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The Relationship between Arctic and Coastal Cod in their Immature Stages illustrated by Frequencies of Genetic Characters

by

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The cod, Gadus morhua L., which inhabit the Norwegian coast and the Barents Sea, form two genetically separate populations (Møller, 1968 a). In spite of the simultaneous spawning in the same areas the two groups of cod have significant differences in frequency of the haemoglobin Hb^1 allele (Sick, 1965) and of the blood types A and E (Møller, 1967). The investigations did not record possible gene flow from one gene pool to another, implying that the Arctic and the coastal cod should be regarded as two sibling species (Møller, 1968 b).

The material presented in this report consists of two main parts: 14 samples of cod fry (Table 1), totalling 914 specimens, from the Vestfjord, Troms, and Finnmark area; and 48 samples of young cod (Table 2), of which the majority were from 3 to 6 years old, totalling about 5.000 specimens, from different localities in northern Norway and in the Barents Sea.

During trawling and long-line fishing the depths were recorded by an echo-sounder, and the approximate mean depth of the different sampling localities were calculated. Some of the samples were collected with shore seine and trap-net. The depths for these samples were estimated to 2 and 15 m, respectively.

The fry blood specimens were acquired from live fish by cutting the tail, while the other blood specimens were obtained by heart puncture of live cod. The handling of the specimens, the method used in the haemoglobin determinations, the blood grouping technique, and the explanation of the nomenclature have been described elsewhere (Sick, 1965; Møller, 1967). However, the blood type E frequency of 9 samples, collected in 1963, was not determined due to lack of anti-sera at that time.

Table 3 gives the distribution of the haemoglobin patterns, the frequency of the Hb^1 allele (q^1), and the depth of the cod fry samples. The frequencies of the samples vary between .088 (sample 7) and .432 (sample 8), and the frequencies differ significantly among samples taken in the same fjord (sample 1-3, 4-7, and 8-9) and in the same year (sample 4 and 6, 5 and 7, and 8 and 9). The differences between these pair of samples from the same fjord are similar with high values of q^1 in shallow water and with low values in deep water.

However, the frequencies have about the same value in the samples 1 and 2, or the difference is contrary with slightly higher values in deep water in the samples 10 and 11, and 12 and 13. Regarding the difference in depth between the samples 11 and 13, and the samples 2, 3, 6, 7, and 9, the main impression is that the frequency of the Hb^1 allele varies to a certain degree with the depth; the lowest values being in deeper water.

This relationship is supported further by treating the samples as grouped data. The depth versus the mean frequency of the samples belonging to the same 50 m class is plotted in Figure 1. Only the frequencies between 51 and 150 m do not appear to fit in the diagram of correlation between depth and frequency of the Hb^1 allele.

The distribution of haemoglobin patterns, the values of q^1, and of the frequency of the blood type E (p^E), together with the depth of the collected samples of young cod are listed in Table 4.

In Figures 2 and 3 the values in samples from different localities of q^1 and p^E, respectively, are represented on a map of northern Norway and the Barents Sea. In localities which in Table 2 are represented with two or more samples, the values in the maps represent the means.

The highest values both of q^1 and p^E are found inshore (Figures 2 and 3), whereas, mostly all of the values in samples from the banks appear to be comparatively low. In most of the fjords with more than one sample, the sample with the lowest value of q^1 and p^E is found near the mouth of the fjord.

However, the figures contain more frequencies which do not fit into this general pattern. Therefore, the values of q^1 and p^E according to the depth of the sample are plotted in Figs. 4 and 5, respectively. Incidentally, the samples collected inshore and the samples within the coastal locality form four different groups as indicated on the figures.

Both in Figures 4 and 5 the frequencies are decreasing with increasing depth. Although there are large variations from one sample to another, the values of the estimated means in each of the groups both for q^1 and p^E are decreasing continually with the values .312 and .920, respectively, near the surface to .109 and .300 at 300 m. The decline in the values of the frequencies appears greatest in the first 100 m.

The values of q^1 and p^E in samples from the sea are low (Figs. 4 and 5). Only one sample (sample 39) has intermediate values of q^1 and p^E, while the others have low or lower values than the samples collected inshore in corresponding depth.

The value of q^1 according to the value of p^E in the same sample is plotted in Figure 6, together with values representing spawning groups of Arctic and coastal cod in the Vestfjord and north to the Laksefjord (Møller, 1968 a). Here too, there are large variations from one sample to another. However, the values correlate (correlation coefficient .77), and the data fits a straight regression line ($y = .089 + .179x$; linear regression coefficient = .179, highly significant P .01). The mean values of the Arctic cod spawning groups fit this line, while the values of the coastal cod spawning groups are slightly different.

Tables 1 and 2 list the haemoglobin patterns, the homozygotes $\underline{HbI^1/HbI^1}$ and $\underline{HbI^2/HbI^2}$; and the heterozygote $\underline{HbI^1/HbI^2}$, in the cod fry and young cod samples, respectively. The total numbers of individuals in several of the samples are low, and the observed numbers of the different patterns of the individual samples in the tables deviate slightly from the expected numbers calculated from the Hardy-Weinberg law of genotype distributions in large random mating populations. However, by treating the samples in larger units it is possible to detect unconformity. The observed and expected distributions of the haemoglobins in cod fry are not in accordance:

	$\underline{HbI^1/HbI^1}$	$\underline{HbI^1/HbI^2}$	$\underline{HbI^2/HbI^2}$
obs.	63	287	564
exp.	46.6	319.7	547.7

$^2 = 9.561$, d.f.= 1, P .005

Similarly, the samples collected inshore or on localities near the coast (sample 1 to 37) of young cod do not fit the Hardy-Weimberg law:

	$\underline{HbI^1/HbI^1}$	$\underline{HbI^1/HbI^2}$	$\underline{HbI^2/HbI^2}$
obs.	150	1051	2633
exp.	118.8	1112.0	2603.2

$^2 = 11.881$, d.f. = 1, P .005

Despite the restricted area of sampling and the limited number of samples it is convincingly demonstrated that the relative strength of Arctic and coastal cod in the northern Norway and the Barents Sea appear to depend on depth and distance from the shore.

The result coincides with the results of previous studies concerning the distribution of Arctic and coastal cod, such as tagging experiments and determination of the otolith types (Hylen, 1964, 1967; Sætersdal, 1956).

The immature stages of the Arctic and the coastal cod forms prefer different environments. The result being another reason to regard the two cod forms as two sibling species.

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Table 1. Date, locality and number of specimens of, and gear used for collected fry samples.

Sample No.	Date	Locality	No. of specimens	Gear
1	4th Oct.1963	Øksfjorden	60	Shore seine
2	4th Oct.1963	Øksfjorden	65	Shrimp trawl
3	27th Oct.1964	Øksfjorden	60	Shrimp trawl
4	3rd Oct.1963	Gausvik, Vaagsfjorden	81	Shore seine
5	28th Oct.1964	Gausvik, Vaagsfjorden	73	Shore seine
6	3rd Oct.1963	Rolla, Vaagsfjorden	77	Shrimp trawl
7	28th Oct.1964	Rolla, Vaagsfjorden	80	Shrimp trawl
8	5th Oct.1963	Eidsfjorden	22	Shore seine
9	5th Oct.1963	Eidsfjorden	84	shrimp trawl
10	9th Oct.1963	Ulsfjorden	85	Shore seine
11	9th Oct.1963	Ulsfjorden	67	Shrimp trawl
12	8th Oct.1963	Altafjorden	68	Shore seine
13	8th Oct.1963	Altafjorden	15	Shrimp trawl
14	1st Nov.1964	Varangerfjorden	77	Shrimp trawl

Table 2. Date, locality and number of specimens of, and gear used for collected samples of young cod.

Sample No.	Date	Locality	No. of Specimens	Gear
1	4th Oct. 1963	Øksfjorden	57	Shrimp trawl
2	27th Oct. 1964	Øksfjorden	80	Shrimp trawl
3	25th Oct. 1965	Øksfjorden	109	Shrimp trawl
4	3rd Oct. 1966	Øksfjorden	115	Shrimp trawl
5	3rd Oct. 1963	Gausvik, Vaagsfjorden	28	Shore seine
6	26th Oct. 1965	Rolla, Vaagsfjorden	26	Shrimp trawl
7	28th Oct. 1965	Maalsnes, Malangen	85	Shrimp trawl
8	30th Sept. 1966	Maalsnes, Malangen	97	Shrimp trawl
9	10th Oct. 1963	Tromsø	191	Trap-net
10	9th Oct. 1963	Breivik, Ulsfjorden	20	Shore seine
11	7th Oct. 1963	Breivik, Ulsfjorden	156	Shrimp trawl
12	11th Nov. 1964	Breivik, Ulsfjorden	115	Shrimp trawl
13	16th Sept. 1966	Breivik, Ulsfjorden	120	Shrimp trawl
14	29th Oct. 1965	Grøtnes, Ulsfjorden	59	Shrimp trawl
15	28th Sept. 1966	Aarøy, Kvenangen	120	Shrimp trawl
16	29th Sept. 1966	Rødøy, Kvenangen	114	Shrimp trawl
17	8th Oct. 1963	Bosekop, Altafjord	156	Shrimp trawl
18	30 Oct. 1964	Bosekop, Altafjord	95	Shrimp trawl
19	30th Oct. 1965	Bosekop, Altafjord	39	Shrimp trawl
20	19th Sept. 1966	Bosekop, Altafjord	120	Shrimp trawl
21	28th Febr.1966	Sørøya N.71°03' E.23°31'	98	Trawl
22	2nd Nov. 1965	St.Tamsøy, Porsangerfj.	173	Shrimp trawl
23	16th March 1966	St. Tamsøy, Porsangerfj.	119	Shrimp trawl
24	20th Sept. 1966	St. Tamsøy, Porsangerfj.	120	Shrimp trawl
25	27th Sept., 1966	Svaerholt, Porsangerfj.	118	Shrimp trawl
26	6th Nov.1964	Maarøy, Laksefjord	96	Shrimp trawl
27	5th Nov. 1964	Kjeldneset, Tanafjord	120	Shrimp trawl
28	21th Sept.1966	Kjeldneset, Tanafjord	119	Shrimp trawl
29	26th Sept.1966	Losvik, Tanafjord	120	Shrimp trawl
30	14th March 1963	Tanasnaget N.71°06',E.29°00'	115	Trawl
31	20th Apr.1964	Tanasnaget N.71°00',E.29°04'	40	Trawl
32	2nd Mar.1966	Tanasnaget N.71°01',E.29°06'	118	Trawl
33	15th Jan. 1967	Tanasnaget N.70°58',E.28°59'	120	Trawl
34	12th Nov.1965	Makkaur	119	Long line
35	2nd Nov.1964	V.Jacobselv, Varangerfj.	93	Shrimp trawl

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Table 2 (ctd.)

Sample No.	Date	Locality	No. of Specimens	Gear
36	23rd Sept.1966	Vadsø, Varangerfjorden	118	Shrimp trawl
37	16th Jan.1967	Kiberg, Varangerfjorden	120	Trawl
38	4th March 1966	Malangsgrunnen,N.69°51',E.16°42'	97	Trawl
39	21st Nov.1964	Malangsgrunnen, N.70°00',E.17°10'	79	Trawl
40	19th Nov.1964	Bear Island N.73°55',E.18°15'	133	Trawl
41	28th Febr.1964	Nordkapp Bank N.72°12',E.24°25'	123	Trawl
42	1st March 1966	Nordkapp Bank N.71°55',E.25°10'	120	Trawl
43	20th Apr.1964	Nordkyn N.71°14', E.27°55'	90	Trawl
44	18th Jan. 1967	East Bank N.70°16', E.32°25'	117	Trawl
45	12th Mar.1963	East Bank N.70°06', E.33°45'	138	Trawl
46	13th Mar.1963	Skolpen Bank N.70°54', E.34°00'	80	Trawl
47	10th Mar.1963	Skolpen Bank N.70°10', E.34°50'	150	Trawl
48	26th Jan.1967	Skolpen Bank N.71°21', E.35°31'	120	Trawl

Table 3. The distribution of the haemoglobin patterns, the frequency of the $\underline{HbI^1}$ allele (q^1), and the depth of the cod fry samples.

Sample	$\underline{HbI^1}/\underline{HbI^1}$ homozygotes	$\underline{HbI^1}/\underline{HbI^2}$ heterozygotes	$\underline{HbI^2}/\underline{HbI^2}$ homozygotes	Total of rare types	q^1	Depth of sample in meter
1	4	19	37	0	.225	2
2	4	22	39	0	.231	200
3	3	14	43	0	.167	200
4	8	19	54	0	.216	2
5	7	32	34	0	.315	2
6	0	15	62	0	.097	300
7	2	10	68	0	.088	240
8	4	11	7	0	.432	2
9	4	36	44	0	.262	250
10	6	29	50	0	.241	2
11	7	28	32	0	.313	125
12	9	25	34	0	.316	2
13	2	6	7	0	.333	70
14	3	21	52	1	.175	200

Table 4. The distribution of the haemoglobin patterns, the frequencies of the $\underline{HbI}^1$ allele (q^1) and the blood type E (p^E), and the depth of the samples of young cod.

Sample	$\underline{HbI}^1/\underline{HbI}^1$ homozygotes	$\underline{HbI}^1/\underline{HbI}^2$ heterozygotes	$\underline{HbI}^2/\underline{HbI}^2$ homozygotes	Total of rare types	q^1	p^E	Depth of sample in meter
1	4	19	34	0	.237		200
2	7	20	48	5	.216	.385	200
3	5	31	72	1	.188	.426	200
4	6	33	70	6	.196	.487	200
5	2	13	13	0	.304		2
6	1	6	18	1	.154	.269	240
7	3	20	62	0	.153	.476	200
8	5	40	52	1	.255	.674	110
9	19	83	88	1	.317	.917	15
10	2	7	11	0	.275		2
11	9	42	105	0	.192		115
12	4	38	70	3	.200	.708	110
13	1	23	96	0	.104	.458	120
14	4	17	38	0	.212	.568	175
15	6	37	76	1	.204	.508	110
16	1	18	89	6	.088	.343	295
17	9	61	86	0	.253		70
18	3	35	57	0	.216	.637	70
19	1	10	27	1	.154	.645	70
20	3	45	70	2	.213	.825	70
21	6	23	69	0	.179	.155	220
22	6	44	122	1	.162	.606	210
23	1	32	86	0	.143	.419	230
24	5	34	79	2	.183	.592	230
25	1	25	86	6	.114	.283	230
26	5	10	80	1	.104	.152	220
27	3	23	92	2	.121	.432	175
28	4	30	82	3	.160	.310	180
29	1	22	96	1	.100	.263	310
30	3	26	86	5	.133		290
31	0	9	31	0	.113	.233	220
32	3	22	89	4	.119	.164	220

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Table 4 (ctd.)

Sample	Hb^1/Hb^1 homozygotes	Hb^1/Hb^2 heterozygotes	Hb^2/Hb^2 homozygotes	Total of rare types	q^1	p^E	Depth of sample in meter
33	5	28	85	2	.158	.383	100
34	2	29	87	1	.139	.187	215
35	2	31	56	4	.188	.641	200
36	1	26	91	0	.119	.244	230
37	7	39	72	2	.221	.368	110
38	1	16	80	0	.093	.208	260
39	5	19	55	0	.184	.575	220
40	3	31	90	9	.139	.101	25o
41	2	23	98	0	.110	.048	265
42	1	23	96	0	.104	.112	255
43	3	14	73	0	.111	.097	250
44	5	21	90	1	.132	.068	180
45	1	21	136	2	.072		220
46	1	14	63	2	.100		180
47	0	25	124	1	.083		230
48	1	17	102	0	.079	.100	190

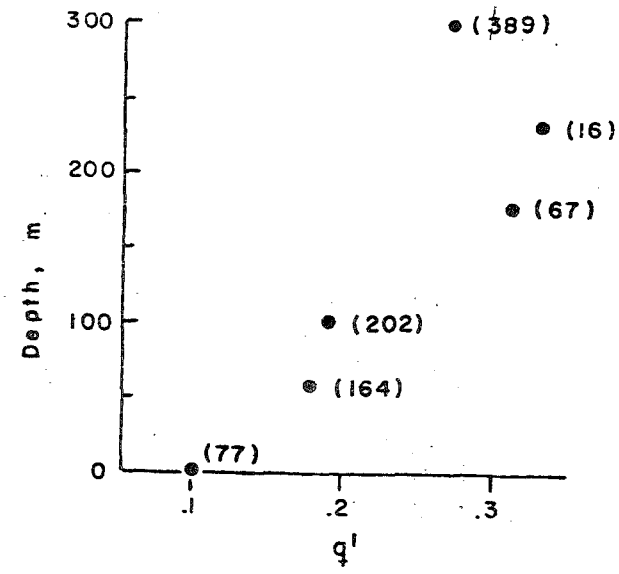

Figure 1. Relationship between frequencies of the Hb I^1 allele (q^1) in samples of cod fry and sampling depths. Figures in brackets represent the number of specimens.

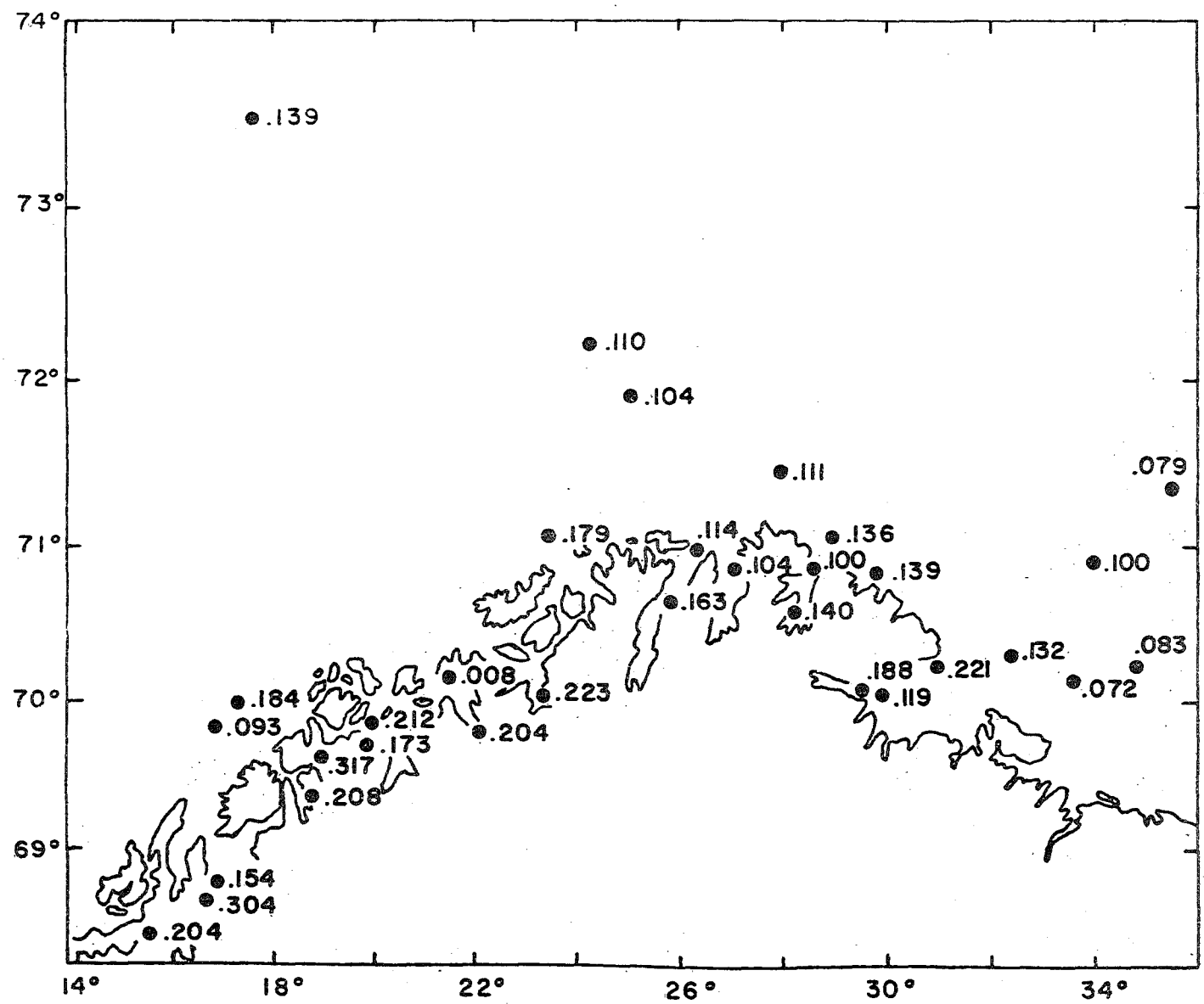

Figure 2. The frequencies of the Hb I^1 allele in the different sampling localities.

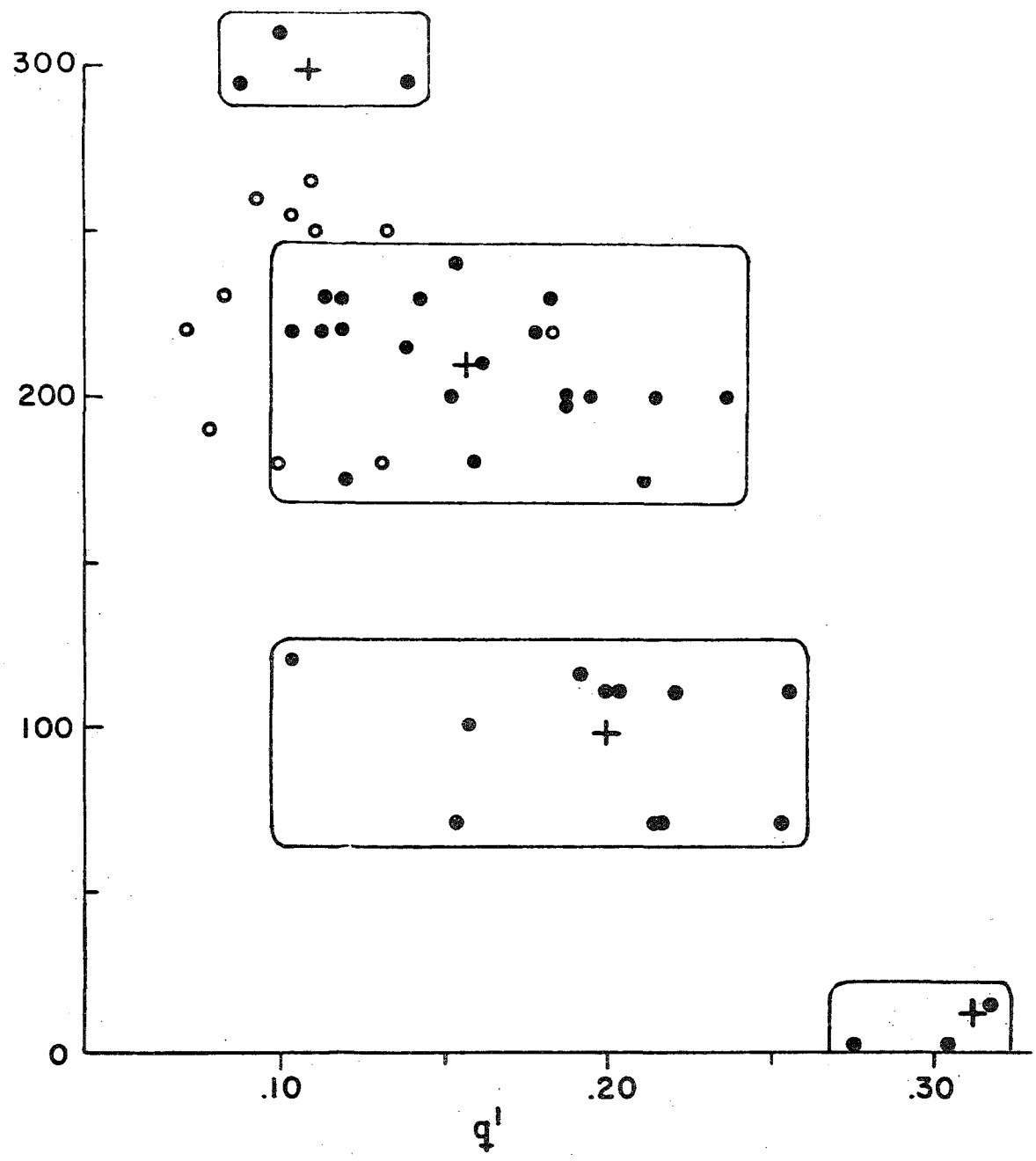

Figure 3. The frequencies of the blood type E in the different sampling localities.

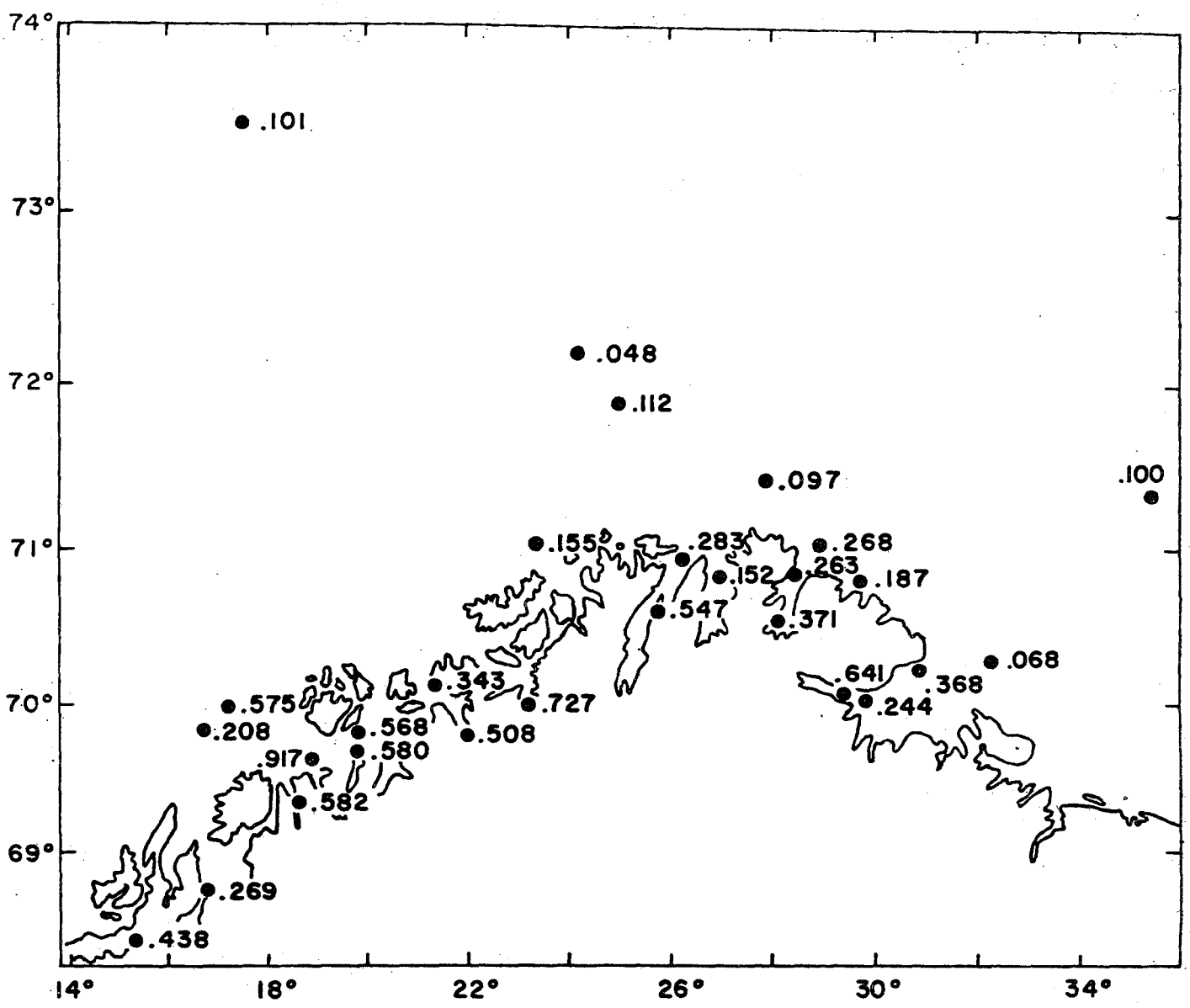

Figure 4. Relationship between frequencies of the Hb I^1 allele (q^1) in samples of immature cod and sampling depths.
Legend: Black dots, sample 1-37; open circles, sample 38 to 48; crosses, means of samples, represented by black dots and which are surrounded by a line.

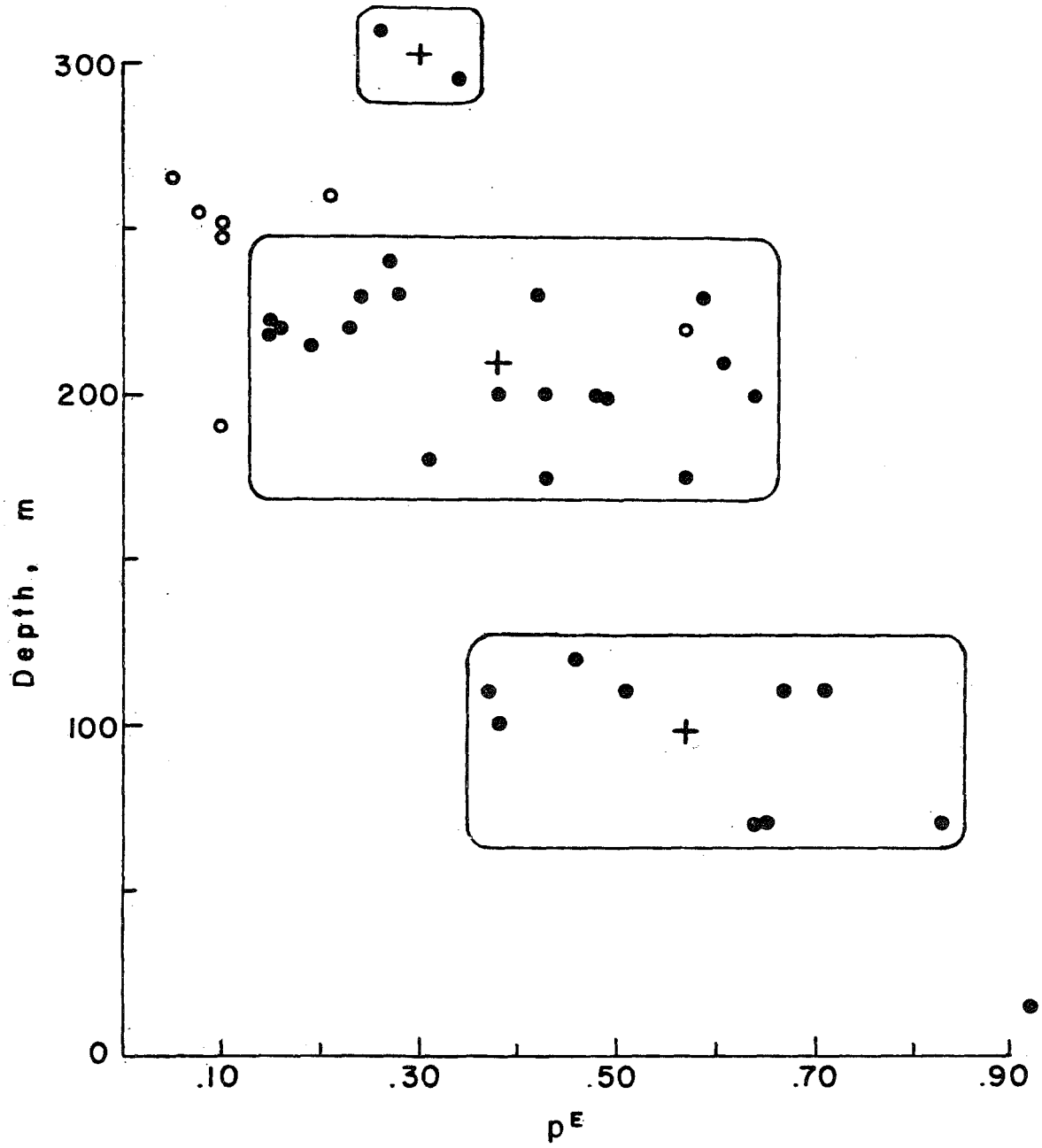

Figure 5. Relationship between frequencies of the blood type E (p^E) in samples of immature cod and sampling depths. Legend: see Figure 6.

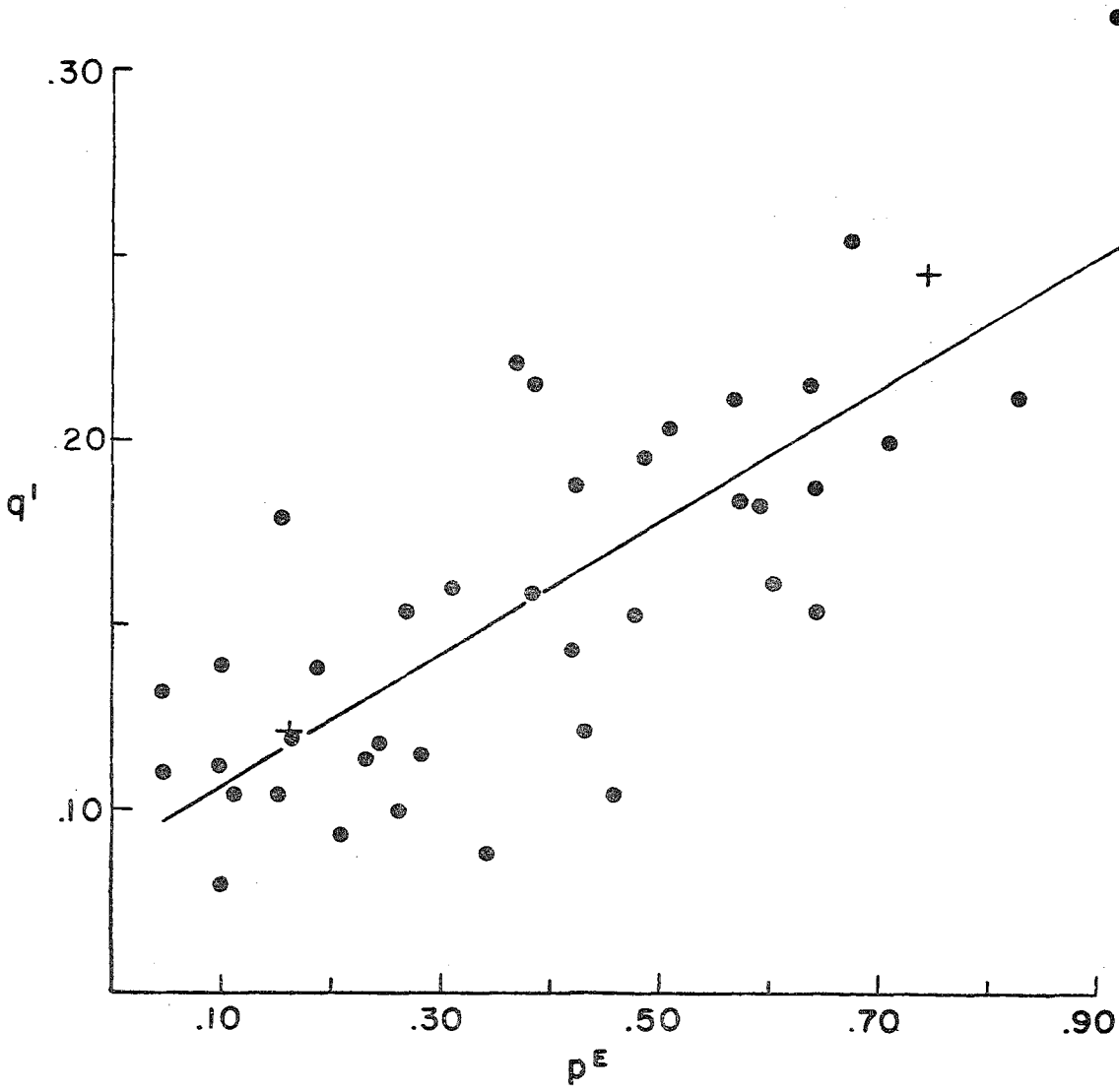

Figure 6. Relationship between frequencies of Hb I^1 allele (q^1) and frequencies of the blood type E (p^E) in the samples.
Legend: Black dots, values of the samples; regression line, y = .089 + 179x; crosses, mean values of the spawning groups of Arctic and coastal cod.