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A POTENTIAL ENVIRONMENTAL FISHERIES PRODUCTION MODEL FOR BANANA PRAWNS IN KEREMA BAY AND THE GULF OF PAPUA

by

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A potential environmental fisheries production model for banana prawns in Kerema Bay and the Gulf of Papua.

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Abstract

An environmental (rainfall) fisheries production model *CLIMPROD*, (FAO, 1993) of the form linear-quadratic-exponential was fitted to annual yield and effort data for banana prawns caught in the Gulf of Papua fishery and annual rainfall at Bereina in the southeast of the region. The same was carried out for Kerema Bay banana prawn yield and effort and annual rainfall at Bereina. Most of the variation in annual yield of banana prawns in the Gulf of Papua fishery and in the Kerema Bay fishing ground appears to be attributable to interannual variation in rainfall in the southeastern part of the Gulf of Papua region.

Introduction

The Gulf of Papua prawn trawl fishery is a relatively small fishery compared to the Australian Gulf of Carpentaria prawn fishery. Both target banana prawn Penaeus merguiensis (though on recent years the latter has targeted tiger prawn also). Banana prawn yield in the Gulf of Papua fishery during 1974 to 1993 ranged from 258 metric tonnes (in 1975) to 673 mt (in 1985) (Table 1), whereas banana prawn yield in the Gulf of Carpentaria during 1970 to 1992 ranged from 1670 mt (in 1970) to 12696 mt (in 1974) (Pownall, 1994).

Studies by Polovina and Opnai (1989) indicated that the annual yield of banana prawns in the Gulf of Papua fishery was inversely related to the minimum monthly rainfall at Baimuru, near Kikori (Fig. 1) during September to December of the preceding year, and suggested that this was perhaps related to postlarval settlement or the survival of early benthic juveniles.

Quadratic regression of banana prawn catch and CPUE from the important Kerema Bay fishing ground (in the Gulf of Papua) on Bereina annual rainfall suggested a parabola relationship between prawn abundance and annual rainfall in the southeastern part of the Gulf of Papua (Evans and Opnai, 1995; Evans et al, 1995).

Other studies (Gwyther, 1980; Polovina and Opnai, 1989; Evans et al, 1995a; Kare et al, 1995) reported on the seasonality, distribution and abundance of recruit-sized banana prawns in the Gulf of Papua and suggested that sub-adult prawns are "flushed" out of estuarine nursery areas at the onset of the monsoon season. When the monsoon season is delayed or weak in nature the offshore migration of juvenile/ sub-adult prawns may be affected, based upon the results of research in the Gulf of Carpentaria (Staples and Vance, 1987). Thus the availability of banana prawns to capture, area by area, is also dependent on the amount and timing of the monsoon in the different parts of the region.

Rainfall varies considerably over the region and there are different regimes (see Figure 1). Monthly variability as a percentage of the maximum is perhaps greatest at Bereina (personal communication, David Vance, CSIRO, May 1995).

Material and Methods

The Kerema Bay data set was used for the analyses as this area is by far the most important in terms of yield (Gwyther, 1980a) (Table 1) along with Bereina rainfall (a station relatively close, in the southeast), which record was obtained by DFMR from the National Weather Service in 1994 (Table 2). As Kerema Bay is by far the most important fishing ground in terms of yield and effort, banana prawn yield and effort data for the Gulf of Papua as a whole was also used along with Bereina rainfall in a separate computer run of the CLIMPROD programme. Data entry was in terms of metric tonnes of tails and thousands of trawl hours, and mm of rain. It should be noted that Kerema Bay data consists of the total catch and effort for the entire southeastern region of the Gulf of Papua: comprising West Kerema, Kerema Bay, Freshwater Bay, Lakekamu Estuary and Iokea data set.

Yield, effort and annual rainfall were entered in the CLIMPROD programme (FAO, 1993) at the CSIRO's Division of Fisheries Laboratory, Cleveland, Australia and the expert system was used to select an appropriate model based upon the known information on its biology in the Gulf of Papua. The coefficient of determination R^2 was given by the programme along with the values of the constants. The model was validated in each case by the CLIMPROD programme's validation process in which the percentage variation in R^2 resulting from the elimination of a single data point from the set is calculated for all of the points. The print-outs from the runs were collated and attached. A straight linear (Schaeffer) model was also fitted to each data set in order to investigate the variation in yield attributable to interannual variation in rainfall in the southeast of the region.

Results

An environmental (rainfall) fisheries production model *CLIMPROD*, (FAO, 1993) was fitted to annual yield and effort data for banana prawns caught in the Gulf of Papua fishery and annual rainfall at Bereina in the southeast of the region. The same was carried out for Kerema Bay banana prawn yield and effort and annual rainfall at Bereina.

The model fitted was selected by the *CLIMPROD*, FAO programme using its "expert" system (linear-quadratic-exponential):

CPUE = aV^(1+b) + cV^(2+b) + dV^(2b)E,

where a, b, c, and d are constants, V is the annual rainfall and E is the annual fishing effort. This is a production model combining on the one hand the linear (Schaeffer) model between the catch per unit of fishing effort (CPUE) and the fishing effort E, and on the other a quadratic (parabola) relationship between CPUE and the environmental variable V when it influences the abundance and a power relationship between the CPUE and V when it influences the catchability coefficient.

The values of the constants are given in the details of the computer print-outs attached. The coefficient of determination R^2 was 0.76 (Gulf of Papua/Bereina data) and 0.82 (Kerema Bay/Bereina data). The straight linear (Schaeffer) production model (CPUE = a + b.E) was also fitted the each of the two data sets and resulted in R^2 values of 0.25 in each case. Thus most of the variation in annual yield of banana prawns in the Gulf of Papua fishery and in the Kerema Bay fishing ground appears to be attributable to interannual variation in rainfall in the southeastern part of the region.

The optimum yields for three different levels of annual rainfall (intermediate, excessive and drought) were given by the model for the Gulf of Papua/Bereina and Kerema Bay/Bereina data sets (Gulf of Papua/Bereina and Kerema Bay/Bereina run print-outs).

For the Kerema Bay/Bereina data set, Y_{max} and production (Y) isovalues were also generated by the CLIMPROD programme for environment (V, annual rainfall from 436 to 1888 mm) on the y-axis and effort (E, annual fishing effort from 17 to 52 thousand trawl hours) (Kerema Bay/Bereina print-out). Y_{max} occurs at intermediate levels of rainfall at Bereina.

Discussion

The models (linear-quadratic-exponential) fitted to the Kerema Bay/Bereina and Gulf of Papua/Bereina data sets were each validated by the validation process. Validation of the model for the Kerema Bay/Bereina data set is attached as print-outs. (See R^2 (%) time plot: the closer the 100% value the different yearly values are, the better the model fitting is. Empirically, it can be assumed that yearly ratios greater than 140% or lower than 60% will invalidate the model fitting (FAO, 1993).

The predicted and observed CPUE series (kg/trawl-hour) for the Gulf of Papua/Bereina data set closely matched which suggested that the model was in fact appropriate. The same was true for the Kerema Bay/Bereina data set (and the match was even closer).

The highest yields in Kerema Bay fishing ground and in the Gulf of Papua fishery are obtained in years when there is an intermediate level of annual rainfall at Bereina (1217 mm rainfall) (GOP/Bereina run print-out and Kerema Bay/Bereina run print-out). In years where there is high (1682 mm) or low (753mm) annual rainfall at Bereina, yields are lower (print-outs): for Kerema Bay/Bereina, yields appear to be equally reduced by excessive rainfall and drought, but this is not true for the Gulf of Papua yield and Bereina rainfall (there is greater reduction in years of excessive rainfall). However, for both Kerema Bay and the Gulf of Papua fishery as a whole, it appears that more effort has to be expended in wetter than average years than in drier than average years to obtain the maximum equilibrium catch (i.e. the optimum yield for the rainfall level). This may be related to reduction in postlarval settlement and/or the survival of newly-settled juveniles (Polovina and Opnai, 1989).

Caution should be excercised with regard to the interpretation of the results for a number of reasons:

(1) The length of the years in the data set is too short (borderline);

(2) Using three functions - linear, quadratic and a power function in the model makes it statistically easier to explain the observations by chance.

(3) The effort is not standardised and the assumption of the model is that it is. It is difficult to standardise because technological advances went occurred at a non-uniform rate.

(4) The rainfall regime at Bereina is similar to that at the Fly Estuary but not similar to that at Kikori and Kerema.

(5) Although the percentage variation in R^2 is reasonable, there is perhaps too much change in the constants when the model is put through the jacknife validation process.

(6) There is only half a parabola and the assumption of the model is that the relation of MSY with rainfall is obviously parabolic.

Suggestions for Further Research

Separation of the banana prawn yield and effort data area by area for the 12 years 1977 to 1988 has been carried out since these analyses were completed at Cleveland. Additional rainfall data has also been obtained for Kerema town and Erave in the middle/upper reaches of the Kikori drainage basin and Lake Kutubu in the Southern Highlands. These data will be matched with the yield and effort data from the appropriate fishing area and entered in the CLIMPROD programme. David Vance at the CSIRO Laboratory, Cleveland is currently carrying out these additional runs. The rainfall regimes at Kutubu, Erave, Baimuru and Kerema are similar and the rainfall data may also be averaged.

Acknowledgements

I would like to thank David Vance and David Die at the CSIRO Division of Fisheries for their kind help and collaboration with this work.

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Summary

An environmental (rainfall) fisheries production model *CLIMPROD*, (FAO, 1993) of the form linear-quadratic-exponential was fitted to annual yield and effort data for banana prawns

caught in the Gulf of Papua fishery and annual rainfall at Bereina in the southeast of the region. The same was carried out for Kerema Bay banana prawn yield and effort and annual rainfall at Bereina. Most of the variation in annual yield of banana prawns in the Gulf of Papua fishery and in the Kerema Bay fishing ground appears to be attributable to inter-annual variation in rainfall in the southeast of the Gulf region.

The model fitted was selected by the *CLIMPROD*, FAO programme using its "expert" system (linear-quadratic-exponential): CPUE = aV^(1+b) + cV^(2+b) + dV^(2b)E, where a, b, c, and d are constants, V is the annual rainfall and E is the annual fishing effort. This is a production model combining on the one hand the linear (Schaeffer) model between the catch per unit of fishing effort (CPUE) and the fishing effort E, and on the other a quadratic (parabola) relationship between CPUE and the environmental variable V when it influences the abundance and a power relationship between the CPUE and V when it influences the catchability coefficient.

The models fitted to the Kerema Bay/Bereina and Gulf of Papua/Bereina data sets were each validated by the validation process. The predicted and observed CPUE series (kg/trawl-hour) for the Gulf of Papua/Bereina data set closely matched which suggested that the model was appropriate. The same was true for the Kerema Bay/Bereina data set (the match was closer). The highest yields are obtained in years when there is an intermediate level of annual rain at Bereina (ca. 1200 mm).

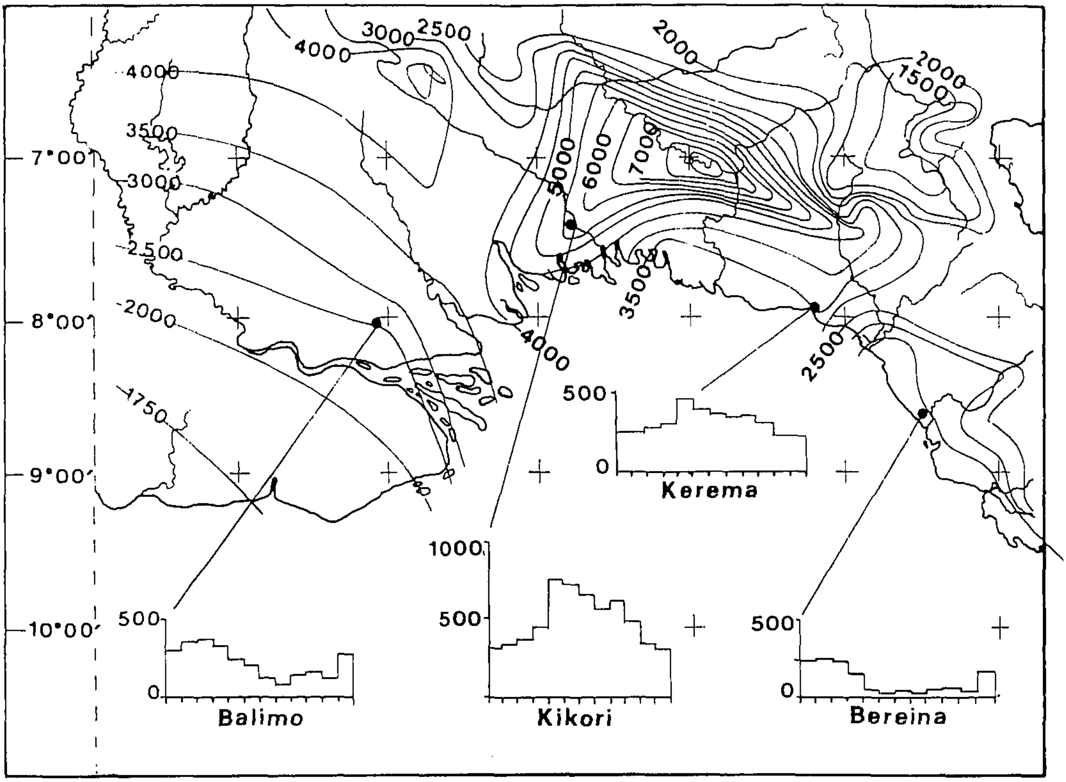


Figure 1. Map of mean annual rainfall (mm) for the Gulf of Papua, showing average monthly rainfall for selected localities. (Source: Anon, 1974)

Table 1: Annual catches (in metric tonnes of tails) and fishing effort (in thousands of trawl hours) of all prawn species combined, banana prawns in the Gulf of Papua, and banana prawns in Kerema Bay.

	G.O.P.			Kerema Bay	
Year	Effort	All Prawns	Banana Prawns	Effort	Banana Prawns
1974	49	733	442	---	---
1975	17	410	258	---	---
1976	48	780	462	---	---
1977	46	562	291	26	221
1978	71	997	531	38	378
1979	78	1221	636	35	350
1980	81	1178	668	38	404
1981	73	1026	517	34	314
1982	69	891	426	33	264
1983	62	1151	638	32	376
1984	75	1114	477	38	296
1985	78	1334	673	37	371
1986	93	1321	571	48	344
1987	91	1165	601	47	304
1988	76	1100	557	---	---
1989	95	1174	591 * ---	---	---
1990	70	873	449	---	---
1991	46	649	371	---	---
1992	41	860	475	---	---
1993	47	756	375	---	---

* Predicted from regression of total catch with banana catch.

MR55002.REC NATIONAL WEATHER SERVICE
FORM R3 TABLE 2: MONTHLY AND YEARLY RAINFALL , BEREINA.

STN NUMBER: 55002 LATITUDE: 08 39 SOUTH LONGITUDE: 146 30 EAST
NAME: BEREINA AGRIC. STATION ELEVATION: 15 METRES

UNIT USED IS IN MILLIMETRES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1976				87.8	118.2	60.8	39.4	29.0	21.8	27.4	131.0	112.2	627.6
1977	285.0	190.0	421.0	147.0	181.0	82.0	12.0	2.0	1.0	85.0	35.0	241.0	1682.0
1978	313.4	89.0	209.8	201.0	113.8	40.0	56.6	21.8	37.2	36.2	12.6	116.4	1247.8
1979	398.0	406.0	71.0	134.2*	82.0	1.0	90.0	36.0	31.0	11.0	103.0	82.0	~~1311.0~~ 1445.2
1980	290.0	169.0	200.0	87.0	91.0	5.0	22.0	0.0	15.0	9.0	0.0	109.0	997.0
1981	385.0	222.0	372.0	8.0	11.0	2.0	12.0	70.0	0.0	2.0	23.0	98.0	1205.0
1982	201.6	475.2	215.8	137.0	20.6	88.0	21.4	44.0	27.0	196.6	53.6	137.8	1618.6
1983	188.6	82.4	195.2	103.4	98.8	25.2	0.4	47.6	0.0	0.8	0.2	10.0	752.6
1984	188.8	67.6	122.6	84.2	114.2	66.2	62.8	18.2	25.6	41.2	27.2	150.4	969.0
1985	149.8	283.0	153.2	149.6	12.4	25.4	33.4	22.4	6.8	62.0	12.0	350.8	1260.8
1986	102.8	189.8	458.4	138.4	97.2	45.2	13.2	60.6	123.0	33.4	185.6	130.2	1577.8
1987	291.0	345.6	151.8	322.0	46.6	34.4	2.8	22.6	12.2	87.2	23.2	85.4	1424.8
1988													
1989													
1990													
1991													
1992	407.2	220.2	205.2	145.2	15.0	0.0	3.2	24.8	6.2	71.4	68.2	114.4	1281.0
1993					32.0	96.2	0.0	19.6	11.8	0.0	5.2	205.8	370.6
1994	299.8	171.4	71.0										542.2

RAINFALL SUMMARY FOR PERIOD 1976 TO 1994, USING ALL AVAILABLE DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MAXIMUM	407.2	475.2	458.4	322	181	96.2	90	70	123	196.6	185.6	350.8	1682
AVERAGE	269.3	223.9	219.0	134.2*	73.8	40.8	26.4	29.9	22.8	47.4	48.6	138.8	887.8
MINIMUM	102.8	67.6	71	8	11	0	0	0	0	0	0	10	0
RAIN YEARS	13	13	13	12	14	14	14	14	14	14	14	14	19

* Substitution of mean for missing data 1979, April

Gulf of Papua Banana Prawn Yield and Effort with Bereina Annual Rainfall, 1977-87 and 1992: CLIMPROD (FAO).

EvansBE2.CLI Gulf of Papua Yield & Effort (Banana Prawn), Bereina annual rain

MODEL FITTING : 0 CPUE=a+b.E (Marquardt Method)
umber of years used for fitting : 12

Iteration n° 6 Trials -2 Total trials 13
lambda: 81.000000 alpha: 4.000000 delta: 0.0000

Number of iterations :	0 it	1 it	6 it
Converging factor R2 :	25.1739	25.1739	25.1739

	Initial Coeff	Previous Coeff	Variation(%)	Actual Coeff
a	11.727988	11.727988	-0.00	11.727988
b	-0.055555	-0.055555	-0.00	-0.055555

Press any key and read comments on this model

C L I M P R O D

MODEL: CPUE = a + b E

This is the conventional linear production model, usually named "Schaefer model".

It does not take into account any environmental influence on the production (white noise).

```
C L I M P R O D
Current known facts
        Model = CPUE=a+b.E
         File = C:\CLIMPROD\EVANSBE2.CLI          Min_E = 41.000000
        Max_E = 93.000000                      Nb_years = 13
   Nb_exploit = 1                              Variance = 2.767707
Var.residuals = 2.070968                             R2 = 25
            a = 11.7279882446                         b = -0.0555547320
```

C L I M P R O D

MODEL: CPUE = aV^(1+b) + c... + dV^(2b) E

This is a gener...ion model combining on the one hand the linear model (Schaefer model) between the CPUE and the fishing effort E, on the other a quadratic (parabola) relationship between CPUE and the environmental variable V when it influences the abundance and a power relationship between the CPUE and V when it influences the catchability coefficient.

This kind of non-monotonic equation is useful when the relationship between CPUE and V is shaped (optimal central value). The graph MSY versus V must OBVIOUSLY be parabolic. If not, the data-set does not justify such a model and it is recommanded to use another model (CPUE = (aV^b) exp(cV^d) for instance).

Moreover, when using these formulae in a non-equilibrium condition

M E S S A G E S

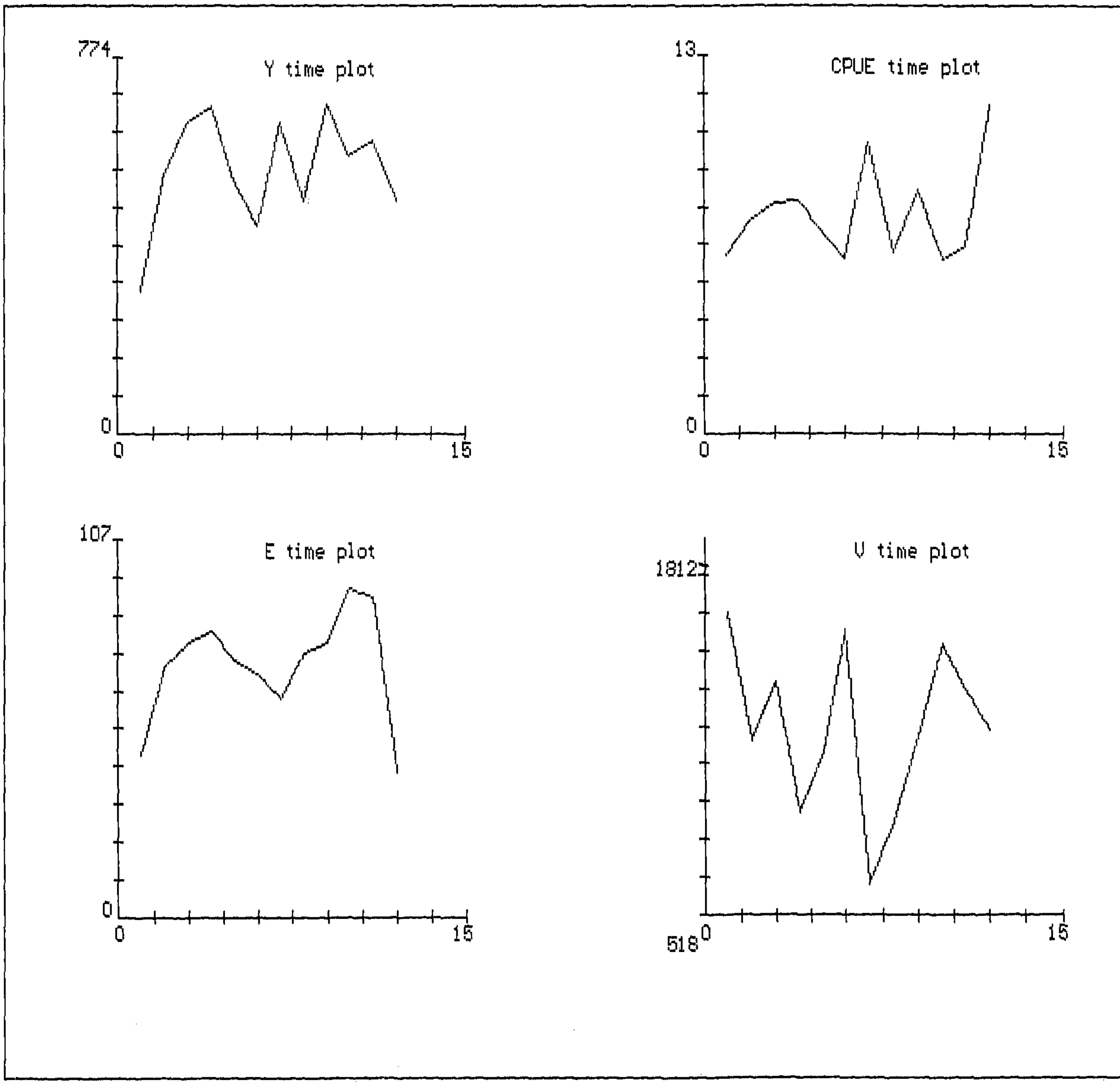
Use arrow keys to scroll the screen (if necessary) and ESC key to continue

C L I M P R O D

and a power relationship between the CPUE and V when it influences the catchability coefficient.

This kind of non-monotonic equation is useful when the relationship between CPUE and V is shaped (optimal central value). The graph MSY versus V must OBVIOUSLY be parabolic. If not, the data-set does not justify such a model and it is recommanded to use another model (CPUE = (aV^b) exp(cV^d) for instance).

Moreover, when using these formulae in a non-equilibrium condition (transitional state) the user must carefully check the temporal stability of the V variable on the time-series graph. In particular, it would be nonsense to allow the program to average two V values with one located on the left side of the parabola and the other on the right.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Y time plot
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CPUE time plot
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E time plot
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V time plot
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518
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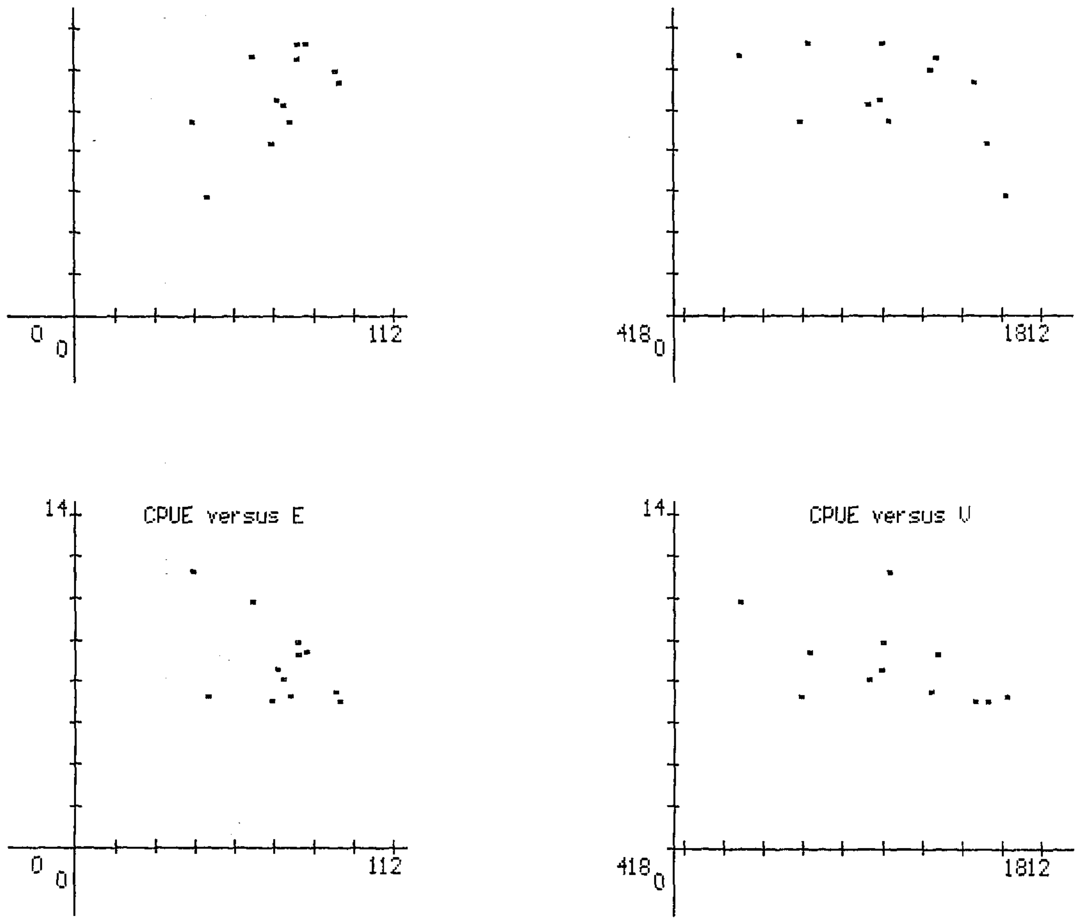
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418
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1812
14
CPUE versus E
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CPUE versus V
418
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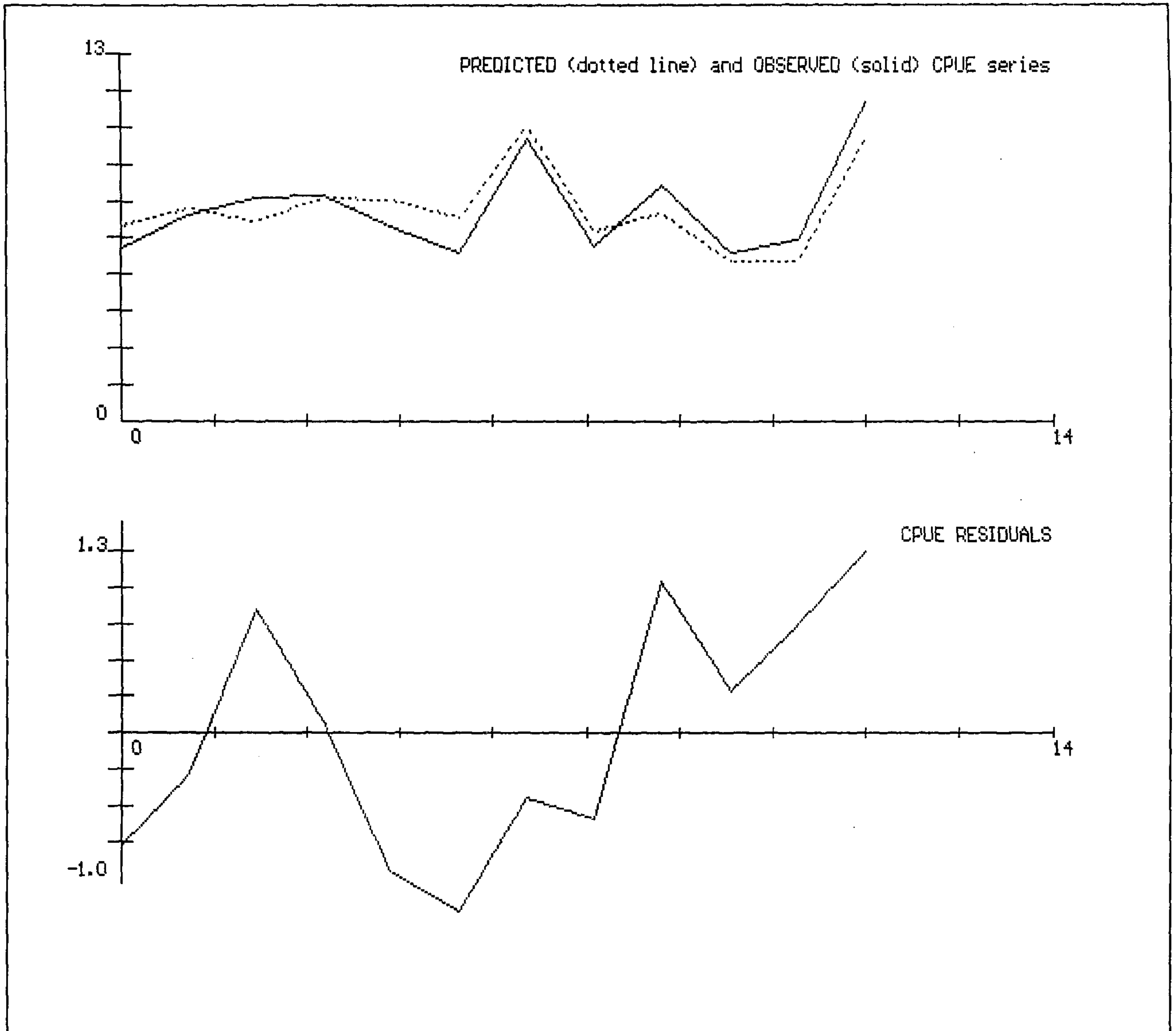
1812

```
                                  C L I M P R O D
Current known facts
        Model = CPUE=a.V^(1+b)+c.V^(2+b)+d.V^(2.b).E
         File = C:\CLIMPROD\EVANSBE2.CLI          Min_E = 41.000000
        Max_E = 93.000000                      Nb_years = 13
   Nb_exploit = 1                               Age_rec = 1
 Climatic_infl = abundance_catchability            Begin = 0
          End = 1                              Variance = 2.767707
 Var.residuals = 0.658998                             R2 = 76
            a = 0.2878890000                           b = -0.3495684333
            c = -0.0001238051                          d = -11.2045452685
```


PREDICTED (dotted line) and OBSERVED (solid) CPUE series
13
0
0
14
CPUE RESIDUALS
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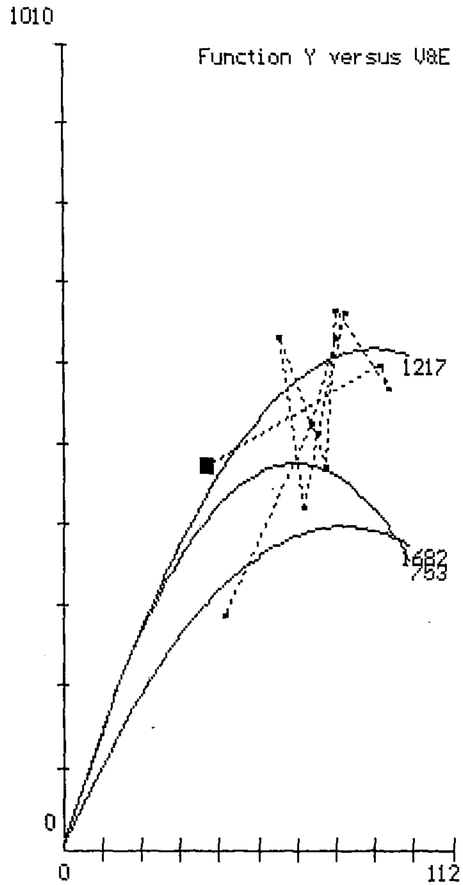
-1.0
0
14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Function Y versus V&E
1217
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753
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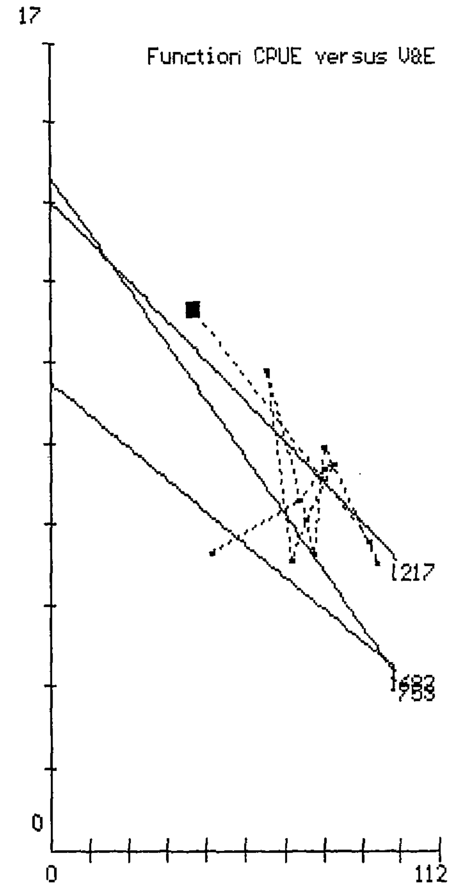
112


17
Function CPUE versus V&E
1217
1682
753
0
0
112

Kerema Bay Banana Prawn Yield and Effort with Bereina Annual Rainfall, 1977-87: CLIMPROD (FAO).

Evans 5. CLI Kerema Bay Yield & Effort (Banana Prawn), Bereina annual rainfall.

MODEL FITTING : 0 CPUE=a+b.E (Marquardt Method)
Number of years used for fitting : 11

Iteration n° 6	Trials -1	Total trials 9			
lambda:	81.000000	alpha:	4.000000	delta:	0.0000

Number of iterations :	0 it	1 it	6 it
Converging factor R2 :	25.4019	25.4019	25.4019

	Initial Coeff	Previous Coeff	Variation(%)	Actual Coeff
a	13.768086	13.768086	-0.00	13.768086
b	-0.127915	-0.127915	-0.00	-0.127915

Press any key and read comments on this model

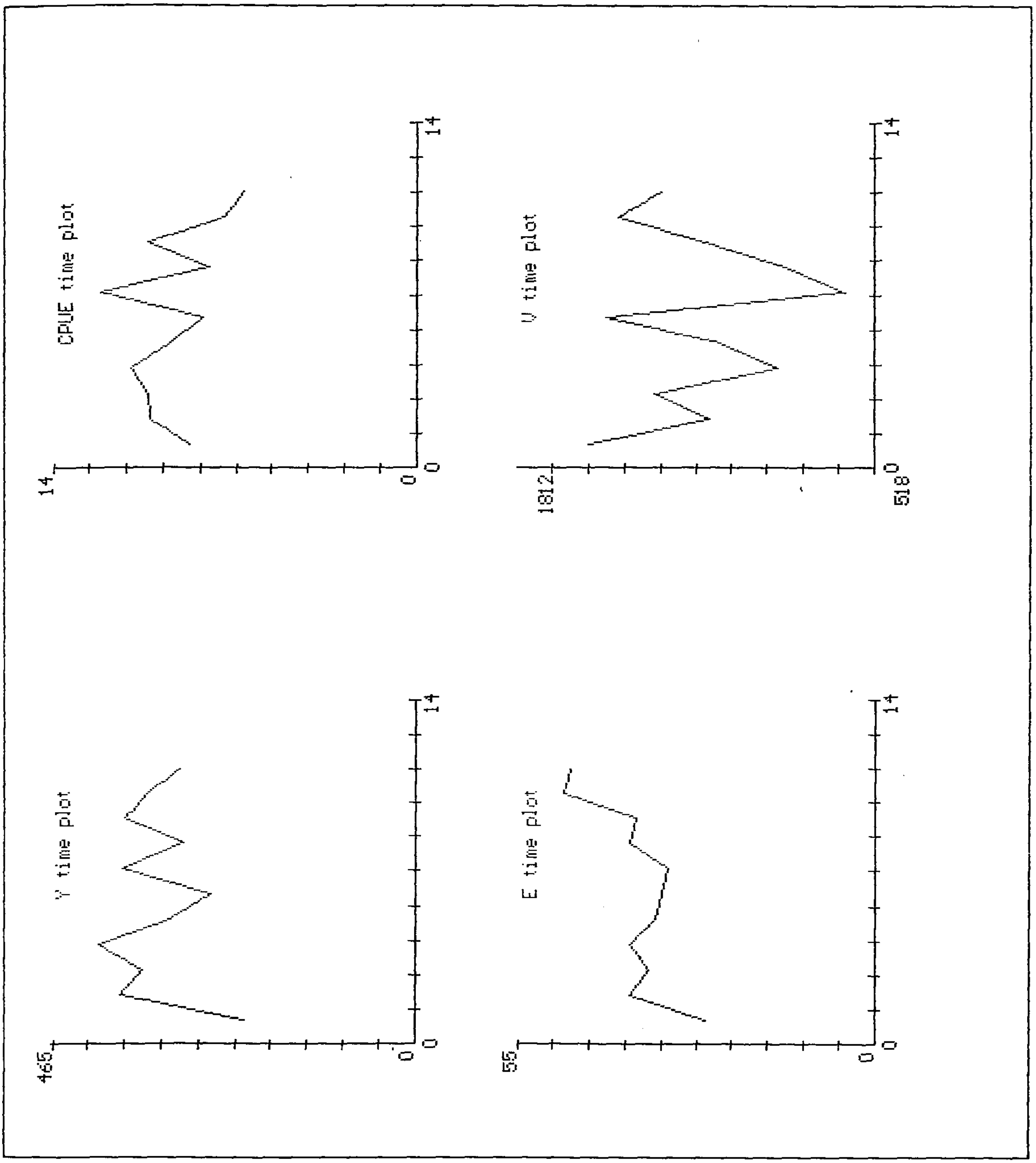
C L I M P R O D

MODEL: CPUE = a + b E

This is the conventional linear production model, usually named "Schaefer model".

It does not take into account any environmental influence on the production (white noise).

```
C L I M P R O D
Current known facts
         Model = CPUE=a+b.E
          File = C:\CLIMPROD\EVANS5.CLI          Min_E = 26.000000
         Max_E = 48.000000                    Nb_years = 12
    Nb_exploit = 1                            Variance = 2.335920
Var.residuals = 1.742553                            R2 = 25
             a = 13.7680855150                       b = -0.1279148933
```


CPUE time plot
14
0
0
14
V time plot
1812
518
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14
Y time plot
465
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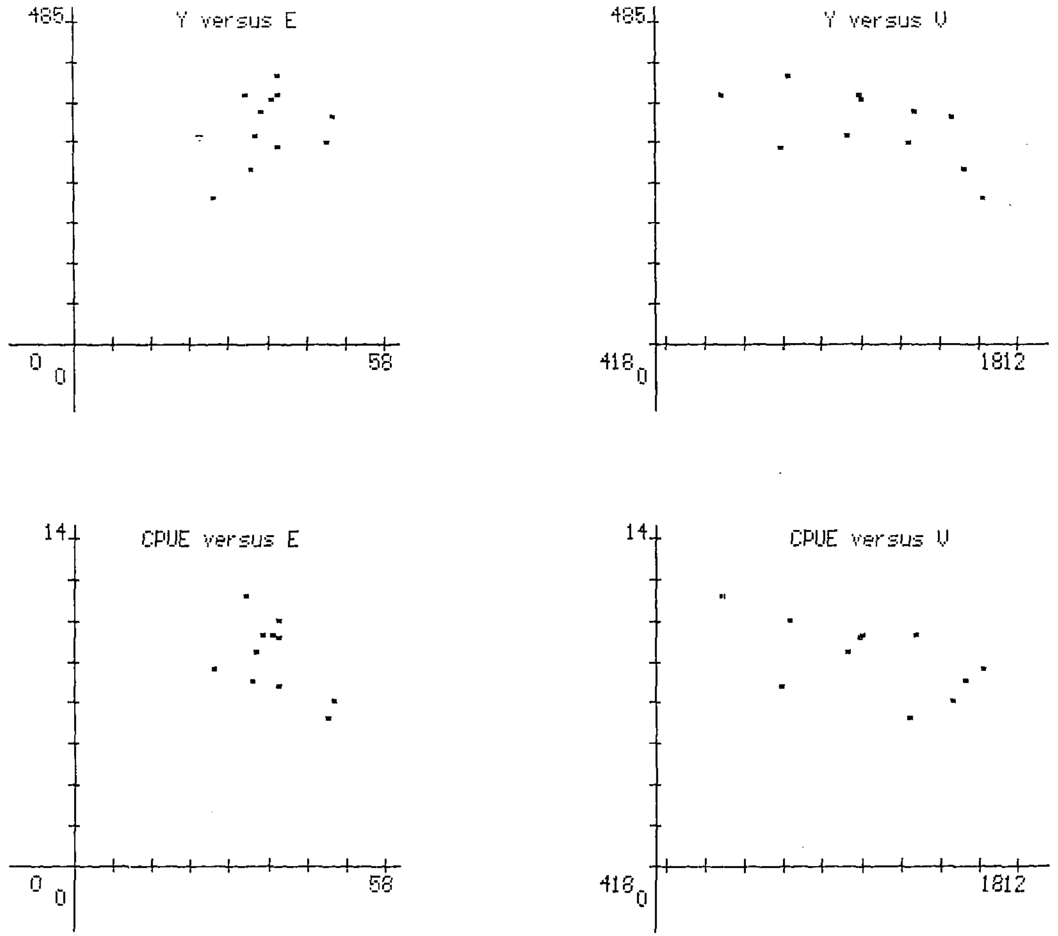
0
14
E time plot
55
0
0
14


Y versus E
485
0
0
58
Y versus V
485
418
0
1812
CPUE versus E
14
0
0
58
CPUE versus V
14
418
0
1812

```
                              C L I M P R O D
        Model = CPUE=a.V^(1+b)+c.V^(2+b)+d.V^(2.b).E
         File = C:\CLIMPROD\EVANS5.CLI          Min_E = 26.000000
        Max_E = 48.000000                    Nb_years = 12
   Nb_exploit = 1                             Age_rec = 1
Climatic_infl = abundance_catchability          Begin = 0
          End = 1                            Variance = 2.335920
Var.residuals = 0.416504                           R2 = 82
            a = 0.2947581856                        b = -0.3436449568
            c = -0.0001219638                       d = -21.0562273884
```

C L I M P R O D

MODEL: CPUE = aV^(1+b) + cV(2+b) + dV^(2b) E

This is a production model combining on the one hand the linear model (Schaefer model) between the CPUE and the fishing effort E, and on the other a quadratic (parabola) relationship between CPUE and the environmental variable V when it influences the abundance and a power relationship between the CPUE and V when it influences the catchability coefficient.

This kind of non-monotonic equation is useful when the relationship between CPUE and V is shaped (optimal central value). The graph MSY versus V must OBVIOUSLY be parabolic. If not, the data-set does not justify such a model and it is recommanded to use another model (CPUE = (aV^b) exp(cV^d) for instance).

Moreover, when using these formulae in a non-equilibrium condition

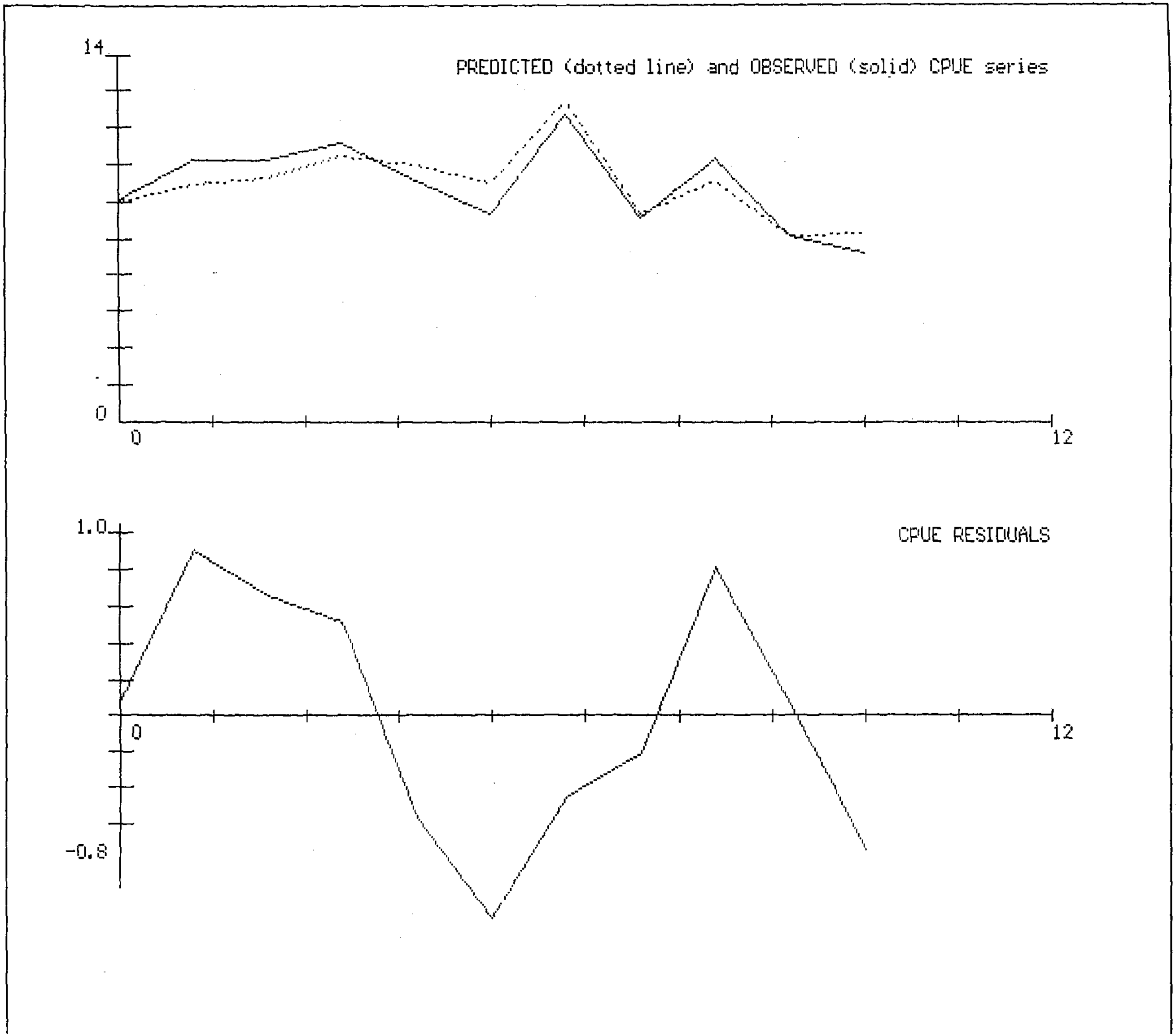
M E S S A G E S

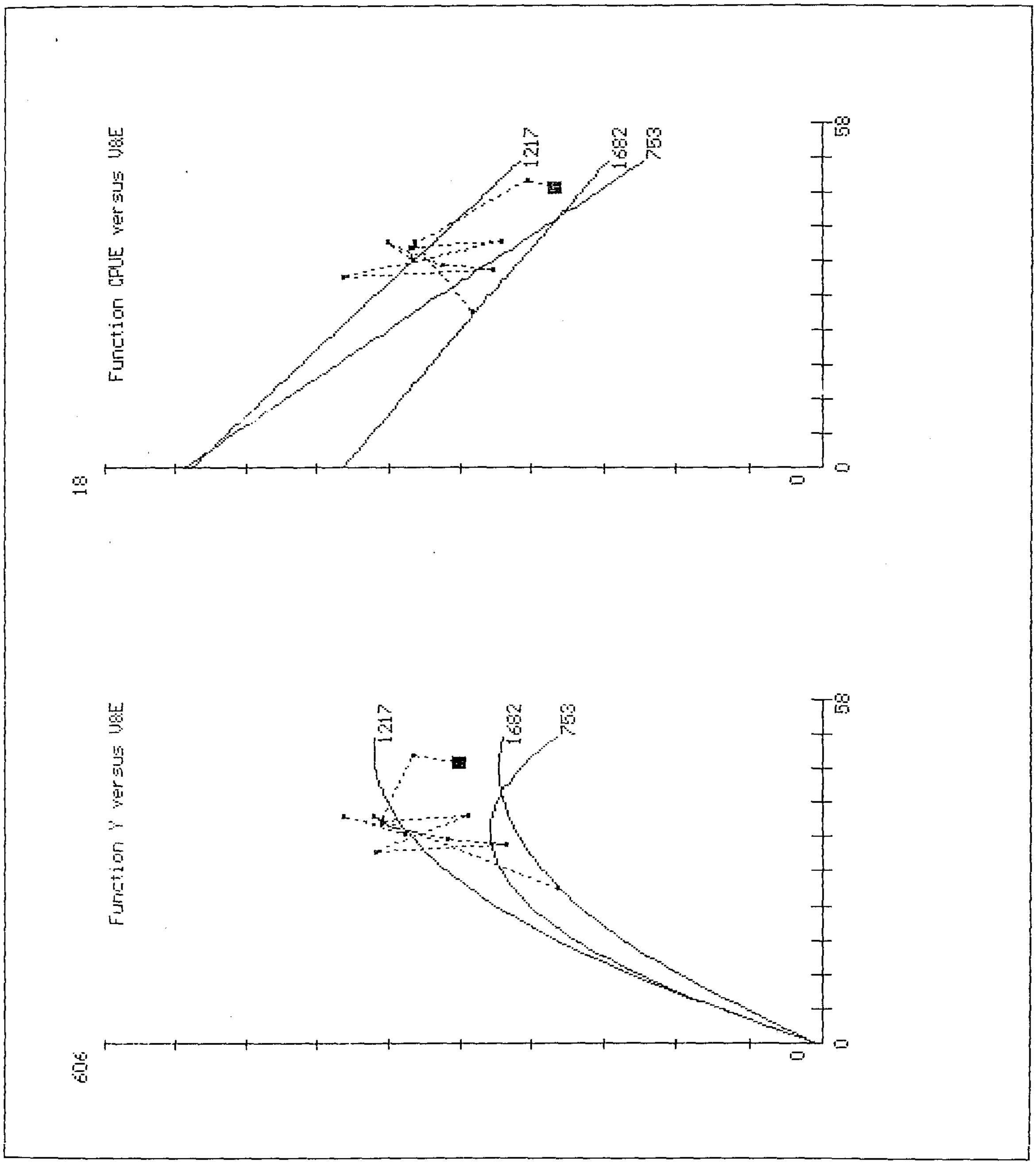
C L I M P R O D

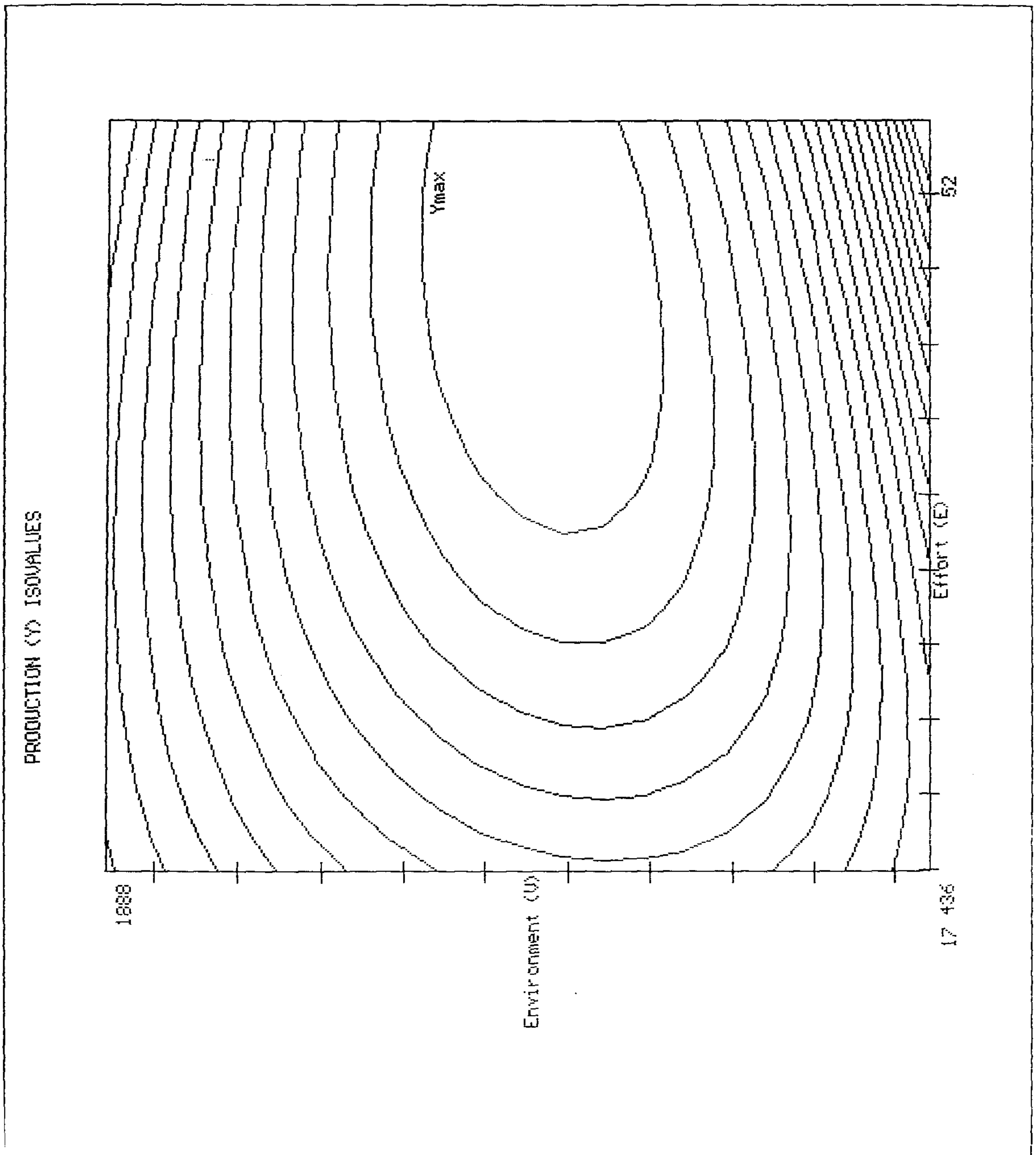
and a power relationship between the CPUE and V when it influences the catchability coefficient.

This kind of non-monotonic equation is useful when the relationship between CPUE and V is shaped (optimal central value). The graph MSY versus V must OBVIOUSLY be parabolic. If not, the data-set does not justify such a model and it is recommanded to use another model (CPUE = (aV^b) exp(cV^d) for instance).

Moreover, when using these formulae in a non-equilibrium condition
(transitional state) the user must carefully check the temporal stability of the V variable on the time-series graph. In particular, it would be nonsense to allow the program to average two V values with one located on the left side of the parabola and the other on the right.


PREDICTED (dotted line) and OBSERVED (solid) CPUE series
14
0
0
12
CPUE RESIDUALS
1.0
-0.8
0
12


Function CRUE versus V8E
1217
1682
753
18
0
0
58
Function Y versus V8E
1217
1682
753
606
0
0
58

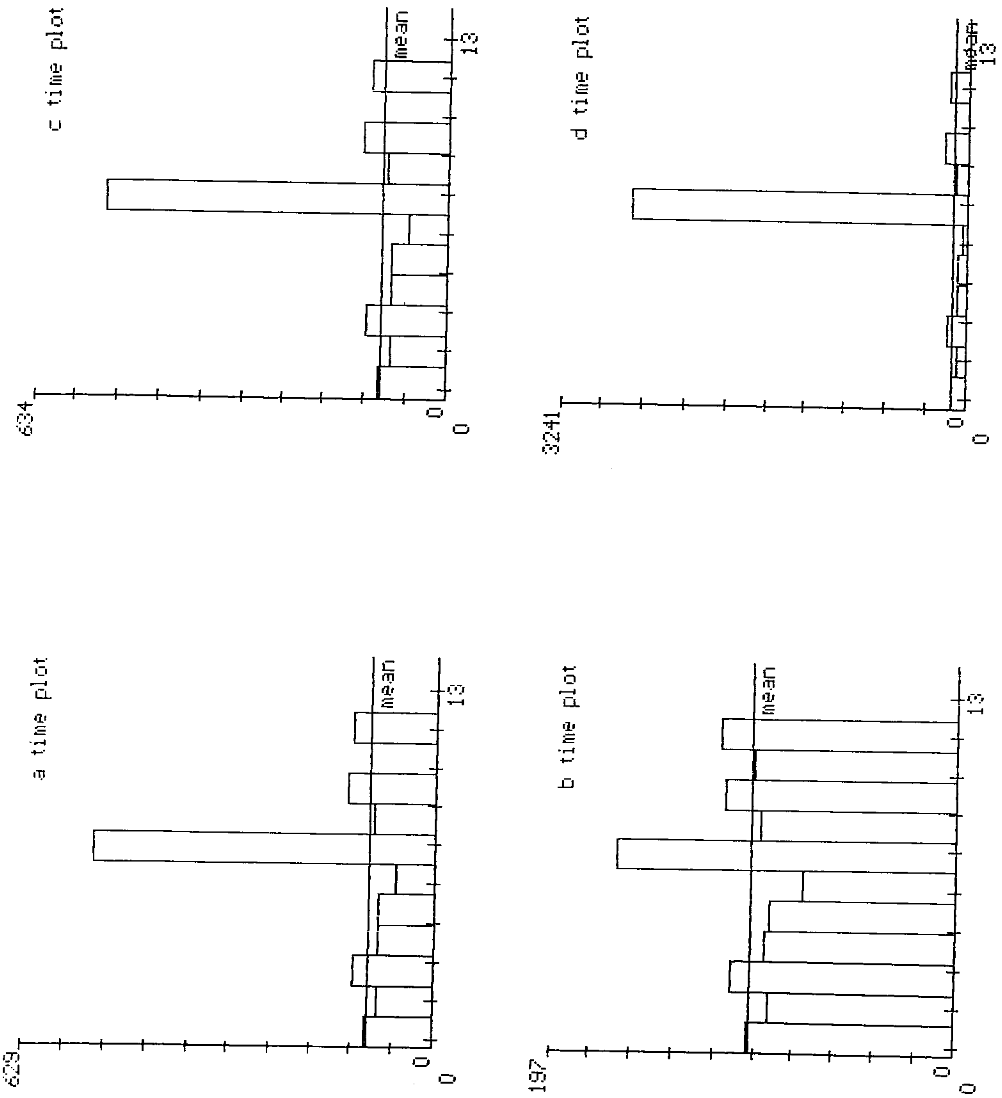

PRODUCTION (Y) ISOVALUES
Ymax
52
Effort (E)
1888
Environment (V)
17 436

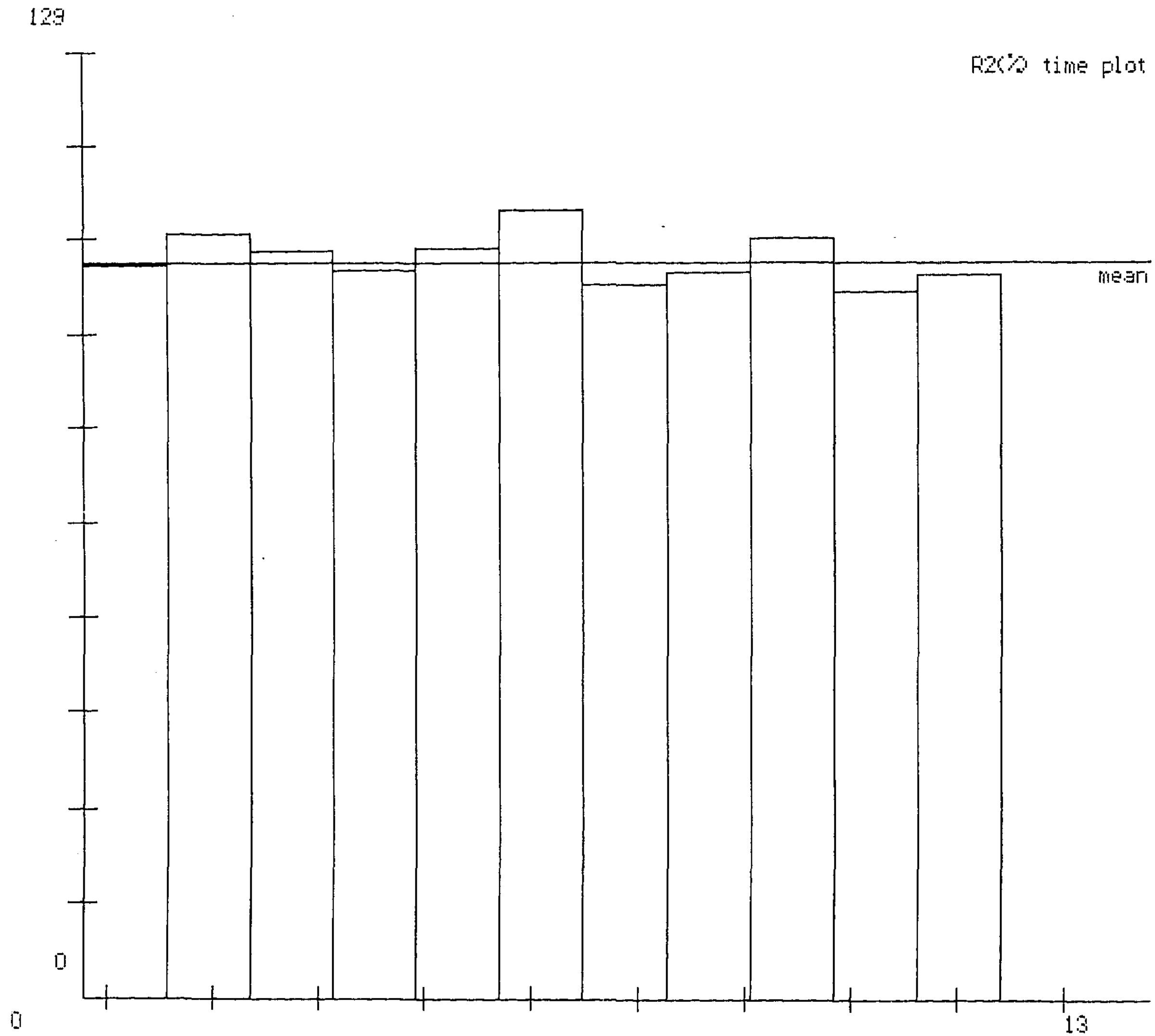
MODEL VALIDATING: CPUE=a.V^(1+b)+c.V^(2+b)+d.V^(2.b).E (Jackknife Method)

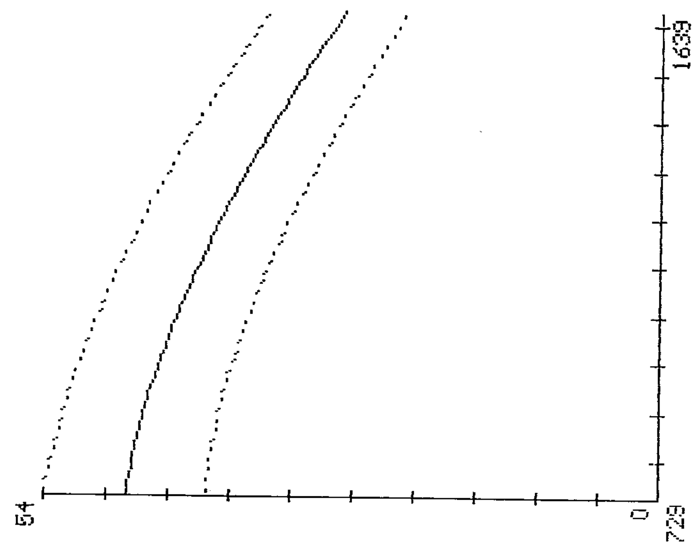
Conventional coefficient of determination R2 =	82.17
Jackknife coefficient of determination R2 =	46.79

Coefficient:	a	b	c	d
Value :	0.2948	-0.3436	-0.0001	-21.0562
Jackknife Standard deviation:	1.1028	0.2268	0.0005	475.2144
Jackknife t-ratio:	0.2673	-1.5153	-0.2645	-0.0443

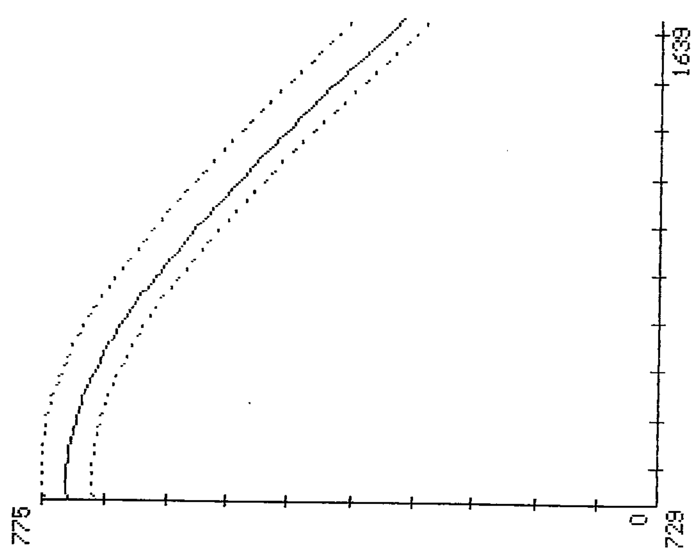
Note these results, then press any key to get graphs showing the stability of coefficients and R2 when removing a year from the data set.


c time plot
634
0
0
13
mean
d time plot
3241
0
0
13
mean
a time plot
629
0
0
13
mean
b time plot
197
0
0
13
mean


R2(%) time plot
129
0
mean
0
13



MS-E versus U



MSY versus U