
lsl*3	1	1.00E+00	7.15E+03	1.57E+03	0.22
lsl*4	1	1.00E+00	6.00E+03	1.32E+03	0.22
dog*1	1	1.00E+00	4.70E+04	1.69E+04	0.360001
dog*2	1	1.00E+00	1.61E+04	7.07E+03	0.440001
dog*3	1	1.00E+00	1.71E+04	7.50E+03	0.440001
ray*1	1	1.00E+00	1.97E+04	3.96E+03	0.201527
ray*2	1	1.00E+00	2.95E+04	6.48E+03	0.22
ray*3	1	1.00E+00	1.73E+04	3.80E+03	0.22
ray*4	1	1.00E+00	3.92E+04	8.62E+03	0.22
spt*2	1	1.00E+00	1.05E+04	4.73E+03	0.450001
spt*3	1	1.00E+00	1.86E+04	8.39E+03	0.450001
spt*4	1	1.00E+00	2.04E+04	1.12E+04	0.550001
scd*1	1	1.00E+00	6.33E+05	1.71E+05	0.270001
pil*1	1	1.00E+00	4.67E+01	1.26E+01	0.270001
off*1	1	1.00E+00	4.62E+03	4.62E+02	0.1
off*2	1	1.00E+00	7.24E+04	7.24E+03	0.1
off*3	1	1.00E+00	1.83E+04	1.83E+03	0.1
off*4	1	1.00E+00	2.77E+04	2.77E+03	0.1
off*5	1	1.00E+00	2.56E+04	2.56E+03	0.1
off*6	1	1.00E+00	4.69E+04	4.69E+03	0.1

Stocks	Calcd change in Biomass	Catch* 10%	Chosen change in Biomass (dB/dY)	Est Mean Production (Pbar)
cod*5	-8.20E+01	81.5	-8.15E+01	7.34E+02
cod*7	1.37E+03	926.7	9.27E+02	1.02E+04
cod*8	5.10E+02	494	4.94E+02	5.43E+03
had*5	2.34E+02	127	1.27E+02	1.40E+03
had*6	7.29E+01	27	2.70E+01	2.97E+02
had*7	-4.01E+02	427	-4.01E+02	3.87E+03
had*8	1.14E+01	42.1	1.14E+01	4.32E+02
sth*5	-4.00E+01	21.3	-2.13E+01	1.92E+02
sth*6	4.40E+02	154	1.54E+02	1.69E+03
sth*7	2.37E+03	416	4.16E+02	4.58E+03
wtg*1	3.04E+02	181	1.81E+02	1.99E+03
wtg*4	2.16E+03	1050	1.05E+03	1.16E+04
wtg*6	6.82E+02	739	6.82E+02	8.07E+03
sdl*2	4.26E+03	287	2.87E+02	3.16E+03
mnk*1	-1.11E+03	439	-4.39E+02	3.95E+03
mnk*2	-9.83E+02	296	-2.96E+02	2.66E+03
mnk*3	7.03E+03	1680	1.68E+03	1.85E+04
plc*2	1.45E+02	148	1.45E+02	1.63E+03
plc*4	3.92E+03	460	4.60E+02	5.06E+03
lsl*1	9.95E+02	629	6.29E+02	6.92E+03
lsl*2	-2.95E+02	35.3	-3.53E+01	3.18E+02
lsl*3	1.60E+03	143	1.43E+02	1.57E+03
lsl*4	1.05E+03	120	1.20E+02	1.32E+03
dog*1	-7.43E+03	1880	-1.88E+03	1.69E+04
dog*2	7.45E+02	643	6.43E+02	7.07E+03
dog*3	6.80E+03	682	6.82E+02	7.50E+03
ray*1	3.00E+01	393	3.00E+01	3.96E+03
ray*2	3.99E+03	589	5.89E+02	6.48E+03
ray*3	8.55E+02	345	3.45E+02	3.80E+03
ray*4	4.87E+03	784	7.84E+02	8.62E+03
spt*2	-1.88E+03	525	-5.25E+02	4.73E+03
spt*3	-2.30E+03	932	-9.32E+02	8.39E+03
spt*4	2.42E+03	1022	1.02E+03	1.12E+04
scd*1	-9.13E+04	19000	-1.90E+04	1.71E+05
pil*1	-6.67E+00	1.4	-1.40E+00	1.26E+01
off*1	0.00E+00	46.2	0.00E+00	4.62E+02
off*2	0.00E+00	724.3	0.00E+00	7.24E+03
off*3	0.00E+00	183.3	0.00E+00	1.83E+03
off*4	0.00E+00	277.1	0.00E+00	2.77E+03
off*5	0.00E+00	256	0.00E+00	2.56E+03
off*6	0.00E+00	468.6	0.00E+00	4.69E+03

From the $\bar{x}$ estimates, the corresponding $\bar{y}$ values are calculated from the production function, and hence $\hat{p}$ calculated using

$$\hat{p} = \bar{p}/\bar{y} \qquad \ldots(50)$$

These calculations are summarised in Table 10 below.

Stocks	Mean Catch (Cbar)	Yield-Biom estimate (C/B)	Biom Est (=Cbr/(C/B)) Bbar	Corr. Catch with Year (rCY)	Slope Catch with Year (dC/dY)
cod*5	815	0.5	1.63E+03	-0.32	-41
cod*7	9267	0.5	1.85E+04	0.61	684
cod*8	4940	0.5	9.88E+03	0.50	255
had*5	1270	0.7	1.81E+03	0.05	164
had*6	270	0.7	3.86E+02	.68	51
had*7	4270	0.7	6.10E+03	-0.57	-281
had*8	421	0.7	6.01E+02	0.19	8
sth*5	213	0.3	7.10E+02	-0.22	-12
sth*6	1540	0.3	5.13E+03	0.68	132
sth*7	4160	0.3	1.39E+04	0.83	710
wtg*1	1810	0.5	3.62E+03	0.34	152
wtg*4	10500	0.5	2.10E+04	0.88	1080
wtg*6	7390	0.5	1.48E+04	0.61	341
sdl*2	2870	0.5	5.74E+03	0.85	2130
mnk*1	4390	0.3	1.46E+04	-0.73	-332
mnk*2	2960	0.3	9.87E+03	-0.62	-295
mnk*3	16800	0.3	5.60E+04	0.97	2110
plc*2	1480	0.2	7.40E+03	0.40	29
plc*4	4600	0.2	2.30E+04	0.96	783
lsl*1	6290	0.2	3.15E+04	0.70	199
lsl*2	353	0.2	1.77E+03	-0.95	-59
lsl*3	1430	0.2	7.15E+03	0.91	320
lsl*4	1200	0.2	6.00E+03	0.87	209
dog*1	18800	0.4	4.70E+04	-0.79	-2970
dog*2	6430	0.4	1.61E+04	0.47	298
dog*3	6820	0.4	1.71E+04	0.98	2720
ray*1	3930	0.2	1.97E+04	0.01	6
ray*2	5890	0.2	2.95E+04	0.60	797
ray*3	3450	0.2	1.73E+04	0.42	171
ray*4	7840	0.2	3.92E+04	0.56	974
spt*2	5250	0.5	1.05E+04	-0.44	-939
spt*3	9320	0.5	1.86E+04	-0.60	-1150
spt*4	10220	0.5	2.04E+04	0.38	1210
scd*1	190000	0.3	6.33E+05	-0.84	-27400
pil*1	14	0.3	4.67E+01	-0.89	-2
off*1	462	0.1	4.62E+03	0.00	0
off*2	7243	0.1	7.24E+04	0.00	0
off*3	1833	0.1	1.83E+04	0.00	0
off*4	2771	0.1	2.77E+04	0.00	0
off*5	2560	0.1	2.56E+04	0.00	0
off*6	4686	0.1	4.69E+04	0.00	0

APPENDIX VI

CATCH RATE FUNCTION

a) **Mathematical Development**

For a single species fishery, the relationship between catch rate ratio (catch per unit effort divided by some standard value such as base year catch per unit effort) and biomass ratio (exploited biomass divided by corresponding standard biomass) would have to conform to the following characteristics:

(i) when b = 0, c = 0

(ii) when b is small c is proportionate to b

(iii) when b = 1, c = 1 (the "status quo" point)

(iv) when b = 1, the marginal effect on b of a change in c can vary between species and stocks

(v) when b approaches infinity there will be a theoretical asymptotic value of c

A function having this form is:

$$c = b/(p + (1 - p)b) \qquad ...(60)$$

where p is some parameter

Differentiating

$$dc/db = p/(p + (1 - p)b)^2 \qquad ...(61)$$

This function satisfies the above criteria, and:

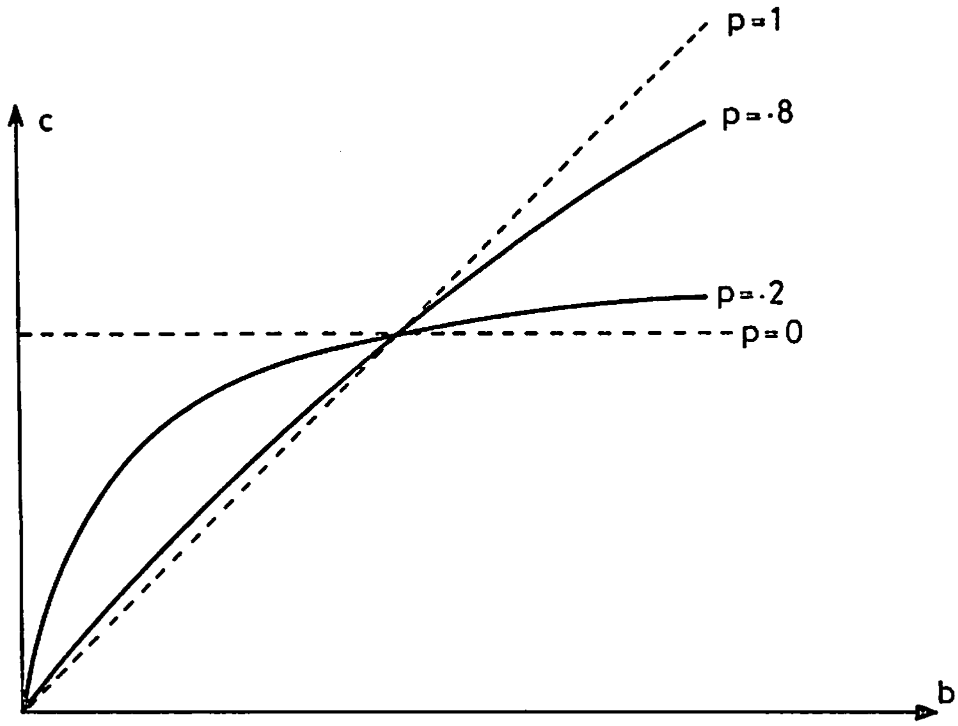
$$\text{when } b = 1,\ dc/db = p$$

$$\text{when } b = 0,\ dc/db = 1/p$$

Thus the parameter p is the gradient of the curve at the point (1,1).

The variation of catch rate function with parameter p is illustrated below:

Figure 10



Extreme cases are:

p = 0: zero catch rate if b = 0
constant catch rate if b $>$ 0

p = 1: density-proportionate catch rate

Divergence from linearity will be greatest in the case of species which maintain shoaling density when the biomass varies. Consider the "p = .2" curve. If technology can maintain the efficient utilisation of "hours fishing" (e.g. purse seiners), then catch rates will not change greatly if biomass rises or falls. Clearly though, if biomass fell to a very low level catch rates would start to fall off more rapidly in the close-to-linear section of the curve.

Divergence from linearity will be least with species not exhibiting shoaling behaviour, as in the "p = .8" curve. Even if a species distributed itself uniformly, in which case the catch per active fishing hour would be density-proportionate, there would still be an overhead time-cost which increases relative to active fishing time if catches increase with biomass. Thus even in such an extreme case there would still be some divergence from linearity.

It is assumed in a mixed fishery that catch rates will respond to change in biomass as if there were parallel, independent fisheries for each of the constituent species. With this simplifying assumption the above model is applied to all fisheries and is implemented in equation (18) as follows.

$\mathbf{c} = CRM_{gf}$ for a given species/ground

$\mathbf{b} = BIO_{fk}/IBIO_{fk}$ for the stock on that ground

$\mathbf{p} = CRP_{fk}$ for the stock on that ground

the appropriate stock is identified by:

$\mathbf{k} = KIE_{gf}$

The catch rate parameters are subjectively determined, with the following general criteria:

(i) High p-values are assigned to demersal species not exhibiting strong shoaling behaviour, and to shellfish.

(ii) Low p-values are assigned to stocks of pelagic species, but the p-value will be higher if such a stock were reduced to a very low current biomass, bringing the status-quo point away from the asympstotic value of c and towards the linear section.

It should be emphasised that the same function and characteristic shape is applied to all stocks/species, but with different linear scaling factors such that the status-quo point can be at any point on the curve (typically, below the "knee" of the curve for demersal and above for pelagic species). Thus an alternative parameterisation of this function would define the ratio of status-quo catch rate to theoretical asymptotic catch rate.

Tentative estimates for catch rate parameters, as provided by MAFF, Lowestoft are listed in Table 10 below. The same value is assumed to apply to all stocks of a species unless otherwise stated.

TABLE 10

Species		Catch Rate Parameter
1	cod	.9
2	had	.9
3	sth	.9
4	wtg	.9
5	hke	.9
6	blw	.1
7	npt	.1
8	sdl	.1
9	mnk	.9
10	plc	.9
11	lsl	.9
12	sol	.9
13	dog	.5
14	ray	.9
15	her	.1
16	spt	.1
17	mac	stock 1 .9
		stock 2 .5
18	scd	.1
19	pil	.1
20	off	.9
21	shr	.9
22	nph	.9
23	lob	.9
24	crb	.9
25	scl	.9
26	qun	.9
27	sqd	.5
28	osh	.9

TABLE 10

Species		Catch Rate Parameter	
1	cod	.9	
2	had	.7	
3	sth	.9	
4	whg	.9	
5	hke	.9	
6	blw	.1	
7	npt	.1	
8	sal	.1	
9	mnk	.9	
10	plc	.9	
11	lel	.9	
12	sol	.9	
13	dog	.5	
14	ray	.9	
15	her	.1	
16	spt	.1	
17	mac	.8	(stock 1)
		.5	(stock 2)
18	scd	.1	
19	pil	.1	
20	oth	.9	
21	sur	.5	
22	nph	.9	
23	lch	.9	
24	cro	.9	
25	scl	.9	
26	gun	.9	
27	sqd	.5	
28	osh	.9	

APPENDIX VII

BIOLOGICAL FEEDBACK PHASE - PROGRAM DOCUMENTATION

The programs associated with FPM are written in UCSD Pascal and currently implemented on an Apple IIe micro computer. However, because of the complexity and size of the model and the vast online data storage requirements, all programs will be transferred to the IBM PC/XT.

For each phase of the model the programs exist as separate units, but on transfer to the IBM will be integrated to form the whole model as shown below:-

	Model Phase	Program Written
	PII	BFEXEC, OCP, ACP
Main Model {	ALE	ALE
	BF	BF
	EFS	-

The programming undertaken for the BF phase not only involves program BF but also includes programs OCP and BFEXEC (from the PII phase) which set up data files to be read by program BF.

Program OCP

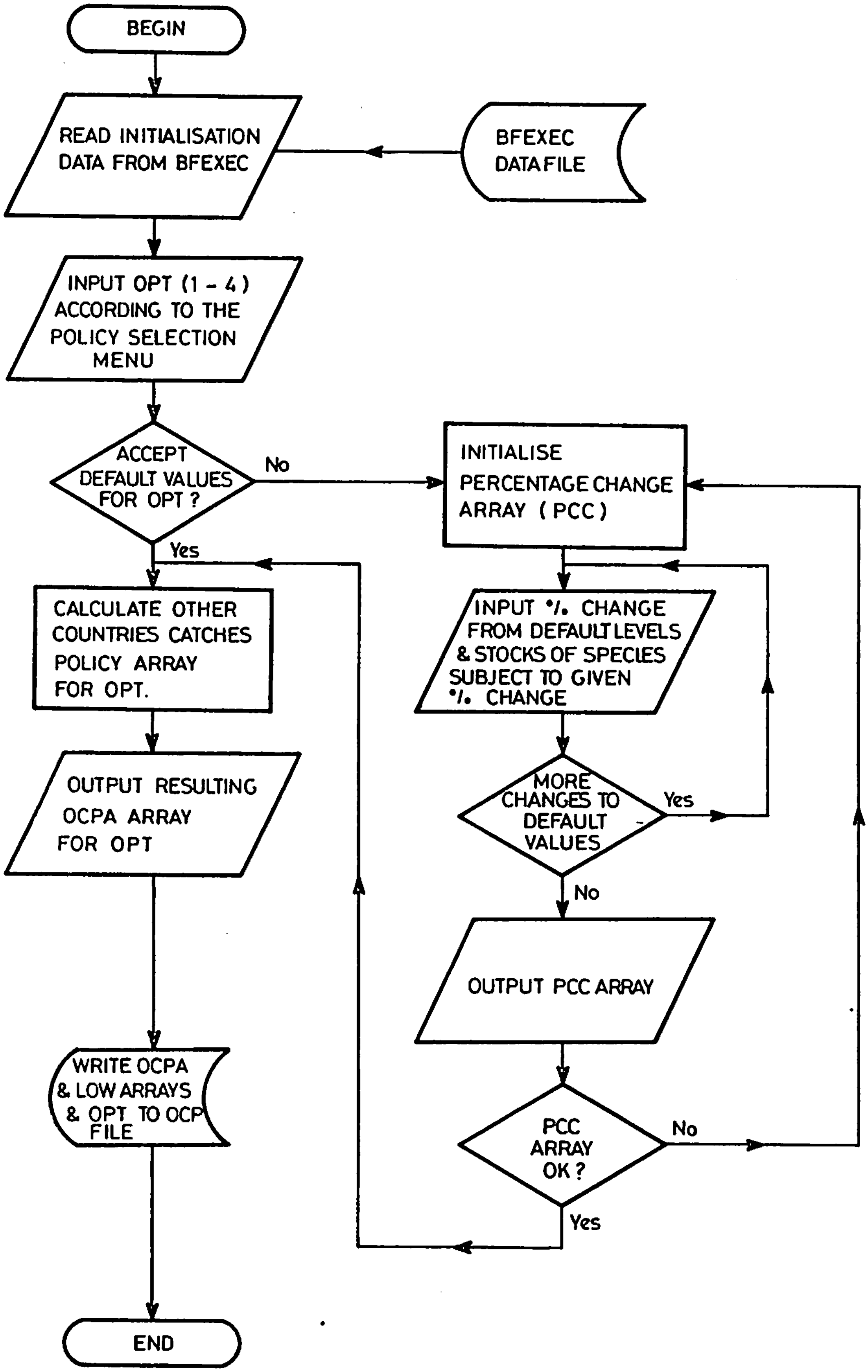
Program OCP (Other Countries Catches Policy) is an interactive policy input routine which has error checking and editing facilities on numerical input. The program offers the policy maker a choice of four options regarding other countries catches and, according to the option selected (OPT), the OCPA array (Other Countries Catches Policy Array) is calculated and written to disk file OCP along with variable OPT and array LOW. The array LOW, whose boolean values are initially set to false, becomes true if OPT = 1 and the UK catch of species F on stock k is low.

This program requires 'initialisation data' which is obtained by reading data file BFEXEC. The following arrays are transferred from the BFEXEC file to program OCP:- ITCK, IBIO, IOCK & NKF. An outline flowchart of OCP program is presented in Fig. 11.

Program BFEXEC

The BFEXEC program, which is not used by the policy maker, enables initialisation data to be transferred from arrays held on disk file BFEXEC.DATA to corresponding arrays declared by programs OCP & BF. User-editing facilities allow the arrays to be changed wholly, partially or by selected individual elements. The following arrays are contained in the BFEXEC.DATA file:-

(i)	KIE	(Grounds, Species)	Stock Identification Element
(ii)	NKF	(Species)	No. of stocks of species
(iii)	ITCFG	(Grounds, Species)	Initial Total Catch of Fish Species from Ground
(iv)	ITCK	(Species, Stocks)	Initial (base year) total UK catch from stock
(v)	CRP	(Species, Stocks)	Catch Rate Parameter
(vi)	IOCK	(Species, Stocks)	Initial Other Countries Catch of Stock of Species
(vii)	IBIO	(Species, Stocks)	Initial biomass
(viii)	PRP	(Species, Stocks)	Production rate parameter
(ix)	PRQ	(Species, Stocks)	Production rate parameter



PROGRAM OCP-OUTLINE FLOWCHART

Fig.11

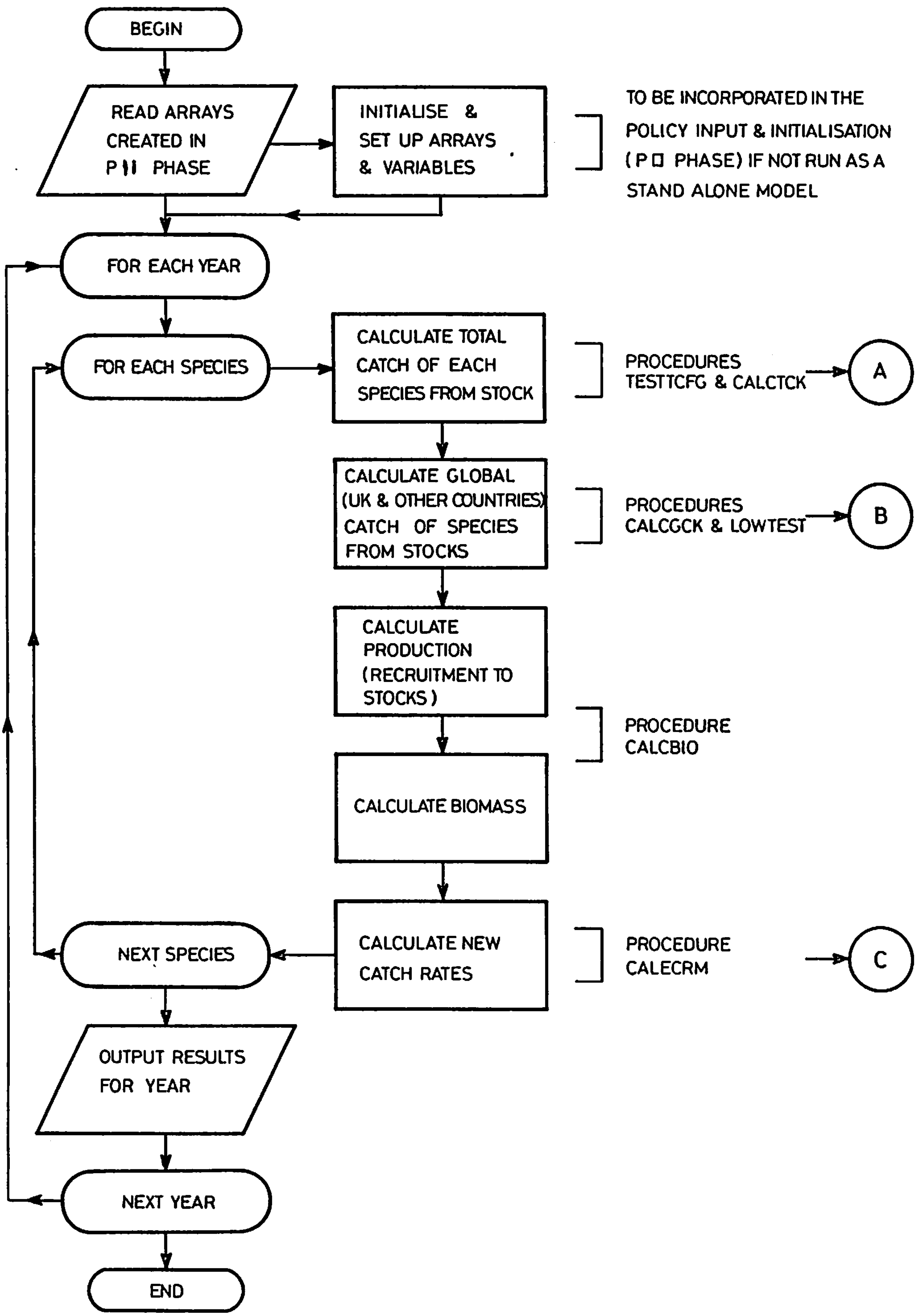
The programming methods and flexible file structures will be applied to the initialisation of other phases using further EXEC files. On transfer to the IBM these EXEC files may be held separately or perhaps grouped together to form a large initialisation data file for the whole model.

Biological Feedback Program

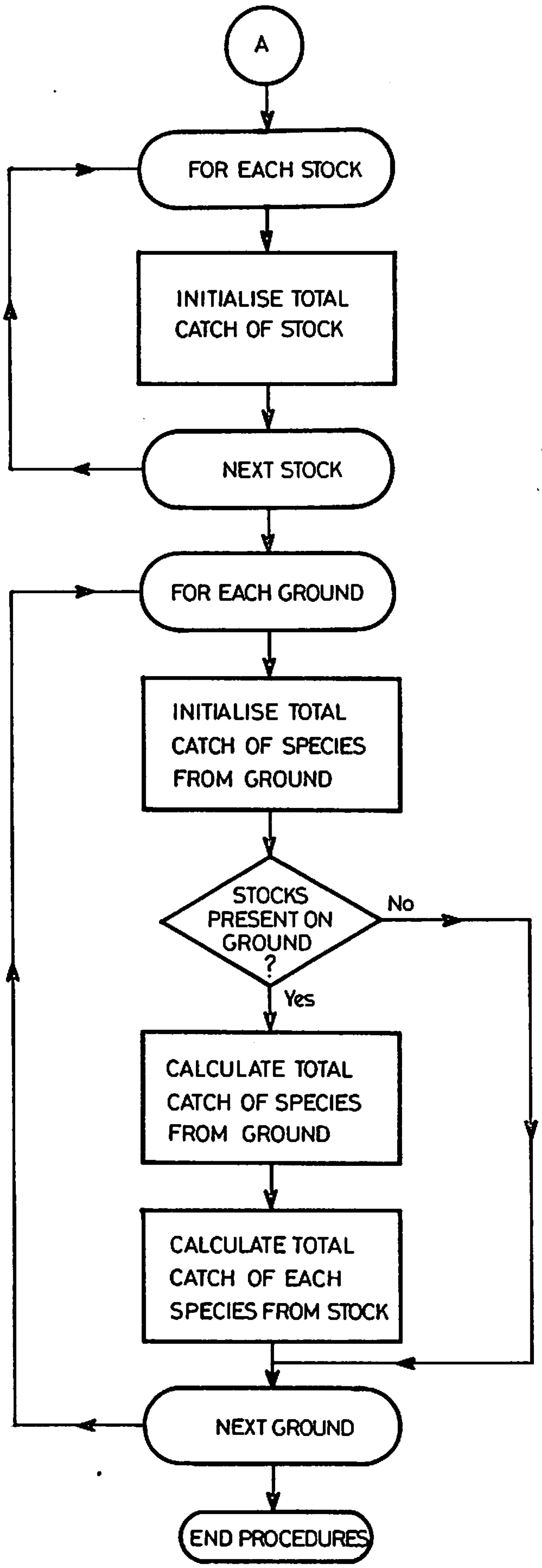
The biological feedback program if used as a stand-alone model, requires access to data files OCP & BPEXEC.DATA in order to read initialisation data containing the following arrays:- PRP, PRQ, CRP, KIE, NKF, ITCFG, IBIO, OCPA & LOW.

In the case of incorporating this program in the main model, then the above information is either created in the PII phase or derived from calculations performed in other phases of the model and passed to the BF program.

The program structure is presented in the following detailed flow diagrams together with an account of all variables used.

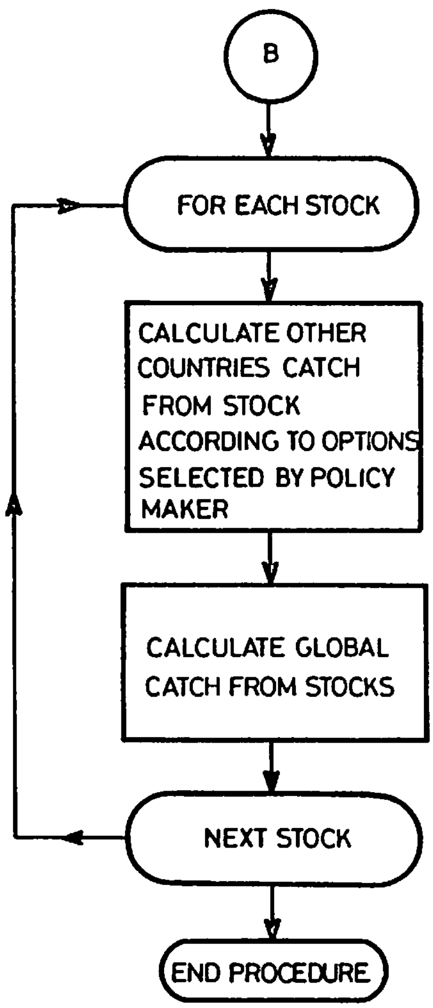


BIOLOGICAL FEEDBACK PROGRAM - OUTLINE FLOWCHART Fig.12

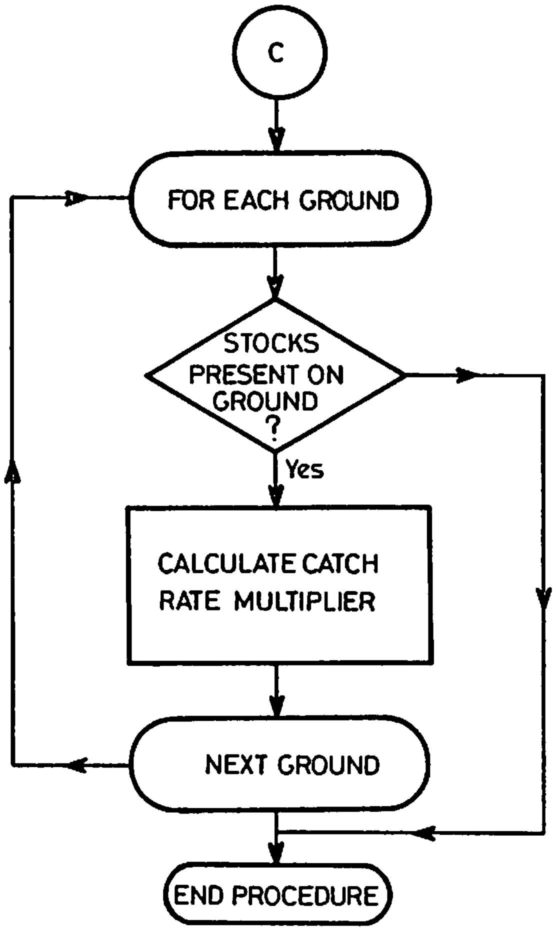


CALCULATE TOTAL CATCH FROM STOCKS

Fig.13



CALCULATE GLOBAL CATCH FROM STOCKS Fig.14



CALCULATE NEW CATCH RATES

Fig.15

Biological Feedback Program - Variables List

I	loop control variables	Years
G		Grounds
K		Stocks
F		Fish species

Arrays

BIO	(F,K)	Biomass
CRM	(G,F)	Catch Rate Multiplier
CRP	(F,K)	Catch Rate Parameter
IBIO	(F,K)	Initial Biomass
ITCFG	(F,K)	Initial Total Catch of Fish Species from Ground
KIE	(G,F)	Stock Identification Element
LOW	(F,K)	Low ratio test on UK catches (Boolean array)
NKF	(F)	Number of Stocks of Fish Species
OCPA	(F,K)	Other Countries Catches Policy
PRP	(F,K)	Production rate parameter
PRQ	(F,K)	Production rate parameter
TCFG	(G,F)	Total Catch of Fish Species from Ground
TCK	(F,K)	Total Catch of Stock

Single Variables

GCK	Global catch from stock
OCK	Other countries catch
OPT	Option from PII phase (program OCP)
PRD	Production (recruitment to exploited biomass)