Stock Assessments for British Columbia Herring in 1984 and Forecasts of the Potential Catch in 1985

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Herring stock abundance in British Columbia waters was assessed for 1984, and forecasts were made for 1985 using three methods: (1) escapement method, (2) age-structured model analysis, and (3) surplus production model analysis.

The abundance of the 1984 adult herring run in British Columbia waters as assessed by the newly developed escapement method was 148,000 tonnes. This is a decrease of 43,000 t (23%) from the 1983 estimate. The 1985 run is forecast at 217,600 t with average recruitment. The 1985 forecasts for poor and good productivity are 118,300 t and 317,100 t respectively. For the south coast particularly it is anticipated that poor productivity will prevail, due to unfavorable environmental conditions.

The forecast from age-structured model analysis for 1985 is 142,000 tonnes. This predicted run size reflects the currently unfavorable conditions.

Assuming poor production the surplus production model analysis predicts a run of 544,000 t. These unrealistically high run sizes result from poor model fits obtained for most of the separate stock data sets.

The recommended 1985 catch level (20% of the weighted 1985 herring run size) for the B.C. coast is 34,100 t. Under conservative management and other constraints encountered administering fisheries, the catch levels recommended herein may be substantially lower.

Key words: Clupea harengus pallasi, Pacific herring, stock assessment, forecasts, surplus production, age-structured analysis

RÉSUMÉ

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Les auteurs ont évalué l'abondance du hareng dans les eaux de la Colombie-Britannique en 1984 et ont fait des prévisions pour 1985 à l'aide de trois méthodes: (1) la méthode d'estimation de l'échappée, (2) l'analyse du modèle de la structure des âges et (3) l'analyse du modèle de la production excédentaire.

Selon la méthode d'estimation de l'échappée récemment mise au point, la remonte du hareng adulte en 1984 a été évaluée à 148 000 t, soit une baisse de 43 000 t (23 %) par rapport à l'estimation de 1983. Pour 1985, on prévoit une remonte de 217 600 t accompagnée d'un recrutement moyen et une productivité de 118 300 t ou de 317 100 t selon qu'elle sera médiocre ou bonne. Sur la côte sud en particulier, on s'attend à une productivité médiocre à cause des conditions environnementales défavorables.

Selon l'analyse du modèle de la structure des âges, on prévoit une remonte de 142 000 t en 1985, ce qui traduit les conditions défavorables actuelles.

En supposant que la production soit faible, on prévoit une remonte de 544 000 t d'après l'analyse du modèle de la production excédentaire. Cette estimation irréaliste est le résultat de mauvais ajustements du modèle obtenus pour la plupart des séries de données sur chaque stock.

Pour 1985, on recommande un total des prises de 34 100 t (20 % de la remonte pondérée du hareng en 1985) pour la côte de la C.-B. En fonction d'une approche gestionnelle prudente ou d'autres contraintes relatives à l'administration des pêches, le taux de capture recommandée pourra être beaucoup moins élevé.

Mots-clés: <u>Clupea harengus pallasi</u>, hareng du Pacifique, évaluation de stock, prévisions, production excédentaire, analyse de la structure des âges

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FOREWORD

This report was prepared by the Herring Population Dynamics Program of the Herring Section (Fisheries Research Branch), and contains proposed catch levels for herring for the 1984/85 season. These recommended catches are based primarily on biological considerations, and may vary with those finally adopted by the Herring Stock Assessment Committee. The final fishing plans adopted by Fisheries Management will be based not only on biological considerations, but also economic and social, enforcement, and other factors.

Results contained in this report were presented to the Herring Stock Assessment Committee in August of 1984.

ACKNOWLEDGMENTS

This document not only presents the efforts of the Population Dynamics Program but numerous other members of the departmental staff play key roles in collection and processing of data. Herring ages were determined by Margret Burke and Karen Charles of the Pacific Biological Station Ageing Unit. Lorena Rosenfeld processed the catch, sample, and spawn data and maintained the pertinent data bases. Also, Field Services personnel and contractors contribute to the sampling effort.

1. INTRODUCTION

1.1 GENERAL

Forecasting the potential catch that can be removed from herring stocks requires an assessment of the status and determination of the factors which affect stock dynamics. Traditionally, yield models have assumed equilibrium conditions implying no changes in age structure, growth, or mortality over time. However, herring are strongly affected by changes in environmental conditions thus making equilibrium models unattractive. The methods we use try to estimate current stock conditions on the basis of which potential catches are recommended that will not have deleterious effects on the stocks.

In this report we present three methods to assess herring stock conditions: (1) escapement method (Schweigert and Stocker 1985), (2) age-structured model analysis (Fournier and Archibald 1982), and (3) surplus production model analysis. The second method uses age composition data; all three methods use catch and spawn deposition information.

1.2 DATA BASE

The main data inputs for these stock assessment methods are spawn survey data, commercial catch landing data, and age composition data from biological samples of commercial catches or from pre-fishery charter and research cruises. These data are available on computer files in a consistent record for the period 1950 to 1984. This time span includes the reduction fishery period to 1968 and the subsequent "roe" fishery period starting in the early 1970s.

Of the three sets of information the spawn data contain the largest measurement errors. We feel that the quality of spawn surveys has improved greatly over the 34-year span of these observations. This improvement is a result of increased numbers of people and vessels being involved in spawn surveys, increased attention to data measurements, increased coverage of subtidal spawnings, and increased research on estimating egg deposition from spawn observations. The only consistent observations made during the 34 years of spawn surveys are the length, the width, and a measure of intensity of spawnings. The escapement method estimates absolute egg numbers from these observations and includes a width conversion to correct for the inability to survey subtidal spawn adequately. The surplus production model uses a spawn index calculated by summing the length of all spawnings in an area. Three different spawn indices are evaluated using the age-structured model. These are: the sum of spawn lengths, the sum of spawn length times intensity, and the sum of spawn length times width times intensity.

Catch information was obtained from landing slip data. All three methods use the landing slip data summed by season (seasons run from July 1 to June 30). The 1983/84 catch figures are based on hailed estimates because sales slip data were not available for timely analysis. The sales slips record catch in tonnes. Numbers of fish in the catch, for use in the age-structured model, were calculated using the average fish weight from catch samples for the season. A small amount of catch obtained off the west coast of Vancouver Island during the reduction period is not included in the W.C.V.I. data set. These fish, caught offshore in the summer, could be either west coast or Strait of Georgia spawners.

Age structure data, obtained from biological samples, are used in the age-structured model. The information from catch samples are used for years when there were commercial fisheries. For years with no fisheries, pre-fishery and research samples are used to obtain age compositions. Additional information obtained from the biological sampling data base and used in the age-structured model includes data on age specific fecundities and average weights at age.

1.3 STOCK CONSIDERATIONS

For the escapement method (Section 2) stock assessments are conducted separately for each management unit and division (Hourston and Hamer 1979). These geographic regions (Fig. 1.1) support or have the potential for roe fisheries and include the spawning ground utilized by the fish (Hourston 1982).

For the age-structured model analysis (Section 3), and the surplus production model analysis (Section 4) stock assessments are conducted separately for each of five data sets. These groupings (Fig. 1.2) divide the coast into three "stocks" in the north (Queen Charlotte Islands, north coast, central coast), and two "stocks" in the south (west coast of Vancouver Island, Strait of Georgia and Johnstone Strait). These stock groupings are a re-definition of the management unit stock concept. The assumption that spawners return to the same management unit in which they previously spawned has been relaxed in this re-definition. The five geographic regions are more in line with west coast herring populations that were originally identified on the basis of mean vertebral number (Tester 1937, 1949), and the division level of data aggregation (Hourston and Hamer 1979).

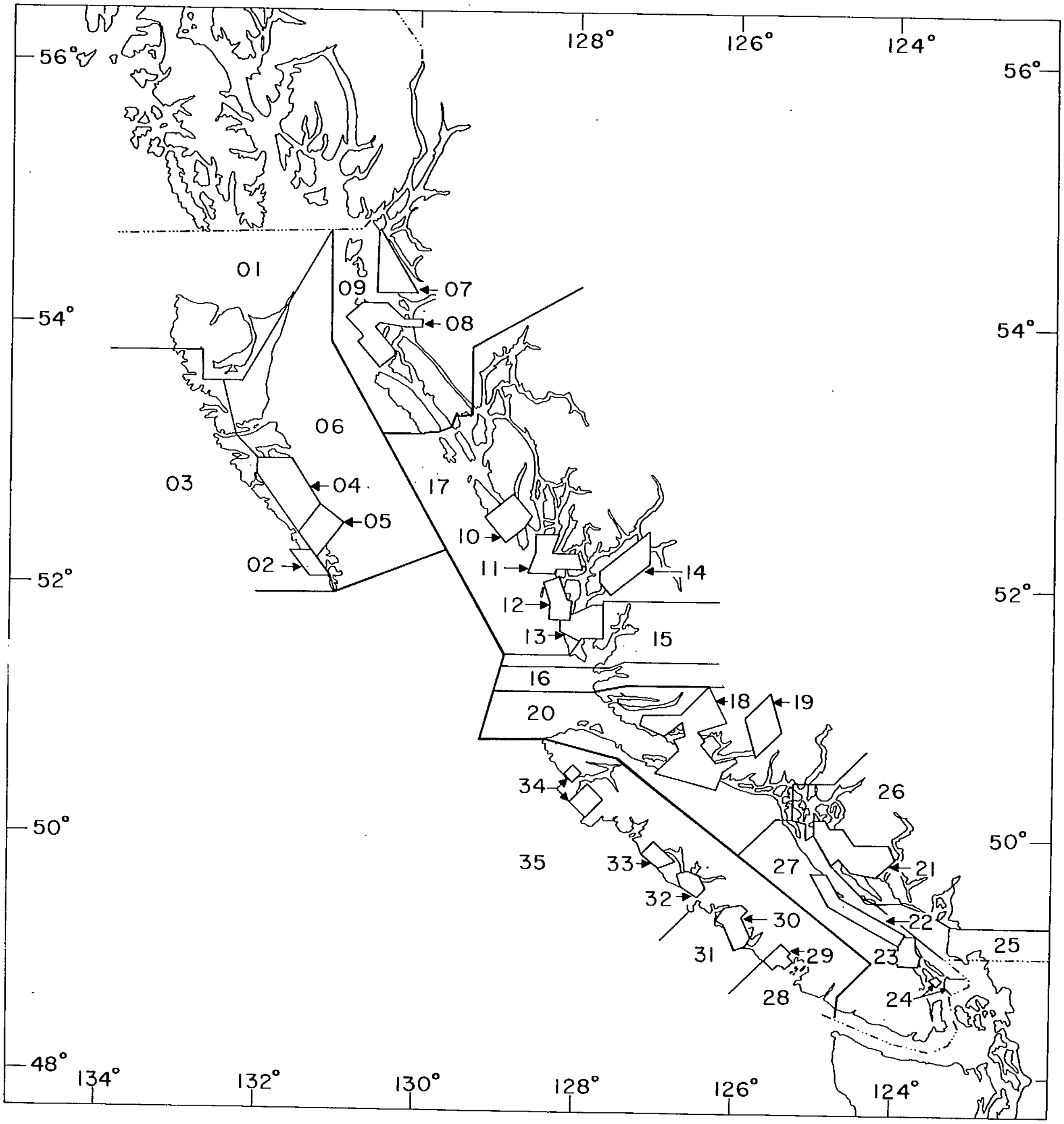


Fig. 1.1. Management units for British Columbia herring roe fisheries.

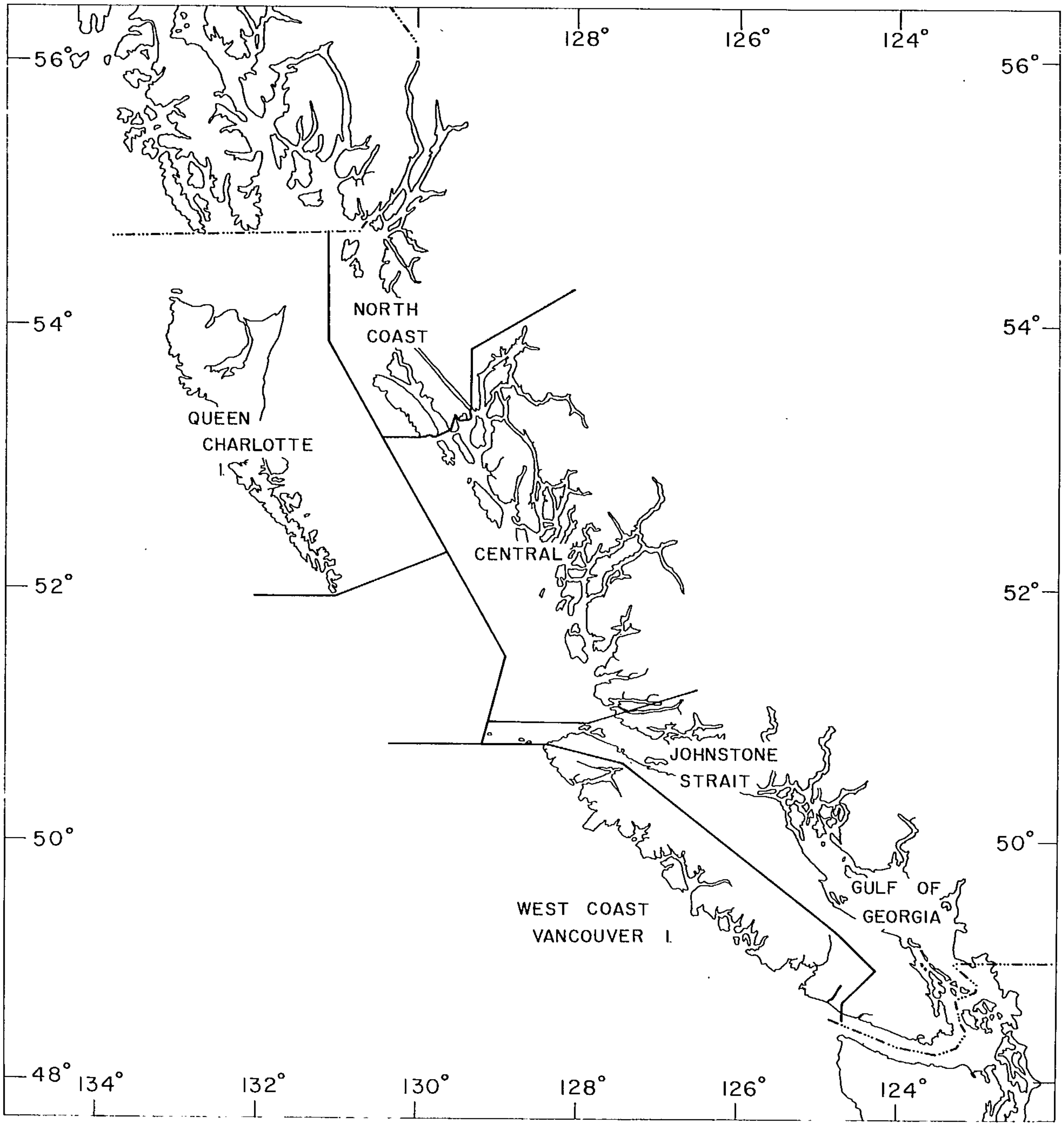


Fig. 1.2. Herring stock groupings for age-structured model analysis, and surplus production model analysis.

2. ESCAPEMENT METHOD

2.1 INTRODUCTION

The escapement method is a new analytical procedure developed for assessing and forecasting herring stock abundance. It is similar in many regards to the Hourston method (Hourston 1981) it has replaced. It differs in that it does not incorporate age structure information and it does not use the egg survival factor to account for egg mortality. It does however correct for the underestimation of spawn widths by fishery officers (Schweigert and Stocker 1985).

The stock assessment may be done at any level of geographic amalgamation from the section level, to management units, to divisions (see Hourston and Hamer 1979, for a description of geographic areas). The analysis has two components, the assessment of the spawning stock in a given year and the forecast of runs in the following year. The spawning stock abundance is dependent entirely on the estimates of egg deposition from fishery officer spawn surveys. Forecasts of runs to management units or divisions have two components. First, the estimate of adults (repeat spawners) obtained from applying an average survival rate to the previous year's spawning escapement. Second, the estimate of production which is an average estimated for the stock from previous years.

2.2 METHODS

We provide only a brief description of this method here as it is described in more detail elsewhere (Schweigert and Stocker 1985). The spawn data collected by fishery officers (F.O.) includes length and width of spawn, and layers of eggs on various spawn substrates. The spawning stock size in any given area in a year is estimated from the fishery officer estimate of area of deposition and intensity. The reported length times a corrected width is used to estimate a total area of deposition. The estimate of the average number of layers of eggs for each spawn are then converted to egg density from a relationship which relates mean egg density in a spawn from counted samples to the F.O. estimates of average layers. The mean egg density times the area estimates the total number of eggs deposited in each individual spawn. Egg depositions within geographic areas are then aggregated to estimate the total spawning escapement at the requisite scale for management. Tonnes of spawners are approximately given by the total egg deposition divided by 200 eggs g^{-1} of female weight. The spawning escapement plus the total catch provides an estimate of the total pre-fishery population for each area in each year.

The forecast of the anticipated spawning run in year t+1 is estimated from the spawning escapement in year t times an estimate of the average survival rate (.64) for one year (Beverton 1963) plus an estimate of stock production. Production was estimated as the average over the time series from 1951 to 1984. Forecasts assuming good and poor production were determined by taking plus or minus one standard deviation of the average value.

2.3 STATUS OF THE STOCKS

Estimates of spawners and hailed roe catches in 1984 and of total pre-fishery abundance for the period 1974-84 for all management units and divisions are shown in Table 2.1 and Figure 2.1. The 1984 pre-fishery biomass for the Queen Charlotte Islands was estimated at 28,000 tonnes. This represents an 11 percent decrease from the 1983 pre-fishery biomass. All management units but Skincuttle and other area 2E show a decrease in abundance over the previous year. For the north coast division the estimated pre-fishery biomass was 19,000 tonnes which is a 29 percent increase over the previous year. North coast stocks appear to have recovered to average levels observed in the early and mid 1970s. The central coast pre-fishery biomass for 1984 was estimated as 30,000 tonnes which is a 17 percent decrease from the 1983 level and indicates that stocks are near the high levels of the mid 1970s. Kitasu Bay appears to be at a historically high level while Queen's Sound and River's Inlet are at historical low levels. Stocks in the other areas are near average values for the period of the roe fishery. Generally, northern stocks appear to be in reasonably good shape relative to historical roe fishery levels.

The estimated pre-fishery biomass in Johnstone Strait division in 1984 was 5,200 tonnes. This is a decrease of 4 percent from 1983 and is part of a continuing decrease begun in 1980. In the Strait of Georgia division the 1984 pre-fishery biomass estimate of 39,000 tonnes represents a decrease of 44 percent from the previous year and leaves the stocks in this area at their lowest levels since the beginning of the roe fishery. Stocks in the Ganges-Plumper area have all but disappeared while stocks in the Yellow Point area are above average for 1974-84. Nanaimo-Comox stocks are about one third of historical levels while Powell River stocks are about average. The 1984 pre-fishery biomass for the west coast of Vancouver Island was 26,800 tonnes which represents a 19 percent decline from 1983 levels. Stocks in all areas have demonstrated a steady decline since about 1980 and are at historical low levels for the period 1974-84. South Clayoquot stocks are up 4 fold over 1983 levels but still well below historical levels.

2.4 FORECASTS

Forecasts of 1985 runs to management units and divisions assuming poor, average, and good production are shown in Table 2.2. The production estimate reflects a net change in biomass which results from growth, recruitment, and migration.

Assuming average production the forecast stock biomass in 1985 is expected to be 31,700 t for the Queen Charlotte Islands, 26,400 t for the north coast, and 40,600 t for the central coast (Table 2.2). Taken together this implies a total pre-fishery biomass of 98,700 t for the northern district. However, since stocks in some of the northern areas are showing signs of a downward trend it is possible that we will see lower than average production in some of these areas. Given poor production forecast runs for the Queen Charlotte Islands, north and central coasts are 16,300, 12,000, and 25,100 t, respectively. Combined the total pre-fishery biomass for the entire north could be as low as 52,400 t. At the management unit level most areas would be expecting no recruitment under poor production conditions. However, there is no reason to expect below average recruitment in all areas of the north simultaneously.

The forecast biomass assuming average production is 17,200 t for Johnstone Strait, 58,600 t for the Strait of Georgia, and 43,100 t for the west coast of Vancouver Island implying a total biomass of 118,900 t for the entire south coast. However, since these areas have all undergone a long term decline to the lowest levels recorded during the history of the roe fishery below average production is anticipated. This implies stock sizes of only 6,200 t for Johnstone Strait, 33,500 t in the Strait of Georgia, and 25,200 t on the west coast of Vancouver Island. However, if one examines the forecasts for individual management units there would be virtually no production in any areas under a poor production scenario. Thus any fisheries would rely solely on the returning adult runs which are at historical lows for both the Strait of Georgia and the west coast of Vancouver Island.

Table 2.1. Catch (tonnes), spawners (tonnes) for 1984, and total abundance (tonnes) for 1974 to 1984 by management unit for Queen Charlotte Islands division.

Year	Management Unit: North Coast 01	Louscoone 02	Other Area2W 03	Laskeek Bay 04	Skincuttle 05	Other Area2E 06	Total QCI Division
1974	3019	3043	3149	0	6783	6850	22843
1975	607	5185	2313	0	7391	5869	21365
1976	2531	7288	1516	442	15119	6386	33283
1977	2472	3976	2275	14	17263	5010	31010
1978	3637	2952	2687	98	16354	4555	30283
1979	1129	720	2124	631	12197	4055	20854
1980	1721	2055	3976	1327	20313	31	29424
1981	1322	536	4267	5712	15981	3284	31102
1982	1879	1160	9618	3536	14066	1923	32181
1983	72	776	10590	8245	10226	1435	31343
1984	0	433	4163	3018	17724	2637	27974
				1984 Catch			
Seine	0	0	0	0	4462	0	4462
Gillnet	0	0	0	502	0	0	502
Spawners	0	433	4163	2516	13262	2637	23010

Table 2.1 (cont'd.) Catch (tonnes), spawners (tonnes) for 1984, and total abundance (tonnes) for 1974 to 1984 by management unit for North Coast division.

Year	Management Unit: Catham Sound 07	Porcher Island 08	Other North 09	Total NC Division
1974	4882	3555	280	8717
1975	2912	4831	103	7846
1976	5809	8009	304	14122
1977	8471	6903	591	15965
1978	3880	5402	2829	12111
1979	5539	6124	1660	13324
1980	3224	9965	607	13796
1981	4259	8551	1444	14253
1982	6058	3428	1784	11270
1983	5140	9006	548	14694
1984	8952	9090	985	19027
	1984 Catch			
Seine	0	1646	0	1646
Gillnet	1574	0	0	1574
Spawners	7378	7444	985	15807

Table 2.1 (cont'd.) Catch (tonnes), spawners (tonnes) for 1984, and total abundance (tonnes) for 1974 to 1984 by management unit for Central Coast division.

Year	Management Unit								Total Central Coast Division
	Kitasu Bay 10	Milbanke Sound 11	Queen's Sound 12	Kwakshua Channel 13	Burke Channel 14	River's Inlet 15	Smith Inlet 16	Other Central 17	
1974	3635	8424	4437	3213	7198	3078	941	3197	34121
1975	5882	5875	3684	4499	5289	5735	1011	3092	35067
1976	3797	15056	6788	3110	6904	2817	826	6821	46118
1977	4378	14517	7558	943	6812	4561	487	907	40162
1978	4823	11868	5412	1988	3016	2199	1424	647	31377
1979	2649	1873	1263	1776	2944	363	282	2299	13450
1980	6006	8191	2943	3016	0	1143	1638	1497	24434
1981	7634	12881	916	2284	1993	562	617	1055	27942
1982	6215	19777	1338	1694	0	712	1789	870	32394
1983	10314	8387	505	2360	1819	96	578	12102	36162
1984	10280	7590	170	2142	4358	455	1068	3979	30042
	1984 Catch								
Seine	695	2613	0	0	0	0	0	0	3308
Gillnet	3371	0	0	0	0	0	0	0	3371
Spawners	6279	4976	170	2142	4358	455	1068	3979	23427

Table 2.1 (cont'd.) Catch (tonnes), spawners (tonnes) for 1984, and total abundance (tonnes) for 1974 to 1984 by management unit for Johnstone Strait division.

Year	Management Unit: Upper Johnstone 18	Management Unit: Knight Inlet 19	Management Unit: Other Johnstone 20	Total JS Division
1974	7210	7664	4517	19392
1975	9876	3789	7410	21076
1976	7210	4642	3721	15574
1977	5324	3921	4021	13266
1978	3196	2064	5065	10326
1979	910	870	4647	6427
1980	4087	2037	5518	11642
1981	2083	2301	3372	7756
1982	1463	3166	1952	6582
1983	862	2545	1957	5363
1984	2049	2295	815	5160
	1984 Catch			
Seine	0	0	150	150
Gillnet	0	0	0	0
Spawners	2049	2295	665	5010

Table 2.1 (cont'd.) Catch (tonnes), spawners (tonnes) for 1984, and total abundance (tonnes) for 1974 to 1984 by management unit for Strait of Georgia division.

	Management Unit						
Year	Powell River 21	Nanaimo Comox 22	Yellow Point 23	Ganges Plumper 24	Area 29 25	Other Gulf 26	Total GS Division
1974	2449	32481	9443	8398	1843	1092	55706
1975	8169	43503	8552	10486	1448	2304	74462
1976	6114	42648	10011	4267	2600	2743	68383
1977	5541	58407	3730	6836	1178	1963	77655
1978	4531	74182	10735	3866	240	10233	103788
1979	17307	39806	15043	2173	0	13121	87451
1980	4991	52468	10544	1820	236	4500	74558
1981	5215	30832	13620	2633	0	3060	55360
1982	7322	59990	9380	844	0	8623	86160
1983	8000	41337	14697	91	0	5909	70033
1984	6837	14165	17421	0	94	487	39004
			1984 Catch				
Seine	3513	0	473	0	0	487	4473
Gillnet	0	6284	0	0	0	0	6284
Spawners	3324	7881	16948	0	94	0	28247

Table 2.1 (cont'd.) Catch (tonnes), spawners (tonnes) for 1984, and total abundance (tonnes) for 1974 to 1984 by management unit for West Coast Vancouver Island division.

Year	Management Unit								Total WCVI Division
	West Barkley 27	Other Area23 28	South Clayoquot 29	Other Area24 30	Nootka Sound 31	Nuchatlitz Inlet 32	Quatsino Sound 33	Other Upper WC 34	
1974	9503	0	9013	1877	4629	11188	526	1163	37898
1975	16848	661	11538	12472	7618	9497	3477	1050	63160
1976	30941	5012	13293	15397	2038	8367	440	905	76391
1977	36873	928	16555	4080	776	6633	1061	533	67437
1978	15593	2620	13454	2671	675	10035	10469	554	56071
1979	21908	620	16968	1624	10884	11616	17844	0	81465
1980	12488	0	16647	2037	0	7666	26587	0	65424
1981	14599	2	11858	3816	4578	5963	6667	0	47483
1982	11441	2	3577	569	0	8449	9142	11	33192
1983	15902	299	1503	1031	0	6166	8367	0	33269
1984	7181	4932	6387	150	118	2290	5724	0	26782
	1984 Catch								
Seine	5581	0	0	0	0	0	0	0	5581
Gillnet	0	0	0	0	0	771	214	0	985
Spawners	1600	4932	6387	150	118	1519	5510	0	20216

Table 2.2. Forecast of the 1985 runs in tonnes (x1000) of fish by management unit and division for poor, average and good production.

Division and Management unit	Adults	Production -1Std	Production Avg.	Production +1Std	Forecast Run Poor	Forecast Run Avg.	Forecast Run Good
Queen Charlotte Is.							
North Coast	0.0	-0.8	0.4	1.6	-0.8	0.4	1.6
Louscoone Inlet	0.3	-0.2	1.3	2.8	0.0	1.6	3.1
Other Area 2W	2.7	-0.6	1.3	3.1	2.1	3.9	5.8
Laskeek Bay	1.6	-0.8	0.6	2.0	0.8	2.2	3.6
Skincuttle Inlet	8.5	-4.7	9.2	23.0	3.8	17.7	31.5
Other Area 2E	1.7	-0.5	4.8	10.1	1.2	6.5	11.8
All QCI	14.7	1.6	17.0	32.3	16.3	31.7	47.1
North Coast							
Catham Sound	4.7	-2.0	4.3	10.6	2.7	9.0	15.3
Porcher Island	4.8	0.5	3.9	7.3	5.3	8.7	12.1
Other North Coast	0.6	-4.0	8.0	20.1	-3.3	8.7	20.7
All NC	10.1	1.9	16.2	30.6	12.0	26.4	40.7
Central Coast							
Milbanke Sound	3.2	-0.9	6.6	14.1	2.3	9.8	17.3
Queen's Sound	0.1	-0.3	4.4	9.1	-0.2	4.5	9.2
Kwakshua Channel	1.4	-0.4	2.4	5.2	0.9	3.7	6.5
Burke Channel	2.8	-0.5	1.7	3.9	2.3	4.5	6.7
River's Inlet	0.3	-0.4	1.5	3.4	-0.1	1.8	3.7
Smith Inlet	0.7	-0.1	0.7	1.6	0.6	1.4	2.3
Other Central	2.5	-0.3	5.6	11.5	2.2	8.2	14.1
All Central	15.0	10.1	25.6	41.1	25.1	40.6	56.1
Johnstone Strait							
Knight Inlet	1.5	-0.1	1.4	2.9	1.3	2.8	4.4
Other Johnstone	0.4	0.2	10.2	20.2	0.6	10.6	20.6
All JS	3.2	3.0	14.0	25.1	6.2	17.2	28.3
Strait of Georgia							
Nanaimo-Comox	5.0	-0.5	15.0	30.4	4.6	20.0	35.4
Yellow Point	10.8	-5.9	4.8	15.4	5.0	15.6	26.3
Ganges-Plumper	0.0	-0.7	2.9	6.6	-0.7	2.9	6.6
Boundary Bay	0.1	-2.3	1.1	4.4	-2.3	1.1	4.5
Other Str Georgia	0.0	-1.4	15.4	32.2	-1.4	15.4	32.2
All Str Georgia	18.1	15.4	40.6	65.7	33.5	58.6	83.8

Table 2.2 (cont'd)

Division and Management unit	Adults	Production			Forecast Run		
		-1Std	Avg.	+1Std	Poor	Avg.	Good
West Coast Vancouver Island							
West Barkley	1.0	-2.2	4.8	11.9	-1.2	5.9	12.9
Other area 23	3.2	-1.4	9.0	19.5	1.7	12.2	22.6
South Clayoquot	4.1	-1.3	2.9	7.1	2.8	7.0	11.2
Other area 24	0.1	-0.7	3.0	6.7	-0.6	3.1	6.8
Nootka Inlet	0.1	-2.8	1.5	5.8	-2.7	1.6	5.9
Nuchatlitz Inlet	1.0	-2.2	4.3	10.8	-1.2	5.3	11.8
Quatsino Sound	3.5	-3.0	1.5	6.0	0.5	5.0	9.5
Other Upper WC	0.0	-3.4	5.2	13.7	-3.4	5.2	13.7
All WCVI	12.9	12.3	30.2	48.1	25.2	43.1	61.1

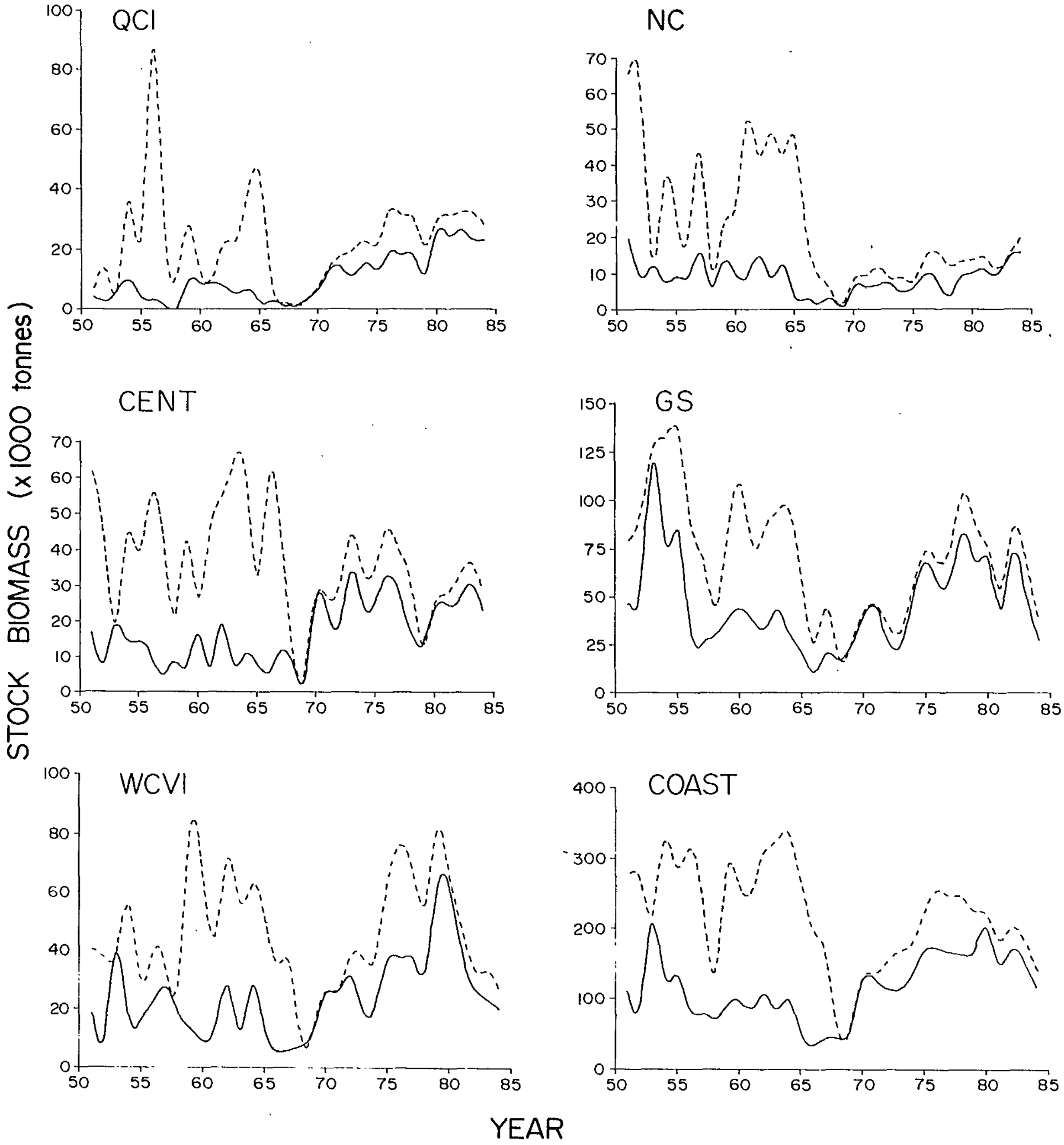


Fig. 2.1. Estimated spawning stock and total abundance by division for 1951-84 using the escapement method.

3. AGE-STRUCTURED MODEL

3.1 INTRODUCTION

An age-structured model has been used to assess B.C. herring stocks since 1982 (Stocker et al. 1983); the model is a modified version of the one described in Fournier and Archibald (1982). The major difference in the version used to assess B.C. herring stocks is the incorporation of spawn survey data. The model includes realistic assumptions about the form of both measurement and process errors. A maximum likelihood method is used to simultaneously esimate all model parameters.

The use of the age-structured model to assess B.C. herring stocks is an ongoing process of refining the model so that it is more consistent with the life history of B.C. herring and with the fisheries being analyzed. A number of major changes have been made to the model for the 1984 stock assessments. The most important of these is the separation of the fishery into two components; one for the gillnet and one for the seine fisheries. In previous analyses catch-at-age data from these two gears were weighted relative to the size of each fishery and input to the model as one age structure. Because these gear types have different selectivities the age information provided to the model may have masked relative cohort strengths.

3.2 METHODS

The general age-structured model used in this analysis has been described in detail elsewhere (Fournier and Archibald 1982); the inclusion of spawn data in the model is also documented (Stocker et al. 1985). The following model description deals primarily with new model developments.

Parameters which are estimated by the model include the instantaneous rates of fishing (F) and natural (M) mortalities as well as the numbers of fish at age j in period r of year i (N_{ijr}) for each year of the data series. The estimates are determined by minimizing an objective function which has terms for all components of the model. Simplified versions (variance estimates and constants are not included) of the major components of the objective function are:

- the log likelihood function for the parameters P_{ijr} and C_{ir}

$$\Sigma_{ijr} S_{ijr} \log P_{ijr} - w\Sigma_{ir} (\log O_{ir} - \log C_{ir})^2$$

- the contribution from the true spawn - recruitment relationship (a Ricker type parameterization is used)

$$- w\sum_{i} (\log (N_{i+1,1,1}) - \log\alpha - \log (TS_i) + \beta TS_i)^2$$

- the contribution from the true spawn-escapement relationship

$$-w\sum_i \left(\log\left(\sum_j f_j N_{ij1}\right) - QSP - \log(TS_i)\right)^2$$

- the contribution from the true spawn - observed spawn relationship

$$-w\sum_i \left(\log(TS_i) - \log(OS_i)\right)^2$$

where S_{ijr} = the number of fish observed to be of age j in period r of year i

P_{ijr} = the actual percentage of fish of age j in the catch in period r of year i

O_{ir} = estimated number of fish caught during period r of year i

C_{ir} = actual number of fish caught during period r of year i

f_j = relative fecundity of fish of age j

TS_i = true spawn in year i

QSP = true spawn - escapement coefficient

OS_i = observed spawn in year i

The penalty weights (w) are assigned by the user and reflect his intuition about the relative accuracy of the data. The spawn related penalty weights used in this analysis are :

20 for the true spawn - escapement relationship

10 for the true spawn - observed spawn relationship

5 for the true spawn - recruitment relationship

These penalty weights reflect our belief that herring do not follow a very strong stock - recruitment relationship , and our mistrust of the earlier spawn index data. By placing the highest weight on the true spawn-escapement relationship the true spawn estimates should follow the escapement estimates from the age structure data to a relatively greater degree.

To investigate the effect of including spawn data in the analysis four sets of computer runs were done for each stock grouping. In the first set the stock reconstruction was done with no spawn information; in the other sets three different spawn indices were used. These were: (1) the sum of length of spawnings, (2) the sum of length times intensity of spawnings, and (3) the sum of length times width times intensity of spawnings.

In most cases the total sample sizes $(\sum_j S_{ijr})$ were rescaled to 400, as discussed in Fournier and Archibald (1982). The exceptions to this are for the years 1966 to 1970 where sample sizes were rescaled to 25. During those years individual fish had not been aged and age compositions had been determined from age-length keys. The effect of rescaling sample sizes to 25 for these years is that the model can deviate to a greater extent from the observed age structure of the catch. The last four age classes (ages 7 to 10) are grouped together.

Instantaneous fishing (F_{ijr}) and natural (M_r) mortality rates are incorporated into the model through the catch equations :

$$P_{ijr}C_{ir}=F_{ijr}/(F_{ijr}+M_r)(1-\exp(-F_{ijr}-M_r))\,N_{ijr}$$

The following two-factor model was used to reparameterize fishing mortality

$$\text{(3.1)} \qquad \log F_{ijr} = a_{ir} + b_{jr} \;,$$

where a_{ir} represents the general level of fishing mortality due to the fishery in period r of year i, and b_{jr} represents the relative level of fishing vulnerability of age class j in period r. Two fishing periods were used in this analysis. The first period uses catch-at-age information from seine gear. This includes the reduction (primarily winter) fisheries prior to 1970, and the food/bait (winter) and seine roe (spawning) fisheries since 1970. The second period uses catch-at-age information from gillnet gear and is represented only by roe fisheries since 1971. Gillnet roe fisheries generally occur after the seine roe fisheries in an area.

The proportion of fish at age two (1+) is highly variable between years of the reduction fisheries. This variability does not relate to differences in cohort size, but is likely the result of concentrated fishing on immature schools. To allow for deviations in fishing mortality for two-yr-olds during these years (i=1 to i=20) an additional term is added to equation 3.1 such that:

$$\log (F_{i,2,1}) = a_{i,1} + b_{2,1} + D_i \;,$$

and the term

$$- p \sum_i D_i$$

is added to the objective function; p is a penalty weight which is set to 2 for all computer runs in this analysis.

In analyses done to date, natural mortality was not well determined by the the model. As a result of this, absolute levels of stock biomass are also not well determined. Instantaneous natural mortality was set to .45 for all stock reconstructions of this analysis. Of the total annual mortality, .40 was assigned to the first fishing period and .05 to the second fishing period. Even with a fixed natural mortality rate the reconstructions for two of the stock groupings (north coast and Queen Charlotte Islands) showed increasing stocks through the time period to unrealistically high levels. To stabilize this tendency an additional term was added to the objective function to penalize for high numbers of 10-year old fish. The term:

$$- p \sum (N_{i,10,2})^2$$

was added to the objective funcation value with a penalty weight (p) of 1×10^{-4}.

Forecast of spawning stocks in 1985 were calculated by assuming all natural mortality for the first period (.40) will occur prior to spawning, and therefore prior to the roe fisheries. The numbers of fish at age prior to the fisheries are therefore the numbers estimated at the beginning of the 1984/85 season minus the number dying through the year. To account for partial recruitment of the younger age-classes (i.e. cohorts not fully mature) we use the proportion vulnerable at each age to the seine gear. We are therefore assuming that the seine gear fishes the spawning stocks non-selectively. This is generally true, though there may be a level of selectivity resulting from the seine fisheries occuring on the early spawning groups which tend to have higher numbers of older fish. The proportion at age available to the seine gear is multiplied by the forecast numbers at age to obtain forecasts of fishable stock size. Biomass estimates are calculated by applying average weights at age to the estimated numbers at age.

3.3 STATUS OF STOCKS

The stock reconstructions (spawning biomass) obtained from the model with each of the three spawn indices and with no spawn data are shown in Fig. 3.1. Reasonable parameter estimates could not be obtained for the Queen Charlotte Island "stock" (area 1, 2W, 2E). Thus, the Q.C.I. analysis in this section uses only area 2E and Louscoone Inlet data (these areas represent over 95% of the fisheries). In general, the reconstructions for each stock follow similiar biomass trends independent of spawn assumptions. This is particularily true for the time period up to the stock declines in the mid to late 1960's. However, with the exception of the west coast Vancouver Island stock, the levels of subsequent stock recovery are substantially lower for the reconstructions using no spawn data. This is likely the result of inconsistent age compostion information in the late 1960s when individual fish were not aged. Because the age compositions are scaled to small sample sizes the model is somewhat flexible in interpreting relative cohort sizes during this period (1966-1970). The inclusion of spawn information adds constraints and results in alternative interpretations of the age composition data. The point is, that there is not enough information in the data to determine the absolute levels of stock recovery in the 1970s relative to stock levels in the 1950s and 1960s unless one is willing to accept that the spawn indices accurately reflect these relative levels.

The objective function values from all computer runs are shown in Table 3.1. These indicate that no one spawn index provides a consistently lower function value for all stock groupings. To maintain consistency in the data used for all stock groupings the sum of length times intensity indices are used for all stock forecasts. These indices produced the lowest objective function value for three of the five stock groupings.

Comparision of one of the spawn indices (length times intensity) and the spawn predicted from escapements, shown in Fig 3.2, indicate the model does not follow the spawn index very closely. This is, of course, because the spawn related penalty weights are set at relatively low levels. The model follows the general level of spawn, indicated by the spawn indices, but does not adhere closely to the annual variability in spawn. However, the value of the spawn data may be in stabilizing the size of the last few cohorts recruiting to the fishery. These cohorts are represented in the fishery for a few years and the spawn data can provide additional information regarding recent stock trends.

For the north coast stock grouping both the spawn index and the spawn predicted from escapement indicate a significant increase in the spawning stock since 1979, with 1984 abundance close to the historic maximum. However, for the Queen Charlotte Islands the spawn index follows a qualitatively different trend than the spawn predicted from escapement for the past five years. The spawn index shows a spawning peak in 1980 with the 1984 spawn only slightly lower than this peak, whereas, the spawn predicted from escapement indicates a peak in 1981 followed by a continuous sharp decline up to 1984. This results from an inconsistency between the spawn index and the age composition data. Since 1980, the Q.C.I. stock has been dominated by the large 1977 year class (45% age 7 in 1984). Because no substantial cohorts have recruited to the fishery since 1980 the stock reconstruction shows a declining population even though the spawn index has remained relatively high. The central coast herring stock also shows a qualitatively different trend in recent years for the two spawn estimates. The spawn index shows increasing spawn from 1979 to 1983 with 1984 levels dropping slightly. The spawn predicted from escapement indicates substantial increase in spawning stocks from 1979 to 1981 followed by continuous decline to 1984. However, for 1983 and 1984 the two spawn estimates are quantitatively similar.

For the Strait of Georgia/Johnstone Strait stock both the spawn index and spawn from escapements indicate a sharp decline in spawning abundance between 1980 and 1984 with the 1984 level close to the historic minimum. Both spawn estimates also show a sharp decline in spawn on the west coast of Vancouver Island in recent years. The spawn index shows a peak in spawning stocks in 1980 whereas the spawn predicted from escapements show a peak in 1975. The two spawn estimates are quantitatively similiar for the last four years.

3.4 FORECASTS

Forecasts of 1985 "fishable" biomass for all stock groupings are shown in Table 3.2. This table contains the predicted biomass of age 4 and older fish, the predicted biomass of age 3 fish, the average biomass (1970-84) of age 3 fish, and the forecast runs based on predicted and average size of the 3-yr old cohort. The predicted strength of the age 3 cohort in 1985 is not well determined by the model because it has only been represented in the fishery in one year (age 2 in 1984). For this reason additional information should be used when available to decide which of the stock forecasts to use for each area.

The forecast biomass of 3-yr olds in the north coast for both the predicted and average estimates is 3,000 tonnes, producing a forecast fishable stock biomass of 33,000 t. The north coast stock has been increasing in recent years, the result of a few strong cohorts (Fig 3.3), so it is reasonable to use the forecast of this total stock size. For both the Queen Charlotte Islands stock and the central coast stock the average biomass of 3-yr olds is significanly greater than the predicted biomass of 3-yr olds. Both stocks have been decreasing over the past three years and the last four cohorts recruited to the stocks (spawn years 1978-1981) have been below average. For these stocks we feel it is advisable to use the forecast biomass obtained with the predicted size of the 3-yr old cohort. This gives forecast biomass estimates of 31,000 t for the Queen Charlotte Islands, and 30,000 t for the central coast.

The predicted biomass of 3-yr-olds on the west coast of Vancouver Island, 42,000 tonnes, is unrealistically high. This forecast is the result of an unusually high proportion at age two in the 1984 seine catch (Rosenfeld et al. 1985). Because of minimal information on this cohort, and to remain consistent with the regularity assumptions, the model interprets this as a large cohort entering the fishery. However, we feel there is an alternative, more realistic interpretation for the high number of mature 2-yr-olds in the spawning stock. A decrease in age at maturity has been observed in a number of other herring populations during periods of severe stock decline. The stock reconstructions for the west coast of Vancouver Island indicate a substantial decrease over the last 8 years, resulting from below average numbers in the last 6 recruited cohorts (Fig. 3.3). Because of concern with the current stock size as well as recruitment of 3-yr olds in 1985 we use a stock forecast based only on age 4 and older fish. This gives a forecast fishable biomass for the west coast of Vancouver Island of 21,000 t.

The current stock situation in the Strait of Georgia/Johnstone Strait grouping appears to be similiar to that on the west coast of Vancouver Island. In 1984 high proportions of mature 2-yr old fish were found in many locations in this area, however, the seine fishery occured on a body of older fish (Rosenfeld et al. 1985). Thus, while the predicted biomass of 3-yr olds is substantially lower than the historic average, we feel the actual cohort size may be substantially lower than model forecasts. Stock reconstruction for this stock grouping indicate considerable stock decline over the last 6 years, as on the west coast of the island. We therefore use the estimate of 4+ fish only for the stock forecast. This gives a fishable biomass for the Strait of Georgia/Johnstone Strait stock grouping of 27,000 t.

Table 3.1. Objective function values for all stock reconstructions using age-structured model analysis.

Division	No spawn data	Spawn 1 (length)	Spawn 2 (length x intensity)	Spawn 3 (length x width x intensity)
	Spawn Index			
Queen Charlotte Islands	758.9	1074.8	1061.8	1159.7
North Coast	941.8	1102.5	1107.7	1122.4
Central Coast	595.5	771.9	769.7	783.9
Strait of Georgia/ Johnstone Strait	682.0	820.0	809.8	854.6
West Coast of Vancouver Island	624.3	804.6	806.7	803.1

Table 3.2. Forecasts of 1985 fishable biomass in tonnes (x1000) of fish, using age-structured analysis.

	Predicted 4+	Predicted age 3	Averages age 3	Predicted Run	Predicted Run-average age 3
QCI (East Coast & Louscoone)	29	2	8	31	37
North Coast	30	3	3	33	33
Central Coast	27	3	8	30	35
West Coast Vancouver Island	21	42	15	63	36
Strait of Georgia/ Johnstone Strait	27	8	15	35	42

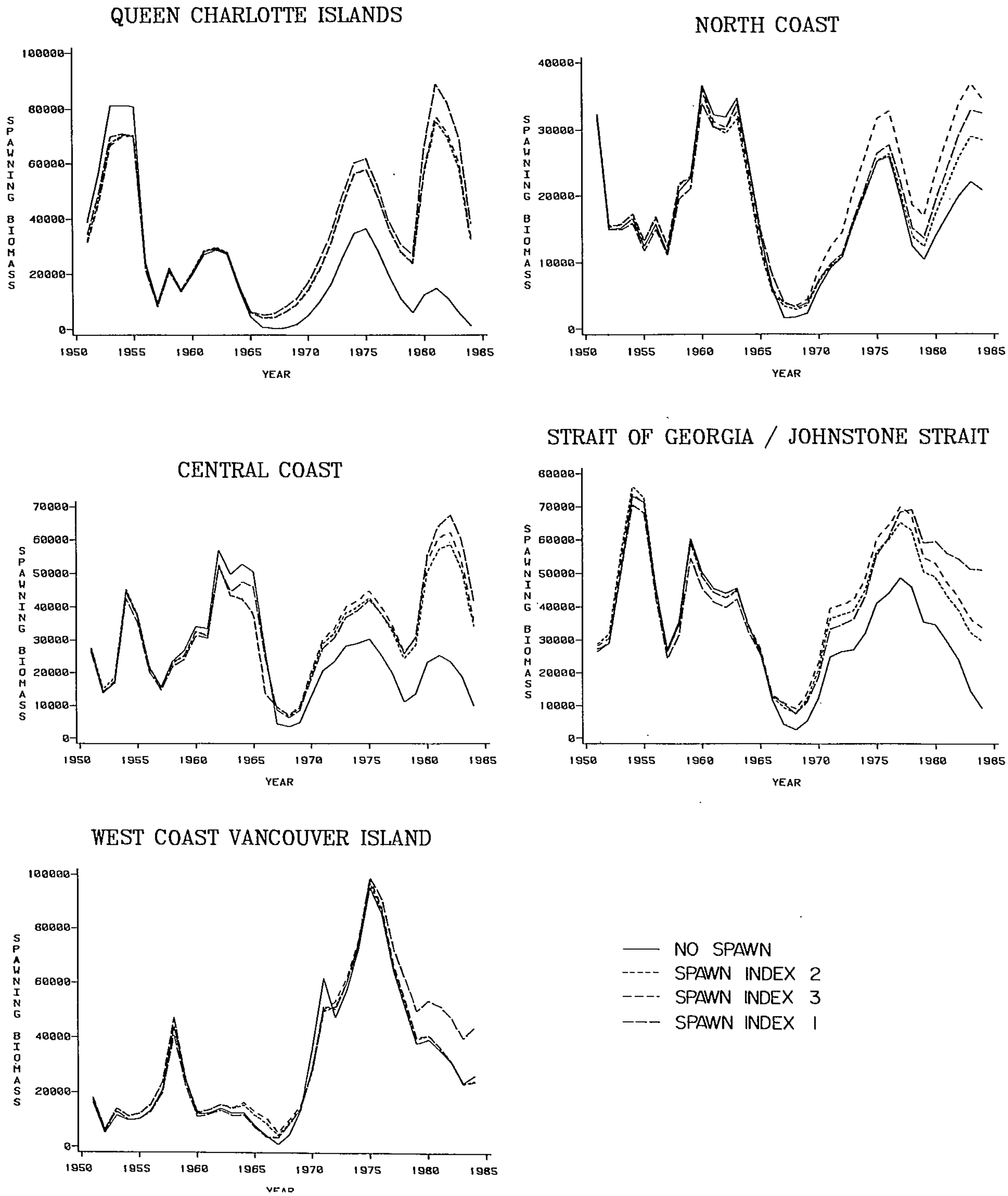


Fig. 3.1. Estimated spawning (post-fishery) biomass (tonnes) of herring, for 1951-1984 using age-structured model analysis.

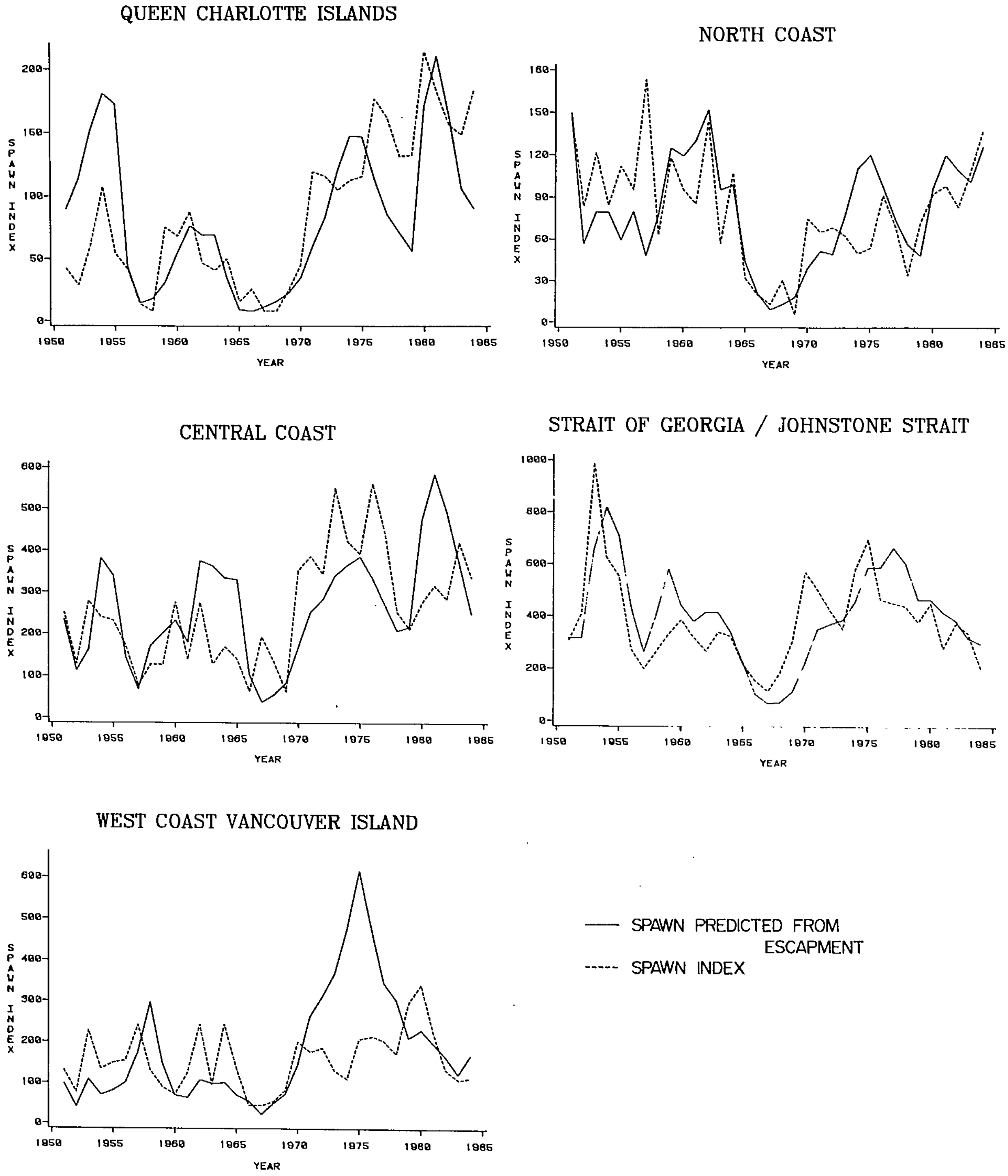


Fig. 3.2. Spawn indices (length x intensity) and spawn predicted from escapements for age-structured model analysis.

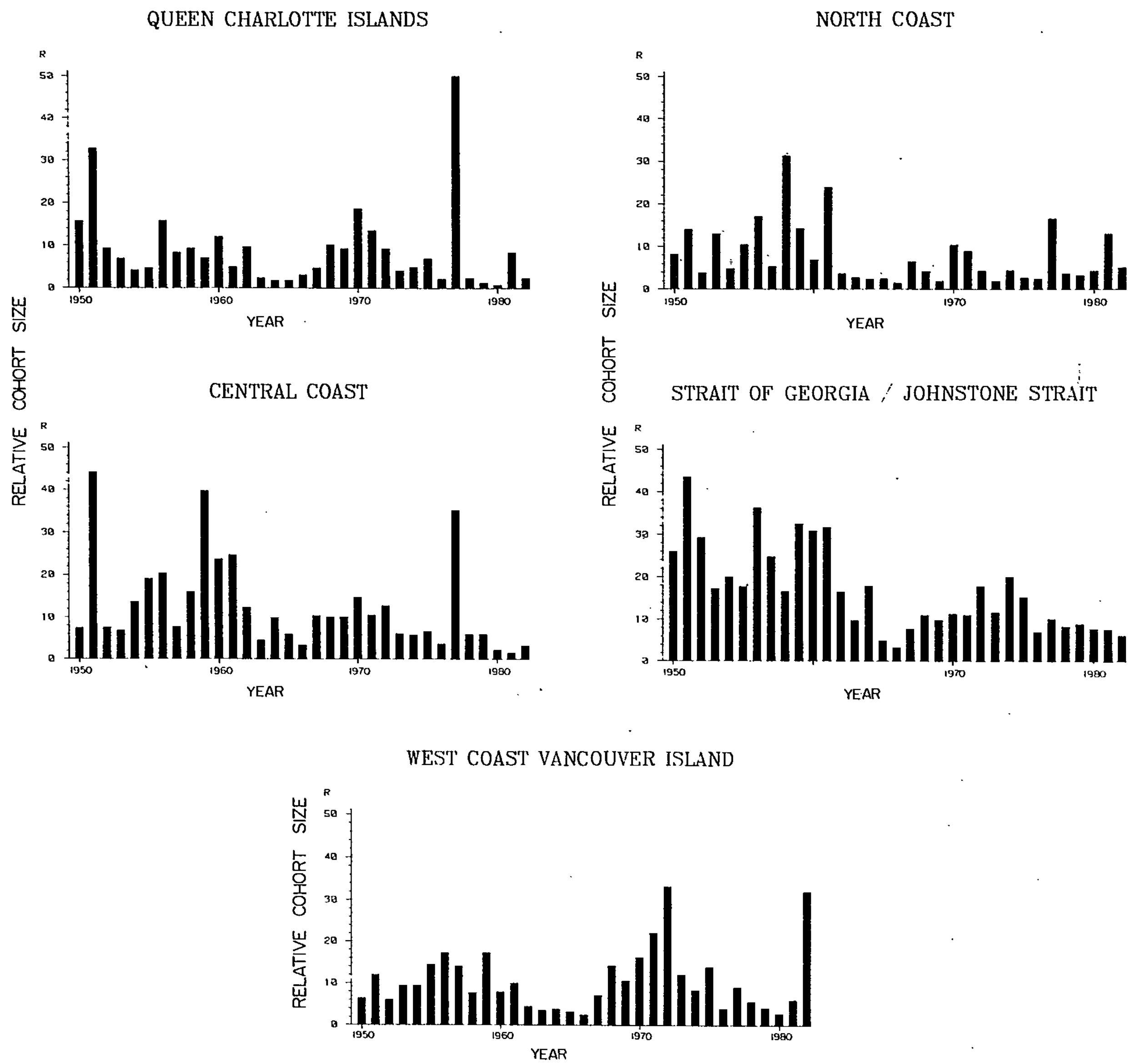


Fig. 3.3. Relative cohort strengths from age-structured model analysis, 1950-1982.

4. SURPLUS PRODUCTION MODEL ANALYSIS

4.1 INTRODUCTION

In surplus production models changes in productivity are expressed in quantitative relationships. Based on productivity estimates, catch estimates are predicted for stocks. We assume that the proportion of the stock dying each year increases with stock size and also that the number of births increase as stock size increases. The difference between births and deaths at any stock size is the source of surplus production to be harvested.

4.2 METHODS

A measure of herring abundance for each stock based on a spawn index (S) was used for these analyses. S is defined as the sum of lengths (km) of spawns. The following relationship between catch and escapement was examined to assess stock sizes and productivity for the years 1951-84:

(4.1) $$E_t + C_t = E_{t-1} + rE_{t-1}[1- \frac{E_{t-1}}{k}]$$

where E_t = escapement biomass in year t
C_t = catch in year t
r = growth parameter
k = unfished equilibrium population size.

If we specify E_t as:

(4.2) $$E_t = \frac{S_t}{q}$$

where S_t = spawn index in year t
q = proportionality constant,

then equations 4.1 and 4.2 can be transformed into a linear regression of the form:

(4.3) $$[\frac{S_t}{S_{t-1}} - 1] = r - \frac{r}{qk} S_{t-1} - q \frac{C_t}{S_{t-1}}$$

Given a time series of C_t's and S_t's, the best estimates of the three model parameters r, k, and q can be obtained by multiple regression.

The production of the population, which is the second term on the right-hand side of equation 4.1, is the difference between pre-fishery biomass in a given year ($E_t + C_t$) and the escapement the previous year (E_{t-1}). For data sets that produced poor model fits average production from 1951-84 was used for forecasting 1985 stock sizes ($\hat{B}_{85}$).

For those data sets which produced significant model fits the average 1985 stock sizes ($\hat{B}_{85}$) were forecast as:

$$(4.4) \qquad \hat{B}_{85} = \frac{1}{q} S_{84} + \frac{r}{q} S_{84} - \frac{r}{kq^2} S_{84}^{2}.$$

A range of runs was forecast, using a jackknife procedure. The jackknife proceeds by removing one years data at a time from the original data and reestimating the model parameters for making the ($\hat{B}_{85}$) prediction.

A major drawback of the surplus production model analysis is the high negative correlation between the production parameter (r) and the proportionality parameter (q). The joint 95% confidence region for the true parameters r and q takes the shape of a long thin negatively sloping ellipse enclosing values of r and q which the data regard as jointly reasonable for the parameters. This means that we could have large stock sizes (small q) with high productivity (high r) as likely as small stock sizes (high q) with low productivity (small r). For reasons relating to these uncertainties the biomass predictions resulting from the surplus production model analysis have to be regarded with caution. For the current assessment the emphasis of this method is primarily to identify stock trends. Predicted runs for 1985 for this method are based on the assumption of poor production.

4.3 STATUS OF STOCKS

Parameter estimates, regression results, and correlations, for the surplus production model analyses are summarized in Table 4.1. Spawn indices (S) and catch (tonnes) for the years 1951-84 are summarized in Table 4.2 for the three northern Divisions as well as the entire North. Predicted and observed pre-fishery biomass trends for the period are shown in Fig. 4.1 for the northern stock groupings. The 1984 pre-fishery biomass for the Queen Charlotte Islands was estimated to be 11% lower than the previous year. The escapement for 1984 was estimated to be 88% higher than the historical average escapement. For the north coast the estimated 1984 pre-fishery biomass is up

12% over the previous year, whereas the escapement is more than twice the historical average. The central coast pre-fishery biomass showed a marked decrease of 24% from 1983. The escapement for 1984 is slightly below historical average.

Spawn indices (S) and catch (tonnes) for the period 1951-84 are summarized in Table 4.3 for the two southern groups as well as the entire south. Production for the two southern stock groupings which produced significant model fits are shown in Fig. 4.2. Predicted and observed pre-fishery abundance trends are shown in Fig. 4.3 for the southern stock groupings. The 1984 pre-fishery biomass for the west coast of Vancouver Island was estimated to be slightly lower than in 1983. The escapement for 1984 was estimated to be 75% of the historical average. For the Strait of Georgia and Johnstone Strait the estimated 1984 pre-fishery biomass has declined by 31% since the previous year. Since 1980 the pre-fishery biomass has declined by 55%. The escapement for 1984 is only 60% of the historical average.

4.4 FORECAST

For data sets that produced poor model fits average production (Table 4.4) from 1951-84 was used to forecast 1985 stock sizes. Forecasts of the ranges of 1985 runs of herring are summarized in Table 4.5. The probability distribution of predicted runs for the Strait of Georgia and Johnstone Strait, and the entire south are shown in Fig. 4.4.

The average run size forecast for the Queen Charlotte Islands is 9% higher than the 1984 pre-fishery biomass. Assuming average production the predicted run size for 1985 for the north coast is 13% higher than the 1984 pre-fishery biomass. The surplus production analysis predicts a run size that is 9% higher than 1984 pre-fishery biomass for the 1985 central coast stock.

Assuming average production the predicted run size for 1985 for the west coast of Vancouver Island is 15% higher than the estimated 1984 pre-fishery biomass. However, this predicted run size is appreciably below historical average. The average run size forecast for the Strait of Georgia and Johnstone Strait is 40% higher than the 1984 pre-fishery biomass. Even this considerable increase, if materialized, would leave the biomass in the Straits below the historical average.

Table 4.1. Parameter estimates, regression results, and correlations for surplus production model analyses.

	Total North	Total South	Strait of Georgia & Johnstone Strait
Parameters			
r	1.0960	0.7819	0.9348
r/qk	-0.0039	-0.0030	-0.0050
t-ratio	-2.91	-3.54	-3.98
P(2 tail)	0.003	<0.001	<0.001
q	-0.7391	-0.4752	-0.5902
t-ratio	-2.43	-2.65	-2.72
p(2 tail)	0.011	0.006	0.005
Regression			
$F_{(2,30)}$	4.67	7.00	8.14
P(F>F)	0.017[a]	0.003	0.002
Correlation			
r_{xy}	0.49	0.56	0.59
rq	-0.76	-0.65	-0.71

[a]not significant at the 1% level.

Table 4.2. Spawn index (S) and catch (x1000 t) by Division for the North, 1951-1984.

	Division							
	QCI		North Coast		Central		Total North	
Year	S	Catch	S	Catch	S	Catch	S	Catch
1951	11.6	2.8	33.2	45.9	72.0	45.2	116.8	93.9
1952	9.0	10.3	19.3	52.4	38.0	36.4	66.3	99.1
1953	22.0	0.0	27.8	1.9	75.5	0.8	125.3	2.6
1954	35.9	26.0	25.3	27.3	60.6	29.5	121.8	82.8
1955	18.2	20.3	36.2	17.8	73.0	31.6	127.4	69.7
1956	21.0	83.7	28.9	10.2	45.4	45.0	95.3	138.8
1957	5.0	25.2	46.6	28.0	28.4	39.5	80.0	92.7
1958	3.8	11.4	22.7	4.5	47.4	12.8	73.9	28.7
1959	44.2	17.6	32.1	10.2	59.6	35.8	135.9	63.6
1960	22.3	3.1	32.6	18.5	79.4	10.8	134.3	32.4
1961	44.9	2.6	29.9	42.7	50.6	38.6	125.4	83.9
1962	31.6	14.7	48.6	27.7	95.1	36.6	175.3	79.0
1963	21.9	17.6	20.2	40.2	40.4	59.0	82.5	116.9
1964	25.2	32.1	33.0	30.3	65.5	50.4	123.7	112.8
1965	9.2	42.4	14.2	44.2	39.9	26.1	63.3	112.7
1966	10.7	6.5	7.8	17.3	25.3	56.3	43.8	80.1
1967	7.9	0.8	6.2	8.0	56.3	33.5	70.4	42.2
1968	6.8	0.2	13.6	2.1	45.3	3.6	65.7	5.9
1969	11.5	0.2	2.2	0.5	31.7	0.1	45.4	0.8
1970	22.3	0.0	34.5	1.5	140.3	0.2	197.1	1.7
1971	38.2	0.4	26.6	3.5	146.7	4.1	211.5	8.0
1972	46.6	4.2	31.3	4.5	156.5	11.2	234.4	19.8
1973	47.7	8.6	24.1	1.6	211.4	10.2	283.2	20.4
1974	63.9	7.2	21.5	3.8	184.4	10.1	269.8	21.1
1975	52.9	8.2	22.8	1.7	197.3	9.9	273.0	19.7
1976	87.4	14.4	36.8	4.3	252.7	13.1	376.9	31.8
1977	96.9	12.9	44.2	8.1	214.0	11.1	355.1	32.2
1978	94.2	12.5	25.4	8.6	119.8	14.1	239.4	35.2
1979	64.8	9.1	30.9	4.3	116.5	0.0	212.2	13.4
1980	101.4	3.4	50.3	3.4	140.8	0.5	292.5	7.4
1981	121.0	6.9	42.2	3.1	143.7	3.0	306.9	13.0
1982	116.6	5.7	39.1	2.0	114.6	6.6	270.3	14.2
1983	91.3	7.3	58.6	0.1	153.9	5.7	303.8	13.1
1984	82.2	4.9	63.4	3.4	115.9	6.6	261.5	14.9

Table 4.3. Spawn index (S) and catch (x1000 t) by Division for the South, 1951-1984.

Year	West coast Vancouver Island		Strait of Georgia & Johnston Strait		Total South	
	S	Catch	S	Catch	S	Catch
1951	47.0	22.0	98.8	47.4	145.8	69.4
1952	26.8	27.0	118.0	53.5	144.8	80.5
1953	64.3	0.0	218.4	8.4	282.7	8.4
1954	45.6	37.6	147.1	71.5	192.7	111.0
1955	49.2	12.6	167.1	70.5	216.3	83.3
1956	51.0	17.6	104.7	73.6	155.7	91.3
1957	63.9	3.1	69.1	72.5	133.0	78.3
1958	58.0	0.6	111.5	23.5	169.5	34.5
1959	30.8	69.8	141.2	55.6	172.0	125.9
1960	30.9	55.8	140.8	76.6	171.7	132.4
1961	35.7	30.8	112.5	51.8	148.2	82.7
1962	55.6	28.4	87.5	75.6	143.1	119.9
1963	39.7	21.2	125.7	79.2	165.4	122.6
1964	69.2	22.1	131.1	89.7	200.3	124.7
1965	52.3	18.8	76.4	65.2	128.7	103.5
1966	22.1	12.4	65.2	53.6	87.3	83.5
1967	21.5	15.4	88.3	45.9	109.8	75.6
1968	22.8	0.0	73.3	5.3	96.1	7.0
1969	32.7	0.0	125.2	0.8	157.9	0.8
1970	65.2	0.0	217.3	0.9	282.5	0.9
1971	63.5	0.0	213.9	1.8	277.4	1.8
1972	64.2	0.0	203.4	13.1	267.6	20.0
1973	42.0	18.3	148.9	17.0	190.9	35.3
1974	31.4	16.9	195.7	6.3	227.1	23.2
1975	63.9	26.1	204.6	7.6	268.5	33.7
1976	64.9	39.0	185.2	13.8	250.1	52.8
1977	69.9	30.1	194.9	18.3	264.8	48.5
1978	76.2	22.9	160.4	24.8	236.6	47.7
1979	83.5	19.4	198.7	20.5	282.2	39.9
1980	89.4	4.5	202.2	5.9	291.6	10.4
1981	66.7	8.7	147.5	12.2	214.2	21.0
1982	45.0	6.1	161.5	12.9	206.5	18.9
1983	37.9	8.8	123.4	18.3	161.3	27.0
1984	38.1	6.6	85.7	10.9	123.8	17.5

Table 4.4. Average herring production and standard deviation (1951-1983) for forecasting 1985 stock sizes (B).

Division/Group	1985 Average production (1000 t)	Standard deviation (1000 t)
West Coast Vancouver Island	17.1	30.4
Queen Charlotte Islands	15.6	26.8
North Coast (3-5)	14.5	20.3
Central Coast	21.6	50.3

Table 4.5 Estimates of the 1984 ranges of spawners, and forecast of the 1985 ranges of runs in tonnes (x1000) of fish for the British Columbia Coast.

Division	1984 Spawners	Forecast Run
Queen Charlottes	79-190	94-207
North Coast	61-146	75-161
Central Coast	111-266	132-289
West Coast of Vancouver Island	47-102	64-119
Strait of Georgia & Johnstone Strait	107-230	179-264

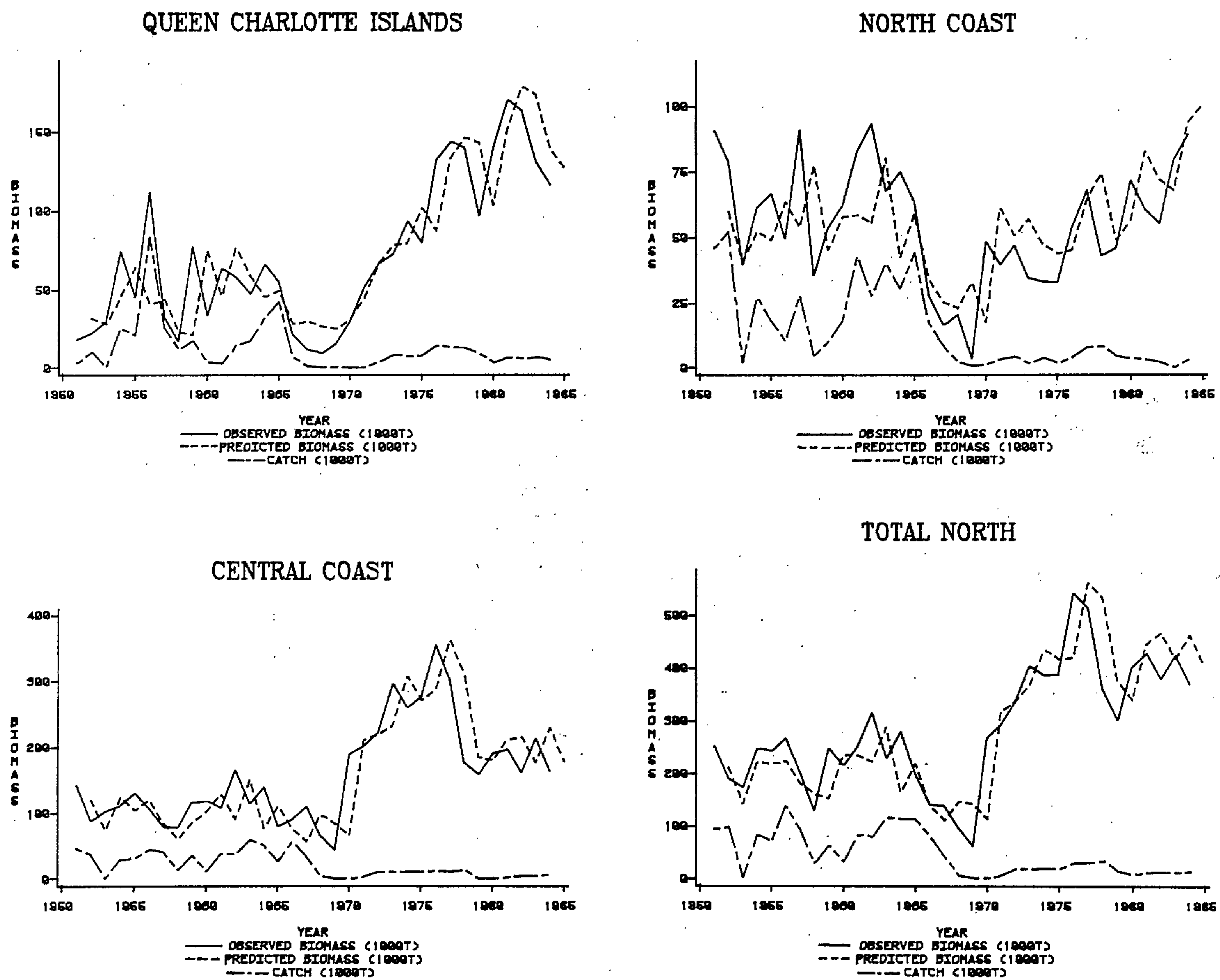
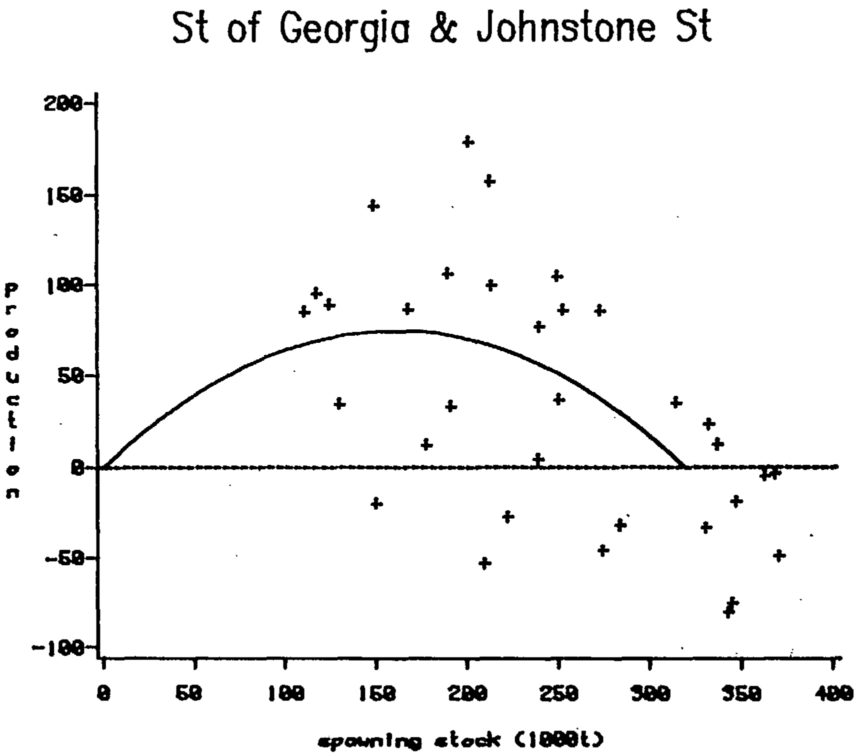


Fig. 4.1. Pre-fishery biomass for northern herring for 1951-1984, using the surplus production model.



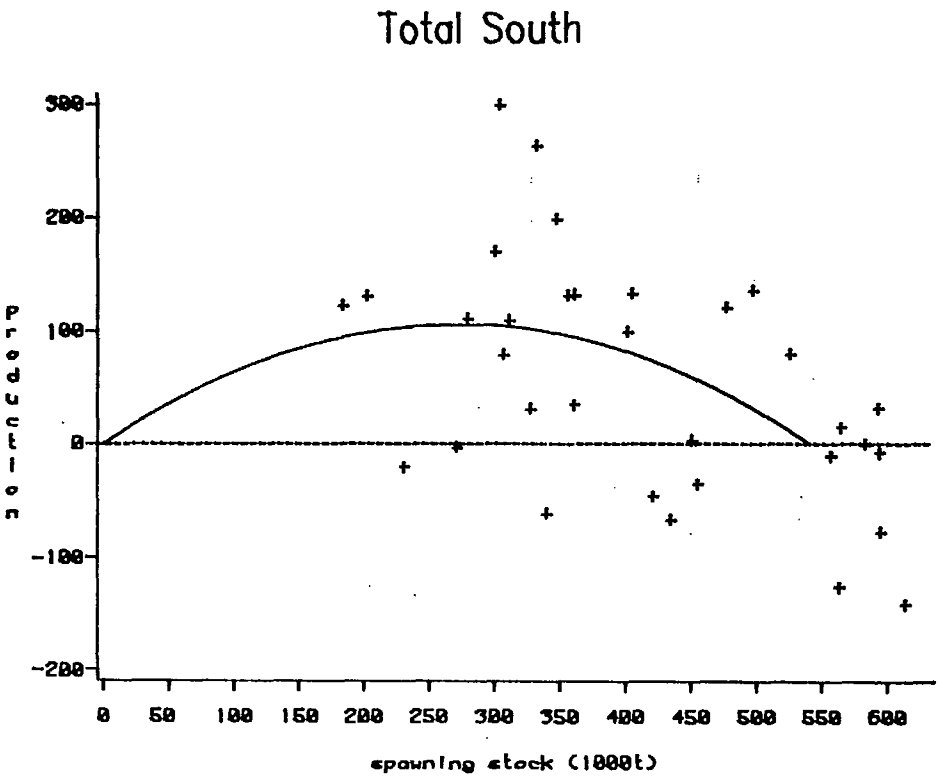


Fig. 4.2. Southern herring production estimates for 1951-1984 using the surplus production model.

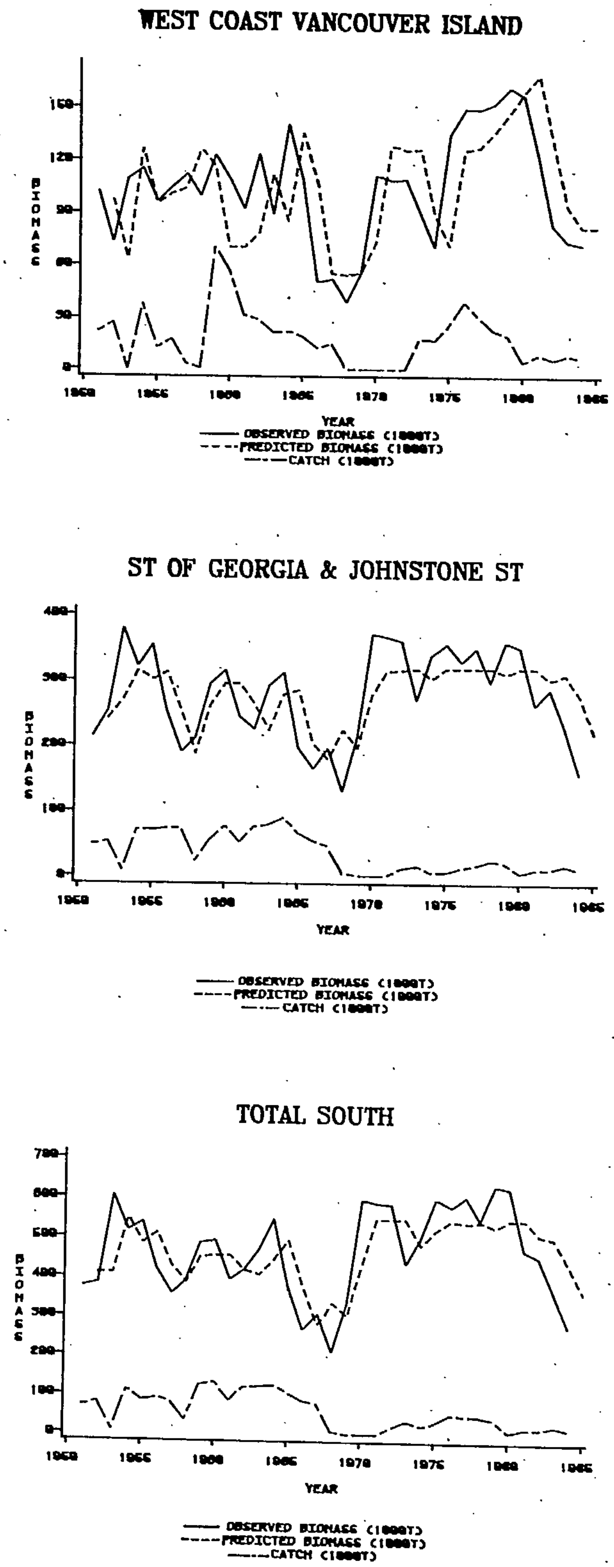


Fig. 4.3. Pre-fishery biomass for southern herring for 1951-1984 using the surplus production model.

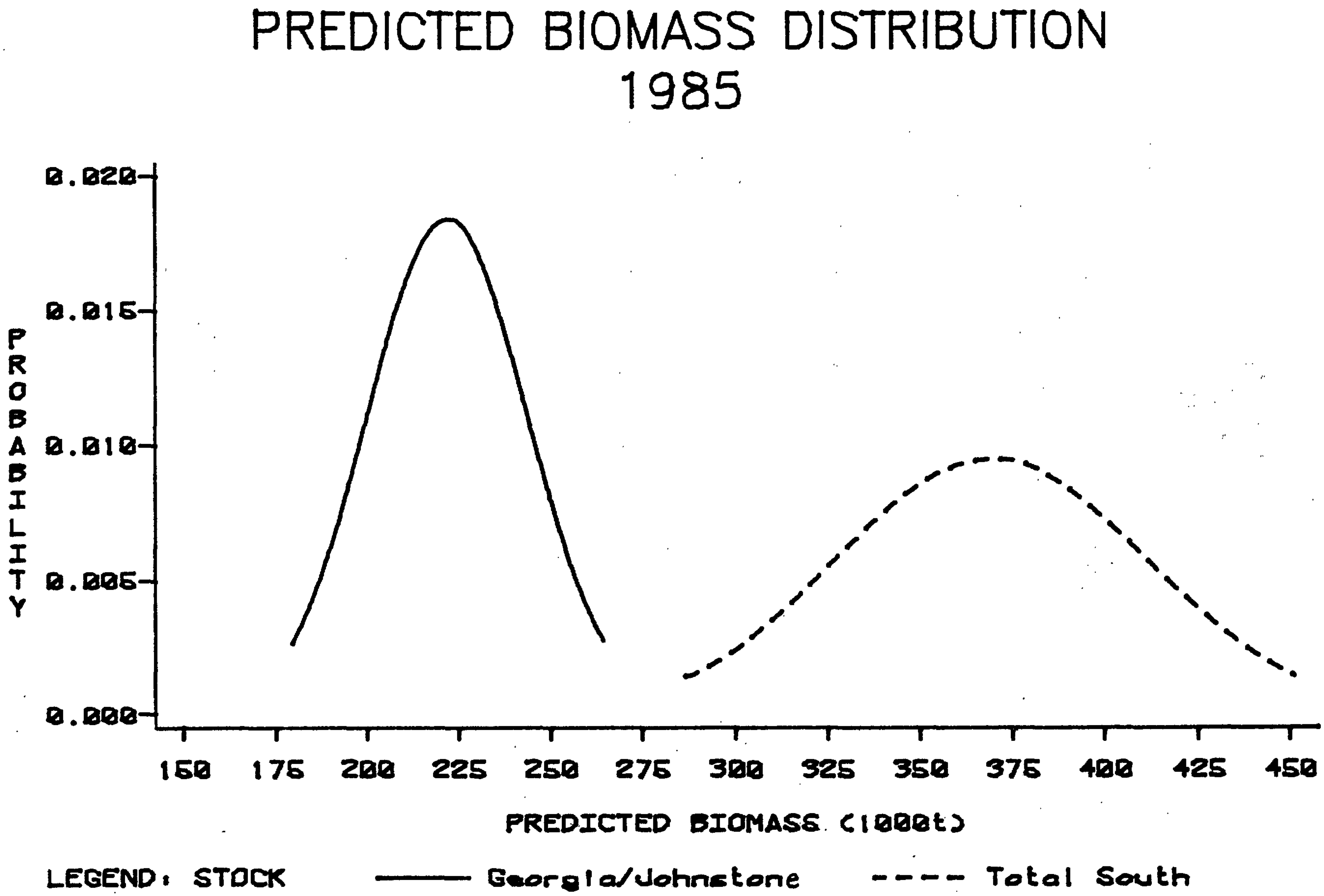


Fig. 4.4. Probability distribution of predicted biomass for south coast herring in 1985 using the surplus production model.

5. CATCH RECOMMENDATIONS

We recommend catch levels at 20% of the "best" forecasts for 1985 pre-fishery stock biomasses. The 20% harvest rate is based on preliminary analysis of stock dynamics which indicate this level will stabilize both catch and spawning biomass while foregoing minimal yield over the long term. While a fixed escapement policy would provide the theoretically optimal solution, that is, highest yields and stock stability, this policy is not attainable at the operational level.

To determine the "best" stock forecasts we used a two step procedure. First, for each of the three methods, and for each stock grouping, one production/recruitment scenario (ie. poor, average, or good) was chosen, as discussed in the previous sections. Secondly, we assigned subjective probabilities to the three alternate assessment methods. Based on intuition and past experience we believe that the revised age-structured model makes the most likely predictions of forecast runs. The newly developed escapement method makes a direct interpretation of spawn survey data, and has good predictive ability regarding returning spawners. However, the other component of prediction, stock productivity, is probably not well determined. We consider surplus production model predictions to be least likely, due to large uncertainties in parameter estimates. We thus assigned subjective probabilities as follows:

Age-structured model	p(AS) = .60
Escapement method	p(ESC)= .35
Surplus production model	p(SP) = .05

The assigned probabilities were used to weight the forecast runs obtained from each method to provide a single "weighted run" for each of the stock groupings (Table 5.1). For the coast as a whole the weighted run is 171,000 t for a possible catch level of 34,100 t.

The forecasts presented in this summary reflect the current unfavourable environmental conditions (i.e. warmer than average water temperatures), but the recommended quotas are based on purely biological considerations. We should point out that management of the various fisheries has practical constraints other than the biological considerations discussed in this report. Thus actual quotas recommended by DFO may differ from those determined herein. Furthermore, the catch levels recommended herein include all fisheries. Catches from food, bait, and special fisheries must be subtracted from recommended catch levels to establish roe herring quotas.

Table 5.1. Summary of 1985 "best" predicted and weighted herring runs (1000 t). (The "best" predicted runs reflect the current unfavourable environmental conditions).

District	Method			Weighted	20%
	Esc.	AS	SP	run	of run
Weighting factors	0.35	0.60	0.05		
Queen Charlotte Islands[a]	32	31	94	35	6.9
North Coast	26	33	75	33	6.6
Central Coast	41	30	132	39	7.8
Strait of Georgia and Johnstone Strait	40	27	179	39	7.8
West Coast Vancouver Island	25	21	64	25	5.0
Total Coast	164	142	544	171	34.1

[a]East coast of Charlottes and Louscoone.

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