PSARC H93:02

APPROVED

HERRING SPAWN INDEX ANALYSIS

by

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October 1993

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Not citable

Introduction

The review of the herring stock assessment document by the PSARC Herring Subcommittee at the 1992 meeting identified an inconsistency in the abundance indices used by the two current assessment methodologies, i.e. the escapment and age-structured models. While the escapement model attempts to provide an absolute estimate of total egg deposition for each assessment region, this estimate was not being used in the age-structured model. Instead, the age-structured model used a relative index which is the sum of the total lengths of spawn adjusted by area specific but time independent estimates of average width and average intensity. The review also identified the need to re-evaluate the conversion equations used in the escapement model to calibrate surface survey observations of width and egg layers to diver widths and egg densities and suggested that this should include a consideration of the uncertainty associated with the escapement model estimate of total egg deposition.

In order to deal with both of these concerns it seemed appropriate to develop a single estimate or index of egg deposition that combined all spawn data sources and presented the best estimate of total escapement. This index could then be used as auxiliary data in the age-structured model to estimate numbers at age and associated parameters. In the process of developing such a modified escapement model, an alternative index of egg deposition per unit length of beach or tonnage per kilometer was developed as one approach to estimating spawning stock biomass for small stocks outside the major assessment regions. The objectives of this document are therefore to describe and discuss several alternative spawn indices, their strengths and weaknesses, and aspects of the estimation of error structure for these data, with a recommendation of the preferred spawn index which may require additional refinements.

Herring spawn data - types of records.

Herring spawn data has been collected systematically in some areas of coastal B.C. since 1929. Fishery Officers, working mainly in Georgia Strait and the west coast of Vancouver Island, initially noted the times and places of major herring spawning. They did not make recordings of the widths of submerged spawning. In fact, they believed that most spawn was intertidal. In 1931, Al Tester at PBS, started a cooperative coast wide herring spawn recording system with data collected by Fishery Officers throughout the B.C. coast. These data included (1) estimated spawn length; (2) estimated width; (3) estimated spawn intensity, on a scale of 1-5, with 1 = light and 5 = heavy; and (4) date of spawning. However, the collections were not complete for many sections of the coast, particularly the Queen Charlotte Islands. In 1951, some systematic changes to the data collections were made, including the estimates of spawn intensity, which changed from 1-5 to a scale of 1-9. The rationale for this change appeared to be to accommodate the practice of reporting intermediate categories (such as 3.5 for an intensity between 3 (medium) and 4 (heavy). In 1981 the intensity classification was abandoned altogether and replaced with an estimate of "egg layers". Throughout the history of the herring spawn data collections, there have been systematic changes in some of the ways the data have been collected.

In the mid-1970's, the importance of the sub-merged component of spawns was recognized. Some spawns were surveyed by divers to get better information, Concurrently, systematic research aimed at getting accurate estimates of egg density started with collections of all eggs from selected sites and numbers of eggs per m^2 were determined from them. Further, it was recognized that many other factors were of potential importance, including the slope of the bottom, and type of vegetation used as a substrate (Haegele et al. 1979). More recently there has also been the recognition of the role of the giant kelp as a spawning substrate in the northern areas and the need to develop assessment procedures to account for spawn deposition on this algae (Haegele and Schweigert 1990).

Uses of herring spawn data in stock assessments.

Until the late 1970's, the roe herring fishery was managed by a fixed escapement policy, <u>within</u> season. The total annual catch was not determined until there was an estimate of the amount of spawn required to 'sustain' the stocks. Regardless of the efficacy of the process, there was little time available to do detailed spawn survey. At best, a 'surface' survey estimation of length and width was all that could be done within a short time.

With the initiation of the annual quota system in 1983, the importance of herring spawn data increased. The herring spawn data provided an estimate of the biomass of the spawning escapement in the previous year. This was the single most important statistic used for setting quotas. Age data was used to monitor the coming and going of strong year classes.

Since the mid-1980's the power of age-structured models has become more appreciated. The B.C. herring data was well suited for these analyses and they have taken a progressively stronger role in the annual assessments. One recommendation has been that the two disparate spawn indices used in the two prevailing assessment models (the escapement model and the age-structured model) be reconciled, so that only one spawn index be used to estimate stock abundance.

A limitation of the escapement model described by Schweigert and Stocker (1988) is that it does not recognize or deal with the time trends inherent in the spawn data. It is recognized that the early spawn data, in the 1950's and 1960's are misleading. Mainly, the estimated spawn widths are too narrow. Also, Hay and Kronlund (1987) noted systematic changes in estimated widths and intensities. These changes had more to do with changes in the methodology used to do the surveys than real changes in the spawn deposition. To deal with time trends in the data, Hay and Kronlund calculated area-specific coefficients of herring spawn. These were area-specific constant estimates of spawn width and intensity that were simply the mean estimates of the width and intensity, averaged over geographical areas called sections, or sub-divisions of the coastal statistical areas.

There are several limitations to doing this. The most severe is that there are a variety of different spawning sites within a section. It is an obvious error to take a simple average of width estimates from such different sites. The reason for this process, however, is that there are only <u>four</u> existing levels of geographical divisions: (1) the entire B.C. coast (2) B.C. Statistical areas, about 30 on the coast, (3) the herring 'sections', about 90 on the coast (4) geographical locations names used for the herring spawn records, about 1900 used.

The use of location names would, theoretically provide the best geographical basis for the index, but there are many reasons why this is not advisable. The use of names changed with time. Sometimes the same location will have several different names. Often, the names are not used with the same precision. For instance, sometimes Fishery Officers recorded a spawn simply as 'Lambert Channel' or 'Barkley Sound' but they provided detailed charts showing the exact spawning position. Other records provide an exact location name, such as Stopper Island in Barkley Sound, or Komas Bluff in Lambert Channel, but the record may, or may not have an accompanying map. Therefore, within the present data base, the use of precise location names can be misleading and we have developed a pooling system described below which encompasses equivalent geographical regions as much as possible.

Review of Previous Spawn Indices

Estimates of spawn escapement have been published annually: from 1937 until 1957 in series published by the provincial British Columbia Fisheries Department (i.e. Taylor et al. 1957) and from 1955 to the present in various informal series published by the Federal Department of Fisheries. Tester (1948) was the first to comment on a series of years of spawning data (1931-1946) for the west coast of Vancouver Island. He proposed two indices of spawn deposition: (1) the cumulative length of spawn: and (2) the cumulative length adjusted for variation in spawn intensity. His main conclusion was that spawning escapement varied substantially among years and that the magnitude of escapement had little relationship with subsequent year-class success.

Stevenson and Outram (1953) developed a relationship between the length of spawn and the number of fish that spawn in a statute mile. They adjusted the total spawn length linearly for differences in intensity relative to medium intensity. The adjustment involved an increase or decrease in the observed length as a function of intensity; the result was an estimated spawn length in statute miles, adjusted to 'medium' intensity. Taylor(1964) extended the analysis using 26 years of spawning data (1937-1962) for 7 different subdivisions of the British Columbia coast. He used the same measure of spawn (statute miles adjusted for intensity). Hourston et al. (1972) re-analyzed the spawn data and incorporated data on spawn widths: for each spawn record an estimate of total spawn area was made and the area was weighted according to the spawn intensity. Further, the British Columbia coast was divided into 110 different sections that were based mainly on the centers of spawning (Hourston and Hamer 1979). These 'spawning sections' were described as geographical sub-divisions of the well established 'statistical areas'. This approach was developed and applied in the early 1970s and was the most comprehensive and biologically realistic of any developed. Spawn data since 1951 were used and the data were grouped according to meaningful geographical divisions called sections. Estimates of spawn deposition were then incorporated into a model which also considered age and size data, and size-specific fecundity data to estimate the biomass of spawning escapement and forecast future runs (Hourston 1981; Hourston and Schweigert 1981). This approach has been modified and extended by Schweigert and Stocker (1988), who developed a method of adjusting width and intensity estimates according to empirical observations and comparisons of Fishery Officer and SCUBA diver surveys. The intent of their work is an estimate of the absolute tonnage of the herring spawning biomass.

New Spawn Indices

Modified Escapement Model

A potential weakness of the existing escapement model methodology is its reliance on a limited sample size of replicate surveyed spawn beds to develop calibration equations that adjust surface spawn width and egg layer data observations to comparable dive survey width and egg density data. The development of any modifications to this model must include a means to integrate the historical surface survey data and recent dive survey estimates of eggs on various algal substrates, estimates of eggs on physical substrates, and eggs on the giant kelp. The measurement procedures for the dive survey data have remained unchanged since they were initiated in 1987. The methodologies for dealing with the dive data have been described extensively (Schweigert et al. 1985, 1990, Haegele and Schweigert 1985, 1990). Instead, we focussed on possible adjustments to the surface spawn width estimates and the spawning intensity or more recently (since 1978) the number of egg layers.

The calibration of spawn widths has been dealt with by developing a superset of existing spawning locations which we have called spawn "pools". The database used to develop the pools consists of herring spawn deposition records collected for the British Columbia coast since 1929. The records prior to 1951 were generally too incomplete for the purposes of this analysis and so were not included. At present, all records in the database are associated with three geographic entities: a statistical area, a herring section, and a location name, the latter two as defined in Haist and Rosenfeld (1988). The herring sections subdivide the thirty-two statistical areas into three to eight subunits. The location name at this point cannot be used to reliably associate a record with a precise geographic location, with the exception of dive survey data collected in the Queen Charlotte Islands, Big Bay / Port Simpson, Kitkatla, and Barkley Sound. Location names otherwise may overlap, some may be a subset of others, and the naming of a particular piece of coastline will vary from year to year depending on the personnel doing the survey. This can lead to morphologically and biologically dissimilar beds being associated or dissociated with a specific location from year to year.

In attempting to improve the resolution of the available spawn indices, it was decided to add a layer of resolution below that of the herring section, associating locations with similar characteristics. The procedure followed to derive these pools consisted of examining the dive records within a section to identify groups of location names contiguous with each other (Hay et al. 1989) and related to coastline segments having uniform topography and vegetation. Ancillary information such as the usual ends of spawn and the usual depth of spawn was also considered during this classification. After the dive survey records had been examined and classified, the location names used in surface survey records were associated with the pools derived for the dive data. This resulted in each herring section within the major assessment areas being subdivided into between one and thirteen subunits.

Analysis of Width Data

The surface and dive survey data sets differ somewhat in their data structure. A single surface survey record represents an average or overall impression of a segment of spawn of arbitrary length. It may represent a complete spawn which is relatively consistant for width, vegetation substrates, and spawn density, or it may represent a part of a spawn which has been subdivided because of changes in these characteristics or the fact that the surveyor worked methodically along the beach, producing one record every few hundred meters.

The dive survey, on the other hand, uses a two stage subsampling methodology (Schweigert et al. 1985) which produces one record for each station along a transect, and several transect records are associated with a location record. At this final level the two types of surveys are equivalent, in that they define the length and width of a segment of spawning beach. In order to equate them, the station records on each transect were rolled up to produce a single record for each transect with a weighted mean of egg layers and vegetation cover. A transect record was then considered to provide estimates of width and layers equivalent to that for a surface survey record. The dive survey subsampling procedure occasionally includes "zero length" transect records, i.e. transects which fall where no spawn occurs. Because the procedure followed when collecting surface survey data normally excludes such bare patches from the survey these transects were also eliminated from the data set.

For each pool within each section for which dive survey data exists, mean and median spawn widths, layers, and vegetation cover were calculated. Because the spawn width data were not normally distributed the median width for each pool was used in determining the width adjustment for the pool. Surface spawn records for which no pool data existed were adjusted by applying the section data or if necessary the assessment region estimate (Appendix Tables 1 and 2). All surface survey records throughout the historical time series were assigned an adjusted width based on these summaries of dive survey information.

Analysis of Egg Density Data

The calibration of the estimates of historical surface survey data requires two steps. The first is to derive an estimate of egg layers from intensity estimates and then to convert egg layers to eggs per square meter. Prior to 1978 spawn deposition was assessed qualitatively based on an intensity scale of either 1-5 or 1-9. Based on research data these estimates can be converted to layers of eggs (Schweigert and Stocker 1988). However, these authors also indicate that for dual surveyed spawns estimates of egg layers for surface surveys tend to exceed layer estimates from dive surveys. To assess this relationhip for a larger data set, we examined the estimated mean of the median egg layer estimates from dive and surface surveys for each pool over all years from 1978 to present (Figure 1). The intent of this analysis was to determine whether it was reasonable to assume that the dive survey estimation procedure for layers was significantly different from that by the surface survey. Although the majority of the dive estimates fall below the 1:1 correspondence line as found by Schweigert and Stocker (1988), the slope of the regression line is not significantly different from zero ($P=0.44$). Therefore, because there is no evidence that the surface layer data need be adjusted to render them comparable to dive survey estimates, we fit the following model to the data in Figure 2:

$$Eggs/m^2 = 14.698 + 212.218\ Layers$$

based on 5111 observations of eggs per square meter from collections of sample quadrats coastwide from 1976-1987 (P=0.0). This relationship was used to estimate egg density for all historical surface survey data from the observed egg layers. The combination of total length and adjusted width to estimate area of spawn deposition and egg density provides an estimate of total egg deposition or spawning escapement. Estimates of total egg abundance from surface surveys are summed with dive survey estimates for each assessment region to estimate total egg deposition for use in the age-structured model analysis.

Biomass Index per Lineal Kilometer

The second index presented here uses an area-specific estimate of spawn width based on surface surveys. We recognize that this is less accurate than the diver-based estimates. However, our intent was to examine methodologies which could be appropriate for dealing with management of smaller stocks where there have been no dive surveys of spawning areas. The comparable estimates for the assessment regions provide a calibration factor relative to the estimates from existing assessment models which would be applicable to these smaller stocks. For most of these smaller stocks, there are only estimates of surface width. Therefore, an index for these stocks should be comparable to an index for the other, harvested stocks. We used the existing surface width data with a recommendation that when diver estimates become available, they should be substituted for the surface estimates. We used estimates of egg density taken from empirical counts of eggs from measured quadrats. During the last 15 years, nearly 6000 of these counts have been obtained from various areas along the B.C. coast (Table 3).

We combined the estimates of surface width and egg density to provide a single coefficient. In fact, the product of these two variables is an estimate of eggs per linear m of shore. This estimate, when divided by 10^5 is an estimate of kg/m or tonnes/km of shore. We derived estimates of the variance of this coefficient from the estimates of variance for the width and density which are assumed independent, following Bevington (1969) where:

$$\frac{\sigma_{\varepsilon}^2}{\varepsilon^2} = \frac{\sigma_w^2}{w^2} \bullet \frac{\sigma_d^2}{d^2}$$

The mean and SE of the new parameter, ε (eggs/m), when multiplied by length of spawn, provides an index of escapement, in terms of total number of eggs (Bindex). The intent of this estimate, however, is <u>not</u> as a new escapement estimate. We recognize that there are several reasons why this estimate of eggs should under-estimate escapement. It does not adequately account for eggs on bottom substrate below the vegetation and it does not account for any spawn deposition on the giant kelp.

Error Structure For Herring Spawn Indices

Age-Structured Model

The spawn index enters the age-structured model as auxiliary information which relates the observed spawn index data relative to predicted egg escapement based on the population structure and weight specific fecundity estimated from catch at age information. The strength of this relationship and the relative weighting of the spawn index and catch at age data in the estimation procedure is reliant on the size of the penalty weight associated with the spawn index data and is a measure of the expected variance associated with this data set. The current penalty weight for the spawn index data is 10 which translates to an average error of 18 percent. The output from this model is relatively insensitive to changes in the weighting so that moderately improved estimates of this variance are unlikely to significantly alter model estimates of stock abundance but the ability to more accurately fix this parameter would assist in more clearly understanding other aspects of model behaviour.

Escapement Model

As outlined above, any spawn index must encompass the diverse data sets which detail herring spawning locations and intensities. To do this in a comprehensive manner requires a common currency which we argue is an estimate or index of the total egg deposition. An assessment of the error structure associated with these data requires an assessment of the variance components associated with each type of data as described below. The simplest component of the total egg deposition estimate is associated with the surface survey data. We assume the surface survey estimate of the total spawn length is negligible and so is assumed to have zero variance. Because much of the spawn is subtidal, the surface survey width estimate will be an under-estimate, therefore, the width is adjusted by a relationship of the form:

$$Wadj_j = \mu + \delta FOWID$$

where FOWID is the surface survey width. The surface survey also estimates the average number of egg layers on various algal substrates in each spawning bed. This estimate is translated into the estimated egg density by a model of the form:

$$\hat{y}_j = \xi + \omega FOLAY$$

where FOLAY is the surface estimate of the number of layers of eggs. The total egg deposition is then estimated as the product of area and egg density, $\hat{y}_i$, by:

$$Total\ Eggs_j = L_j(Wadj_j)\hat{y}_j$$

The variance components associated with the dive survey estimates are more complex. The estimate of total egg numbers on understory algal substrates involves taking numerous samples along each of several transects which span the width of the spawn. The formula for the estimate of eggs per spawn in this case is:

$$Total\ Eggs_i = L_i\left(\frac{\sum W_k}{m}\right)\left(\frac{\sum \hat{y}_k}{n}\right)$$

where m is the total number of transects, n is total number of sample areas in the spawn, W_k is the width of spawn along each transect, and y_k is the egg density estimate for each sampling quadrat as estimated from the usual egg prediction model (Schweigert et al. 1993):

$$\hat{y}_i = \alpha\ Cover^{\beta} Layers^{\gamma} Qsize_i$$

Similar estimators can be derived to describe the estimation procedure for eggs on bottom substrates and for the giant kelp, *Macrocystis* sp. The estimate of the total population of eggs in each assessment region is simply the sum of the estimated population of eggs estimated in each of the spawning beds by each of the survey techniques. The estimate of the total population of eggs in a region with a combination of surface and dive survey data would then be given by:

$$\sum \left[L_i\left(\frac{\sum W_i}{m}\right)\left(\frac{\sum \hat{y}_i}{n}\right)\right] + \sum \left[L_j(Wadj_j)\hat{y}_j\right]$$

Because each of the component relationships have an associated imprecision or variance, it is possible to sum the variances for the individual component techniques in each egg bed following Goodman (1960) since if

$$E_S \sim N(\mu,\sigma^2) \wedge E_D \sim N(\tau,\xi^2)$$

where E_S is the surface survey egg estimate in a bed and E_D is the dive survey egg estimate in the same egg bed, then

$$Var\ (E_S + E_D) = \sigma^2 + \xi^2$$

To estimate the variance associated with each survey technique in a particular spawn bed we require an estimate of the variance for a product of area, A, and egg density and following Goodman (1960) derive the following estimator:

$$v(A\hat{y}) = (\bar{A})^2 var(\hat{y}) + (\bar{y})^2 var(A) - var(A)var(\hat{y})$$

For surface spawn estimates each bed has only a single width and layer estimate making it difficult to establish the magnitude of variability for these data. It is possible, as we have done above, to approximate the variance of both width and egg density estimates from dive survey data. For the dive survey estimates of spawn, the average width and average egg density could be computed directly from the sample values taken from that specific spawn by the usual formulae. In both cases, we assume that the estimated spawn length is determined with negligible error and so can be factored out as a constant. Therefore, the equation to calculate the variance of the estimate of total egg deposition for spawn *j* is given by:

$$var(\hat{Y}) = L_j^2[(\bar{w})^2 var(y) + (\bar{y})^2 var(w) - var(y)var(w)]$$

and the estimated variance for the total population of eggs is given by

$$var(\hat{E}_T) = \sum var(\hat{E}_S) + \sum var(\hat{E}_D)$$

Propagation of Errors

It is also possible to estimate the variance of each spawn by partial derivatives, but this results in Goodman's estimate without the final cross-product term. Its formula is

$$\sigma_{E_S}^2 \approx \sigma_A^2(\frac{\partial E_S}{\partial A})^2 + \sigma_{\hat{y}}^2(\frac{\partial E_S}{\partial \hat{y}})^2$$

and it gives an estimated variance of

$$var(E_S) = L_j^2[(\bar{y}_i)^2\sigma_w^2 + (\bar{w}_i)^2\sigma_y^2]$$

for surface surveys and a similar estimate for dive surveys, with the variances for the dive surveys coming from the sample, and the variances for the surface surveys coming from historical means or comparable dive survey data.

One can break the surface survey down further and take partial derivatives with respect to the calibration equations for egg layers and width adjustment for which the formula for the estimated variance changes somewhat as:

$$\frac{\partial E_S}{\partial FOWID} = L_j\delta(\xi + \omega FOLAY)$$

and

$$\frac{\partial \hat{y}}{\partial FOLAY} = L_j\omega(\mu + \delta FOWID_j)$$

The equation of variance for the surface survey now becomes

$$var(E_S) = L_j^2[\delta^2(\xi + \omega FOLAY)^2\sigma_{FOWID}^2 + \omega^2(\mu + \delta FOWID_j)^2\sigma_{FOLAY}^2]$$

where the variances for FOWID and FOLAY would have to be assumed from simultaneous research surveys.

It should be apparent from the foregoing that although it is possible to derive analytical solutions that theoretically permit estimation of the variance associated with the estimate of total egg deposition they are not particularly tractable and because they assume normality of the various variables encompassed by them are probably not very realistic. Our conclusion is that the best approach to the estimation of variance associated with the total egg deposition estimate or escapement model biomass estimate is through a bootstrapping of all components of the estimation process, of which some component have previously been described for the dive survey data (Schweigert, 1993).

Results and Discussion

The calculated estimates for the various spawn indices described above as well as those used in previous assessments are presented in Tables 1 to 5. They include estimates of total length of spawn, total area of spawn, tonnes per kilometer of beach or Bindex and a range of stock sizes based on plus or minus one standard error of the mean Bindex, total tonnes of escapement from the modified escapement model described here, total length of spawn, estimates of total area using the new and old methods of adjusting spawn widths, total tonnes from the old escapement model, and the Hay index previously used in the age-structured model. The total spawn length used to develop the Bindex is also shown to be less than for the escapement model estimates. This represents the accidental deletion of a few records from the files generated to conduct those analyses. The discrepancy only occurs in a few years since 1985 and does not affect the overall conclusions. The correlations among the various indices are presented in Table 6. It is evident that the correlations among all the potential candidate indices are very high and there is no clear superiority of one index relative to the others. A previous analysis of similar index data and the age-structured model estimates of abundance was similarly inconclusive. We feel that the most appropriate spawn index is that which attempts to deal with interannual variation in components of egg deposition such as spawn width and egg density. Because the modified escapement modelling approach described here attempts to account as much as possible year to year changes in these components of the egg deposition it appears to be the most appropriate index at this time. In addition, the adjustments to width for many areas of the coast are based on limited data and these may be enhanced as additional diver estimates become available. The secondary index based on constant width and egg density (Bindex) provides estimates of abundance that are substantially lower than the new escapement model estimates but these may also be improved with additional dive survey data. The latter appears to provide an acceptable although very conservative approach to the estimation of spawning biomass for areas outside the major assessment regions.

An important unanswered question is whether the assumption of a time constant spawning bed width is reasonable and if so what potential biological mechanisms are involved. In any given location is would sometimes be physically impossible for one very large school of herring to deposit all of its eggs at one geographical focus. The potential spawn width and intensity are limited by the topography and surface area or foliage of the submergent and inter-tidal vegetation: steep-sided locations with narrow bands of sparse vegetation tend to have narrow, low intensity spawn deposition. In contrast, wide locations with dense vegetation have the potential for wide, high-intensity spawn deposition. However, there is clearly some interannual variation in the amount of the available substrate which is used. It is not readily evident whether this degree of variability in width significantly affects the estimate of total stock abundance. We believe that this assumption can be assessed by incorporating the varibility within a bootstrap estimate at the level of the pools described here as a component of the total variance estimate associated with the estimated spawning escapement level in each assessment region.

The impacts of the new spawn indices on stock abundance estimates for the five assessment regions is presented in Figure 3 for the escapement model. The changes to the calibration methodologies resulted in relatively minor impacts to the estimated stock abundances in all five regions. Similarly, the use of the modified escapement model total egg estimate as the abundance index in the age-structured model spawning biomass estimates is presented in Figure 4. Again, there are relatively minor differences in estimates of spawning biomass based on the new egg index and on the Hay index used in previous assessments for all stocks but the Prince Rupert District where spawning biomass is now lower than previously estimated. Finally, the effects of assuming a much larger variance in the spawn index data is presented in Figure 5. Current stock assessments based on the age-structured model assume a penalty weight of 10 which is equivalent to a standard deviation of 0.22 in the spawn index data. Alternately, a penalty weight of 1 which is equivalent to a standard deviation of 0.71 in the spawn index data does not result in appreciably different estimates of total spawning biomass in 3 assessment regions. However, it does result in estimates of spawning biomass which are much higher than those assuming a lower variance in the spawn data for the Prince Rupert District and in much lower estimates of biomass for the Strait of Georgia. In both instances, these biomass estimates are inconsistant with other information on stock abundance suggesting that the assumption of a lower variance for the spawn index data is more appropriate.

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Table 1. Spawn indicies for the Queen Charlotte Islands.

Year	No Rec	Hay Length	Area HA	Bindx mean	Bindx -SE	Bindx +SE	New Es t	ES Length	New Area	Old Area	Old Es t	Old Hay I
51	12	9736	26.2	633	408	858	2234	9736	32	97	4191	172
52	5	7998	17.0	911	733	1090	2163	7998	39	72	3051	122
53	8	15569	36.3	946	688	1203	4183	15569	69	150	5702	254
54	9	33643	75.5	3166	2319	4012	9605	33643	155	293	11514	451
55	10	18188	38.6	2198	1793	2603	6108	18188	95	146	5840	277
56	10	20966	53.6	1235	820	1650	3839	20966	100	167	5592	372
57	2	4708	9.6	570	476	664	1578	4708	27	39	1495	71
58	3	2559	5.7	265	210	320	787	2559	14	21	783	41
59	7	24770	63.2	1955	1498	2411	6706	24770	119	208	8085	367
60	6	14716	33.5	1575	1266	1885	6416	14716	68	141	7017	202
61	7	28869	66.1	3217	2603	3832	6692	28869	135	235	8612	423
62	8	15354	38.4	1346	1045	1646	4611	15354	85	147	5338	241
63	8	12110	32.9	773	569	977	6167	12110	92	110	4465	213
64	9	12979	27.3	1475	1195	1754	4215	12979	65	119	4830	181
65	6	6215	11.9	650	542	758	1446	6215	27	51	1889	76
66	12	9742	21.2	1204	928	1479	2754	9742	51	95	3525	145
67	7	2104	4.0	214	176	251	873	2104	12	21	942	33
68	11	2788	7.5	392	261	524	748	2788	14	23	817	42
69	2	3839	8.3	447	370	524	1870	3839	21	37	1799	59
70	27	12073	37.9	1143	737	1550	4453	12073	66	196	8211	237
71	5	26460	71.4	2763	2013	3512	13678	26460	154	265	12599	479
72	25	26336	73.0	2363	1591	3136	9951	26336	131	248	10845	467
73	46	34247	66.5	2719	2043	3395	10913	34247	170	301	11772	561
74	29	42265	98.8	3096	2256	3936	9717	42265	201	356	13139	714
75	24	32423	72.4	2395	1708	3083	11408	32423	181	283	11525	571
76	63	58689	128.7	5444	4160	6729	16330	58689	301	492	18615	912
77	43	62380	149.6	5805	4219	7391	15488	62380	323	516	18206	1056
78	62	49725	129.9	4724	3328	6120	12275	49725	268	436	14994	872
79	93	37593	92.9	2948	1958	3939	10575	37593	176	317	12150	652
80	159	68917	176.1	7478	5456	9500	19884	68917	321	627	25853	1059
81	231	74803	181.5	6921	5161	8681	19679	74803	387	752	26983	1158
82	100	61977	167.0	5662	4045	7280	18812	61977	347	596	22013	992
83	121	56559	156.3	7527	5724	9329	19889	56559	361	538	19944	805
84	114	54500	141.2	5550	4074	7027	21703	54500	303	523	22150	837
85	62	48725	127.5	5167	3806	6527	14662	48725	258	463	17721	773
86	43	20136	52.4	2240	1642	2838	5596	20136	114	182	6719	319
87	89	44695	111.6	4065	2941	5189	13418	44695	300	367	15277	715
88	45	46402	124.2	6067	3620	6793	14489	48505	347	424	16771	608
89	89	84130	207.3	10086	7333	12839	24242	85840	659	746	25821	1219
90	19	65620	182.3	8555	6138	10972	25958	65620	465	470	25364	926
91	16	52730	137.3	6603	4849	8357	14220	55510	293	300	14644	716
92	14	45840	151.9	6684	4793	8574	9500	45840	298	298	9500	658
93	20	46551	121.1	3850	2599	5003	5775	50551	177	204	6646	723

Table 2. Spawn indicies for the Prince Rupert District

Year	No Rec	Hay Length	Area HA	Bindx mean	Bindx -SE	Bindx +SE	New Es t	Sum Length	New Area	Old Area	Old Es t	Old Hay I
51	20	33170	171.4	4379	3136	5624	31184	33170	303	552	27967	1058
52	20	19311	114.7	3092	2257	3927	19225	19311	191	200	9957	641
53	32	27755	151.3	4070	3100	5040	26926	27755	277	278	14016	961
54	29	25298	118.3	2504	1787	3221	13979	25298	200	232	9951	835
55	27	36243	134.9	2810	2048	3573	21773	36243	310	308	12738	869
56	31	28871	144.0	3374	2551	4198	15388	28871	218	291	12506	951
57	30	46631	201.2	5098	3566	6629	28377	46631	352	425	19301	1279
58	13	22697	62.6	1403	851	1954	11581	22697	185	211	8514	507
59	10	32064	228.8	6497	5043	7950	37909	32064	413	349	16197	1285
60	20	32649	155.6	3546	2557	4535	20187	32649	309	320	13146	1087
61	28	29878	148.8	3723	2647	4788	13428	29878	249	387	14482	990
62	33	48574	241.1	6130	4461	7800	26556	48574	414	496	20094	1530
63	21	20200	137.5	3617	2764	4469	15404	20200	250	384	15151	783
64	35	33028	201.9	5347	4085	6609	29402	33028	395	389	16316	1185
65	21	14180	76.6	1633	1180	2086	6170	14180	126	177	6278	501
66	6	7769	63.4	1912	1445	2378	7499	7769	137	149	5769	332
67	13	6168	38.2	967	707	1227	2677	6168	54	90	3057	222
68	33	13594	78.1	2053	1451	2655	5369	13594	125	207	6508	433
69	9	2194	12.6	296	221	371	878	2194	17	23	900	74
70	27	34541	126.8	2806	1878	3735	8958	34541	196	355	11904	886
71	32	26590	113.8	2657	1802	3512	9696	26590	209	267	9685	716
72	31	31300	158.5	4277	3038	5533	9959	31300	273	308	10896	1000
73	42	24111	118.8	2879	1993	3766	11190	24111	201	291	11112	730
74	48	21489	106.9	2679	1913	3445	8814	21489	179	259	8843	670
75	41	22813	118.8	2911	2085	3736	10188	22813	197	294	10572	814
76	106	36760	180.0	4183	2875	5501	14593	36760	267	419	15834	1158
77	121	44188	218.5	5090	3520	6667	10235	44188	310	505	15617	1438
78	80	25395	107.1	2149	1379	2920	4971	25395	167	261	7577	750
79	58	30940	111.6	2523	1690	3356	7926	30940	169	381	13730	814
80	104	50260	218.7	4636	3358	5913	13993	50260	347	529	17155	1529
81	61	42227	167.9	3528	2252	4804	10669	42227	222	483	17131	1175
82	79	39135	170.4	4453	3157	5749	12472	39135	290	427	14917	1305
83	115	58621	300.5	7039	4939	9139	19993	58621	505	796	26310	1826
84	192	63420	327.3	8034	5765	10303	22373	63420	505	828	28013	2032
85	177	55176	363.9	19800	11521	28078	35674	55176	574	776	31994	2056
86	213	57880	332.1	8887	6449	11325	32654	57880	821	920	30186	2084
87	173	83559	367.4	8616	5858	11374	32075	83559	553	1004	38140	2555
88	64	56099	267.5	7075	5170	8980	32685	65119	887	886	32092	2107
89	16	40333	190.1	4911	3597	6228	12783	40333	441	446	12931	1479
90	14	47487	280.3	7714	5783	9646	19398	47487	539	539	19398	1745
91	35	75265	388.8	9742	6964	12560	21131	77265	610	608	20843	2568
92	17	56026	330.0	8073	5578	9452	35992	56026	1052	1057	36540	1905
93	26	44386	279.2	7639	5604	9674	20916	42286	458	467	21115	1566

Table 3. Spawn indicies for the Central Coast

Year	No Rec	Hay Length	Area HA	Bindx mean	Bindx -SE	Bindx +SE	New Est	Sum Length	New Area	Old Area	Old Est	Old Hay I
51	32	57994	116.7	12936	4625	21248	25143	57994	367	468	20886	834
52	25	29865	40.2	3657	1812	5501	11713	29865	153	240	10351	343
53	42	56164	69.4	6792	4300	9283	20705	56164	278	454	20187	629
54	25	41679	61.2	8126	5342	10910	19199	41679	202	332	16308	487
55	37	47225	63.2	8390	5510	11269	15711	47225	219	376	16061	553
56	17	29796	44.2	4203	2311	6095	8876	29796	105	236	11557	394
57	11	18371	29.1	4239	2710	5767	6214	18371	90	146	5960	213
58	21	29374	45.7	5687	2644	8730	5852	29374	126	241	8276	367
59	35	27969	40.7	3768	1912	5623	4851	27969	114	221	7409	364
60	31	54164	85.9	6296	2656	9935	20309	54164	252	443	20331	681
61	15	25224	39.3	3204	1219	5189	8552	25224	136	207	8393	314
62	53	65740	104.1	8709	5039	12379	19497	65740	270	540	22499	860
63	27	32082	43.5	4491	2465	6517	9972	32082	134	253	10918	394
64	27	33571	49.2	3752	2201	5303	7604	33571	119	281	11690	430
65	18	12542	20.1	2629	1636	3622	2811	12542	53	120	4486	171
66	21	11791	18.1	1323	768	1879	2371	11791	47	140	4990	158
67	22	22506	40.6	2582	1802	3361	5940	22506	79	185	8219	322
68	33	27756	49.9	4411	2995	5827	6427	27756	105	225	8973	376
69	19	13408	22.2	2117	1350	2884	2403	13408	52	112	3959	172
70	39	46059	96.8	7853	4658	11048	13993	46059	211	466	19352	637
71	33	25667	47.9	4551	2481	6621	6601	25667	103	207	8029	341
72	91	32162	56.9	6991	4703	9279	5774	32162	142	260	8583	435
73	141	69199	150.7	14572	8708	20435	20689	69199	323	602	23747	964
74	78	67327	121.8	11908	6559	17258	16309	67327	326	561	19662	893
75	123	60856	110.2	10015	5488	14543	14764	60856	305	535	18952	795
76	192	104849	194.6	23420	14348	32491	21494	104849	429	864	30004	1426
77	216	91670	174.7	18904	12417	25391	20227	91670	416	780	27962	1223
78	181	54620	104.3	12081	7456	16707	13798	54620	262	470	16712	732
79	138	51053	102.0	9407	5002	13813	9862	51053	239	442	14408	694
80	165	84523	159.2	17350	10527	24172	21886	84523	399	813	30389	1159
81	294	95104	185.9	20035	12342	27728	21205	95104	392	872	32771	1320
82	164	92713	186.5	20320	12349	28290	23160	92713	393	861	33660	1302
83	202	117166	193.2	18510	10472	26548	22798	117166	406	1024	41185	1605
84	203	85090	151.9	15123	8891	21355	18770	85090	333	734	27875	1075
85	212	90496	148.5	14811	8742	20879	12048	90496	305	792	24676	1155
86	221	98339	161.9	17269	9878	24661	21735	98339	414	518	21633	1262
87	173	86454	150.3	15286	8723	21849	17579	86454	338	777	28714	1160
88	142	141839	239.1	28882	16041	41724	36078	145339	566	1157	48385	1871
89	102	130142	213.9	30892	9969	51816	53424	130142	864	1097	42133	1996
90	192	131978	239.4	29832	16253	43410	40562	147478	603	894	42748	1884
91	129	126956	236.8	27067	11161	42974	32516	140006	857	1015	32225	1989
92	201	232494	388.5	40053	21872	58233	49541	246114	868	1626	70363	2999
93	121	169645	306.9	46174	16227	76064	56688	179155	1081	1312	55584	2912

Table 4. Spawn indicies for the Strait of Georgia

Year	No Rec	Hay Length	Area HA	Bindx mean	Bindx -SE	Bindx +SE	New Est	Sum Length	New Area	Old Area	Old Est	Old Hay I
51	65	68833	380.0	24189	17447	30930	56915	68833	649	753	34418	3080
52	94	91068	405.4	30574	23008	38149	60960	91068	746	904	40368	3589
53	117	142781	561.8	43189	29876	56539	89231	142781	958	1327	66533	4994
54	112	118117	449.2	35479	24266	46692	85717	118117	831	1130	58643	3624
55	118	131918	518.3	44478	30870	58029	61415	131918	850	1420	61857	3873
56	129	69613	238.8	20181	14493	25869	26368	69613	466	772	28653	2125
57	47	48327	203.3	16769	12295	21243	23974	48327	340	462	19469	1790
58	99	71710	196.2	18126	12960	23292	17882	71710	386	715	25462	1631
59	85	93485	366.5	28474	19196	37753	42800	93485	634	858	32216	3134
60	95	83374	314.2	21912	15091	28734	34053	83374	605	731	30171	2548
61	84	75388	241.3	16407	10896	21918	25608	75388	424	661	26280	2160
62	77	51592	197.7	13345	8968	17722	20745	51592	290	499	21624	1774
63	74	62801	198.5	14644	9954	19335	27919	62801	355	557	24678	1687
64	79	62872	217.3	14908	9480	20336	20344	62872	355	573	22079	1867
65	50	49931	183.5	10795	7212	14378	18833	49931	289	407	16078	1590
66	48	26211	63.6	4835	3171	6500	5122	26211	126	237	7629	460
67	54	32116	85.9	5967	4024	7911	6505	32116	166	293	9339	635
68	66	33982	103.4	8510	6554	10466	10084	33982	191	338	12216	786
69	86	57991	163.4	12216	9227	15208	15665	57991	285	488	18191	1183
70	119	106942	377.0	25322	19206	31439	35005	106942	557	909	35144	3020
71	145	100306	349.4	25747	19615	31880	38434	100306	572	1022	38272	2841
72	130	80701	263.8	19795	15085	24505	20828	80701	434	680	23175	2044
73	115	67391	244.7	18278	13781	22775	15790	67391	360	754	25017	1830
74	121	111546	421.7	37218	28488	45948	46071	111546	721	1082	42970	3539
75	137	128514	543.2	40391	29606	51177	60775	128514	839	1212	51616	4512
76	141	111369	532.8	42630	31239	54021	47489	111369	783	1251	48153	4286
77	164	123403	688.5	48986	36462	61510	52632	123403	1069	1491	53285	5940
78	179	124623	700.8	48930	35590	62272	89059	124623	1330	1634	66163	5282
79	152	148532	756.1	51919	36297	67543	55646	148532	1160	2576	92754	6038
80	138	119094	670.3	43491	30284	56697	68788	119094	1199	1654	65613	5219
81	104	80166	498.1	32221	22641	41800	45077	80166	849	1270	44344	3567
82	99	102957	745.0	47525	34921	60129	84959	102957	1484	1907	72758	5155
83	67	74444	442.6	27454	18260	36660	43423	74444	657	1066	45673	3365
84	35	54037	322.8	20533	14383	26683	27240	54037	520	737	27340	2668
85	66	51900	294.5	17738	12529	22948	26581	51900	711	769	28121	2435
86	59	84651	527.5	33830	24582	43078	60847	84651	929	1001	63247	4550
87	40	92400	547.5	37327	26423	48231	38717	92400	913	935	38712	4543
88	32	67001	492.9	29600	19758	39443	25314	67001	833	897	28120	3758
89	64	113110	744.1	48101	34338	61865	53954	113110	1530	1695	56845	6054
90	34	118620	881.0	57393	34892	80000	58912	118620	1623	1628	58962	5528
91	28	90170	667.7	37637	25090	50183	43221	90170	1199	1240	44399	5204
92	42	107703	859.5	48729	28843	68852	79866	114803	1912	1920	80156	6291
93	46	139685	980.6	66697	46995	86399	84905	152985	2584	2630	86273	8451

Table 5. Spawn indicies for the West Coast Vancouver Island

Year	No Rec	Hay Length	Area HA	Bindx mean	Bindx -SE	Bindx +SE	New Est	Sum Length	New Area	Old Area	Old Est	Old Hay I
51	33	37247	148.1	9196	7470	11028	17972	37247	344	384	15854	1021
52	25	23455	98.7	5718	4629	6832	13211	23455	200	217	8251	619
53	60	41723	188.6	11836	9634	14120	27667	41723	378	475	22116	1274
54	54	29505	142.2	9282	7594	11016	15615	29505	283	258	9814	935
55	61	31094	132.8	7980	6415	9599	17813	31094	303	263	10269	952
56	70	49275	283.0	19616	16385	22848	31876	49275	474	533	21072	1660
57	57	56406	334.1	23434	19648	27449	41033	56406	474	475	22658	2041
58	83	54006	234.6	12812	10082	15718	19007	54006	470	489	17363	1402
59	64	28847	134.8	8979	7423	10544	17196	28847	282	270	10830	880
60	48	22380	79.6	3590	2686	4546	8020	22380	196	189	6560	529
61	49	29498	71.2	2343	1332	3591	10565	29498	171	256	11234	581
62	46	52237	199.9	7605	5415	10403	27183	52237	358	438	21826	1240
63	39	25907	69.5	2651	1813	3607	10447	25907	161	236	10081	483
64	34	65214	216.0	7985	5399	11142	24828	65214	404	561	24541	1455
65	31	42132	151.8	7062	5328	9198	19671	42132	364	352	12904	1188
66	26	20154	71.1	3312	2484	4299	3727	20154	122	168	5311	478
67	21	17546	64.7	3757	2896	4760	4857	17546	107	166	5730	446
68	31	20850	95.1	5267	4275	6327	10607	20850	205	189	7133	603
69	30	21822	101.8	5977	4897	7094	11277	21822	225	294	11095	690
70	50	56136	219.8	10882	8450	13524	31429	56136	496	550	21712	1427
71	78	59101	261.8	12535	9687	15674	29394	59101	579	638	24233	1686
72	80	58059	288.9	17663	14542	20903	34752	58059	596	696	27299	1929
73	69	29395	140.3	7449	5814	9320	17050	29395	277	302	12173	913
74	90	28200	133.0	6596	5151	8194	25902	28200	348	392	17369	920
75	262	54982	244.0	12647	9575	15963	44744	54982	647	652	28031	1663
76	165	61864	301.9	17039	13192	21015	49823	61864	686	755	32187	1820
77	165	63685	351.2	19779	15730	23835	47580	63685	741	851	34281	2001
78	165	57411	286.3	17130	13716	20544	34582	57411	727	673	23993	1834
79	214	64296	350.1	20990	16880	25258	56984	64296	710	1290	50849	2116
80	189	55608	295.9	17480	14259	20700	52174	55608	652	827	34903	1851
81	219	59045	294.8	16077	12912	19346	46393	59045	647	737	31145	1780
82	114	39607	206.7	13029	10833	15225	26684	39607	427	455	17388	1365
83	117	28584	148.4	9345	7717	10973	15792	28584	286	428	15588	937
84	67	31410	220.0	12548	9837	15277	18621	31410	374	551	18700	1090
85	118	33965	216.6	11889	9262	14526	29805	33965	870	853	27264	1032
86	109	46234	273.6	15575	12607	18544	38711	46234	962	949	37383	1431
87	103	23142	168.5	11368	9316	13461	29823	57242	847	1013	31148	1775
88	202	71143	353.9	19690	15647	23744	35730	72243	1011	1160	36983	2206
89	97	54844	261.1	13486	9931	17041	41001	58209	969	1066	41357	1617
90	128	53093	286.6	14101	10912	17616	43102	53093	909	918	38250	1662
91	55	38185	222.3	9546	6865	12446	27250	41085	761	734	25522	1132
92	54	37780	324.8	12492	7471	17513	36917	39080	1075	1063	35269	1013
93	85	65280	331.2	16411	11897	20976	29340	69330	919	1060	32598	1757

Table 6. Correlation Matrices of herring spawn indices by assessment region. Correlations are shown for (1) 'No Rec' or the number of records of spawning each year; (2) The sum of the spawn lengths; (3) The area estimated by Hay using a combination of diver and surface widths, estimated for each area 'pool'; (4) a new index based on 'pool-specific widths and egg density counts; (5) A new escapement estimate in tonnes based on a new escapement index and biomass estimate by Schweigert; (6) a sum of lengths estimated by Schweigert (this was included only to confrim that there were significant differences in the data extraction between Hay and Schweigert; (7) a new area of spawning based on diver-estimated spawn widths; (8) the old estimate of spawn width based on previous methods used for the escapement model; (9) the old estimate of escapement, in tonnes; (10) the old index by Hay.

QCI

	(1) No Recs	(2) Sum Len-H	(3) Area DH	(4) NEW Hay-I	(5) NEW Es-t	(6) SUM Len-S	(7) New AreaS	(8) Old AreaS	(9) Old Es-t
2. Sum L H	0.722								
3. Area DH	0.698	0.988							
4. Bindx	0.641	0.957	0.971						
5. NEW Es t	0.693	0.933	0.928	0.925					
6. Sum L JS	0.713	0.999	0.988	0.958	0.928				
7. New Area	0.643	0.956	0.958	0.970	0.936	0.956			
8. Old Area	0.818	0.964	0.945	0.909	0.938	0.957	0.928		
9. Old Es t	0.778	0.953	0.940	0.916	0.978	0.946	0.923	0.978	
10. Old HayI	0.735	0.990	0.974	0.917	0.918	0.988	0.928	0.964	0.964

PRD

	No Recs	Sum Len-H	Area DH	NEW Hay-I	NEW Es-t	SUM Len-S	New AreaS	Old AreaS	Old Es-t
2. Sum L DH	0.614								
3. Area DH	0.590	0.941							
4. Bindx	0.577	0.745	0.877						
5. New Es t	0.297	0.647	0.746	0.709					
6. Sum L JS	0.604	0.997	0.935	0.739	0.651				
7. New Area	0.401	0.793	0.864	0.729	0.776	0.808			
8. Old Area	0.652	0.895	0.900	0.750	0.704	0.900	0.900		
9. Old Es t	0.582	0.869	0.894	0.784	0.820	0.872	0.872	0.967	
10. Old HayI	0.597	0.973	0.979	0.819	0.701	0.975	0.860	0.908	0.885

CC

	No Recs	Sum Len-H	Area DH	NEW Hay-I	NEW Es-t	SUM Len-S	New AreaS	Old AreaS	Old Es-t
2. Sum L DH	0.703								
3. Area DH	0.740	0.989							
4. Bindx	0.665	0.961	0.971						
5. New Es t	0.475	0.904	0.892	0.934					
6. Sum L JS	0.686	0.998	0.988	0.962	0.906				
7. New Area	0.558	0.926	0.929	0.965	0.958	0.930			
8. Old Area	0.730	0.980	0.980	0.950	0.885	0.973	0.915		
9. Old Es t	0.666	0.981	0.973	0.948	0.918	0.978	0.905	0.982	
10. Old HayI	0.667	0.987	0.985	0.985	0.930	0.988	0.965	0.973	0.971

GS

	No Recs	Sum Len-H	Area DH	NEW Hay-I	NEW Es-t	SUM Len-S	New AreaS	Old AreaS	Old Es-t
2. Sum L DH	0.513								
3. Area DH	0.102	0.820							
4. Bindx	0.239	0.902	0.973						
5. New Es t	0.287	0.831	0.827	0.856					
6. Sum L JS	0.485	0.998	0.835	0.913	0.838				
7. New Area	-0.027	0.723	0.955	0.914	0.793	0.754			
8. Old Area	0.262	0.848	0.935	0.937	0.795	0.865	0.908		
9. Old Es t	0.289	0.880	0.916	0.929	0.900	0.891	0.865	0.954	
10. Old HayI	0.131	0.843	0.982	0.969	0.835	0.860	0.946	0.931	0.918

WC

	No Recs	Sum Len-H	Area DH	NEW Hay-I	NEW Es-t	SUM Len-S	New AreaS	Old AreaS	Old Es-t
2. Sum L DH	0.586								
3. Area DH	0.639	0.877							
4. Bindx	0.644	0.783	0.937						
5. New Es t	0.772	0.792	0.889	0.847					
6. Sum L JS	0.594	0.945	0.866	0.787	0.806				
7. New Area	0.575	0.628	0.820	0.695	0.770	0.716			
8. Old Area	0.634	0.672	0.838	0.730	0.812	0.767	0.945		
9. Old Es t	0.681	0.749	0.870	0.769	0.909	0.808	0.896	0.966	
10. Old HayI	0.689	0.888	0.910	0.917	0.874	0.943	0.716	0.769	0.818

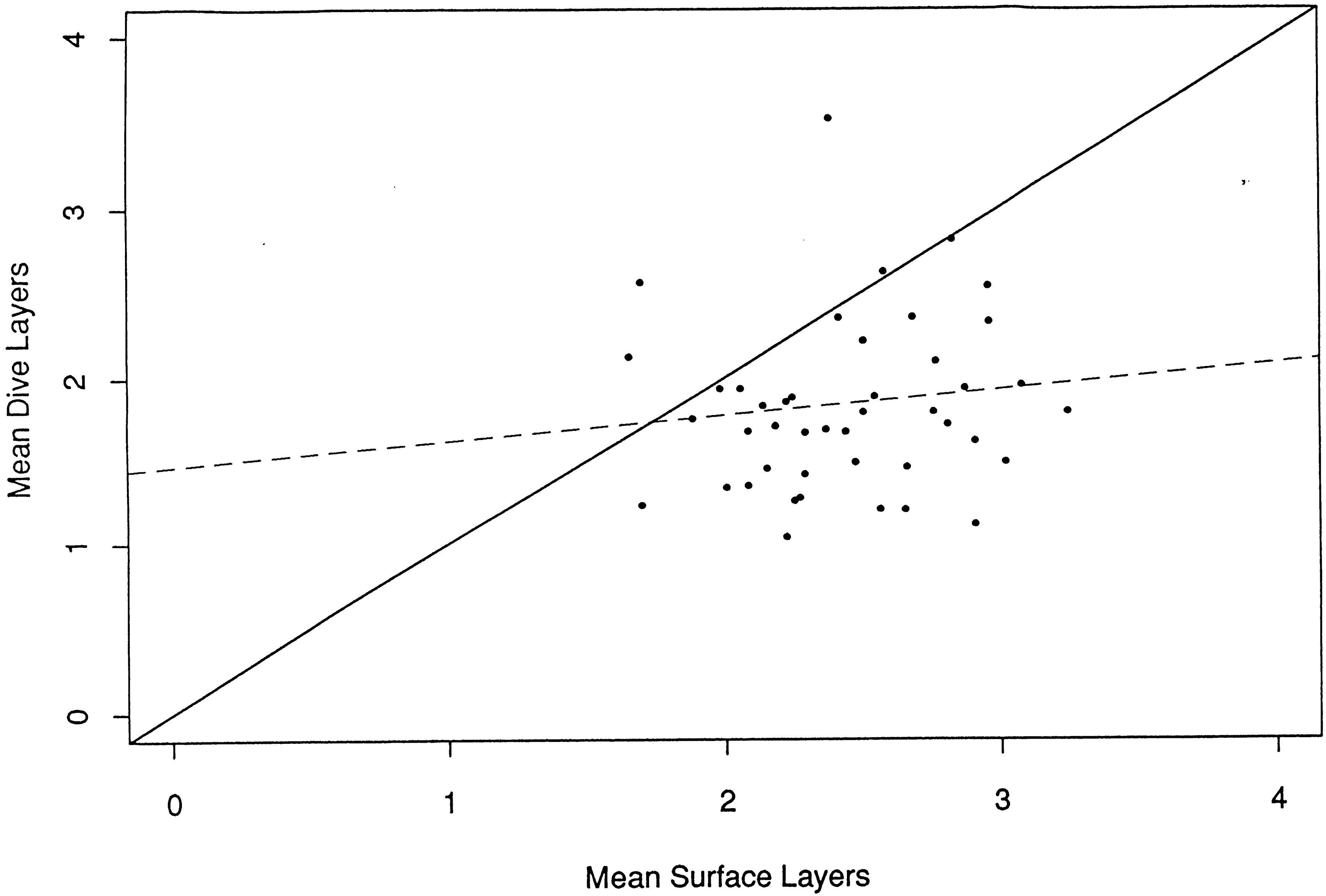


Fig. 1. A comparison of the mean of the annual median surface and dive egg layer estimates for each pool described in Appendix 1 from 1977-1993. The dotted line is the fitted regression.

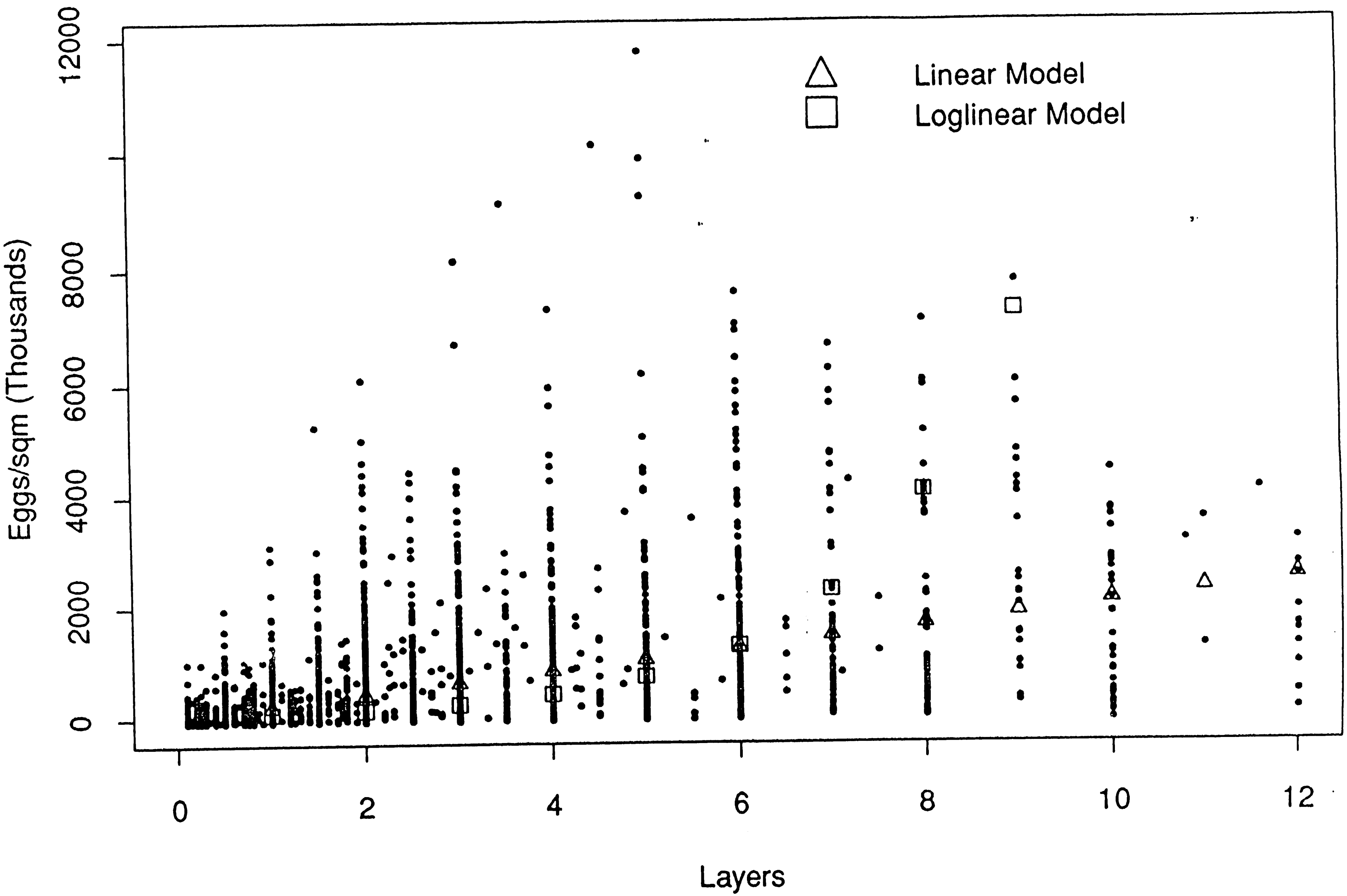


Fig. 2. Relationship between egg layers and egg density from counted egg samples for linear and lognormal fitted models.

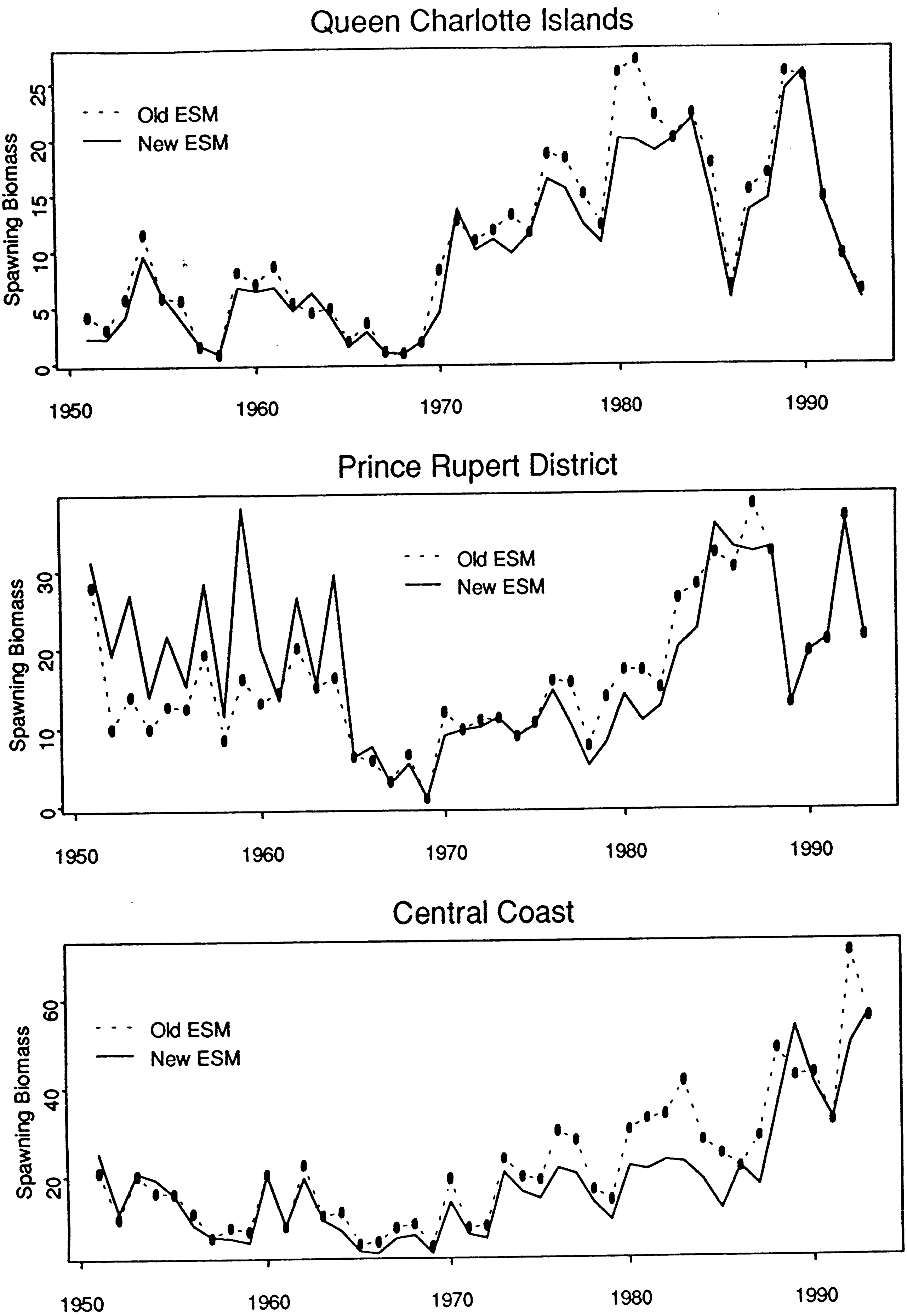
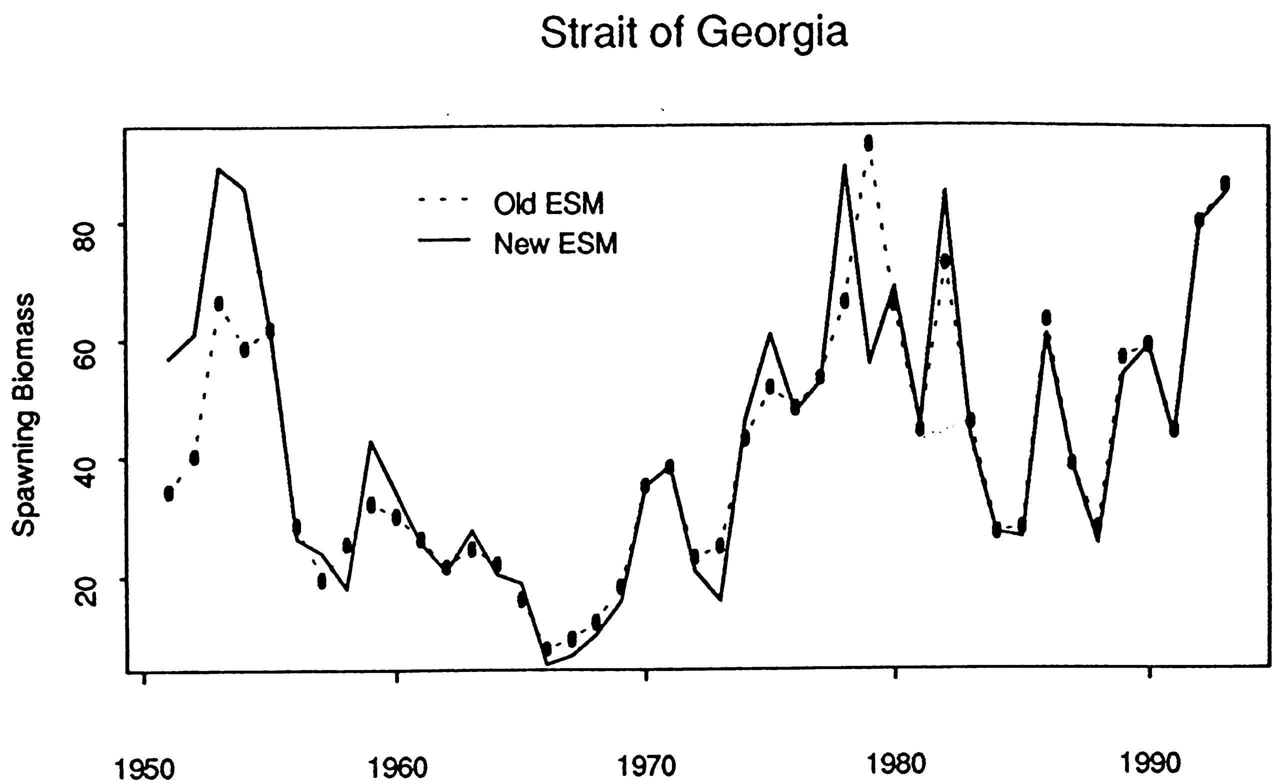


Fig. 3. Spawning stock biomass trends for the five assessment regions based on the old escapement model and the modified escapement model analyses.



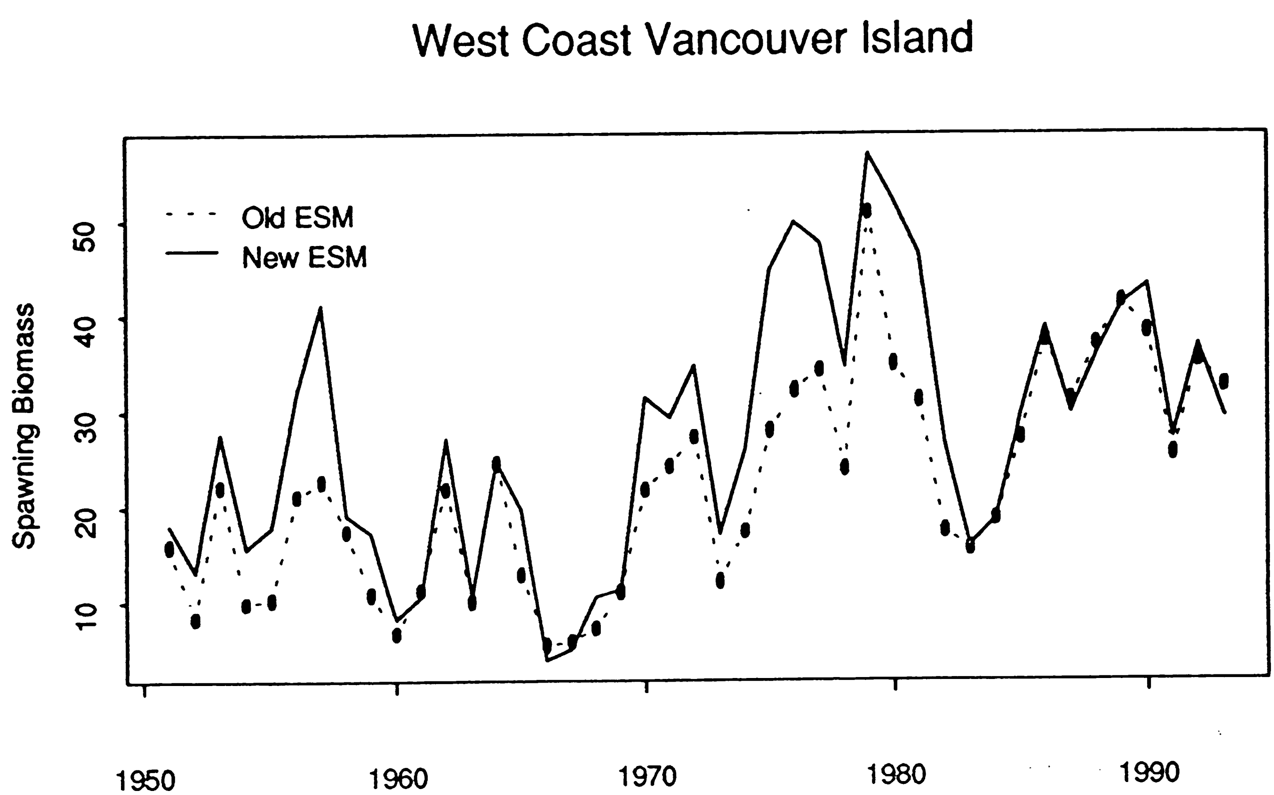


Fig. 3. (cont'd). Spawning stock biomass trends for the five assessment regions based on the old escapement model and the modified escapement model analyses.

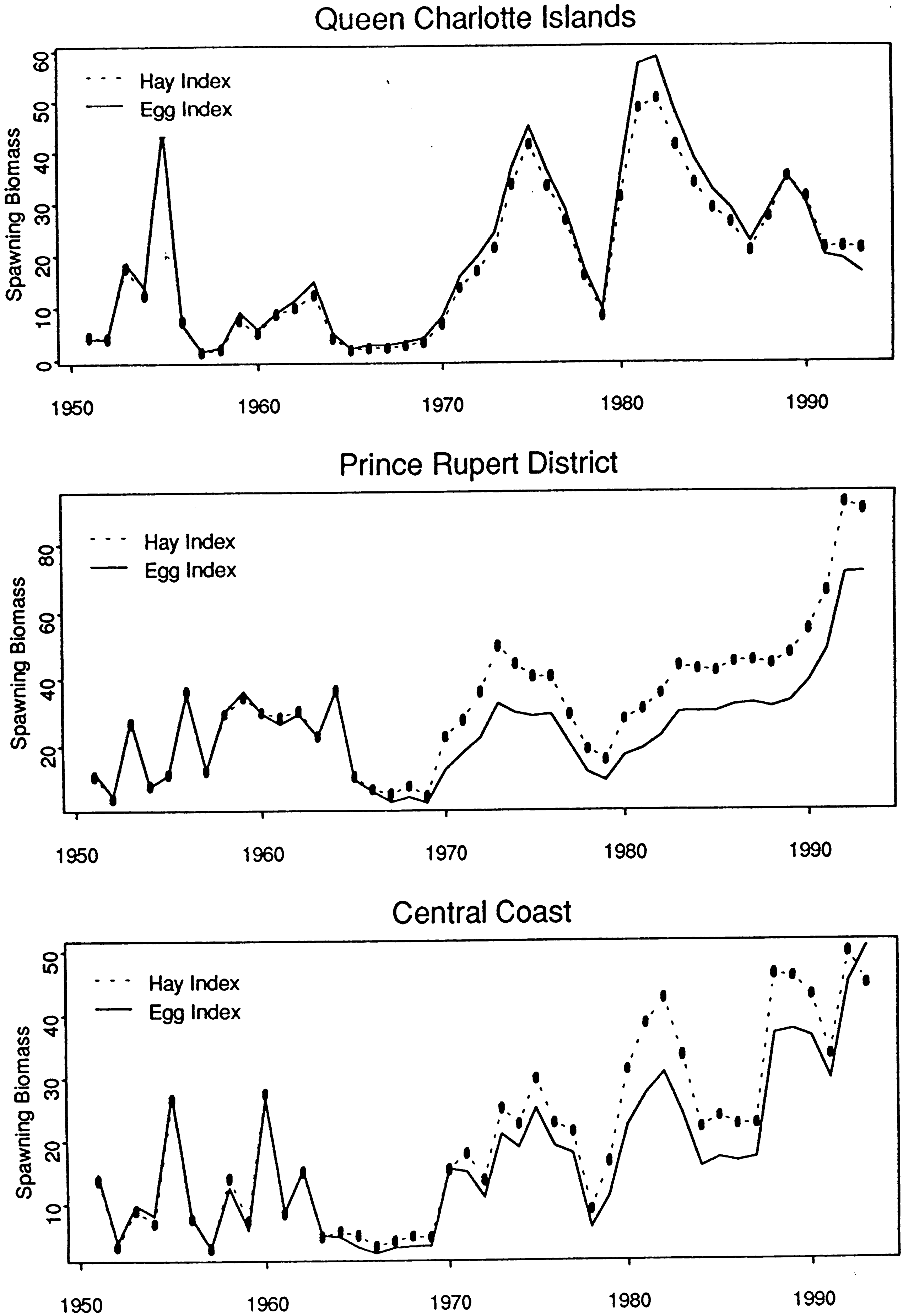
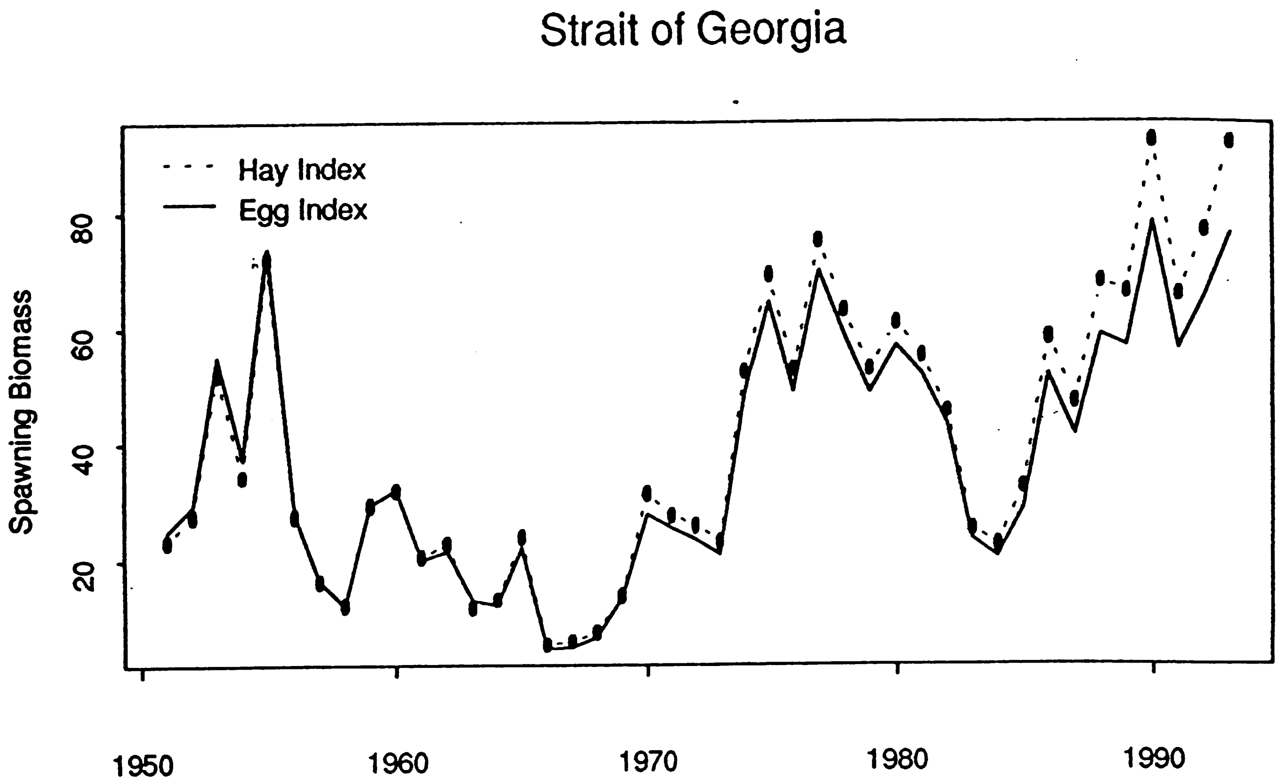


Fig. 4. Spawning stock biomass trends for the five assessment regions based on the age-structured assessment model with the egg index and Hay index as spawn indices.



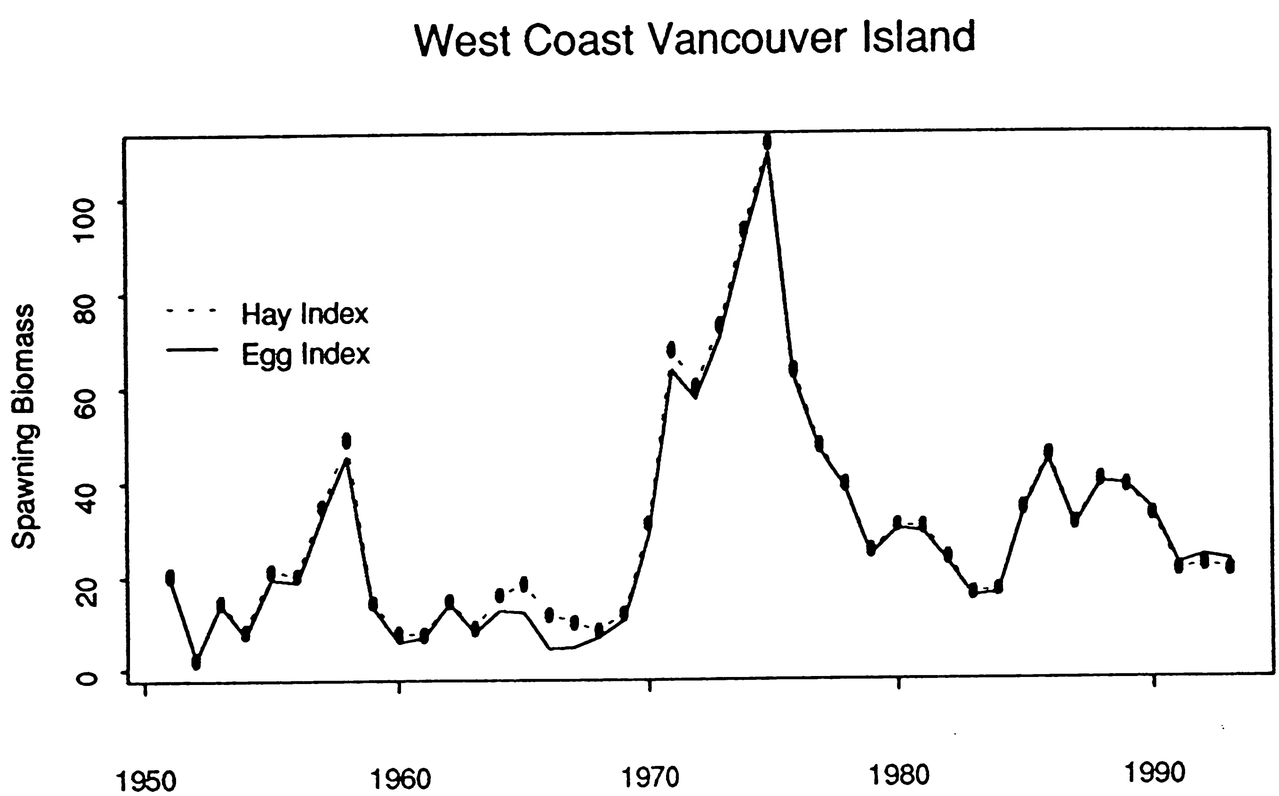


Fig. 4. (cont'd). Spawning stock biomass trends for the five assessment regions based on the age-structured assessment model with the egg index and Hay index as spawn indices.

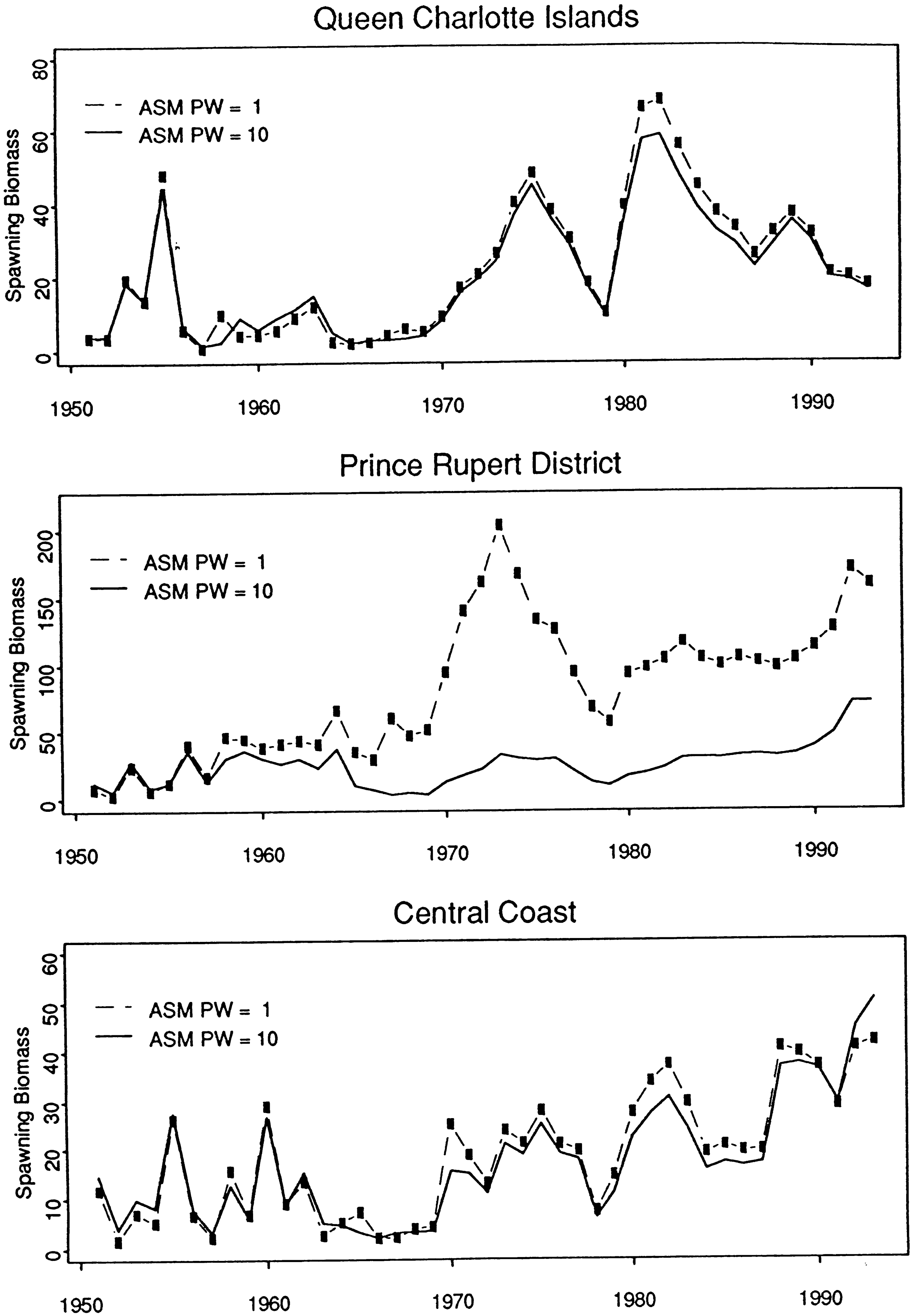
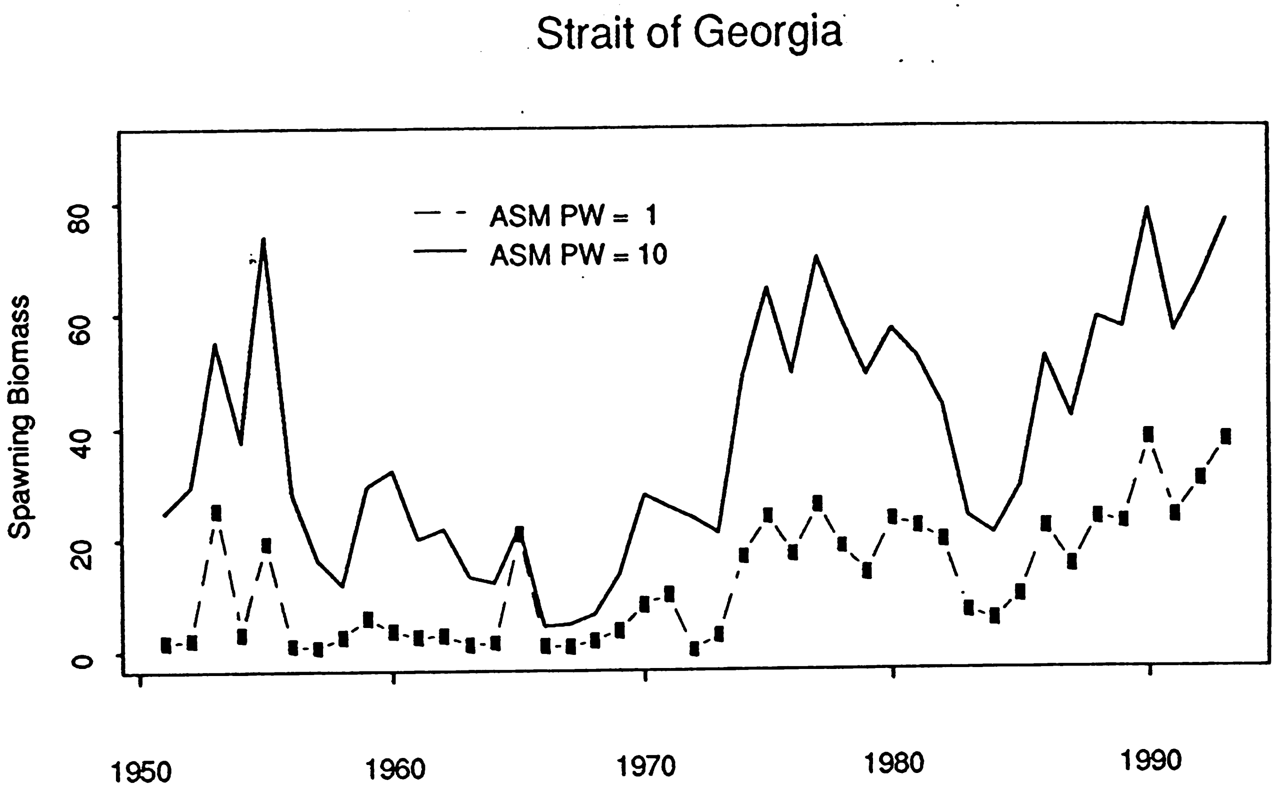


Fig. 5. Spawning stock biomass trends for the five assessment regions based on the age-structured assessment model assuming alternative penalty weights or relative variances for the total egg spawn index.



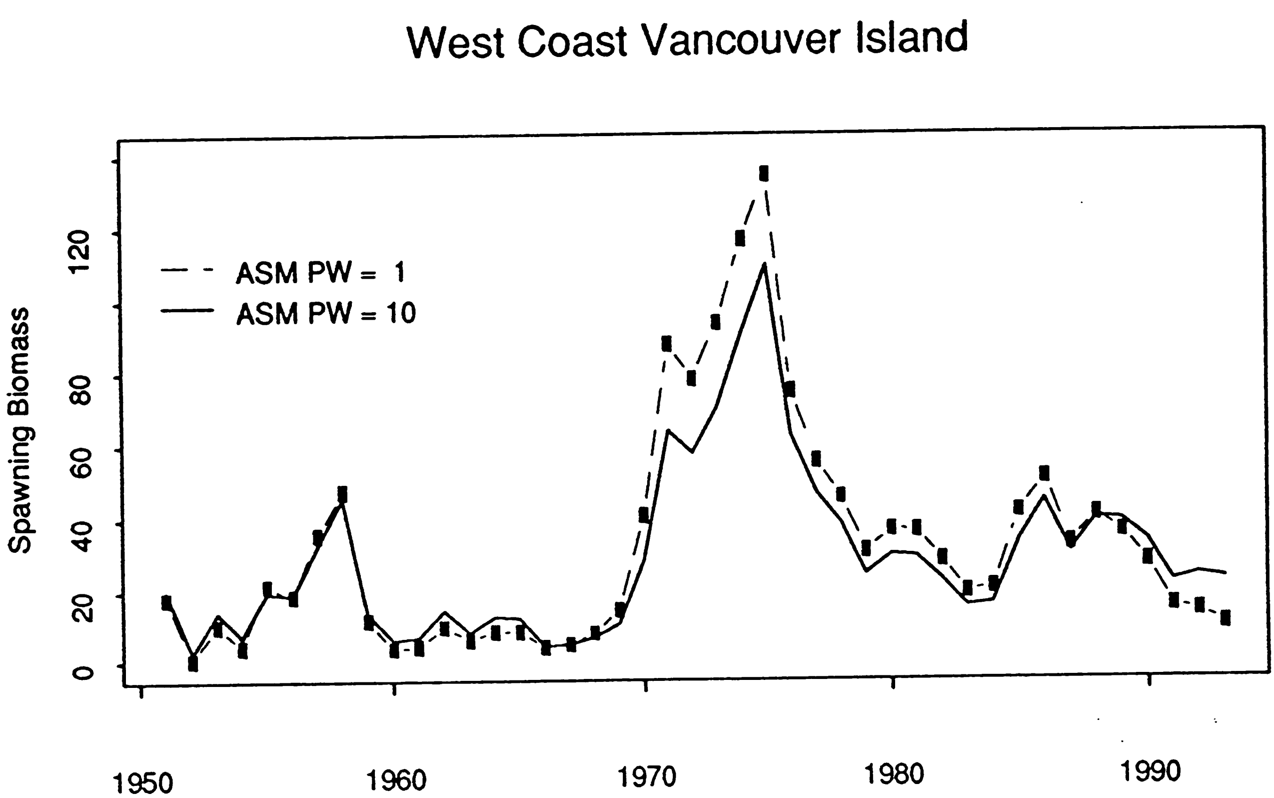


Fig. 5. (cont'd). Spawning stock biomass trends for the five assessment regions based on the age-structured assessment model assuming alternative penalty weights or relative variances for the total egg spawn index.

Appendix Table 1. Median width estimates for each spawn pool identified within individual sections for the total egg deposition index.

Section	Pool	Sample Size	Median Width
6	11	42	45
6	12	14	20.5
21	11	12	50.5
21	12	41	54
21	13	57	120
21	14	14	56.5
21	15	26	45
21	16	29	25
21	17	5	55
23	11	7	65
24	11	46	39
24	12	21	21
24	13	21	23
24	14	16	16
24	15	13	19
24	16	19	55
24	17	8	23.5
25	11	54	32.5
25	12	7	52
25	13	17	52
25	14	12	13.5
25	15	39	58
25	16	9	90
25	17	9	80
33	11	9	30
33	12	10	50
33	13	7	30
33	14	13	31
33	15	14	40.5
41	11	3	150
42	11	17	103
42	12	31	160
42	13	41	90
42	14	36	52.5
42	15	3	23
42	16	47	105
42	17	21	90
42	18	7	266
42	19	73	250
43	13	12	26.5
43	14	31	40
43	15	10	26.5

Appendix Table 1 (cont'd). Median width estimates for each spawn pool identified within individual sections for the total egg deposition index.

Section	Pool	Sample Size	Median Width
43	17	4	17
52	11	15	35
52	12	9	84
52	13	9	28
52	14	5	24
52	15	6	61.5
52	16	49	57
52	17	40	80
52	18	3	80
52	19	5	95
52	20	2	71.5
52	21	8	70.5
52	22	10	55
52	99	7	120
67	11	75	30
67	12	103	40
67	13	26	65
72	11	10	29
72	12	44	23
72	13	30	60
72	14	4	36
72	15	11	41
72	16	32	16.5
72	17	30	36
72	18	18	34
72	19	24	25
72	20	18	69.5
72	21	7	55
72	22	5	28
72	23	17	24
74	11	53	26
74	12	40	24
74	14	52	50
74	15	80	25.5
74	16	93	40
74	17	58	29.5
76	11	6	32
77	13	54	41
78	11	3	140
141	11	7	109
141	12	9	119
142	12	170	110.5

Appendix Table 1 (cont'd). Median width estimates for each spawn pool identified within individual sections for the total egg deposition index.

Section	Pool	Sample Size	Median Width
142	13	45	503
142	14	134	95.5
142	15	90	91
142	16	6	105.5
142	17	25	27
143	11	55	146
143	12	21	160
143	13	21	129
143	14	10	108.5
143	15	7	48
172	11	13	80
173	11	9	60
173	12	39	21
173	13	49	36
173	14	111	35
173	15	60	60.5
173	16	41	72
173	17	3	22
173	18	7	36
173	19	7	46
173	20	9	28
233	11	13	28
243	11	11	54
244	11	3	23
244	12	3	24
244	14	3	14
252	99	17	35
253	1	27	41
253	99	90	97
272	99	83	42
273	99	100	30.5

Appendix Table 2. Estimates of the median spawning bed widths for each section and assessment region based on diving survey estimates.

Section	Sample Size	Median Width
6	56	44.5
21	184	60
23	7	65
24	144	30
25	147	37
33	53	37
41	3	150
42	277	115
43	58	28
52	168	60
67	204	38
72	250	28
74	376	31.5
76	6	32
77	54	41
78	3	140
141	16	118
142	470	102.5
143	114	131.5
172	13	80
173	335	40
232	377	103
233	13	28
242	65	189
243	11	54
244	9	24
245	74	181
252	17	35
253	90	97
272	83	42
273	100	30.5
QCI	538	45
PRD	568	70
CC	893	33
GULF	948	85
WC	659	118

Appendix Table 3. Pool Conversion Table for the new standardized index. The pool numbers are shown in the left column as a single digit number preceeded by a 3 digit number representing the Statistical area and section. The number of records used for calculation of surface width, mean and stadard deviation of width are shown. The number of records, mean and standard deviation are also shown for the egg density data that are calculated for each section.(SEC). When no egg density data were available for specific sections, the data from a representative section were used.

Pool	No	Mean width	SD width	SEC	No. Rec	Mean density	SD density
10	62	8.629	6.644	21	185	593707	900732
20	222	26.198	50.192	21	185	593707	900732
30	200	12.230	23.014	21	185	593707	900732
40	30	11.967	17.835	21	185	593707	900732
50	176	11.290	15.956	21	185	593707	900732
60	1	8.000	*	21	185	593707	900732
61	198	19.758	24.409	21	185	593707	900732
62	9	26.556	24.203	21	185	593707	900732
63	26	33.038	67.297	21	185	593707	900732
110	29	34.552	135.369	21	185	593707	900732
120	132	65.598	113.616	21	185	593707	900732
210	19	50.684	84.149	21	185	593707	900732
211	57	27.211	21.908	21	185	593707	900732
212	85	23.176	25.491	21	185	593707	900732
213	64	44.266	50.060	21	185	593707	900732
214	198	20.409	21.704	21	185	593707	900732
215	69	19.435	16.721	21	185	593707	900732
216	63	22.429	18.224	21	185	593707	900732
217	7	43.000	41.729	21	185	593707	900732
220	371	16.496	25.314	21	185	593707	900732
231	93	34.849	60.900	23	41	256773	321027
232	87	15.356	28.022	23	41	256773	321027
233	6	7.000	6.782	23	41	256773	321027
234	22	16.591	14.328	23	41	256773	321027
235	17	37.588	47.973	23	41	256773	321027
240	8	16.125	11.205	24	87	409611	509181
241	86	14.756	14.834	24	87	409611	509181
242	2	39.500	13.435	24	87	409611	509181
243	85	16.788	10.986	24	87	409611	509181
244	23	15.652	10.241	24	87	409611	509181
245	1	30.000	*	24	87	409611	509181
246	11	24.545	25.773	24	87	409611	509181
247	35	12.743	9.448	24	87	409611	509181
248	27	18.111	12.574	24	87	409611	509181
249	10	18.300	12.970	24	87	409611	509181
250	35	17.971	18.616	25	71	218719	371378
251	113	27.407	49.385	25	71	218719	371378
252	64	22.453	22.485	25	71	218719	371378
253	4	33.000	28.577	25	71	218719	371378
254	10	27.600	19.856	25	71	218719	371378
255	107	33.355	35.971	25	71	218719	371378
256	3	72.000	33.451	25	71	218719	371378
257	74	27.351	26.587	25	71	218719	371378
258	56	33.446	32.074	25	71	218719	371378
259	33	22.091	20.452	25	71	218719	371378
320	38	16.395	38.856	25	71	218719	371378
330	1	14.000	*	33	35	242234	324601
331	52	22.212	13.794	33	35	242234	324601
332	120	32.342	62.325	33	35	242234	324601
333	24	23.042	27.518	33	35	242234	324601
334	47	21.085	18.782	33	35	242234	324601
335	37	31.054	40.444	33	35	242234	324601
410	4	12.500	4.655	41	7	3863420	3357141
411	2	237.500	194.454	41	7	3863420	3357141
420	1	0.000	*	42	351	305343	525899
421	49	26.653	27.181	42	351	305343	525899
422	25	100.480	87.089	42	351	305343	525899
423	105	87.352	111.715	42	351	305343	525899
424	111	38.270	41.209	42	351	305343	525899
425	6	14.833	6.014	42	351	305343	525899

426	192	82.031	104.294	42	351	305343	525899
427	57	65.719	92.098	42	351	305343	525899
428	51	84.765	103.801	42	351	305343	525899
429	202	92.059	127.424	42	351	305343	525899
430	8	10.500	9.442	43	103	161393	328887
431	48	48.875	66.278	43	103	161393	328887
432	20	28.150	44.036	43	103	161393	328887
433	92	28.152	49.008	43	103	161393	328887
434	118	30.669	39.600	43	103	161393	328887
435	97	28.330	47.131	43	103	161393	328887
436	18	81.500	97.837	43	103	161393	328887
437	29	29.172	75.771	43	103	161393	328887
510	42	25.738	33.180	43	103	161393	328887
514	2	27.500	3.536	43	103	161393	328887
520	54	46.870	43.551	52	284	148809	365619
521	99	26.929	32.884	52	284	148809	365619
522	17	36.882	17.582	52	284	148809	365619
523	19	16.842	24.591	52	284	148809	365619
524	27	33.519	37.189	52	284	148809	365619
525	16	31.187	44.468	52	284	148809	365619
526	113	38.319	45.970	52	284	148809	365619
527	149	32.228	33.390	52	284	148809	365619
528	72	48.333	71.120	52	284	148809	365619
529	217	49.194	69.684	52	284	148809	365619
530	3	10.000	0.000	52	284	148809	365619
531	12	13.167	35.868	52	284	148809	365619
532	1	123.000	*	52	284	148809	365619
533	100	13.040	17.280	52	284	148809	365619
542	1	20.000	*	52	284	148809	365619
610	18	11.111	7.275	52	284	148809	365619
620	99	4.717	4.163	52	284	148809	365619
630	140	10.907	12.079	52	284	148809	365619
640	35	6.314	6.637	52	284	148809	365619
650	15	4.000	2.070	52	284	148809	365619
660	49	12.939	15.989	52	284	148809	365619
670	273	18.758	18.813	67	36	550645	686459
671	232	16.879	20.363	67	36	550645	686459
672	262	22.321	25.805	67	36	550645	686459
673	44	43.750	113.435	67	36	550645	686459
674	195	21.482	28.116	67	36	550645	686459
681	5	2.000	0.707	67	36	550645	686459
710	13	19.462	17.280	67	36	550645	686459
720	27	12.148	20.771	72	98	1088755	1712584
721	5	21.800	15.385	72	98	1088755	1712584
722	59	9.458	11.205	72	98	1088755	1712584
723	6	57.167	38.540	72	98	1088755	1712584
724	28	23.321	23.719	72	98	1088755	1712584
725	20	9.500	14.749	72	98	1088755	1712584
726	234	10.269	25.493	72	98	1088755	1712584
727	29	37.759	36.534	72	98	1088755	1712584
728	91	19.769	25.899	72	98	1088755	1712584
729	265	17.211	24.301	72	98	1088755	1712584
730	126	6.643	11.591	72	98	1088755	1712584
741	81	22.667	42.340	74	125	1699634	3215998
742	203	11.818	18.320	74	125	1699634	3215998
743	60	9.283	19.759	74	125	1699634	3215998
744	437	23.265	32.194	74	125	1699634	3215998
745	77	23.104	48.577	74	125	1699634	3215998
746	105	17.000	22.197	74	125	1699634	3215998
747	204	21.608	37.696	74	125	1699634	3215998
758	177	14.605	19.141	74	125	1699634	3215998
761	450	16.993	27.751	76	26	301143	379179
770	1	5.000	*	76	26	301143	379179
773	106	16.396	19.455	76	26	301143	379179
780	6	13.833	12.024	76	26	301143	379179
781	51	19.255	50.766	78	13	3245980	3507283
820	45	6.089	13.706	80	13	1060384	1740720
830	224	3.272	3.032	80	13	1060384	1740720
840	202	3.243	2.831	80	13	1060384	1740720
850	554	17.200	29.913	80	13	1060384	1740720
860	76	23.000	40.498	80	13	1060384	1740720
910	40	4.575	3.748	90	15	543782	681725

920	116	37.655	83.342	90	15	543782	681725
930	333	22.465	53.512	90	15	543782	681725
1020	323	12.873	31.757	90	15	543782	681725
1030	57	4.456	4.881	90	15	543782	681725
1110	8	5.625	7.050	90	15	543782	681725
1120	103	2.602	2.662	90	15	543782	681725
1210	9	10.111	10.080	90	15	543782	681725
1220	194	25.191	51.489	90	15	543782	681725
1230	184	15.440	33.467	90	15	543782	681725
1240	78	15.103	32.854	90	15	543782	681725
1250	234	17.662	47.750	90	15	543782	681725
1260	480	5.131	8.930	90	15	543782	681725
1270	626	7.088	25.549	90	15	543782	681725
1310	1	20.000	*	90	15	543782	681725
1320	184	14.886	32.201	90	15	543782	681725
1330	65	5.400	9.273	90	15	543782	681725
1340	266	6.515	12.807	90	15	543782	681725
1350	204	15.603	23.307	90	15	543782	681725
1360	40	8.925	20.334	90	15	543782	681725
1410	4	24.000	30.638	14	1370	527330	1324556
1411	7	121.571	125.154	14	1370	527330	1324556
1412	3	115.333	83.936	14	1370	527330	1324556
1420	3	19.333	30.925	14	1370	527330	1324556
1421	140	38.629	76.237	14	1370	527330	1324556
1422	151	94.020	131.849	14	1370	527330	1324556
1423	65	168.800	182.779	14	1370	527330	1324556
1424	63	66.413	67.194	14	1370	527330	1324556
1425	38	75.921	60.477	14	1370	527330	1324556
1426	107	94.748	144.296	14	1370	527330	1324556
1427	10	43.000	45.709	14	1370	527330	1324556
1431	125	64.432	69.020	14	243	820450	1192742
1432	46	86.087	90.468	14	243	820450	1192742
1433	36	98.111	71.722	14	243	820450	1192742
1434	73	71.110	63.218	14	243	820450	1192742
1435	34	65.265	105.484	14	243	820450	1192742
1510	17	8.941	17.750	15	87	351935	526751
1520	374	64.128	110.995	15	87	351935	526751
1610	1	16.000	*	15	87	351935	526751
1620	54	12.722	17.292	15	87	351935	526751
1630	220	11.759	18.098	15	87	351935	526751
1640	62	9.048	19.885	15	87	351935	526751
1650	134	28.007	39.425	15	87	351935	526751
1720	524	37.447	68.662	17	170	1023564	988665
1730	8	11.375	16.784	17	228	997834	2027662
1731	49	19.347	23.489	17	228	997834	2027662
1732	79	23.481	51.384	17	228	997834	2027662
1733	100	44.590	71.885	17	228	997834	2027662
1734	87	24.874	37.996	17	228	997834	2027662
1735	239	23.900	38.139	17	228	997834	2027662
1736	144	21.493	34.129	17	228	997834	2027662
1737	10	12.500	19.518	17	228	997834	2027662
1738	156	29.288	53.645	17	228	997834	2027662
1739	54	18.722	24.573	17	228	997834	2027662
1810	945	24.239	31.512	17	228	997834	2027662
1820	188	21.181	37.420	17	228	997834	2027662
1910	80	41.050	64.635	17	228	997834	2027662
1920	4	6.750	4.500	17	228	997834	2027662
1930	73	17.712	19.522	17	228	997834	2027662
2020	7	14.571	14.887	17	228	997834	2027662
2200	1	18.000	*	17	228	997834	2027662
2310	124	22.242	40.576	17	228	997834	2027662
2320	19	18.579	34.561	23	997	458110	923104
2321	55	45.673	54.759	23	997	458110	923104
2322	186	36.806	49.471	23	997	458110	923104
2323	511	56.119	104.153	23	997	458110	923104
2324	265	31.732	43.568	23	997	458110	923104
2325	74	32.459	35.173	23	997	458110	923104
2326	12	26.250	23.538	23	997	458110	923104
2330	84	24.393	44.958	23	997	458110	923104
2410	55	8.564	8.108	24	121	295639	571574
2421	24	72.875	58.540	24	121	295639	571574
2422	127	36.024	57.372	24	121	295639	571574

2423	9	268.333	256.797	24	121	295639	571574
2424	32	33.906	45.099	24	121	295639	571574
2430	72	6.028	5.751	24	121	295639	571574
2431	83	12.241	14.152	24	121	295639	571574
2432	81	12.160	12.181	24	121	295639	571574
2433	12	10.667	12.405	24	121	295639	571574
2434	143	9.755	13.976	24	121	295639	571574
2440	7	3.429	6.803	24	7	322046	267776
2441	95	18.232	28.343	24	7	322046	267776
2442	25	13.760	11.688	24	7	322046	267776
2443	9	8.000	6.205	24	7	322046	267776
2444	57	9.035	10.342	24	7	322046	267776
2445	126	19.421	38.298	24	7	322046	267776
2450	2	61.500	74.246	24	152	538270	752918
2451	71	166.873	194.869	24	152	538270	752918
2452	35	38.286	54.223	24	152	538270	752918
2453	34	168.324	136.249	24	152	538270	752918
2454	134	76.090	71.117	24	152	538270	752918
2455	65	30.785	43.950	24	152	538270	752918
2456	96	27.927	43.914	24	152	538270	752918
2457	40	19.875	28.885	24	152	538270	752918
2458	280	22.550	30.912	24	152	538270	752918
2459	368	36.948	67.300	24	152	538270	752918
2510	11	6.636	13.351	24	152	538270	752918
2520	245	29.469	83.249	25	3	132755	140733
2530	735	75.966	96.234	25	243	836040	1223931
2610	58	13.707	23.199	24	152	538270	752918
2620	169	19.568	21.553	24	152	538270	752918
2630	139	11.921	15.693	24	152	538270	752918
2710	7	6.714	8.098	24	152	538270	752918
2720	151	39.490	63.546	27	26	964668	1567545
2730	428	43.589	59.811	27	131	835223	1158754
2740	29	12.897	12.995	27	131	835223	1158754
2800	38	10.605	14.007	15	87	351935	526751
2910	15	103.867	173.641	15	87	351935	526751
2920	4	24.000	8.981	15	87	351935	526751