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Inshore Exploitation of Atlantic Cod, *Gadus morhua*, in Labrador and Eastern Newfoundland Waters

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Abstract

Cohort analysis of the numbers by age-group of Atlantic cod caught off southern Labrador and eastern Newfoundland during 1961-80 were used, together with certain assumptions on inshore migration of cod and the seasonal nature of the offshore and inshore fisheries, to estimate rates of inshore exploitation of the stock during 1961-76. The results indicated that during 1961-74 only a small proportion (about 5%) of the cod, which survived the offshore fishery each year, were actually caught in the inshore fishery in the same year, although the proportions were higher in 1975 and 1976. Factors affecting the annual inshore migration of cod and the estimation of inshore exploitation rates are discussed.

Introduction

It has long been recognized that cod off Labrador and eastern Newfoundland undergo an annual cycle of inshore-offshore migrations (Templeman and Fleming, 1956; Templeman, 1962, 1965, 1966; Hodder, 1965). This migration pattern was subsequently confirmed by extensive tagging studies (Templeman, 1979; Lear 1982). These cod live in deep warm-water areas of the continental shelf and slope during winter and early spring when the prespawning and spawning concentrations support a lucrative offshore fishery by otter trawlers. In the spring with the warming of surface water, they migrate to coastal waters where they support an inshore fishery by codtraps, line gears and gillnets. With the cooling of the water in autumn, the cod move progressively deeper and ultimately retreat to their overwintering areas on the continental shelf and slope, thus completing the annual cycle.

For statistical and management purposes, the Labrador-East Newfoundland cod stock occupies the region composed of NAFO Divisions 2J, 3K and 3L, extending from southern Labrador to the northern part of the Grand Bank (Fig. 1). In this paper, the technique of cohort analysis (Pope, 1972) is utilized, together with certain assumptions, to partition the fishery into offshore and inshore seasonal components and thus obtain "rates of inshore exploitation", which represent the actual numbers of fish caught in the inshore fishery relative to the numbers remaining in the population at the end of the offshore fishery in each year.

Materials and Methods

The basic data used for this analysis are the estimated numbers of cod by age-group in the nominal catches of the offshore and inshore fisheries during 1961-76 (Table 1), the numbers by age-group in the population at the beginning of each year (Table 2), and the total fishing mortality coefficients by age-group (Table 3A), the latter two matrices being derived from cohort analysis of 1961-80 catch-at-age data by Wells (MS 1981). Data for 1977-80 were not included in this study because the results from cohort analysis are not reliable for 3-4 years prior to the final year (1980) of input data (Pope, 1972).

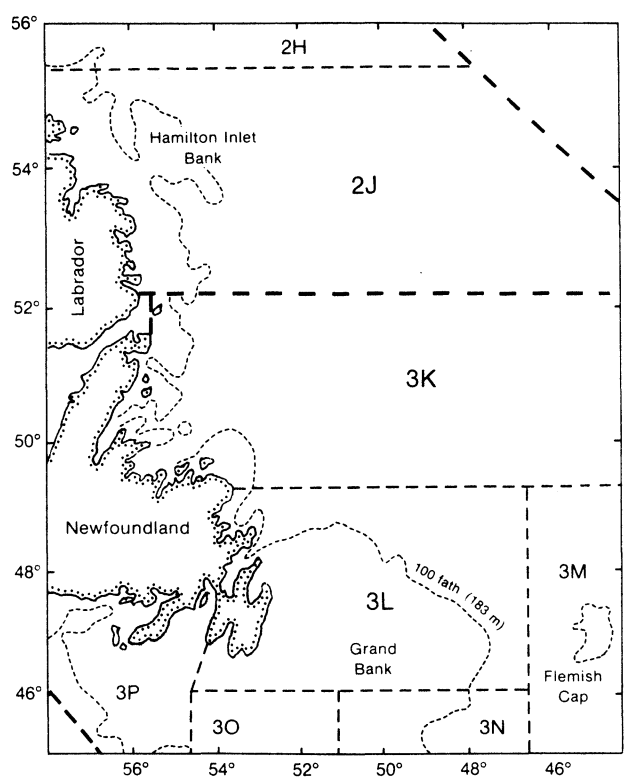

Fig. 1. Map showing NAFO Divisions referred to in the text.

TABLE 1. Estimated numbers of cod by age-group in the nominal catches from the offshore and inshore fisheries of the Labrador-East Newfoundland region (NAFO Div. 2J+3KL), 1961-76. (Offshore fishery is defined as that by otter and pair trawls; inshore fishery is that by all other gears.)

	Numbers of cod (10^3) by age-group											
Year	4	5	6	7	8	9	10	11	12	13	>13	Total
Offshore fishery												
1961	20,315	29,100	45,871	39,033	30,959	26,675	19,839	11,284	10,447	8,436	12,406	254,365
1962	18,550	43,788	49,683	39,523	24,483	17,092	15,704	8,767	7,855	6,854	17,230	249,529
1963	20,522	44,333	89,262	45,914	21,440	11,588	8,690	6,474	3,169	3,005	7,957	262,354
1964	16,391	41,337	49,161	85,696	44,072	15,838	9,910	6,915	4,921	4,051	8,554	286,846
1965	18,710	33,513	55,842	57,194	58,869	30,577	12,209	5,748	2,813	3,107	8,286	286,868
1966	51,540	80,145	53,425	53,674	27,857	20,245	7,211	3,128	1,444	1,205	2,743	302,617
1967	67,077	87,368	86,579	50,571	34,372	15,603	13,503	5,028	2,525	1,652	2,024	366,302
1968	73,084	177,680	135,555	76,589	35,716	21,033	6,959	4,647	2,905	1,414	1,990	537,572
1969	26,210	75,309	143,330	96,205	46,830	16,982	10,921	5,301	3,860	2,544	2,506	429,998
1970	43,578	65,035	83,341	74,907	25,387	9,153	2,782	1,408	845	308	379	307,123
1971	61,302	80,915	89,106	51,910	21,977	10,172	3,707	1,847	1,048	969	1,617	324,570
1972	64,137	105,268	69,188	52,303	27,321	10,700	5,757	2,634	1,491	1,222	2,727	342,748
1973	33,750	84,931	56,514	33,519	25,769	12,974	7,027	3,464	1,936	1,058	849	261,791
1974	7,461	29,057	70,172	59,209	34,548	17,867	9,837	5,375	2,793	943	1,662	238,924
1975	6,580	19,760	30,749	36,139	34,337	12,163	6,951	2,159	1,134	810	570	151,352
1976	48,982	23,998	20,209	15,104	12,927	10,528	4,000	1,516	556	294	366	138,480
Inshore fishery												
1961	11,953	16,592	12,591	6,312	3,944	2,805	2,330	1,512	1,578	1,340	1,959	64,916
1962	8,132	22,032	10,290	9,112	3,906	3,656	2,895	2,000	1,900	1,184	4,843	69,950
1963	6,547	14,840	26,602	11,961	7,320	3,598	2,681	1,587	948	850	2,839	79,773
1964	10,285	14,984	9,796	12,354	5,753	4,353	1,882	1,518	1,190	760	3,337	66,212
1965	9,324	12,120	9,639	5,668	8,327	2,776	2,465	1,097	869	774	2,083	55,052
1966	14,750	14,089	9,796	6,097	2,799	3,800	1,617	1,524	810	631	1,754	57,667
1967	11,373	13,536	10,625	4,681	4,448	1,587	2,600	934	835	461	1,276	52,356
1968	18,522	21,364	9,443	4,313	2,175	1,398	688	727	457	488	1,124	60,699
1969	11,888	21,057	10,040	4,440	2,512	1,288	619	701	330	276	747	53,998
1970	13,650	12,276	10,620	3,882	1,486	828	794	468	284	170	548	45,006
1971	7,744	11,135	5,311	3,789	2,142	1,125	603	296	193	128	518	32,984
1972	15,663	11,332	7,012	3,697	2,279	1,100	643	366	209	178	273	42,752
1973	6,913	9,581	2,727	1,804	1,500	1,198	555	373	232	122	369	25,374
1974	6,339	6,443	4,528	2,091	1,552	733	363	125	107	57	138	22,476
1975	8,383	6,149	3,980	2,719	1,283	1,174	735	239	129	69	94	24,954
1976	15,405	10,616	4,902	2,875	1,939	769	470	358	138	118	178	37,768

TABLE 2. Population numbers of cod by age-group in NAFO Div. 2J+3KL at the beginning of the year, as estimated by cohort analysis, 1961-76.

	Numbers of cod (10^5) by age-group									
Year	4	5	6	7	8	9	10	11	12	13	Total
1961	8,110	4,840	3,010	1,770	1,290	1,000	680	530	380	240	21,850
1962	5,401	6,790	3,716	1,945	1,110	756	673	462	329	397	21,579
1963	5,787	4,181	4,963	2,500	1,153	651	432	383	280	181	20,511
1964	5,122	4,493	2,887	3,015	1,523	683	396	250	240	192	18,801
1965	6,872	3,952	3,169	1,830	1,581	796	377	217	129	141	19,064
1966	8,184	5,373	2,823	2,002	929	687	350	175	116	72	20,711
1967	9,261	6,100	3,547	1,740	1,098	483	345	207	101	74	22,956
1968	6,729	6,872	4,082	2,024	924	548	240	137	115	52	21,723
1969	5,794	4,680	3,826	2,030	925	413	246	128	63	63	18,168
1970	5,379	4,399	2,960	1,744	752	312	172	97	50	14	15,879
1971	5,907	3,886	2,902	1,573	715	372	165	108	62	31	15,721
1972	4,775	4,212	2,348	1,522	784	367	202	96	70	40	14,416
1973	2,089	3,187	2,393	1,233	739	374	194	108	51	42	10,410
1974	1,278	1,342	1,755	1,424	690	358	177	90	54	22	7,190
1975	1,354	922	777	761	611	238	125	53	24	18	4,883
1976	2,659	973	520	322	271	178	75	33	22	8	5,061

In order to derive estimates of the rates of inshore exploitation, it was necessary to calculate instantaneous fishing mortality rates by age-group for the offshore fishery and the numbers of cod remaining in the population at the end of the offshore fishery. The calculations are based on the assumption that most of the cod in the offshore fishery are taken during January-June in each year.

TABLE 3. Estimates of total fishing mortality from cohort analysis and offshore fishing mortality (FO) by age-group for cod in NAFO Div. 2J+3KL, 1961-76.

	Fishing mortality estimates by age-group									
Year	4	5	6	7	8	9	10	11	12	13
A. Total fishing mortality										
1961	0.042	0.110	0.240	0.330	0.350	0.390	0.440	0.310	0.420	0.580
1962	0.056	0.113	0.197	0.323	0.333	0.360	0.364	0.299	0.399	0.250
1963	0.053	0.170	0.298	0.296	0.323	0.298	0.345	0.266	0.176	0.270
1964	0.059	0.149	0.256	0.446	0.449	0.395	0.400	0.463	0.329	0.320
1965	0.046	0.136	0.259	0.478	0.633	0.623	0.564	0.424	0.381	0.360
1966	0.094	0.215	0.284	0.401	0.454	0.488	0.326	0.351	0.246	0.320
1967	0.098	0.202	0.361	0.433	0.495	0.500	0.724	0.387	0.465	0.370
1968	0.163	0.386	0.499	0.583	0.604	0.601	0.431	0.571	0.396	0.510
1969	0.075	0.258	0.585	0.794	0.889	0.677	0.728	0.734	1.317	0.660
1970	0.125	0.216	0.432	0.692	0.503	0.438	0.263	0.243	0.278	0.500
1971	0.138	0.304	0.445	0.497	0.466	0.409	0.341	0.241	0.239	0.490
1972	0.204	0.365	0.444	0.522	0.540	0.439	0.430	0.425	0.315	0.480
1973	0.243	0.397	0.319	0.380	0.524	0.545	0.567	0.494	0.642	0.380
1974	0.127	0.346	0.636	0.646	0.863	0.853	1.008	1.124	0.906	0.680
1975	0.131	0.372	0.680	0.833	1.032	0.958	1.141	0.694	0.916	0.800
1976	0.312	0.499	0.762	0.960	0.937	1.207	1.091	1.026	0.441	0.810
B. Offshore fishing mortality (FO)										
1961	0.027	0.065	0.175	0.261	0.289	0.326	0.364	0.252	0.338	0.457
1962	0.037	0.070	0.152	0.240	0.261	0.270	0.280	0.222	0.287	0.200
1963	0.038	0.118	0.210	0.214	0.217	0.207	0.238	0.196	0.127	0.192
1964	0.034	0.102	0.196	0.353	0.361	0.278	0.303	0.342	0.243	0.250
1965	0.029	0.099	0.206	0.391	0.493	0.513	0.413	0.324	0.258	0.261
1966	0.069	0.171	0.222	0.331	0.369	0.369	0.244	0.208	0.141	0.194
1967	0.079	0.163	0.295	0.363	0.401	0.400	0.526	0.293	0.303	0.266
1968	0.122	0.315	0.426	0.504	0.518	0.524	0.345	0.437	0.306	0.333
1969	0.049	0.185	0.497	0.683	0.751	0.561	0.651	0.523	1.014	0.548
1970	0.089	0.169	0.349	0.595	0.435	0.368	0.187	0.178	0.170	0.261
1971	0.116	0.247	0.387	0.423	0.388	0.336	0.270	0.198	0.215	0.548
1972	0.153	0.303	0.369	0.444	0.452	0.364	0.354	0.337	0.252	0.033
1973	0.186	0.326	0.284	0.333	0.453	0.450	0.474	0.408	0.506	0.064
1974	0.064	0.257	0.541	0.568	0.739	0.735	0.864	0.972	0.775	0.004
1975	0.053	0.254	0.534	0.685	0.881	0.761	0.864	0.554	0.680	0.633
1976	0.215	0.298	0.521	0.671	0.689	0.956	0.811	0.652	0.307	0.483

The instantaneous fishing mortality rate (FO(a,t)) for each age-group *a* in the offshore fishery during the first half of year *t* (Table 3B) was obtained by iteration from the relationship

$$\frac{FO(a,t)(1-\exp(-(FO(a,t)+M/2)))}{FO(a,t)+M/2} = \frac{CO(a,t)}{N(a,t)} \qquad (1)$$

where M = instantaneous (annual) natural mortality coefficient, which was assumed to be constant for all ages and years and estimated to be about 0.2 (Pinhorn, 1975);

CO(a,t) = catch in numbers at age *a* in the offshore fishery in year *t*;

N (a,t) = numbers at age *a* in the population at the beginning of year *t* (i.e. beginning of the offshore fishery).

Having derived the matrix FO(a,t), the number of cod at each age present in the population at the end of the offshore fishery (i.e. 30 June) in each year (NO(a,t)) was calculated from the formula

$$NO(a,t) = N(a,t)\exp(-(FO(a,t)+M/2)) \qquad (2)$$

and the rate of inshore exploitation at age *a* in year *t* is given by

$$I(a,t) = CI(a,t)/NO(a,t) \qquad (3)$$

where CI(a,t) = number of cod at age *a* caught in the inshore fishery in year *t*.

Results and Discussion

The estimated rates of inshore exploitation (Table 4) by the method described above depend on two basic assumptions: (a) the offshore and inshore fisheries occur during January-June and July-December of each year respectively, and (b) the inshore migration of cod occurs instantaneously on 1 July in each year. To test the validity of the first assumption, the offshore and inshore catches were summarized by month for

TABLE 4. Estimated rates of inshore exploitation by age-group for cod in NAFO Div. 2J+3KL, 1961-76. (Overall averages derived from weighting inshore exploitation rates by population numbers.)

Year	Rates of inshore exploitation by age-group									Overall average[a]
	5	6	7	8	9	10	11	12	13	
1961	0.041	0.055	0.051	0.045	0.043	0.055	0.041	0.064	0.097	0.048;
1962	0.039	0.036	0.066	0.051	0.070	0.063	0.060	0.085	0.040	0.045
1963	0.044	0.073	0.066	0.087	0.075	0.087	0.056	0.042	0.063	0.063
1964	0.041	0.045	0.064	0.060	0.093	0.071	0.095	0.070	0.056	0.050
1965	0.038	0.042	0.050	0.094	0.064	0.109	0.077	0.109	0.079	0.051
1966	0.034	0.048	0.047	0.047	0.088	0.065	0.119	0.089	0.118	0.046
1967	0.029	0.044	0.043	0.068	0.053	0.141	0.060	0.124	0.087	0.041
1968	0.047	0.039	0.039	0.044	0.048	0.043	0.091	0.060	0.145	0.045
1969	0.060	0.048	0.048	0.064	0.065	0.055	0.096	0.160	0.084	0.056
1970	0.037	0.056	0.045	0.034	0.043	0.061	0.068	0.065	0.174	0.045
1971	0.041	0.030	0.041	0.049	0.047	0.053	0.037	0.046	0.102	0.039
1972	0.040	0.048	0.042	0.051	0.048	0.050	0.059	0.042	0.083	0.044
1973	0.046	0.017	0.023	0.035	0.056	0.051	0.058	0.083	0.045	0.034
1974	0.069	0.049	0.029	0.052	0.047	0.054	0.041	0.043	0.052	0.050
1975	0.095	0.097	0.078	0.056	0.117	0.155	0.087	0.117	0.045	0.090
1976	0.163	0.176	0.193	0.152	0.124	0.156	0.229	0.094	0.264	0.167
Mean	0.054	0.056	0.058	0.062	0.068	0.079	0.079	0.081	0.096	

[a] Overall average for 1961–74 (and 95% confidence limits) = 0.047 (0.042–0.051).

the 1961-79 period. During this period, the proportion of the offshore catch taken during January-June varied between 53% (1962) and 86% (1973) with an overall average of 71%. The trend during 1961-79 was toward a larger proportion of the offshore catch being taken in January-June in the 1970's (74-86%) than in the 1960's (53-76%). The proportion of the inshore catch taken during July-December varied between 54% (1971) and 86% (1974) with an overall average of 74%. In fact, virtually the entire inshore catch throughout the 1961-79 period was taken during June-December. Unfortunately, the data base is not adequate to consider the problem by month and/or division, because the sampling data collected during the period do not allow the numbers caught by age-group to be derived by month and division for every year. It is obvious that the second assumption regarding migration is not valid because all cod migrating inshore do not do so on 1 July of each year. Data do not exist to measure the degree of deviation from this assumption, but the deviation should be minimal because inshore migration generally occurs rather quickly in June (Templeman, 1979).

The basic assumption that all offshore fishing occurred before 1 July and all inshore fishing occurred after 30 June is violated to different degrees during the period under investigation. To evaluate the effect of such violations on the calculation of rates of inshore exploitation, the proportion (P) of the nominal catch of cod by the offshore fleet in January-June was assumed to be equal to the proportion of the numbers of cod caught by the offshore fleet (CO(t)) during the same period for all age-groups combined. Then

$$\frac{CO(t)\,P}{N(t)} = \frac{FO'(t)\,(1-\exp(-(FO'(t)+M/2)))}{FO'(t)+M/2} \qquad (4)$$

where FO'(t) = true offshore fishing mortality rate for the January-June period.

Application of this equation to data for the worse year (1962) when only 53% of the offshore catch was taken in January-June indicated only an 8% difference in the calculated rates of inshore exploitation for all age-groups combined. Therefore, the violation of this assumption has no significant effect on the results of the analysis.

The "rate of inshore exploitation" used in this paper (Equation 3) is the ratio of the number of cod taken in the inshore fishery during July-December in year *t* to the number present at the end of the offshore fishery on 30 June in year *t* (Table 4). It is not in fact the "true" rate of exploitation in the inshore fishery as usually defined (Ricker, 1975, p. 5), because it can be easily shown that, if two fisheries on the same stock occur consecutively and if only a portion of the total stock is available to the second fishery (which closely approximates the situation described in this paper), the sum of the fishing mortalities and the sum of the rates of exploitation (calculated separately for each fishery in relation to the stock at the beginning of the year) both exceed the fishing mortality and the rate of exploitation relevant to the total fishery in that year. The true fishing mortality and the rate of exploitation for the inshore fishery in a given year must be calculated in relation to the stock present at the beginning of the inshore fishery in that year and not from the beginning of the calendar year. In this case, the "rate of inshore exploitation" is the product of the proportion of cod migrating to coastal waters (migration factor) and the proportion of those migrants which are actually caught in the inshore fishery (true rate of inshore exploitation) in a given year.

Average rates of inshore exploitation for each year (Table 4) do not include age-group 4 because of very low fishing mortalities for this age-group (Table 3) and the inherent bias associated with discarding of small fish, both having a disproportionate effect on the average rates due to the large numbers of age-group 4 fish in the population. The averages for age-groups 5–13 showed no significant trends during 1961–74 but increased substantially during 1975–76. These high values may have resulted from increased fishing mortality in coastal waters or increased rate of inshore migration or a combination of both, but no data exist to determine which of the two factors was more important.

Examination of the average rates by age-groups (Table 4) revealed a regular increase from age 5 to 13 ($r^2 = 0.97$, $P < 0.001$). It is well known that most fishing gears, including those used in the inshore fishery, exhibit a pattern of selectivity such that older fish up to a certain age are progressively more susceptible to capture than younger fish (Beverton and Holt, 1957). Also, there is evidence that younger and smaller cod of the Labrador-East Newfoundland stock migrate to shallow coastal and bank areas as the surface and near-surface water becomes warmer in summer, whereas older and larger fish migrate to the fringes of the coastal shelves below the cold intermediate water layer (Templeman, 1979). Therefore, the increasing trend in the averages with age may have resulted from a combination of differential selectivity and migration with age.

The "rate of inshore exploitation", as defined in this paper, is really a measure of success of fishing in coastal waters, in that it is the product of the proportion of cod migrating inshore and the proportion of the inshore population that is actually caught in the inshore fishery. The implication is that, on the average, at least 4.7% of the total population in the offshore area must have migrated inshore annually during 1961–74, but the upper limit may be 100%. In fact, the estimates show that 17% or more of the stock migrated inshore in 1976 (Table 4).

The success of fishing in inshore waters in a given year, as measured by the rates of inshore exploitation, may be influenced by many factors (Templeman, 1966). Among the most important of these are inshore fishing effort, cod biomass, capelin biomass and environmental conditions, chiefly temperature. For a given availability of cod in inshore waters, higher fishing effort results in higher catches. Also, the size of the cod biomass may affect the extent of inshore migration, the rate of migration varying with the level of biomass. For example, when abundance of cod is low, a larger proportion of the population could be sustained by the food supply in offshore areas and fewer would migrate to inshore waters in search of food. The main food of cod in summer is capelin (*Mallotus villosus*) and the inshore migration of cod in early summer is presumed to be a feeding migration for capelin (Templeman, 1965). Therefore, the abundance of capelin and the extent to which they migrate to inshore areas probably affect the success of the inshore fishery. Also, in the inshore areas of Div. 2J+3KL, cod are found in summer usually where water temperatures are 0° to 5° C (Templeman and May, 1965). Therefore, the extent to which water of this temperature range exists in inshore areas probably influences the success of inshore fishing, but the effect is likely to be greater for codtraps than for gillnets and longlines. A detailed account of the effect of various factors on the success of the inshore fishery by various gears was given by Templeman (1966).

Akenhead *et al.* (1982), using a gross index of inshore availability of cod during 1972–80 by dividing the inshore cod catch in a given year by the estimated biomass of cod at the beginning of the year, found that capelin biomass and temperature were significant variables influencing the availability of cod inshore. However, the authors had severe reservations about the interpretation of the correlation for a variety of reasons listed in their paper. Because estimates of capelin abundance before 1972 do not exist and the data series used in the present analysis extends only to 1976, no correlation of capelin biomass with rates of inshore exploitation was attempted in this paper.

In order to estimate the proportion of cod migrating to inshore waters each year from rates of inshore exploitation, it is necessary to know the ratio of the numbers of cod caught inshore to the numbers present in inshore waters. The traditional technique of calculating partial fishing mortalities from ratios of catches in the respective fisheries (ICES, 1981) is not applicable in this case because the fisheries generally do not overlap in time, and, in any case, only a portion of the cod remaining from the offshore fishery is available to the inshore fishery because not all cod migrate inshore. Therefore, some other means of estimating fishing mortalities for the inshore area must be found. One such method would be to tag cod on their shoreward migration at a time when it is reasonably certain that these are the cod which will contribute to the inshore fishery. Recaptures in the inshore fishery in the same year would provide the basis for estimating the proportion caught of the cod actually present in inshore waters. Migration rates could be calculated from these estimates and the rates of inshore exploitation derived for the tagging years from cohort analysis by the method outlined in this paper. Research along these lines is presently underway.

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