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A model of estimating biological attachment of fish stocks to exclusive economic zones

By

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Abstract

The paper describes a model of calculating indices of attachment of fish stock to fisheries zones based on biological parameters. Input data are weight by age, mortality rate and the percentage area distribution of an "average" year class of the stock throughout its lifespan. The model calculates indices of biomass distribution and biomass production by area on a per recruit basis for any predetermined stage of life (age groups, spawners, etc.). Assuming that these indices of an average year class throughout its lifespan equal the sum of the respective indices of all year classes in one year, the calculated indices can be used as keys in allocating catch quotas of joint stocks to fishery zones. The model is implemented on a spread sheet (Excel) and data of the northern blue whiting stock are used as an example.

I. Introduction

The establishment of the exclusive economic zones involved extended rights of ownership and management responsibilities of the fish resources to the coastal states. This is verified in the Law of the Sea, which in general terms expresses the view that the coastal states should be entitled to a quota share proportioned to the share of the stock distribution within the economic zone of the states. When a stock occurs within the zones of two or more coastal states, the Law suggests that the states should seek to agree upon measures necessary to coordinate and ensure the conservation and development of the stock. Two different principles have been adopted as basis for sharing of joint fish resources; (a) historical fishing performance and (b) zonal attachment, based on biological criteria. The aim of this paper is to describe and discuss methods of quantifying criteria of zonal attachment based on biological parameters.

II. Zonal attachment

Referring to the establishment of the 200 miles exclusive economic zones, ICES published in 1978 an extensive report on biological data of importance for zonal attachment of fish resources in the ICES region (Anon. 1978). Provided that a total allowable catch (TAC) of the stock was set, the report suggested that the following biological criteria could form the basis for calculating sub-quotas for different zones:

1. The occurrence and migration of the fishable part of the stock.

2. The occurrence of juvenile and pre-recruit fish.

3. The spawning areas and the distribution of eggs and larvae.

In addition, the history of the fishery including the distribution of catch, and the state of exploitation should be taken into account when negotiating the quota sharing of joint stock. The report gives, however, no guidance as to how the different factors should be quantified, weighed and added into an overall formula for calculating the respective sub-quotas of the zones. It only states that information of this type should form the basis of negotiation for a long-term proportional allocation of the TAC.

International working groups have in later years updated the information and added new stocks to the list of shared fishery resources in the ICES area. In the late 1970's Norway and EC established working groups to deal with the joint North Sea stocks (Anon. 1979, Anon. 1986) and a group of scientists from Norway, EC and Iceland considered the problems of quota sharing of capelin in the Iceland-Greenland-Jan Mayen area (Anon. 1983). The Norway/EC Working Group did not propose any quantitative definition of the term zonal attachment, but expressed the view that in the application of the criteria, main emphasis should be given to the distribution of the fishable part of the stocks. The state of exploitation was taken into account when Norway and EC agreed on the quota sharing of the North Sea herring stock. Acknowledging that the juvenile herring is distributed in the EC zone mainly, whereas the adults spawn in the EC zone and migrate to the Norwegian zone for wintering, the parties agreed on a sliding scale giving Norway a larger share when the spawning stock is relatively big (low exploitation rate). This was a step in the direction of calculating an index of zonal attachment taking into account the state of exploitation.

In the quota sharing of the capelin stock in the Iceland-Greenland-Jan Mayen area a discrete model for calculating the zonal attachment was used for the first time. In this model the occurrence of the stock by zone is defined as the distribution of stock biomass times the length of the period a year-class, on an average, occurs in the respective zone during its lifespan. Assuming that the sum of these indices of a year class throughout its lifespan, equals the sum of the corresponding indices of all year classes in one year, the total index was calculated from data on stock destribution by age, weight by age and mortality rate.

The model of biomass distribution by zones.

The biomass distribution (B) of a year class at age (t) in an area (i) is given by the equation:

$$B_{it} = p_{it} \cdot R_0 \cdot e^{-Zt} \cdot W_t$$

where R_0 is number of recruits at age 0, Z is the total instantaneous mortality rate, w_t is the weight at age t and p_{it} is the percentage of biomass present in the area (i) at age t. The equation is valid for any time unit t (year, half year, quarter, month etc.), which may be chosen according to seasonal migration pattern of the stock in relation to zones and in according to available data on p.

The total biomass distribution in area (i) is the sum of biomass from all periods (time units) the year class occurs in the area B_i.

$$B_i = R_0 \cdot \Sigma\, p_{it} \cdot W_t \cdot e^{-Zt}$$

The percentage share (Pi) of the total biomass distribution (B) in the area (i) is:

$$P_i = (B_i / B) \cdot 100 = ((\Sigma p_{it} \cdot W_t \cdot e^{-Zt}) / (\Sigma W_t \cdot e^{-Zt})) \cdot 100$$

When W and p are known, the model calculates an index of relative biomass distribution by area as a function of the mortality coefficient Z = F + M, where F and M are the fishing and natural mortality coefficients respectively. This index may be defined as an index of biological attachment to economic zones in which the state of exploitation has been taken into account. The model is implemented on a spread sheet as shown in Table 1, using data from the blue whiting stock as an example.

Biomass production by zones.

Another suggested index for biological attachment to zones is the growth in biomass when the stock is present in the zone (Engesæter 1992). Such a biomass production index (b_{it}) can be modelled in a similar way as the model of biomass distribution.

$$b_{it} = R_0 \cdot p_{it} \cdot (e^{-Z(t+1)} \cdot W_{t+1} - e^{-Zt} \cdot W_t) = R_0 \cdot p_{it} \cdot e^{-Zt} \cdot (e^{-Z} \cdot W_{t+1} - W_t)$$

The total biomass production (b_i) is:

$$b_i = R_0 \cdot \Sigma p_{it} \cdot e^{-Zt} \cdot (e^{-Z} \cdot W_{t+1} - W_t)$$

where the biomass is summed for the periods when the stock is present in the area (i) and when $(e^{-Z} \cdot W_{t+1} - W_t) > 0$. The percentage share is then:

$$P_i = (b_i / b) \cdot 100 = (\Sigma p_{it} \cdot e^{-Zt} \cdot (e^{-Z} \cdot W_{t+1} - W_t) / \Sigma e^{-Zt} \cdot (e^{-Z} \cdot W_{t+1} - W_t)) \cdot 100$$

when b is the sum of the biomass production from the area as a whole. The implementation of this model is illustrated in Table 2.

Biological attachment of the blue whiting stock.

Data of the northern blue whiting stock has been chosen as an example of application. In order to take care of the seasonal spawning migration, one quarter of a year is used as time unit, and data on seasonal distribution of a year class on zones by age and quarter are derived from various sources (Blindheim and Monstad 1981, Monstad 1990, reports of the Blue Whiting Working Group). A map of the relevant economic zones is shown in Fig. 1. Data on weight by age and mortality rates are derived from the Working Group reports 1990-1992. The figures applied are subjected to the author's judgement of available information, and the results should therefore be taken as an example of the model only.

The model is implemented on a spread sheet as shown in the table of biomass distribution (Table 1), and biomass production (Table 2). The two first columns refer to age and quarters, and the calculations are made on an input number of 100 individuals (column 3). The further columns to the right show input data of natural death and fishing mortality on a yearly basis, and the total death by quarter is calculated in column 6. The weight by age is entered in column 7, and the biomass by age and the increase/decrease in biomass by age between quarters are calculated and given in column 9 (Table 1) and 9 and 10 respectively (Table 2).

These figures are allocated to zones (columns 16 to 19) according to the percentage biomass distribution as given in columns 11 to 14 (12 to 15 in Table 2). It is assumed that there is no change in the migration pattern after age 6, and the older age groups can therefore be handled together as plus-group. The number N_{t+} in this plus-group is calculated as:

$$N_{t+} = N_t /(1 - e^{-Z})$$

where Z is the average total mortality on age group older than t. W_{t+} is judged from data of the Blue Whiting Working Group reports, 1990-1992.

The calculated biomass distribution and increase in biomass by zones are summed by quarters and the percentage biomass by zones are calculated and shown in the rows at the bottom of the Tables 1 and 2. In summing the indices of biomass production, the figures with negative values are omitted.

Application of the model.

In general, the model may be used as a tool to quantify biological criteria for establishing catch allocation keys of shared fish species.In addition to the two vital stock parameters weight by age and instantaneous mortality rate, an input parameter of stock distribution by age is required. This parameter is quantified in relative terms only (percent) and may be derived from general knowledge of stock distribution and migration patterns of the fish. For migratory species such as blue whiting, the fish normally change their distribution pattern when reaching sexual maturity, and the adults undertake seasonal migrations between feeding and spawning areas and to selected areas for wintering. This behaviour determines the stock biomass distribution by areas or zones and can be simulated if the input parameters are available by the relevant seasons. In the case of blue whiting parameters by quarters seem to be sufficiently detailed to simulate the relevant feature of the life history of fish.

The effect of fishing is simulated by altering the fishing mortality F. By increasing F stepwise, the model simulates the biomass distribution (and production) of the stock in a steady state for the respective level of exploitation. In general, a high F favours the share of zones inhabited by the immature fish when using the index of biomass distribution, whereas the biomass production index may be less affected by variation in F. This is the case for blue whiting as illustrated in Fig. 2. In this case , four zones are considered, the Norwegian zone, the EC zone, the Faroes zone and the remaining part of the distribution area which includes Iceland, Jan Mayen and international waters. In the present state of exploitation (F=.2), the calculated indices of relative occurrence are 35%, 33%, 19% and 13% in the four zones respectively by increasing the exploitation, the Norwegian share, which consists of juveniles mainly, will increase at the cost of all the other zones, especially the International-Iceland-Jan Mayen zone, which is inhabited by the older age groups only. The EC and the Faroes zones are less affected because these zones contain both immature and adult fish. The corresponding index of biomass production gives a higher share to Norway at the present level of F (42%), but the percentage share of production decreases slightly with increasing

F. The biomass production index of the EC-zone is low because the zone represents the spawning area, in which the growth in biomass is negative. The biomass production index does, however, favour the share of the International-Iceland-Jan Mayen zone compared to the index of distribution, because these zones include the main feeding areas of the adults.

Column 10 (Table 1) gives space for a weighting factor K which enables the user to give different weights to the various stages of life and areas (juveniles-adults, spawning area-feeding area). In considering the zonal attachment of the North Sea stocks, the Norway-EC Working Group expressed the view that in applying the various criteria of biological attachment, the main emphasis should be given to the fishable stock. An illustration of giving double weight to the adult blue whiting stock is shown in Figure 3. As expected this would increase the share of EC and"Other" at the cost of the share given to Norway, depending on the exploitation rate. At the present state of exploitation the Norwegian share of biomass distribution would be reduced from 35% to 29%, whereas the reduction in the share would be less on a higher level of exploitation (53% to 50%). The option has, however, little effect on the biomass production indices.

This example of application may illustrate how the model can be used to translate political agreements on quota sharing into statistical terms.

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															A:Norway	B:EC	H:Faroe	G-E-I:Other	
Blomass.																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Age	Quarter.	N	M	F	Z	W	N*(1- exp(-z))	N * W	K-factor	%-A	%-B	%-H	%-G-E-I	Sum	A	B	H	G-E-I	Sum
0	4	100,0	0,2		0,05	50	4,88	5000	1	50	35	15		100	2500	1750	750	0	5000
1	1	95,1	0,2		0,05	60	4,64	5707	1	60	25	15		100	3424	1427	856	0	5707
1	2	90,5	0,2		0,05	70	4,41	6334	1	60	25	15		100	3800	1583	950	0	6334
1	3	86,1	0,2		0,05	85	4,20	7316	1	60	25	15		100	4390	1829	1097	0	7316
1	4	81,9	0,2		0,05	90	3,99	7369	1	60	25	15		100	4421	1842	1105	0	7369
2	1	77,9	0,2		0,05	90	3,80	7009	1	60	25	15		100	4206	1752	1051	0	7009
2	2	74,1	0,2		0,05	95	3,61	7038	1	60	20	15	5	100	4223	1408	1056	352	7038
2	3	70,5	0,2		0,05	105	3,44	7399	1	60	20	15	5	100	4440	1480	1110	370	7399
2	4	67,0	0,2		0,05	110	3,27	7374	1	50	20	25	5	100	3687	1475	1843	369	7374
3	1	63,8	0,2		0,05	110	3,11	7014	1	5	85	10		100	351	5962	701	0	7014
3	2	60,7	0,2		0,05	90	2,96	5459	1	10	60	25	5	100	546	3275	1365	273	5459
3	3	57,7	0,2		0,05	130	2,81	7500	1	40	10	25	25	100	3000	750	1875	1875	7500
3	4	54,9	0,2		0,05	140	2,68	7683	1	40	15	25	20	100	3073	1153	1921	1537	7683
4	1	52,2	0,2		0,05	140	2,55	7309	1	5	85	10		100	365	6212	731	0	7309
4	2	49,7	0,2		0,05	110	2,42	5462	1	10	60	25	5	100	546	3277	1366	273	5462
4	3	47,2	0,2		0,05	160	2,30	7558	1	35	5	25	35	100	2645	378	1889	2645	7558
4	4	44,9	0,2		0,05	170	2,19	7639	1	30	5	30	35	100	2292	382	2292	2674	7639
5	1	42,7	0,2		0,05	160	2,08	6839	1	5	85	10		100	342	5813	684	0	6839
5	2	40,7	0,2		0,05	130	1,98	5285	1	10	50	25	15	100	529	2643	1321	793	5285
5	3	38,7	0,2		0,05	190	1,89	7348	1	30	5	25	40	100	2204	367	1837	2939	7348
5	4	36,8	0,2		0,05	200	1,79	7358	1	25	5	30	40	100	1839	368	2207	2943	7358
6+	1	193,0	0,2		0,05	200	9,42	38610	1	5	85	10		100	1930	32818	3861	0	38610
6+	2	183,6	0,2		0,05	160	8,96	29381	1	5	40	25	30	100	1469	11753	7345	8814	29381
6+	3	174,7	0,2		0,05	190	8,52	33189	1	25	5	20	50	100	8297	1659	6638	16594	33189
6+	4	166,2	0,2		0,05	200	8,10	33232	1	20	10	25	45	100	6646	3323	8308	14954	33232
													Sum:		71166	94679	54160	57405	277411
													%-total:		26	34	20	21	100

Table 1. Calculation sheet (Excel) of biomass distribution by economic zones of blue whiting. For further explanation, see text.

Biomass Increment																A:Norway	B:EC	H:Faroe	G-E-I:Other	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Age	Quarter.	N	M	F	Z	W	N*(1- exp(-z))	Biomass	Incr.	K-faktor	%-A	%-B	%-H	%-G-E-I	Sum	A	B	H	G-E-I	Sum
0	4	100,0	0,2		0,05	50	4,88	5000	0	1	50	35	15		100	0	0	0	0	0
1	1	95,1	0,2		0,05	60	4,64	5707	673	1	60	25	15		100	404	168	101	0	673
1	2	90,5	0,2		0,05	70	4,41	6334	596	1	60	25	15		100	358	149	89	0	596
1	3	86,1	0,2		0,05	85	4,20	7316	934	1	60	25	15		100	561	234	140	0	934
1	4	81,9	0,2		0,05	90	3,99	7369	50	1	60	25	15		100	30	12	7	0	50
2	1	77,9	0,2		0,05	90	3,80	7009	-342	1	60	25	15		100	0	0	0	0	0
2	2	74,1	0,2		0,05	95	3,61	7038	27	1	60	20	15	5	100	16	5	4	1	27
2	3	70,5	0,2		0,05	105	3,44	7399	344	1	60	20	15	5	100	206	69	52	17	344
2	4	67,0	0,2		0,05	110	3,27	7374	-24	1	50	20	25	5	100	0	0	0	0	0
3	1	63,8	0,2		0,05	110	3,11	7014	-342	1	5	85	10		100	0	0	0	0	0
3	2	60,7	0,2		0,05	90	2,96	5459	-1479	1	10	60	25	5	100	0	0	0	0	0
3	3	57,7	0,2		0,05	130	2,81	7500	1942	1	40	10	25	25	100	777	194	486	486	1942
3	4	54,9	0,2		0,05	140	2,68	7683	174	1	40	15	25	20	100	70	26	44	35	174
4	1	52,2	0,2		0,05	140	2,55	7309	-356	1	5	85	10		100	0	0	0	0	0
4	2	49,7	0,2		0,05	110	2,42	5462	-1756	1	10	60	25	5	100	0	0	0	0	0
4	3	47,2	0,2		0,05	160	2,30	7558	1993	1	35	5	25	35	100	698	100	498	698	1993
4	4	44,9	0,2		0,05	170	2,19	7639	77	1	30	5	30	35	100	23	4	23	27	77
5	1	42,7	0,2		0,05	160	2,08	6839	-761	1	5	85	10		100	0	0	0	0	0
5	2	40,7	0,2		0,05	130	1,98	5285	-1477	1	10	50	25	15	100	0	0	0	0	0
5	3	38,7	0,2		0,05	190	1,89	7348	1962	1	30	5	25	40	100	589	98	491	785	1962
5	4	36,8	0,2		0,05	200	1,79	7358	9	1	25	5	30	40	100	2	0	3	4	9
6+	1	193,0	0,2		0,05	200	9,42	38610	-341	1	5	85	10		100	0	0	0	0	0
6+	2	183,6	0,2		0,05	160	8,96	29381	-8778	1	5	40	25	30	100	0	0	0	0	0
6+	3	174,7	0,2		0,05	190	8,52	33189	3622	1	25	5	20	50	100	905	181	724	1811	3622
6+	4	166,2	0,2		0,05	200	8,10	33232	41	1	20	10	25	45	100	8	4	10	18	41
														Sum:		4646	1245	2672	3881	12444
														%-total:		37	10	21	31	100

Table 2. Calculation sheet (Excel) of biomass increment by economic zones of blue whiting. For further explanation, see text.

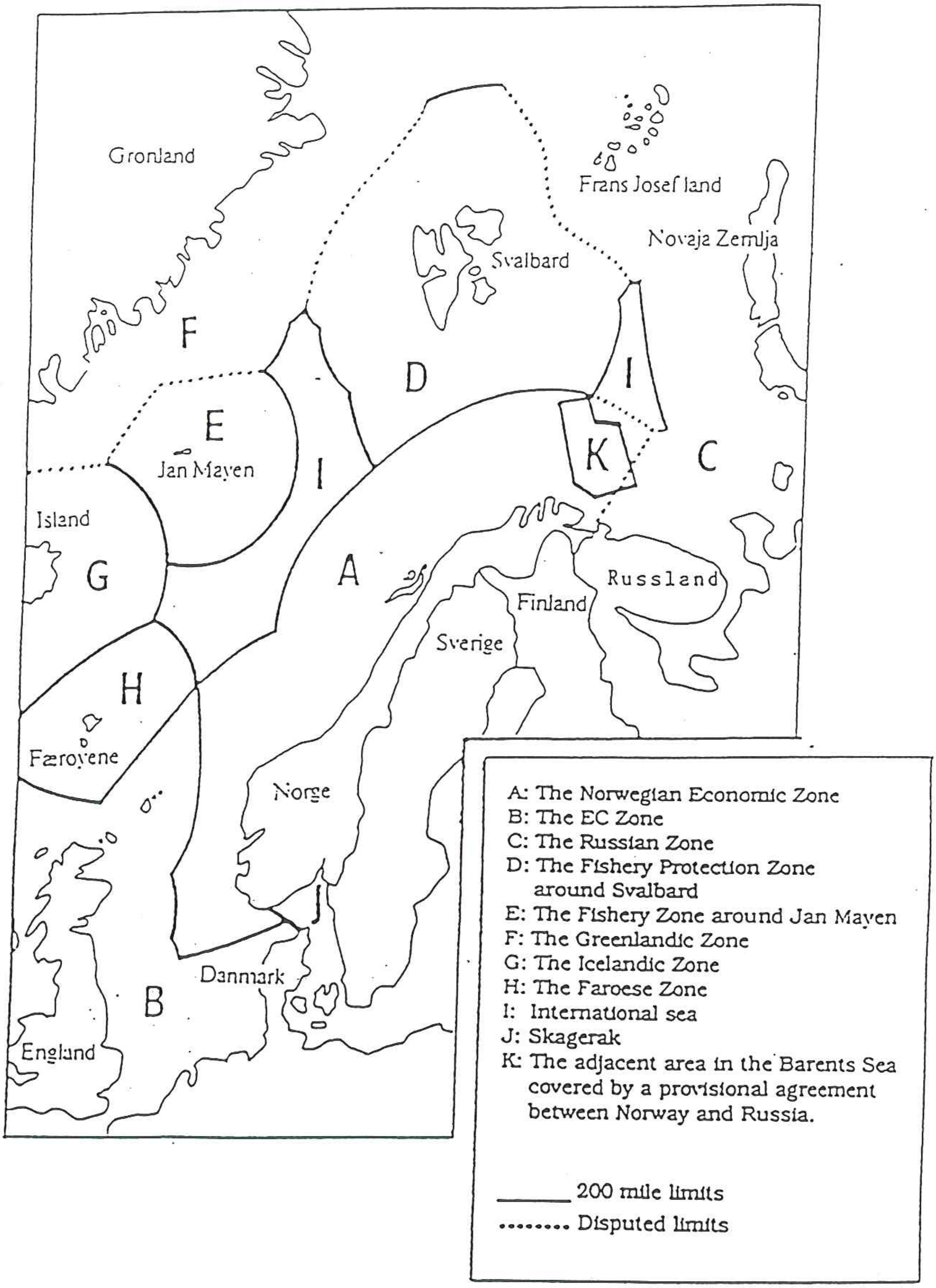


Figure 1. Map of economic zones (Engesæter 1992).

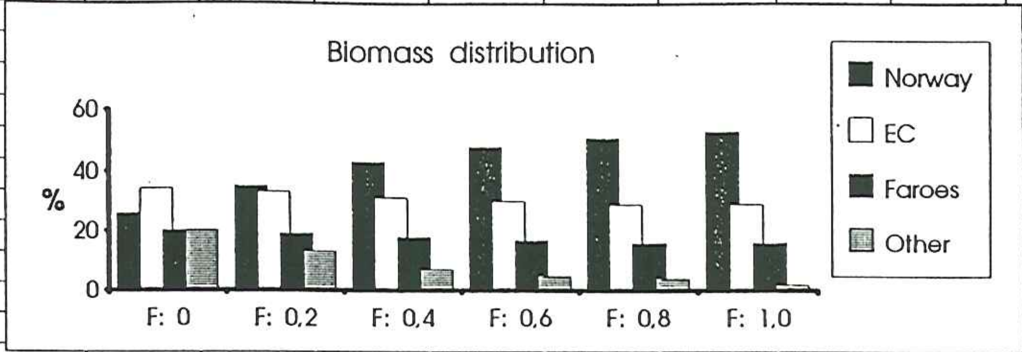
Blue whiting.

Biomass distribution.

	F: 0	F: 0,2	F: 0,4	F: 0,6	F: 0,8	F: 1,0
Norway	26	35	43	48	51	53
EC	34	33	31	30	29	29
Faroes	20	19	18	17	16	16
Other	20	13	7	5	4	2

Biomass production.

	F: 0	F: 0,2	F: 0,4	F: 0,6	F: 0,8	F: 1,0
Norway	37	42	43	37	37	38
EC	10	12	12	8	8	8
Faroes	21	21	22	25	25	25
Other	31	24	23	31	30	29



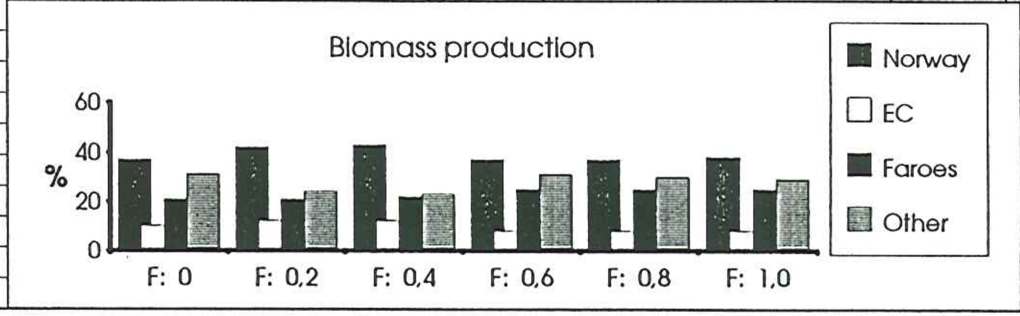


Figure 2. Biomass distribution and biomass production indices of blue whiting by economic zones as a function of the fishing mortality F.
For further explanation, see text.

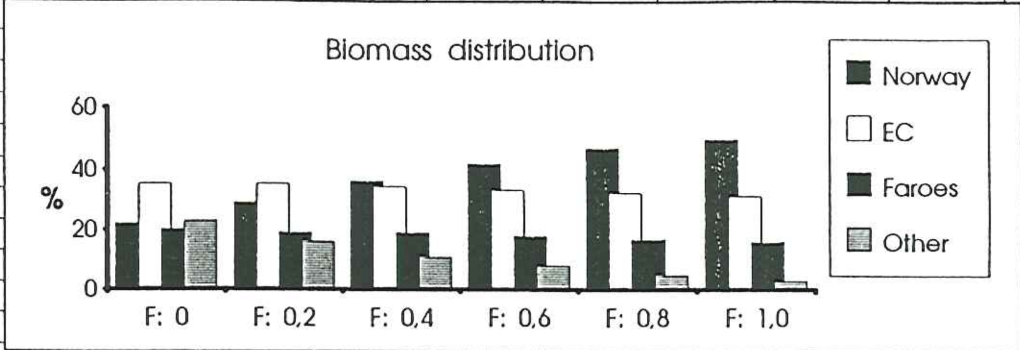
Blue whiting.

Biomass distribution.

	F: 0	F: 0,2	F: 0,4	F: 0,6	F: 0,8	F: 1,0
Norway	22	29	36	42	47	50
EC	35	35	34	33	32	31
Faroes	20	19	19	18	17	16
Other	23	16	11	8	5	3

Biomass production.

	F: 0	F: 0,2	F: 0,4	F: 0,6	F: 0,8	F: 1,0
Norway	35	39	40	37	37	38
EC	8	10	10	8	8	8
Faroes	22	23	23	25	25	25
Other	35	29	27	31	30	29



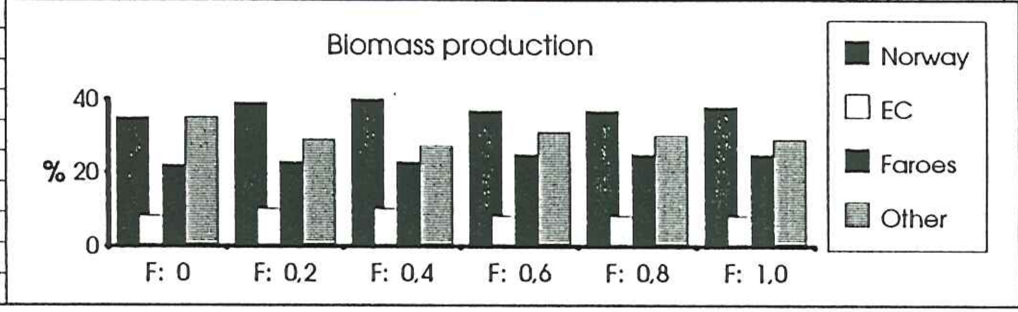


Figure 3. Biomass distribution and biomass production indices of blue whiting by economic zones as a function of the fishing mortality F. The K-factor (Tables 1 and 2) for ages 3+ = 2. For further explanation, see text.