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1979 4WX Herring Assessment

by

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Abstract

The 1979 herring catch "against quota" in 4WX was 55,182 ton, an historical low and considerably below the quota of 99,000 t. An additional 41,021 t of predominantly juvenile herring were caught in 4Xb, and are not considered in the quota. The catch of adult fish was exceptionally poor whereas the juvenile catches were good. The exceptional 1970 year-class was still important in the "overwintering" and "spawning" components of the fishery but overall, when all gear types are included, the age composition was dominated by the 1976 and 1977 year-classes. The catch rates for both the winter and summer purse seine fisheries declined to historical lows. Since there was good evidence of increases in catchability (q) with time and population decline, the effective effort series for the overall fishery was adjusted accordingly. Starting fishing mortalities (F) for the cohort analysis were selected by optimizing the two regressions for "fishable" population on CPUE index and of weighted F on fishing effort. The fully recruited F was 0.5. Since there was evidence that the partial recruitment pattern has changed over the last two years (less effort applied against the younger ages), the size of the incoming year-classes (the 1976 and 1977) were estimated independently using regressions involving N.B. weir catch rates and environmental variables. The results predict a very strong 1976 year-class at age 2 of 3.74×10^9 and a 1977 at age 2 of 1.42×10^9. If accurate the 1980 (January 1) 2+ biomass is 550,000 t. The $F_{0.1}$ catch for 1980 following the historical partial recruitment pattern is 92,000 t which should climb to 107,000 t by 1982. If however, the 1976 year-class is 50% of the predicted size a 1980 $F_{0.1}$ catch is 55,800.

Résumé

En 1979, les prises de hareng pour la partie du stock qui est régie par TPA dans 4WX, totalisèrent 55,182 tonnes, un minimum historique, et furent de beaucoup inférieures au TPA de 99,000 tonnes. A cela viennent s'ajouter les 41,021 t prélevées dans 4Xb, surtout des harengs juveniles, qui ne sont pas inclus dans le quota. Les prises de poissons adultes furent exceptionnellement faibles, alors que celles des jeunes furent bonnes. La classe d'âge exceptionnelle de 1970 était encore bien représentée dans les prises prélevées durant la ponte et durant la periode hivernale mais, si l'on combine tous les types d'engins de pêche, les classes d'âge de 1976 et 1977 étaient dominantes. Les taux de captures dans la pêche à seine coulissante, tant dans la pêche hivernale que dans la pêche estivale, tomberent à un minimum historique. Comme on avait de bonnes indications que le coefficient de "capturabilité" (q) avait augmenté avec le temps et en fonction de la diminution de l'abondance, la série d'effort effectif pour l'ensemble de la pêche fut corrigée. Les taux de mortalité par pêche pour 1979 furent choisis en optimisant la regression de la biomasse disponible à la pêche vs l'indice de p.u.e. et celle du F pondéré vs l'effort de pêche. Le F sur les âges complètement recrutés était de 0.5. Puisque les coefficients de recrutement partiels semblent avoir changés durant les deux dernières années (moins d'effort dirigé vers les jeunes), l'abondance des classes d'âge 1976 et 1977 fut estimé, indépendamment de l'analyse des cohortes, à l'aide de régressions impliquant les taux de captures des parcs à hareng (weirs) du Nouveau Brunswick et certaines variables de l'environnement. Les résultats indiquent que la classe d'âge de 1976, à deux ans, serait très abondante (3.74×10^9 poissons) et que la classe d'âge de 1977 (à deux ans) serait de 1.42×10^9 poissons. Si ces prévisions sont exactes, la biomasse des poissons de 2 ans et plus au 1^er^ janvier 1980 serait de 550,000 t. Si les coefficient de recrutement partiel reviennent au modèle historique, la prise correspondant à $F_{0.1}$ serait 92,000 t en 1980 et atteindrait 107,000 t en 1982. Par contre, si l'abondance de la classe d'âge de 1976 était la moitié de celle prévue, la prise correspondant à $F_{0.1}$ serait 55,800 t en 1980.

INTRODUCTION

The major stock component in the 4WX management unit spawns off southwest Nova Scotia during the late summer and early autumn, overwinters in the Chedabucto Bay area, and returns to summer feed in the vicinity of the highly productive tidally-induced fronts off southwest Nova Scotia. The larvae metamorphose within the Bay of Fundy in the spring of the first year and subsequently move into the nursery grounds in the shallow embayments on both sides of the Bay of Fundy. A large proportion of the juveniles recruit to the migratory adult population in their third year.

From tagging studies (W. Stobo, pers. comm.), it has been concluded that there is some intermixing in 4Xa of adults from the Gulf of Maine spawning stock during the summer feeding part of the annual migration. Also there is an unknown degree of mixing of the Gulf of Maine, and perhaps historically of the Georges Bank stock, with the "southwest Nova Scotia" juveniles in the 4X(b) nursery grounds. The biological evidence presented in Sinclair *et al*. (1980) suggests that the relative contribution of the component stocks in the 4Xb juvenile fishery has changed in the early 70's. Finally, there are thought to be a number of small "local" stocks of herring along the "South" and "Eastern" shores of Nova Scotia (Statistical districts 8 to 31) which are assumed not to intermix with the larger migratory southwest Nova Scotia stock. The tagging results from the 4Vn and 4Wa winter fisheries suggest, however, that this assumption may not be appropriate (Sinclair *et al*. 1979).

Based upon the above "working hypothesis" concerning stock composition of herring caught in 4WX, the juveniles caught in 4Xb and both the juveniles and adults caught in statistical districts 8-31 within 4WX during the summer have not traditionally been included in the analytical assessment. Since 1978, however, the juveniles caught in the Liverpool area during the early spring, which are thought to be due to an expansion of range of the "southwest Nova Scotia" 1976 year-class, have been included. Also, in 1972 and 1973, large winter catches of juveniles by the purse seine fleet in 4Xb, principally of the 1970 year-class, were included. Thus the area of catch included in the 4WX analytical assessment has been flexible in response to relevant biological information.

In the 1978 assessment, two "stock" options were assessed: the traditional "stock" described above, and option 2 which included, in addition to the "traditional areas", the total catch from the autumn-winter juvenile purse seine 4Xb fishery plus 30% of the New Brunswick weir and "shut-off" catches. The option 2 stock assessment resulted in a change in the relative strength of year-classes in comparison to the "traditional" stock assessment. It was felt that the new year-class strength time series might provide a better data base for recruitment prediction. Primarily for this reason, the second stock option has been considered again in this assessment. The ICNAF subareas used in the description of the 4WX stock are shown in Figure 1.

CATCH DESCRIPTION

The seasonal catch distribution by gear type is shown in Table 1 and Figure 2. The juveniles are essentially caught year-round by the purse seine fleet (autumn-winter "brit" fishery), by the spring Liverpool trap fishery, and by the summer-autumn Bay of Fundy weir and "shut-off" fisheries. The adults are caught during overwintering in 4Wa by the purse seine fleet, and during the summer and early autumn off southwest Nova Scotia by the combined purse seine, weir and gill-net fisheries. The seasonal and distributional characteristics of the 1979 fishery were similar to previous years, except for (i) a relatively late peak in the drift gill-net fishery on the spawning fish, (ii) the above-mentioned expansion of range of juvenile fishery off Liverpool, and (iii) a minimal autumn "brit" fishery.

The annual catch trends for the various gears are shown in Figure 3 and Figure 4. The 1979 purse seine catches in 4Wa and 4Xa are historical lows (Figure 3). The gill-net fishery which selects for the larger fish has also declined in spite of increased effort during the last three years (Figure 4). The fixed gears in the Bay of Fundy, however, reported large catches of, predominantly, juveniles (Figure 4). There was believed to be some under-reporting (by an unknown amount) for these gears via sales to the United States. In sum, the 1979 juvenile catches were good and the adult catches exceptionally poor. In spite of the good juvenile catches, the overall catch in 1979, as defined by both stock options, was an historical low (Figure 5). The TAC of 99,000 t was undercaught by 44%, but the catch was close to the $F_{0.1}$ catch estimated in the last assessment (60,000 t).

BIOLOGICAL SAMPLING AND CATCH RECORDING

The 4WX herring catches have been well-sampled with respect to other stocks. This is reflected in the catch-to-sample ratios for 1977 to 1979 shown in Tables 2 and 3. There are, however, some minor problems with the evenness in the distribution of the samples. The temporal coverage is relatively even except for the gill-net catches (1977 and 1979) (Table 2). Some geographical areas are less well covered than others, but not consistently from year to year. For example, the purse seine areas 17, 18 and 19 (see fig. 20 and 21 for the area definitions) had a high as an 1,800 ton-to sample ratio for 1978; and the Grand Manan weirs (areas 110 and 111) in 1977 and the area 101 and 102 weirs in 1979 were less well sampled than other weir areas (Table 3). Overall, however, the fishery is very well sampled in time and space. There has been a major breakdown, however, in the "area of catch" reporting system by the purse seine fleet. Two systems for identifying the catch location by the purse seine fleet are in operation: the log records and the delivery slips. Both were a failure. Almost 50% of the purse seine catch in 4Xa and 4Xb was not recorded by location in 1979, such that the length frequency samples could not be matched to catch-by-area for most months. Thus, within each of these months, each sample from the purse seine catch was weighted equally. This problem and the above-mentioned under-reporting of weir catches via U.S. sales deserve serious consideration by the Atlantic Herring Management Committee. In spite of these problems, the catch reporting system and the biological sampling program carried out at St. Andrews must be considered to provide excellent age composition data for the 4WX herring stock when compared to the general "state of the art".

AGE COMPOSITION

The overall percentage age composition of the catch of the various components of the fishery are shown in Table 4 and Figure 6. In each histogram, the 1970 and 1971 catches have been adjusted in accordance with the criteria adopted by Stobo et al. 1978. The adjustment is deemed necessary due to an ageing problem for the 1970 year-class. The catch of the "predominantly adult" fishery components included a large percentage of three- and four-year olds (1976 and 1975 year-classes). The 1973 year-class was not very strong in the gill-net or 4Xa purse seine fisheries. The large 1970 year-class was still important in the "overwintering" and "spawning" components. The juvenile components caught a higher proportion of three-year olds of the strong 1976 year-class and almost no one-year olds. There are some interesting differences in age composition by area and month that are not reflected in the combined age compositions. For example, the Grand Manan weirs caught a higher proportion of three-year olds than did weirs in other New Brunswick areas, and west Grand Manan consistently (every month) caught bigger fish than east Grand Manan. One-year olds were only caught in New Brunswick weirs within area 106 (see fig. 21) in the more estuarine waters. Annapolis Basin and St. Mary's Bay weirs caught predominantly two-year olds, while weirs on the outwards side of Digby Neck caught a higher proportion of three-year olds. In sum, there is a consistent gradient in the proportional catches of two- and three-year olds from enclosed bays to open water. The two stock option percentage age composition histograms are shown in Figure 7. The dominance of juveniles in the catch, irrespective of the option, is striking.

EFFORT

In the assessment of the 1978 fishery (Sinclair et al. 1979), the question of changes in catchability in the purse seine fishery, due to stock size fluctuations and increases in efficiency by the fleet, was considered at some length. It was accepted that there was some evidence for "learning" by this component of the fishery; and thus the cohort analysis, "fitted" with the effort series adjusted by learning, was the option retained for management advice. It is of interest that the $F_{0.1}$ generated TAC from this option was much closer to the actual catch than was the TAC generated from the cohort analysis "fitted" without the learning adjustments. The adjustment of the effort by the purse seine fleet is considered again in this assessment.

Trends in fishing mortality (F) per unit of effort (E) are calculated using the "catch equation". Population numbers were generated for option 2 stock, fitted with (method 2) and without (method 1) learning-adjusted CPUE and effort time series. Thus method 1 includes the optimistic or high estimate of recent population levels, while method 2 uses the lower recent population estimates. Catch-at-age for the two purse seine components and the two population matrices, for the relevant years for which there is data available on CPUE for the fleet, provides the input data for the calculation of F-at-age. The F values were weighted by the "fishable" population numbers (POP x PR for each component). The weighted F values, divided by the raw E estimates, provide the "q" estimates shown in Table 5 and Figure 8. There is good evidence of increases in "q" with time and with changes in stock size.

The log records from 1976 to 1980 have been re-analyzed to generate three CPUE indices: catch per successful night (the traditionally-used index, since this was how the logs were coded for the data storage); catch per set; and catch per night fished. As adult stock has decreased over the last four years, the catch per night fished in 4Xa has decreased by 66%, while the catch per successful night has decreased by less than 30%. The catch per set decreased by an intermediate amount and appears to have levelled off. This could indicate that school size initially decreases with decreasing stock size, but at some lower school size, there begins to be re-grouping of schools to maintain a minimum size in spite of further decreasing stock size.

The CPUE indices and their method of calculation are shown in Table 7 and Figure 9. The effective value of a successful night's fishing was increased by 10% (not compounded) from 1967 to 1976 and, subsequently, by 7.5%. The reduction in the rate of increase for the last three years was included to compensate for the opposite trend -- reduction of the power of a night's fishing -- imposed by nightly boat quotas. The overall result is that a 1979 night is equal to about two 1967 nights. The fixed gear CPUE indices were not included in the calculation due to the uncertainties in both the actual effort involved, including the effect of market demand on catch per weir. The fixed gear effort and CPUE estimates are shown in Figure 10 and Table 9. The marked differences in the two weir CPUE distributions suggest that separate stocks, or stock mixtures, are being fished.

The two effort series (one adjusted for learning and the other without adjustment) appropriate for each stock option are shown in Table 8.

POPULATION SIZE

For each of the catch matrices, option 1 and 2 stocks (Table 10), partial recruitments were calculated from the average fishing mortality-at-age from, respectively, 1973 to 1976 and 1972 to 1976.

The two P. R. vectors are:

	AGE									
	1	2	3	4	5	6	7	8	9	10
PR Option 1	-	0.38	0.46	0.73	0.80	1	1	1	1	1
PR Option 2	0.023	0.82	0.44	0.80	0.82	1	1	1	1	1

These PR vectors were used in adjusting the starting F values, but since there was a marked change in the PR vectors for option 2 in the early 1970's, an average PR vector for all years was used to define the "fishable" population for weighting F. F's for older ages in years 1965 to 1976 were the average values for the fully recruited ages (5 to 7). Several iterations were made to adjust the F's for older ages. Starting F's for 1979 were set by optimizing the two regressions for "fishable" population on CPUE index and of weighted F on fishing effort. There is evidence that q has changed from observation of the time distribution of "non-adjusted" CPUE in Figures 11 and 13. The effort series for option 2 has problems. The series are derived from predominantly adult fishery logs, and the additional catches included in option 2 are juveniles. The 1972 and 1968 points, during which very high juvenile catches are incorporated into the catch matrix, are clearly anomalous (Figure 14). The CPUE regressions involving the learning adjustment have higher R^2 than those without the adjustment. The starting F values for the four "final" analyses are:

	Learning	Non-learning
Option 1	0.5	0.30
Option 2	0.5	0.32

The population and F matrices for the best runs (using the learning adjustments for "fitting") are shown in Tables 11 and 12. The upper right-hand corner of the matrices, however, have been adjusted.

There is good evidence that there has been a marked change in the partial recruitment during 1978 and 1979. The purse seine fleet indicate that they have avoided small fish. Also, if the 1972 to 1976 PR vectors are used in the cohort analyses, only a moderately good 1976 year-class is generated. The evidence from the juvenile fisheries, juvenile range expansion, and fishermen's reports during 1977, 1978 and 1979 indicates that this year-class is a large one. Because of the likely changes in the partial recruitment for two- and three-year olds over the last two years, the upper right-hand corner of the population matrices was fitted using several recruitment predictors and subsequently the recent PR on younger ages re-estimated using the catch equation.

Three predictive regressions for year-class size estimated at age 1 or 2, depending on the stock option, are considered (Table 13). The environmental regression developed with Dr. W. Sutcliffe (R^2 = 0.86, for option 2 time series of 1963 to 1975 age one year-class strengths) involves Sable Island wind parallel to the southern shore (WIN 230°) and sea level at Halifax (in cm). Work is in progress to decompose the sea level record into several constituents, including the Nova Scotia current, in order to indicate possible causal relationships with herring larval survival. The relationship between "predicted" year-class strength and cohort analysis estimates (option 2) are shown in Figure 16. It is to be noted that the two exceptionally poor year-classes of 1974 and 1975 are well "predicted". This opens the possibility that their poor strength might have been due to environmental factors rather than due to stock size feedback processes.

The second regression, shown in Figure 17, for option 2 has the highest R^2 value, but due to the change in PR during 1978 and 1979, the ratio of age two numbers in stock option 1 catch to total catch in tonnes (same option) is an inappropriate predictor. The figure does indicate, however, that PR has changed. The third regression involves the New Brunswick weir age two catch. The New Brunswick age one and Nova Scotia weir age two catch were less well correlated with cohort analysis estimated year-class strengths.

Using the mean of the estimates of 1976 and 1977 year-classes from regressions 1 and 3, and the subsequent catches, the upper right-hand corner is as shown in Tables 11 and 12. The population is projected to the beginning of 1980 using the 1979 catches-at-age and the "catch equation". The resultant population biomass (2+) distribution from 1965 to 1980 is shown in Figure 15. The accuracy of the 1980 estimate is critically dependent on the above "predictions" of the 1976 and 1977 year-classes. Following these predictions, the new (1979) PR estimates for age two and three are:

	AGE	
	2	3
Option 1	0.17	0.14
Option 2	0.32	0.18

The calculation suggests a 55% decrease in the partial recruitment of age two fish, and a 70% decrease on age three fish during 1979.

YIELD PER RECRUIT

Using the following mean weights-at-age (g), which were estimated from the weight-at-age of all components of the fishery, and assuming a return to the 1972-1976 PR distribution, yield per recruit curves were derived.

AGE									
1	2	3	4	5	6	7	8	9	10
WT (Option 1)									
10.64	24.37	93.93	164.75	226.00	253.13	285.86	314.75	343.85	369.52
WT (Option 2)									
9.97	25.87	85.38	161.71	224.40	253.05	285.56	314.49	343.47	369.52
PR (Option 1)									
0	0.38	0.46	0.73	0.80	1	1	1	1	1
PR (Option 2)									
0.023	0.82	0.44	0.80	0.82	1	1	1	1	1

The following $F_{0.1}$ values were estimated:

Option 1 . . . . 0.293

Option 2 . . . . 0.246

PROJECTIONS

The following input parameters were used in the five-year projection for stock option 1:

i weight-at-age (as in yield per recruit)
ii partial recruitment (as in yield per recruit)
iii catch-at-age for 1979 from Table 10
iv population-at-age (for January 1, 1979) from Table11
v ℓn G. M. recruitment (1965-1977) equal to 13.78
vi $F_{0.1} = 0.293$

The projected tonnes expected to be caught for each age in 1980 are shown in Table 14. The detailed five-year projections, at the $F_{0.1}$ criteria, are shown in Table 15 and the annual catch graphically shown in Figure 19. A 1980 $F_{0.1}$ catch of 92,000 t is estimated which would climb to 107,000 t by 1982 as the 1976 and 1977 year-classes maximize their biomass.

If, however, the actual size of the 1976 year-class at age three was as low as 50% of the "predicted" size used in the above projections, the $F_{0.1}$ catch in 1980 and 1981 would be, respectively, 55,800 and 67,300 t.

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Table 1. Provisional catch (t) during 1979 4WX herring fishery

	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
4W															
Purse seine (Chedabucto Bay)	166	7528	6379												14073
Fixed gear ("non-stock")															
$4X_a$ Southwest Nova Scotia															
Purse seine							4	1554	8143	8565	6343	647	9		25265
Gill net (stock)						2	243	463	254	753	2632	16			4363
Weir							1153	4671	2667	581	93	111	31		9307
Trap (Liverpool)					2174										2174
$4WX_a$ Stock Total	166	7528	6379		2174	2	1400	6688	11064	9899	9068	774	40		55182
$4X_b$ New Brunswick															
Purse seine			2605	368								130	30	60	3193
Weir			286	52			26	1055	7373	9957	4900	6050	2704	74	32477
Shut-offs							16	386	873	1419	529	1850	278		5351
$4X_b$ Total			2891	420			42	1441	8246	11376	5429	8030	3012	134	41021

Table 2. Temporal distribution of catch to sample ratio for 4WX herring fishery (1977 to 1979).

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Purse Seine												
1977	-	-	-	-	382	72	184	112	109	160	130	107
1978	-	-	-	-	139	598	498	157	294	164	-	-
1979	217	123	-	-	4	222	140	182	396	389	40	-
$4W_a$ 78/79	220	-	-	-	-	-	-	-	-	-	-	226
Gill net												
1977	-	-	-	-	348	271	1118	462	945	-	-	-
1978	-	-	-	-	21	116	114	305	219	-	-	-
1979	-	-	-	-	←	481	→	188	378	→	-	-
N. S. weirs												
1977	-	-	-	-	366	127	1021	1144	50	15	-	-
1978	-	-	-	-	176	200	212	95	22	51	239	28
1979	-	-	-	-	64	126	127	73	-	111	15	-
Liverpool fishery												
1978	-	-	171	-	-	-	-	-	-	-	-	-
1979	-	-	50	-	-	-	-	-	-	-	-	-
N. B. weirs + Shut-offs												
1977	-	-	-	-	-	42	136	93	110	169	123	107
1978	-	-	-	-	17	43	148	114	236	270	-	132
1979	286	52	-	-	14	51	97	228	155	132	142	37

Table 3. Spatial distribution of catch to sample ratio for 4WX herring fishery (1977 to 1979).

Purse seine	AREA 10	11	12	13	14	15	16	17	18	19	4Wa
1977	41	17	149	242	398	243	325	413	276	554	-
1978	-	-	14	39	26	49	77	713	1813	1030	-
1979	Catch not well reported by area										220

Gill net	AREA 463	465	466
1977	361	927	733
1978	2	410	595
1979	-	246	no samples

N. S. weir	AREA 113	114	115	116
1977	79	no sample	282	154
1978	104	482	92	101
1979	89	265	38	97

N. B. Weirs	AREA 101	102	103	104	105	106	107	108	109	110	111	Shut-offs
1977	-	20	59	48	48	34	144	101	28	474	534	-
1978	255	57	99	33	259	57	114	510	121	149	276	-
1979	652	599	102	36	91	53	97	254	53	221	175	145

Table 4 Catch-at-age (x 10^{-3}) by gear for the 1979 4WX herring fishery.

	AGE												
	1	2	3	4	5	6	7	8	9	10	11+	Total	TONNES
4Wa													
Purse-seine	0	0	6703	1059	1578	9291	7140	10869	12334	2593	1526	53093	14,073
4Xa													
Purse-seine	0	2022	69557	34598	2353	7944	6531	7229	8898	874	366	140372	25,265
Liverpool	0	294	24151	2206	62	30	15	2	5	-	-	26765	2,174
Gill net	0	8	1668	4678	537	2027	1578	2441	2937	367	136	16377	4,363
Weir	154	102926	80870	3215	87	403	257	282	370	0	14	188578	9,307
4WX													
"Traditional" Stock	154	105250	182949	45756	4617	19695	15521	(9981)[2] 20823	(35386)[2] 24544	3834	2042	425185	55,182
4Xb													
Purse-seine	157	65273	43493	1444	22	-	-	-	-	-	-	110389	3,193
Weir and Shut-offs[1]	2396	423731	247356	12236	822	841	479	1005	190	-	-	689056	37,828
4Xb TOTAL	2553	489004	290849	13680	844	841	479	1005	190	-	-	799445	41,021
4WX													
"Option 2" Stock	1030	297642	300649	50871	4886	19948	15665	(10060)[2] 21125	(35666)[2] 24601	3834	2042	742292	70,681

[1] Preliminary estimate - shut-offs not yet analysed separately.

[2] Adjusted 1970 and 1971 catch-at-age (see text for rational).

Table 5. Catchability trends for the 4Xa and 4Wa purse seine fisheries.

4Xa Estimates (x 10^{-6})

YEAR	METHOD 1	METHOD 2
1967	77	78
1968	75	76
1969	68	69
1970	74	74
1971	77	77
1972	89	87
1973	90	87
1974	79	76
1975	101	95
1976	115	105

4Wa Estimates (x 10^{-5})

YEAR	METHOD 1	METHOD 2
1973	18	19
1974	27	28
1975	33	34
1976	27	28
1977	30	31
1978	43	45

Table 6. Recent trends in various C.P.U.E. indices for the 4WX herring purse-seine fishery.

4X Summer Fishery

	1976	1977	1978	1979	4 Year % decrease
% of catch accounted for in logs	72	47	36	28	-
Catch (t) per successful night	44.6	37.4	39.5	31.7	29
Catch (t) per set	34.0	24.0	20.9	18.7	45
Catch (t) per recorded nights fishing	36.9	28.3	31.7	12.5	66

4Wa Winter Fishery

	1976	1977	1978	1979	1980	4 year (76-79) % decrease
% of catch accounted for in logs	71	75	28	69	46	-
catch (t) per successful night	127.4	100.3	(143.6)	71.0	68.2	44%
catch (t) per set	-	47.2	(63.3)	34.6	46.9	-
catch (t) per recorded nights fishing	103.1	78.5	(119.1)	52.0	54	49%

Table 7. Derivation of catch per unit effort index using catch and effort data from 4WX purse-seine fishery.

	4X SUMMER FISHERY							4W WINTER FISHERY							CPUE INDEX[d]	
YEAR	CPUE[a]	CPUE/ AVE.	CATCH[c]	EFFORT	EFFORT ADJ.	CPUE[7] ADJ.	CPUE ADJ/AVE.	CPUE[b]	CPUE/ AVE.	CATCH[c]	EFFORT	EFFORT ADJ.	CPUE ADJ.	CPUE ADJ/AVE.	WITHOUT "LEARNING"	WITH "LEARNING"
1967	55.5[1]	1.28	117382	2115	2115	55.5	1.88	-	-	-	-	-	-	-	1.28	1.88
1968	52.8[1]	1.21	133267	2524	2776	48.0	1.63	-	-	-	-	-	-	-	1.21	1.63
1969	41.7[1]	0.96	84525	2027	2432	34.8	1.18	-	-	-	-	-	-	-	0.96	1.18
1970	39.0[1]	0.90	70849	1817	2362	30.0	1.02	-	-	-	-	-	-	-	0.90	1.02
1971	32.6[1]	0.75	35071	1076	1506	23.3	0.79	-	-	-	-	-	-	-	0.75	0.79
1972	45.0[1]	1.03	61158	1359	2039	30.0	1.02	74.5[4]	0.82	25656	344	344	74.5	1.06	0.97	1.03
1973	49.1[1]	1.13	36618	746	1194	30.7	1.04	73.6[4]	0.81	7921	108	119	66.6	0.94	1.07	1.02
1974	45.2[1]	1.04	76859	1700	2890	26.6	0.90	132.0[4]	1.46	27107	205	246	110.2	1.56	1.15	1.07
1975	50.9[1]	1.17	79605	1564	2815	28.3	0.96	146.5[4]	1.62	27030	185	241	112.2	1.59	1.28	1.12
1976	44.6[2]	1.03	58396	1309	2487	23.5	0.80	103.1[2]	1.14	37196	361	505	73.7	1.04	1.07	0.89
1977	37.4[2]	0.86	68538	1833	3620	18.9	0.64	78.5[2]	0.87	23251	296	437	53.2	0.75	0.86	0.67
1978	39.5[2]	0.91	57973	1468	3009	19.3	0.65	65.3[6]	0.72	17274	265	411	42.0	0.59	0.87	0.64
1979	31.7[3]	0.73	25265	797	1694	14.9	0.51	52.0[2]	0.57	14073	271	440	32.0	0.45	0.67	0.49
AVE.	43.5					29.5		90.7					70.6			
% decline	43					73									48	74

[1] Stobo et al. CAFSAC Res. Doc. 78/25
[2] Re-analysis of logs.
[3] Preliminary analysis of present year logs.
[4] Stobo ICNAF Res. Doc. 75/39.
[5] Stobo ICNAF Res. Doc. 76/VI/21.
[6] Interpolated (see text for rational).
[7] 10% learning till 1976, 7.5% till 1979 (see text for rational.)

[a] CPUE is the catch per successful night.
[b] CPUE is the catch per recorded nights fishing.
[c] Catch taken from Table 2.
[d] CPUE INDEX = $\frac{[\text{CPUE/AVE (4W Purse-seine) x catch}] + [\text{CPUE/AVE (4X purse-seine) x catch}]}{\text{catch (4W + 4X purse-seine)}}$

Table 8. Derivation of standardized effort units using catch and CPUE indices from Tables 2 and 7 respectively.

	CATCH		EFFORT UNITS[1]			
			Traditional Stock		Option 2 stock	
YEAR	Stock Total "Traditional"	Stock Total Option 2	without learning	with learning	without learning	with learning
1967	135,853	165,721	106,135	72,262	129,470	88,149
1968	154,139	205,996	127,388	94,564	170,245	126,378
1969	137,260	158,156	142,979	116,322	164,746	134,031
1970	175,633	194,903	195,148	172,189	216,559	191,081
1971	124,233	132,743	165,644	157,257	176,991	168,029
1972	153,428	163,048	158,173	148,959	168,091	158,299
1973	120,093	127,986	112,236	117,738	119,613	125,476
1974	139,170	155,009	121,017	130,065	134,790	144,868
1975	142,745	152,143	111,519	127,451	118,862	135,842
1976	114,006	126,335	106,548	128,097	118,070	141,919
1977	115,935	120,007	134,808	173,037	139,543	179,115
1978	89,363	107,543	102,716	139,630	123,613	168,036
1979	55,182	69,723	82,361	112,616	104,064	142,292

[1] Total catch divided by appropriate CPUE index from Table 7.

Table 9. Normalized catch-per-unit effort for N.B. and N.S. weirs

YEAR	N.B. WEIRS EFFORT	CATCH	CPUE	CPUE/AVE.	N.S. WEIRS EFFORT	CATCH	CPUE	CPUE/AVE.
1965	195	31684	162	1.18	25	12021	481	1.34
1966	195	35601	183	1.34	25	7711	308	.86
1967	195	29932	153	1.12	25	12475	499	1.39
1968	195	32114	165	1.21	25	12571	503	1.40
1969	195	25646	132	0.97	25	10744	430	1.20
1970	195	15073	77	0.56	25	11706	468	1.31
1971	195	12139	62	0.45	25	8081	323	.90
1972	195	31995	164	1.20	25	6766	271	.76
1973	195	19088	98	0.72	25	12492	500	1.39
1974	195	19028	98	0.72	25	6436	257	.72
1975	195	30819	158	1.16	25	7404	296	.82
1976	195	29206	150	1.10	25	5959	238	.66
1977	195	30697	157	1.15	25	5213	209	.58
1978	223	33570	150	1.10	30	8057	269	.75
1979	228	32477	142	1.04	28	9307	332	.93
		Ave.	137			Ave.	359	

Table 10. Catch matrices for 4WX herring, two stock options

OPTION 1

Age	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
2	210796	43630	47948	751706	70536	106916	144167	649254	29656	118301	235590	19922	55634	114169	105250
3	26450	270068	68430	79933	384467	58166	173662	71984	562616	45600	158941	161637	19468	22045	182949
4	232147	58591	238394	65107	118960	285361	106170	148516	109530	616206	92356	130597	192823	10641	45756
5	49752	308775	109814	274518	160723	201097	113561	77207	34422	53199	383646	72334	106061	107530	4617
6	10592	45479	159203	72827	110852	120223	75593	75384	25562	15254	50599	219788	55066	60431	19695
7	1693	13970	57948	90617	62506	111911	93620	49065	19361	8120	9357	18960	150588	27286	15521
8	561	7722	4497	31977	22595	41257	50022	48700	17604	5313	3238	4967	12466	96741	9981
9	54	1690	409	15441	6345	21271	36618	26055	19836	10964	3481	3556	2873	9838	35386
10	37	215	296	5668	2693	7039	7536	13792	9661	5787	2842	1835	1253	2169	3834
11+	1	1	148	1175	722	2674	5695	11679	11120	7359	4599	3071	3448	1499	2042

OPTION 2

1	270691	155038	760548	165450	131016	701539	116446	2488	10741	14630	5064	15538	257721	74181	1030
2	1353215	957110	672535	2624279	407137	687275	461719	852042	173224	656526	403385	111848	189762	657067	297643
3	55452	578797	170940	241056	563336	79677	195586	73963	635546	85415	198067	209452	33598	54265	300649
4	251140	88177	299915	90890	133895	290248	109111	151837	114169	626728	95354	136595	203132	12610	50871
5	52098	330927	113836	300099	165501	203116	114791	78505	34748	53598	388564	76808	109578	107909	4886
6	10668	46272	160506	74314	115024	121474	76244	76000	25729	15270	51254	222827	58683	60801	19948
7	1730	13979	58301	91591	64512	112680	94581	49381	19379	8138	9691	19441	152930	27384	15665
8	586	7726	4533	32212	23225	41539	50397	49057	17642	5325	3513	5077	12571	96787	10283
9	54	1697	410	15465	6439	21291	36722	26164	19854	10977	3570	3694	2874	9838	35443
10	37	224	296	5672	2694	7043	7553	13803	9663	5796	2890	1893	1253	2169	3834
11+	1	1	148	1175	722	2674	5715	11683	11127	7372	4652	3105	3448	1499	2042

Table 11 Estimated population numbers and fishing mortalities for stock option 1 (using adjusted effort)

POPULATION NUMBERS 20/ 3/80

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
2	2574045	1522095	1255365	2360627	619334	793365	868267	5012530	701830	1040158	1134902	93809	336036	3740000	1420000	965113
3	960953	1916714	1206708	984421	1252547	443244	552811	580429	3516443	547776	744566	716008	58778	224783	2958979	1067657
4	1304513	762829	1324905	926051	733649	677618	310267	295467	410082	2369944	407220	465783	439963	30508	164090	2257538
5	343610	857990	571536	869033	699275	493022	296582	157959	107525	236640	1382780	249837	263182	185738	15349	93262
6	93351	236307	423072	368570	463110	427090	221692	140066	59466	56888	145608	784987	139099	119507	54772	8424
7	44016	66845	152321	202329	235863	278859	240889	113107	46466	25557	32774	73430	443821	64058	43164	27199
8	4258	34505	42088	72276	83659	136551	127049	112513	48208	20525	13577	18366	42963	227112	27757	21435
9	1069	2978	21263	30389	30241	48050	74467	58757	48052	23541	11997	8186	10543	23896	98409	13784
10	369	827	909	17039	10909	19018	20093	27835	24531	21393	9353	6672	3485	6032	10662	48869
	5326184	5401089	4998166	5830735	4128587	3316816	2712118	6498664	4962603	4342421	3882776	2417079	1737869	4621634	4793186	4503281

FISHING MORTALITY 20/ 3/80

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
2	0.095	0.032	0.043	0.434	0.135	0.161	0.203	0.154	0.048	0.134	0.261	0.267	0.202	0.034	0.085
3	0.031	0.169	0.065	0.094	0.414	0.157	0.426	0.147	0.195	0.097	0.269	0.287	0.456	0.115	0.071
4	0.219	0.089	0.222	0.081	0.197	0.626	0.475	0.811	0.350	0.339	0.289	0.371	0.662	0.487	0.365
5	0.174	0.507	0.239	0.429	0.293	0.599	0.550	0.777	0.437	0.286	0.366	0.386	0.589	1.021	0.400
6	0.134	0.239	0.538	0.246	0.307	0.373	0.473	0.903	0.644	0.351	0.485	0.370	0.575	0.818	0.500
7	0.043	0.263	0.545	0.683	0.347	0.586	0.561	0.653	0.617	0.433	0.379	0.336	0.470	0.636	0.500
8	0.157	0.284	0.126	0.671	0.355	0.406	0.571	0.651	0.517	0.337	0.306	0.355	0.387	0.636	0.500
9	0.057	0.987	0.021	0.824	0.264	0.672	0.784	0.673	0.609	0.723	0.387	0.654	0.358	0.607	0.500
10	0.117	0.336	0.441	0.453	0.316	0.519	0.528	0.776	0.563	0.352	0.405	0.359	0.500	0.500	0.500
	0.119	0.178	0.176	0.322	0.295	0.403	0.407	0.240	0.210	0.259	0.313	0.343	0.490		

Table 12 Estimated population numbers and fishing mortalities for stock option 2 (using adjusted effort)

POPULATION NUMBERS 20/ 3/80

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	3647558	2858061	6566916	1440807	1942624	2282264	6696987	1151080	2096528	1731278	272791	670955	6870000	2750000	114194	1905014
2	4427969	2741437	2199698	4688364	1029928	1471938	1233781	5377664	940173	1706773	1404213	218760	535272	5392037	2184533	92564
3	1050838	2400875	1378470	1192426	1463962	474841	583249	592354	3631900	613009	803338	784675	77902	266540	3822498	1520400
4	1361866	910178	1441953	973923	758159	688863	316672	300550	418054	2398482	424603	478499	452917	33380	169123	2858420
5	348899	887761	583532	909197	715140	499575	301366	160541	108682	238969	1396624	261356	268166	187016	15919	92817
6	93304	238514	427402	374752	472847	435755	225230	142870	60406	57540	147154	791872	144481	120405	55476	8650
7	43656	66738	153410	204695	239579	283056	246852	115415	48205	26176	33293	74103	446708	65193	43564	27549
8	4295	34177	41992	72849	84715	137778	129790	116525	49812	21932	14067	18489	43079	227356	28597	21634
9	1088	2986	20991	30278	30497	48344	75217	60662	51014	24819	13138	8339	10544	23896	98567	14202
10	360	842	909	16815	10796	19143	20316	28355	25991	23802	10388	7526	3485	6032	10662	48948
	10979833	10141568	12815272	9904105	6748247	6341557	9829460	8046017	7430765	6842781	4519610	3314574	8852553	9071854	6543133	6590198

FISHING MORTALITY 20/ 3/80

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
1	0.086	0.062	0.137	0.136	0.077	0.415	0.019	0.002	0.006	0.009	0.021	0.026	0.042	0.030	0.010
2	0.412	0.488	0.412	0.964	0.574	0.726	0.534	0.192	0.228	0.554	0.382	0.833	0.497	0.144	0.162
3	0.060	0.310	0.147	0.253	0.554	0.205	0.463	0.148	0.215	0.167	0.318	0.350	0.647	0.255	0.091
4	0.228	0.128	0.261	0.109	0.217	0.627	0.479	0.817	0.359	0.341	0.285	0.379	0.685	0.540	0.400
5	0.180	0.531	0.243	0.454	0.295	0.597	0.546	0.777	0.436	0.285	0.367	0.393	0.601	1.015	0.410
6	0.135	0.241	0.536	0.247	0.313	0.368	0.469	0.886	0.636	0.347	0.486	0.372	0.596	0.817	0.500
7	0.045	0.263	0.545	0.682	0.353	0.580	0.551	0.640	0.588	0.421	0.388	0.342	0.475	0.624	0.500
8	0.163	0.287	0.127	0.671	0.361	0.405	0.561	0.626	0.497	0.312	0.323	0.362	0.389	0.636	0.500
9	0.056	0.989	0.022	0.831	0.266	0.667	0.776	0.648	0.562	0.671	0.357	0.673	0.358	0.607	0.500
10	0.120	0.345	0.441	0.461	0.320	0.515	0.522	0.756	0.522	0.311	0.364	0.323	0.500	0.500	0.500
	0.236	0.291	0.222	0.591	0.327	0.515	0.179	0.228	0.180	0.294	0.338	0.330			

Table 13. Predictive regressions for recent year-class size of the 4WX herring stock (options 1 and 2)

Year-class strength "predictive" regressions	Predicted year-class size ($\times 10^{-9}$) at age 2. 1976	1977
Option 1 (y = year-class strength at age 2)		
1. $y\ (\times 10^{-8}) = -11.3 + 7.36$ WIN 230° $- 273$ LEVHXR ($R^2 = 0.83$)	3.79	0.715
2. $y\ (\times 10^{-3}) = 3.48\ (\times 10^5) + 6.82\ (\times 10^5)$ [age 2 numbers to tonnes caught ratio, stock option 1] ($R^2 = 0.70$)	1.22[1]	1.65
3. $y\ (\times 10^{-3}) = -3.42\ (\times 10^5) + 5.21\ (\times 10^3)$ [N. B. weir catch at age 2 ($\times 10^{-6}$)] ($R^2 = 0.55$)	3.69	1.89
MEAN	3.74[2]	1.42

	Predicted year-class size ($\times 10^{-9}$) at age 1. 1976	1977
Option 2		
1. $y\ (\times 10^{-9}) = -1.80 + 1.35$ WIN 230° $- 0.476$ LEVHXR ($R^2 = 0.86$)	6.96	1.56
2. $y\ (\times 10^{-9}) = 0.84 + 1.21$ [age 2 numbers to tonnes caught ratio, stock option 1] ($R^2 = 0.88$)	2.39[1]	3.15
3. $y\ (\times 10^{-9}) = -0.385 + 0.00925$ [N.B. weir catch at age 2 ($\times 10^{-6}$)] ($R^2 = 0.69$)	6.77	3.53
MEAN	6.87[2]	2.75

[1] Large underestimate due to change in P.R.

[2] #2 estimates not included in increase due to their underestimation.

Table 14. Projected catch-at-age for 1980 and 1981.

AGE	LENGTH (inches)	WEIGHT (in t.)	%
2	6 to 9	2,250	2
3	9 to 10	11,487	13
4	10 to 11	65,144	70
5	11 to 12	4,007	4
6	12	493	1
7	12	1,798	2
8	12	1,561	2
9	12	1,096	1
10+	12	4,374	5

Table 15. 5 year projection of 4WX herring population and catch distributions (input parameters detailed in text).

POPULATION NUMBERS 24/ 3/80

	79	80	81	82	83	84
2	1420000	965113	965113	965113	955113	955113
3	2958979	1067657	706911	706911	706911	706911
4	164090	2257538	763904	505792	505792	505792
5	15350	93262	1492399	504997	334366	334366
6	54772	8424	60402	966557	327063	216553
7	43165	27199	5146	36893	590364	199767
8	27758	21435	16613	3143	22534	360589
9	93409	13784	13093	10147	1920	13763
10	10563	43869	8419	7997	6198	1172
	4793136	4503281	4031993	3707548	3460259	3304026

POPULATION BIOMASS 24/ 3/80

	79	80	81	82	83	84
2	34605.40	23519.79	23519.79	23519.79	23519.79	23519.79
3	277936.90	100285.00	66400.15	66400.15	66400.15	66400.15
4	27033.83	371929.32	125853.12	83329.17	83329.17	83329.17
5	3459.10	21077.26	337282.10	114129.22	75566.60	75566.60
6	13864.44	2132.47	15289.45	244664.50	82789.36	54816.03
7	12339.15	7775.10	1470.91	10546.16	168761.56	57105.39
8	8736.83	6746.80	5228.91	989.21	7092.50	113495.52
9	33837.93	4739.79	4501.88	3489.05	660.06	4732.56
10	3940.19	18057.91	3111.15	2954.99	2290.18	433.26
	415763.77	556253.44	582657.45	550022.24	510409.38	479398.46

CATCH NUMBERS 24/ 3/80

	79	80	81	82	83	84
2	105250	92337	92337	92337	92337	92337
3	182949	122289	80969	80969	80969	80959
4	45756	395408	133798	88590	88590	88590
5	4617	17731	283742	96012	63571	63571
6	19695	1949	13972	223579	75654	50092
7	15521	6292	1190	8534	136550	46209
8	9981	4958	3843	727	5212	83410
9	35386	3189	3029	2347	444	3184
10	3834	11304	1948	1850	1434	271
	422939	655457	614827	594944	544771	508632

CATCH BIOMASS 24/ 3/80

	79	80	81	82	83	84
2	2565	2250	2250	2250	2250	2250
3	17184	11487	7605	7605	7605	7605
4	7538	65144	22043	14595	14595	14595
5	1043	4007	64126	21699	14367	14367
6	4985	493	3537	55594	19150	12680
7	4437	1798	340	2439	39037	13209
8	3142	1551	1210	229	1641	26253
9	12167	1095	1041	807	153	1095
10	1417	4177	720	684	530	100
Subtotal	54479	92014	102872	105903	99328	92155
11+	857					
Total	55336					

Fishing mortality 24/3/80

	79	80	81	82	83	84
2	0.035	0.111	0.111	0.111	0.111	0.111
3	0.071	0.135	0.135	0.135	0.135	0.135
4	0.365	0.214	0.214	0.214	0.214	0.214
5	0.400	0.234	0.234	0.234	0.234	0.234
6	0.500	0.293	0.293	0.293	0.293	0.293
7	0.500	0.293	0.293	0.293	0.293	0.293
8	0.500	0.293	0.293	0.293	0.293	0.293
9	0.500	0.293	0.293	0.293	0.293	0.293
10	0.500	0.293	0.293	0.293	0.293	0.293

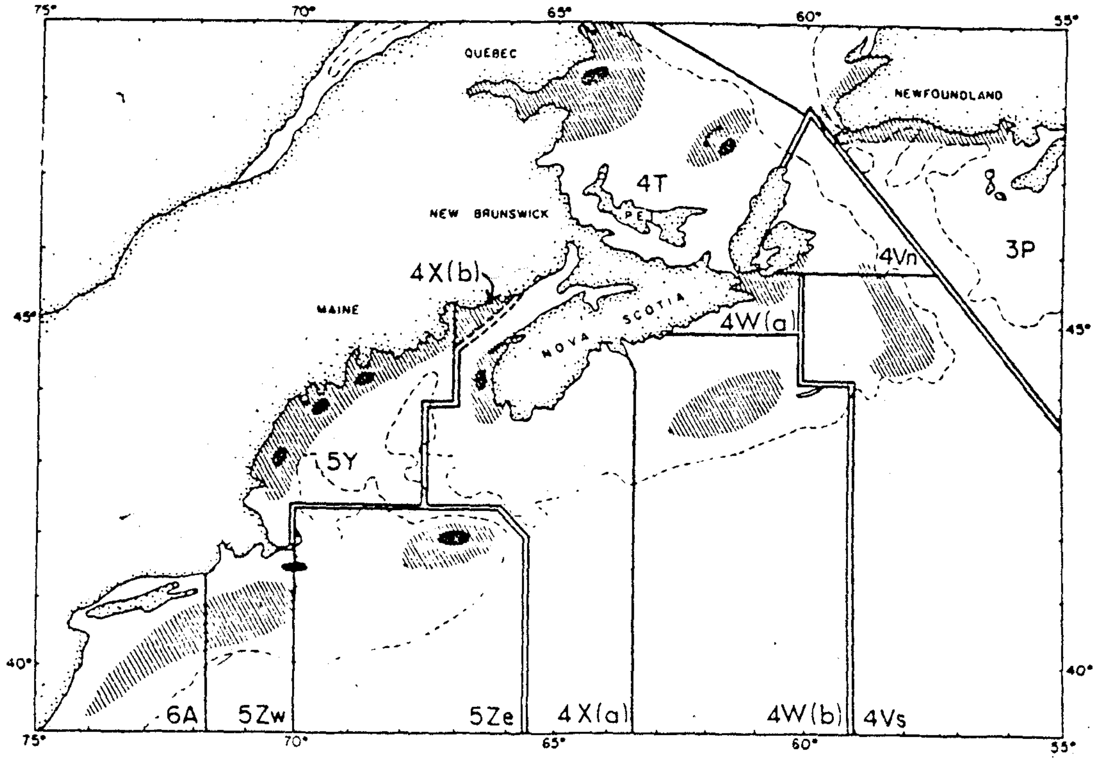

Fig. 1. Herring stock structure in Subareas 4 and 5 and Statistical Area 6. (Double lines indicate stock management areas; solid black areas indicate the general spawning grounds.)

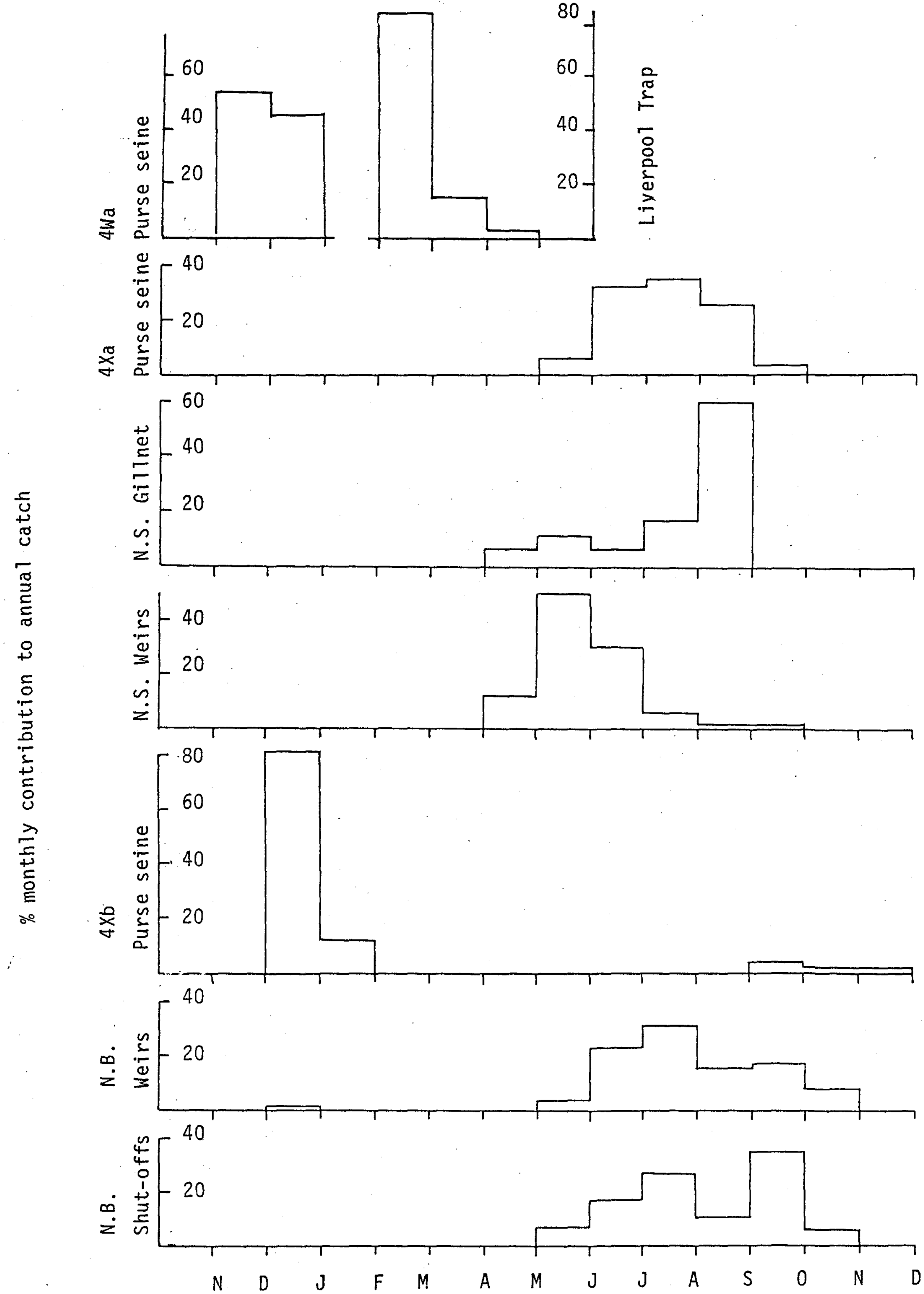

Figure 2. Percentage monthly catch per gear.

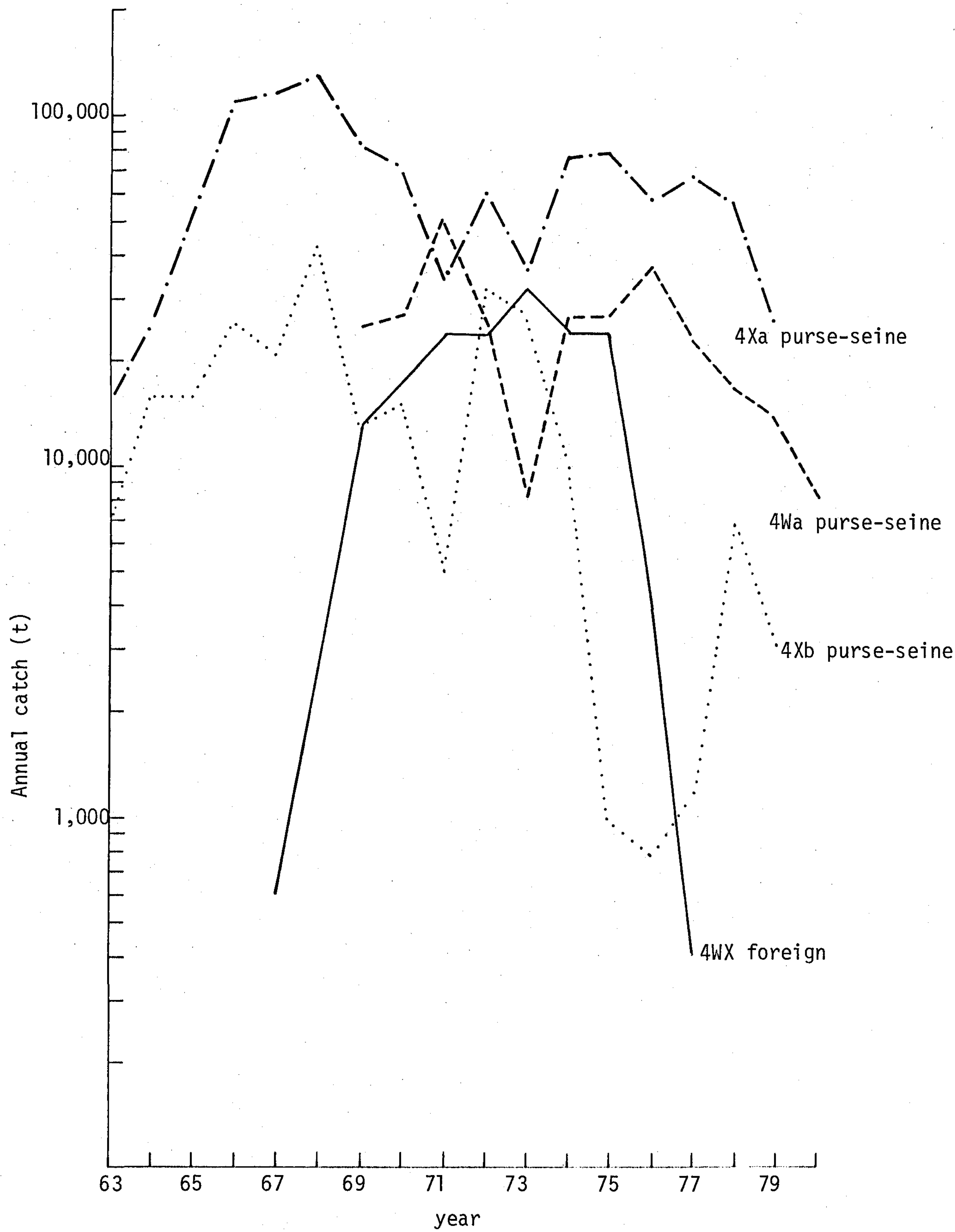

Fig. 3. 4WX mobile gear herring catch (1963 to 1980)

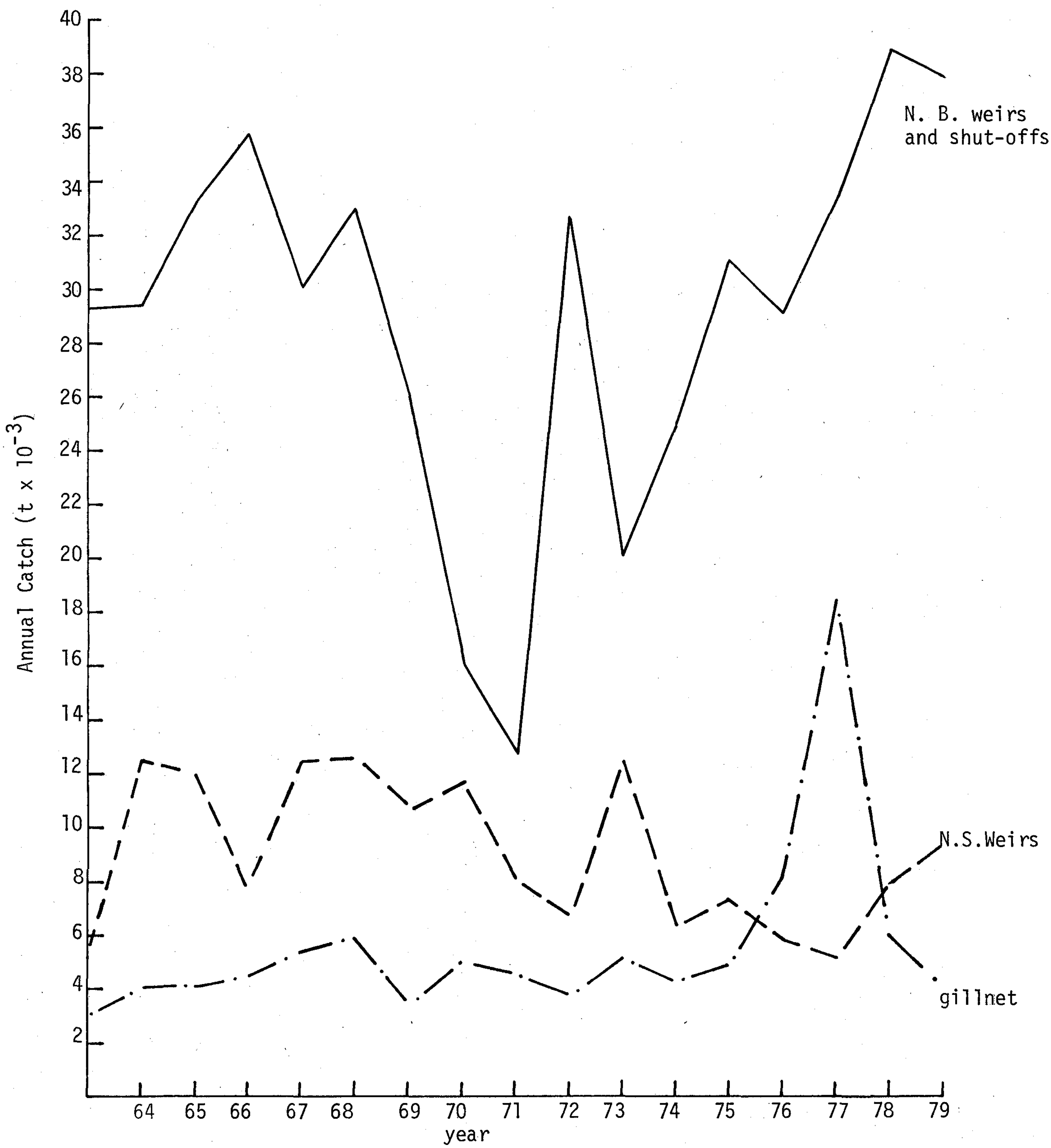

Fig. 4. 4X Fixed Gear Herring Catch (1963 to 1979)

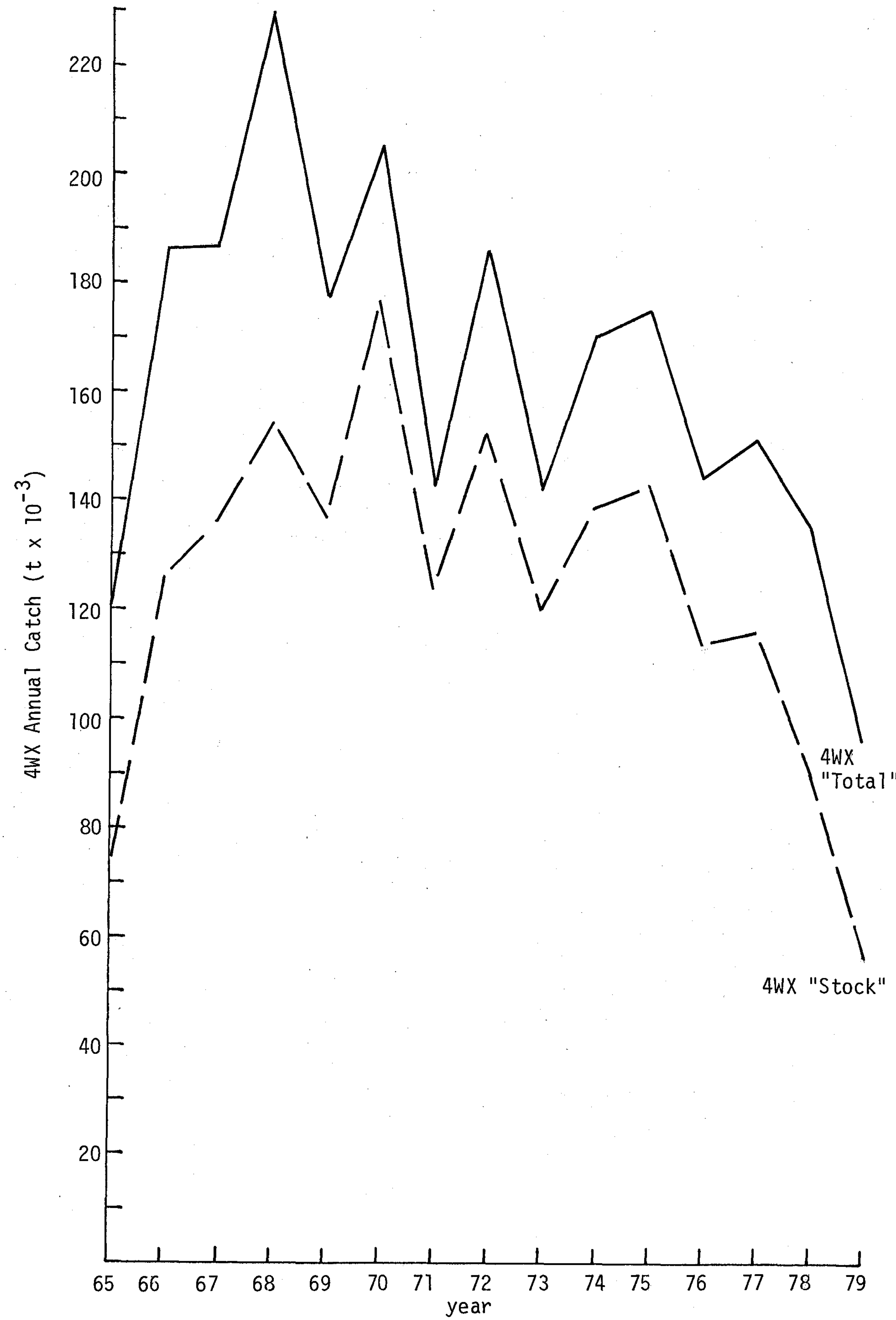

Fig. 5. 4WX Herring annual catch (1965-1979)

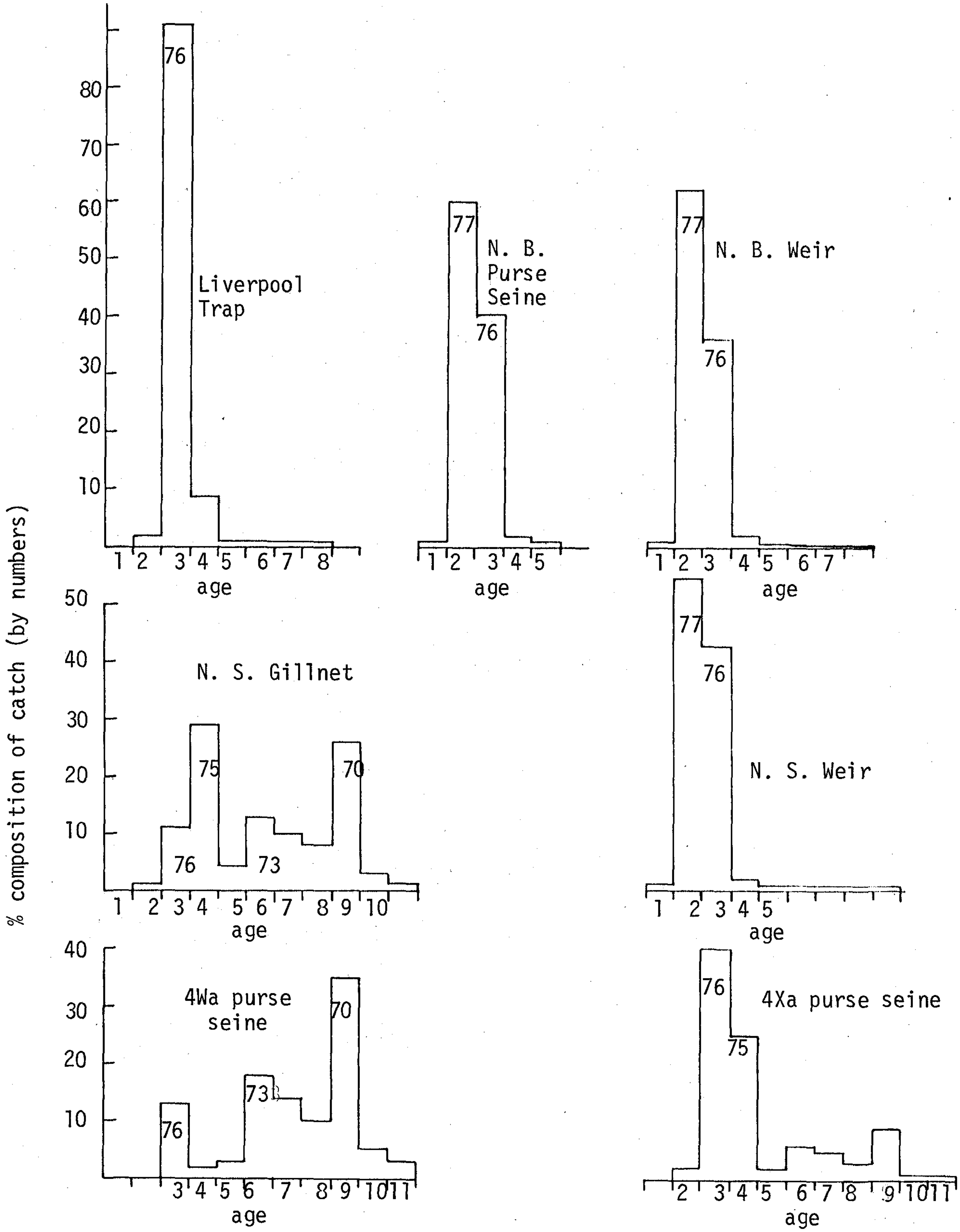

Fig. 6. Percent age composition by gear for the 1979 herring (4WX) fishery.

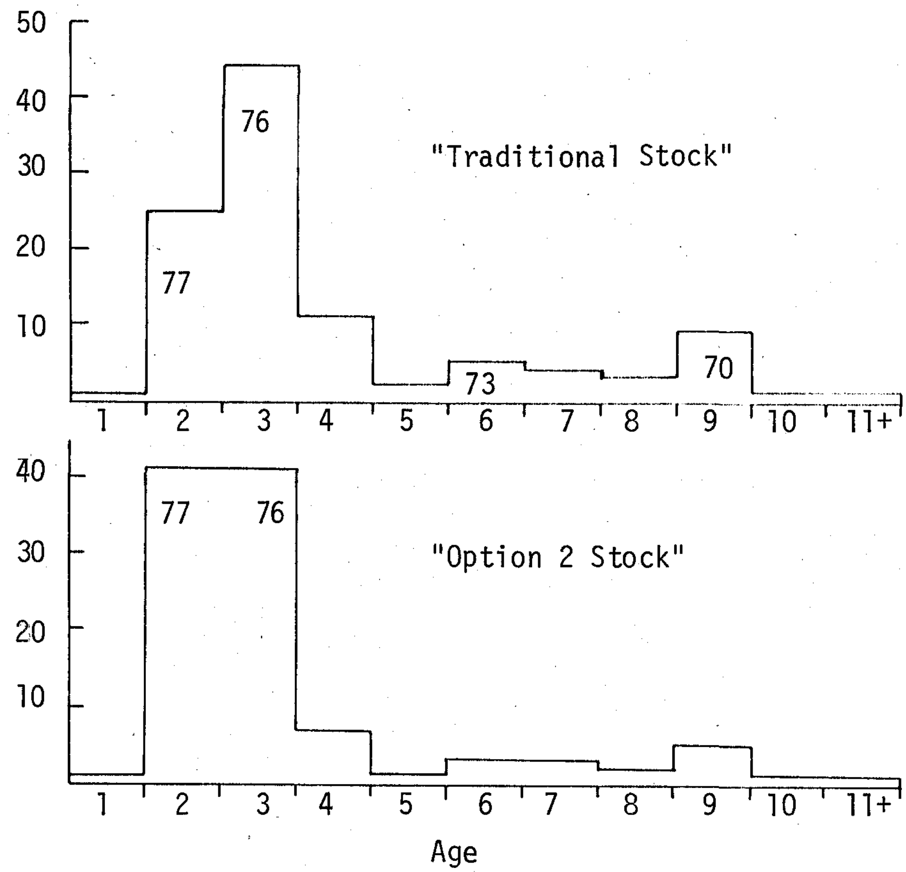

Fig. 7. Percent age composition of 1979 removals from traditional stock and from Option 2 Stock.

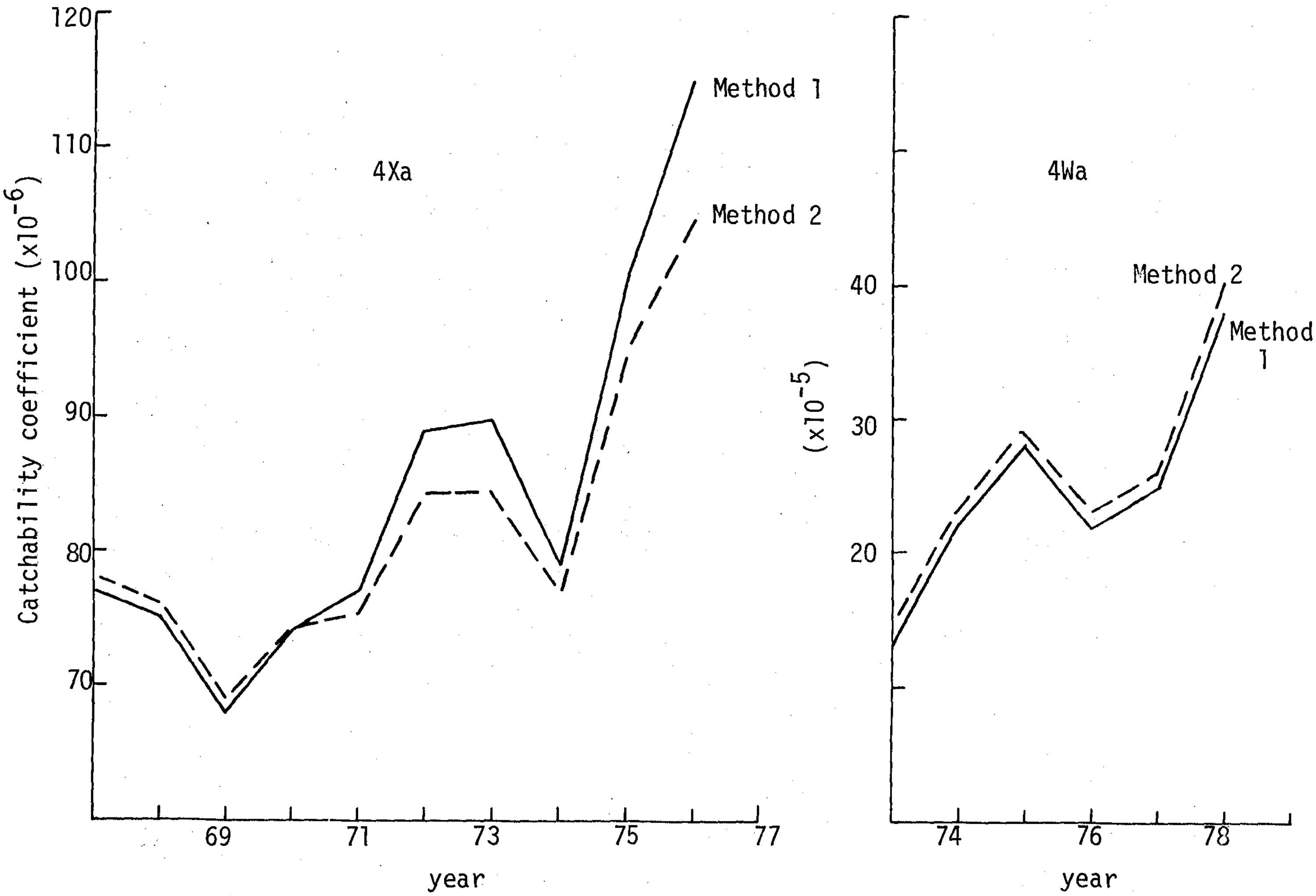

Fig. 8. Catchability coefficient trends for the 4Xa and 4Wa purse seine fisheries.

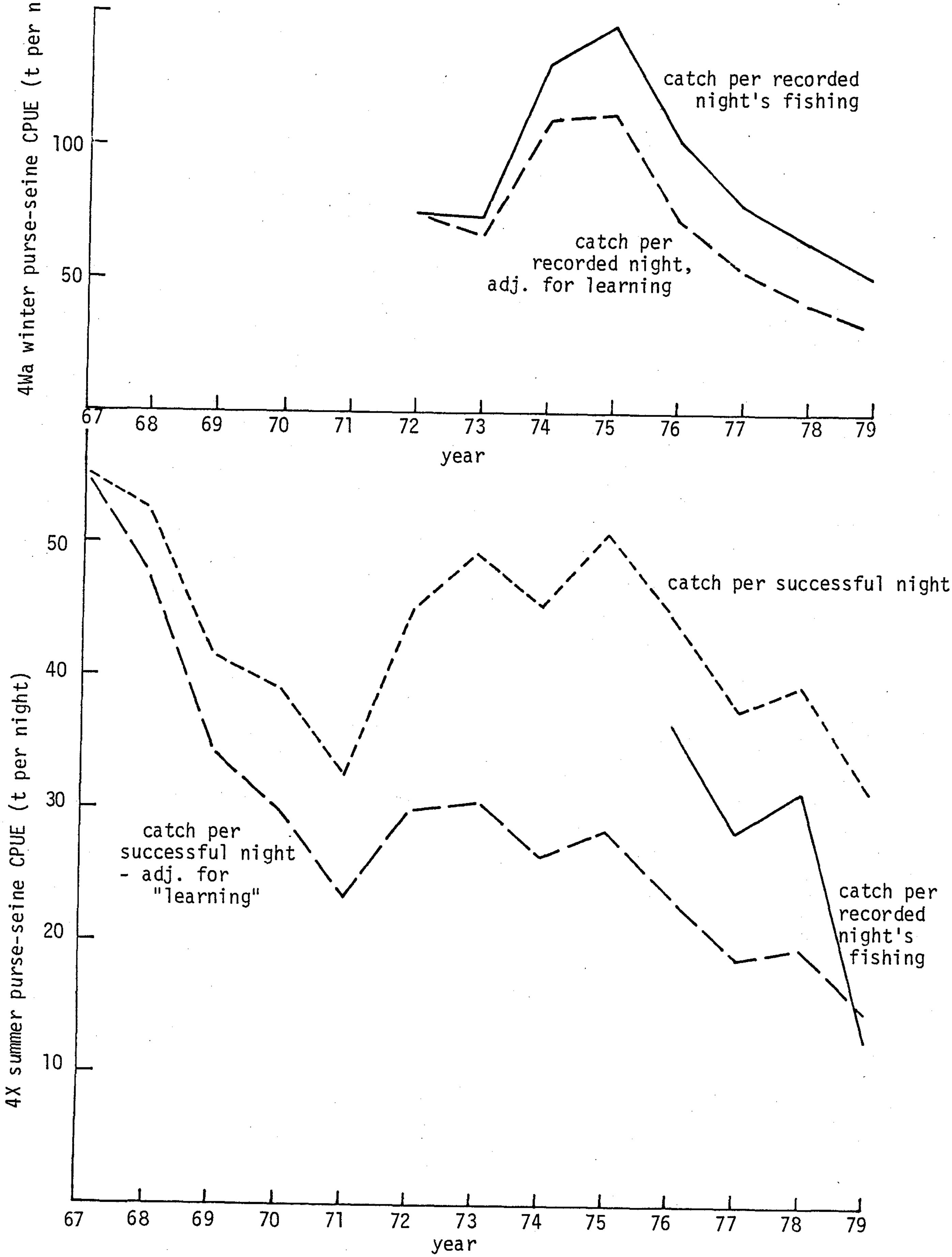

Fig. 9. CPUE distributions for 4WX Purse-seine fishery (1967-1980)

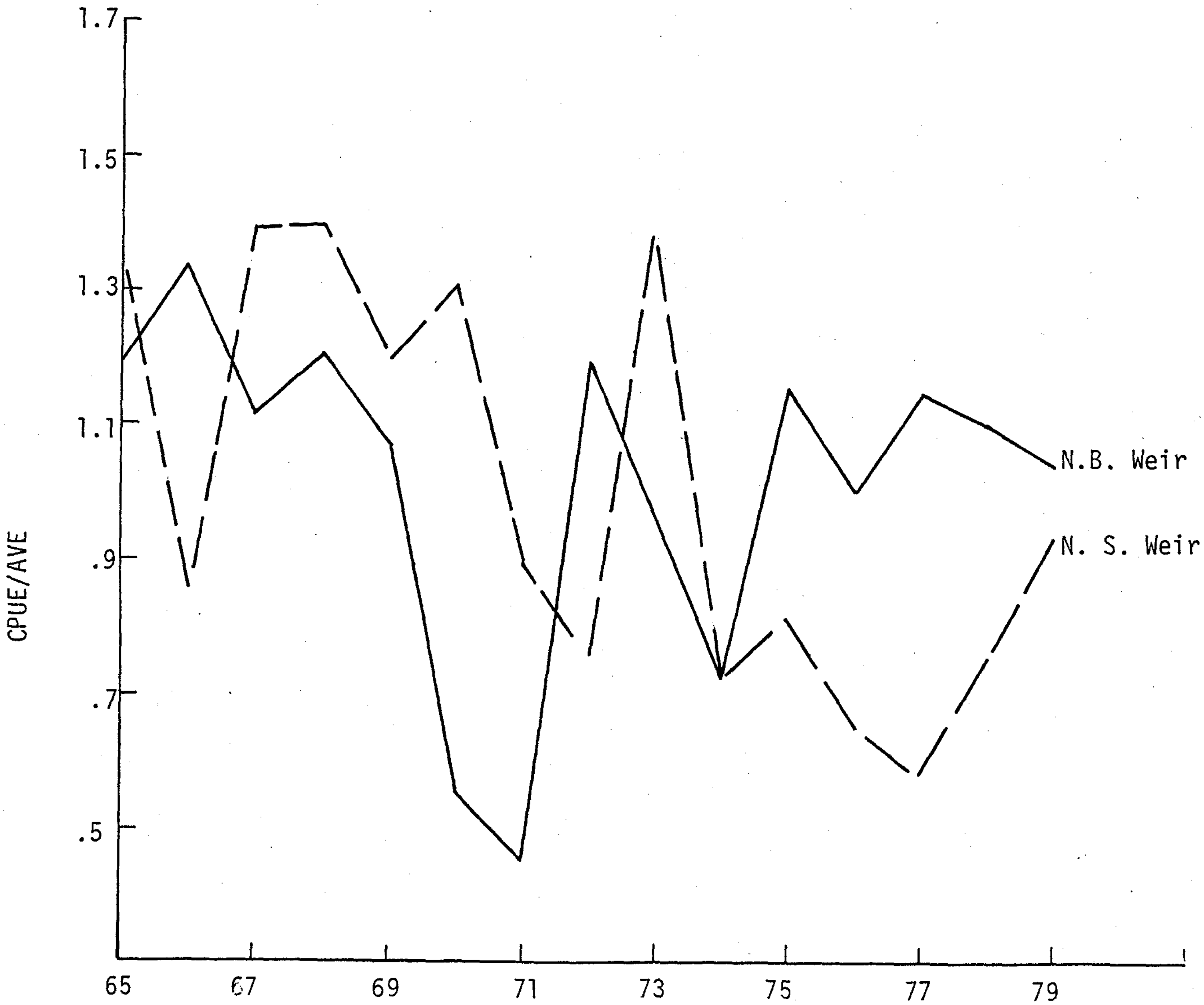

Fig. 10. Normalized CPUE for New Brunswick and Nova Scotia weirs.

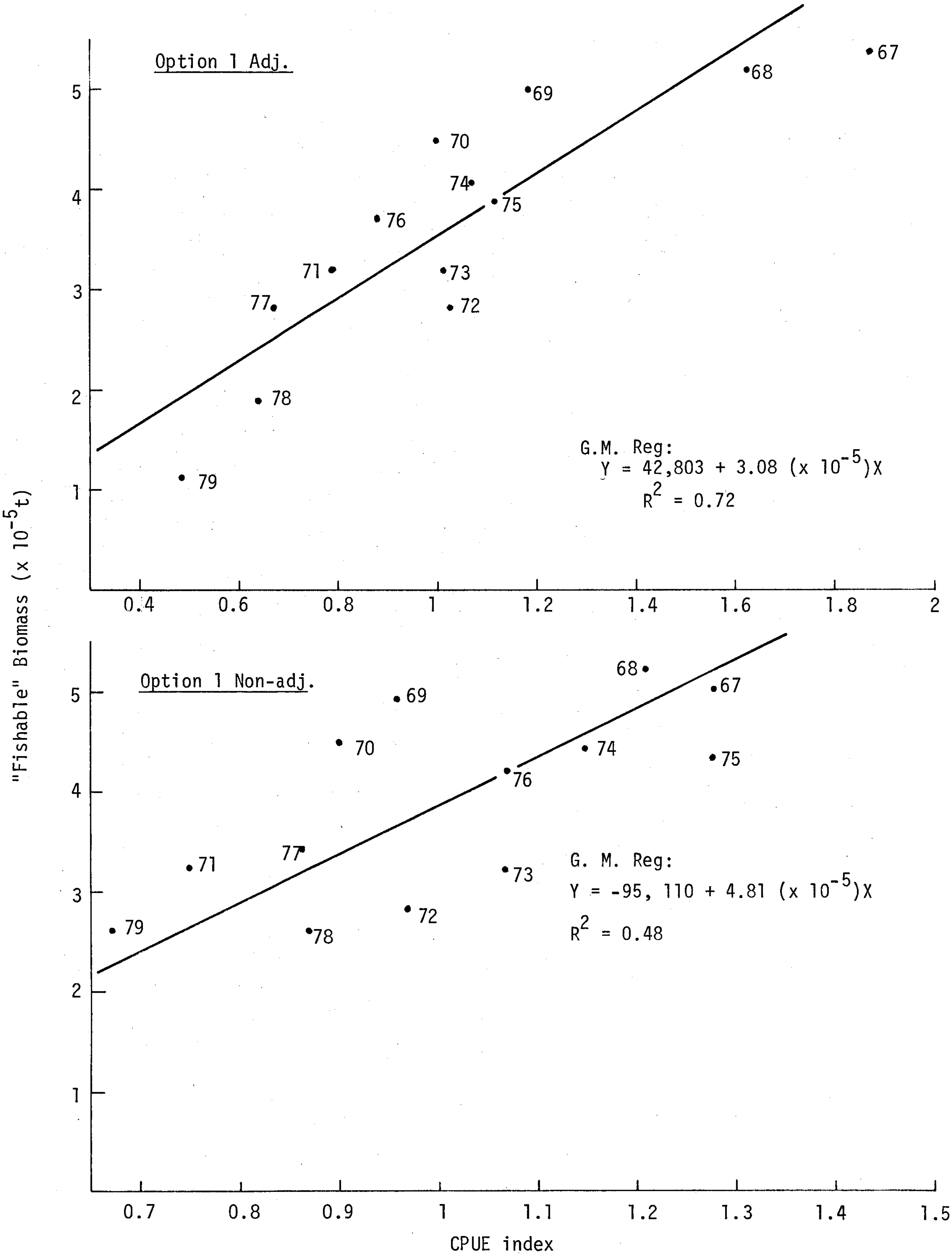

Fig. 11. Fishable Biomass vs. CPUE Index.

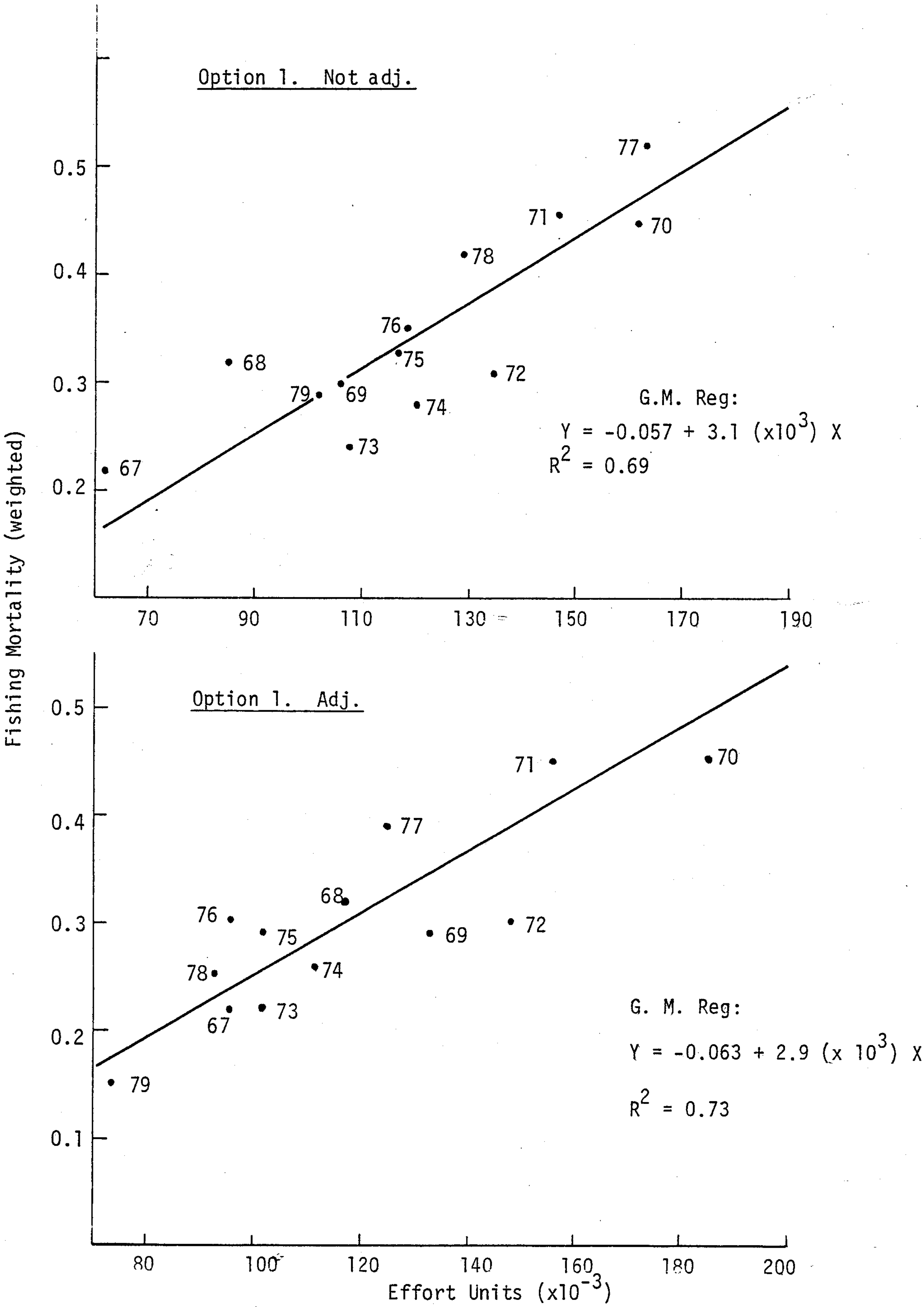

Fig. 12. Fishing Mortality vs. Fishing Effort.

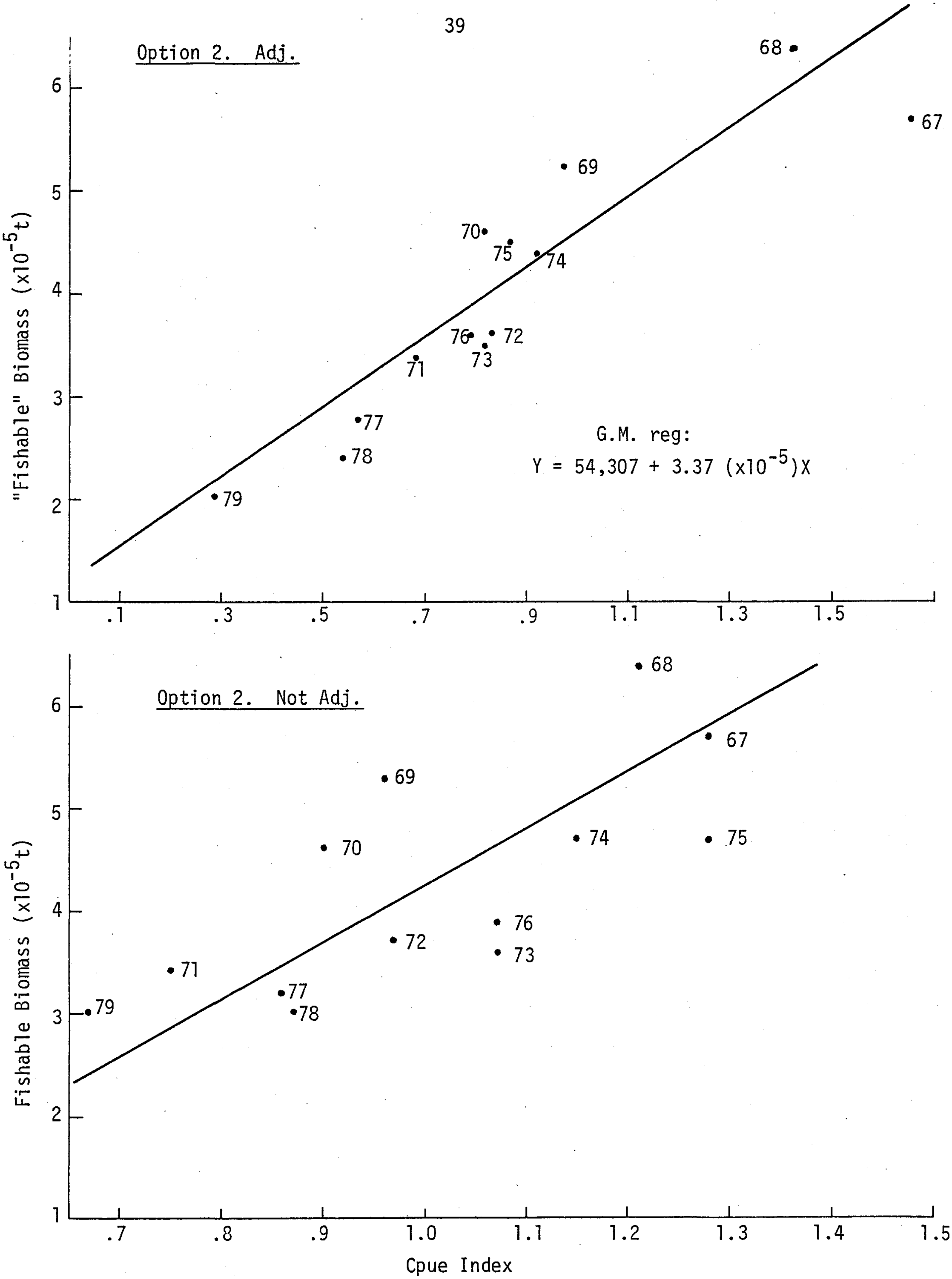

Fig. 13. Fishable Biomass vs. Fishing Effort

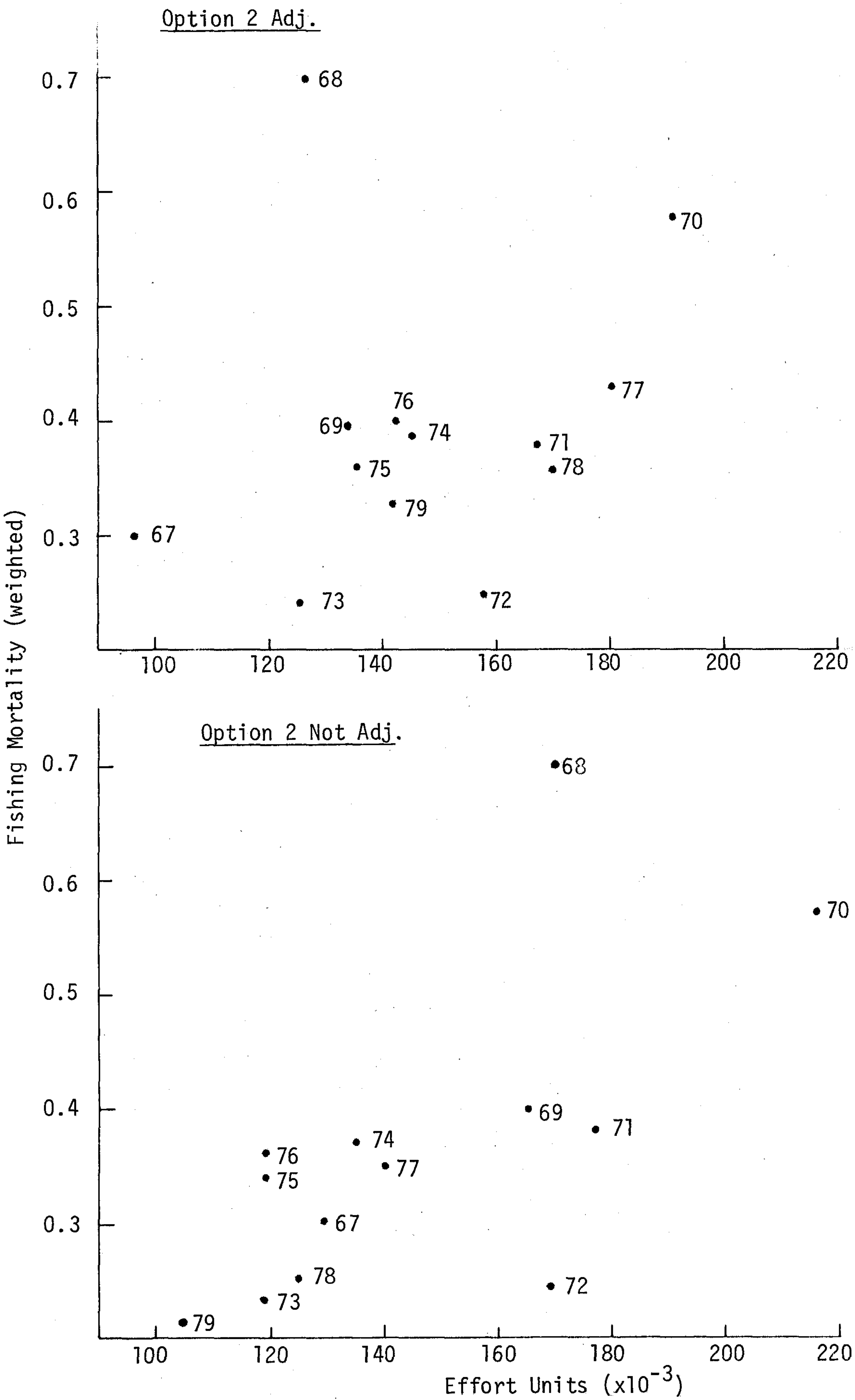

Fig. 14. Fishing Mortality vs. Fishing Effort.

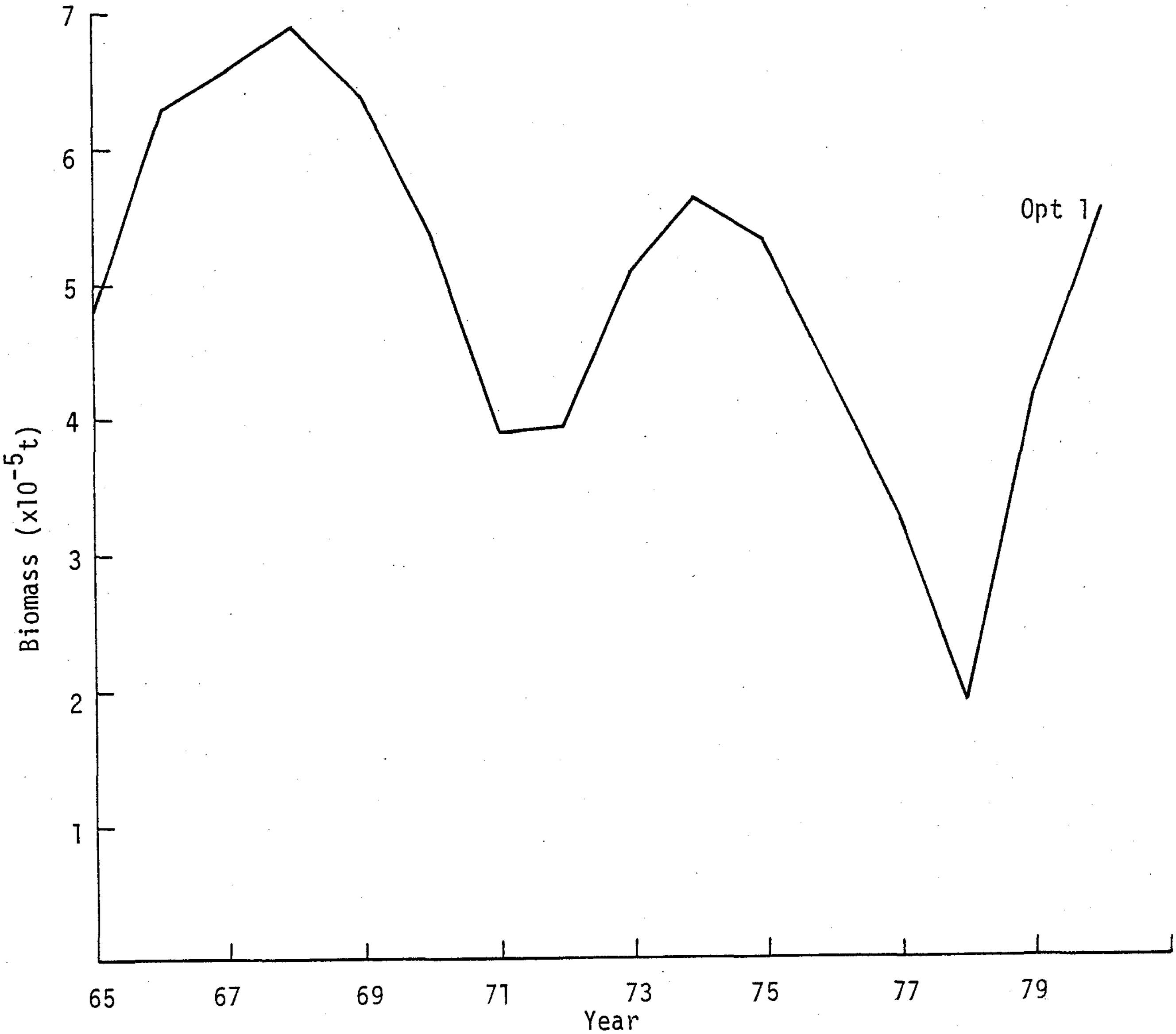

Fig. 15. Temporal distribution of 4WX herring biomass stock option 1.

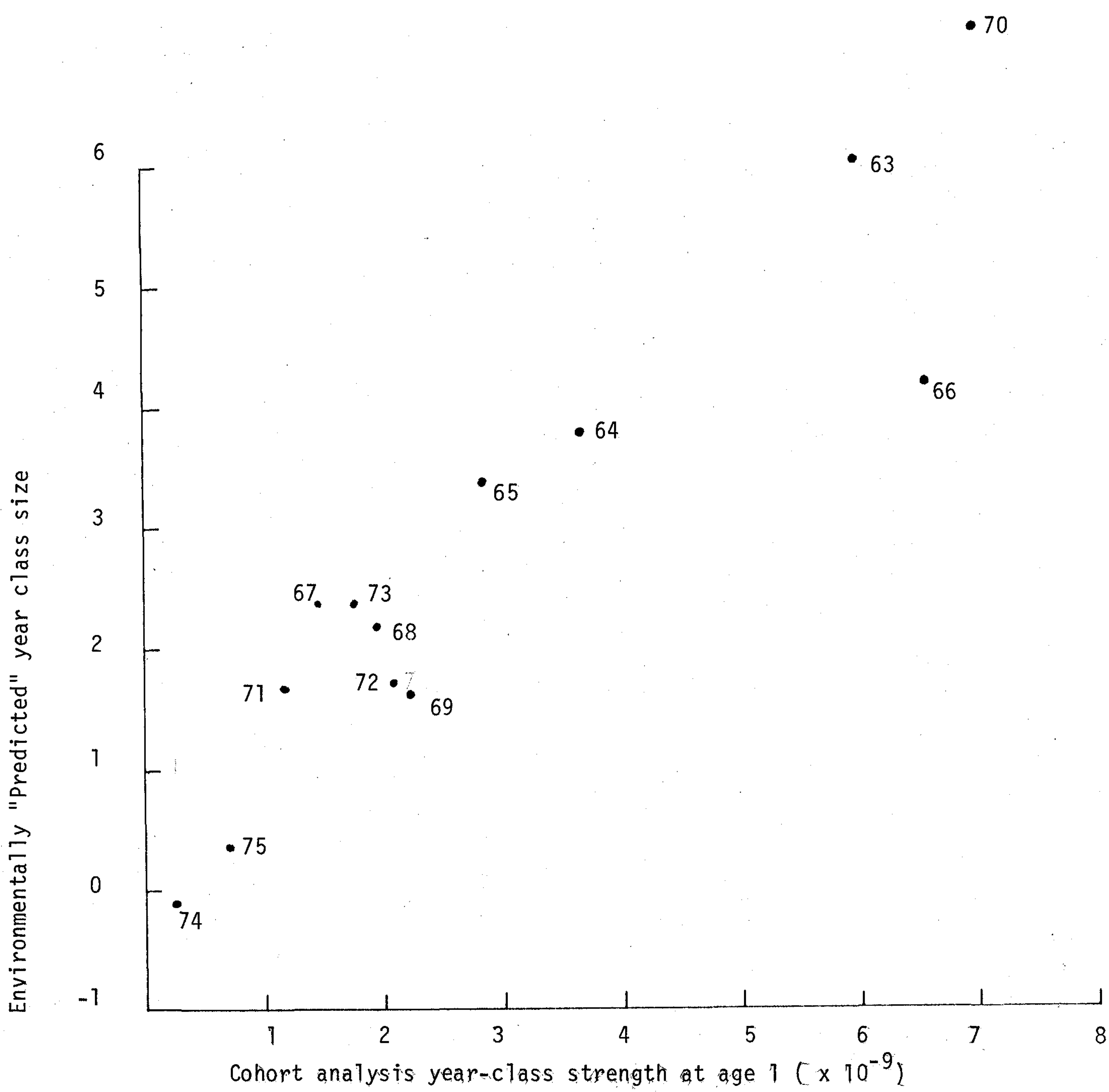

Figure 16. Relationship between environmentally predicted year class strengths at age and cohort analysis estimates.

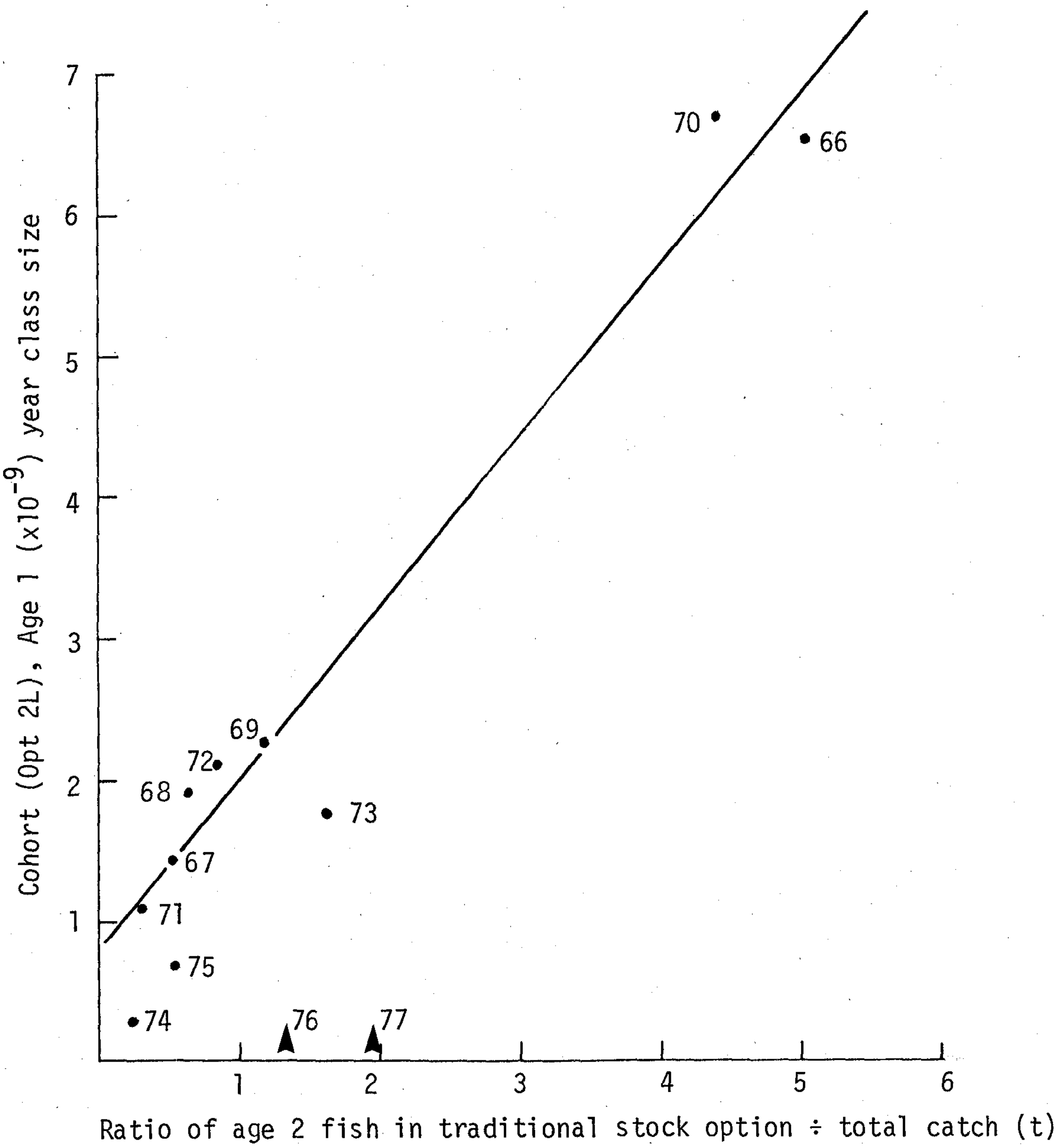

Fig. 17. Regression of cohort year-class strength estimate (at age 1) on proportion of age 2 fish in stock option 1 catch.

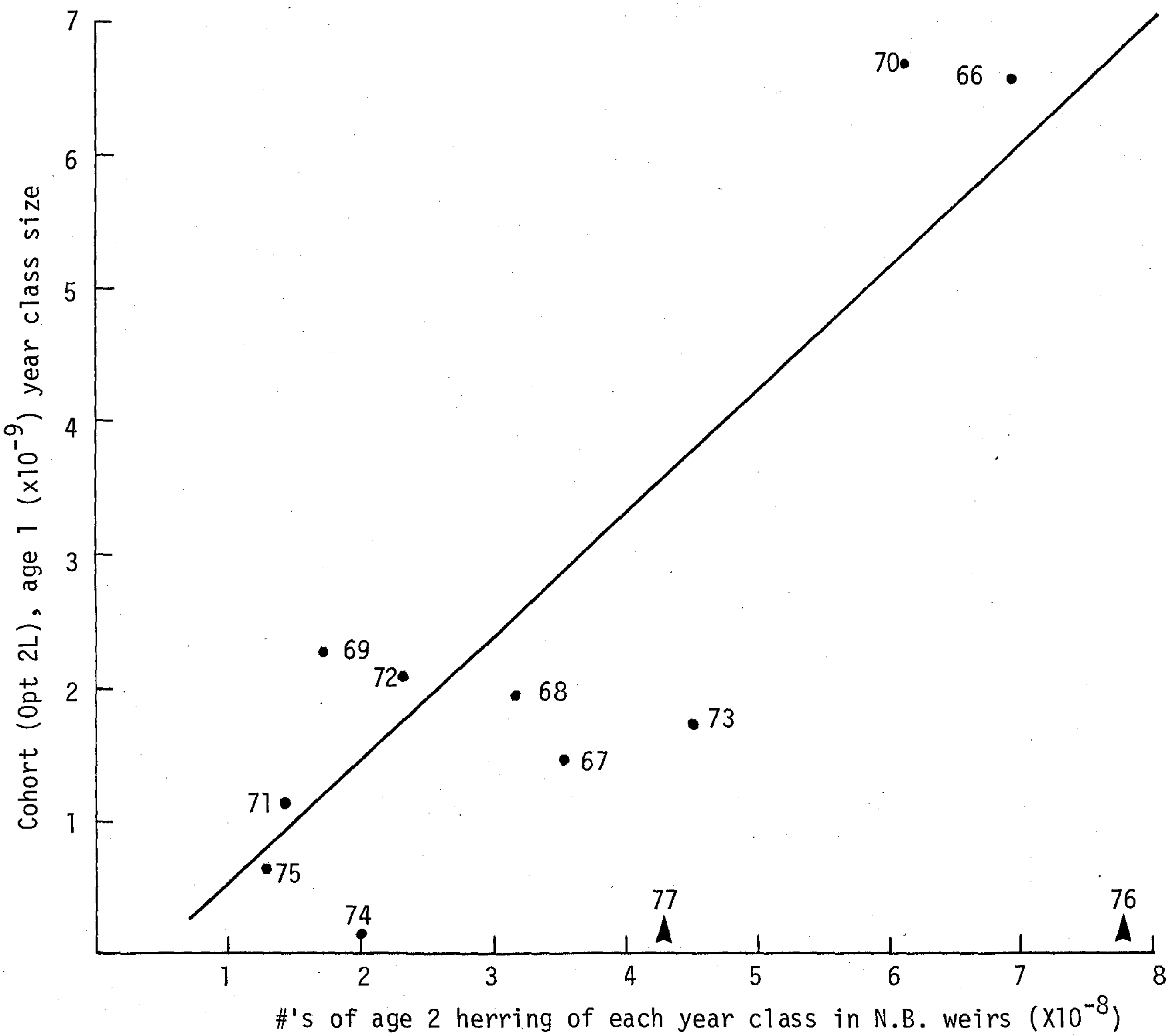

Fig. 18. Regression of cohort analysis year class strength (at age 1) on catch of year-class at age 2 in N. B. weirs.

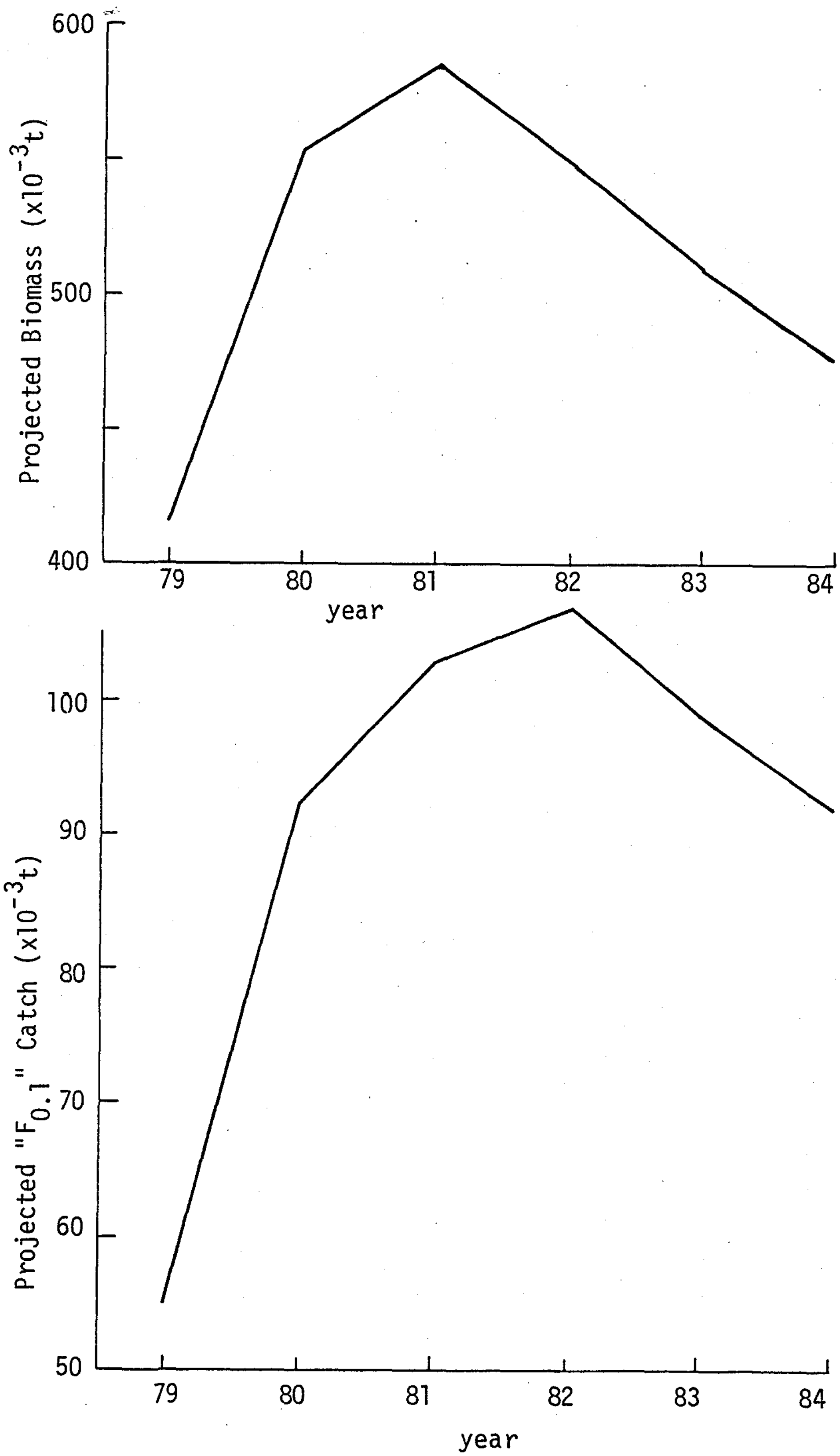

Fig. 19. Five-year projection of population biomass and catch ($F_{0.1}$)

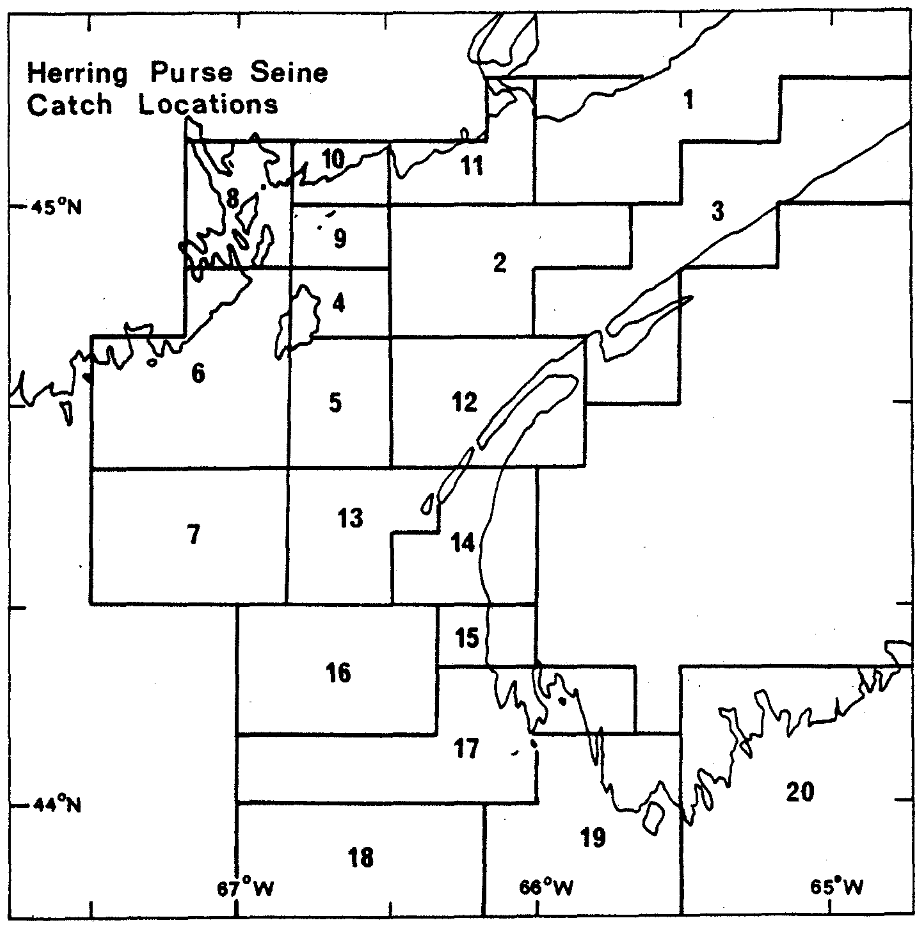

Figure 20. Herring purse seine catch locations.

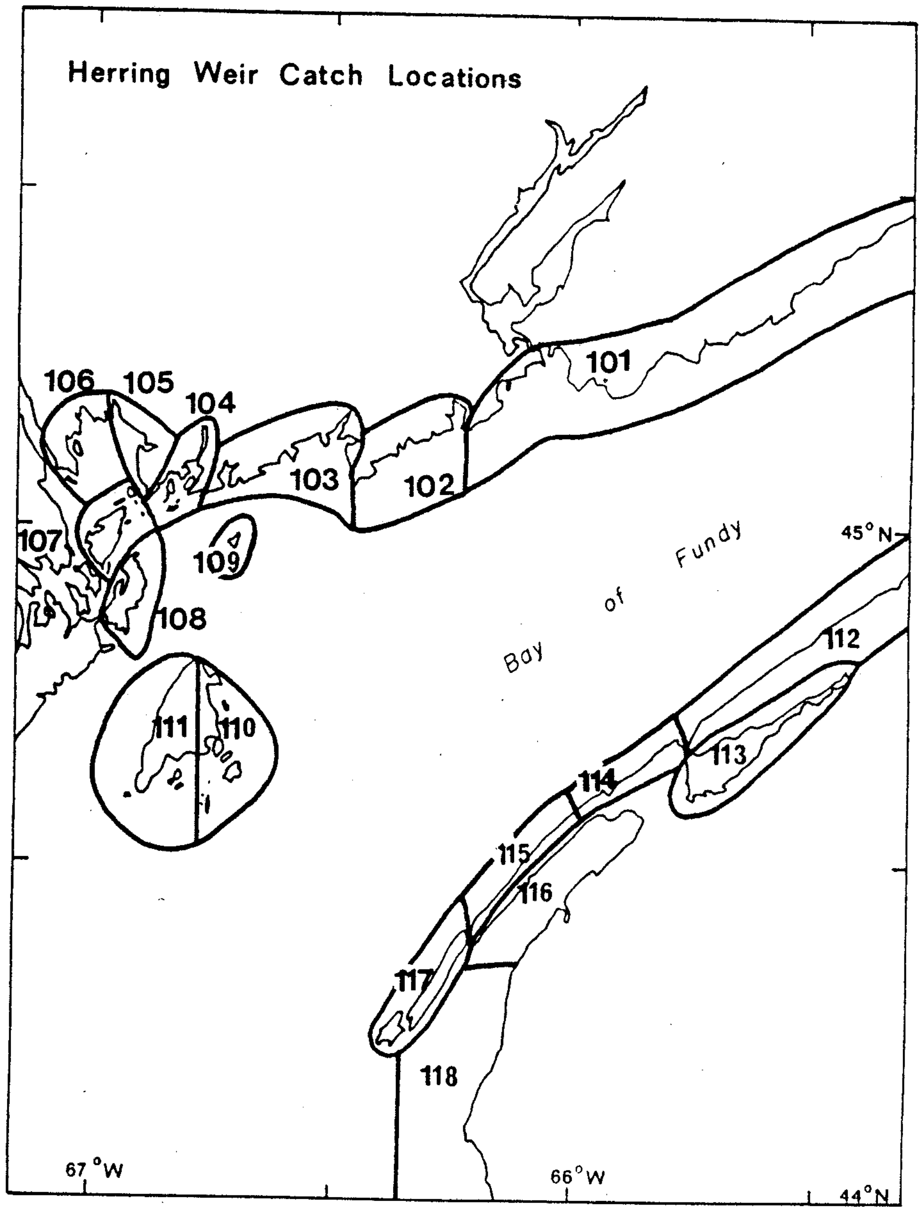

Figure 21. Herring weir catch locations.