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Simulation and assessment of the dynamics of American plaice stocks in the Gulf of St. Lawrence (4T)

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Introduction

The fishery for the Gulf of St. Lawrence(4T) American plaice (Hippoglossoides platessoides F.) increased substantially in the early 1950's with the advent of otter trawling which increased the effort through the 1960's declining slightly thereafter. Simultaneously, the fishing effort by Danish seiners has increased steadily from the late 1950's through the present. The total landings have fluctuated around the present (1977) quota of 10,000 MT over the same period (Fig. 1). The present work represents the first comprehensive assessment of the stock since the initial study by Powles (1964,1965, 1969). A major concern of this earlier study and others (Powles 1969, Jean 1963) was the discarding of small plaice taken as bycatches in the preferred cod fishery. The magnitude of this wastage (25 - 50 % by weight) was felt to be a cause for concern relative to longterm yield to the fishery. The present work incorporates information collected on contract by MacLaren Atlantic Ltd. (MS 1976) on discarding into a model of the stock dynamics. The effects of various rates of exploitation on the dynamics of the plaice stock were then simulated to determine the optimal management strategy for maximum longterm stability and yield to the fishery.

Material and Methods

The basic information on the population size and structure came from commercial sampling for age and length frequencies that were applied to total commercial landings to derive information on the catches at age. If no age information was available in a particular year the data from an adjacent year was applied to the landings. The data on length at age was used to describe the von Bertanlanffy growth curve for this species emphasizing the sexual dimorphism of the species exemplified by disparate longevity and growth (Fig. 2). The aforementioned discarding of small plaice was estimated from numbers landed and discarded at various lengths (Fig. 3). The lengths from Fig. 2 were used to estimate percent by number discarded at age (Table 1).

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No plaice younger then age 5 are landed but the numbers of 3 and 4 year olds caught was estimable from their selection relative to 5 year old fish.

TABLE 1. Percent of male and female plaice discarded at each age by the fishery.

Age	3	4	5	6	7	8	9	10	11	12	13	14	15
Male	100	100	97	91	81	67	31	17	9	4	1	0	0
Female	100	100	95	86	69	27	9	2	0	0	0	0	0

The number of fish discarded at each age (Table 2) was then combined with the landings at age to provide an estimate of the total catch at age for both sexes for each year from 1964-1977 (Tables 3,4) The total effort expended in this fishery was estimated by determining the total number of trips made by the 25-50 ton Danish seiners and their total catch and using their catch-per-unit-effort as an index of total effort to apply to the total catch of plaice in the Gulf of St. Lawrence (4T) and thereby to estimate the total effective effort for each year. This was necessary because flatfish are frequently not separated in landings or are bycatches of the trawler fisheries for cod. Seiners generally concentrated on plaice and land little of other species thus providing a relatively unbiased estimate of effort (Table 5). Total landings are the actual revised estimates from ICNAF Statistical Bulletin (Vol. 23, 1973), up to 1971 thereafter being estimated, as the sum of known plaice landings and the estimated proportion of plaice in the unspecified flounder landings. Results from 1964-71 indicate this to be a good estimate of total known plaice landings.
No reasonable estimates of natural mortality were obtained so the earlier estimates of.13 for females and.17 for males (Powles 1969) were used in this study. The method of sequential population analysis or cohort analysis (Pope 1972) was used to determine numbers at age (Tables 6, 7). The resulting estimates of fishing mortality (F) (Table 8,9) at age were weighted by numbers and regressed against an estimate of effective total effort (Fig. 4) to determine the terminal F for 1977 where fishing was not complete on all cohorts. The ordinary rather then geometric regression was assumed correct. The biomass caught per tow in the research cruises was also regressed against the biomass estimates from the cohort analysis (Fig. 5) to estimate the terminal fishing mortality. It should be noted that even a terminal F of zero in 1977 would not make this relationship linear through the origin suggesting that there may be an effect of the different selection patterns in the research and commercial data. The strength of recruiting year-classes was also correlated with the catch-per-tow of 3 year olds (Fig. 6) from the annual fall research cruises in the Gulf of St. Lawrence.

Sampling during 1968-1970 did not cover the entire Gulf as did the subsequent cruises so the catches in these years were corrected on the basis of the relative catches at the same stations.
An attempt was made to estimate recruitment to the plaice stock from egg and larval information collected on the annual ichthyoplankton cruises in the southern Gulf of St. Lawrence since 1965.
The methodology is described in detail by Lett et al. (1975). The only two gear types considered were the one meter nets and 6 ft Isaacs-Kidd trawl. The geometric mean number of egg and larvae for each cruise was assumed to be an index of abundance. Egg abundance was estimated from the 1 meter net on the spring cruise. Only cruises after July 1 were considered to estimate larval abundance catches as eggs were felt to be incompletely hatched prior to this date (Powles 1964). Catches from the two gears were averaged to obtain an index of larval abundance for the various cruises (Table 10). The production of eggs was previously shown to be related to the growth rate of the mature segment of the population (Lett 1977). Maturity ogives are available from research cruises for 1969-1976. As no trends were apparent a combined ogive (Fig. 7.) was used to determine the weighted mature female growth rate ($\hat{W}$).:

$$\hat{W} = \frac{\Sigma\ (Wi - W_{i-1}) \times N_i \times M_i}{\Sigma\ N_i \times M_i} \qquad (1)$$

Where W_i is the mean weight at age, N_i the numbers at age from cohort analysis and the M_i the maturity at age.

This growth rate was related to the egg production per mature female (Fig. 8) by the function:

$$\frac{E}{N} = 93.11\ \hat{W}^{2.935}$$

Where E is the egg catch from the spring research vessel cruise, N the number of mature females and $\hat{W}$ the weighted female growth rate.

The regression was significant at the 5% level with F =10.58 (F 1,7/5.59). This relationship was used to predict the number of eggs caught on a cruise and this was related to the larvae catches from Table 7. numerous models have been proposed to describe larval mortality (Cushing 1975, Ware 1975) but no concensus is evident. The proportion of larvae (Larv) surviving from the initial number of eggs (Eg) was regressed against elapsed time (T) in days and an interaction term to describe the effects of temperature (tp = mean June-July) on egg survival:

$$\text{Larv} = 4635 \text{ eggs } e^{-.0955186T - .882115tp + .000269t \times tp^2}$$

The relationship is significant at the 5% level F = 4.91 ($F_{3.12}$ / 3.49) accounting for 55.09% of the variation in larval numbers.

The number of larvae was estimated on August 1 (t = 90) and related to the number of recruiting 3 year olds with a Ricker-type recruitment function incorporating the mean summer (May-October) temperature for the years from the larval to recruiting stage:

$$N_3 = 11499568\,\text{Larv}^{-.32695\text{Larv} - .36296\,\text{Temp.}}$$

Where N_3 is the number of three year old recruits, Larv is the number of larvae, and temp is the mean temperature at Entry Is. from May to October inclusive for the three years preceding and including year i, the relationship accounts for 91.14% of the variation in the number of recruits with F = 36.02 ($F_{2,7}$/4.74) although the fitting procedure is autocorrelated so the goodness of fit is somewhat exaggerated.

The general information on the various biological parameters of the plaice stock cited above and their effect on the dynamics of the population are incorporated into a stochastic computer simulation.

Simulation of Stock Dynamics

A system simulation written in A Programming Language (APL) was constructed to describe the dynamics of the Gulf of St. Lawrence plaice stocks and determine the potential long-term yields under various exploitation regimes. The simulation is initialized by entering the number of 3-21 year old males and females estimated by cohort analysis. Various instantaneous fishing mortality rates (F) may be applied to the stock. The value entered is applied to the female subpopulation since they represent the greatest proportion of the landings while the F applicable to the male subpopulation is calculated from the geometric regression of male and female fishing mortality:

$$F_m = -.003579 + 1.83297\,F_f, \quad r = .893 \qquad (5)$$

where F_m is the male fishing mortality and F_f the female mortality. The relationship is significant at the 1% level, F = 31.45 ($F_{1,8}$/532). The catch in numbers by the fishery may then be calculated using the catch equation from Beverton and Holt (1957) and the respective male and female natural mortalities (M):

$$C_a = \frac{N_a \cdot \partial_a F}{\partial_a F + M}\left[1 - e^{(-\partial_a F + M)}\right] \qquad (6)$$

where C_a is the catch at age in numbers, F and M the fishing and natural mortality rates, and ∂_a the selection factor at age.

The numbers discarded at age were then determined by applying the proportion discarded at age (Table 1) to the catches. It should be noted that discards averaged 48 percent by number and 26 percent by weight for the period 1964-1977 with no obvious trends relative to the various catch levels. This is somewhat less then estimates by Powles (1969) and Jean (1963) but very comparable to estimates from the computer simulation for yellowtail (Sissenwine 1977) using a linear discard model and estimating discarding at 39.5 percent by number and 26.3 percent by weight. The discards at age are then subtracted from the catch at age to determine landings at age in numbers. The weight landed was obtained as the product of the numbers landed at age and weight at age from commercial samples.

The growth of the population is interpolated from a curve of average weight increments at age since no viable relationship to predict growth could be defined. Instead, the weight next year (W_{t+1}) for males and females is calculated from:

$$W_{t+1} = W_t \left(1 + \frac{\Delta W}{W_t}\right) \qquad (7)$$

where $\frac{\Delta W}{W_t}$ is interpolated from an empirical curve of $^{\Delta W}/W_t$ versus W_t based on weights from research cruises. The change in weight may then be calculated as:

$$\Delta W = W_{t+1} - W_t \qquad (8)$$

The weight of the individuals in the initial or age 3 group was obtained by calculating a length stochastically. The length at age three was assumed to be normally distributed and determined by the mean plus a random normal deviate times the standard deviation of the length. This length (L_3) is converted to weight (W_3) at age three by:

$$W_3 = .00445\ L_3^{\ 3.22137} \qquad (9)$$

and added to the front of the vector describing weight at age in year t+1.

The weighted growth rate may then be determined from the ΔW in equations (8) and (1). The numbers at age in year t+1 are obtained from the numbers at age in year t and the total mortality rate:

$$N_{t+1} = N_t\ e^{-(\partial_a F + M)} \qquad (10)$$

The index of the number of eggs produced per mature female is then predicted from (2) and larvae caught on August 1 from (3). The number of age 3 recruits is calculated from (4). The two temperature variables in the simulation were assumed normally distributed and were therefore determined for each year as the sum of the mean and the standard deviation times a random normal deviate. Recruits were subdivided into male and female assuming 39.54 percent of the former and added to the front of the vector of numbers at t+1 calculated by (10). The number of males and females were truncated at ages 17 and 21, respectively. The population biomass was then calculated as the sum of the products of numbers at age and weights at age from research cruise samples.

Results of the Simulation

The simulation was run ahead for 50 years at a variety of levels of fishing mortality at which time an equilibrium or stable situation was assumed. The mean catch and biomass were determined for the last 20 years of each run and used to describe a Graham-Schaeffer plot of average yield and biomass (Fig 9). The maximum sustainable yield is approximately 17000 tons at a 3+ biomass of about 1.35 x 10^5 mt slightly below the present level of 1.48 x 10^5 mt. Variances in the catch are small which is the rule in the historical landings by the fishery (Fig. 1) where effort has varied considerably (Table 5). The optimal fishing mortality level needed to reach MSY is F = .27 which is comparable to the $F_{0.1}$ levels from the yield per recruit formulation (Fig. 10) of Beverton and Holt (1957) who applied it to North Sea plaice and found it useful because of the small variation in recruitment in that stock. However, the yield per recruit estimate is considerably above the 2/3 F_{msy} = .18 necessary to obtain the optimal biomass estimated by simulation. The management objective of 2/3 F_{msy} biomass equal to 175,000 mt was evaluated by doing a number of catch projections for different quota levels based on our knowledge of recruitment to the stock. A stochastic element was added to the discard component of the quota based on the mean estimated weight discarded, its standard deviation and a random normal deviate to account for variations in the degree of discarding from year to year. The optimal biomass will be attained under a range of quotas from the present 10,000 mt to 15,000 mt although of course the latter will require 1 1/2 years longer then the former (Fig. 10). It is therefore recommended that the quota be retained at 10,000 mt to allow the continued rebuilding of the stocks to obtain an optimal level of biomass.

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Table 2a. Estimated number of male plaice discarded at each age for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	176	575	476	1151	2075	1775	42	150	1550	2150	3150	2450	701	675
4	206	675	558	1350	2435	2083	49	176	1819	2523	3696	2875	820	787
5	227	744	615	1488	2684	2296	56	194	2005	2781	4074	3169	906	873
6	880	2973	2872	3974	2882	2468	102	637	5905	2013	3610	4530	2296	2801
7	968	3048	3679	4050	2468	2115	473	1138	4157	1232	2959	4932	1948	2328
8	1001	2627	3516	3094	1643	1407	627	1224	2514	735	1636	2907	1295	1040
9	255	572	710	667	360	304	173	257	528	168	331	621	261	185
10	174	291	341	365	198	169	177	169	280	87	145	265	133	80
11	71	115	136	121	74	64	79	71	97	31	39	95	49	25
12	26	31	39	44	24	21	37	22	28	10	11	24	16	9
13	3	5	5	5	3	3	5	3	4	1	1	4	2	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2b. Estimated number of female plaice discarded at each age for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	76	1154	269	663	216	187	22	87	303	72	72	187	634	1312
4	92	1382	322	795	259	225	26	104	363	86	86	225	757	1572
5	106	1520	373	874	285	247	30	120	399	95	95	247	836	1729
6	455	2906	1609	2592	2408	2064	129	516	3864	1333	1769	2482	2955	3483
7	799	3081	3009	3165	3205	2744	327	1022	4688	1983	2288	3532	2762	5208
8	288	767	1005	808	927	794	176	339	1191	595	692	1022	693	952
9	89	141	226	159	195	167	63	85	189	126	153	202	158	198
10	24	32	46	28	42	36	16	20	36	27	33	43	35	33
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Catch at age of males including estimated discards for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	176	575	476	1151	2075	1775	42	150	1550	2150	3150	2450	701	675
4	206	675	558	1350	2435	2083	49	176	1819	2523	3696	2875	822	792
5	234	767	634	1534	2767	2367	56	200	2067	2867	4200	3267	934	900
6	967	3267	3156	4367	3167	2712	112	700	6489	2212	3967	4978	2523	3078
7	1195	3763	4542	5000	3047	2611	584	1405	5132	1521	3653	6089	2405	2874
8	1494	3921	5248	4618	2452	2100	936	1827	3752	1097	2442	4339	1933	1552
9	822	1845	2290	2151	1162	981	558	828	1703	543	1067	2004	842	597
10	1024	1711	2006	2149	1164	996	1039	995	1646	510	854	1560	781	473
11	784	1274	1515	1346	825	707	875	793	1081	346	434	1053	545	277
12	644	771	967	1094	612	524	928	549	700	244	276	612	391	235
13	315	467	507	499	336	288	473	317	376	140	138	381	216	82
14	170	190	143	211	98	84	181	53	78	35	48	117	73	29
15	80	77	61	177	47	41	84	37	30	20	11	35	37	28
16	41	64	69	41	33	28	78	11	13	11	8	25	26	9
17	58	64	15	70	36	29	30	12	25	10	14	14	79	12

Table 4. Catch at age of females including estimated discards for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	76	1154	269	663	216	187	22	87	303	72	72	187	634	1312
4	92	1382	322	795	259	225	26	104	363	86	86	225	760	1572
5	106	1600	373	920	300	260	30	120	420	100	100	260	880	1820
6	529	3379	1871	3014	2800	2400	150	600	4493	1550	2057	2886	3436	4050
7	1158	4465	4361	4587	4645	3977	474	1481	6794	2874	3316	5119	4003	7548
8	1066	2842	3721	2993	3434	2940	652	1255	4411	2203	2564	3786	2568	3525
9	986	1568	2513	1762	2171	1859	699	943	2105	1398	1698	2242	1754	2198
10	1182	1586	2321	1398	2111	1807	776	991	1780	1373	1639	2137	1761	1659
11	1085	1076	1266	837	1560	1336	904	754	1110	916	1120	1373	1325	1196
12	2043	1575	1571	1007	2604	2230	1999	1584	1445	1404	1612	1861	2345	1384
13	1018	690	709	465	1344	1151	1260	839	660	680	750	843	1123	735
14	593	410	353	356	866	741	807	672	370	490	425	456	722	388
15	347	213	179	171	470	402	374	420	213	271	216	252	374	133
16	221	206	138	146	480	411	314	488	136	302	251	219	416	90
17	215	190	139	87	328	281	211	400	77	192	196	108	304	69
18	78	112	55	31	207	177	85	268	33	132	134	72	192	95
19	168	150	93	61	263	225	151	348	54	155	138	87	250	62
20	71	87	48	78	158	136	38	222	22	113	101	63	125	51
21	80	86	186	63	163	140	47	214	15	93	98	100	204	29

Table 5. Catch and effort statistics for the Gulf of St. Lawrence plaice stocks

YEAR	Weight Plaice Landed	Additional Landing[a]	Total Landings (mt)	Catch/Effort 25-50 Ton Danish Seiners	Total Effective Effort
1964	6916	923	7836	2.13	3679
1965	8778	1623	10385	2.45	4239
1966	9362	2405	11780	2.95	3993
1967	7534	1813	9351	1.98	4723
1968	6921	2622	9568	2.21	4329
1969	6584	1614	8192	3.58	2288
1970	7582	1598	9201	3.73	2467
1971	7627	1876	9513	4.09	2326
1972	8294	884	9178	4.06	2261
1973	6905	899	7804	4.09	1908
1974	8485	454	8939	4.09	2186
1975	8443	1813	10256	4.86	2110
1976	11193	472	11665	5.45	2140
1977[b]	7411	1598	9009	6.25	1441

[a] Proportion of plaice in the unspecified flounder landings.

[b] Minus Quebec landings.

Table 6. Estimated numbers of female plaice at age from cohort analysis with a natural mortality of .13 for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	46716	45358	51657	66484	87003	69653	71971	77701	95874	87991	93322	82272	86491	104343
4	41863	40950	38748	45108	57758	76195	60987	63177	68147	83902	77197	81878	72067	75353
5	42286	36674	34663	33723	38864	50474	66696	53528	55379	59500	73593	67706	71686	62569
6	35962	37032	30704	30088	28750	33846	44078	58537	46890	48234	52153	64528	59209	62123
7	29907	31083	29352	25207	23595	22621	27471	38564	50839	36964	40902	43868	53958	48771
8	20597	25176	23110	21687	17836	16366	16136	23678	32475	38276	29765	32808	33723	43629
9	15357	17088	19443	16807	16238	12444	11616	13558	19616	24383	31546	23733	25261	27205
10	11446	12561	13535	14718	13107	12224	9184	9545	11022	15251	20101	26109	18739	20538
11	8655	8943	9544	9710	11614	9531	9041	7338	7453	8011	12105	16115	20924	14805
12	6905	6583	6845	7194	7742	8737	7117	7091	5737	5505	6176	9580	12864	17132
13	4046	4149	4305	4538	5374	4358	5582	4377	4743	3684	3518	3913	6668	9098
14	2875	2599	2996	3116	3550	3459	2748	3721	3057	3546	2598	2386	2646	4803
15	1772	1969	1898	2300	2402	2305	2343	1657	2638	2338	2655	1883	1668	1647
16	1316	1231	1530	1499	1860	1669	1648	1707	1062	2117	1799	2129	1417	1115
17	1013	948	888	1214	1179	1183	1081	1153	1042	805	1576	1344	1664	855
18	553	688	655	649	985	728	776	751	637	843	527	1200	1079	1176
19	759	413	499	523	541	671	474	602	409	529	616	337	986	768
20	242	509	222	351	403	229	378	274	202	308	319	412	215	632
21	125	146	366	150	236	205	73	296	33	157	165	186	303	71

Table 7. Estimated numbers of male plaice at age from cohort analysis with a natural mortality of .17 for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	35506	33137	31960	34664	39710	41219	42267	46331	56760	68116	78873	50232	63128	89327
4	33509	29794	27428	26526	28188	31596	33145	35621	38950	46463	55493	63649	40129	52616
5	32289	28081	24517	22628	21140	21545	24743	27918	29890	31190	36882	43422	51058	33100
6	26673	27027	22987	20101	17682	15293	16002	20824	23370	23319	23681	27258	33633	42218
7	18791	21615	19801	16494	12948	12008	10412	13398	16925	13756	17642	16335	18424	26058
8	12370	14756	14779	12533	9323	8125	7733	8247	10013	9566	10208	11529	8188	13335
9	8753	9064	8848	7648	6332	5614	4926	5664	5280	5002	7063	6369	5741	5132
10	5744	6630	5952	5361	4477	4275	3835	3643	4019	2890	3721	4979	3533	4070
11	3276	3906	4022	3179	2549	2708	2691	2282	2160	1879	1970	2354	2768	2263
12	2008	2045	2125	2002	1446	1392	1636	1467	1196	829	1267	1264	1019	1834
13	851	1103	1017	905	684	657	694	528	734	367	475	816	504	501
14	532	429	502	392	305	268	290	151	154	274	180	274	339	226
15	198	293	187	292	137	168	149	79	79	58	199	108	124	219
16	143	93	176	102	84	73	104	49	32	39	31	158	59	71
17	83	83	20	85	48	41	36	16	31	15	23	19	110	26

Table 8. Estimated fishing mortality (F) for female plaice from cohort analysis assuming a natural mortality of .13 for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	.002	.028	.006	.011	.003	.003	.000	.001	.003	.001	.001	.002	.008	.013
4	.002	.037	.009	.019	.005	.003	.000	.002	.006	.001	.001	.003	.011	.022
5	.003	.048	.012	.030	.008	.006	.000	.002	.008	.002	.001	.004	.013	.031
6	.016	.102	.067	.113	.110	.079	.004	.011	.108	.035	.043	.049	.064	.072
7	.042	.166	.173	.216	.236	.208	.019	.042	.154	.087	.090	.133	.082	.180
8	.057	.128	.189	.159	.230	.213	.044	.058	.157	.063	.096	.131	.085	.090
9	.071	.103	.148	.119	.154	.174	.066	.077	.122	.063	.059	.106	.077	.090
10	.117	.145	.202	.107	.189	.172	.094	.117	.189	.101	.091	.091	.106	.090
11	.144	.137	.153	.097	.155	.162	.113	.116	.173	.130	.104	.095	.070	.090
12	.379	.295	.281	.162	.445	.318	.356	.272	.313	.318	.327	.232	.216	.090
13	.313	.195	.193	.116	.311	.331	.276	.229	.161	.219	.258	.261	.198	.090
14	.249	.184	.134	.130	.302	.260	.376	.214	.138	.160	.192	.228	.344	.090
15	.235	.123	.106	.083	.234	.206	.187	.315	.090	.132	.091	.154	.274	.090
16	.198	.197	.101	.110	.322	.305	.227	.364	.147	.165	.161	.116	.376	.090
17	.257	.241	.183	.080	.352	.292	.234	.463	.082	.294	.142	.090	.217	.090
18	.163	.191	.094	.052	.254	.301	.124	.480	.057	.183	.317	.066	.211	.090
19	.270	.491	.222	.133	.732	.444	.416	.962	.152	.376	.273	.323	.316	.090
20	.377	.201	.263	.271	.544	1.010	.114	2.002	.124	.497	.413	.178	.975	.090
21	.235	.188	.135	.095	.294	.280	.235	.340	.112	.190	.192	.153	.270	.090

Table 9. Estimated fishing mortality (F) for male plaice from cohort analysis assuming a natural mortality of .17 for 1964-1977.

AGE	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	.005	.019	.016	.037	.059	.048	.001	.004	.030	.035	.044	.055	.012	.008
4	.007	.025	.022	.057	.099	.074	.002	.005	.052	.061	.075	.050	.023	.016
5	.008	.030	.029	.077	.154	.127	.002	.008	.078	.105	.132	.085	.020	.030
6	.040	.141	.162	.270	.217	.215	.008	.037	.360	.109	.201	.222	.085	.082
7	.072	.210	.287	.401	.296	.270	.063	.121	.401	.128	.255	.521	.153	.127
8	.141	.342	.489	.513	.337	.330	.141	.276	.524	.133	.302	.527	.297	.135
9	.108	.251	.331	.366	.223	.211	.132	.173	.433	.126	.180	.420	.174	.135
10	.216	.330	.457	.574	.333	.293	.349	.353	.590	.213	.288	.417	.275	.135
11	.302	.439	.528	.618	.435	.334	.437	.476	.788	.224	.274	.667	.241	.142
12	.429	.529	.684	.904	.619	.527	.962	.523	1.014	.386	.271	.751	.540	.150
13	.517	.618	.783	.918	.767	.649	1.357	1.065	.816	.541	.382	.710	.631	.195
14	.428	.660	.372	.882	.431	.418	1.141	.483	.807	.150	.343	.626	.268	.150
15	.582	.338	.440	1.079	.469	.311	.953	.725	.540	.474	.062	.437	.395	.150
16	.377	1.383	.557	.580	.561	.548	1.721	.284	.586	.372	.339	.190	.659	.150
17	.406	.598	.546	.797	.515	.437	.977	.567	.744	.342	.284	.561	.436	.150

Table 10. Indices of plaice egg and larval abundance from ichthyoplankton cruises 1965-1975 in the Gulf of St. Lawrence.

Date	Geometric mean egg catch/ 100,000 m^3	Geometric mean catch of larvae/ 100,000 m^3	Days elapsed between egg and larval catches
1965 June 1	15896		
Sept 15		1.26	106
1966 June 1	14385		
Aug 5		3.57*	65
1967 May 31	15860		
July 24		10.44	83
Aug 27		3.04	87
Oct 2		1.60	123
1968 May 29	7274		
Aug 12		3.29*	75
1969 May 20	14341		
July 23		7.16	64
Aug 25		1.84	97
Sept 15		.54	118
1970 May 25	3507		
Aug 25		3.24	91
1971 May 15	6730		
Aug 29		2.79	106
1972 May 24	4795		
Aug 27		2.64	95
1973 May 31	2021		
Aug 25		2.77	86
Sept 16		.62	108
1974 Aug 25		2.72	91
1975 May 25	14985		
Aug 27		2.42	94

* Mean from two cruises.

Table 11. Recruitment and temperature indices to estimate the number of 3 year old plaice entering the fishery.

Year	3 yr old Recruits	Estimated # Larvae (Aug 1)	Mean Entry Is. Temperature[a)]
1965	78495	6.551	11.30
1966	83616	6.021	11.59
1967	101147	2.394	11.81
1968	126713	2.029	12.18
1969	110872	3.140	12.34
1970	114238	2.439	12.45
1971	124031	2.021	12.54
1972	152633	3.675	12.08
1973	156107	.914	11.97
1974	172194	4.0172	11.70
1975	132504	5.0172	11.59
1976	149619	4.396	11.86
1977	193670	5.307	11.73

a) Mean temperature at Entry Is. for the 3 years preceeding and including year i.

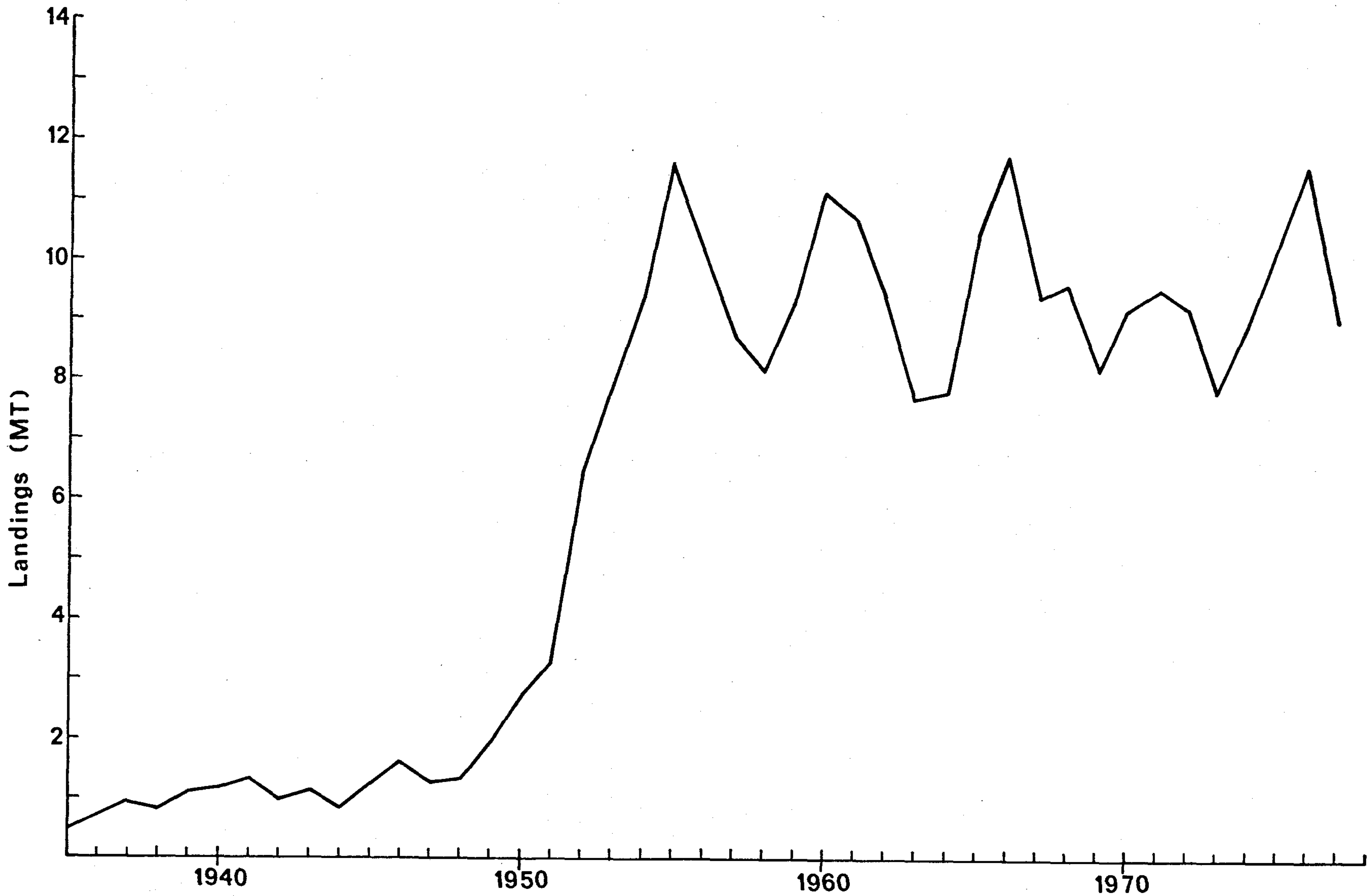


Fig. 1. Historical landings in the Gulf of St. Lawrence (4T) plaice fishery.

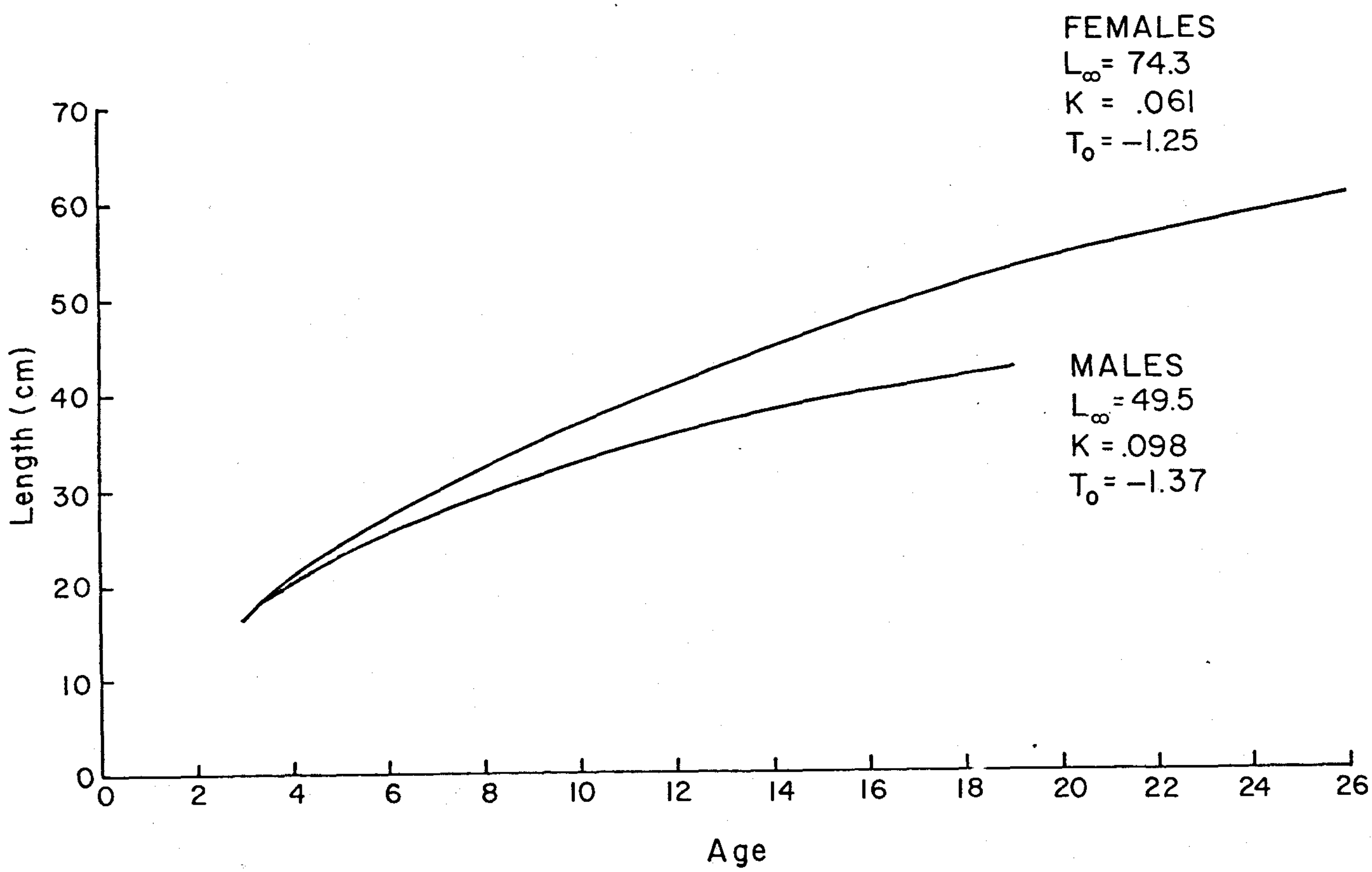


Fig. 2. Male and female von Bertanlanffy growth curves for 1964-1977.

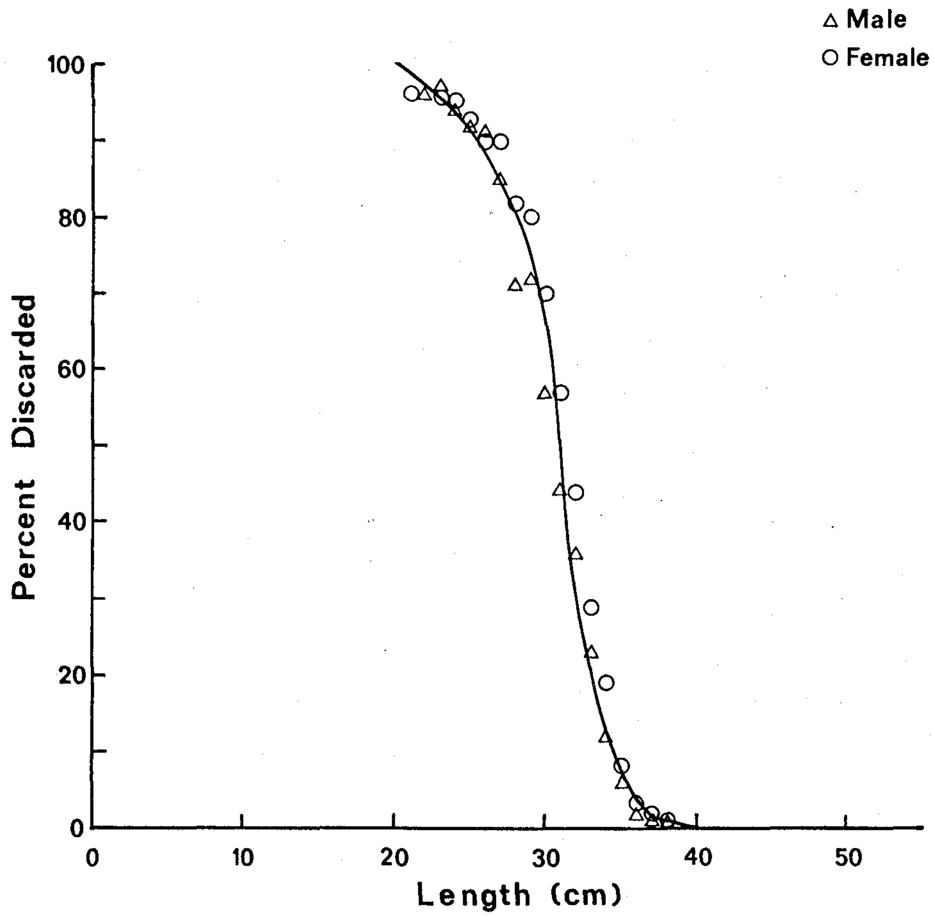


Fig. 3. Estimated percentage male and female plaice discarded at length.

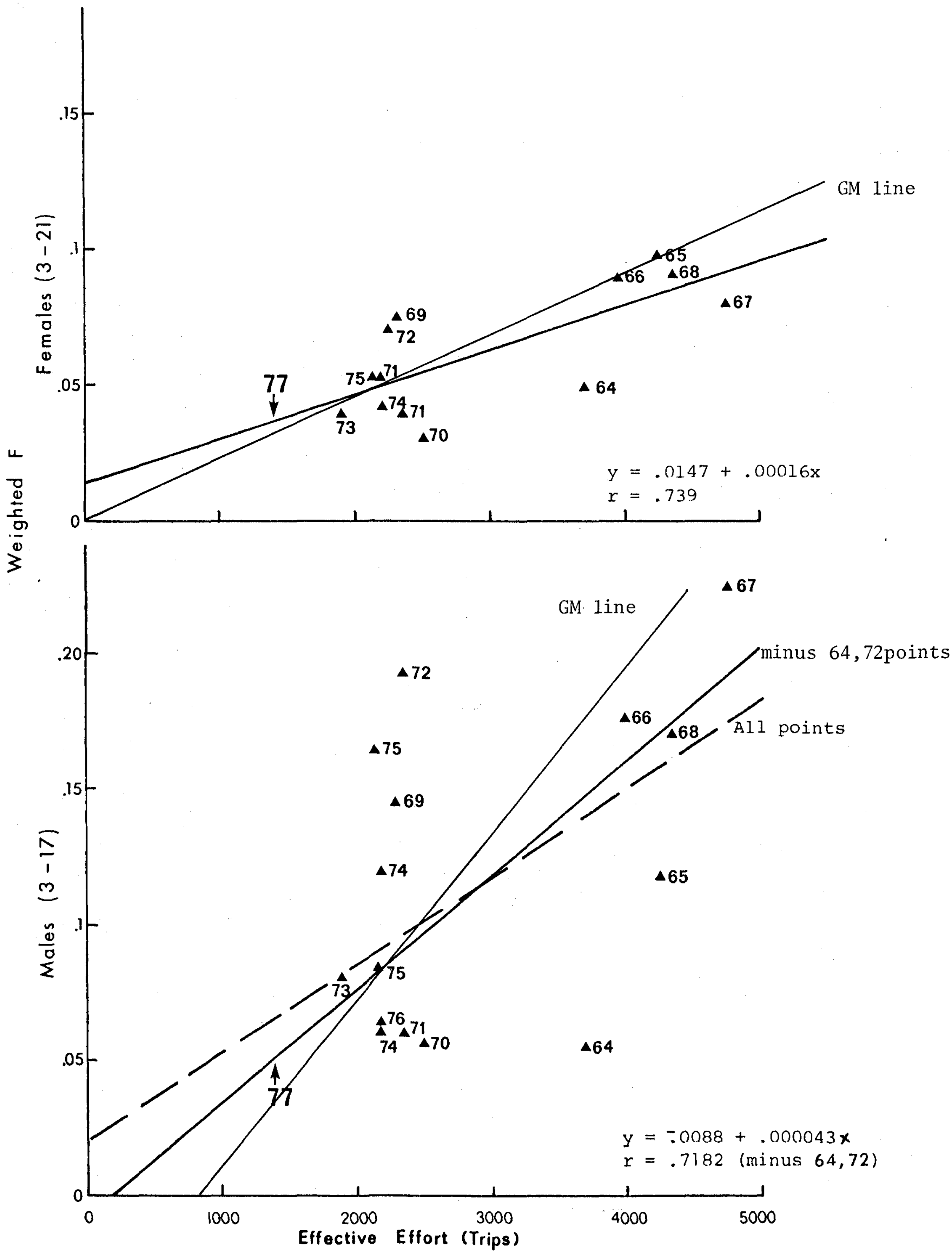


Fig. 4. Relationship of the fishing mortality estimated by cohort analysis and the estimated total effort for 1964-1977.

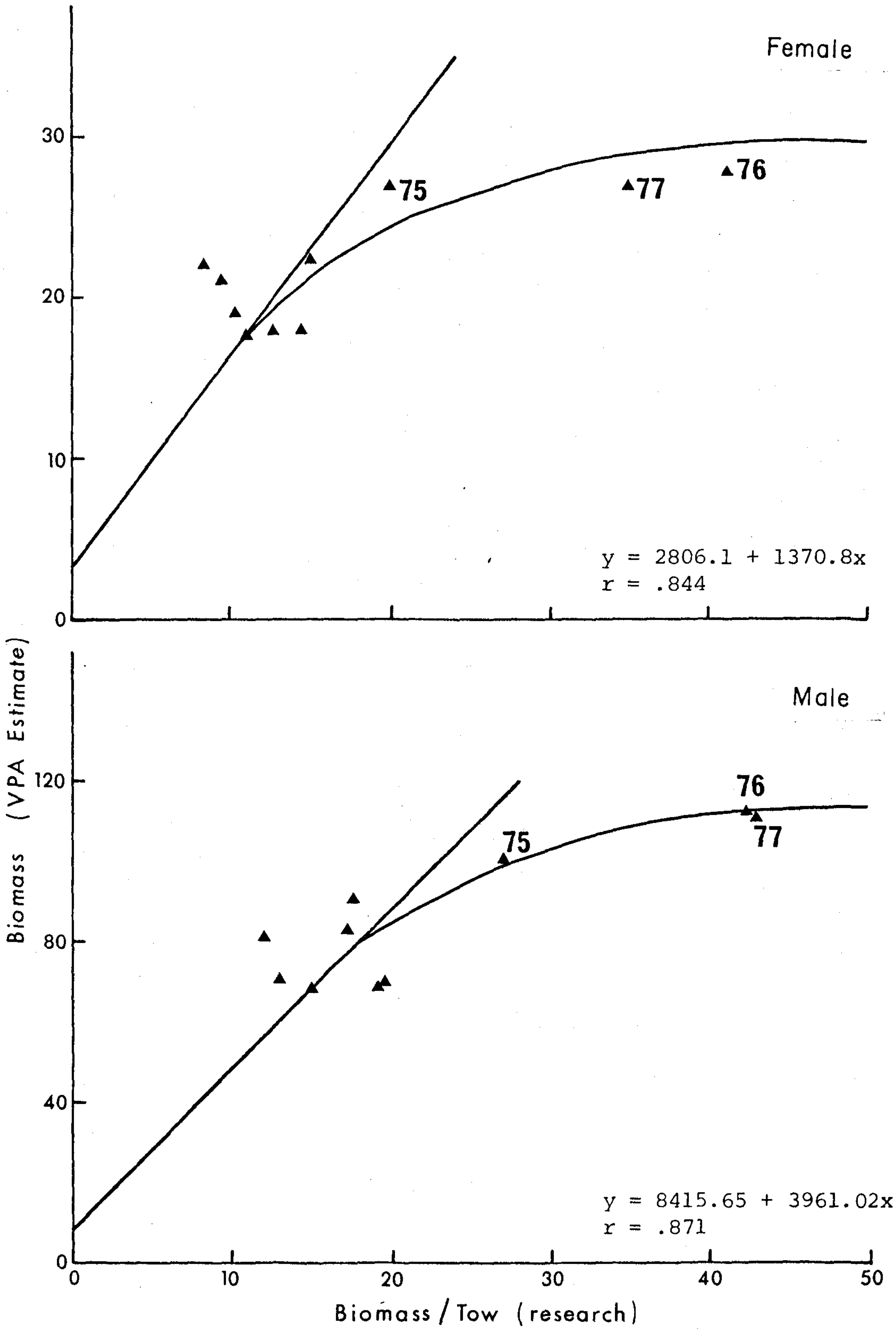


Fig. 5. Relationship between the biomass estimated by cohort analysis and the biomass caught per tow from research cruises 1968-1977.

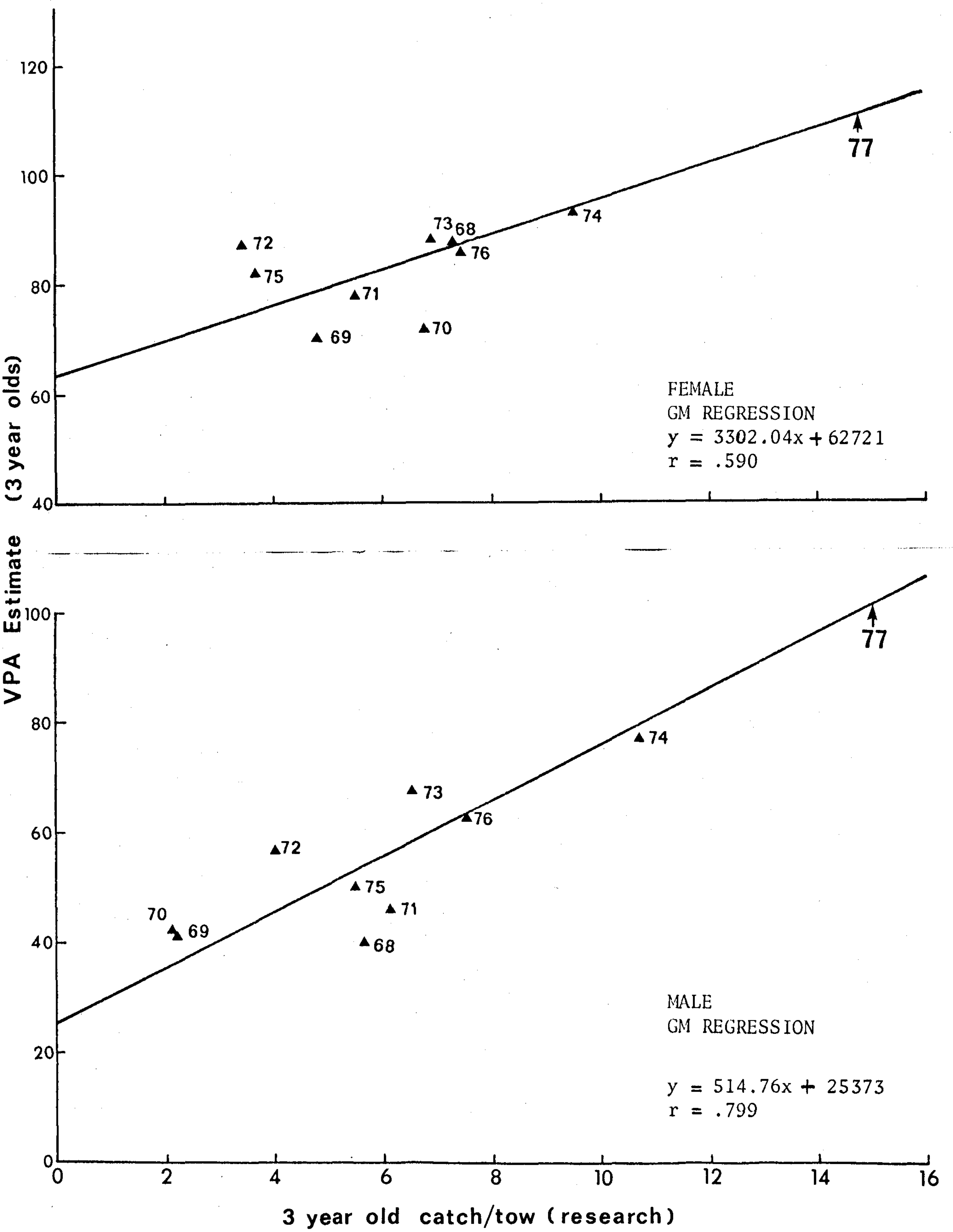


Fig. 6. Geometric regression of catch per tow on research cruises and the estimated 3 year old recruiting year-classes.

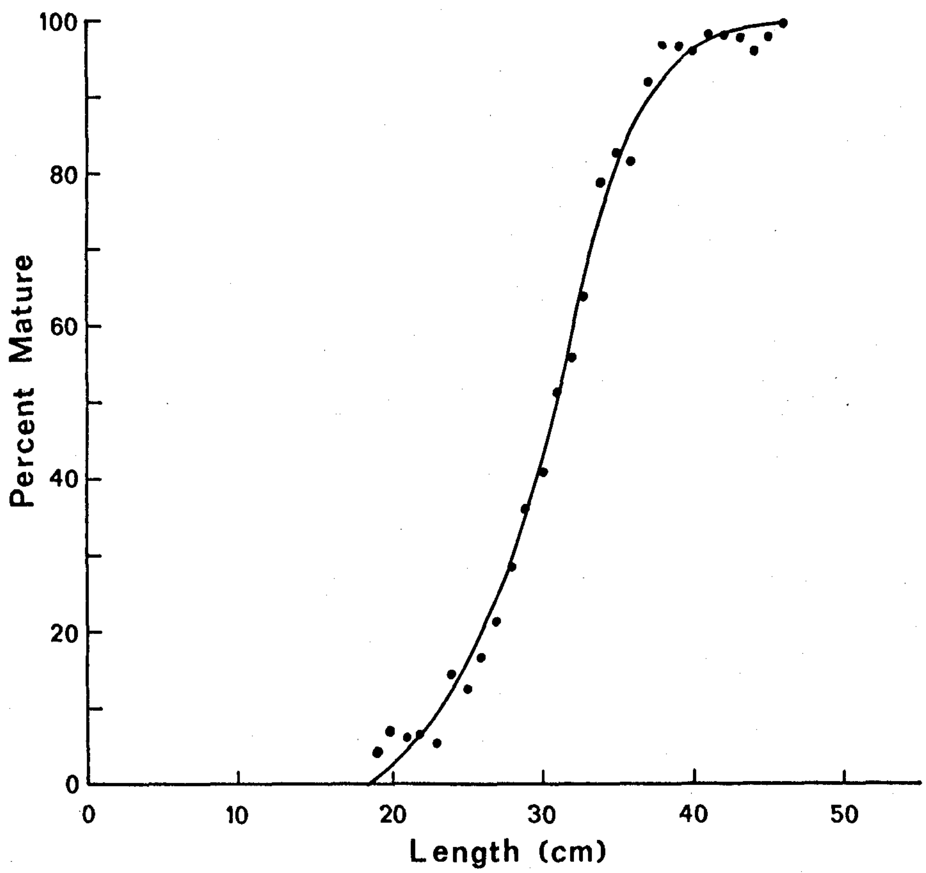


Fig. 7. Average maturity at length for female plaice from research cruises.

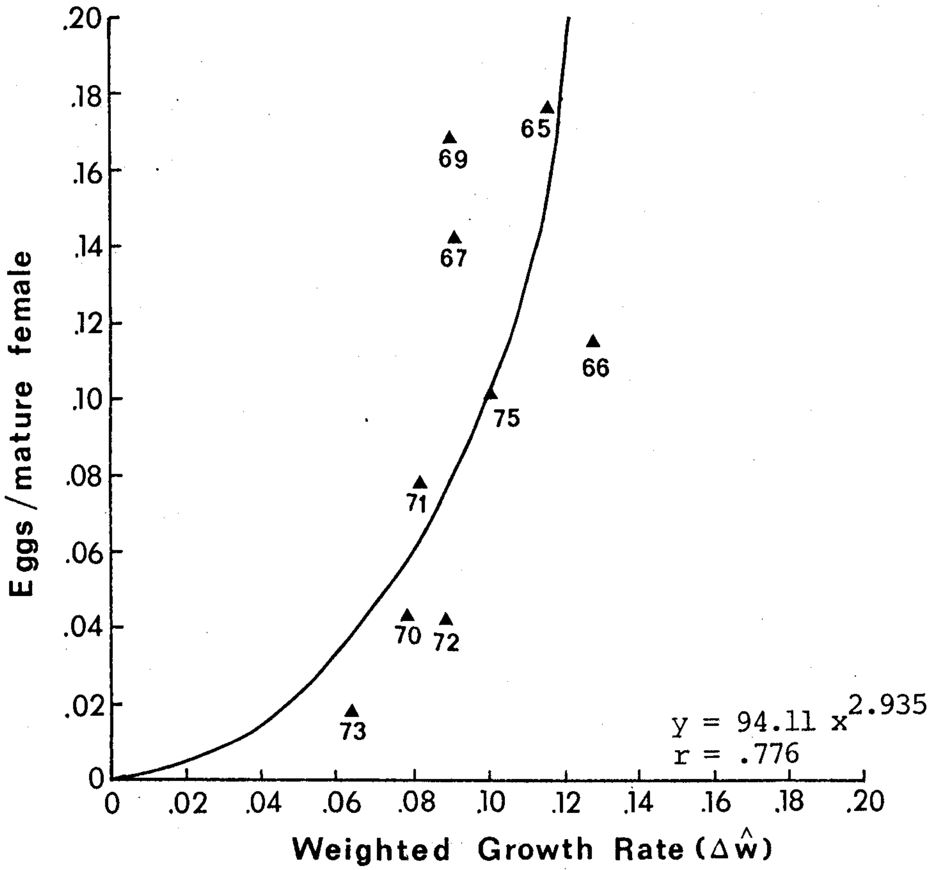


Fig. 8. Relationship between the estimated egg production per [redacted] female growth rate.

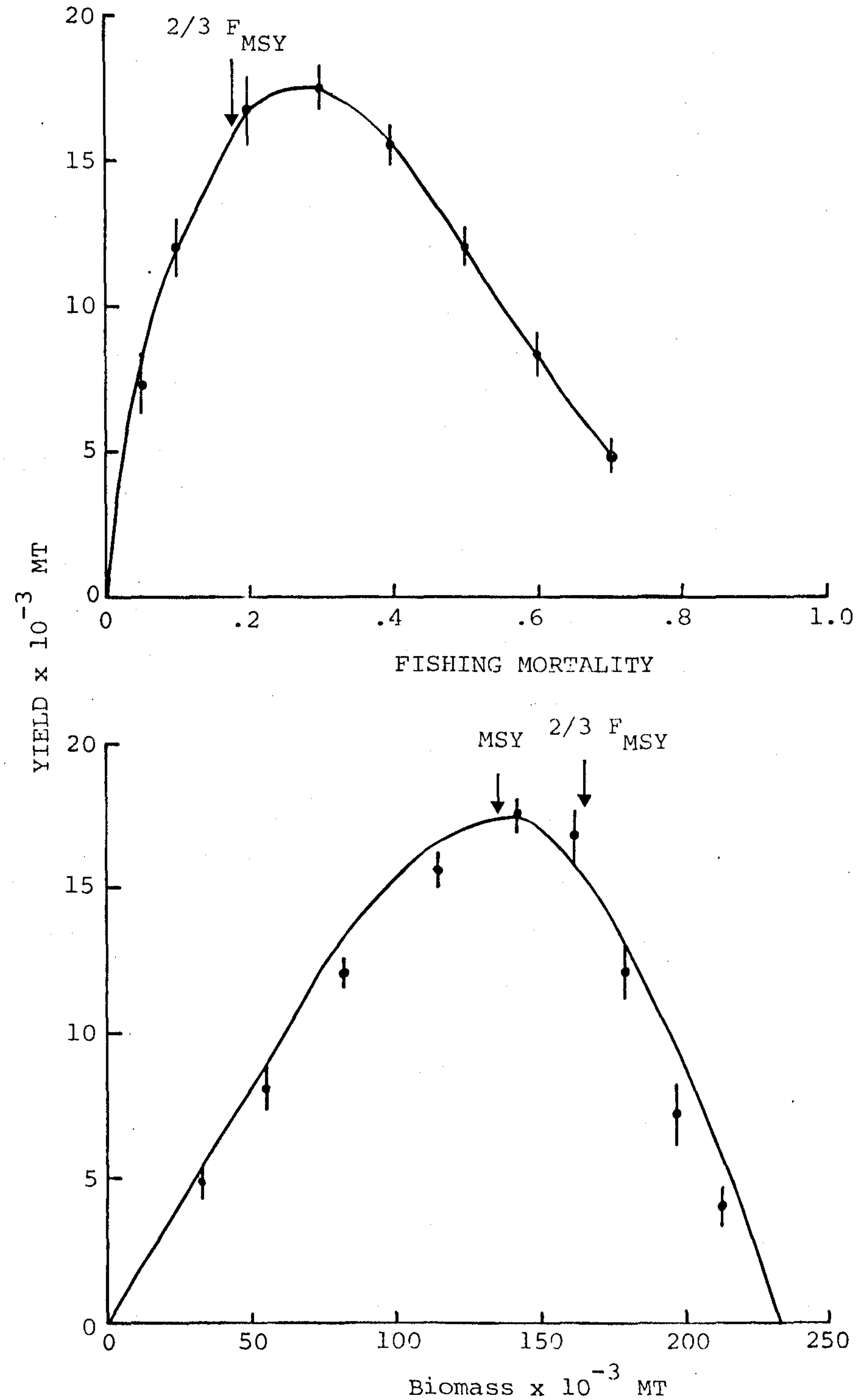


Fig. 9. Graham - Schaeffer curve determined by simulation of the plaice stocks.

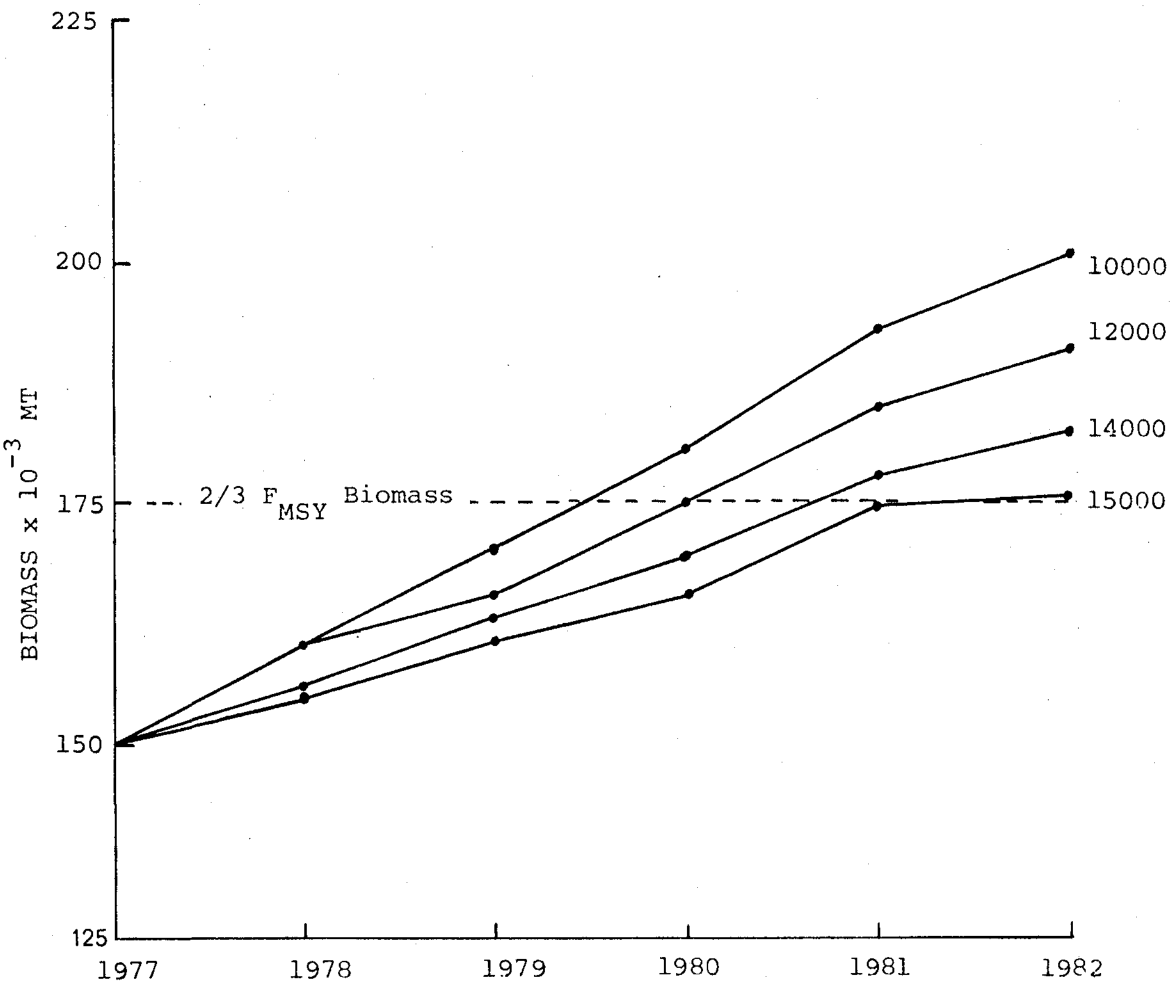
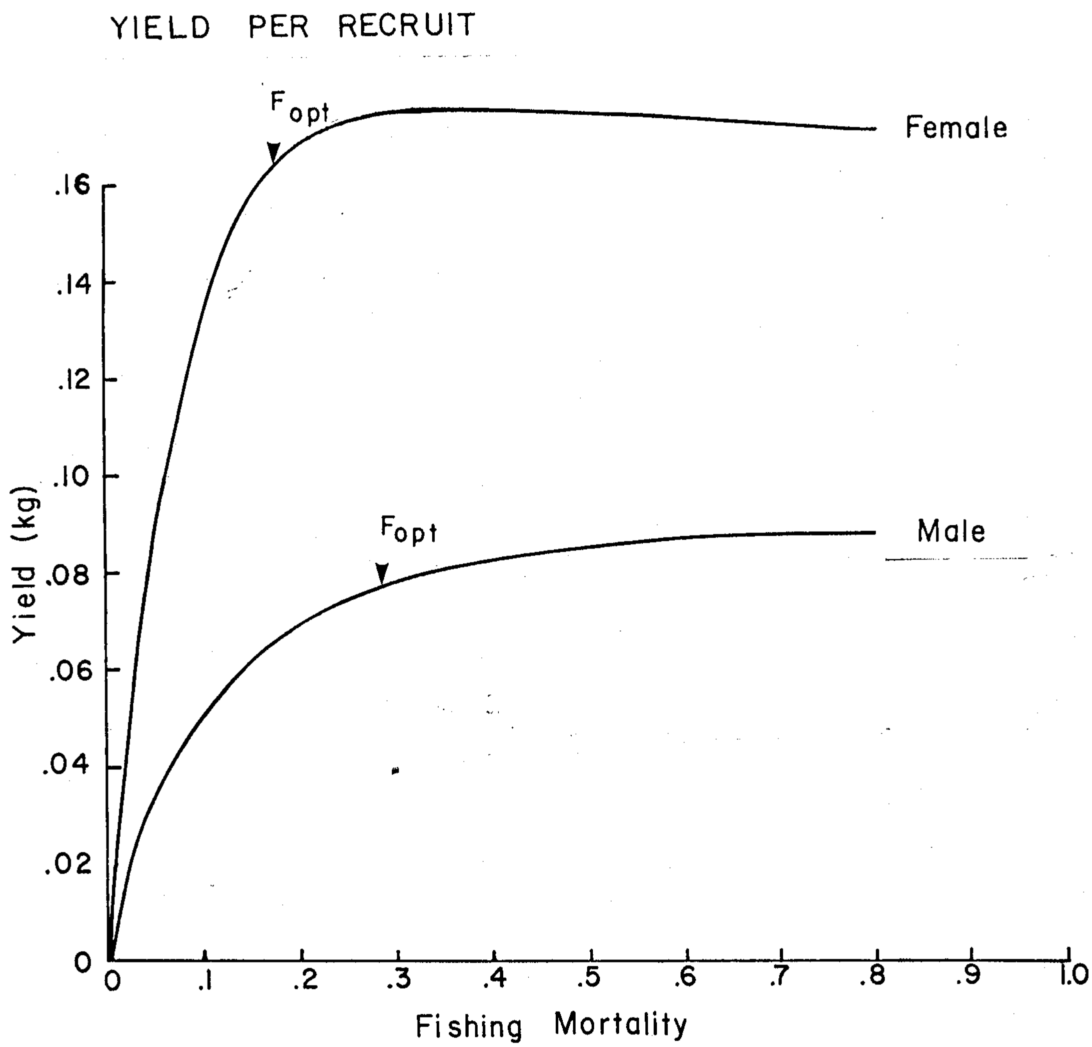


Fig. 10. Projected stock sizes under a variety of quota restrictions.


YIELD PER RECRUIT
F opt
Female
F opt
Male
Yield (kg)
.16
.14
.12
.10
.08
.06
.04
.02
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Fishing Mortality