International Council for
the Exploration of the Sea

C.M.1974/H:39
Pelagic Fish (N) Cttee

The Stock-Recruitment Pattern of the Downs Herring
as found from VPA-Stock-Estimates

by

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Introduction

The North Sea herring is often considered as composed of three major stocks, the Downs, Banks and Buchan herring, Cushing (1). As the stocks show different migration patterns and the fishing effort on herring is not equally distributed, major differences in the total mortality on the stocks are likely to exist. Therefore the treatment of the North Sea herring as a unit stock may not be justified when analysing stock-recruitment data.

If the migration pattern is known and if the catches can be split up on subareas, the fishing mortalities generated in each subarea may be found under similar assumptions as in VPA-analysis.

The Downs is probably the heaviest exploited herring stock in the North Sea and thus the most likely one in which to find a clear stock-recruitment relationship. This has been attempted in the last paragraph of the present paper.

Calculations and Results

1. The migration patterns of the three North Sea herring stocks are
   described by the whereabouts in various parts of the year.
   The North Sea is split into the three ICES divisions IVa, IVb
   and IVc and two different migration patterns are considered,
   one for I-ringers and one for II-ringers and older.
   The migration patterns used in these calculations are given in
   the text table below:

   Whereabouts

Age	Part of the year	Downs	Banks	Buchan
Iw.r.	o-1	IVb	IVb	IVb
IIw.r.	o-o.6	IVb	IVa	IVa
	o.6-o.8	IVa	IVa	IVa
	o.8-1.o	IVc	IVb	IVa

2. Let the fishing mortality F be independent of the stock the fish
   belong to and let the natural mortality M be independent of age,
   area and stock. The Beverton and Holt model (3) relates the catch
   in numbers C to stock size N by the formulas of the appendix.
   When M, the natural mortality and the fishing mortalities of the
   oldest (VIII w.r.) age for each of the three ICES divisions in the
   North Sea is known, i.e. assumptions equivalent to VPA analysis (2)
   the equations may be solved numerically. This was done using the
   RC7ooo (Nova-12oo) mini computer of the Danish Institute; the
   programme is written in BASIC. The resulting fishing mortalities
   and stock sizes are given in table 1. The stocks are in numbers
   as at 1 January.

3. The herring spawn for the first time when it is about 2 w.r. old
   and for the southern stock Baxter (4) gives the relationship

   $$e = 0.02185 \, L^{4.329o} = 277.77 \times W - 12768$$

   where e is the fecundity of a single fish, i.e. the number of eggs
   spawned, L is the length and W is the weight of the fish. Using
   mean weights from (2) and assuming a sex ratio of 1:1 the total
   fecundity E for the Downs stock may be calculated.
   If the Beverton and Holt (3) relation

   $$R = \frac{1}{\alpha + \beta/E} \qquad \text{(R: number of Recruits)}$$

holds, then $\frac{1}{R}$ should be a linear function of $\frac{1}{E}$.

$\frac{1}{R}$ vs $\frac{1}{E}$ is shown in fig. 1.

General Remarks

The plot fig. 1 does not show a clear stock recruitment relationship, but perhaps some idea of the range of β and a "read" estimate of α, say:

$$940 < \beta < 7700$$

$$\alpha = 3_{10} - 10$$

Stock recruitment plots for the two extremes of β are given in fig. 2 together with the equilibrium lines using $M = 0.1$ and (1) fishing mortality $F_{o.w.r.} = 0.14$, $F_{1.w.r.} = 0.7$, and $F_{2.w.r.} = 0.7$ and (2) $F_{o.w.r.} = 0.02$, $F_{1.w.r.} = 0.2$ and $F_{2.w.r.} = 0.4$

It may be concluded that the stock is heavily exploited almost to the limit of extinction as the left most equilibrium line is likely to be an underestimate of the fishing mortalities generated on the Downs stock at present.

References:

(1)   Cushing D.H., Fishery Biology
      The University of Wisconsin Press (1968)

(2)   Report from the North Sea Herring Assessment
      Working Group C.M. 1972/H:13 (mimeographed) (1972)

(3)   Beverton R.J.H. & Holt S.J., On the Dynamics of
      Exploited Fish Populations.
      Fishery Invest. London Ser. 2.19 (1957)

(4)   Baxter I.G.
      Fecundities of Winter-spring and Summer-autumn
      Herring Spawners.
      J. Cons. Intern. Explor. Mer 25 (1959).

Appendix

Formular used for estimating stock strengths of the North Sea herring stocks.

I-w.r.

$$C_{IVb} = (N_{Downs} + N_{Banks} + N_{Buchan}) \times E_{IVb} \times (1-\exp(-Z_{IVb}))$$

$$N' = N \times \exp(-Z_{IVb}) \quad \text{for Downs Banks and Buchan}$$

⤢ II-w.r.

$$C_{IVa} = N_{Downs} \times \exp(-0.6 \times Z_{IVb}) \times E_{IVa} \times (1-\exp(-0.2 \times Z_{IVa}))$$

$$+ N_{Banks} \times E_{IVa}(1-\exp(-0.8 \times Z_{IVa}))$$

$$+ N_{Buchan} \times E_{IVa}(1-\exp(-Z_{IVa}))$$

$$C_{IVb} = N_{Downs} \times E_{IVb}(1-\exp(-0.6 \times Z_{IVb}))$$

$$+ N_{Banks} \times \exp(-.8 \times Z_{IVa}) \times E_{IVb} \times (1-\exp(-0.2 \times Z_{IVb}))$$

$$C_{IVc} = N_{Downs} \times \exp(-0.6 \times Z_{IVb} - 0.2 \times Z_{IVa}) \times E_{IVc} \times (1-\exp(-0.2 \times Z_{IVc}))$$

$$N'_{Downs} = N_{Downs} \times \exp(-0.6 \times Z_{IVb} - 0.2 \times Z_{IVa} - 0.2 Z_{IVc})$$

$$N'_{Banks} = N_{Banks} \times \exp(-0.8 \times Z_{IVa} - 0.2 \times Z_{IVb})$$

$$N'_{Buchan} = N_{Buchan} \times \exp(-Z_{IVa})$$

N' is stock size one w.r. older than N

$Z = F + M$ and is age specific.
$E = F/Z$

C is the catch in numbers

F is the fishing mortality

M is the natural mortality

Table 1

VPA stock estimates of Buchan (Bu), Banks (Ba) and Downs (Do)
North Sea herring. V.P. is the virtual population in 10^9 of
fish and Eff.F. is the effective fishing mortality to which the
stock was exposed.

W.		1947 Bu.	Ba.	Do.	1948 Bu.	Ba.	Do.
0	V.P.	0.5	2.7	5.5	0.4	1.7	3.7
0	Eff.F.	0	0	0	0	0	0
1	V.P.	0.5	0.8	4.6	0.5	2.5	5.0
1	Eff.F.	0	0	0	0	0	0
2	V.P.	0.6	1.7	2.2	0.5	0.7	4.1
2	Eff.F.	0.11	0.1o	0.15	0.o5	0.o4	0.o5
3	V.P.	1.5	0.1	1.6	0.5	1.4	1.7
3	Eff.F.	0.11	0.11	0.19	0.15	0.16	0.29
4	V.P.	0.9	0.4	2.5	1.2	0.1	1.2
4	Eff.F.	0.14	0.14	0.23	0.o9	0.11	0.22
5	V.P.	0.4	0.9	1.7	0.7	0.3	1.8
5	Eff.F.	0.14	0.15	0.25	0.18	0.17	0.3o
6	V.P.	1.5	0.4	1.6	0.3	0.7	1.2
6	Eff.F.	0.12	0.19	0.42	0.14	0.16	0.38
7	V.P.	0.3	0.8	0.7	1.2	0.3	1.o
7	Eff.F.	0.12	0.21	0.5o	0.o7	0.11	0.39
8	V.P.				0.3	0.6	0.4
8	Eff.F.				0.1	0.14	0.6
Total	V.P. ≥ 2	5.2	4.3	10.3	4.7	4.1	11.4

W.		1949			1950			1951			1952			1953			1954		
		Bu.	Ba.	Do.	Bu.	Ba	Do.	Bu.	Ba.	Do.	Bu.	Ba.	Do.	Bu.	Ba.	Do.	Bu.	Ba.	Do.
0	V.P.	1.0	1.2	2.6	0.3	1.8	4.1	1.7	0.6	4.0	2.3	1.2	3.4	1.1	5.6	2.4	2.6	0.3	4.7
	Eff.F.	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0.02	0.03	0.03	0.03
I	V.P.	0.4	1.6	3.4	0.9	1.1	2.4	0.2	1.6	3.7	1.6	0.6	3.6	2.1	1.1	3.1	1.0	4.9	2.1
	Eff.F.	0	0	0	0	0	0	0.09	0.09	0.09	0.14	0.14	0.14	0.19	0.19	0.19	0.21	0.21	0.21
2	V.P.	0.4	2.2	4.5	0.4	1.4	3.1	0.8	1.0	2.2	0.2	1.3	3.1	1.2	0.4	2.9	1.6	0.8	2.3
	Eff.F.	0.04	0.04	0.10	0.06	0.07	0.16	0.02	0.07	0.34	0.11	0.13	0.52	0.15	0.19	0.52	0.18	0.20	0.72
3	V.P.	0.4	0.6	3.6	0.4	2.0	3.7	0.3	1.2	2.3	0.7	0.8	1.4	0.2	1.1	1.7	1.0	0.3	1.5
	Eff.F.	0.07	0.07	0.19	0.13	0.13	0.25	0.09	0.13	0.45	0.08	0.11	0.41	0.23	0.25	0.65	0.19	0.24	0.96
4	V.P.	0.4	1.1	1.2	0.4	0.5	2.7	0.3	1.5	2.6	0.2	1.0	1.4	0.6	0.7	0.8	0.1	0.8	0.8
	Eff.F.	0.07	0.10	0.29	0.08	0.10	0.25	0.12	0.18	0.50	0.10	0.13	0.48	0.10	0.13	0.57	0.15	0.21	0.92
5	V.P.	1.0	0.1	0.9	0.3	0.9	0.8	0.3	0.4	1.9	0.2	1.2	1.5	0.2	0.8	0.8	0.5	0.5	0.4
	Eff.F.	0.08	0.11	0.29	0.06	0.08	0.34	0.15	0.17	0.36	0.13	0.15	0.42	0.11	0.13	0.50	0.06	0.12	1.18
6	V.P.	0.6	0.2	1.2	0.8	−	0.6	0.3	0.7	0.5	0.2	0.3	1.2	0.2	0.9	0.9	0.2	0.6	0.4
	Eff.F.	0.15	0.20	0.65	0.07	0.11	0.44	0.09	0.11	0.43	0.15	0.17	0.42	0.11	0.15	0.54	0.1	0.13	0.99
7	V.P.	0.3	0.5	0.7	0.4	0.2	0.6	0.7	−	0.3	0.2	0.6	0.3	0.2	0.2	0.7	0.1	0.7	0.5
	Eff.F.	0.17	0.19	0.66	0.17	0.17	0.61	0.07	0.11	0.34	0.12	0.14	0.69	0.10	0.13	0.44	0.07	0.13	1.13
8	V.P.	1.0	0.2	0.6	0.2	0.4	0.3	0.3	0.1	0.3	0.6	−	0.2	0.2	0.5	0.1	0.1	0.2	0.4
	Eff.F.	0.1	0.18	0.72	0.1	0.12	0.54	0.1	0.22	0.84	0.1	0.18	0.72	0.1	0.12	0.54	0.1	0.12	0.54
Total	V.P. ≥ 2	4.1	4.9	12.7	2.9	5.4	11.8	3.0	4.9	10.1	2.3	5.2	9.1	2.8	4.6	7.9	3.6	3.9	6.3

Stock in number and fishing mortalities by North Sea herring stocks (Buchan, Banks and Downs)

7.

W.		1955 Bu.	1955 Ba.	1955 Do.	1956 Bu.	1956 Ba.	1956 Do.	1957 Bu.	1957 Ba.	1957 Do.	1958 Bu.	1958 Ba.	1958 Do.	1959 Bu.	1959 Ba.	1959 Do.	1960 Bu.	1960 Ba.	1960 Do.
0	V.P.	1.8	1.7	3.6	0.3	2.0	2.2	7.7	8.0	0.5	2.9	1.7	1.9	2.5	0.1	5.4	1.5	0.1	0.4
	Eff.F.	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0	0	0	0.11	0.11	0.11
1	V.P.	2.2	2.8	4.1	1.5	1.5	3.2	0.3	1.8	1.9	6.8	7.2	4.8	2.6	1.5	1.7	2.3	0.1	4.9
	Eff.F.	0.40	0.40	0.40	0.33	0.33	0.33	0.43	0.43	0.43	0.27	0.27	0.27	0.35	0.35	0.35	0.63	0.63	0.63
2	V.P.	0.7	3.6	1.6	1.4	0.2	2.5	1.0	1.0	2.1	0.2	1.0	1.1	4.7	4.9	3.3	1.6	1.0	1.1
	Eff.F.	0.25	0.32	0.85	0.17	0.31	1.15	0.13	0.25	1.12	0.08	0.27	1.29	0.21	0.45	1.39	0.16	0.28	1.15
3	V.P.	1.2	0.6	1.0	0.5	2.4	0.6	1.0	0.1	0.7	0.8	0.7	0.6	0.1	0.7	0.3	3.4	2.8	0.7
	Eff.F.	0.30	0.32	0.92	0.33	0.38	0.99	0.32	0.35	1.04	0.52	0.54	1.26	0.33	0.45	1.46	0.24	0.36	1.02
4	V.P.	0.7	0.2	0.5	0.8	0.4	0.4	0.3	1.5	0.2	0.7	0.1	0.2	0.4	0.4	0.2	0.1	0.4	0.1
	Eff.F.	0.23	0.25	0.86	0.32	0.33	0.88	0.29	0.38	0.92	0.32	0.35	0.85	0.72	0.68	1.34	0.28	0.33	0.96
5	V.P.	0.1	0.6	0.3	0.5	0.2	0.2	0.5	0.2	0.1	0.2	0.9	0.1	0.6	–	0.1	0.2	0.2	–
	Eff.F.	0.35	0.35	0.85	0.23	0.23	0.93	0.42	0.48	0.98	0.41	0.50	1.21	0.5	0.5	0.8	0.5	0.6	1.1
6	V.P.	0.4	0.4	0.1	0.1	0.4	0.1	0.4	0.1	0.1	0.3	0.1	–	0.1	0.5	–	–	–	–
	Eff.F.	0.23	0.25	0.80	0.40	0.40	1.01	0.41	0.48	1.02	0.31	0.37	0.96	0.5	0.5	0.8	–	–	–
7	V.P.	0.1	0.5	0.1	0.3	0.3	–	–	0.2	–	0.2	0.1	–	0.2	0.1	–	–	–	–
	Eff.F.	0.10	0.12	0.56	0.11	0.17	1.21	0.70	0.72	1.36	0.25	0.27	0.77	0.5	0.5	0.8			
8	V.P.	0.1	0.6	0.1	0.1	0.4	0.1	0.3	0.2	–	–	0.1	–	0.2	–	–			
	Eff.F.	0.1	0.1	0.48	0.1	0.18	0.72	0.2	0.26	0.74	0.5	0.5	0.8	0.5	0.5	0.8			
	V.P. ≥2	3.3	6.5	3.7	3.7	4.3	3.9	3.5	3.3	3.2	2.4	3.0	2.0	6.3	6.6	3.9	5.3	4.4	1.9

Stock in number and fishing mortalaties by North Sea herring stocks (Buchan, Banks and Downs).

W.R.		1961 Bu.	Ba.	Do.	1962 Bu.	Ba.	Do.	1963 Bu.	Ba.	Do.	1964 Bu.	Ba.	Do.	1965 Bu.	Ba.	Do.	1966 Bu.	Ba.	Do.
0	V.P.	12.6	1.3	2.9	4.6	1.9	0.7	5.3	1.8	0.8	6.2	2.8	2.0	6.9	2.1	0.7	3.1	1.3	0.6
	Eff.F	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.06	0.06	0.05	0.05	0.05	0.02	0.02	0.02	0.08	0.08	0.08
1	V.P.	1.2	0.1	0.3	11.2	1.1	2.6	4.1	1.7	0.6	4.6	1.5	0.7	5.3	2.4	1.7	6.2	1.9	0.6
	Eff.F	0.24	0.24	0.24	0.16	0.16	0.16	0.23	0.23	0.23	0.61	0.61	0.61	0.44	0.44	0.44	0.18	0.18	0.18
2	V.P.	1.1	-	2.4	0.9	0.1	0.2	8.6	0.9	2.0	3.0	1.2	0.5	2.2	0.8	0.3	3.1	1.4	1.0
	Eff.F	0.10	0.32	1.58	0.19	0.26	0.74	0.19	0.39	1.15	0.28	0.61	1.41	0.53	0.61	0.85	0.55	0.70	1.03
3	V.P.	1.3	0.7	0.3	0.9	-	0.4	0.7	0.1	0.1	6.5	0.5	0.6	2.0	0.6	0.1	1.2	0.4	0.1
	Eff.F	0.18	0.23	0.75	0.21	0.18	1.06	0.17	0.40	1.17	0.31	0.52	1.35	0.62	0.62	1.07	0.57	0.66	0.93
4	V.P.	2.5	1.8	0.2	1.0	0.5	0.1	0.7	-	0.1	0.5	-	-	4.3	0.3	0.1	1.0	0.3	-
	Eff.F	0.35	0.45	0.95	0.2	0.26	0.74	0.13	0.27	0.89	0.30	0.39	0.54	0.58	0.69	1.75	0.46	0.43	0.33
5	V.P.	0.1	0.3	-	1.6	1.0	0.1	-	-	-	0.5	-	0.1	0.3	-	-	2.2	0.1	-
	Eff.F	0.5	0.44	0.62	0.5	0.6	1.1	-	-	-	0.25	0.44	1.06	0.5	0.6	1.1	0.5	0.6	1.1
6	V.P.	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-
	Eff.F	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.6	1.1	-	-	-
Total ≥2	V.P.	5.0	2.8	2.9	4.4	1.6	0.8	10.0	1.0	2.2	10.5	1.7	1.2	9.2	1.7	0.5	7.5	2.2	1.1

Stock in number and fishing mortalities by North Sea herring stocks (Buchan, Banks and Downs).

W.		1967			1968			1969			1970			1971		
		Bu.	Ba.	Do.	Bu.	Ba.	Do.	Bu.	Ba.	Do.	Bu.	Ba.	Do.	Bu.	Ba.	Do.
0	V.P.	0.1	6.o	1.9	2.9	3.6	2.1									
	Eff.F.	0.o9	0.o9	0.o9	0.11	0.11	0.11									
1	V.P.	2.6	1.o	0.5	0.1	4.9	1.6	2.4	2.J	1.7						
	Eff.F.	0.56	0.56	0.56	0.48	0.48	0.48	0.47	0.47	0.47						
2	V.P.	4.7	1.4	0.5	1.3	0.5	0.3	0.1	2.8	0.9	1.3	1.6	1.0			
	Eff.F.	0.23	0.49	1.27	1.o4	1.o6	1.17	0.73	0.71	0.91	0.47	0.72	1.46			
3	V.P.	1.6	0.6	0.3	3.3	0.8	0.1	0.4	0.2	0.1	-	1.2	0.3	0.8	0.7	0.2
	Eff.F.	0.69	0.88	1.3o	2.77	2.33	1.46	0.58	0.63	0.89	1.oo	0.86	0.9o	0.5	0.5	0.8
4	V.P.	0.6	0.2	-	0.7	0.2	0.1	0.2	0.1	-	0.2	0.1	-	-	0.5	0.1
	Eff.F.	0.56	0.75	1.42	0.92	0.96	1.24	0.64	0.65	1.o6	0.5	0.5	0.8	0.5	0.42	0.56
5	V.P.	0.6	0.2	-	0.3	0.1	-	0.3	0.1	-	0.1	-	-	-	-	-
	Eff.F.	0.56	0.49	0.41	0.5	0.6	1.1	0.75	0.82	1.o5	0.5	0.5	0.8	-	-	-
6	V.P.	-	-	-	0.3	0.1	-	-	-	-	0.1	-	-	-	-	-
	Eff.F.	-	-	-	0.5	0.44	0.62	-	-	-	0.5	0.6	1.1	-	-	-
Total	V.P. $N \geq 2$	7.5	2.4	0.8	5.9	1.7	0.5	1.0	3.2	1.0	1.7	2.9	1.3	0.8	1.2	0.3

Stock in number and fishing mortalities by North Sea herring stocks (Buchan, Banks and Downs).

Fig.1

$\frac{1}{R}$ vs $\frac{1}{E}$ (R: recruits and
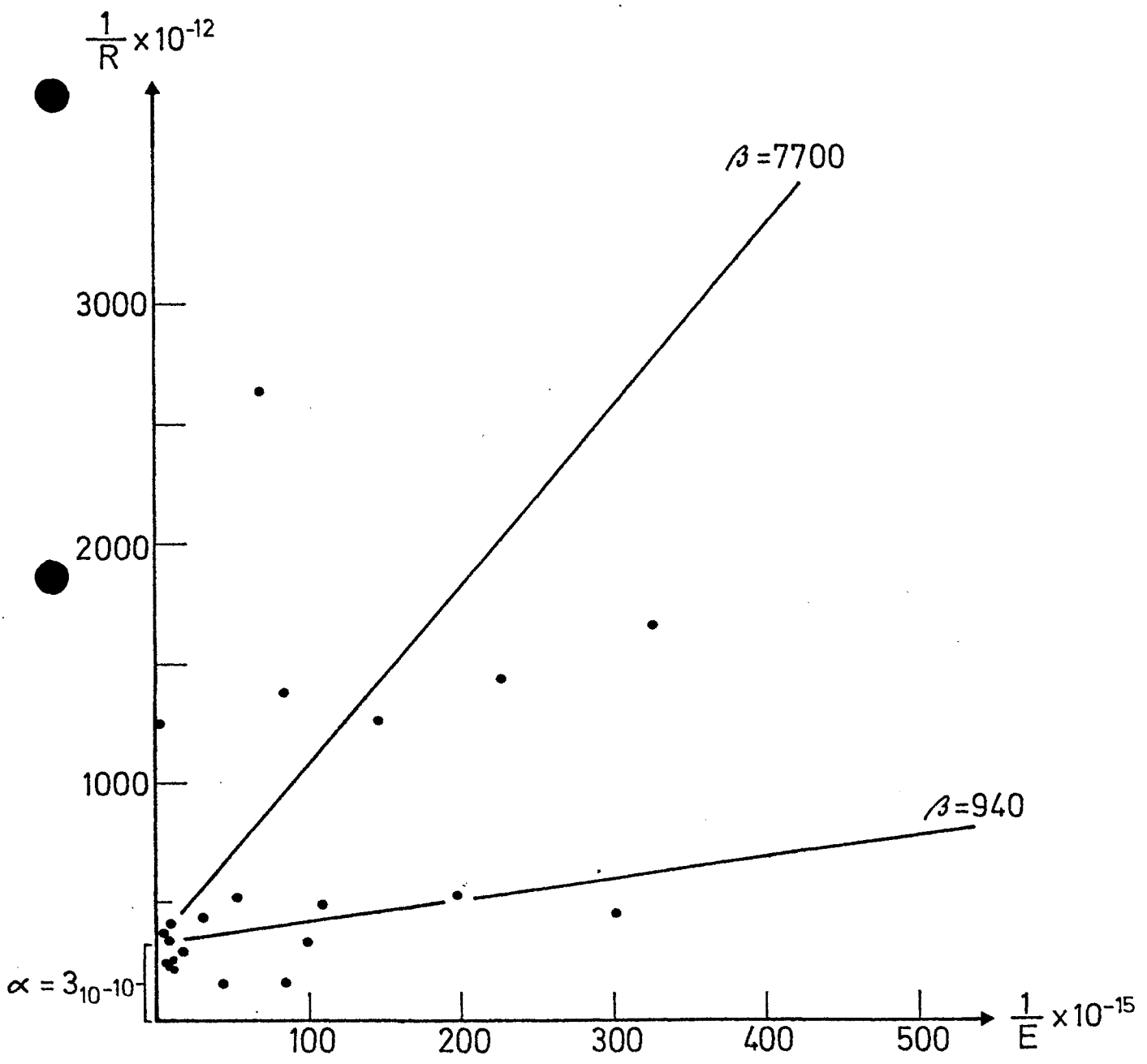
E: fecundity of Downs herring)

Fig.2

Stock-Recruitment curves
for Downs herring.
The solid curves are calculated
from the Beverton and Holt model
with
curve a $(\alpha = 3_{10}-10_1 \beta = 940)$
curve b $(\alpha = 3_{10}-10 \beta = 7700)$
M=0.1