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A short history of the Downs stock of herring

D. H. Cushing

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The data on the Downs stock of herring were re-examined and the year-classes during the early part of the Second World War were low because of the stock recruitment relationship. This was near linear. There was a positive correlation between *Pseudo/Para*, the preferred food of the larval herring, when the quantity of *Pseudo/Para* was declining. However, the decline in *Pseudo/Para* did not affect the stock recruitment relationship.

Key words: Downs stock, stock recruitment relationship, *Pseudo/Para*.

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Introduction

The Downs stock of herring collapsed in 1955 and recovered to a small degree in the early eighties. The collapse was attributed to recruitment overfishing (Cushing and Bridger, 1966). However, from Burd's (1978) analysis of the long-term trends in recruitment and in stock in the North Sea, it appeared that a natural change had occurred during the Second World War; this point will be re-examined. As recovery has been partly secured, the nature of the stock/recruitment relationship in the Downs stock will be reviewed.

The identity of the stock

After the collapse of the East Anglian herring drift net fishery in the late fifties and sixties there was some discussion on the status of the Downs stock as a unit of management (Cushing and Burd, 1957; Anon., 1965; Cushing and Bridger, 1966); the stock has a distinct growth rate and a distinct time of spawning and the recruitments of the Downs stock were not correlated with those of the Dogger and Buchan spawning groups. Hempel and Blaxter (1967) showed that the egg dry weights of the three spawning groups differed considerably: Buchan, 0.16–0.17 mg; Dogger, 0.22–0.28 mg; and Downs, 0.34–0.39 mg. Zijlstra (1973) contrasted the egg weights and fecundities of the Downs group with those of the two northern groups of autumn-spawning herring in the North Sea. The Buchan and Dogger stocks spawn between August and October and the fish lay small eggs and fecundity is rather high (ca. 100 000; $F=5.793\,L^3-56\,680$, where F is fecundity in numbers of eggs and L is length in cm). The Downs stock spawns in November and December and the fish lay large eggs and fecundity is relatively low (ca. 50 000; $F=2.8266\,L^3-16\,680$). Zijlstra showed that the year-to-year differences in fecundity and egg size were very small and concluded that the difference between the two stocks was a profound one, perhaps of genetic origin (but genetic analysis, King *et al.*, 1987, has not established differences between coastal/oceanic stocks in the north-east Atlantic).

The fisheries in the Southern Bight and in the eastern English Channel exploited a homogeneous stock, the Downs stock (Cushing and Bridger, 1966), which has been studied for about 70 years. The stock was reduced to very low levels in the sixties and seventies and recovered after catches were banned from 1977–1980. In principle, the dependence of recruitment on parent stock should be well described. There are, however, two drawbacks. The first is that the adult stock has also been exploited in the central North Sea, together with the Bank stock, and the catches of the two groups cannot be distinguished throughout the whole period. The proportion caught there should be about the same through the period of examination; Dr Corten has pointed out that fishing mortality increased in the northern North Sea during the late sixties, in which case more Downs fish must have been caught there and numbers would be underestimated. The second drawback is that the immature fish (0, I, and II groups) have been taken since 1950 in an industrial fishery in the eastern North Sea. The stocks cannot be distinguished there very easily, so recruitment was estimated at 3 years of age as two-ringers.

The simplest definition of a unit stock requires that the vital parameters are homogeneous (Anon., 1960; Cushing, 1960). Cushing and Bridger (1966) used such evidence to establish the identity of the Downs stock in mortality rates and in recruitment. The argument is extended in Figure 1

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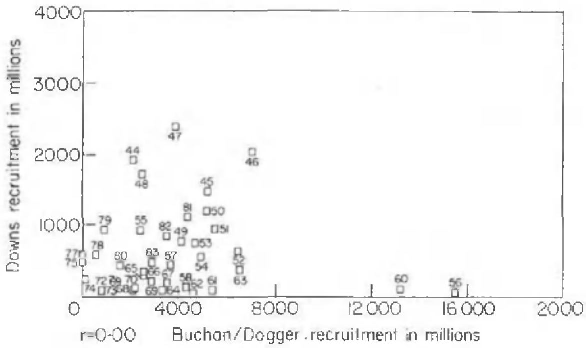

Figure 1. Correlation of recruitment to the Downs stock with that to the stock in the rest of the North Sea.

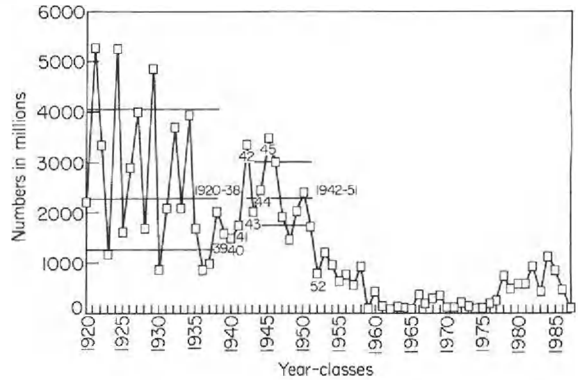

Figure 2. Time series of year-classes in the Downs stock from 1920 to 1987. The lines show geometric means and one standard deviation for two periods, 1920 to 1938 and 1942 to 1951. The wartime year-classes are marked as is the year-class 1952, which started the collapse of the East Anglian fishery.

which shows the lack of correlation between recruitment as two-ringers to the Downs stock and that to the Buchan and Dogger groups in IVa and IVb ($r = 0.22$; $p \ll 0.05$) between 1947 and 1983. This is strong evidence of the discrete nature of the Downs stock. The status of the Downs stock as a unit of management was reasserted by the Working Group on the Herring South of 62°N of the International Council for the Exploration of the Sea (Anon., 1990).

Material and methods

Catches in numbers at age were obtained in two ways: (a) between 1923 and 1946, from tonnages caught in ICES areas IVc and VIId, divided by weights at age; (b) total catches in numbers between 1947 and 1989, taken from Anon. (1972, 1990). Age distributions were taken from Hodgson (1929) for 1923, from Cushing and Burd (1957) for the period 1924–1938, from Cushing (1968) for the period 1946–1960 for the East Anglian drift net fishery, and from Gilis (1948) for the period 1941–1945 on the Belgian spent herring fishery. From Burd (1962), lengths at age were taken for the period 1932–1958 and those for 1932 were extended back to 1923; Burd (1978) showed that for this period the lengths of the 4-year-old fish remained about the same between 1923 and 1933. Lengths at age were converted to weight at age using $W = 0.0078 \times l^3$, where W is weight in g and l is length in cm (Gulland, 1983).

Stock in numbers at age by year-classes was estimated by virtual population analysis (Gulland, 1965; Pope, 1972). From 1960 to 1989, the stock quantities in numbers at age were taken from Anon. (1990). Catches in numbers in 1923 were extended back to earlier years with notional mortalities to provide estimates of spawning stock biomass of the older age groups for the years 1923 to 1925. There was no fishing in the years 1939 and 1940 and zero catches were interpolated within the year-classes where appropriate; the Belgian fleet fished steadily from 1941 onwards. The proportions of immature fish at ages 3 to 5 between 1923 and 1951 were taken from Cushing and Burd (1957) and were used to reduce total biomass (of two-ringers and older) to spawning stock biomass between 1923 and 1951; it will be recalled that the Downs herring before 1952 recruited partly at 3 years of age and partly at 4 (i.e. as two- and three-ringers, Cushing and Burd, 1957). Spawning stock biomass was estimated as at 31 December. It was always assumed that the fish exploited by the East Anglian Fishery were on a spawning migration.

Results

Figure 2 shows the time series in recruitment from 1920 to 1987. The wartime year-classes are marked, some of which are low, if not as low as the lowest pre-war year-classes. The year-class of recruitment failure in the East Anglian fishery, 1952, is also marked because it started the collapse of the East Anglian fishery in 1955. The horizontal lines show the geometric means of recruitment (+/− one standard deviation): (1) for the pre-war period, 1920 to 1938; and (2) for the post-war period, 1942 to 1951 (the 1942 year-class recruited in 1945). In the pre-war period, year-classes were both higher and lower than in the post-war period; indeed, a large year-class was often followed by a poor one. The year-classes 1921, 1924, and 1929 were larger than any successor, but there is no difference between the pre- and post-war means.

Figure 3a shows the spawning stock biomass for the years 1923 to 1989. During the 1920s the stock remained at a steady level of 700 000–850 000 tonnes. It declined during the 1930s. From 1942–1946, the stock increased to about 900 000 tonnes and remained high until 1949, after which a decline started. Figure 3b shows the stock in numbers for the same period, 1923–1990. The immediate post-war stock in numbers is about the same or a little less than that in the 1920s. In contrast, the post-war spawning

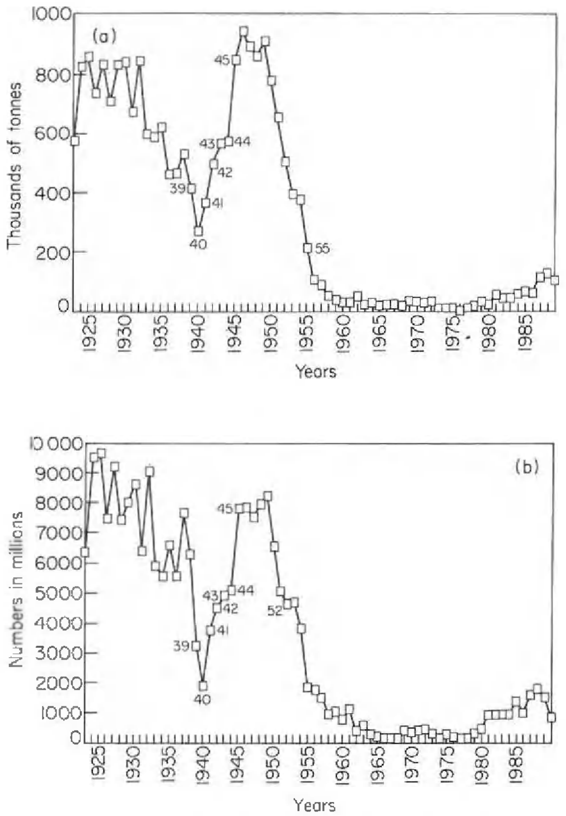

Figure 3. Time series of: (a) spawning stock biomass; and (b) stock numbers from 1923 and 1989.

stock biomass is a little greater because of an increment of growth. The remarkable point about the spawning stocks is the decline in the 1930s. The numbers between 1945 and 1949 were less than those in the 1920s, perhaps as a consequence of the decline in stock in the 1930s. The sharp decline in stock after 1949 started when trawling started on the spawning grounds in 1950.

The collapse of the East Anglian fishery in 1955 was attributed by Hodgson (1957) to the then new industrial fishery for immature herring in the eastern North Sea. At that time, it consisted of a spring fishery for O and I groups and an autumn fishery between August and September for I and II groups followed by a O group fishery in November. In both fisheries the O groups were probably early autumn spawners and the II groups would have left the eastern North Sea much earlier in the year (Burd, 1962). So the Downs component probably comprised I group fish only.

The industrial fishery in the eastern North Sea started in 1950 and by 1954 the catch had reached 100 000 tonnes. Let us suppose that 80 000 tonnes of I group of an average weight of 45 g were caught in 1954, in numbers about 1.8×10^9. Aasen *et al.* (1961), from a tagging experiment on the Bloden Ground in the eastern North Sea, estimated that about 15% of the Downs recruits were caught annually during the fishing season. The 1952 year-class amounted to about 0.8×10^9 as two-ringers in East Anglia, of which about 120 million would probably have been taken in the industrial fishery. As shown in Figure 2, this is a small part of the reduction from the post-war mean.

The stock numbers in Burd's (1978) figure 139 do not differ very much in the 1920s and early 1930s from those in Figure 3b, but the results shown in Figures 2 and 3 are quite different from Burd's, which led to the suggestion that natural changes had occurred during the war and after it. Figure 2 shows no evidence for a natural change based on the post-war series of recruitments in the East Anglian fishery, 1942–1951, and the stock in numbers between 1945 and 1949 matched that in the 1920s.

An interesting point is that the catch per unit of effort in 1946 was high in the East Anglian drift net fishery, 10 tonnes/shot. The pre-war and post-war catches per effort and spawning stock biomasses were as in Table 1.

Table 1. The pre-war and post-war catches per unit effort and spawning stock biomass.

	Catches per unit effort (tonnes per shot)	Spawning stock biomass (thousand tonnes)
1935	5.0	622
1936	4.7	459
1937	5.1	465
1938	6.1	529
Mean	5.2	519
1946	10.0	941
1947	6.6	889
1948	5.9	859
1949	5.0	908
Mean	6.9	899

The post-war increment in spawning stock biomass (*1.81) is much greater than that in catch per effort (*1.27), despite the high value of catch per unit effort in 1946. But the spawning stock biomass in 1947–1949 remained high, whereas the catches per effort were reduced by 40% as compared with that in 1946. The increment in stock after the war is a consequence of the wartime year-classes after 1941. Figure 4 shows the dependence of catch per effort on spawning stock biomass for the period 1924–1959. The data appeared to arrange themselves towards an asymptote at high stock, and as any fitted curve had to pass through the origin, a hyperbolic relationship was fitted non-linearly with FISHPARM (Saila *et al.* 1988):

$$y = 1/(a + b/SSB),$$

where y is catch per unit effort; a is the slope at the origin, b is a coefficient of saturation of the drift nets, SSB is spawning stock biomass.

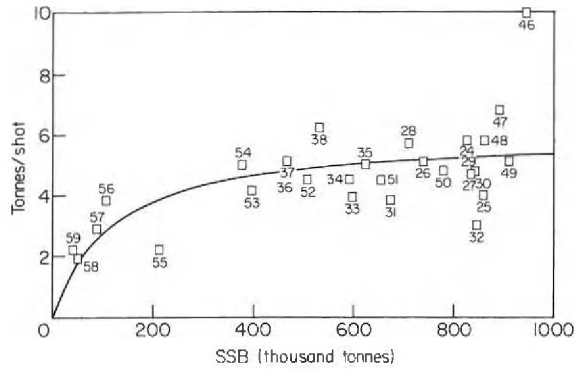

Figure 4. The dependence of catch per unit effort in tonnes per shot upon spawning stock biomass between 1924 and 1959. The curve fitted is a hyperbolic function where a is the slope at the origin and b is a saturation coefficient ($y = 1/(a + b/SSB)$).

Table 2. Constants of the four stock/recruitment relationships as fitted non-linearly with the Marquardt algorithm (with Fishparm); standard errors in parentheses.

	a	b	k	r^2
Beverton and Holt	0.000093 (0.00001)	0.2358 (0.063)		0.60
Ricker	4.107 (1.102)	0.0003 (0.000036)		0.60
Shepherd	57.76 (2232)	0.244 (0.781)	0.0072 (1.694)	0.61
Power law	14.99 (15.02)	0.781 (0.1532)		0.61

Note that the standard errors are approximate only.

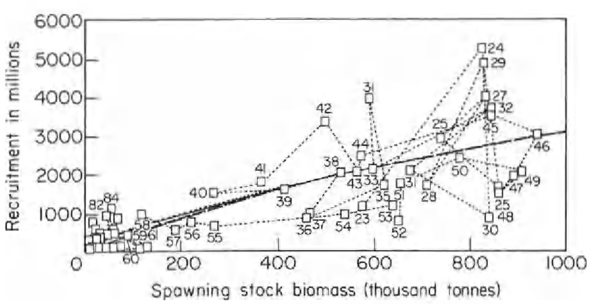

Figure 5. The stock/recruitment relationship for the Downs stock from 1923 to 1987 (in year-classes). The data are fitted by four models: Beverton and Holt, Ricker, Shepherd, and the power law and are fitted by the Marquardt algorithm (with Fishparm). (Saila *et al.*, 1988).

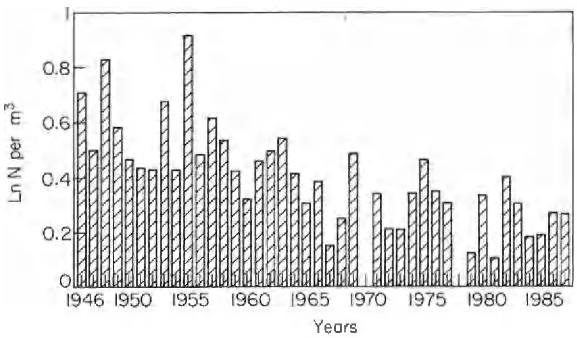

Figure 6. The decline in *Pseudocalanus/Paracalanus* in the Southern Bight of the North Sea from the Continuous Plankton Recorder Network (in 30-mile squares) from 1946 to 1985.

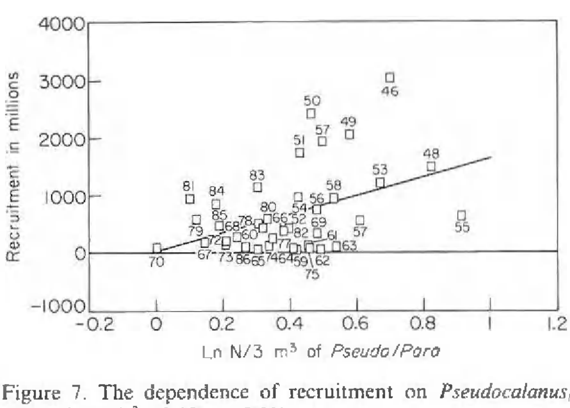

Figure 7. The dependence of recruitment on *Pseudocalanus/Paracalanus* ($r^2 = 0.19$; $p < 0.01$)

Thus, the drift nets tended to become saturated with increase of spawning stock biomass and the catch per effort in 1946 is seen to be anomalous. The asymptotic relationship of catch per effort on SSB fits the data fairly well, accounting for 42% of the variance. However, the drift nets did detect the decline in abundance after 1954 at low spawning stock biomass.

Figure 5 shows the stock/recruitment relationship for the Downs stock of herring between 1923 and 1987 (in year-classes). The data are fitted with four curves: Beverton and Holt, Ricker, Shepherd, and a power law; they were fitted non-linearly by the Marquardt algorithm (with Fishparm). There is no real difference between them, although the Ricker curve and the power law appear to underestimate the slope at the origin. The concentration of observations near the origin prevents adequate fits with traditional methods. Table 2 gives the statistics of the curves fitted as in Figure 5.

The same results were obtained with the Quasi–Newton method and with Simplex for the Beverton and Holt, Ricker, and the power law, but with the Shepherd curve the results were slightly different. The three poor wartime year-classes, 1939, 1940, and 1941, lie quite close to the

Table 3. ANOVAs on the effect of *Pseudo/Para* on the stock recruitment relationship.

	Coefficient	Standard error	t (two tail)	p	F (ratio of regression to residuals)
Ln recruitment on ln SSB					
constant	3.815	0.278	13.71	0.000	111.950
Ln SSB	0.562	0.053	10.58	0.000	
Ln recruitment on ln stock and ln *Pseudo/Para*					
constant	4.088	0.369	11.077	0.000	19.028
Ln SSB	0.538	0.099	5.410	0.000	
Ln *Pseudo/Para*	−0.873	0.902	0.960	0.340	

line. They are associated with the stock decline just before the Second World War (see Figure 3). The 1952 year-class, which started the collapse of the East Anglian fishery, was the lowest until that time and it lies well below the fitted stock recruitment curve; the subsequent year-classes, 1953–1957, all lie below the line. Dr Corten suggests that this was a period of possibly unfavourable hydrographic conditions as evinced by the increased abundance of southern species (Aurich, 1953). He also noted that during the 1970s recruitment might have been reduced by the great salinity anomaly of the Seventies. It is also possible that the industrial fishery had a greater effect than the average reduction in recruitment of 15% estimated from a tagging experiment (Anon., 1961).

It was often asked during the 1960s why the Downs stock did not recover when the fishing effort was reduced. From 1957 to 1983, the spawning stock biomass remained below 100 000 tonnes and it did not recover until fishing was stopped. It was the small remaining fishery with high fishing mortalities on the adult stock (up to 1.0 in the 1960s and 1970s; see the Working Group Reports of ICES) and the continuing industrial fishery that prevented recovery; the proportion of Downs fish in the industrial catches cannot be allocated on a year-to-year basis. Had the slope at the origin been sharper, the stock might well have recovered as effort was relaxed. In other words, from the shape of the stock/recruitment curve, only a severe reduction in fishing mortality would have encouraged recovery.

It is an unusual stock/recruitment relationship, nearly linear to the point of highest stock, which means that a decline in stock from 900 000 tonnes must generate a decline in recruitment, if sustained. It is almost the near linear stock recruitment relationship postulated by Shepherd and Cushing (1990). From the stock/recruitment curve, we would expect recruitment to decline as stock declined. This is a sufficient explanation for the collapse of the East Anglian fishery, given the variation of recruitment about the near linear relationship. During the Second World War the stock was unexploited for only 2 years, 1939 and 1940, and the pristine stock was never approached.

It is assumed that the proportion of catches of adult fish in the central North Sea remained the same throughout the time series; attempts have been made in the past to estimate that proportion but none would be valid for the whole period. Catches in area IVb increased during the 1930s and were high from 1946 onwards until they declined in the late 1950s and early 1960s. A proportion of Downs recruits may have been taken in that fishery which would account for the slight loss of recruits during the 1930s.

Hardy (1924) showed that the larval herring in the Southern Bight of the North Sea depended almost exclusively on *Pseudocalanus*. Dickson *et al.* (1988) found that between the 1950s and the 1970s, under increased northerly winds, the stocks of phytoplankton and zooplankton were reduced in the north-east Atlantic but recovered in the 1980s. They attributed this to the delayed onset and delayed development of the production cycle, particularly in the western North Sea, north of the Dogger. Figure 6 shows the decline in *Pseudocalanus/Paracalanus* in the Southern Bight as sampled with the continuous plankton recorder, using data from 30-mile squares (reproduced with kind permission of Dr John Gamble). A marked decline by a factor of two to three occurred between the 1950s and the late 1970s but the recovery recorded by Dickson *et al.* (1988) in the North Sea and in the north-east Atlantic in the 1980s is probably absent.

In Figure 7 is given the dependence of recruitment on *Pseudocalanus/Paracalanus* between 1946 and 1985 ($r^2 = 0.19$; $p < 0.01$); this relationship is similar to that published by Parmanne and Sjöblom (1984, 1987). The question arises whether the decline of the Downs stock was related at all to the decline of *Pseudo/Para*. Two ANOVAS were calculated, first of all of ln recruitment on spawning stock biomass, or the power law stock and recruitment relationship and, second, of ln recruitment on ln SSB and ln *Pseudopara* (Table 3).

If we compare the two, the coefficients for the constant and for ln SSB are very close, as are the standard errors, but that for ln *Pseudopara*, although negative, is not significant. The conclusion is that despite the dependence of herring larvae on *Pseudocalanus* and despite the correlation between herring recruitment and ln *Pseudo-para*, the Downs stock was more affected by recruitment overfishing than by the decline of *Pseudocalanus*.

Discussion

The East Anglian drift net fishery ended in 1967 when a single drifter sailed from the port of Lowestoft. Of course, other fisheries continued in the Southern Bight and in the Eastern English Channel. The collapse was due to recruitment overfishing caused mainly by the fishery on the adult stock. The industrial fishery did reduce recruitment perhaps by 15% each year, a small proportion as compared with the effect of the adult fishery, but a possibility remains that this proportion was somewhat higher. The effect of the industrial fishery on the prevention of recovery during the 1960s and 1970s has not been investigated. From the evidence presented here, there is no evidence of a natural change during the war years.

The stock/recruitment relationship is unusual in that the degree of compensation is low. Catches of recruits were taken outside the Southern Bight and it remains possible that the distribution of recruits is biased, but the greater proportion of catches must have been taken in the Bight and in the eastern English Channel. Recruitment depends positively upon the preferred food of the larval herring, *Pseudocalanus/Paracalanus*, which declined markedly between the 1950s and the 1980s. So far as can be seen, the stock recruitment relationship was not affected by the decline in larval food, for any decline in recruitment due to the decline in *Pseudo/Para* could not be detected.

Beverton (1990) examined the collapses of 10 pelagic stocks in terms of fishing or natural causes, resilience, catchability, persistence, and genetics. He concluded that fishing was the major cause of collapse in most cases. This is true of the Downs stock of herring, although from the shape of the stock/recruitment relationship it is not very resilient. Collapse was due to a sudden increase in catchability (Cushing and Bridger, 1966) as trawlers found the spawning grounds from 1950 onwards. The stock is slowly recovering, so it is persistent. Of the genetic structure, little is known. A collapse by natural causes did not take place as far as can be seen. Dr Corten points out that there is a reduced chance of environmental effect with a shrunken stock.

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Appendix Table 1. Stock recruitment, and pseudo/para.

	Spawning stock biomass (thousand tonnes)	Recruitment millions (as two-ringers)	Ln *Pseudo* (in per 3 m^3)
	575	1149	
	824	5238	
1925	858	1620	
	737	2894	
	832	3976	
	708	1689	
	827	4843	
1930	839	868	
	673	2081	
	844	3681	
	596	2085	
	589	3912	
1935	622	1689	
	459	839	
	465	984	
	529	2007	
	412	1566	
1940	266	1477	
	364	1743	
	497	3344	
	565	2021	
	571	2445	
1945	845	3464	
	941	3003	0.7020
	889	1920	0.4980
	859	1470	0.8230
	908	2033	0.5790
1950	777	2395	0.4640
	654	1721	0.4320
	650	772	0.4250
	639	1188	0.6710
	539	949	0
1955	267	629	0.9140
	221	745	0.4800

Appendix Table 1. *Continued.*

	Spawning stock biomass (thousand tonnes)	Recruitment millions (as two-ringers)	Ln *Pseudo* (in per 3 m^3)
1955	187	555	0.6100
	118	925	0.5310
	113	60	0.4210
1960	89	424	0.3180
	128	128	0.4570
	58	56	0.4900
	74	109	0.5380
	17	90	0.4100
1965	5	51	0.3020
	7	374	0.3810
	8	184	0.1470
	5	287	0.2480
	20	338	0.4810
1970	16	89	0.0000
	18	91	0.3390
	29	205	0.2090
	6	119	0.2070
	7	70	0.3420
1975	7	87	0.4590
	2	201	
	7	247	0.3470
	14	757	0.3050
	29	486	0.1200
1980	21	582	0.3330
	58	580	0.1000
	46	936	0.3980
	46	436	0.3020
	56	1124	0.1800
1985	67	846	0.1870
	61	470	
	115	87	
	125		
	101		