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Biological Sampling Of BC Herring: Analysis Of Sampling Requirements For Characterizing Age Structure And Other Biological Characteristics Of Fisheries And Spawning Populations

Échantillonnage biologique du hareng dans les eaux de la C.-B. – analyse des exigences en matière d'échantillonnage pour la caractérisation de la structure des âges et des autres caractéristiques biologiques des pêches et des populations reproductrices

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ABSTRACT

Data collected through the herring biological sampling program is one of the major inputs to the stock assessment models, but a comprehensive review of the program and data collected through the program has not been completed. The work presented here, a continuation from an initial review of the biological sampling program presented to CSAP in September 2010, focuses on analyses of samples from the roe and test fisheries collected since 1972. Specific questions addressed in the report are:

- Is there evidence for spatial or temporal structure (sub-stocks) within herring stock assessment regions?
- Do Sn-roe and test fisheries sample different populations?
- Are there sex-related differences in biological characteristics that should be captured in the stock assessment?
- Can gonadosomatic indices be used to associate herring samples with spawning events?
- Is the assumption that test fishery samples are representative of spawning populations (in some years) reasonable?
- Is there an objective basis for weighting roe fishery and test fishery samples in developing age-compositions for stock assessments?
- Has the precision of age compositions changed over time?
- How would a decrease in sampling effect the precision (and accuracy) of age-compositions?

Cluster analysis of seine-caught age compositions indicates that samples taken within each stock assessment region are unlikely to come from a single homogeneous population. There is a high degree of consistency in the age composition of samples taken with most sections, and consistency among samples decreases with increased geographical separation. On average, the mean age of samples taken from seine roe fisheries tend to be slightly higher than those taken in the test fishery, and the mean age of samples taken early in the spawning season tend to be slightly higher than the mean age of samples taken later in the spawning season.

Gillnet roe fisheries are highly selective for female fish at younger ages (to age 6 or 7), while sex ratios in seine-caught samples indicate a higher proportion of males (than females) for ages 2 and 3. Sex-specific differences in length-at-age are trivial.

Gonadosomatic indices (ratio of ovary weight to body weight) show promise for predicting when sampled herring would reach full maturity, and hence potentially associating samples with spawning events. Further work is required to develop a methodology.

There are no indications that the precision of age compositions (seine and gillnet roe fisheries and test fisheries) have decreased in recent years. Age composition estimates from the seine and gillnet roe fisheries are generally quite precise, and a reduction in the number of samples collected from these fisheries would not likely compromise the integrity of the data for stock assessments. Collection of 6 to 12 samples from each fishery would result in “effective” sample sizes of approximately 300 fish, resulting in reasonable c.v.s for proportions-at-age that are not small (c.v.s ≤ 0.25 for proportions ≥ 0.05). For the test fishery, a reduction in sampling effort (simulated by 14 day sampling periods) would potentially decrease the precision and accuracy of age composition estimates substantially.

RÉSUMÉ

Les données recueillies dans le cadre du programme d'échantillonnage biologique du hareng sont les principaux intrants des modèles d'évaluation des stocks, mais un examen approfondi du programme n'a pas été mené et la collecte de données dans le cadre du programme n'est pas terminée. Le travail présenté ici, la continuité d'un examen initial du programme d'échantillonnage biologique présenté au Centre des avis scientifiques du Pacifique (CASP) en septembre 2010, porte sur les analyses d'échantillons d'œufs de hareng et pêches expérimentale recueillis depuis 1972. Le rapport contient les questions particulières suivantes :

- Y a-t-il des données indiquant une structure spatiale ou temporelle (stocks secondaires) au sein des régions d'évaluation des stocks de hareng?
- Est-ce que les échantillons prélevés à partir des pêches du hareng rogué pratiquées au senneur et les pêches expérimentale échantillonnent différentes populations?
- Existe-t-il des différences entre les sexes dans les caractéristiques biologiques qui devraient être contenues dans l'évaluation des stocks?
- Peut-on utiliser les indices gonadosomatiques pour lier des échantillons de harengs à des événements de ponte?
- L'hypothèse que les échantillons de pêches expérimentale sont représentatifs des populations de reproducteurs (durant certaines années) est-elle raisonnable?
- Y a-t-il un critère objectif pour pondérer les échantillons de pêche du hareng rogué et de pêche expérimentale en élaborant des compositions par âge pour les évaluations de stocks?
- La précision des compositions par âge a-t-elle changé au fil du temps?
- Dans quelle mesure une diminution de l'échantillonnage aura-t-elle une incidence sur la précision (et l'exactitude) des compositions par âge?

L'analyse des regroupements des compositions par âge capturées par senneurs indique que les échantillons prélevés dans chaque région d'évaluation des stocks ne proviennent probablement pas d'une population homogène unique. La composition par âge des échantillons prélevés dans la plupart des sections est très uniforme, et l'uniformité parmi les échantillons diminue avec l'augmentation de la séparation géographique. En moyenne, l'âge moyen des échantillons prélevés à partir des pêches du hareng rogué pratiquées au senneur a tendance à être légèrement plus élevé que celui des échantillons prélevés dans la pêche expérimentale, et l'âge moyen des échantillons prélevés au début de l'époque du frai a tendance à être légèrement plus élevé que l'âge moyen des échantillons prélevés plus tard dans l'époque du frai.

Les pêches du hareng rogué pratiquées au filet maillant sont très sélectives pour les jeunes femelles (jusqu'à 6 ou 7 ans), tandis que les proportions mâles-femelles dans les échantillons attrapés au senneur indiquent une proportion plus élevée de mâles (que de femelles) chez les poissons de 2 et de 3 ans. Les différences entre les sexes dans la longueur selon l'âge sont insignifiantes.

Les indices gonadosomatiques (proportion du poids des ovaires par rapport au poids corporel) permettraient de prédire à quel moment les harengs échantillonnés atteindraient leur pleine maturité et par le fait même, peut-être associer des échantillons à des événements de ponte. D'autres travaux sont nécessaires pour élaborer une méthodologie.

Rien n'indique que la précision des compositions par âge (pêches du hareng rogué pratiquées par senneur et filet maillant et pêches expérimentale) a diminué au cours des dernières années. Les estimations de la composition par âge des pêches du hareng rogué pratiquées au senneur et au filet maillant sont généralement assez précises, et une réduction du nombre d'échantillons prélevés dans ces pêches ne serait pas susceptible de compromettre l'intégrité des données

des évaluations de stocks. Le prélèvement de six à douze échantillons de chaque pêche produirait des tailles d’échantillons « efficaces » d’environ 300 poissons, produisant des coefficients de variation raisonnables dans des proportions selon l’âge qui ne sont pas petits (coefficient de variation ≤ 0,25 pour des proportions de ≥ 0.05). Pour la pêche expérimentale, une réduction de l’effort d’échantillonnage (simulé par des périodes d’échantillonnage de 14 jours) pourrait considérablement diminuer la précision et l’exactitude des estimations des compositions par âge.

1 INTRODUCTION

B.C. herring biological sampling programs provide information on the age structure and biological characteristics of the catch and populations primarily for use in stock assessments. A review of the data collected through the program is warranted at this time because of some current issues: reductions in funding and restrictions on the number of age samples processed each year have led to concerns that the data quality may be decreasing; a recent review of the herring stock assessment model has suggested changes in the way the roe and test fishery data is used in stock assessments; and a management strategy evaluation (MSE) is planned for herring in the near future and will require realistic operating models of stock and sub-stock structure.

An initial evaluation of the herring bio-sampling program was presented to the Centre for Science Advice Pacific (CSAP) Pelagics Standing Committee in September 2010 (DFO 2010). The analyses presented in this report continues on that work, with a particular focus on analyzing the seine-caught biological samples to investigate spatial and temporal structure of the age compositions that may relate to sub-stock structure. Specific objectives for this work, as formulated in the CSAP terms of reference are: 1) to investigate effects of varying spatial and temporal sampling coverage to adequately characterize fish size and age structure of Pacific Herring stocks in the major assessment areas; 2) to evaluate whether the accuracy and precision of estimates of biological characteristics has changed over time, and 3) to determine if patterns in biological characteristics are indicative of similarities or differences among stocks in some areas (i.e. sub-stock structure).

1.1 HERRING FISHERIES AND BIO-SAMPLING PROGRAMS

Herring catch sampling programs have been in place since the mid 1940's, though stock assessments routinely use data beginning in 1950 when comprehensive coast-wide programs were in place. Before 1971 the majority of the herring catch was caught by purse seine in winter fisheries (November through February) for reduction to fish meal. Since then the majority of the herring catch is taken by seine (Sn-roe) and gillnet (Gn-roe) gear in the spring just prior to spawning (February – March). These fisheries are for a roe product so maximizing roe yield is a key fisheries objective. Minor fisheries for food, bait and other purposes have continued throughout the history of the fishery.

A herring test fishing program, using seine gear, began in 1975. Initially, the primary objective of the program was to test roe maturity to inform the time and location of seine fishery openings. As roe-herring fisheries became more localized in space and time, an ancillary objective of the program was to obtain biological samples in areas that did not have seine fisheries.

Biological samples are collected from all (most) herring fisheries. Additional samples are taken from sets made through the test fishing program. The test fishing program does not randomly sample the herring in an area. Although the test fishing program provides guidelines to ensure broad spatial and temporal sampling, there is no basis for determining the relative amount of fish represented by each sample.

Virtually all fish that are sampled are aged, so age-length keys are not used to develop age compositions.

1.2 HISTORICAL USE OF HERRING AGE COMPOSITION DATA IN STOCK ASSESSMENTS

Age-structured assessments of B.C. herring stocks have been conducted routinely since the 1970s. Initially, analyses were conducted by adding estimates of the catch-at-age to estimates of spawners-at-age to obtain population abundance-at-age and projecting these forward one year (Hourston and Schweigert 1981). Analyses were conducted at the herring section level (Figure 1, Figure 2), and summed across sections within “management units” (generally 3-4 sections within a “management unit”, Hourston and Hamer, 1979). The age composition of spawning fish was assumed to be equivalent to that of the seine-caught fish (Sn-roe and/or test fishery) within each section.

For the 1982 herring stock assessment, an integrated, separable catch-age model was developed for the herring stock assessment (Stocker et. al. 1983) based on the analytical methods developed by Fournier and Archibald (1982). The initial model combined herring catches from all fisheries, but for the 1984 assessment the model was extended to separately model the Gn-roe, Sn-roe, and winter (“other”) fisheries (Haist et al. 1985). The assessment model assumed that the Sn-roe fishery (and test fishery) was non-selective for spawning herring (i.e. the age compositions of Sn-caught fish represented the age-compositions of spawning fish). Test fishery data was combined with Sn-roe fishery data to increase the spatial and temporal coverage of the samples representing the spawner age compositions. For the 2008 herring stock assessment, the assumption that the age composition of Sn-caught fish reflected the age-composition of spawning fish was modified: a fixed maturity ogive was assumed and a selectivity ogive estimated for the Sn-roe fishery. The practice of combining Sn-roe and test fishery age-composition data was not changed.

A recent review of the herring stock assessment model made a number of recommendations (Haist et al., 2010). Those related to the use of biological data in the assessment model include: 1) Sn-roe and test fisheries should not be combined, but rather treated as separate fisheries in the model, and 2) sexually explicit dynamics should be modelled.

1.3 OVERVIEW OF PAPER

In addition to the addressing the objectives specified in the CSAP terms of reference for this paper, some additional questions related to the use of the herring bio-sampling data in stock assessments are explored. These not only have relevance to the stock assessment, but provide context for the future MSE work where development of realistic operating models is critical to ensure value in the MSE outputs. Specifically, the questions addressed in this paper are:

- Is there evidence for spatial or temporal structure (sub-stocks) within herring stock assessment regions (SARs)?
- Do Sn-roe and test fisheries sample different populations?
- Are there sex-related differences in biological characteristics that should be captured in the stock assessment?
- Can gonadosomatic indices (GSI) be used to associate herring samples with spawning events?
- Is the assumption that test fishery samples are representative of spawning populations (in some years) reasonable?
- Is there an objective basis for weighting roe fishery and test fishery samples in developing age-compositions for stock assessments?
- Has the precision of age compositions changed over time?
- How would a decrease in sampling effect the precision (and accuracy) of age-compositions?

Analyses presented here are not definitive relative to these questions. Rather, they are a first step towards identifying issues and developing methods to address the questions. The analyses presented are limited to samples collected from roe fishery catches and through the test fishery program.

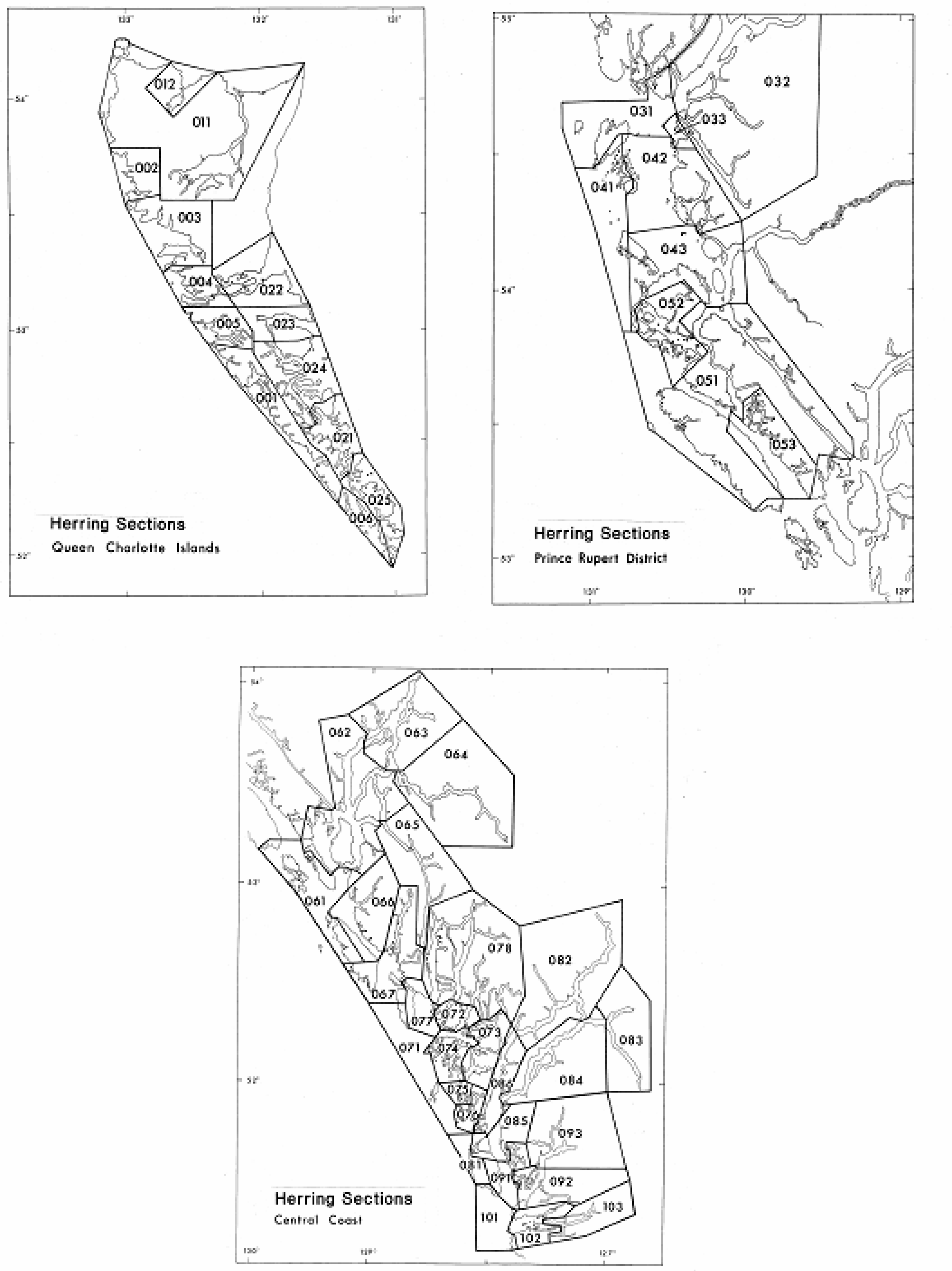

Figure 1: Herring sections in Northern B.C. (taken from Midgley 2003).

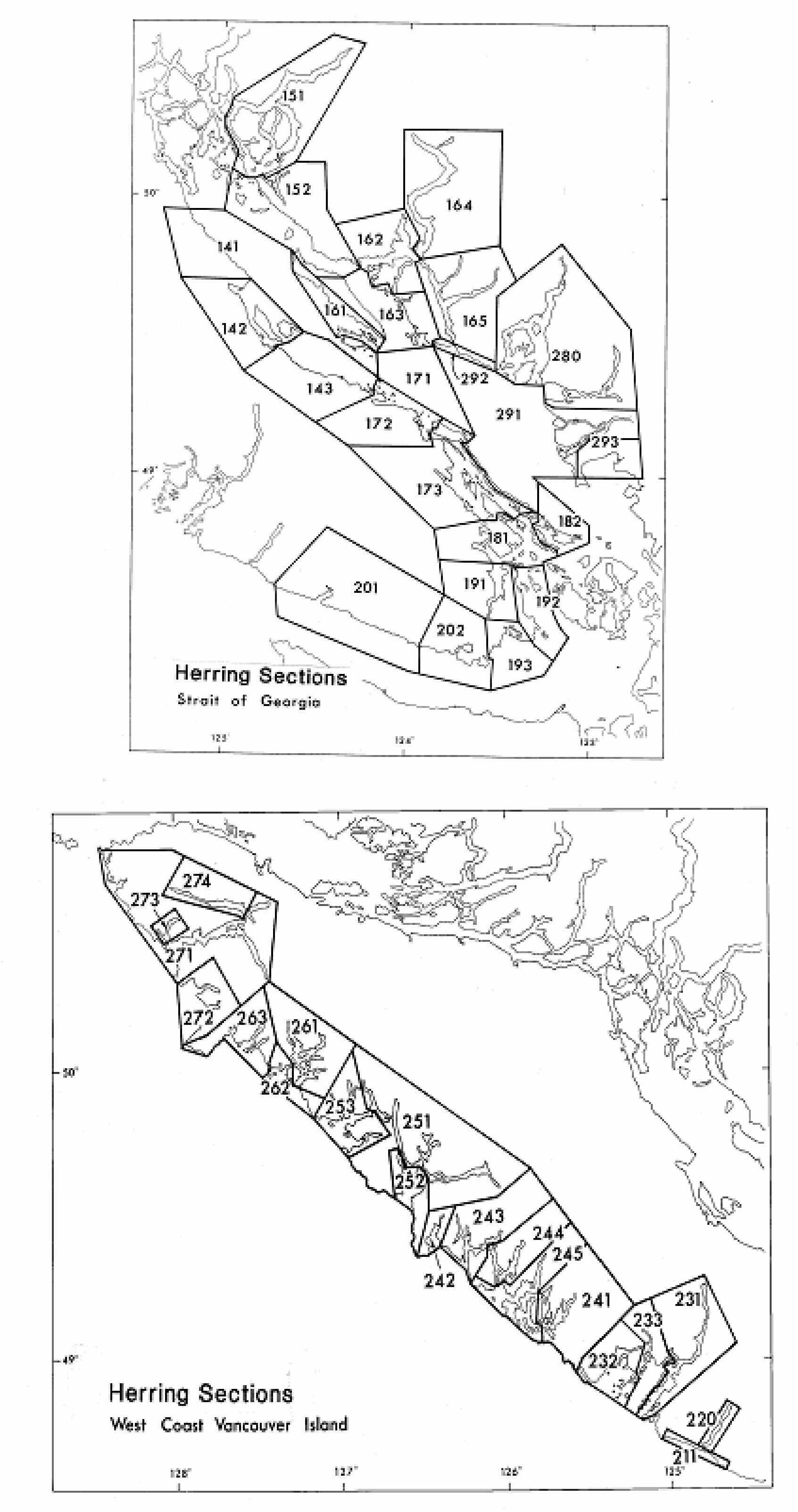

Figure 2: Herring sections in Southern B.C. (taken from Midgley 2003).

Age frequency data: spatial and temporal patterns

In this section characteristics of the seine-caught biological samples are explored to determine if there are patterns that imply sub-stock structure or temporal trends. The focus is on the sample age-compositions and the geographical units are herring section within SARs. Selection of samples from the bio-sampling database is described in Appendix A.

The herring purse seine fishing sets generally capture entire fish schools, so this gear is potentially non-selective for the fish in the area at a particular time. For the test fishery, the net is “dried up” to aggregate the fish and samples are taken from a “boil” of fish in attempt to obtain random samples. Potentially these samples may not be truly random if there is depth-structure in how the fish aggregate in the net. For the seine fishery, samples are taken when the catch is unloaded so the sampling design can ensure random samples from the catch.

The specific questions addressed in this section are:

- Do the seine-caught samples indicate sampling from a homogeneous population within a SAR, or is there evidence of sub-stock structure?
- Is there evidence that the age structure changes over the spawning season?
- Is there evidence that the age structure of the Sn-roe fishery samples differs from that of the test fishery?

1.4 CLUSTER ANALYSIS OF AGE FREQUENCY DATA

In this section a cluster analysis procedure is developed for investigating spatial and temporal patterns in the seine-caught age frequency samples. Cluster analysis was selected for two reasons: 1) it can readily deal with the autocorrelation structure of multinomial samples, and 2) sample co-variates (e.g. sampling date or sampling locations) can be examined to determine patterns in cluster formation.

Three alternative clustering algorithms are presented and simulation tested to evaluate their relative performance at separating known age frequency samples. Then, the best performing algorithm is applied to the herring age frequency data.

1.4.1 AIC to determine the number of clusters

The clustering algorithm uses the Akaike Information Criteria (Akaike 1974) to determine the number of clusters to form from a set of age frequency samples. AIC is commonly used for model selection as it provides an objective basis for finding the model that best describes that data with the minimum of free parameters.

For the clustering algorithm, AIC is used to select between two models: 1) two samples (or two clusters of samples) are from a single (statistical) population, and 2) two samples (or two clusters of samples) are from distinct (statistical) populations. The age-frequency data is assumed to be multinomial distributed.

Given two age frequency samples (or two clusters of samples) the log-likelihood that the samples come from the same statistical population (with proportions at age *j*, $\hat{p}_j^*$) is given by (ignoring constants):

$$\ln L\left(\hat{p}^*\right) = \sum_{j=1}^{n_j} N_j^1 \ln\left(\hat{p}_j^*\right) + \sum_{j=1}^{n_j} N_j^2 \ln\left(\hat{p}_j^*\right), \qquad \text{eq. 1}$$

and the log-likelihood that they come from different statistical populations (with proportions at age *j*, $\hat{p}_j^1 \text{ and } \hat{p}_j^2$) is given by:

$$\ln L\left(\hat{p}^1, \hat{p}^1\right) = \sum_{j=1}^{n_j} N_j^1 \ln\left(\hat{p}_j^1\right) + \sum_{j=1}^{n_j} N_j^2 \ln\left(\hat{p}_j^2\right), \qquad \text{eq. 2}$$

where N_j^1 and N_j^2 are the number of fish in age-class *j* in each of the samples (or cluster of samples) and the proportion-at-age parameters are estimated by their maximum likelihood values:

$$\hat{p}_j^* = \left(N_j^1 + N_j^2\right) \Big/ \sum_{j=1}^{n_j} \left(N_j^1 + N_j^2\right) \qquad \hat{p}_j^1 = N_j^1 \Big/ \sum_{j=1}^{n_j} N_j^1 \qquad \hat{p}_j^2 = N_j^2 \Big/ \sum_{j=1}^{n_j} N_j^2 \qquad \text{eq. 3}$$

The AIC for the two models is then,

$$AIC^* = 2n \; - 2\ln L\left(\hat{p}^*\right) \qquad AIC^{1,2} = 2\left(2n\right) - 2\ln L\left(\hat{p}^1, \hat{p}^2\right)$$

where *n* is the number of age classes. The model with the lowest AIC is selected as best describing the data. The difference in the AIC for the two models (*dAIC*), used in the clustering algorithm, is

$$dAIC = AIC^* - AIC^{1,2}.$$

1.4.2 Clustering algorithms

Three alternative clustering algorithms, based on the *dAIC* measure described above, are presented and then applied to simulated data to investigate their performance. The algorithms are all based on agglomerative hierarchical clustering: hierarchical because they find successive clusters using previously established clusters, and agglomerative because they begin with each sample as a separate cluster and merge them into successively larger clusters.

The first algorithm (A1) uses a standard approach, combining the two samples and/or clusters of samples that are closest (lowest *dAIC*) at each step. The second algorithm (A2) builds clusters one at a time, until there are no additional samples that meet the negative *dACI* criterion. The third algorithm (A3) uses the same clustering process as A1, but uses a quasi-AIC criterion with a variance inflation factor to determine the number of clusters. The rationale for algorithm A3 is that as clusters become larger (i.e. N_j^1 and N_j^2 become larger) the precision of the proportions become smaller so that differences between the proportions $\left(\hat{p}_j^1 \text{ and } \hat{p}_j^2\right)$ must be smaller for the samples to be combined. The A3 algorithm is designed to allow a more parsimonious solution.

The three algorithms are defined as follows:

Algorithm 1: (standard approach)

1) Calculate *dAIC* for each pair of samples.

2) Given at least one negative *dAIC*, combine the two samples with the lowest *dAIC* into a cluster.
3) Calculate *dAIC* for all paired combinations of clusters and samples not already in a cluster.
4) Given at least one negative *dAIC*, combine the cluster(s) and/or sample(s) with the lowest *dAIC* into a cluster.
5) Repeat steps 3 and 4 until there are no negative *dAICs.*

Algorithm 2: (cluster-by-cluster)

1) Calculate *dAIC* for each pair of samples not in a cluster.
2) Given at least one negative *dAIC*, combine the two samples with the lowest *dAIC* into a new cluster *i.*
    a. Calculate the *dAIC* for cluster *i* and all remaining samples not in a cluster.
    b. Given at least one negative *dAIC*, add the sample with the lowest dAIC to cluster *i*.
    c. Return to step 2a if there was a negative *dAIC* at step 2b, otherwise return to step 1.

Algorithm 3: (standard approach with quasi-AIC)

The algorithm is the same as A1, but at each step the total samples sizes $\left(N^k = \sum_j N_j^k\right)$ are adjusted by $\tilde{N}^k = \left(1/N^k + 0.0015\right)^{-1}$, and the $\tilde{N}_j^k = N_j^k \tilde{N}^k / N^k$ replace the N_j^k in equations 1 to 3 above (for *k*=1 and *k*=2). Figure 3 shows the relationship between the adjusted samples sizes and the actual sample sizes.

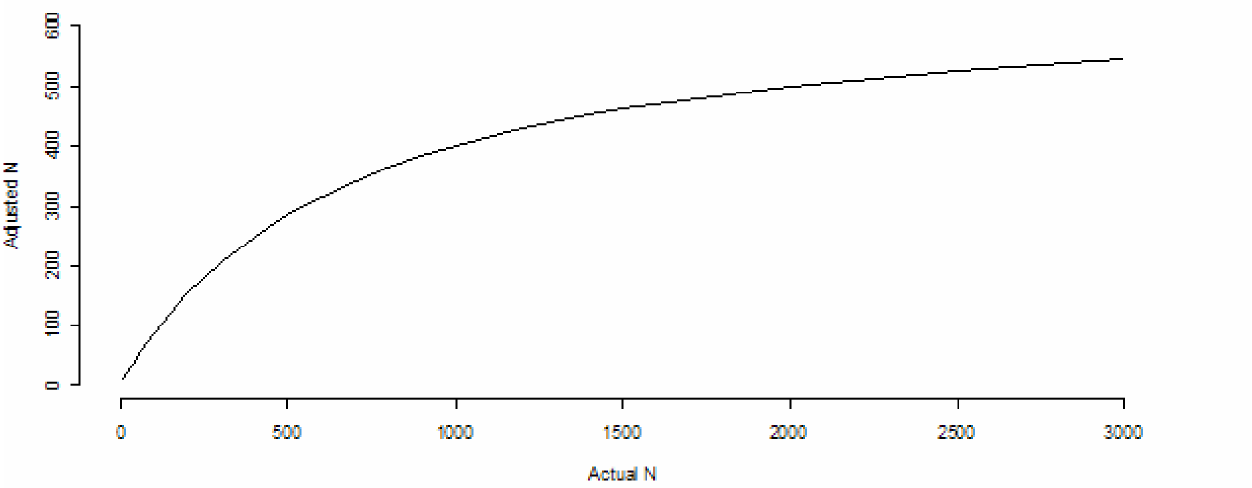

Figure 3: The relationship between the actual sample size and the adjusted sample size used in clustering algorithm A2.

1.4.3 <u>Simulation tests of clustering algorithms</u>

The three clustering algorithms were tested with simulated data. Multinomial samples were randomly generated for three specified sets of age distributions where the distributions were constructed such that the separation among the age classes was either good, moderate, or poor (Figure 4). For each trial, 10 random samples (multinomial distribution) were simulated for each of the three age frequencies. The alternative clustering algorithms were used to separate the 30 age frequencies into clusters. Each simulation trial was repeated 100 times to generate performance statistics for the clustering algorithms.

The performance of each clustering algorithms was measured by:

- The number of clusters estimated.
- The proportion of samples assigned to an incorrect cluster (the number of samples in a cluster where the dominant samples came from a different simulated age frequency).
- The probability that a sample from age frequency group *i* is in the same cluster as a sample from age frequency group *j.*

When age frequency samples were simulated with good separation of the age classes all three clustering algorithms performed well with no samples assigned to incorrect clusters (Table 1). Algorithm A1 tended to over-estimate the number of age frequency groups relative to the number simulated, while algorithms A2 and A3 correctly estimated 3 clusters for all trials (Table 1 and Table 2).

With moderate or poor separation of the simulated age classes, algorithm A2 performed poorly, assigning a high proportion of samples to an incorrect cluster (Table 2). Often fewer than 3 clusters were generated, and sometimes all the samples from one simulated age frequency were clustered with all the samples from another age frequency.

Algorithms A1 and A3 generally had good performance with A1 overestimating the number of clusters for all scenarios and A3 underestimating the number of clusters under the poor age frequency separation scenario. Overall, the performance of A3 was somewhat better than A1 with a higher probability that two samples simulated from the same age frequency are assigned to the same cluster (Table 2).

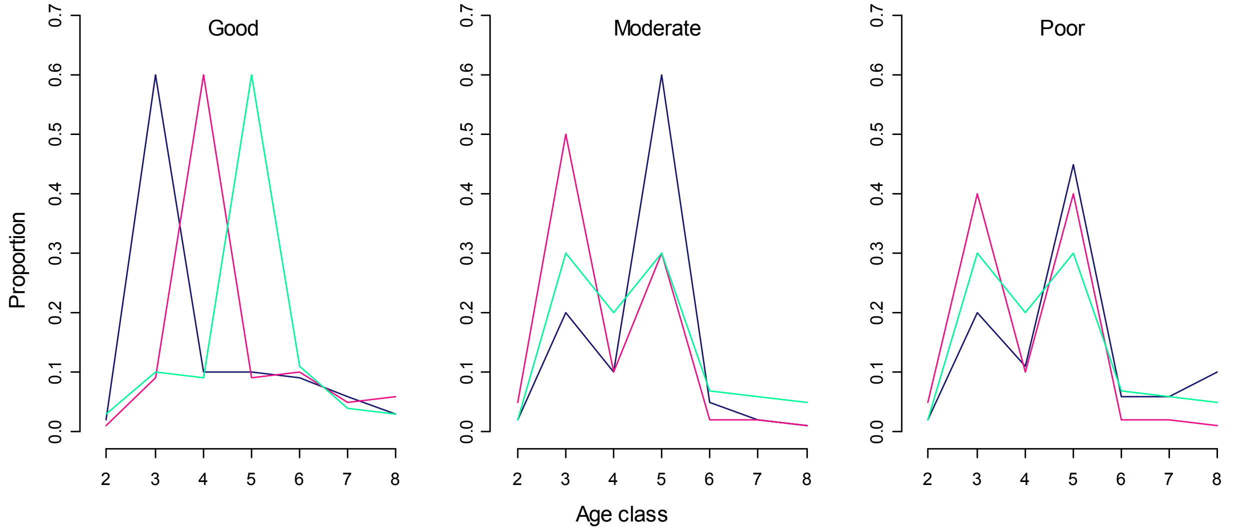

Figure 4 The mean proportions-at-age used to simulate multinomial age frequency data under good, moderate, and poor separation of the three age frequencies.

Table 1 The proportion of samples that were assigned to an incorrect cluster and the mean number of clusters formed for clustering algorithms A1, A2, and A3 with good, moderate and poor separation of the simulated age frequencies.

	Proportion incorrect			Mean number of clusters		
	A1	A2	A3	A1	A2	A3
Good	0.000	0.000	0.000	3.08	3.00	3.00
Moderate	0.003	0.273	0.003	3.07	2.55	3.00
Poor	0.024	0.536	0.031	3.13	1.98	2.98

Table 2 The probability that a sample simulated from age frequency group i *is in a cluster with a sample simulated from group frequency group* j *for clustering algorithms A1, A2, and A3 and the three levels of separation in group means (good, moderate, and poor).*

	Age frequency	A1			A2			A3		
	Group	1	2	3	1	2	3	1	2	3
Good	1	0.99			1.00			1.00		
	2	0.00	0.98		0.00	1.00		0.00	1.00	
	3	0.00	0.00	0.99	0.00	0.00	1.00	0.00	0.00	1.00
Moderate	1	1.00			0.90			1.00		
	2	0.00	0.98		0.10	0.93		0.00	0.99	
	3	0.00	0.01	0.98	0.25	0.55	0.89	0.00	0.01	0.99
Poor	1	0.93			0.93			0.96		
	2	0.00	0.97		0.62	0.76		0.00	1.00	
	3	0.05	0.01	0.90	0.95	0.65	0.98	0.08	0.01	0.90

1.4.4 Cluster analysis of herring Sn-caught age frequency data

Cluster analysis was performed on the combined seine roe fishery and test fishery age frequency data. The number of aged fish per sample ranged from 40 to 132 (Appendix A). Fish in age-class 1 were included with fish in age-class 2 and all fish aged 8 and older were combined into a single age-class. Separate cluster analyses were run for each SAR and year, but herring sections with fewer than 10 samples over all years were not included in the analysis.

The A3 clustering algorithm was applied to the herring seine-caught age frequency data. Overall, the algorithm assigned 845 clusters to the 9,045 age frequency samples. For comparison, the A1 and A2 clustering algorithms resulted in 1,332 and 739 clusters, respectively. Results presented here are from the A3 algorithm.

The number of clusters formed for each SAR and year ranged from 1 to 9, with a mean of 3.7. A full set of figures showing the spatial-temporal pattern of clusters and the estimated age-frequencies in each cluster is provided in Appendix Figure 1. Only a subset of those figures is presented here for illustrative purposes.

There are no consistent patterns in the spatial and temporal distribution of age-composition clusters that hold over all years. But, there are some patterns that repeat through the sequence. In some cases, there is only one dominant year-class represented in the age frequencies, and among-cluster differences in the age frequencies are small (see HG-1983 and WCVI-1997, Figure 5a). In other cases there are two (or more) dominant year-classes, and the relative proportions of the dominant year-classes differ among clusters (see HG-1984 and WCVI-1990, Figure 5a). The clusters may reflect spatial structure, as for example shown for PRD from 1993 to 1995 (Figure 5b). During those years, the dominant year class seen in sections 33 and 42 differed from that in section 52. This pattern does not, however, hold through the entire time series. There are occasional samples with predominantly 2-year fish and these can appear at any time during the sampling period (Figure 5c). Finally, the clusters that contain Sn-roe fishery samples generally also contain test fishery samples (Figures 5a, 5b, and 5c).

A summary statistic was calculated to provide a measure of the consistency of age frequency samples within each herring section and among the herring sections. The statistic is the probability that a sample from section *i* is in the same cluster as a sample from section *j*. That is, for each SAR and year, the probability that a sample selected at random from section *i* is in the same cluster as a sample selected at random from section *j*. The statistic is calculated for each years' data (where there is a least 1 sample from section *i* and one sample from section *j*, or two samples when *i*=*j*), and then averaged over all years.

The probabilities that two samples from a section will be assigned to the same cluster are generally high, with higher probabilities for sections in the northern SARs than for sections in the southern SARs (Table 3). Values are highest in A2W, where between 70% (section 3) and 84% (section 5) of samples from a section are in clusters with other samples from that section. For a few of the herring sections, the probability that two samples from the section are assigned to the same cluster is relatively low (less than 0.4 for sections 132, 173, 181, 192, and 233, Table 3) suggesting these may be areas with transient herring schools rather than staging areas.

In general, the closer the geographical proximity of two sections, the higher the probability that age frequency samples from the sections will be assigned to the same cluster (Table 3). For A2W, the age compositions in each section are relatively distinct from those in other sections. Section 6 in HG and section 135 in SoG stand out in that the is a high degree of consistency in the age compositions within the section and little consistency with other sections within the SAR.

An extension of the age composition clustering algorithm that included mean lengths-at-age in the likelihood was explored to see if there was evidence for size-at-age differences among the herring sections. The overall number of clusters increased but the separation of the data by section did not increase. Results from those analyses are not presented here.

1.5 SN-ROE VERSUS TEST FISHERY SAMPLES

The cluster analysis was run on the combined Sn-roe and test fishery data set so that similarities and differences between these two sources of seine-caught samples could be investigated.

The majority of Sn-roe samples cluster in groups that also include test fishery samples. Over all years, the proportion of Sn-roe samples in clusters that also include test fishery samples ranged from 0.962 for the WCVI SAR to 0.995 for the PRD SAR (Table 4, Appendix Figure 1). This is not surprising given there is often intense test fishery sampling in an area prior to a seine fishery opening.

Commonality in the SN-roe and test fishery clusters does not preclude the seine fishery being selective, for example, for larger, older fish. Mean age was used to detect differences in age frequency between the Sn-roe and test fishery samples. Samples were treated as simple random samples – that is, there was no weighting of the samples. For each Sn-roe fishery and test fishery (defined either by section or SAR and year), the mean age was calculated across all samples, and a paired t-test used to evaluate the null hypothesis of no difference in the mean age between the two data sources.

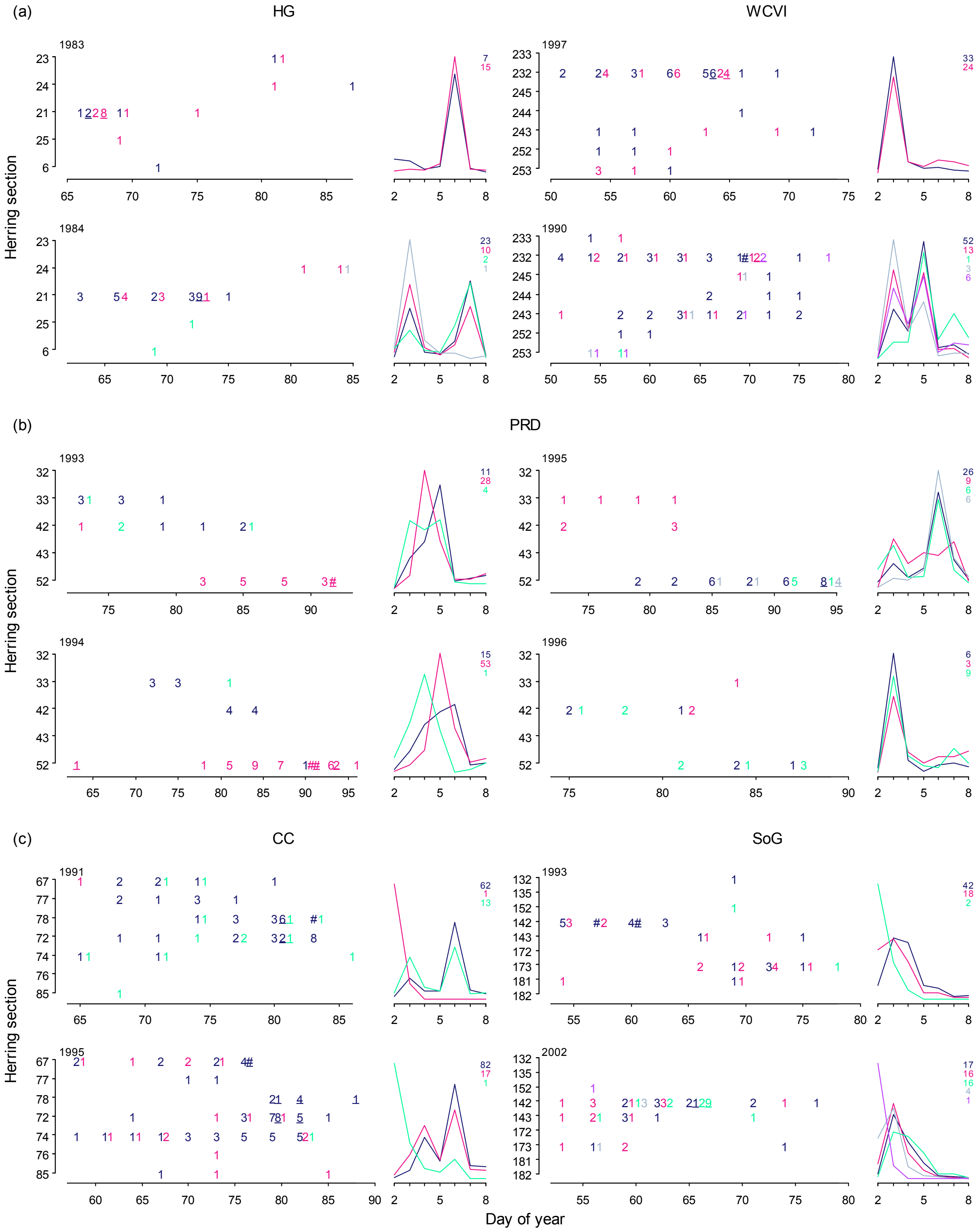

Figure 5: Age-composition clusters: Number plots show the number of samples by cluster, herring section and day of year (amalgamated over 3 day intervals); each cluster is plotted with a distinct colour; Sn-roe fishery samples are underlined; and the symbol "#" indicates more than 9 samples. The line plots show the proportions-at-age for each cluster, using the same colour scheme as the number plots, and the total number of samples in each cluster is written in the upper right of those plots.

Table 3   Cluster analysis results: Probability that a sample from section i *will be in the same cluster as a sample from section* j*. Sections are ordered to reflect their proximity. N is the total number of samples across years.*

SAR	Section	N	2	3	5
A2W	2	101	0.72		
	3	169	0.47	0.70	
	5	90	0.23	0.34	0.84

			23	24	21	25	6
HG	23	61	0.57				
	24	96	0.24	0.66			
	21	348	0.22	0.44	0.69		
	25	377	0.23	0.38	0.50	0.59	
	6	181	0.16	0.12	0.05	0.15	0.72

			32	33	42	43	52
PRD	32	44	0.55				
	33	157	0.30	0.66			
	42	237	0.32	0.46	0.55		
	43	33	0.07	0.29	0.46	0.76	
	52	778	0.27	0.30	0.34	0.53	0.73

			67	77	78	72	74	76	85
CC	67	308	0.61						
	77	233	0.60	0.74					
	78	217	0.44	0.47	0.56				
	72	428	0.53	0.54	0.52	0.59			
	74	581	0.44	0.49	0.47	0.53	0.52		
	76	103	0.22	0.16	0.22	0.20	0.23	0.50	
	85	121	0.26	0.38	0.34	0.32	0.36	0.35	0.59

			132	135	152	142	143	172	173	181	182
SoG	132	44	0.24								
	135	31	0.13	0.81							
	152	267	0.26	0.33	0.52						
	142	1112	0.13	0.26	0.21	0.47					
	143	268	0.11	0.15	0.20	0.41	0.46				
	172	228	0.19	0.09	0.18	0.33	0.35	0.46			
	173	334	0.31	0.10	0.21	0.28	0.31	0.39	0.36		
	181	66	0.20	0.05	0.10	0.18	0.26	0.22	0.26	0.38	
	182	26	0.18	0.02	0.06	0.16	0.23	0.29	0.30	0.25	0.31

			233	232	245	244	243	252	253
WCVI	233	29	0.20						
	232	1084	0.31	0.51					
	245	113	0.18	0.37	0.50				
	244	43	0.21	0.37	0.49	0.54			
	243	290	0.23	0.38	0.31	0.34	0.46		
	252	165	0.09	0.29	0.13	0.30	0.38	0.61	
	253	309	0.06	0.26	0.12	0.19	0.26	0.36	0.51

There are 142 year/area combinations with both Sn-roe and test fishery data when the age frequency data is summarized by SAR; the combinations increase to 217 when the data is summarized by section. The Sn-roe mean ages tend to be higher than the test fishery mean ages, with 79% and 71% of the year/area combinations having higher Sn-roe mean age for the SAR and section means, respectively (Table 5, Figure 6). The proportion of differences that are significant at the 0.05 probability level is also higher with data summarized by SAR than by section (Table 5).

These results support the hypothesis that the Sn-roe fishery is selective for older (larger) fish. The greater differences when mean age is calculated at the SAR level suggests that the selectivity occurs both through the selection of the section where the fisheries occur and the location/timing of fisheries within sections. The temporal trend in the differences between Sn-roe and test fishery mean age suggests there may be a trend in fisheries becoming more selective (Figure 6). The differences in mean age between the Sn-roe and test fishery are not generally large, averaging 0.23 years over all SARs and years.

Table 4: Proportion of SN roe fishery samples that cluster in groups that also include test fishery samples (1975- 2010).

HG	PRD	CC	SoG	WCVI	A2W
0.992	0.995	0.973	0.999	0.962	0.987

Table 5: The number of positive and negative differences in the mean age between Sn-roe test fishery samples (Sn-roe minus test) when data is summarized by SAR and by section. The proportion of differences that are significant (α =0.05) is shown in parentheses.

Geographical Unit	Total	Negative	Positive
Section	217	64 (0.53)	153 (0.68)
SAR	142	30 (0.53)	112 (0.82)

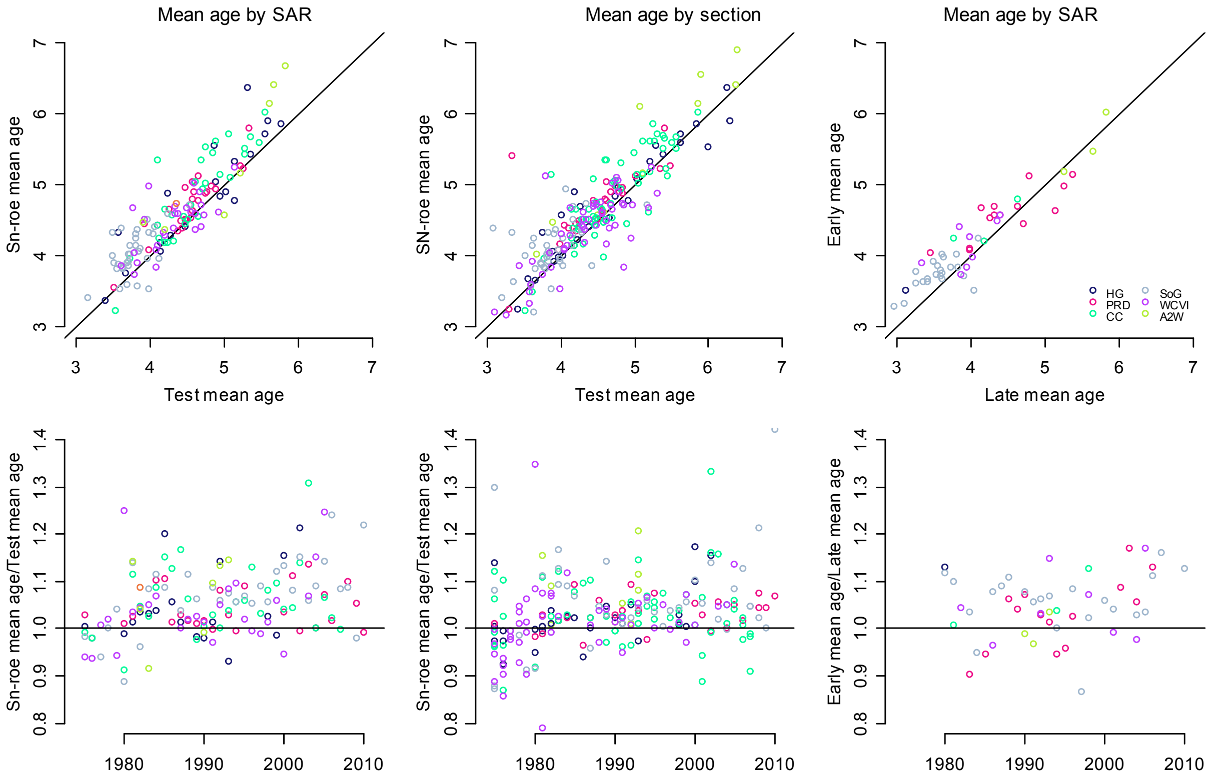

Figure 6: Sn-roe versus test fishery mean age and the ratio of Sn-roe to test fishery mean age over time, calculated over SAR and section (left and middle panels), and the early versus late mean age and the ratio of early to late mean age over time, calculated over SAR (right panels).

1.6 EARLY VERSUS LATE TEST FISHERY SAMPLES

The results of the cluster analysis did not result in any obvious temporal patterns in the formation of clusters. However, a shortage or lack of samples late in the season may preclude detection of patterns.

Temporal differences in age frequency can be directly assessed by comparing the mean age of fish collected early and late in the test fishing season. However, the duration of the test fishery is variable as is the timing of the test fishery relative to spawn deposition. Ideally, it would be useful to be able to relate temporal changes in age frequency to differences in the spawning populations. To that end, early and late test samples are defined here relative to the timing of spawn deposition for the SAR.

Early and late test fishery samples are defined as those collected up to the date of the 25th quantile of spawn deposition and from (and later than) the date of the 75th quantile of spawn deposition (see Appendix A for a description of spawn data processing). Mean ages are compared only where there are a minimum of three samples for both the early and the late sampling period.

Of the 51 SAR/year combinations with a minimum of 3 samples collected both early and late in the season (relative to spawn deposition), 78% had a higher mean age for the early samples than for the late samples. Of these, 85% were significantly different at the 0.05 probability level (paired t-test). On average, there was a 14 day difference between the mean date of the early and late samples, and the average difference in mean age was 0.17 years (Table 6). The magnitude of the difference in mean age is small, similar to the magnitude of the difference in mean age between the Sn-roe and test fisheries.

2 SEX RATIOS

The herring stock assessment model does not distinguish between the sexes, although sex-specific data is collected so a two sex model could be constructed for assessments. Additional value may come from a sex-specific model if there are sex-specific differences in availability or gear selectivity or if there are significant differences in growth between the sexes.

There is considerable inter-annual variability in sex ratios-at-age, so the data is averaged over all years (1972 – 2010) so that general patterns can be detected. For the Sn-roe and test fisheries, males are more prevalent at age 2, and to a lesser extent at age 3 (Figure 7). Counter-intuitively, given the mean age of Sn-roe samples tends to be higher than test fishery samples (section 2.2), the proportion male-at-age 2 is higher for the Sn-roe fishery than for the test fishery. This pattern appears to hold over the entire sampling history (Figure 8). For older fish (ages 4 to 8+), the proportion male tends to be close to 0.5 (Figure 7). The Gn-roe fisheries are highly selective for females at ages up to 6 or 7 (Figure 7).

Male mean lengths-at-age are consistently less than female lengths-at-age, though differences between the sexes are minor (Figure 9).

*Table 6: Summary information for test fishery samples collected early and late in the season (before first and after last quartile of spawn deposition): number of samples; mean day of year samples collected; mean age; and the difference in mean age between early and late samples. * denotes significance at the 0.05 level.*

		Number of Samples		Mean day of year		Mean age		
SAR	Year	Early	Late	Early	Late	Early	Late	Difference
HG	1980	12	6	72.3	100.2	3.51	3.10	0.41*
PRD	1983	34	13	76.7	97.9	4.63	5.13	-0.50*
PRD	1985	17	5	81.0	93.4	4.45	4.70	-0.25*
PRD	1988	20	10	81.6	94.8	4.52	4.25	0.27*
PRD	1989	14	4	79.4	95.0	4.58	4.40	0.18*
PRD	1990	12	32	78.4	88.7	5.12	4.78	0.35*
PRD	1992	9	4	77.1	89.5	4.10	3.98	0.11
PRD	1993	11	5	75.7	91.2	4.69	4.62	0.07
PRD	1994	10	16	77.1	92.6	4.98	5.26	-0.28*
PRD	1995	7	23	77.3	89.6	5.16	5.38	-0.22*
PRD	1996	12	4	80.8	88.5	4.07	3.97	0.10
PRD	2002	18	12	77.8	93.9	4.69	4.31	0.38*
PRD	2003	24	4	78.8	93.3	4.04	3.45	0.59*
PRD	2004	6	9	75.5	87.7	4.56	4.32	0.24*
PRD	2006	13	4	79.2	89.5	4.67	4.13	0.54*
CC	1981	13	9	70.3	91.9	4.20	4.17	0.03
CC	1994	39	8	73.6	86.9	4.81	4.63	0.17*
CC	1998	34	5	69.7	82.0	4.24	3.76	0.48*
SoG	1980	34	7	62.2	74.0	4.02	3.60	0.42*
SoG	1981	33	21	58.9	72.2	3.98	3.63	0.36*
SoG	1983	27	7	55.4	75.4	4.24	4.10	0.15*
SoG	1984	60	5	59.3	81.6	3.71	3.91	-0.20*
SoG	1986	57	9	60.1	77.1	3.33	3.08	0.24*
SoG	1987	28	13	58.6	74.7	3.86	3.55	0.32*
SoG	1988	46	4	61.4	77.3	3.61	3.26	0.36*
SoG	1990	27	11	56.8	76.5	3.67	3.40	0.27*
SoG	1991	42	11	60.1	71.5	4.02	3.81	0.22*
SoG	1992	39	7	64.3	75.1	3.73	3.52	0.21*
SoG	1993	28	24	58.0	71.3	3.64	3.40	0.23*
SoG	1994	44	6	61.5	70.5	3.83	3.83	0.01
SoG	1996	65	5	62.3	78.0	3.63	3.34	0.28*
SoG	1997	62	8	62.3	77.8	3.51	4.04	-0.54*
SoG	1998	50	11	60.2	73.3	3.68	3.60	0.08*
SoG	2000	8	19	55.3	70.6	3.79	3.58	0.21*
SoG	2001	45	14	59.3	67.4	3.76	3.61	0.15*
SoG	2004	33	11	60.9	73.2	3.83	3.72	0.11*
SoG	2005	9	11	55.9	64.6	3.71	3.59	0.12*
SoG	2006	19	5	58.3	72.2	3.29	2.96	0.33*
SoG	2007	29	7	62.0	72.4	3.78	3.25	0.52*
SoG	2010	9	28	56.8	66.1	3.93	3.49	0.44*
WCVI	1982	28	22	61.1	70.9	4.58	4.38	0.20*
WCVI	1986	42	4	64.2	76.5	3.72	3.86	-0.13*
WCVI	1992	14	29	56.5	68.9	4.49	4.35	0.14*
WCVI	1993	13	6	55.9	69.2	4.42	3.84	0.57*
WCVI	1998	8	9	54.8	71.4	4.27	3.98	0.29*
WCVI	2001	11	11	60.3	68.5	3.98	4.02	-0.03
WCVI	2004	19	4	59.8	75.5	3.84	3.93	-0.09
WCVI	2005	15	4	59.7	75.5	3.89	3.33	0.56*
A2W	1990	9	10	67.0	82.0	5.18	5.25	-0.06
A2W	1991	16	5	69.7	89.2	5.48	5.66	-0.18*
A2W	1993	4	7	70.8	90.6	6.02	5.83	0.20

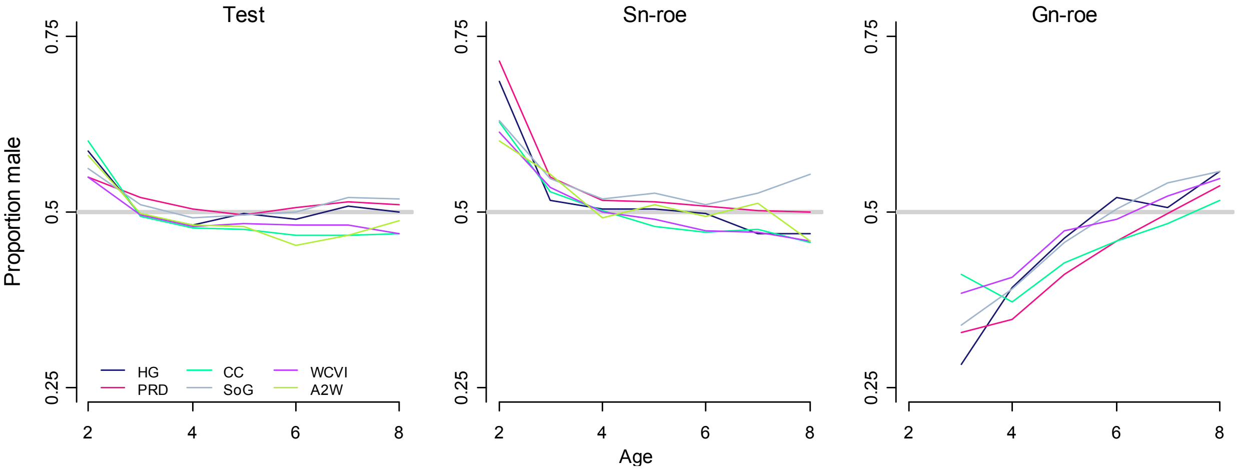

Figure 7: Proportion male in test, Sn-roe, and Gn-roe fisheries by SAR. Proportions are averaged over all years.

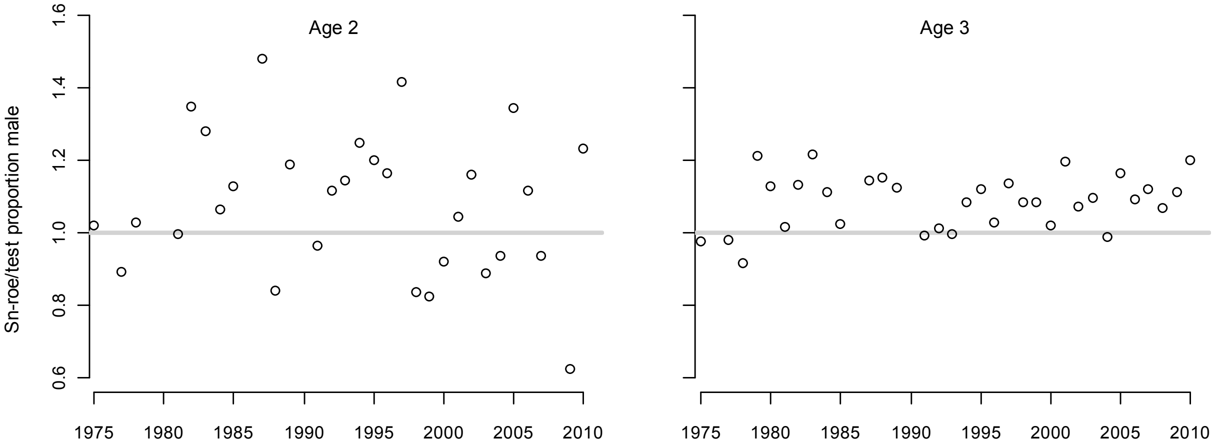

Figure 8: Ratio of Sn-roe to test fishery proportion male over time for age 2 and age 3 fish from the Strait of Georgia.

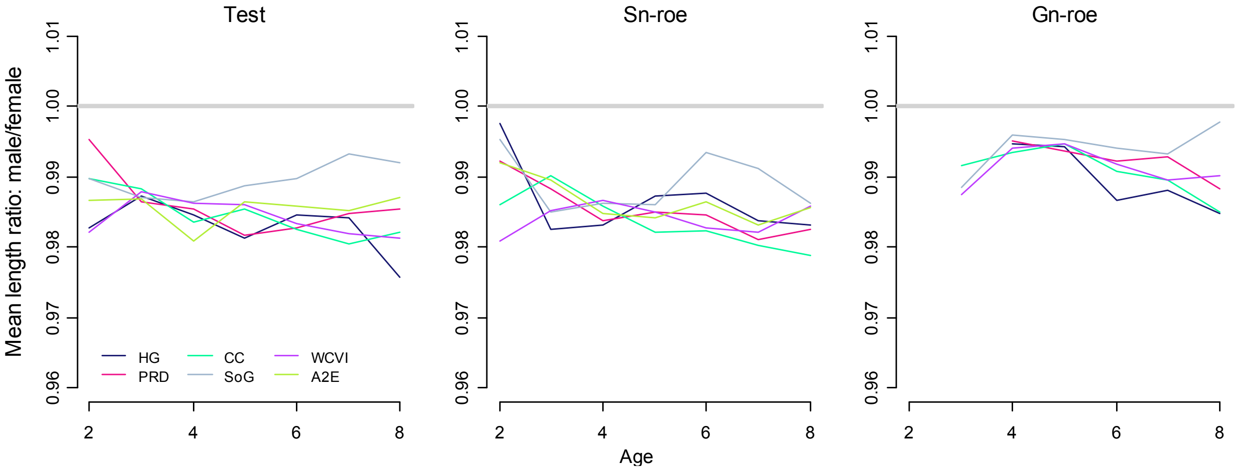

Figure 9: Ratio of male to female mean length-at-age for test, Sn-roe, and Gn-roe fishery samples, by SAR.

3 RELATIVE GSI TO PREDICT TIME OF SPAWNING

Ware and Tanasichuk (1990) developed a method to forecast when female B.C. herring are fully ripe, and hence when spawning may be initiated. It may be feasible to use their approach to predict the time of spawning for individual herring samples and thus associate the samples with spawn events. Potentially this could provide a basis for weighting test fishery samples relative to the proportion of the total spawn biomass they represent.

Ware and Tanasichuk (1990) noted that maximum ovary size is size-dependant, and developed a relationship to predict the maximum gonadosomatic index (GSI = ovarian weight/body weight) as a function of fish size. For fish samples that were previously frozen, the predicted maximum GSI (*Q*) is given by: $Q = 7.28W^{0.26}$ where *W* is total body weight (Ware and Tanasichuk 1990). The linear increase in GSI relative to the maximum (*Q*) was used to predict the date of maximum maturity. Additional complexity in forecasting spawn timing arose because some samples are comprised of fish in different maturity groups (maturing at different rates) and fish sometimes attain their maximum maturity and hold at that level for some time before a spawn event is initiated (Ware and Tanasichuk 1990).

Size-specific differences in GSI are well supported by herring bio-sampling data (Figure 10). These size-specific differences appear to hold throughout the maturation period. Patterns in GSI development differ among areas and years: in some cases the samples appear to represent a homogeneous group with a consistent increase in GSI over time (see Central Coast, 1994, Figure 10); in other cases the samples appear to comprise different maturity groups representing earlier and later spawners (see West Coast Vancouver Island, 1982, Figure 10).

The theoretical size-specific maximum GSI of Ware and Tanasichuk (1990) provides a basis to standardize the GSI of individual fish in a sample. That is, the ratio GSI/Q should approach 1 for all fish as they attain full maturity. This relative GSI measure was calculated for all Sn-caught fish (Sn-roe and test fisheries), and summarized by the mean for each sample. Sample selection was as described in Appendix A, however only females with developing or mature gonads (maturity stages III through VI) were selected. Gonad weight data were not collected from 1975 to 1981.

Results indicate that the theoretical maximum size-specific GSI of Ware and Tanasichuk (1990) is not appropriate for all years and areas. The sample mean relative GSIs generally increase substantially beyond 1 (Figures 11 to 16), suggesting significantly higher GSIs at full maturity and spawning in many years/areas. Ware and Tanasichuk (1990) estimated their theoretical maximum from a sample of fish collected in the northern Strait of Georgia in 1984. It is possible that their sample did not contain adequate numbers of large fish, or that the maximum GSI is area and or time dependent. If a GSI-based approach is to be used to predict earliest potential spawning dates for samples of maturing herring, more work would be required to understand the factors that determine the maximum GSI.

Although the formula used to calculate theoretical maximum GSI does not appear to be appropriate, the relative GSI, which adjusts for individual fish size, may be a useful index of the relative maturity of fish samples. Minimally, it should provide an indication of fish samples that have significantly less developed gonads that will likely spawn later.

Note that during the CSAP review meeting, R. Tanasichuk provided an alternative equation for predicting the size-specific maximum GSI for B.C. herring. Some preliminary analyses were conducted to see if this equation provided more consistent estimates of the maximum GSI. With the revised predictor there were still significant numbers of samples with mean relative GSI values greater than 1, indicating additional work is required to investigate factors affecting maximum GSI. A summary of that analysis is presented in Appendix B.

Figures 11 through 16 show the sample mean relative GSIs and the cumulative density of spawn deposition for each SAR and year. These figures may be useful to select years in which biological sampling continues through the period when most of the spawn was deposited, and hence the samples can be assumed to reflect the spawning populations.

In some years and SARs, the bio-sample data indicate a fairly homogeneous body of fish at similar maturity states and maturing at similar rates (eg. 1986 and 1994 in CC, Figure 13; 1994 and 2003 in SoG, Figure 14). In other instances, there appear to be groups of fish at different maturity stages that will likely spawn at different times (eg. 1983 and 2009 in PRD, Figure 12; 1983 and 2009 in CC, Figure 13).

There are numerous examples where sampling continues past the 75th quantile of spawn deposition, and/or there are samples of fish with low relative GSI at the end of the sampling period indicating they will spawn at a later date (eg. 1990 and 2002 in HG, Figure 11; 1990, 1994, and 2002 in PRD, Figure 12; 1983, 1987, and 1994 in CC, Figure 13; 2000 and 2010 in SoG, Figure 14; 1985 and 1999 in WCVI, Figure 15). Potentially, these data may reflect the spawning population. Also, there are many examples where the sampling period terminates well before the completion of spawning and inferences about the bio-sampling data representing the spawning populations would be inappropriate.

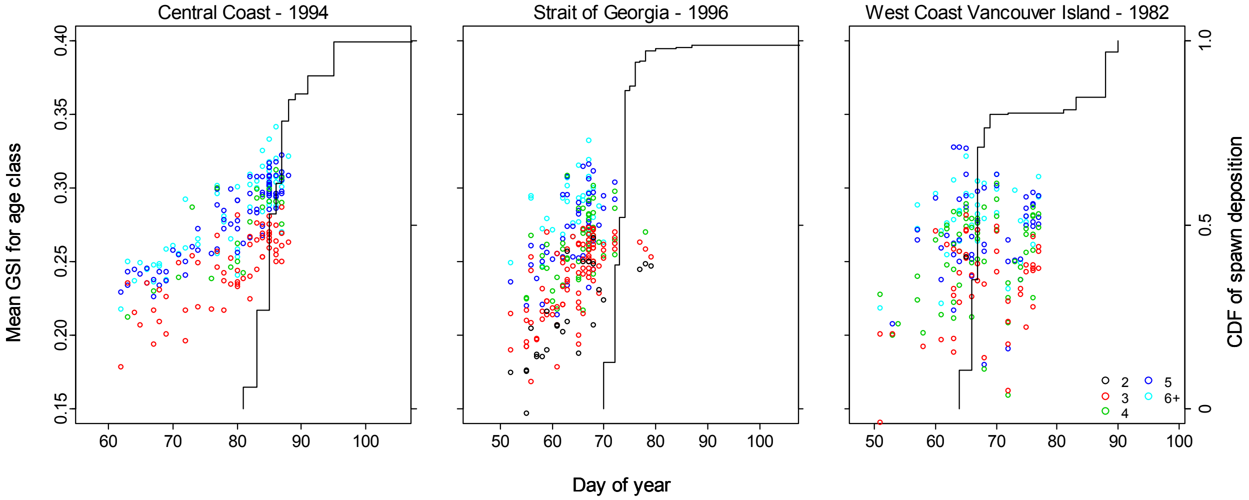

Figure 10: Mean age-specific GSI by day of year and the cumulative density function (CDF) for spawn deposition (solid black line) for herring samples collected in: Central coast, 1994; Strait of Georgia, 1996; and West coast of Vancouver Island, 1982. The symbol colour indicates the age-class.

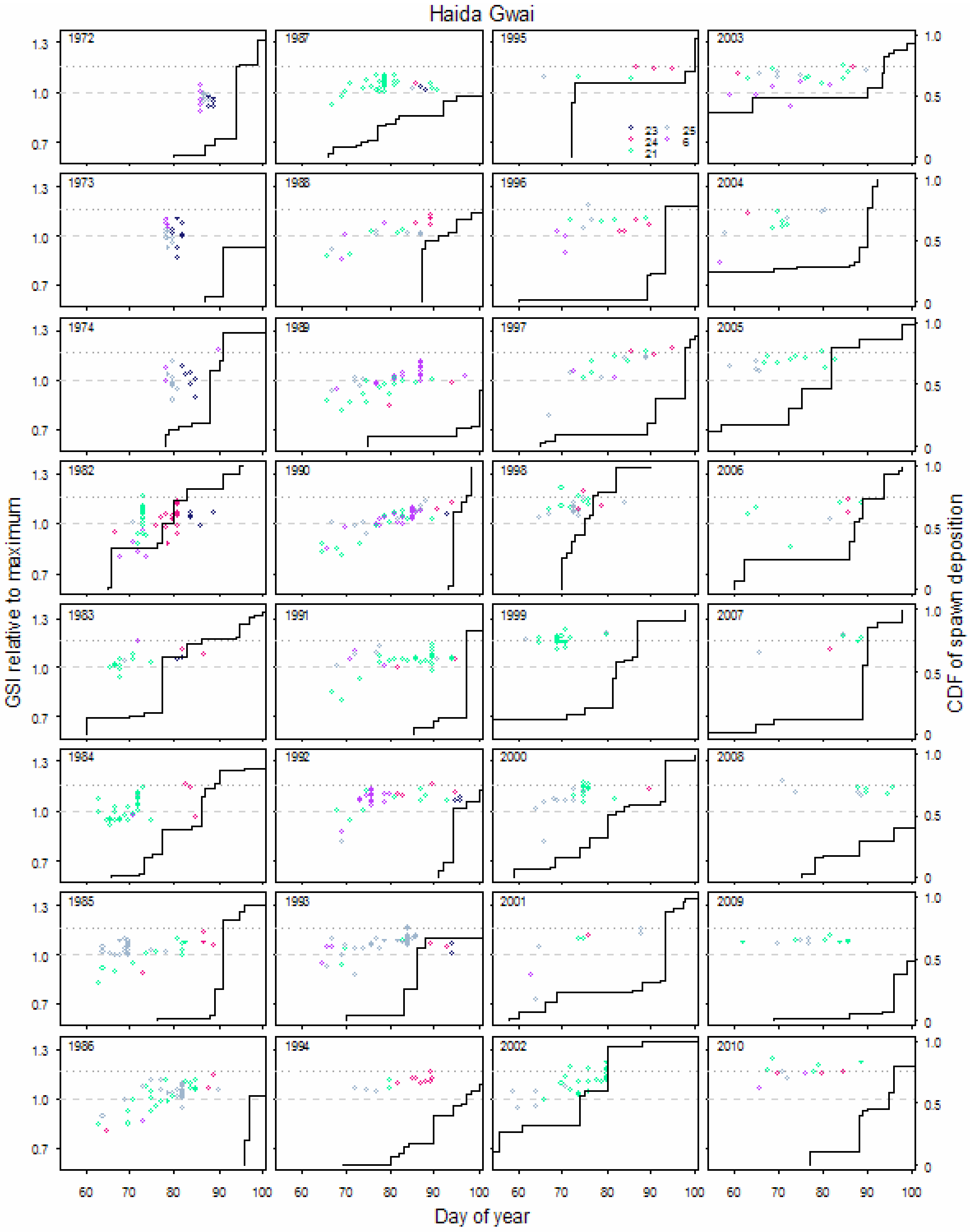

Figure 11: Mean of relative gonadosomatic index (GSI/Q) by herring sample and cumulative density function (CDF) of spawn deposition by day of year for the Haida Gwai stock assessment region, 1972-2010. The two dashed horizontal lines indicate a relative GSI of 1 and the 0.75 quantile of spawn deposition.

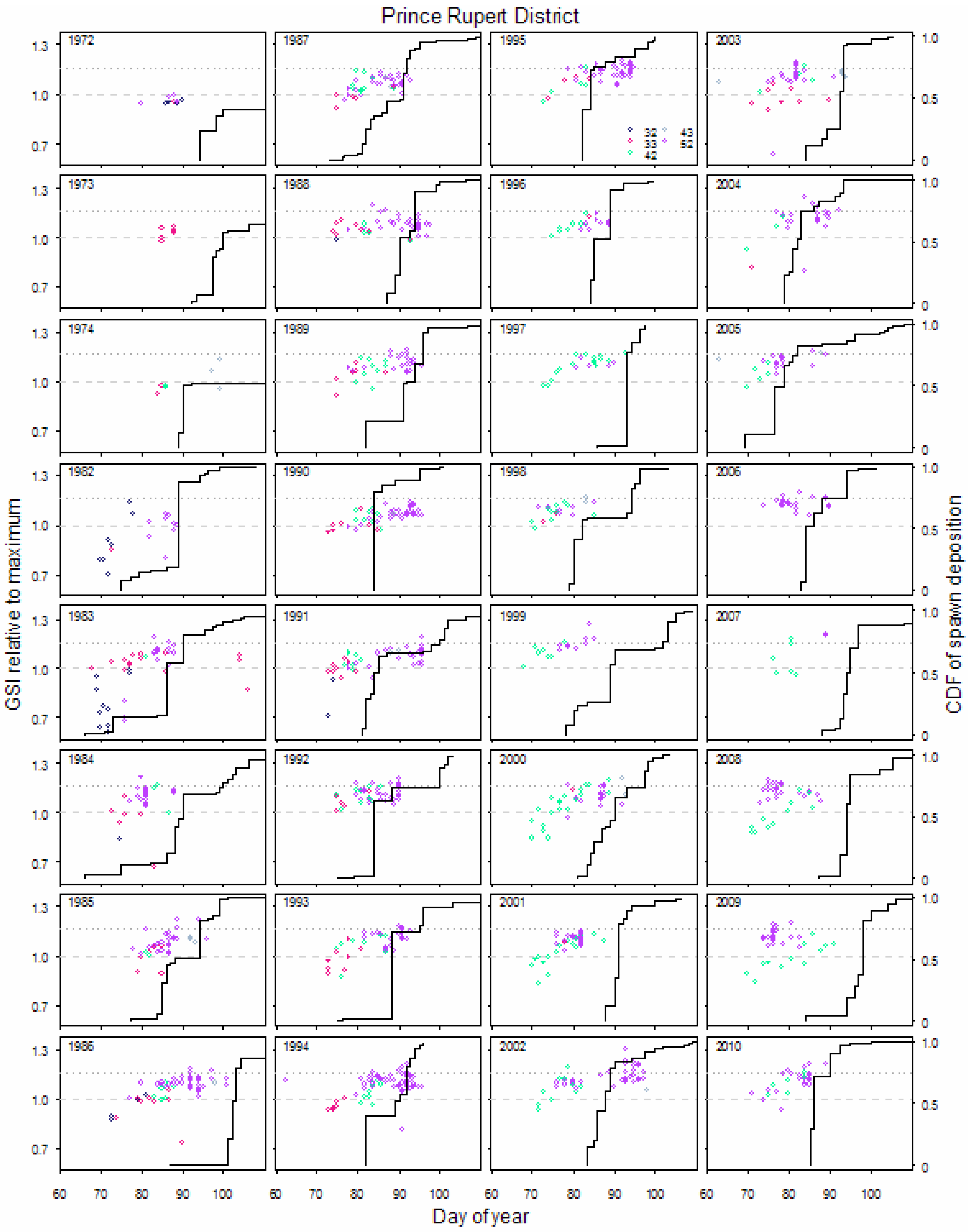

Figure 12: Mean of gonadosomatic index (GSI) relative to estimated maximum by herring sample and cumulative density function (CDF) of spawn deposition by day of year for the Prince Rupert District stock assessment region, 1972-2010. The two dashed horizontal lines indicate a relative GSI of 1 and the 0.75 quantile of spawn deposition.

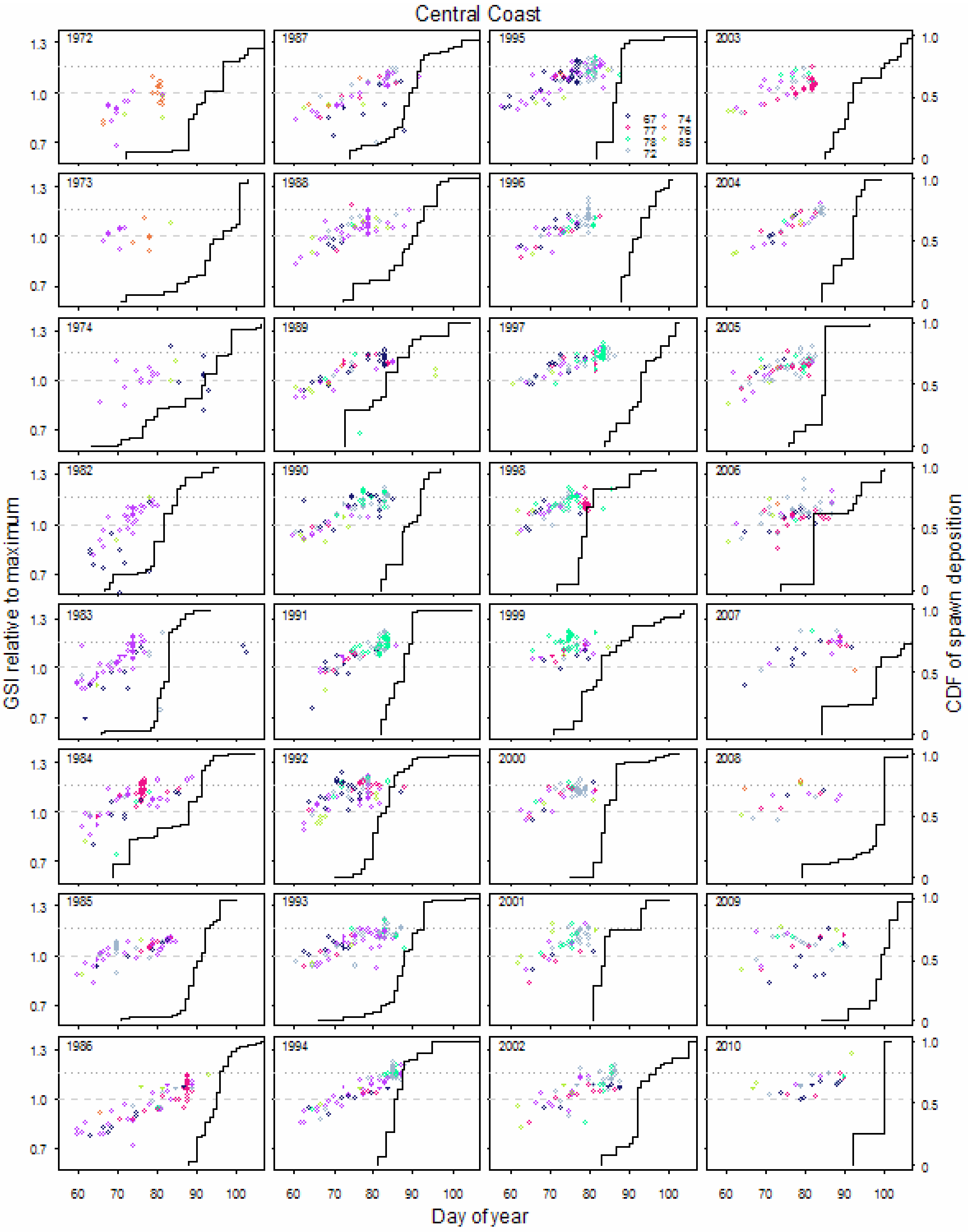

Figure 13: Mean of gonadosomatic index (GSI) relative to estimated maximum by herring sample and cumulative density function (CDF) of spawn deposition by day of year for the Central Coast stock assessment region, 1972-2010. The two dashed horizontal lines indicate a relative GSI of 1 and the 0.75 quantile of spawn deposition.

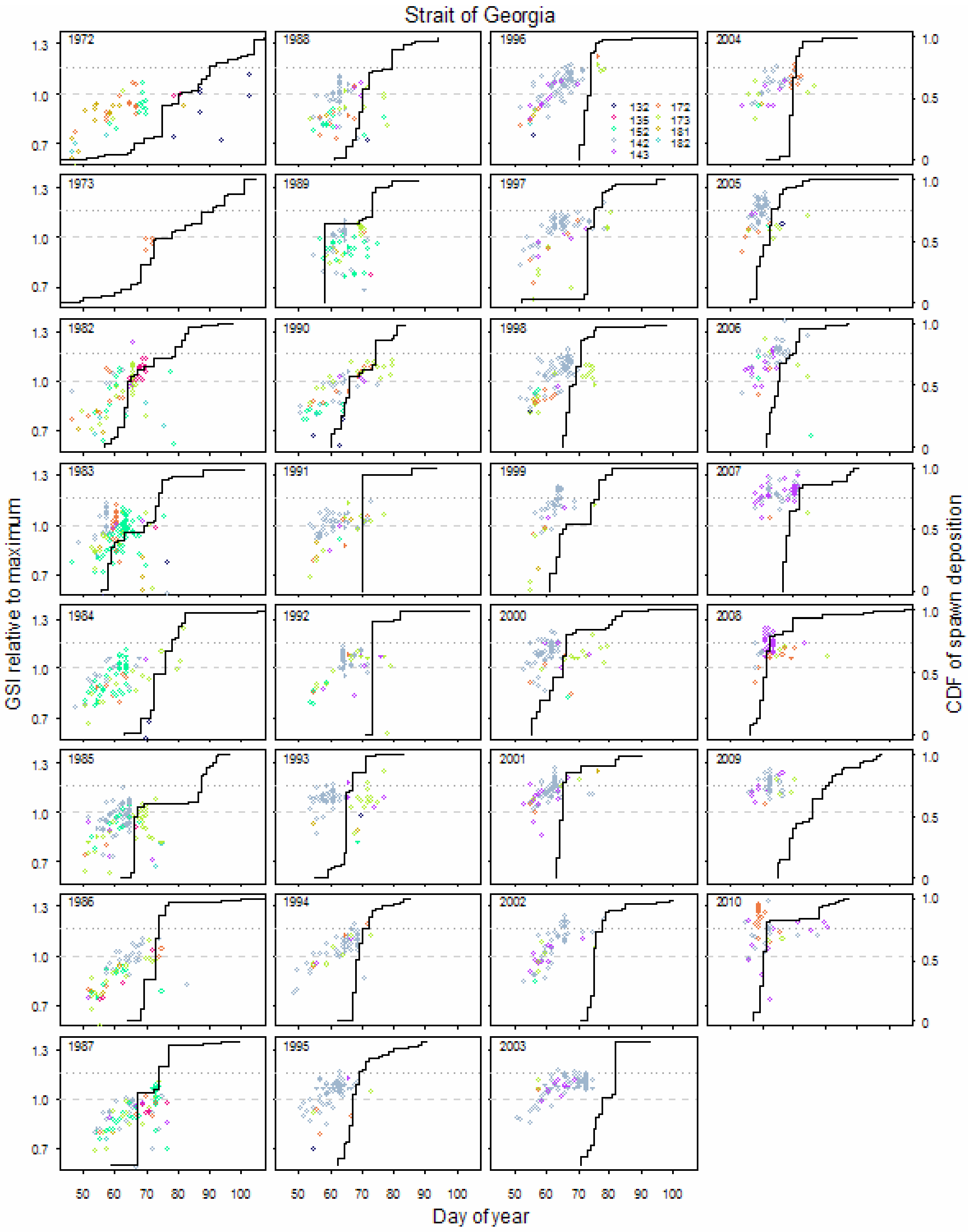

Figure 14: Mean of gonadosomatic index (GSI) relative to estimated maximum by herring sample and cumulative density function (CDF) of spawn deposition by day of year for the Strait of Georgia stock assessment region, 1972-2010. The two dashed horizontal lines indicate a relative GSI of 1 and the 0.75 quantile of spawn deposition.

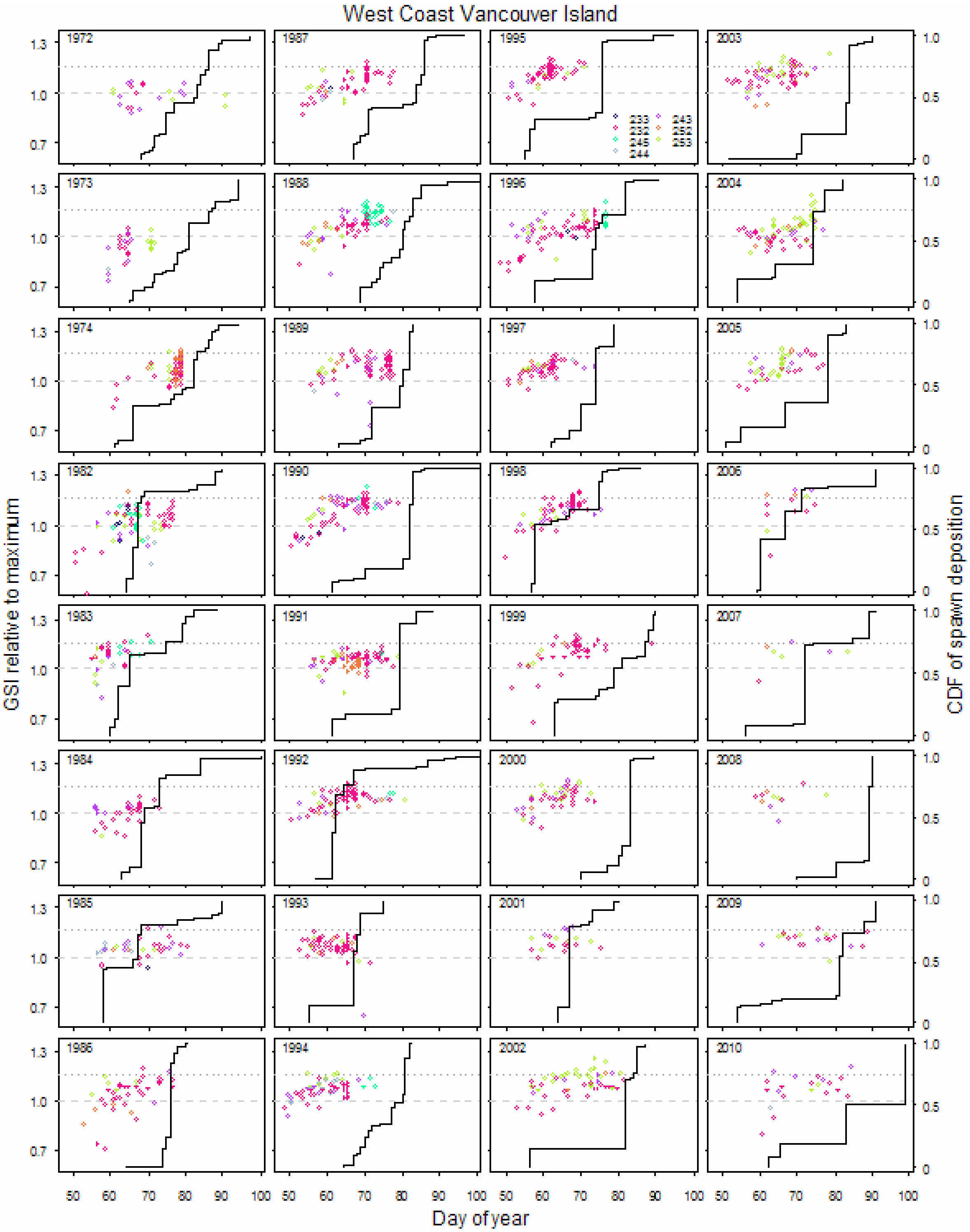

Figure 15: Mean of gonadosomatic index (GSI) relative to estimated maximum by herring sample and cumulative density function (CDF) of spawn deposition by day of year for the West Coast Vancouver Island stock assessment region, 1972-2010. The two dashed horizontal lines indicate a relative GSI of 1 and the 0.75 quantile of spawn deposition.

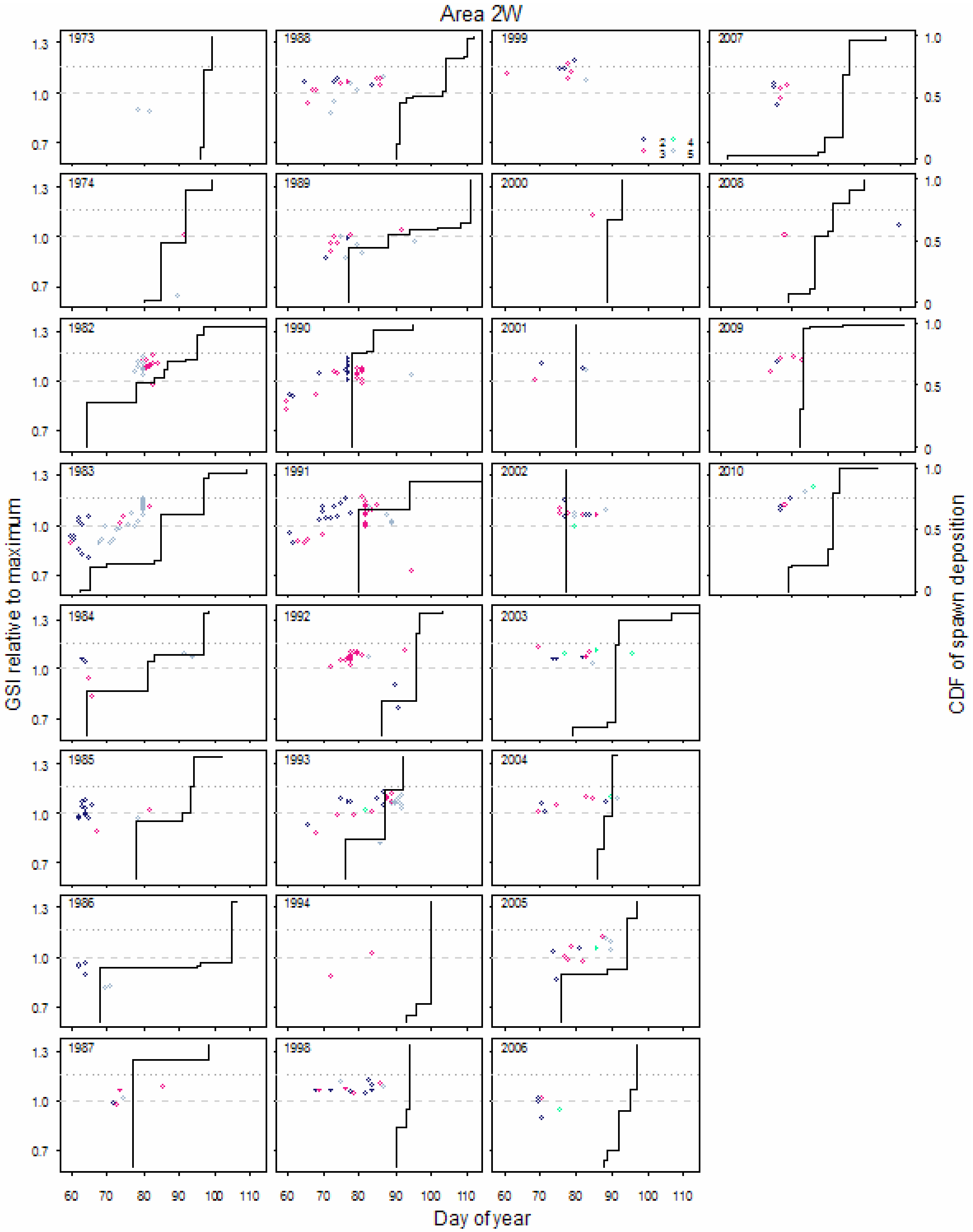

Figure 16: Mean of gonadosomatic index (GSI) relative to estimated maximum by herring sample and cumulative density function (CDF) of spawn deposition by day of year for the Area 2W stock assessment region, 1972-2010. The two dashed horizontal lines indicate a relative GSI of 1 and the 0.75 quantile of spawn deposition.

3.1 PREDICTING RELATIVE GSI WITH LMS

Linear models (LMs) were fitted to the sample relative GSI data to investigate co-variates that might explain the patterns in the relative GSI. Simple additive models were used, and a normal error distribution assumed. The co-variates associated with each sample that were tested included: day-of-year (*doy*), year (*yr*), section (*sec*), cluster associated with sample (*clus*, see section 2.14.), average fish weight (*wt*), and average age (*age*). Only mature or maturing female fish were used to calculate average fish weight and average age. Year, section, and cluster were treated as categorical variables. Cluster was tested only as an interaction term with year, and section was tested both as an additive term (not presented) and as an interaction term with year. The LMs were fitted separately to data from each SAR.

AIC was used as the basis for selecting the model that provided the best balance between model complexity and parameter parsimony. The sequence of models presented is (interaction terms are noted with colons):

M1: *doy*
M2: *yr* + *doy*
M3: *yr:sec +doy*
M4: *yr:clus +doy*
M5: *yr:clus* + *doy* + *wt*
M6: *yr:clus +doy* + *wt* + *age*
M7: *yr:clus:sec* + *doy* + *wt +age*

The increasing more complex models are generally preferred, based on the AIC criterion (Table 7). For all SARs except SoG, including cluster in the LM is preferred over including section (compare M3 and M4 in Table 7). It is interesting that the cluster structure developed on the basis of commonality in age-frequencies, to some extent also accounts for differences in ovary maturity.

For all SARs, LMs that include mean weight and mean age are preferred over models without these co-variates. In theory, the relative GSI metric should account for size-based differences in maturity, but the decrease in AIC when these terms are included in the LMs suggests this is not the case (compare AIC for models M5 and M6 with model M4 in Table 7). The increase in R^2 when the mean weight and mean age terms are added to the LM is quite small for the 3 northern SARs, but substantially larger for the 2 southern SARs (compare R^2 for models M5 and M6 with model M4 in Table 7). The most complex model, M7, is the preferred model for all the SARs. This model includes a year-cluster-section interaction term suggesting both clusters and sections account for variability in the relative maturity state of samples.

Parameter estimates for the additive terms in model M7 are relatively consistent among the SARs (Table 8). With the exception of the CC SAR, the *doy* parameters all suggest an average daily increase in relative GSI of about 0.005. For the CC the rate of increase in GSI appears to be higher. The parameter estimates suggest that higher mean weight results in higher relative GSI and higher mean age results in lower relative GSI (Table 8). These results support the conclusion that the Ware and Tanasichuk (1990) equation for predicting maximum GSI based on fish weight does not fully account for variation in maximum GSI.

Table 7: AIC and R^2 values from LMs fitted to sample-specific relative GSI estimates.

	AIC					R^2				
Model	HG	PRD	CC	SoG	WCVI	HG	PRD	CC	SoG	WCVI
M1	-1636.2	-1643.0	-3485.6	-1048.3	-2814.8	0.067	0.070	0.249	0.007	0.063
M2	-2000.8	-1891.9	-4032.4	-1900.7	-3118.1	0.466	0.299	0.472	0.361	0.262
M3	-2179.7	-2164.6	-4366.9	-2331.1	-3262.0	0.658	0.518	0.635	0.549	0.421
M4	-2225.4	-2824.9	-4721.9	-2150.2	-3324.8	0.675	0.738	0.682	0.495	0.429
M5	-2239.2	-2909.6	-4822.9	-2411.7	-3489.8	0.681	0.758	0.700	0.555	0.488
M6	-2241.9	-2920.3	-4831.1	-2456.2	-3515.9	0.683	0.760	0.702	0.565	0.498
M9	-2315.8	-3045.4	-5180.0	-3226.0	-3809.4	0.770	0.818	0.818	0.771	0.680

*Table 8: Parameter estimates for day-of-year (*doy*), mean weight (*wt*) and mean age (*age*) parameters estimated for linear models (M7) fitted to sample mean GSI for the major SARs.*

	HG	PRD	CC	SoG	WCVI
Doy	0.0059	0.0047	0.0086	0.0056	0.0049
Wt	0.0011	0.0016	0.0014	0.0064	0.0028
Age	-0.0099	-0.0157	-0.0217	-0.0953	-0.0616

Table 9: Estimates of the range in days on which individual herring samples attain the same relative GSI, based on model M7, by SAR and year.

Year	HG	PRD	CC	SoG	WCVI
1972	29.4	1.1	28.0	122.8	43.8
1973	22.2	1.6	6.0	0.0	22.9
1974	15.5	21.1	60.3		23.7
1982	68.0	131.3	78.9	133.8	177.1
1983	29.8	145.8	84.6	158.8	54.5
1984	29.4	124.3	36.2	159.7	30.0
1985	76.5	114.7	11.8	167.1	44.0
1986	12.9	141.1	82.6	99.9	62.2
1987	12.0	29.8	111.0	150.9	25.8
1988	19.6	21.1	34.4	91.8	112.9
1989	22.1	106.1	44.7	81.5	98.0
1990	16.6	21.0	11.6	116.1	78.0
1991	23.9	53.5	27.5	36.3	39.8
1992	24.5	22.3	14.7	22.8	28.0
1993	42.9	18.5	27.2	20.8	92.6
1994	4.6	149.0	8.5	15.4	38.0
1995	20.6	7.6	15.7	30.7	13.3
1996	33.1	9.2	15.4	48.5	45.1
1997	32.9	7.3	17.0	48.9	9.6
1998	24.6	17.4	13.2	38.0	16.1
1999	9.1	6.8	22.1	45.1	87.1
2000	39.0	53.3	9.5	43.4	20.8
2001	51.3	41.6	30.4	43.4	15.2
2002	14.3	31.6	27.7	26.6	58.2
2003	42.7	50.6	9.8	30.6	24.7
2004	40.1	41.8	7.0	32.9	24.4
2005	8.7	27.8	18.1	20.1	24.8
2006	18.6	0.8	25.0	103.2	63.0
2007	11.5	31.2	38.5	19.4	39.0
2008	29.8	24.0	26.7	44.7	30.8
2009	4.8	32.1	33.7	32.0	9.7
2010	18.3	16.4	21.9	39.6	69.3

Mean year effects were estimated as the mean of the interaction terms *yr:clus:sec* for each year. Then, cluster-section effects (*clus:sec*) were calculated by removing the mean year effect from the *yr:clus:sec* terms. Finally, the difference between the maximum and minimum of the *clus:sec* effects for each year, divided by the day-of-year term (*doy*), provides an estimate of the range in date on which samples attain the same relative GSI. This measure may be indicative of the range in spawning dates implied by the relative GSI across all samples collected in a given SAR and year.

The estimated year effects show an increasing trend over time for all SARs (Figure 17). This implies that for a given day-of-year the relative GSI is higher in recent years than in earlier years. This could result from a trend towards earlier spawning, but the spawning date data do not support that conclusion. Likely, the apparent trend is associated with the Q-wt relationship that was assumed to estimate the relative GSI for individual fish. If this relationship has changed over time, or if is not correctly adjusting for size effects, then the relative GSI measures would not be comparable among years. There may be effects that are related to the general trend of smaller fish size-at-age (Schweigert et al. 2002).

The estimated range in dates when individual herring samples attain the same relative GSI are given in Table 9. A number of the estimates appear implausible (i.e. >100 days). There are a number of potential reasons for this, including: the *doy* parameters, estimated as averages across all years, do not account for inter-annual variation in maturation rates; and, some samples contain fish that will not mature that year.

The linear GSI modelling results presented here are not intended to be definitive, but rather to show the potential for this approach in predicting the earliest potential spawn dates for biological samples. The maturation process is likely more complex than described by the models presented. The theoretical maximum GSI, developed by Ware and Tanasichuk (1990), clearly needs further work to account for discrepancies between the predicted and observed maxima.

Ideally, LMs would be fitted to the individual fish GSI measurements rather than the sample mean relative GSI, and weight and age effects estimated from the combined data. This would allow an exploration of the factors that influence the maximum GSI, and potentially allow association of samples with spawning events. The analyses presented here demonstrate the potential for this approach, however further work is beyond the scope of this paper.

4 SAMPLE WEIGHTING FOR STOCK ASSESSMENTS

Past herring stock assessments have combined the Sn-roe and test fishery samples to estimate the age composition of a “combined” Sn fishery. Each sample is treated as a simple random sample, with no weighting to reflect the proportion of the catch or fraction of the population the sample represents. A recent review of the herring stock assessment model suggested the Sn-roe and test fishery age composition data be treated as separate fisheries in the assessment model. This approach is supported by analyses presented here which indicate the Sn-roe fisheries are selective for older fish. The sample weighting considerations presented here assume the roe fishery data will be treated separately from test fishery data in stock assessments.

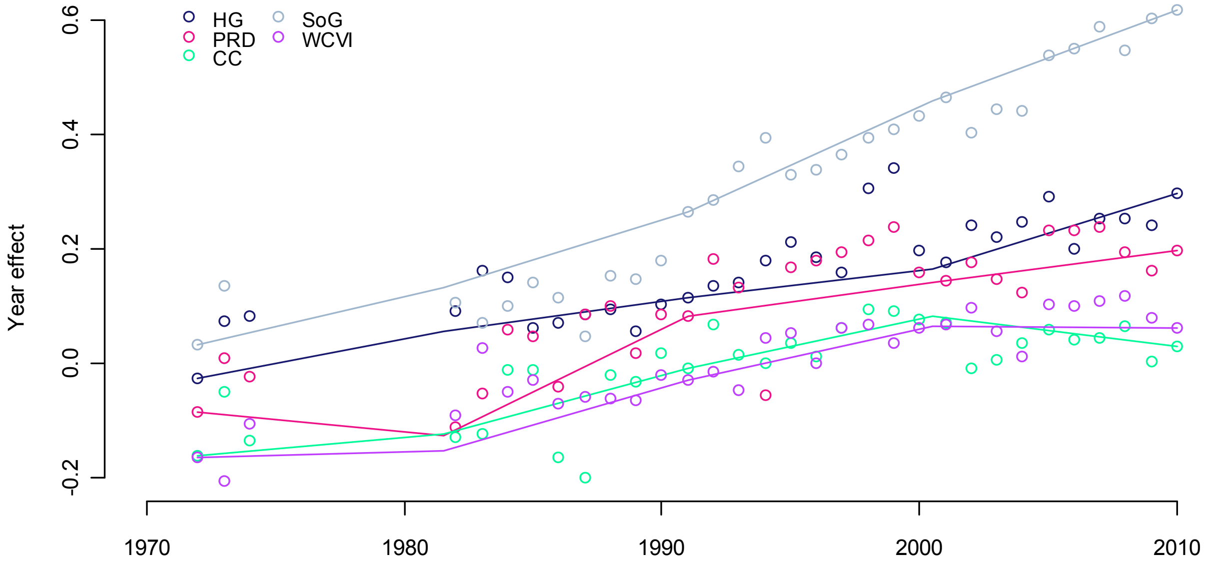

Figure 17: Estimated "year" effects from model M7 fits to relative GSI data, by SAR and year. The lines were fitted using a spline interpolation.

4.1 ROE FISHERIES

For stock assessments, a standard approach for weighting catch sample data is to stratify fisheries by spatial, temporal, or gear attributes that may affect the age-composition and weight the strata age compositions by the relative amount of catch in each stratum. Individual samples may be weighted by the fraction of the catch that was sampled. This approach adjusts for non-random sample selection, and should result in age composition estimates that reflect the actual removals by the fisheries. When there are major differences in fishery selectivity (or vulnerability) due to gear selectivity and/or other spatial or temporal patterns related to fish behaviour, assessment models generally account for the differences by modelling multiple fisheries and estimating separate selectivity parameters for each fishery.

The B.C. herring stock assessment model assesses three fisheries: Sn-roe, Gn-roe, and "other" fisheries. The "other" fishery category is predominantly comprised of pre-1970 reduction fishery catch and more recently food and bait catch. Biological samples collected from the herring fisheries are treated as simple random samples of the overall catch (no sample weighting). Temporal or spatial stratification of the fisheries and biological sampling data may result in age compositions that better reflect the actual removals by the fisheries. Investigation of potential spatial or temporal stratification of the herring fishery age frequency data is limited here to analysis of the Sn-roe fishery.

Herring Sn-roe fisheries have varied in the spatial and temporal extent of openings over the history of the fishery. During the 1970s fishery openings generally encompassed a number of herring sections and extended over multiple days (see sample collection patterns, Appendix Figure 1). During the 1980s and 1990s openings were generally geographically limited (a single section) and of short duration (less than a day). With the inception of "pool" fisheries in 1998, the spatial and temporal extent of the Sn-roe openings increased.

Historically, sample collection guidelines specified 10 samples for each Sn-roe opening and 6 samples for each Gn-roe opening. This protocol changed in 2007 to account for the broader spatial and temporal range of the pool fisheries. Since then the protocol has been to obtain 20 samples from each Sn-roe opening and 12 samples from each Gn-roe opening. The definition of "opening" is necessarily vague - does a fishery that has two openings in a single day within a limited geographic area count as two openings? Where multiple openings are sampled, sampling is not proportional to the catch.

To investigate the potential to stratify the Sn-roe herring catch and bio-sampling data, catch (from the PBS catch database) and biological sampling data were stratified by section and date. Frequently there is very poor overlap in recorded catch dates and the recorded biological sampling dates. Also the sections to which herring catch is attributed are not always consistent with the sections attributed to biological samples (see Appendix Table 1).

Additional information on Sn-roe fishery openings is available from the Roe Herring Integrated Fisheries Management Plan (IFMP, DFO 2010). The IFMP provides a general description of the area opened for each fishery – herring sections were inferred from these descriptions, but these could be incorrect.

There are considerable inconsistencies among the three information sources – IFMP, PBS catch database, and PBS biological sampling data base (see Appendix Table 1). In general, the IFMP fishery opening dates are consistent with the dates attributed to the biological samples. In many years it appears that the PBS catch database reports landing dates rather than fishery dates. In general, the IFMP reported total catches are consistent with the PBS catch database total catches, but there are inconsistencies here as well.

Given the inconsistencies among the information sources on the dates and locations of herring catch, there is no basis at this time for stratifying the herring Sn-roe fishery data. The current approach of weighting all samples equally is likely the best approach until the inconsistencies in the catch data can be resolved.

4.2 TEST FISHERIES

If test fisheries are to be treated as separate fisheries in the herring stock assessment models, questions arise about how individual samples should be weighted and what assumptions made about the selectivity of the fisheries. Over the history of this fishery, the sampling period has been highly variable relative to the spawning period (see Figures 11 to 16). For some years it may be reasonable to assume that test fishery age compositions reflect the age composition of spawning fish, but for other years this assumption would be inappropriate. One option would be to use only the age composition data from years where the sampling period covers the majority of spawn events.

In addition to determining the appropriate modelling assumptions for the test fishery, an appropriate process for weighting the individual samples is required. Ideally, there would be a basis for weighting the age compositions of the clusters (of similar age compositions, see section 2.1.4), relative to the fraction of the population represented by the cluster. However, information to support this form of weighting is not available.

Two feasible options for weighting the test fishery sample age composition data are: 1) assume each sample is a random sample from the population and weight each sample equally, or 2) weight the age composition estimates for each section by the proportion of the total spawn in that section. Neither approach is ideal. The two approaches could potentially generate very different age compositions for some years, as suggested by the differences in the distribution of samples by section and the distribution of spawn by section (Appendix Figure 2).

No suggestions are made here about how test fishery data should be incorporated into herring stock assessment models. Rather, the issue is raised to promote consideration and discussion of the topic.

5 SAMPLE SIZE CONSIDERATIONS

The cluster analysis (section 2.1.4) generally resulted in more than one cluster being formed for each Sn-roe and test fishery when fisheries are defined as they are used in the stock assessment model – that is, all samples collected in a SAR each year. This implies extra multinomial heterogeneity. The actual standard errors of the estimated proportions-at-age will be greater than expected from random sampling of a multinomial distribution. In this section sample size considerations are explored. In particular, 1) has the precision of the proportion-at-age estimates changed over time, and 2) how would decreases in sampling effect the precision of the proportion-at-age estimates.

Ideally, sample size considerations would include an objective basis for weighting samples relative to the proportion of the catch or the proportion of the stock abundance they represent. At this time there is no objective basis for weighting individual samples, so in the following analyses all samples are treated as simple random samples. Fisheries are defined by SAR and year, that is, all the catch and samples taken by either Gn-roe, Sn-roe, or test fisheries in a SAR and year.

5.1 PRECISION OF AGE FREQUENCIES

For each Sn-roe fishery, the standard deviations of the proportions-at-age (among samples) are compared with the theoretical standard deviations based on multinomial sample sizes of 20 or 100 fish (Figure 18). In general the standard deviations are consistent with between 20 and 100 aged fish per sample.

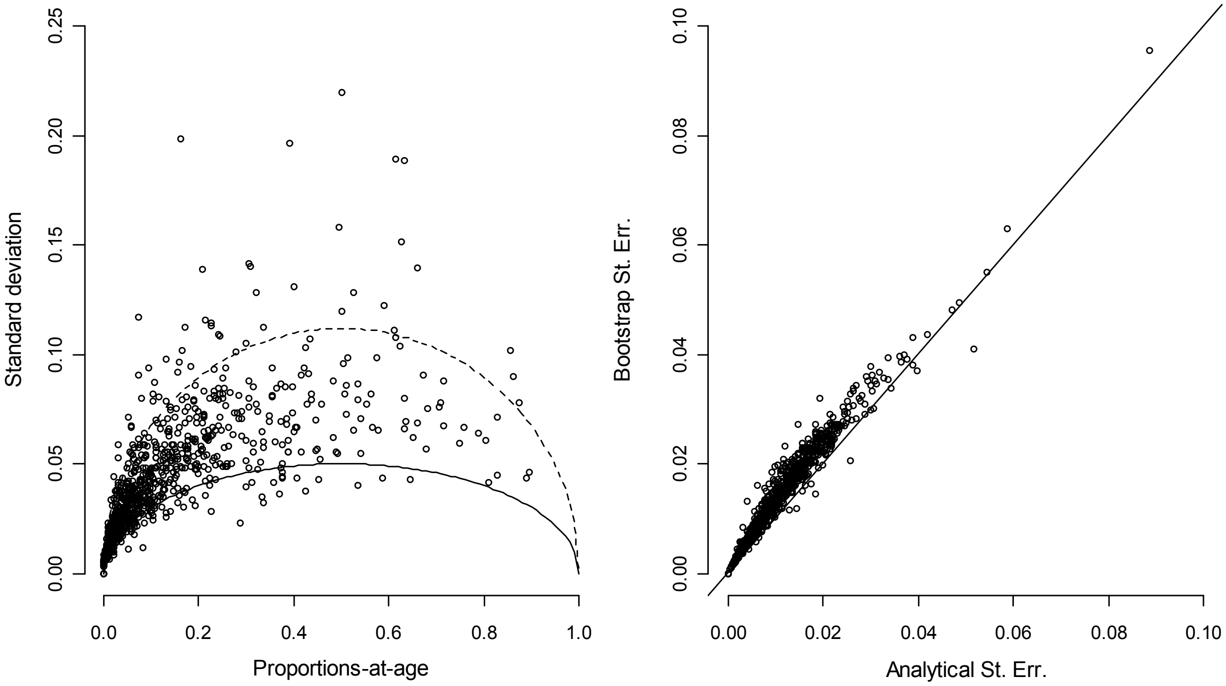

Figure 18: Left panel - standard deviations versus mean proportion-at-age, and the expected standard deviations for multinomial samples of 20 (solid line) and 100 (dashed line). Right panel – analytical versus bootstrap estimates of the standard error of the mean proportions-at-age. Data are from all Sn-roe fisheries, 1972-2010.

Bootstrap estimates (Efron and Tibshirani 1998) of the standard errors of the proportions-at-age were calculated using the following procedure. Given a fishery with *N* samples collected and each sample *i* comprised of n_i aged fish $(i = 1, 2, 3 \ldots N)$:

1) Randomly re-sample *N* samples with replacement.
2) For each random sample *i*, randomly sample from the n_i aged fish, with replacement.
3) Calculate the mean proportions-at-age for the *N* random samples.

The bootstrap procedure is repeated 1000 times, and the standard deviation of the proportions-at-age provides the bootstrap estimate of their standard errors.

Analytical and bootstrap estimates of the standard errors of the proportions-at-age for the Sn-roe fisheries are compared in Figure 18. In general the bootstrap estimates are higher than the analytical estimates, suggesting the data contain more outliers than expected given multinomial distributions. The bootstrap procedure is used to estimate precision in the following analyses.

For each fishery, a simple summary statistic that reflects the overall precision of the sample is more useful than the set of standard error estimates for each of the proportions-at-age. Chih (2010) proposes such a statistic based on the effective sample size statistic of McAllister and Ianelli (1997). The effective sample size (*EffN*) is calculated by comparing the variance that would be expected with simple random sampling from a multinomial distribution with the variance observed from bootstrap re-sampling. *EffN* is calculated as (Chih 2010):

$$EffN = \sum_{j=2}^{j=8} \left(\frac{\overline{p}_j \left(1 - \overline{p}_j\right)}{SS_j} \right)$$

$$\text{where:} \quad \overline{p}_j = \frac{\sum_{i=1}^{N} p_{ij}}{N}, \quad SS_j = \frac{\sum_{k=1}^{K} \left(p_{kj} - \overline{p}_j\right)^2}{K},$$

p_{ij} is the proportion at age j in sample i,
N is the number of samples,
p_{kj} is the proportion at age j in bootstrap replicate k, and
K is the numer of bootstrap replicates.

The ratio of the *EffN* to the actual number of fish aged, *A* $\left(A = \sum_{i=1}^{N} n_i \right)$, is a measure of the over-dispersion of the samples (ϕ) relative to multinomial sampling assumptions.

Estimates of the effective sample sizes (*EffN*), the over-dispersion parameters (ϕ), and the number of samples collected for each fishery (*N*) are shown in Figure 19. *EffN* is a measure of the relative precision of the samples. For the Sn-roe and Gn-roe fisheries there is no indication that the sampling precision has decreased in recent years. In the early years of the fisheries, the sampling precision was lower for the Gn-roe fisheries and lower, but also more variable, for the Sn-roe fisheries.

Lower values for the ϕ parameter indicate greater over-dispersion, with a value of 1 indicating the samples are consistent with random samples from a multinomial distribution. In the early years of the fisheries, when there were more openings with larger spatial and temporal distribution, the data indicate greater over-dispersion for the Sn-roe fisheries and to a lesser extent for the Gn-roe fisheries (Figure 19).

For the test fisheries, there is no obvious time trend in *EffN*, though possibly a slight decrease in the last three years. The *EffN* and ϕ parameter estimates and the actual sample sizes (*N*) tend to be lower for the HG and A2W SARs, suggesting that greater sampling coverage in these areas relative to other SARs may be warranted. The over-dispersion parameter tends to be lower for the test fisheries than for either the Sn-roe or Gn-roe fishery, supporting more intensive sampling for the test fisheries.

5.2 ALTERNATE SAMPLING REGIMES

In this section the question, “how would a decrease in sampling effort affect sampling precision”, is explored.

5.2.1 Sn-roe and Gn-roe fisheries

For all Sn-roe and Gn-roe fisheries since 1999 (beginning of pool fisheries) the sampling precision (*EffN*) is estimated for scenarios assuming there were fewer samples than the actual number collected. The bootstrap procedure described above is used, but the number of randomly selected samples for each trial is replaced *N-k*, where *k* is set to values ranging from 0 to 8. The *N-k* samples are selected from the *N* samples available for each fishery, and the bootstrap procedure is terminated when *N-k* is less than 3.

The relationships between *EffN* and sample size are nearly linear for all the re-sampled fisheries (Figure 20), with some fisheries having higher *EffN* at a given sample size than others (related to the over-dispersion parameter, ϕ).

Sampling precision objectives have not been set for the herring bio-sampling program, but such objectives would be useful to evaluate the effectiveness of the program. For multinomial sample sizes ranging from 100 to 1000, Figure 21 shows the c.v. of proportion estimates for proportions ranging from 0.01 to 0.99. For small proportions, the c.v.s are high unless sample sizes are quite large. This raises the question - for stock assessment purposes, how important is it to have precise estimates of small proportions in the age composition? Given issues related to sample weighting and process error relative to modelling assumptions, precise estimates of small proportions are not likely to be critical. For a proportion of 0.05, effective sample sizes of 300 and 400 result in c.v.s of 0.25 and 0.22, respectively. This is likely adequate for stock assessments. To obtain an *EffN*s of about 300 for the Sn-roe and Gn-roe fisheries, sample sizes between 6 and 12 would generally be adequate (Figure 20).

5.2.2 Test fisheries

To investigate the effect of reduced sampling effort in the test fishery, it is not realistic to simulate a random reduction in the number of samples processed. Reductions in test fishery effort would result in fewer sampling days, which potentially could also reduce the spatial distribution of the samples collected.

The range in the number of days over which samples have been collected historically has been relatively consistent (Figure 22). To simulate a reduction in test fishing effort, only samples collected from the 6th through the 19th day of the actual test fishery sampling period are used to estimate the proportions-at-age. This simulates a 14-day test fishing period, and introduces a bias in the sampled proportions-at-age relative to the assumed “true” proportions-at-age generated from the full sampling period. That is, the calculation of *EffN* will be affected by both sampling precision and bias because the mean proportions-at-age will differ for the 14-day window relative to the full sampling period.

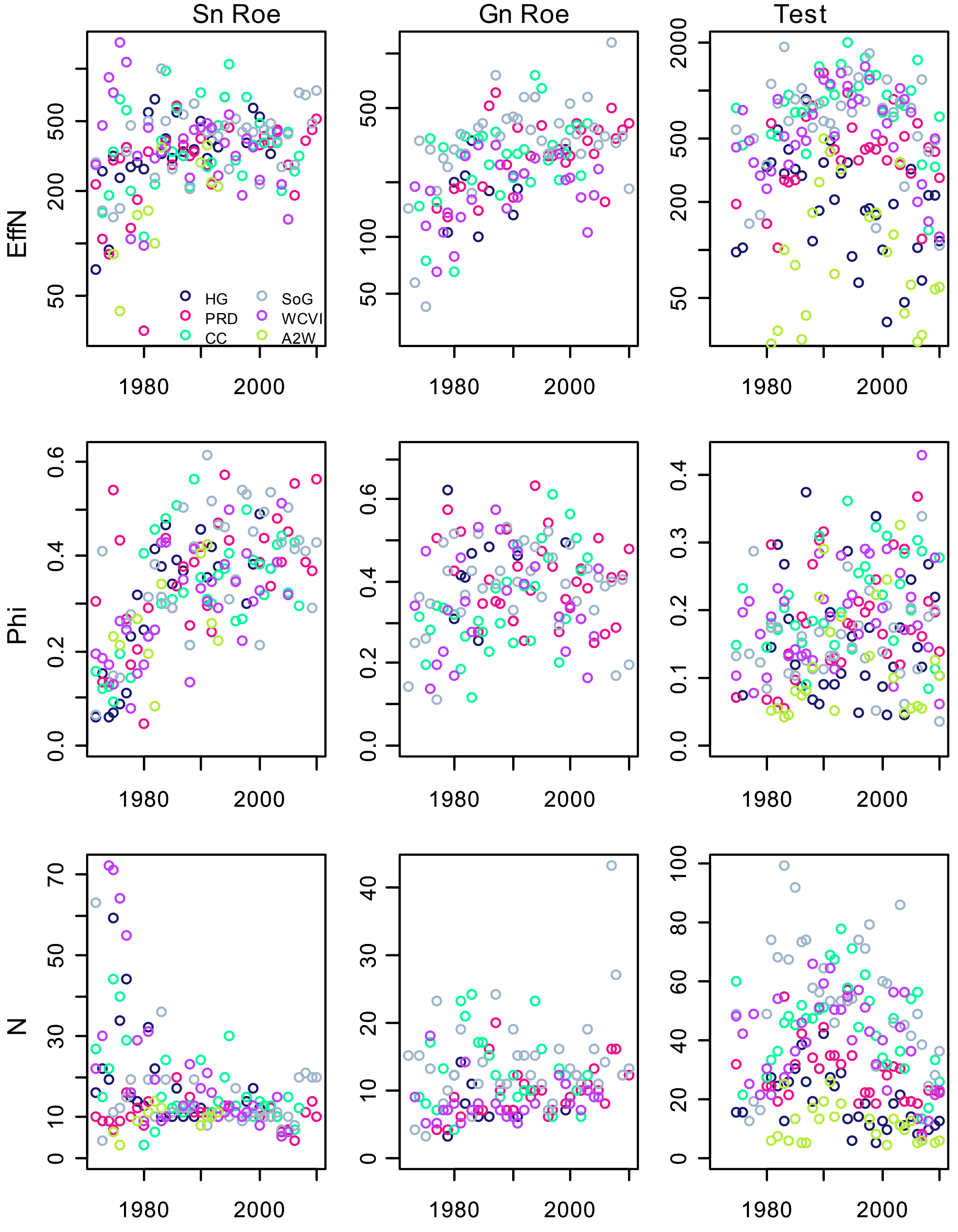

*Figure 19: Estimates of the effective N (*EffN*), the over-dispersion parameter phi (* EffN/A*), and the actual number of samples collected (*N*) for herring Sn-roe, Gn-roe, and test fisheries, by SAR and year.*

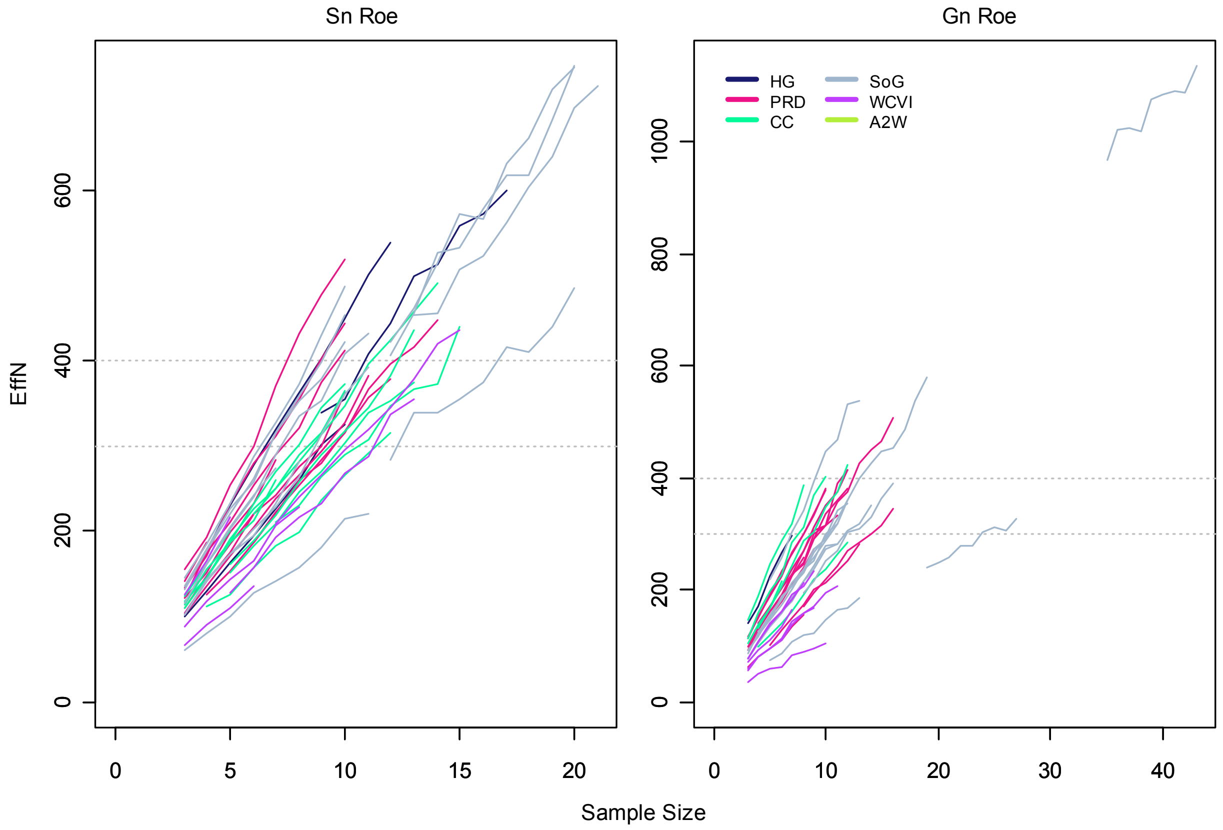

Figure 20: Bootstrap estimates of effective N (EffN) for Sn-roe and Gn-roe fisheries re-sampled with progressively fewer samples. Each line shows results from one fishery (SAR and year) and the point furthest to the right is the EffN when the bootstrap sample size equal to the actual number of samples for the fishery. Dashed lines are drawn at EffNs of 300 and 400.

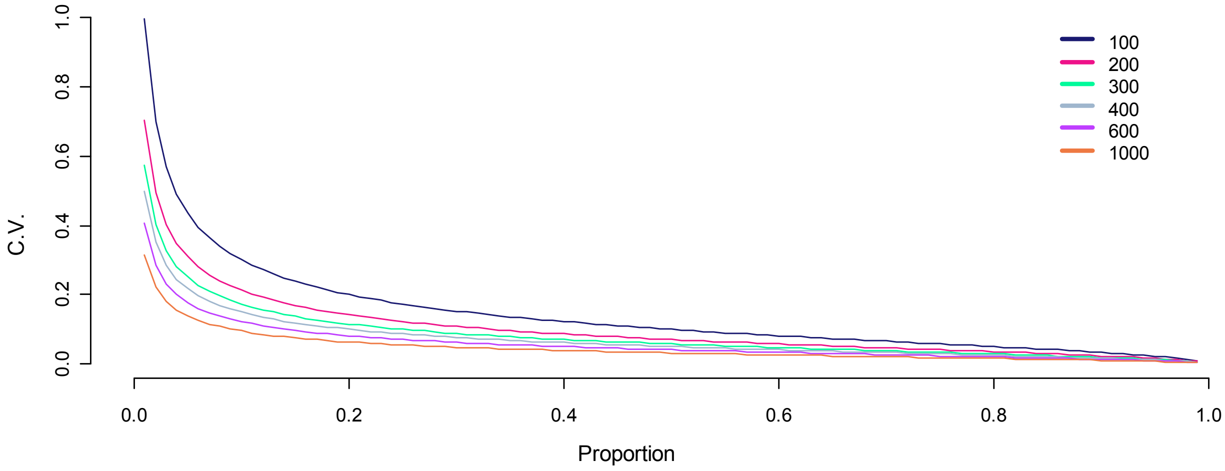

Figure 21. C.V. of proportions-at-age for the multinomial distribution with sample sizes between 100 and 1000.

On average, a reduction in the test fishery sampling period to 14 days resulted in 32% fewer samples (90% range, 17%-57%, Figure 23). The average reduction in *EffN* was 49% (90% range, 20%-78%, Figure 23). For the full sampling coverage, 7% of fisheries had *EffN*s less than 100. This increased to 26% when the sampling window was reduced to 14 days.

These results suggest that there could be a significant reduction in the accuracy and precision of estimated age compositions from the test fishery with a reduction in the durations of the test fishery charters. However, these results need to be taken in the context that the analyses assume an un-weighted treatment of all test fishery samples collected in a SAR and year provide unbiased estimates of the populations.

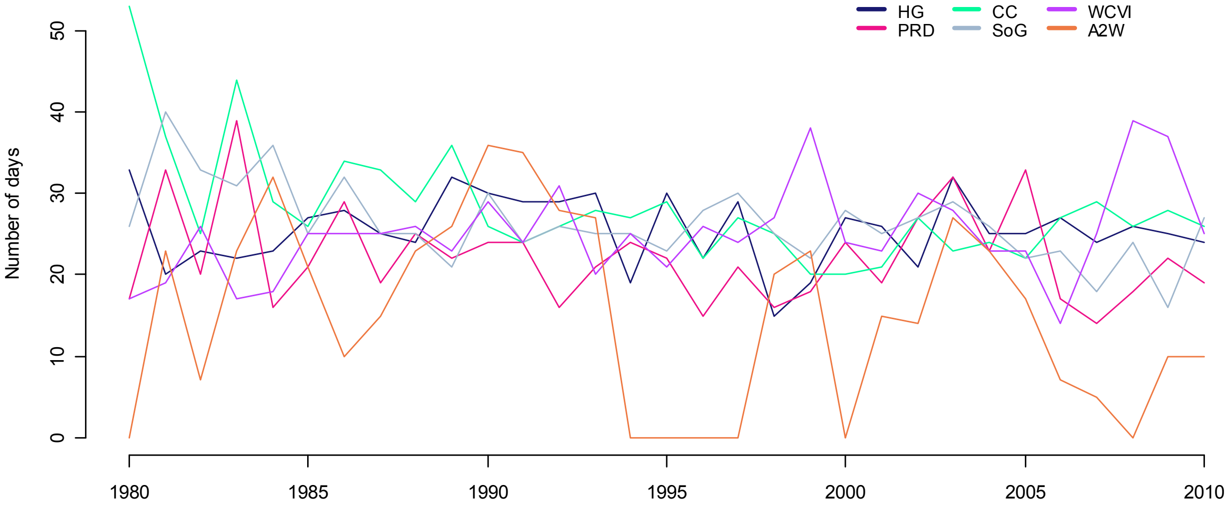

Figure 22: The number of days between the date the first and the last test fishery sample was collected, by SAR and year.

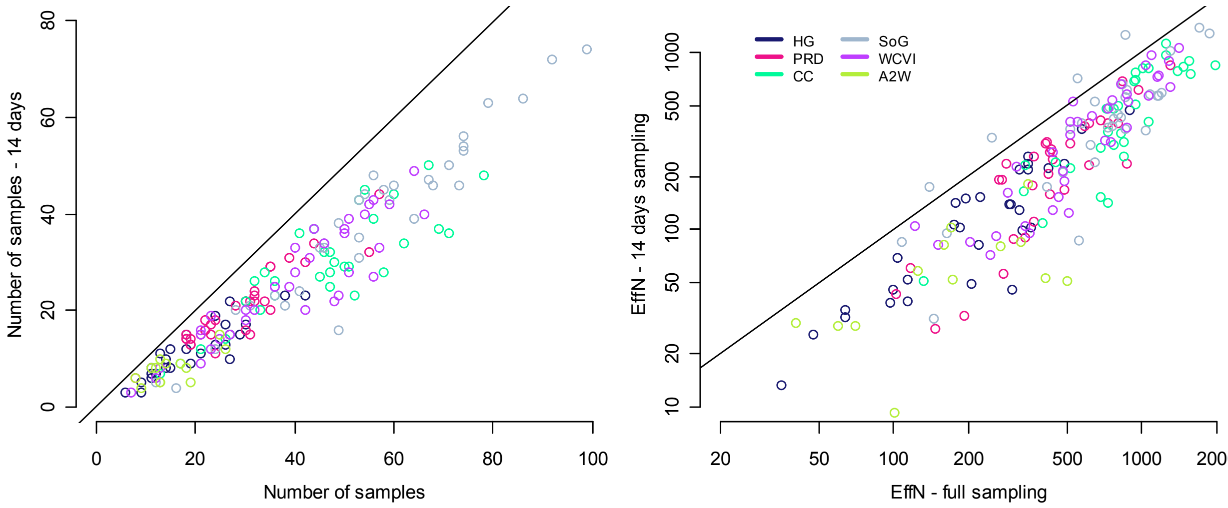

*Figure 23: The total number of test fishery samples (*N*) versus the “mid” 14-day number of samples collected by SAR and year (left panel), and the* EffNs *for the full sampling period and the “mid” 14-day period, by SAR and year (right panel).*

6 DISCUSSION

Data collected through the herring biological sampling program is one of the major inputs to the stock assessment models, but a comprehensive review of the program and data collected through the program has not been completed. The work presented here, a continuation from an initial review of the biological sampling program presented to CSAP in September 2010, focuses on analyses of samples from the roe and test fisheries collected since 1972.

Clustering algorithms were developed and tested with simulated data, and the best-performing algorithm applied to age compositions from Sn-caught herring samples. Cluster analysis separates samples into clusters based on the similarity of measured characteristics, age compositions in this case. Attributes of the samples within each cluster can then be examined to determine if there are persistent patterns, for example spatial or temporal structure.

The cluster analysis indicates that samples taken within each stock assessment region are unlikely to come from single homogeneous populations. There is a high degree of consistency in the age composition of samples taken within most sections, particularly in the northern B.C. SARs. Consistency among samples decreases with increased geographical separation. There are no obvious temporal patterns in the age frequency clusters, but the mean age of samples taken early in the spawning season tend to be slightly higher than the mean age of samples taken later in the spawning season. On average, the mean age of samples taken from the seine roe fishery tend to be slightly higher than those taken in the test fishery.

Schweigert (1991) applied discriminant function analysis to B.C. herring size and age structure data to investigate the validity of the stock structure used for stock assessments. That analysis found strong differentiation among fish from the five major stock assessment regions. Within SARs they found differentiation among spawning beds in some years and overlap in others, with generally higher differentiation in the northern B.C. SARs. The Schweigert analysis was based on spawning beds, which combined data from some sections, but results were generally consistent with those found here.

Sex-specific differences in biological characteristics were examined in terms of sex ratios and size-at-age. Results indicate the gillnet roe fisheries are highly selective for female fish at ages up to 6. Sex ratios in seine-caught samples indicate a higher proportion of males than females for ages 2 and 3, in particular for the Sn-roe fishery. Sex-specific differences in length-at-age are trivial. Given the highly sex selective nature of the gillnet roes fisheries, a sex-specific model may be more appropriate for the B.C. herring stock assessment.

A relative gonadosomatic index (the ratio of ovary weight to body weight) was developed based on the predicted GSI at maximum ripeness (Ware and Tanasichuk 1990). The predicted maximum GSI is size-dependent so a relative measure can potentially adjust for size-specific GSI among fish in a sample. However, the maximum GSI of Ware and Tanasichuk (1990) does not appear to be appropriate for all years and areas, as the maximum is exceeded in many years.

Linear modeling suggests a number of factors that affect the mean relative GSI of herring samples, beyond the obvious year and day-of-year effects. The sample clusters, determined from the cluster analysis, significantly improved model fits for all SARs except the SoG. This suggests another level of commonality among samples in a cluster, beyond the age compositions. Mean weight and mean age were also significant factors in the linear models predicting mean relative GSI, consistent with the conclusion that the Ware and Tanasichuk (1990) maximum GSI does not account for factors influencing variation in maximum GSI.

A relative GSI measure shows promise for predicting when sampled herring would reach full maturity, and hence potentially for associating samples with spawning events. Further work is required to understand the factors affecting the maximum GSI and to develop a methodology for predicting date of maximum roe development.

Potential approaches for weighting the Sn-roe and test fishery age composition data for use in stock assessments were discussed. For the Sn-roe fishery, inconsistencies in the catch database preclude using that data source to spatially and/or temporally stratify the catch at this time. For the test fishery, there is no objective basis for sample weighting given the presence only sampling approach. Potentially, the relative GSI measure discussed above could be developed to predict when samples would attain maximum roe development and then associated samples with spawning events.

There is no indication that the precision of age compositions (Sn-roe, Gn-roe and test fisheries) have decreased in recent years. Age composition estimates from the seine and gillnet roe fisheries are generally quite precise, and a reduction in the number of samples collected from these fisheries would not likely compromise the integrity of the data for stock assessments. Collection of 6 to 12 samples from each fishery would result in “effective” sample sizes of approximately 300 fish, resulting in reasonable c.v.s for proportions-at-age that are not small (c.v.s ≤ 0.25 for proportions ≥ 0.05). An analysis of the B.C. herring sampling design (Schweigert and Sibert, 1983) also concluded that it was difficult to obtain precise estimates of rarer age classes and these were not likely critical for stock assessment. For the test fishery, a reduction in sampling effort (simulated by 14 day sampling periods) would potentially decrease the precision and accuracy of age composition estimates substantially.

7 CONCLUSIONS

The following is a point summary of conclusions from this study, relative to the questions specified in section 1.3.

Is there evidence for spatial or temporal structure (sub-stocks) within herring stock assessment regions?

Do Sn-roe and test fisheries sample different populations?

- Spatial structure exists, but is not consistent over time.
- There is temporal structure, but it is relatively minor (mean age decreases by 0.17 yrs).
- Sn-roe fisheries are selective for older fish (mean age higher by 0.23 yrs).
- Weighting of test fishery samples could have significant effect on age-compositions used for stock assessment.
- Cluster analysis useful to inform simulation of age frequencies for MSE.
    - Samples not from a homogeneous (statistical) population.
    - Often 2 (or more) dominant year-classes.
    - MSE can use the observed patterns of differences between Sn-roe and test fishery samples and early and late samples.
- Clustering algorithm should be applied to the herring pre-1970 fisheries sample data.
    - By northern/southern B.C. to determine if consistency in age compositions by SAR.

Are there sex-related differences in biological characteristics that should be captured in the stock assessment?

- Length-at-age related differences are minimal.
- Sex-selectivity of Gn fishery warrants modelling sexes separately.

Can gonadosomatic indices (GSI) be used to associate herring samples with spawning events?
Is the assumption that test fishery samples are representative of spawning populations (in some years) reasonable?

- GSI to associate samples with spawn events has potential.
  - Need to determine factors that affect maximum GSI.
  - Further analysis is warranted.
- Test fishery samples likely reflect age-composition of spawners in years where sampling continues through later spawn events.

Is there an objective basis for weighting roe fishery and test fishery samples in developing age-compositions for stock assessments?

Sn-roe and Gn-roe fisheries:

- Problems in databases preclude any one information source as definitive about areas/dates of fishery openings (required for sample weighting).
- A definitive information source for fishery data should be developed.
- Then an investigation of whether stratification is warranted can be done.

Test fisheries:

- First requires decision on how test fishery age-compositions will be used in stock assessment. What assumptions will be made about this data source?
- Weighting considerations likely related to how data will be used.
- Potentially, a process for weighting the age-comps from each cluster or associating samples with spawn events?

Has the precision of age compositions changed over time?
How would a decrease in sampling effect the precision (and accuracy) of age-compositions?

- No evidence for a decrease in the precision of age composition data over time.
- Precision criteria for bio-sampling program should be developed.
  - For example, for fishery age-comps, a c.v. of 0.25 or less for all proportions <= 0.05.
  - This would provide an objective basis for determining sample size requirements, and for on-going evaluation of the program.
- Reduced sampling of Sn-roe fishery would have the least impact on effective sample sizes.
- Reduced sampling of test fishery would have the greatest impact on effective samples sizes, affecting both bias and precision, but this is dependent on the assumption that the full age-composition is “correct”.
- When decision made on how test fishery data will be incorporated into the assessment, changes to the sampling design should be further investigated.
- Effective samples sizes should be the starting basis for weighting age-comp data in the assessment.

8 ACKNOWLEDGEMENTS

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APPENDIX A: DATA SELECTION

Bio-sample data:

Bio-sample data was extracted from the access database “Vivian Haist 30Sept2010 Biosample Location and Spawn Data.mdu”. For the Sn-roe and test fishery samples, only samples with gear code “Seine” and sample source code “Roe Fishery” or “Test Fishery” were selected. The table below shows the number of samples and number of fish selected that met those criteria (Total). Then, additional criteria - that the fish had age, length and weight information, eliminated a small number of samples and fish. Finally, only samples that had a minimum of 40 fish were retained and used in the analyses. The number of fish per sample ranged from 40 to 132, with the majority of samples comprised of 85 to 100 fish (Figure A1). For the GSI related analyses only fish with gonad weight were used.

Sample selection for Sn-roe and test fishery samples:

	Number of samples	Number of fish	
Total	9723	956,378	
With age	9676	854,248	
With length & weight	9676	854,056	
Sample size >= 40 fish	9595	851,664	40-132 fish/sample
Have gonad weight	7888	663,245	

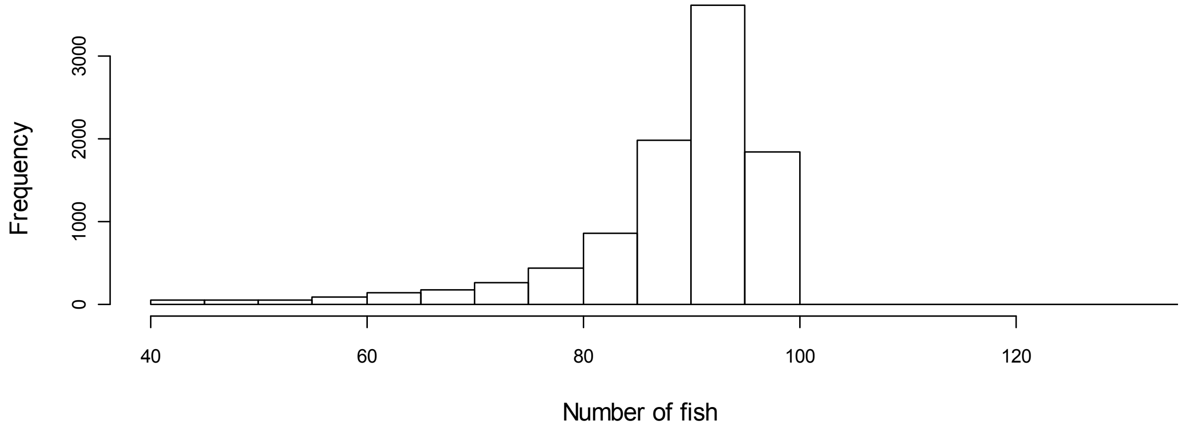


Figure A1: Frequency of the number of fish per sample for all selected Sn-roe and test fishery samples.

Spawn Survey Data:

An excel data file (“spawn biomass for Vivian 2010.xls) was provided. This file had information on spawn and survey dates (start and end), location, source (dive or survey) and tonnes of spawners as estimated from the egg deposition data.

Spawn and survey dates were incomplete. Of the 22,395 records, 22,037 had “start” spawn date recorded. Where recorded, the “start of spawn date” was selected as the best timing information. An additional 219 records had either “end spawn” date or “start of survey” date. For

these records, the earliest of the two dates was selected as the best timing information. The "end of survey" date does not appear to be useful.
The 150 records with no useable date information account for 0.65% of the total spawn deposition.

Using primarily "start of spawn" data to reflect spawn timing could potentially bias analyses if the duration of spawning events has changed over time (how "events" are recorded). For records with both start and end spawn dates, where the "end spawn date" is later than "begin spawn date", and the spawning duration was <31 days (19874 observations) the average duration of spawning events was calculated for each year. The data do not suggest any trend in the average duration of spawn "events" (Table below).

Year	Avg. Duration
1971	4.9
1972	3.8
1973	5.2
1974	5.6
1975	5.8
1976	5.8
1977	3.4
1978	2.8
1979	2.3
1980	3.4
1981	3.1
1982	3.4
1983	3.3
1984	3.7
1985	3.6
1986	2.7
1987	3.7
1988	2.8
1989	3.2
1990	4.4
1991	3.5
1992	3.2
1993	3.2
1994	3.5
1995	3.9
1996	3.0
1997	3.3
1998	3.0
1999	4.3
2000	3.3
2001	3.5
2002	2.9
2003	3.9
2004	4.2
2005	5.5
2006	2.7
2007	4.0
2008	3.3
2009	2.5
2010	3.2
Avg.	3.7

APPENDIX B: ALTERNATIVE EQUATION TO PREDICT MAXIMUM GSI.

Ron Tanasichuk has updated the equation to predict maximum GSI for fish that have previously been frozen (R. Tanasichuk, pers. comm.) The analyses presented here were conducted to determine if the revised predictor is more consistent with herring sampling observations. Using the original predictor, based on Ware and Tanasichuk (1990) the mean relative GSIs (mean of the ratio of individual fish GSI to their predicted maximum) for many samples was greater than 1 (the maximum expected value).

The revised equation for the maximum GSI (Q) is:

$$Q = 8.54W^{0.24},$$

where W is total body weight. This revised equation predicts higher maximum GSIs for a given body weight than the original equation (Figure B1). As a result, the sample mean relative GSIs are lower. However, there are still significant numbers of samples with relative GSI measures greater than 1.

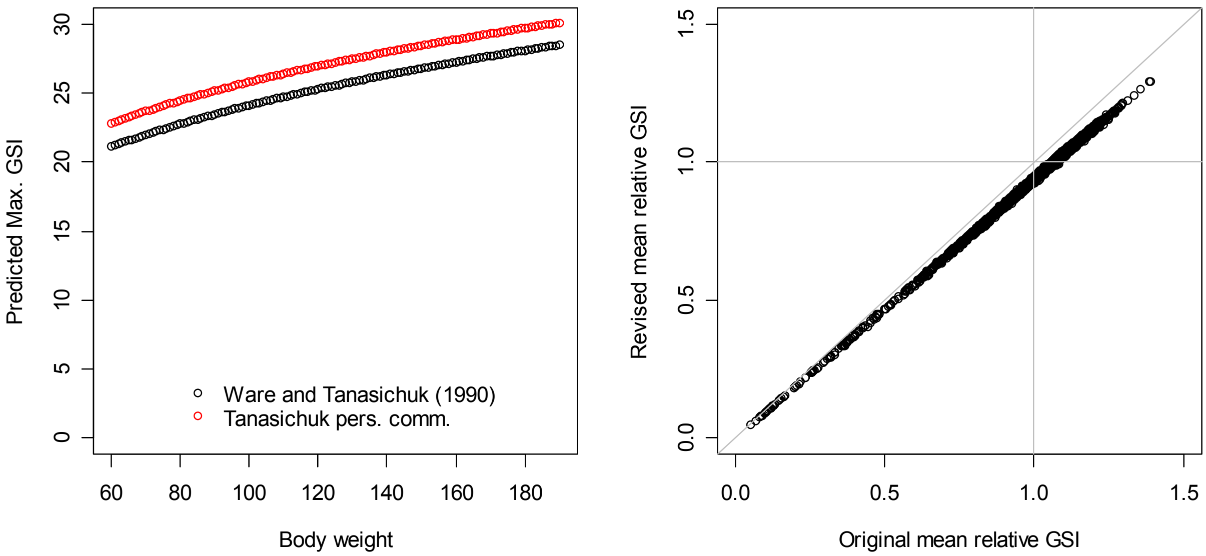


Figure B 1. Left panel: Predicted maximum GSI versus body weight using the original (Ware and Tanasichuk 1990) predictor and the revised (Tanasichuk, pers. comm.) predictor. Right panel: Sample mean relative GSI using the original and revised maximum GSI equation.

To further assess if the revised equation for predicting maximum GSI would substantively change the conclusions in this document, the linear model that had been fit to the relative GSI data (model M7, Section 4.1) was fit to the revised relative GSI data. The 'year' effects from this model fit still showed substantial year trends (Figure B2), indicating the revised maximum GSI equation has not resolved the problems previously noted.

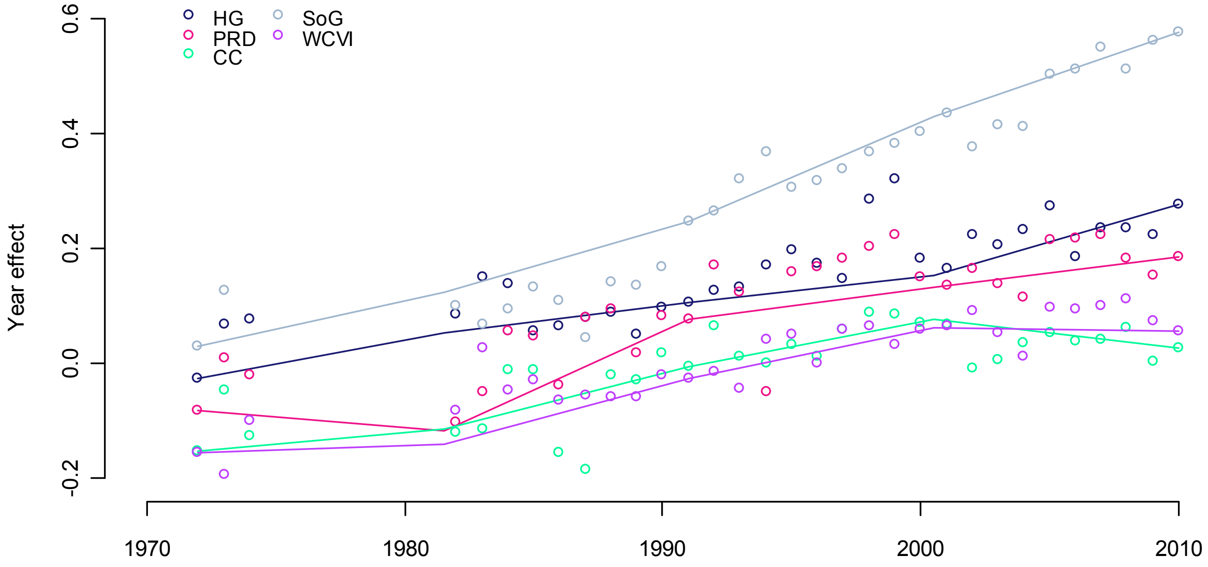


Figure B 2. Estimated "year" effects from model M7 (see Section 4.1) fits to the revised relative GSI data, by SAR and year. The lines were fitted using a spline interpolation.

APPENDIX TABLES AND FIGURES:

Appendix Table 1: Haida Gwai and A2W seine roe herring fishery summary: location, herring section (inferred from location name), catch (tonnes), and dates from the IFMP; total area catch (t), section catch, and dates by herring section from PBS catch database; and dates and number of samples (N) by section from the PBS bio-sampling database.

Year	IFMP Seine Fishery Summary					PBS Catch database			PBS Bio-Samples	
	Location	Sec.	Catch (t)	Date(s)	Sec.	Tot. Catch	Sec. Catch	Date(s)	Date(s)	N
1980	Skincuttle Inlet	25	2106	Mar 23	25	2106	1313	Mar 23-26	Mar 23-27	10
	Louscoone Inlet	6		Mar 19-21	6		793	Mar 20-23	Mar 19-21	4
1981	Skincuttle Inlet	25	3884	Mar 17	25	4654	2996	Mar 17-23	Mar 17-18	30
	Inskip Inlet	5		Mar 21	5		441	Mar 24-26	Mar 21	5
	Atli Inlet	24		Mar 24	24		887	Feb-25-Mar 31	Mar 24-Apr 16	5
	Rennel Sound	3		Mar 25	3		329	Mar 25-28	Mar 25	6
1982	Lower Juan Perez	21	2353	Mar 14	21	3871	1526	Mar 14-17	Mar 14	13
	Inskip Channel	5		Mar 20	5		947	Mar 23-30	Mar 20-21	6
	Atli Inlet	24		Mar 22	24		599	Mar 16-26	Mar 22	10
					22		292	Mar 14-26		
					25		228	Mar 15-22		
					3		279	Mar 24	Mar 22-25	8
1983	Lower Juan Perez	21	4600	Mar 09	21	7169	4601	Mar 09-10	Mar 08-09	10
	Inskip Channel	5		Mar 21	5		1804	Mar 21	Mar 21	12
					3		715	Mar 21		
					22		51	Mar 09		
1984	Lower Juan Perez	21	4016	Mar 02	21	4474	4016	Mar 12-24	Mar 12	10
					22		458	Mar 12		
1985	Skincuttle Inlet	25	4383	Mar 11	25	4383	4383	Mar 11	Mar 11	10
1986	Skincuttle Inlet	25	2468	Mar 23	25	2528	2468	Mar 23	Mar 23	17
					22		60	Mar 23		
1987	Juan Perez Sound	21	1720	Mar 20	21	1720	1720	Mar 20	Mar 20	10
1989	Louscoone Inlet	6	1099	Mar 28	6	1099	1099	Mar 28	Mar 28	10
1990	Port Louis	2	5250	Mar 18	2	7217	1967	Mar 18	Mar 18	8
	Louscoone Inlet	6		Mar 26	6		5250	Mar 26	Mar 26	12
1991	Rennell Sound	3	5776	Mar 23	3	5740	1962	Mar 23	Mar 23	10
	Burnaby Strait	21		Mar 31	21		3778	Mar 31	Mar 31	10
1992	Louscoone Inlet	6	3311	Mar 16	6	3319	2035	Mar 16-18	Mar 16	10
	Rennell Sound	3		Mar 18	3		1284	Mar 18-19	Mar 18	10
1993	Skincuttle Inlet	25	3148	Mar 25	25	3372	2452	Mar 25-27	Mar 25	10
	Port Louis	2		Mar 28	2		126	Mar 31	Mar 28	2
	Rennell Sound	3		Mar 29-30	3		745	Mar 29-31	Mar 29-30	6
	Inskip Inlet	5		Mar 31-Apr 1	5		49	Apr 01	Mar 31	3
1998	Huston Inlet	25	1372	Mar 14	25	1371	650	Mar 15-26	Mar 14-25	10
	Huston Inlet	25		Mar 15-16						
	Skincuttle Inlet	25		Mar 25						
	Lower Juan Perez	21		Mar 15-17	21		721	Mar 16-19	Mar 15-17	4
1999	Skaat Harbour	21	2253	Mar 10	21	2207	2207	Mar 11-14	Mar 10-13	17
2000	Island Bay/Skaat Harbour	21	1488	Mar 15	21	1488	1431	Mar 16-19	Mar 15-16	11
	Skaat Harbour/Skincuttle	21,25		Mar 16	25		57	Mar 16	Mar 15	1
2002	Juan Perez	21	455	Mar 22	21	456	456	Mar 22-23	Mar 21	10

Appendix Table 1 (cont.): Prince Rupert District seine roe herring fishery summary: location, herring section (inferred from location name), catch (tonnes), and dates from the IFMP; total area catch (t), section catch, and dates by herring section from PBS catch database; and dates and number of samples (N) by section from the PBS bio-sampling database.

Year	IFMP Seine Fishery Summary				PBS Catch database				PBS Bio-Samples	
	Location	Sec.	Catch (t)	Date(s)	Sec.	Tot. Catch	Sec. Catch	Date(s)	Date(s)	N
1980	Kitkatla Inlet	52	1641	Mar 29-31	52	1641	1641	Mar 23-Apr 03	Mar 31	7
					42				Apr 01	1
1981	Kitkatla Inlet	52	1051	Mar 27	52	1221	1051	Mar 25-Apr 01	Mar 27	13
					33				Mar 18	1
1982	-		-	-	52		170	Apr 02-03		
1984	Kitkatla Inlet	52	1653	Mar 21	52	1653	1653	Mar 21-28	Mar 21	10
1985	Kitkatla Inlet	52	2800	Mar 28	52	2799	2799	Mar 28-30	Mar 28	11
1986	Kitkatla Inlet	52	3444	Apr 02	52	3444	3444	Apr 02-04	Apr 02-04	20
1987	Kitkatla Inlet	52	1740	Mar 31-Apr 1	52	1740	1740	Mar 31-Apr 01	Mar 31-Apr 01	11
1988	Kitkatla Inlet	52	3252	Apr 04	52	3252	3252	Apr 04	Apr 04	16
1989	Kitkatla Inlet	52	3452	Apr 02,03	52	3452	3452	Apr 02-03	Mar 20-Apr 03	11
1990	Kitkatla Inlet	52	2018	Apr 03,04	52	2018	2018	Apr 03	Apr 03-04	11
1991	Kitkatla Inlet	52		Apr 06	52	1348	1348	Apr 06	Apr 06	11
1992	Kitkatla Inlet	52	1116	Mar 30	52	1132	1132	Mar 30	Mar 30	10
1993	Kitkatla Inlet	52	1814	Apr 01	52	2002	2002	Apr 01	Apr 01	11
1994	Kitkatla Inlet	52	1830	Apr 02,03	52	2014	2014	Apr 02-06	Mar 04-Apr 03	13
1995	Kitkatla Inlet	52	723	Apr 04,05	52	706	706	Apr 04-05	Apr 04-05	12
2000	Kitkatla Inlet	52	1239	Mar 27-28	52	1239	1149	Mar 28-30	Mar 27-28	10
					51		90	Mar 29		
2001	Kitkatla Inlet	52	761	Mar 23	52	761	761	Mar 23-26	Mar 23	10
2002	Kitkatla Inlet	52	1868	Apr 3-6	52	1868	1868	Apr 04-08	Apr 03-06	12
2003	Kitkatla Inlet	52	1255	Mar 23	52	1255	1255	Mar 23-25	Mar 23	10
2004	Kitkatla Inlet	52	1493[1]	Mar 27,29	52	1494	1494	Mar 28-30	Mar 27-29	6
2005	Kitkatla Inlet	52	1422[1]	Mar 18-20	52	1422	1215	Mar 19-22	Mar 18-20	7
					51		207	Mar 18-19		
2006	Kitkatla Inlet	52	744[1]	Mar 24,25	52	744	744	Mar 23-24	Mar 23-26	4
2008	Kitkatla Inlet	52	513	Mar 15-18	52	513	513	Mar 16-19	Mar 15-18	9
					42				Mar 12-24	2
2009	Kitkatla Inlet	52	713	Apr 7,8	52	713	713	Mar 17-19	Mar 17-18	14

Appendix Table 1 (cont.): Central Coast seine roe herring fishery summary: location, herring section (inferred from location name), catch (tonnes), and dates from the IFMP; total area catch (t), section catch, and dates by herring section from PBS catch database; and dates and number of samples (N) by section from the PBS bio-sampling database.

	IFMP Seine Fishery Summary				PBS Catch database				PBS Bio-Samples	
	Location	Sec.	Catch (t)	Date(s)	Sec.	Tot. Catch	Sec. Catch	Date(s)	Date(s)	N
1980	-		-	-	67				Mar 24-28	3
1981	-		-	-	73	263	75	Mar 19		
					74		188	Mar 18-20		
					72				Mar 14	1
1982	Stryker Bay	74	2258	Mar 15	74	2258	2258	Mar 14-22	Mar 15	6
1983	East Houghton Islands	74	2061	Mar 15	74	2061	1899	Mar 15-19	Mar 15-17	14
					73		162	Mar 15		
					72			Mar 15	Mar 23	1
1984	East Higgins Pass	77	3588	Mar 16-17	77	3588	3303	Mar 16-17	Mar 16-17	24
					72		35	Mar 19		
					74		249	Mar 16-17		
1985	Spiller Channel	72	2715	Mar 11	72	2715	2715	Mar 11	Mar 11	11
					78				Mar 11	1
1986	E. Higgins Pass	77	2018	Mar 29	77	2018	2018	Mar 23-29	Mar 29	13
1987	Seaforth/Spiller Channel	72,74	2343	Mar 29	74	2344	2344	Mar 25	Mar 25	9
					72				Mar 25	2
1988	Stryker/Thompson Bay	74	3166	Mar 19	74	3166	3166	Mar 19	Mar 19	13
1989	Kitasu Bay	67	6165	Mar 24	67	6165	3394	Mar 24	Mar 24	10
	E. Higgins	77		Mar 25	77		2771	Mar 25	Mar 25	3
1990	Spiller Channel	72	4841	Mar 19,24	72	4840	4781	Mar 19-24	Mar 19-24	12
					76		59	Mar 19		
					78				Mar 19-24	12
1991	Spiller Channel	72	6622	Mar 23	72	6594	6039	Mar 23	Mar 23	3
					76		3	Mar 23		
					78		552	Mar 23	Mar 23	7
1992	Seaforth / Spiller	72,74	6271	Mar 19	72	6596	1637	Mar 19	Mar 19	6
					74		4959	Mar 19	Mar 19	5
1993	Seaforth / Spiller	72,74	7852	Mar 24	72	7954	6294	Mar 24-25	Mar 24-25	9
					74		1609	Mar 25	Mar 24	1
					78		51	Mar 24	Mar 24	4
1994	Seaforth / Spiller	72,74	9104	Mar 26,27	72	9249	8001	Mar 26-30	Mar 26-28	13
					78		1248	Mar 26-27	Mar 26-27	7
1995	Kitasu Bay	67	7626	Mar 18	67	7692	1981	Mar 18	Mar 18-19	11
	Spiller Channel	72		Mar 22,23	72		4263	Mar 22-25	Mar 21-23	13
					74		49	Mar 25		
					78		1399	Mar 22-23	Mar 22-29	6
1996	Seaforth / Spiller	72,74	3538	Mar 20	72	3645	1607	Mar 20-22	Mar 20	13
					74		1996	Mar 20-23		
					78		43	Mar 23		
1997	Spiller Channel	72	2545	Mar 25	72	3014	1096	Mar 25-27		
					74		638	Mar 27-28		
					78		1280	Mar 25-28	Mar 25	10
1998	Spiller Channel	72	7184	Mar 16-18	72	7184	3182	Mar 17-20	Mar 16	3
					78		4003	Mar 17-20	Mar 16-18	12
1999	Spiller Channel	72	5413	Mar 16-17	72	5551	66	Mar 21		
					78		5485	Mar 06-20	Mar 16-17	10
2000	Spiller Channel	72	5908	Mar 17-19	72	5908	5545	Mar 18-21	Mar 17-19	14
					74		309	Mar 18-21		
					78		54	Mar 19		

Appendix Table 1 (cont.): Central Coast seine roe herring fishery summary: location, herring section (inferred from location name), catch (tonnes), and dates from the IFMP; total area catch (t), section catch, and dates by herring section from PBS catch database; and dates and number of samples (N) by section from the PBS bio-sampling database.

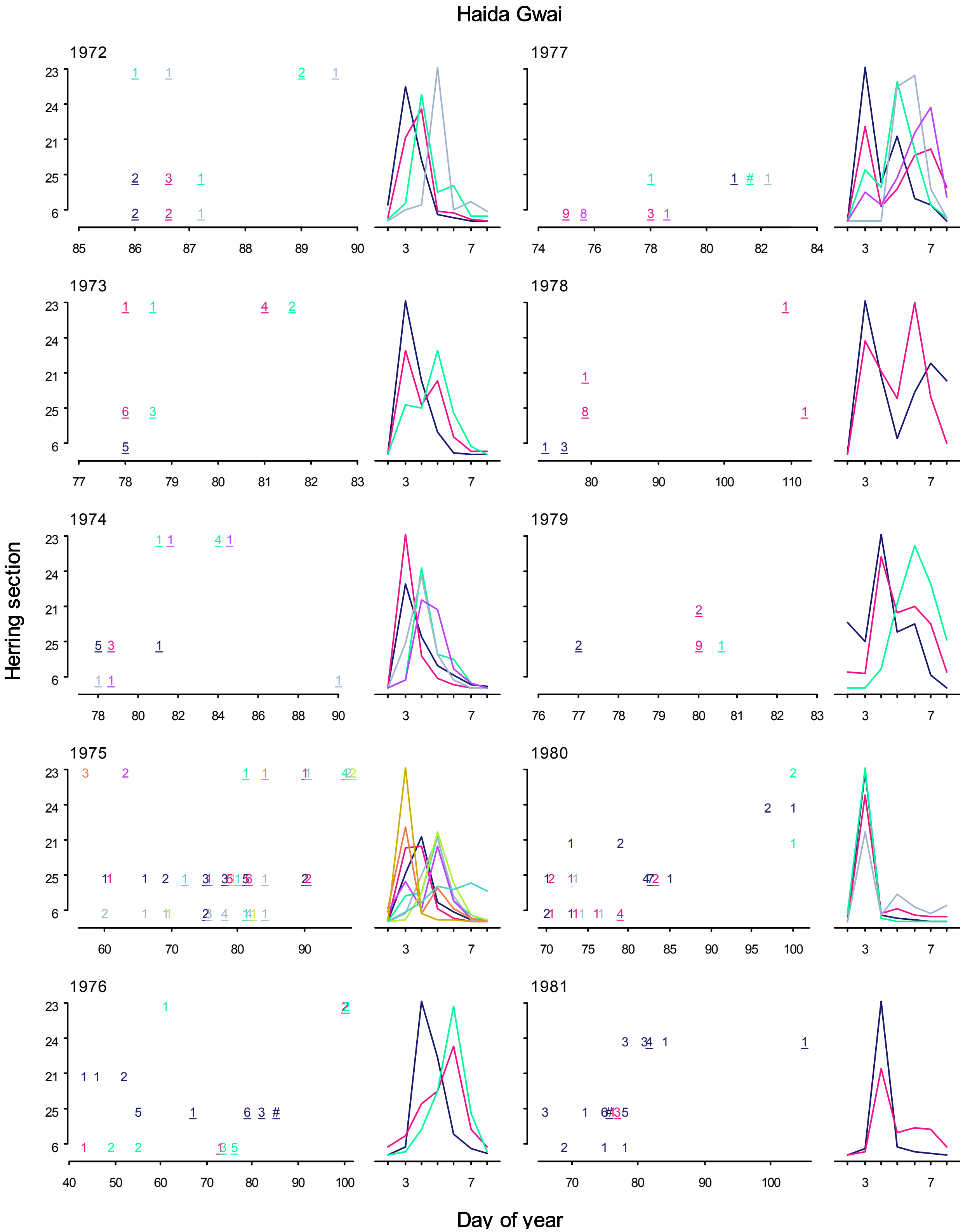
	IFMP Seine Fishery Summary					PBS Catch database			PBS Bio-Samples	
	Location	Sec.	Catch (t)	Date(s)	Sec.	Tot. Catch	Sec. Catch	Date(s)	Date(s)	N
					78		295	Mar 20-21	Mar 18	1
2002	Spiller Channel / East Higgins Pass	72,77	2391	Mar 27-29	72	2391	1573	Mar 28-31	Mar 27-29	9
					77		219	Mar 31	Mar 28-29	2
					67		73	Mar 31-Apr 01		
					74		30	Mar 30		
					78		496	Mar 28-30	Mar 27	2
2003	East Higgins Pass	77	1863	Mar 23-24	77	1863	1863	Mar 24-28	Mar 23-24	10
2004	Seaforth / Spiller	72,74	2321[1]	Mar 24-25	72	2322	1780	Mar 25-28	Mar 24-25	6
					74		542	Mar 25-27	Mar 24	2
2005	Seaforth / Spiller	72,74	3282[1]	Mar 22- 24	72	3282	2052	Mar 23-25	Mar 22-24	9
					74		205	Mar 23-25		
					77		957	Mar 23-25	Mar 22	6
					78		68	Mar 24-25		
2006	Lambard/Neekas Inlet	72,78	2458[1]	Mar 21 -25	72	2598	855	Mar 22-30	Mar 21-28	3
	E. Higgins Pass	77		Mar 26-28	74		75	Mar 30	Mar 28	1
	Seaforth/Spiller	72,74		Mar 27-28	77		1641	Mar 27-30	Mar 24-26	3
					78		28	Mar 30		
2007	Clifford Bay,Waskesui Pass /East Higgins Pass/Kitasu Bay	67,74, 77	398	Mar 15-Apr 3	67	398	56	Apr 03	Mar 19-Apr 02	3
					74		245	Mar 31-Apr 01	Mar 27-30	7
					77		97	Apr 03-04	Mar 30-Apr 01	2

Appendix Table 1 (cont.): Strait of Georgia seine roe herring fishery summary: location, herring section (inferred from location name), catch (tonnes), and dates from the IFMP; total area catch (t), section catch, and dates by herring section from PBS catch database; and dates and number of samples (N) by section from the PBS bio-sampling database.

Year	IFMP Seine Fishery Summary				PBS Catch database				PBS Bio-Samples	
	Location	Sec.	Catch (t)	Date(s)	Sec.	Tot. Catch	Sec. Catch	Date(s)	Date(s)	N
1980	Lambert Channel	142		Mar 06	142	169	169	Mar 07-09		
					143				Mar 07	1
1981	Hornby - Denman	142	2081	Mar 7-8	142	2081	2050	Mar 04-09	Mar 04	19
					132		32	Mar 31-Apr 03		
1982	Pylades Channel	173	3312	Mar 7-8	173	3312	3298	Mar 07-12	Mar 07-08	11
					135		13	Mar 13		
1983	Cape Lazo	142	7780	Feb-27	142	7780	1719	Feb 27-Mar 02	Feb-27	11
	Powell River	152		Mar 4-5	152		3879	Mar 04-05	Mar 04-05	15
	Nanoose Bay	172		Mar 02	172		1928	Mar 01-05	Mar 02	10
					173		255	Mar 02		
1984	Powell River	152	4126	Mar 2-4	152	4126	3638	Mar 02-04	Mar 02-04	19
					173		488	Mar 06-09		
1985	Hornby - Denman	142	2644	Mar 06	142	2645	2645	Mar 06-07	Mar 06	11
1987	Powell River	152	3111	Mar 6,7	152	3111	3111	Mar 14-15	Mar 14-15	12
1988	Baynes Sound	142	1471	Mar 03	142	1471	1471	Mar 03	Mar 03	12
1989	Pylades/Stuart Channel	173	1417	Mar 11,12	173	1417	639	Mar 11-12	Mar 11-12	8
					142		778	Mar 06-07	Mar 06-07	11
1991	Baynes Sound	142	925	Mar 02	142	1131	1131	Mar 02	Mar 02	8
1992	Baynes Sound	142	3112	Mar 04	142	3209	3209	Mar 04	Mar 04	10
1993	Baynes Sound	142	3976	Mar 02	142	4024	4024	Mar 02	Mar 02	10
1994	Baynes Sound	142	4447	Mar 10	142	4587	4587	Mar 09-12	Mar 10	11
1995	Baynes Sound	142	3818	Mar 4-5	142	3885	3885	Mar 02-06	Mar 04-05	10
1996	Baynes Sound	142	6346	Mar 7-8	142	6821	6821	Mar 07-09	Mar 07-08	17
1997	Baynes Sound	142	8537	Mar 04	142	8539	8539	Mar 03-09	Mar 04	9
1998	Baynes Sound	142	5678	Mar 8-9	142	5678	5678	Mar 07-11	Mar 08-09	11
1999	Baynes Sound	142	4630	Mar 05	142	4542	4542	Mar 05-09	Mar 05-06	11
2000	Lower Baynes Sound	142	6068	Mar 2-4	142	6068	6068	Mar 02-05	Mar 02-03	11
2001	Baynes Sound	142	6675	Mar 04	142	6676	6676	Mar 04-07	Mar 04	10
2002	Baynes Sound	142	8786	Mar 7-8	142	8787	8787	Mar 07-11	Mar 07-08	10
2003	Baynes Sound	142	9886	Mar 14	142	9886	9886	Mar 14-17	Mar 14	11
2004	Nanoose/Northumberland	172,173	7019	Mar 10-13	172	7019	6937	Mar 10-14	Mar 10-13	7
					173		82	Mar 13		
2005	Baynes Sound	142	6994[1]	Feb 28- Mar 2	142	6995	6995	Mar 01-06	Feb 28- Mar 02	10
2006	Baynes Sound	142	8219[1]	Mar 6-10	142	8381	8254	Mar 07-11	Mar 06-16	8
					143		127	Mar 07-09		
2007	French Creek/Chrome Island/Baynes Sound	142,143	3865	Mar 12-14	142	3865	683	Mar 13-15	Mar 11-13	5
					143		3181	Mar 12-15	Mar 11-13	15
2008	French Creek/ Qualicum Beach	143	6045	Mar 1, 2, 4, 5	143	6046	6046	Mar 01-06	Mar 01-14	20
					142				Feb 29	1
2009	Baynes Sound	142	5683	Mar 04	142	5685	5685	Mar 04-07	Mar 04	20

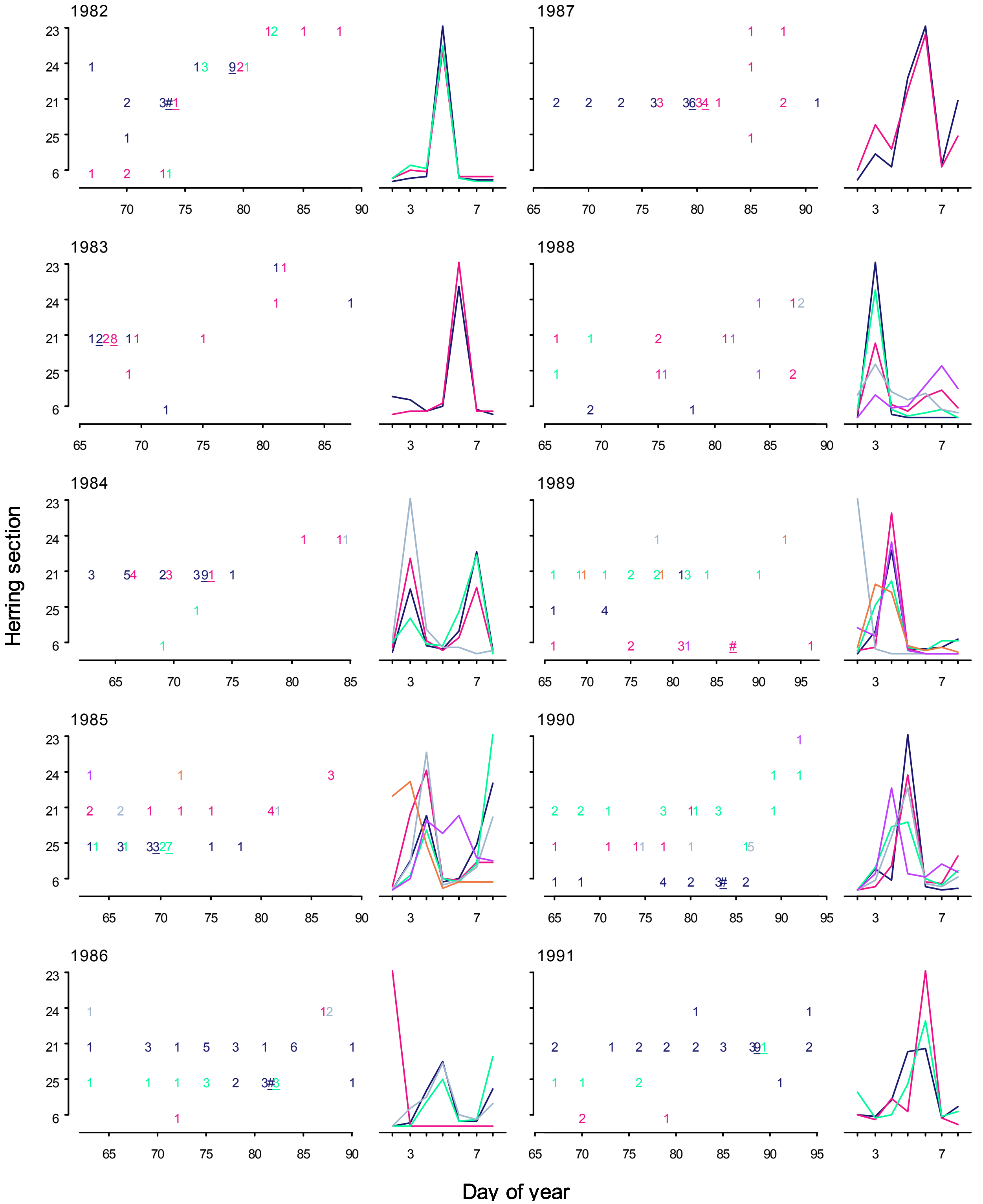
Appendix Table 1 (cont.): West coast Vancouver Island seine roe herring fishery summary: location, herring section (inferred from location name), catch (tonnes), and dates from the IFMP; total area catch (t), section catch, and dates by herring section from PBS catch database; and dates and number of samples (N) by section from the PBS bio-sampling database.

Year	IFMP Seine Fishery Summary					PBS Catch database			PBS Bio-Samples	
	Location	Sec.	Catch (t)	Date(s)	Sec.	Tot. Catch	Sec. Catch	Date(s)	Date(s)	N
1980	Clayoquot Sound	240	1682	Mar 7-8	241	1682	311	Mar 08		
					245		1202	Mar 08-11	Mar 06-08	8
					232		170	Mar 14-17		
1981	Barkley Sound	230	5009	Mar 11	232	5008	2796	Mar 03-22	Mar 09-20	23
					245		105	Mar 11-15		
					252		2070	Mar 05-14	Mar 08	6
					253		37	Mar 17		
					233				Mar 11	2
1982	Barkley Sound	230	2370	Mar 17-18	232	2370	2050	Mar 05-22	Mar 16-18	12
	Clayoquot Sound	240		Mar 08	241		33	Mar 09-12		
					245		287	Mar 08-10	Mar 08	7
	Winter Harbour	273		Mar 7,8						
1983	Barkley Sound	230	6141	Mar 01	231	6141	190	Mar 01		
					232		5951	Mar 01-03	Mar 01	10
1984	Barkley Sound	230	5718	Mar 08	231	5718	1916	Mar 08		
					232		3802	Mar 08-14	Mar 08	10
1987	Barkley Sound	230	13098	Mar 12	232	13098	13098	Mar 12-13	Mar 12	13
1988	Barkley Sound	230	7598	Mar 11	232	7598	5095	Mar 11	Mar 11	13
	Cypress Bay	245		Mar 11	245		2503	Mar 11	Mar 11	10
1989	Barkley Sound	230	8913	Mar 13,17	232	8913	8913	Mar 13-17	Mar 13-17	14
1990	Barkley Sound	230	7093	Mar 11,12	232	7093	7093	Mar 11-12	Mar 11-12	17
1991	Cook Channel	252	5575	Mar 10	252	5630	1625	Mar 10	Mar 10	10
	Barkley Sound	230		Mar 12	232		4005	Mar 12	Mar 12	11
1992	Stopper Island / Toquart Bay	232	2833	Mar 6-8	232	2854	2854	Mar 06	Mar 06-08	16
1993	Barkley Sound	230	5239	Mar 11	232	5305	5305	Mar 07	Mar 07	10
1994	Barkley Sound	230	5463	Mar 07	232	5264	5264	Mar 07	Mar 07	11
1995	Barkley Sound	230	1478	Mar 03	232	1478	1478	Mar 03	Mar 03-04	13
1996	Barkley Sound	230	719	Mar 14-16	232	790	345	Mar 15	Mar 14-15	4
	Tofino	241?		Mar 16	245		445	Mar 15	Mar 17	7
1997	Barkley Sound	230	6253	Mar 04	232	6157	6157	Mar 04	Mar 04	10
1998	Barkley Sound	230	4878	Mar 09	232	4878	4878	Mar 10	Mar 09	11
1999	Barkley Sound	230	2912	Mar 10	232	2911	2911	Mar 11	Mar 09-11	12
					253				Feb-25	1
2000	Barkley Sound	230	496	Mar 8-9	232	496	496	Mar 09	Mar 08-09	8
2003	Barkley Sound	230	2073	Mar 10-14	232	2073	2073	Mar 11	Mar 10-14	15
2004	Rosa Harbour	253	3347[1]	Mar 14-15	253	3347	3347	Mar 15	Mar 14-15	5
2005	Esperanza Inlet	253	2955[1]	Mar 7 - 8	253	2955	2955	Mar 07	Mar 07-08	6

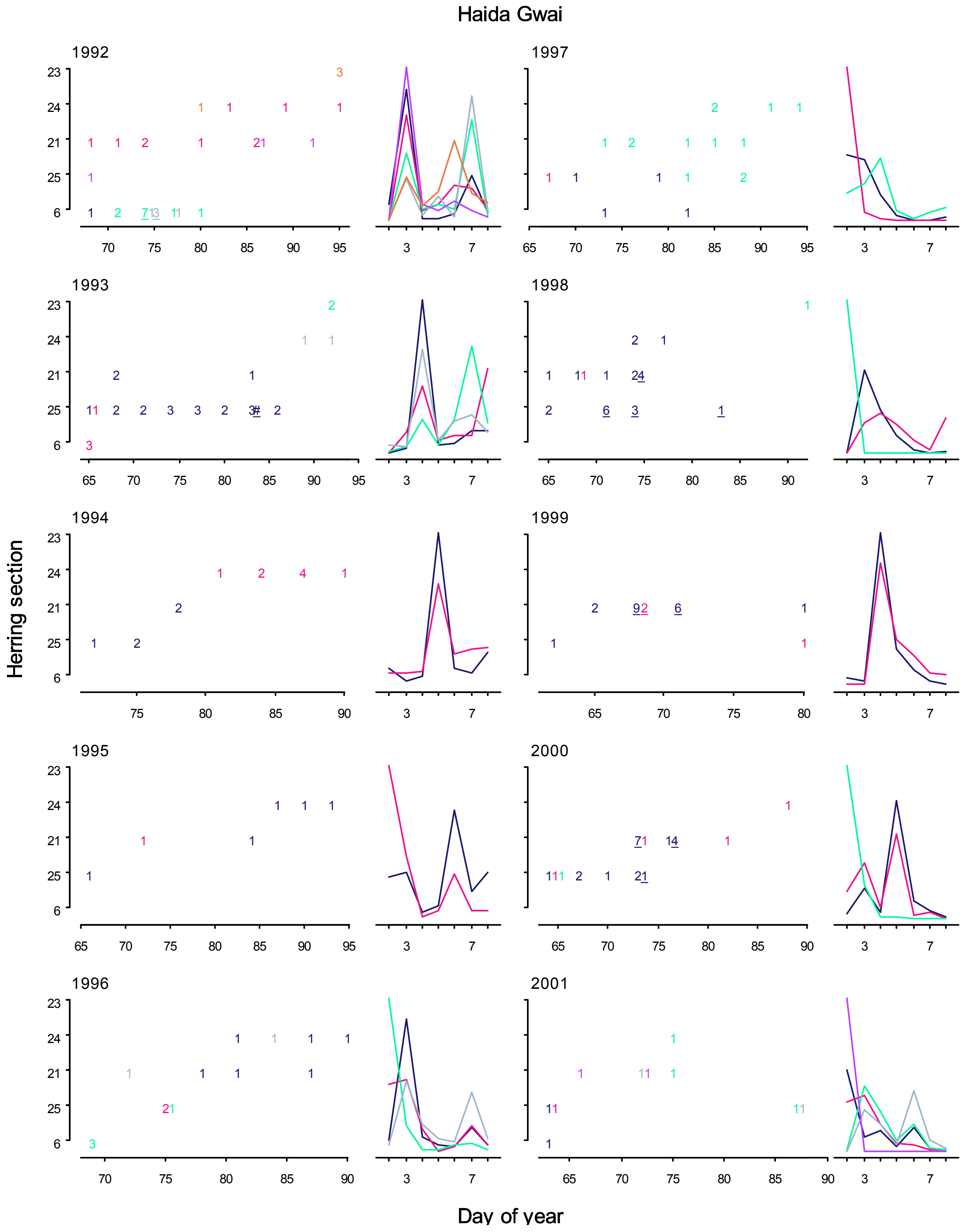


Appendix Figure 1. Age-composition clusters for the Haida Gwai SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

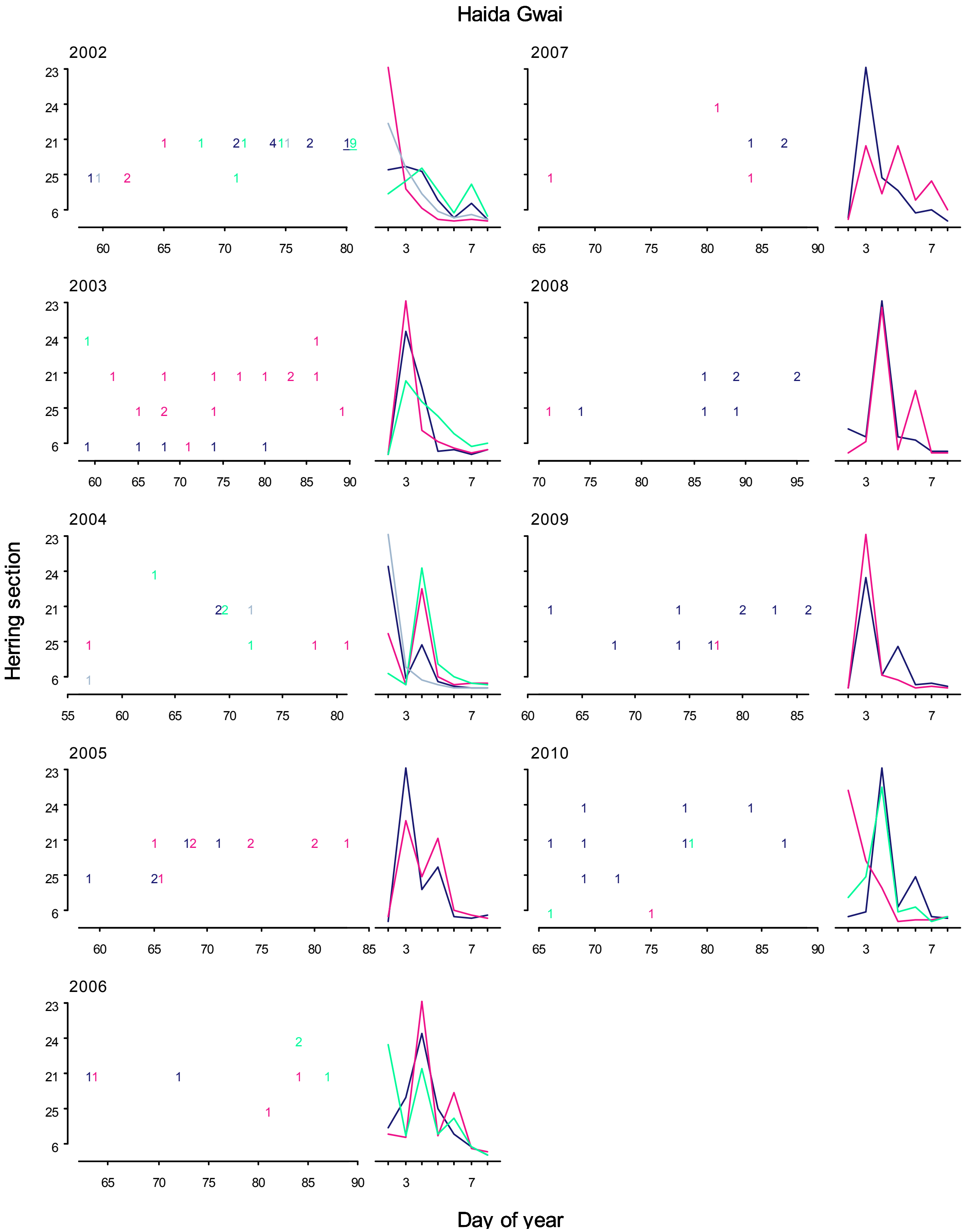
Haida Gwai



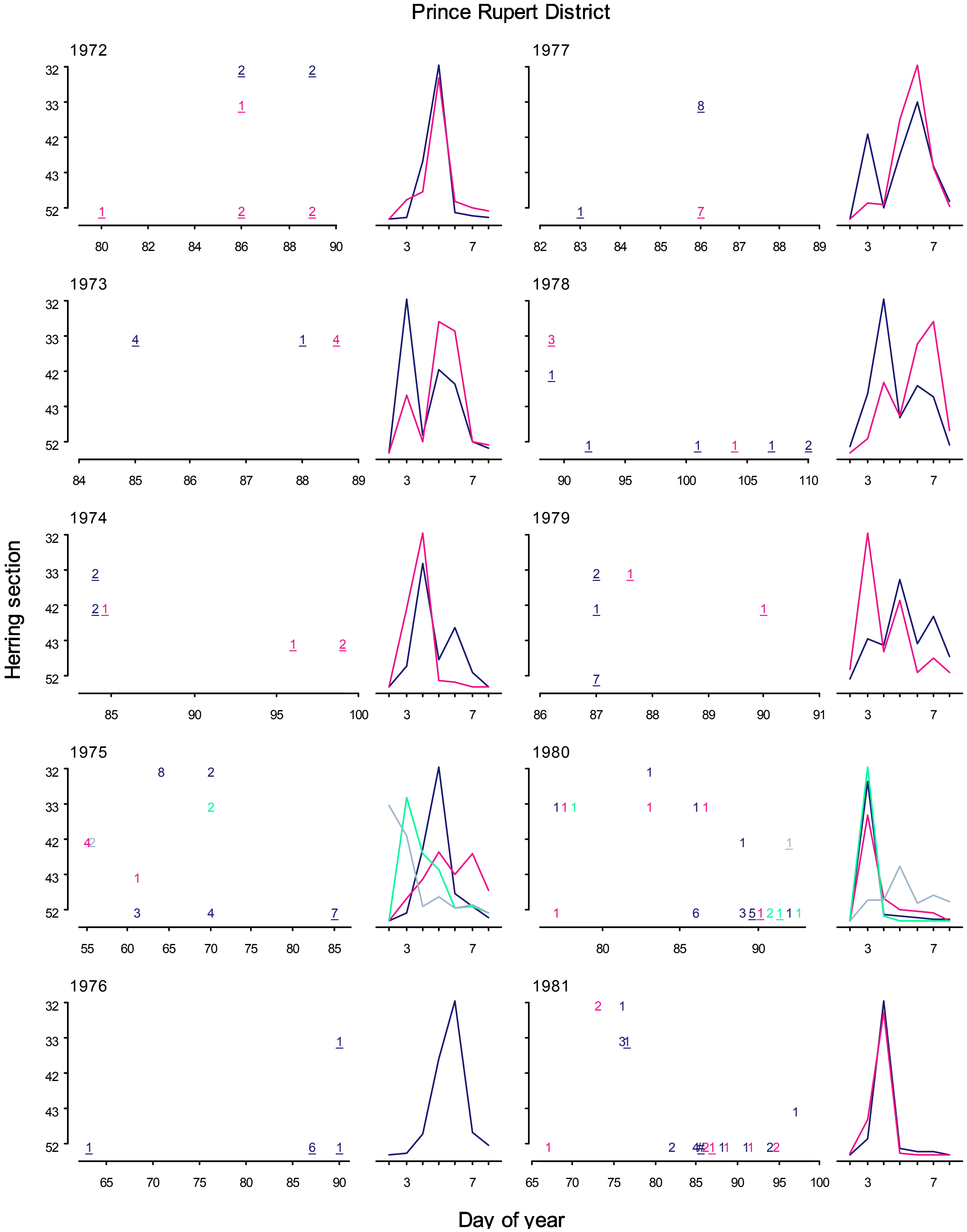
Appendix Figure 1 (cont). Age-composition clusters for the Haida Gwai SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



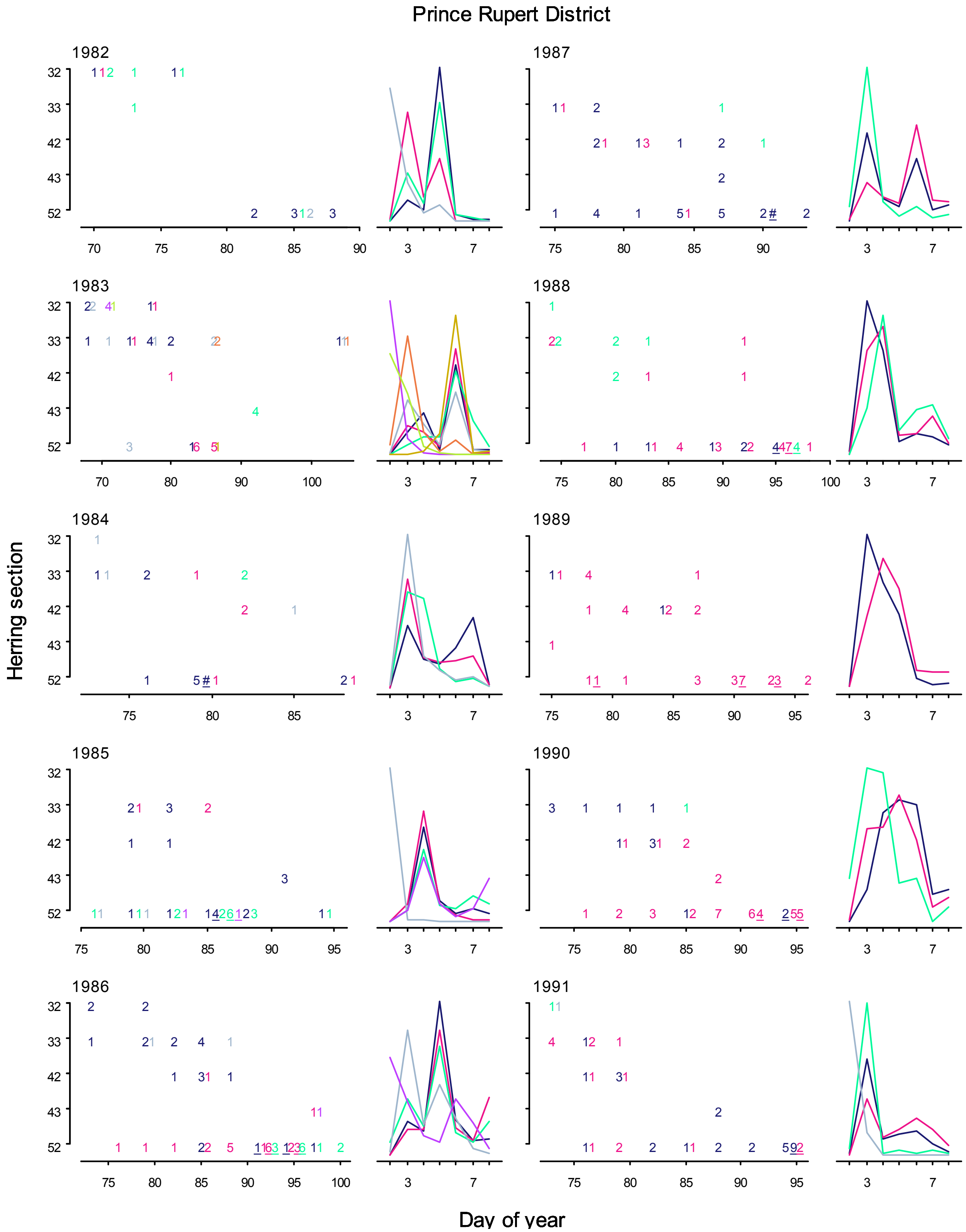
Appendix Figure 1 (cont). Age-composition clusters for the Haida Gwai SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



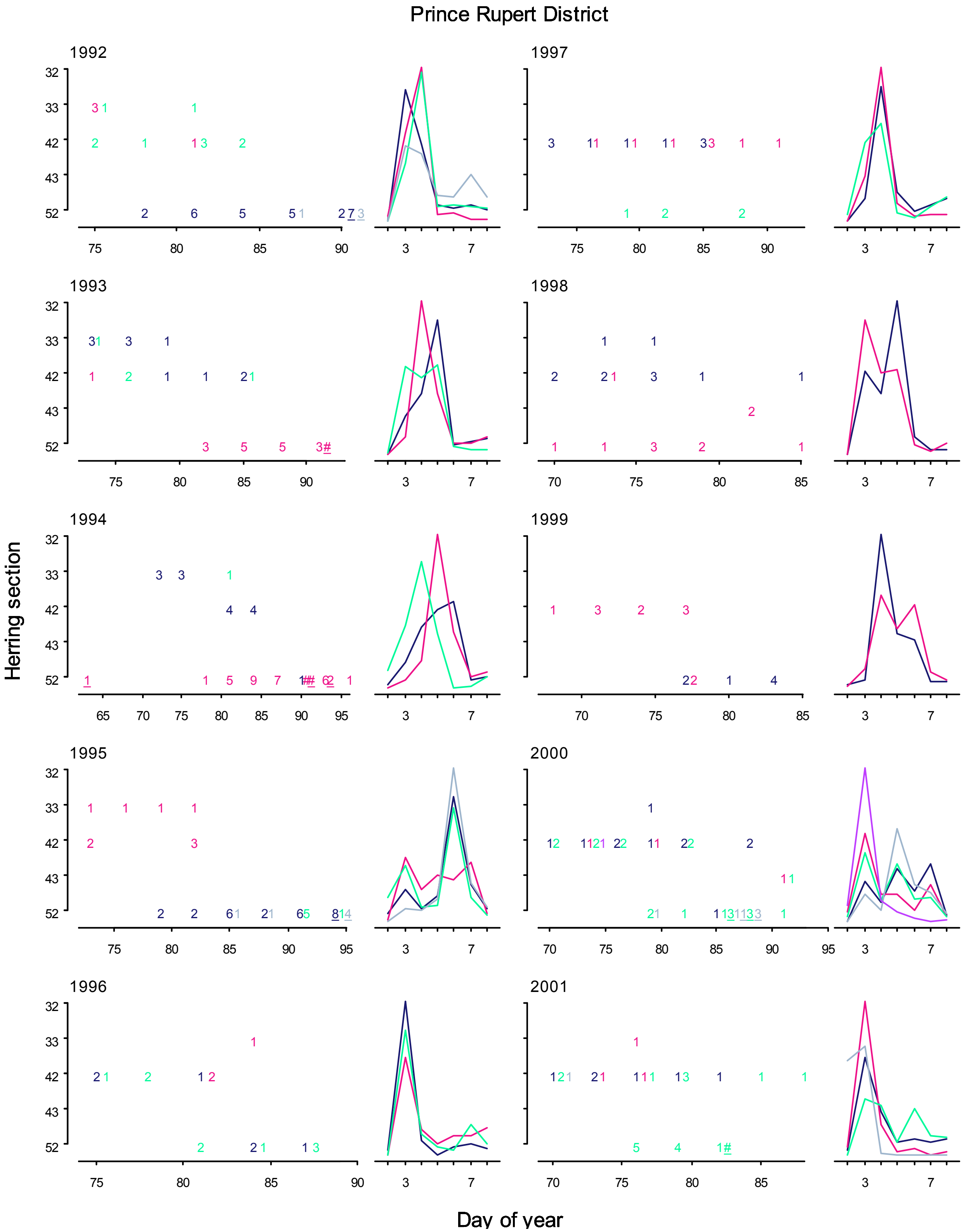
Appendix Figure 1 (cont). Age-composition clusters for the Haida Gwai SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



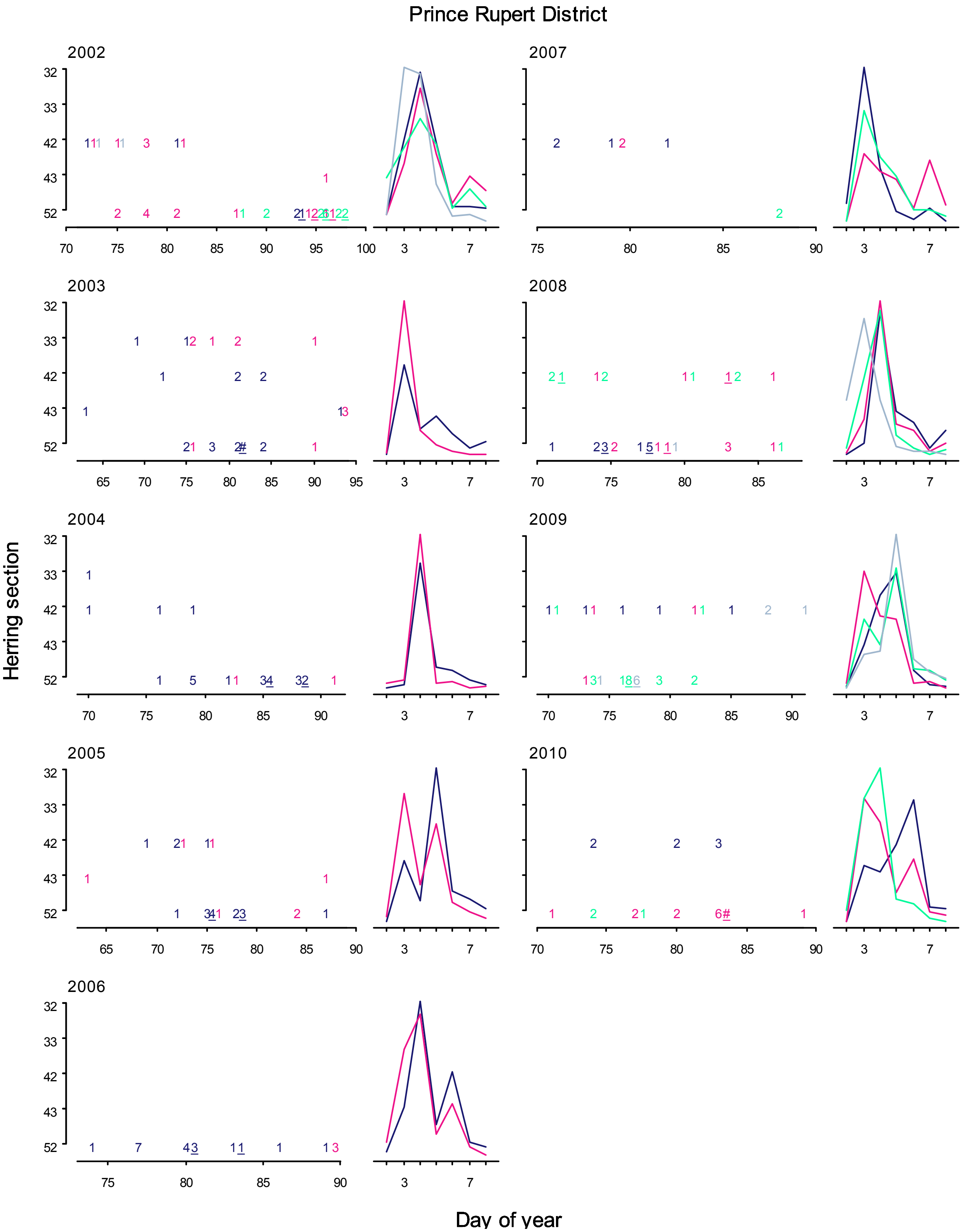
Appendix Figure 1 (cont). Age-composition clusters for the Prince Rupert District SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



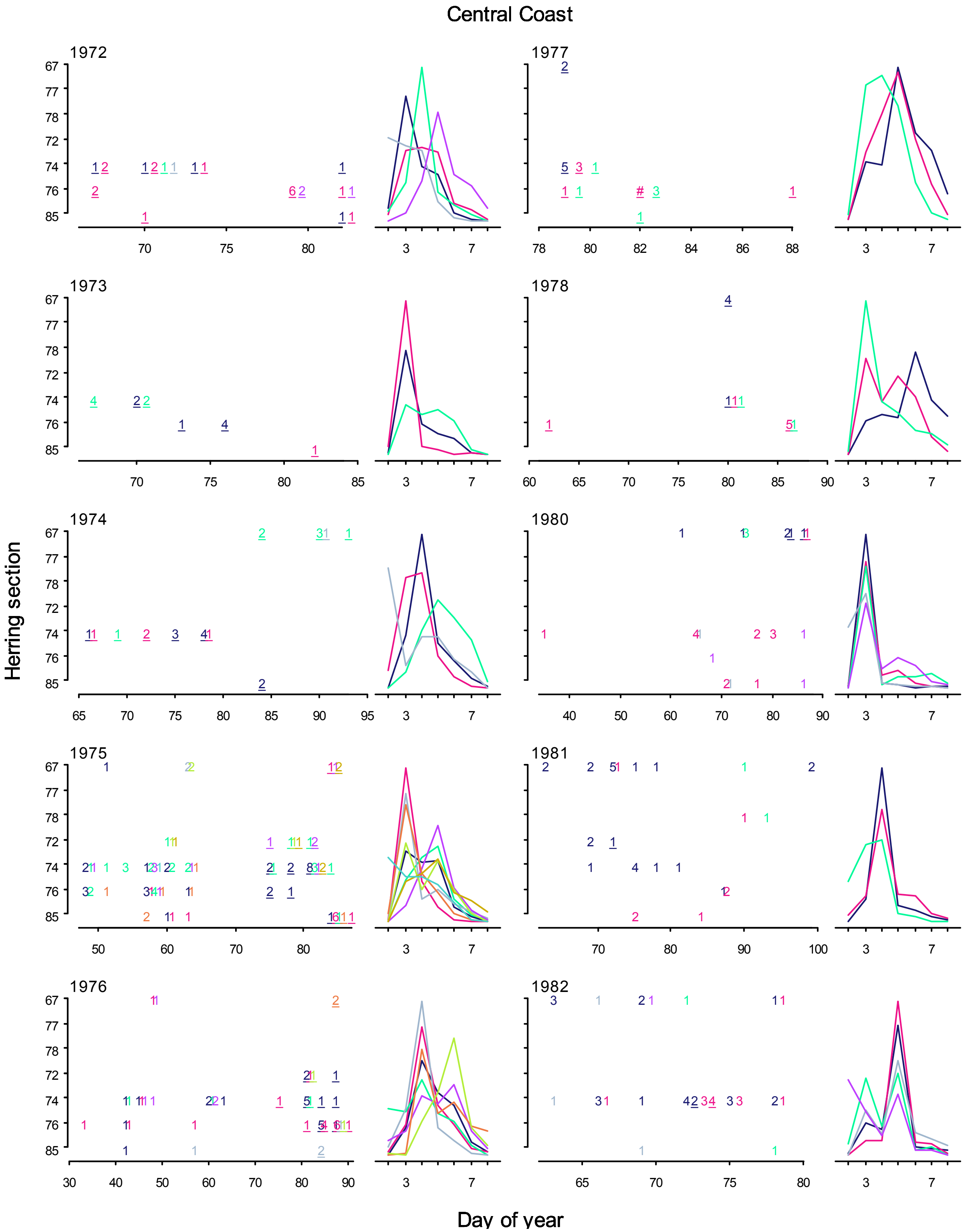
Appendix Figure 1 (cont). Age-composition clusters for the Prince Rupert District SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



Appendix Figure 1 (cont). Age-composition clusters for the Prince Rupert District SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

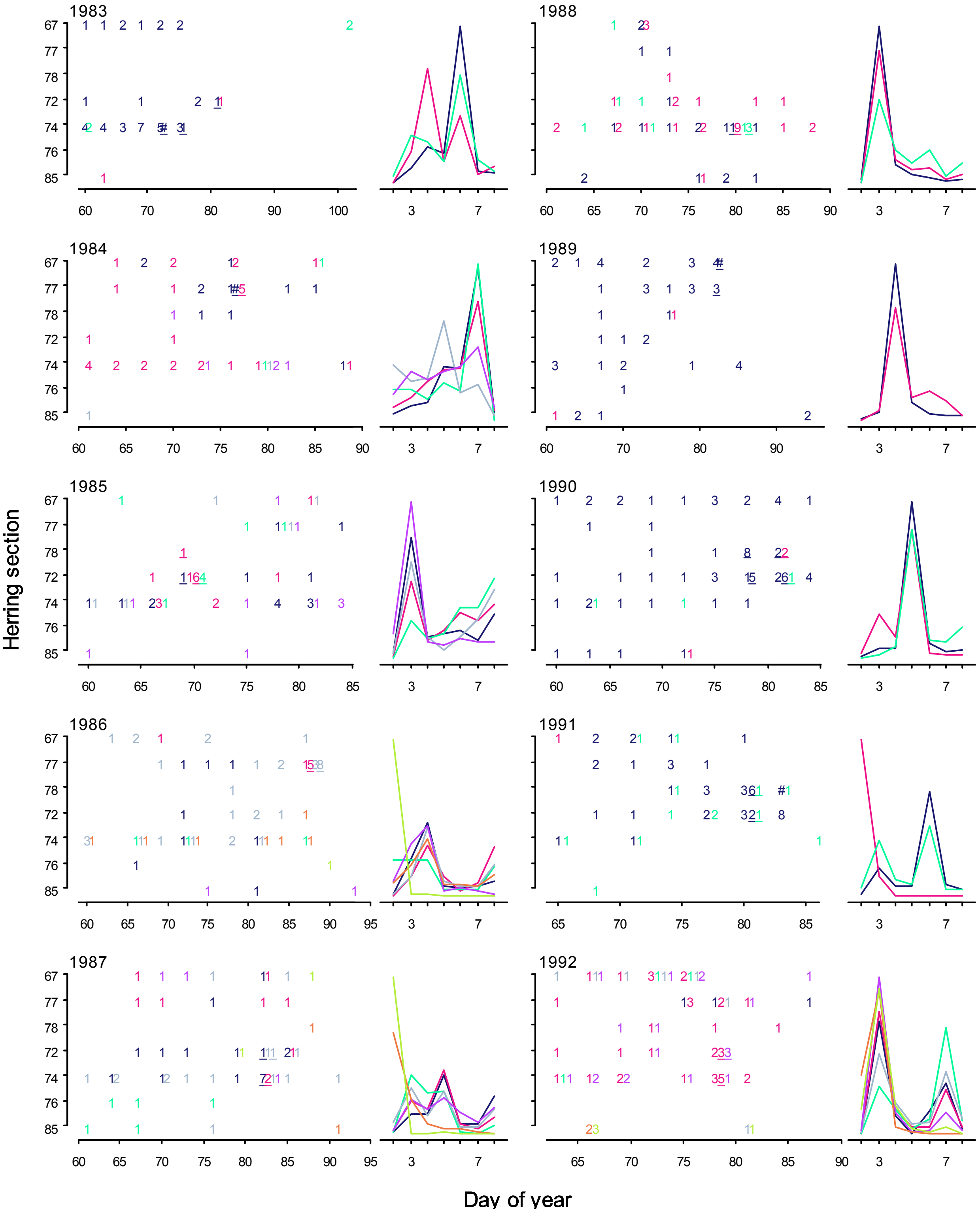


Appendix Figure 1 (cont). Age-composition clusters for the Prince Rupert District SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

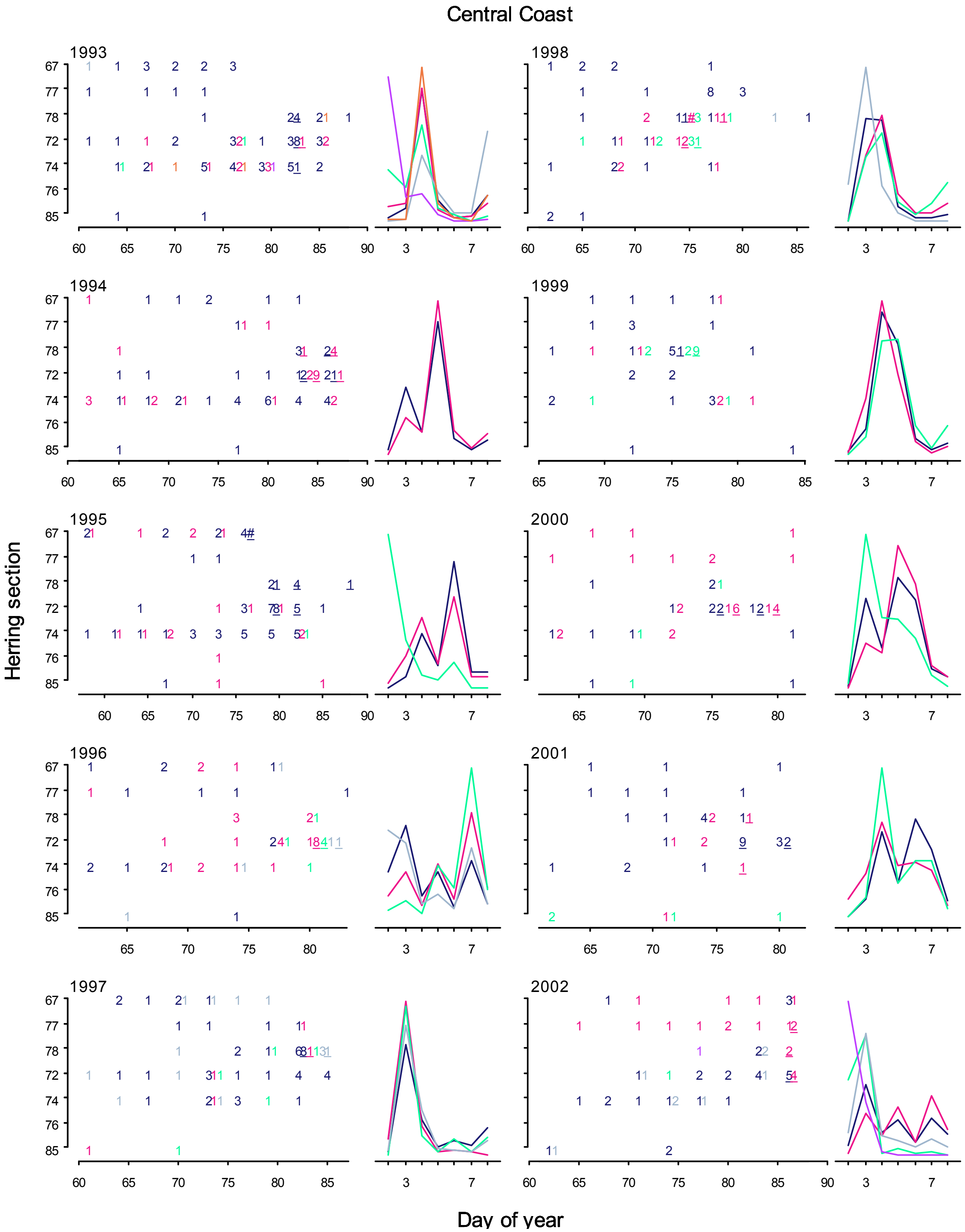


Appendix Figure 1 (cont). Age-composition clusters for the Central Coast SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

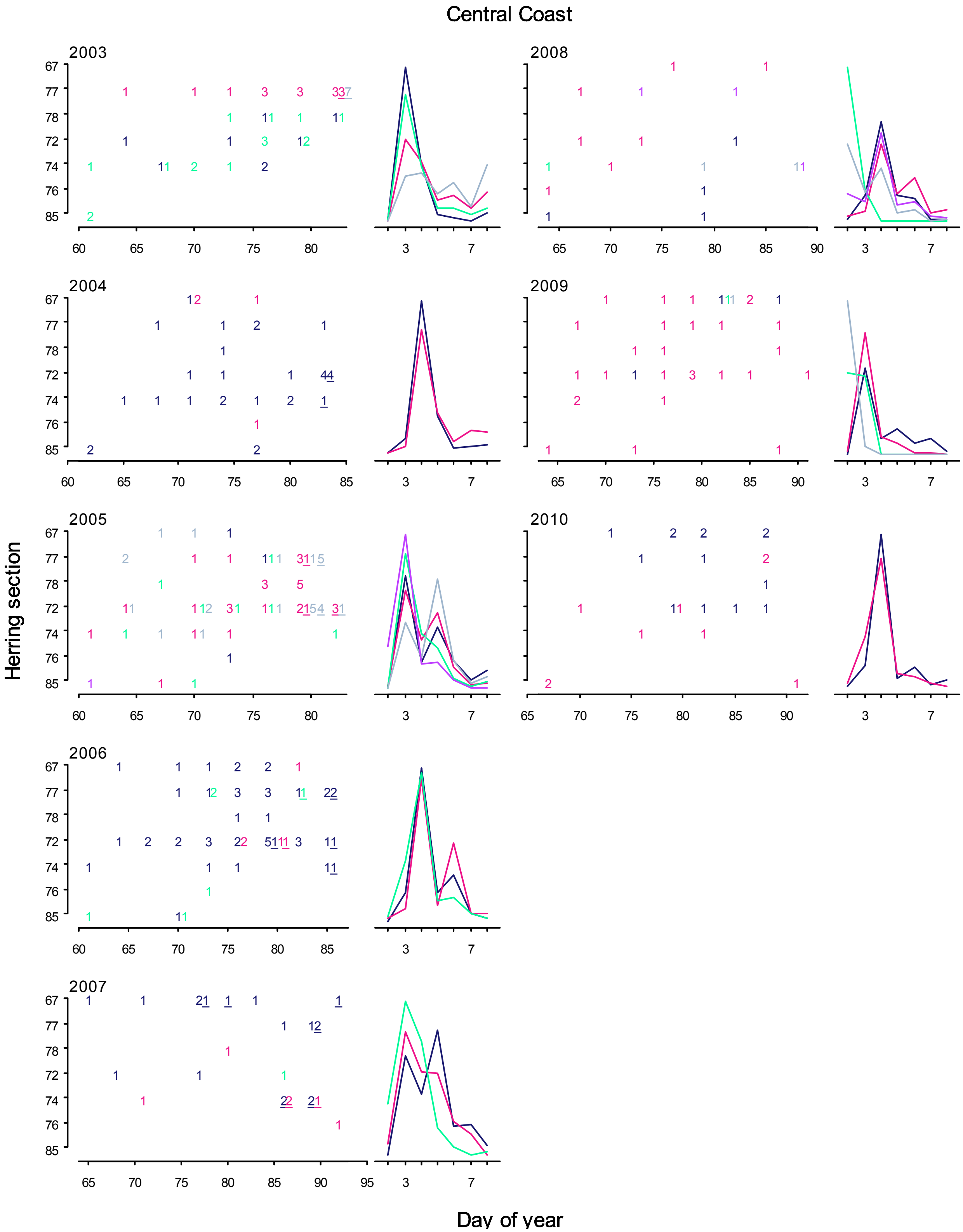
Central Coast



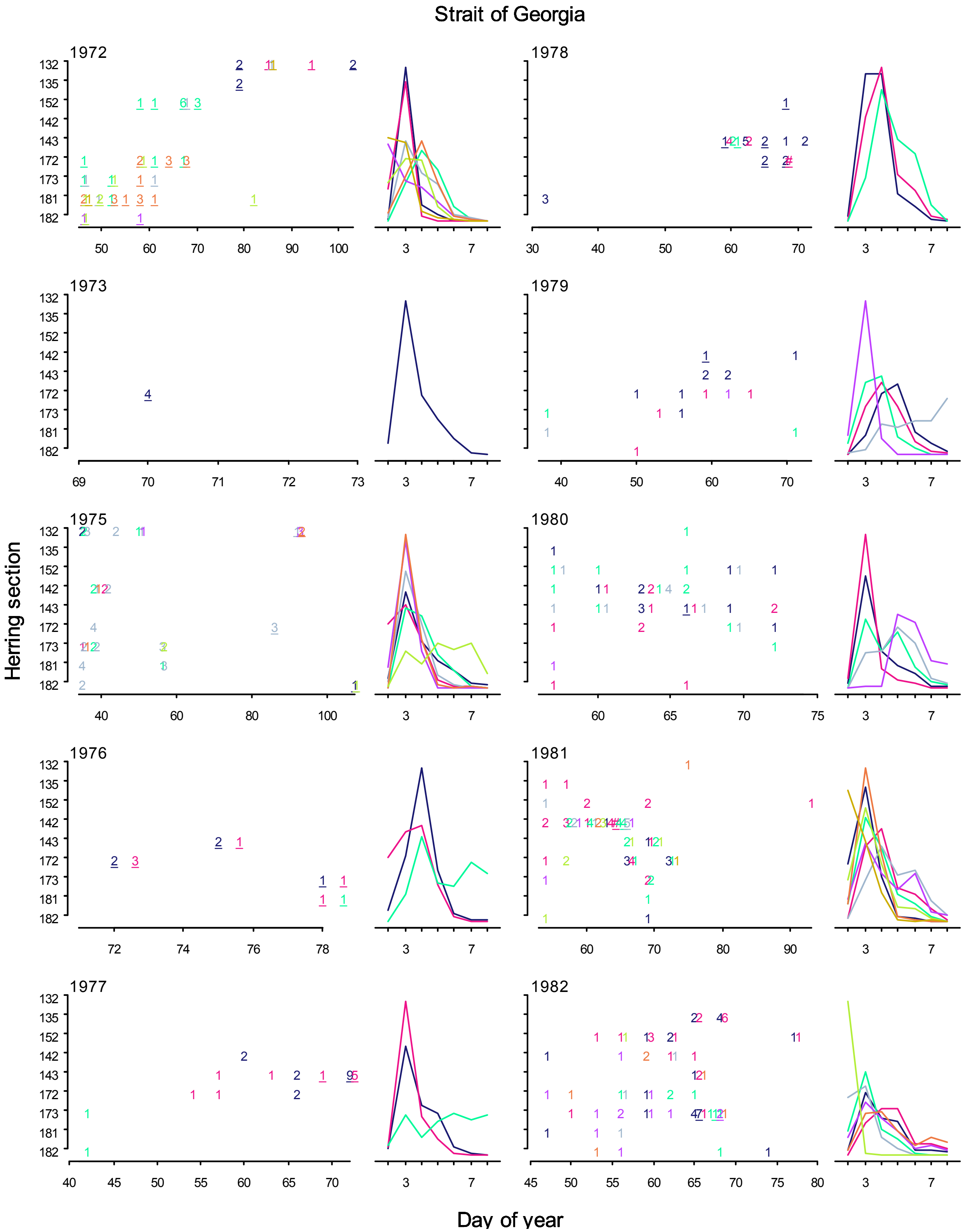
Appendix Figure 1 (cont). Age-composition clusters for the Central Coast SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



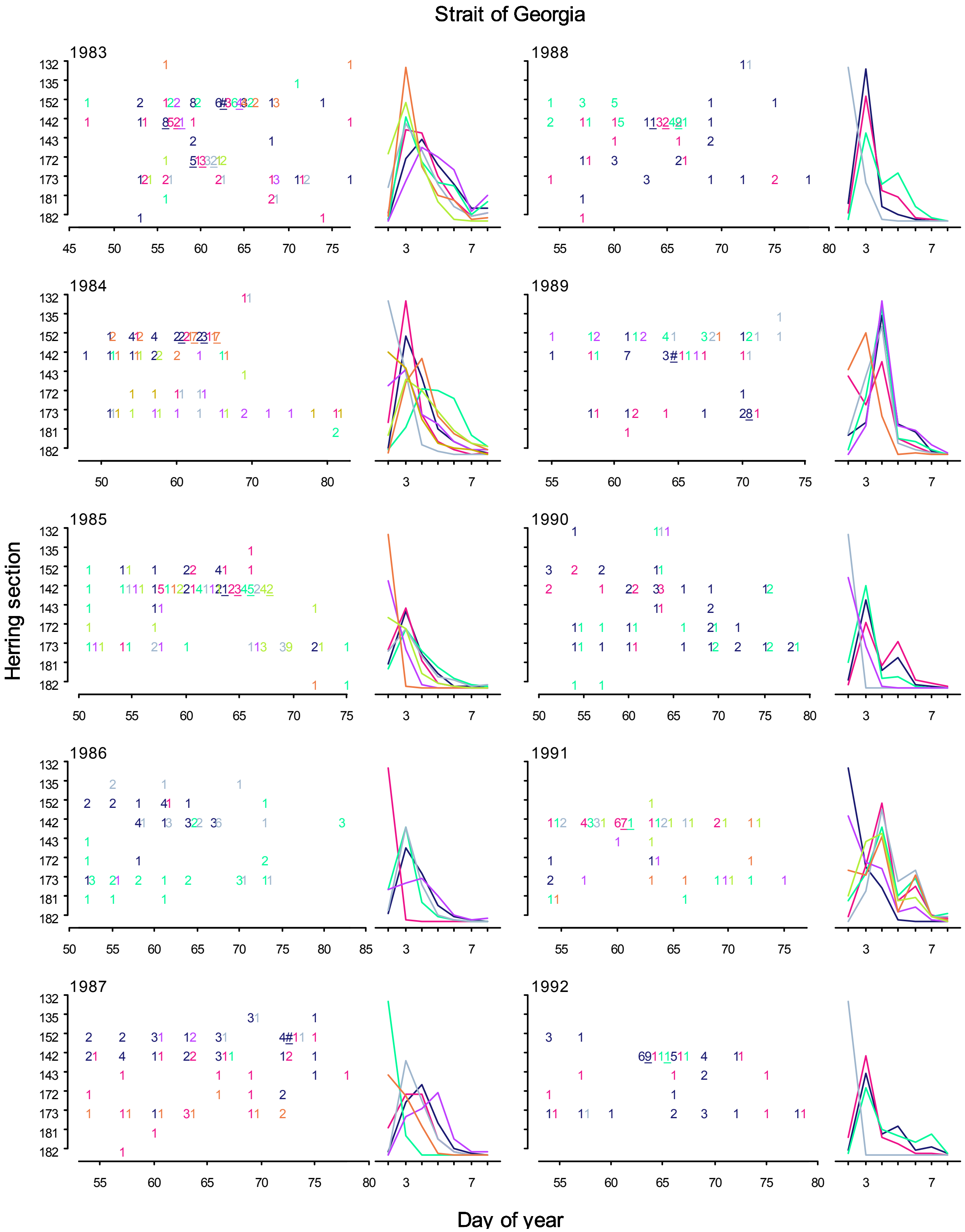
Appendix Figure 1 (cont). Age-composition clusters for the Central Coast SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



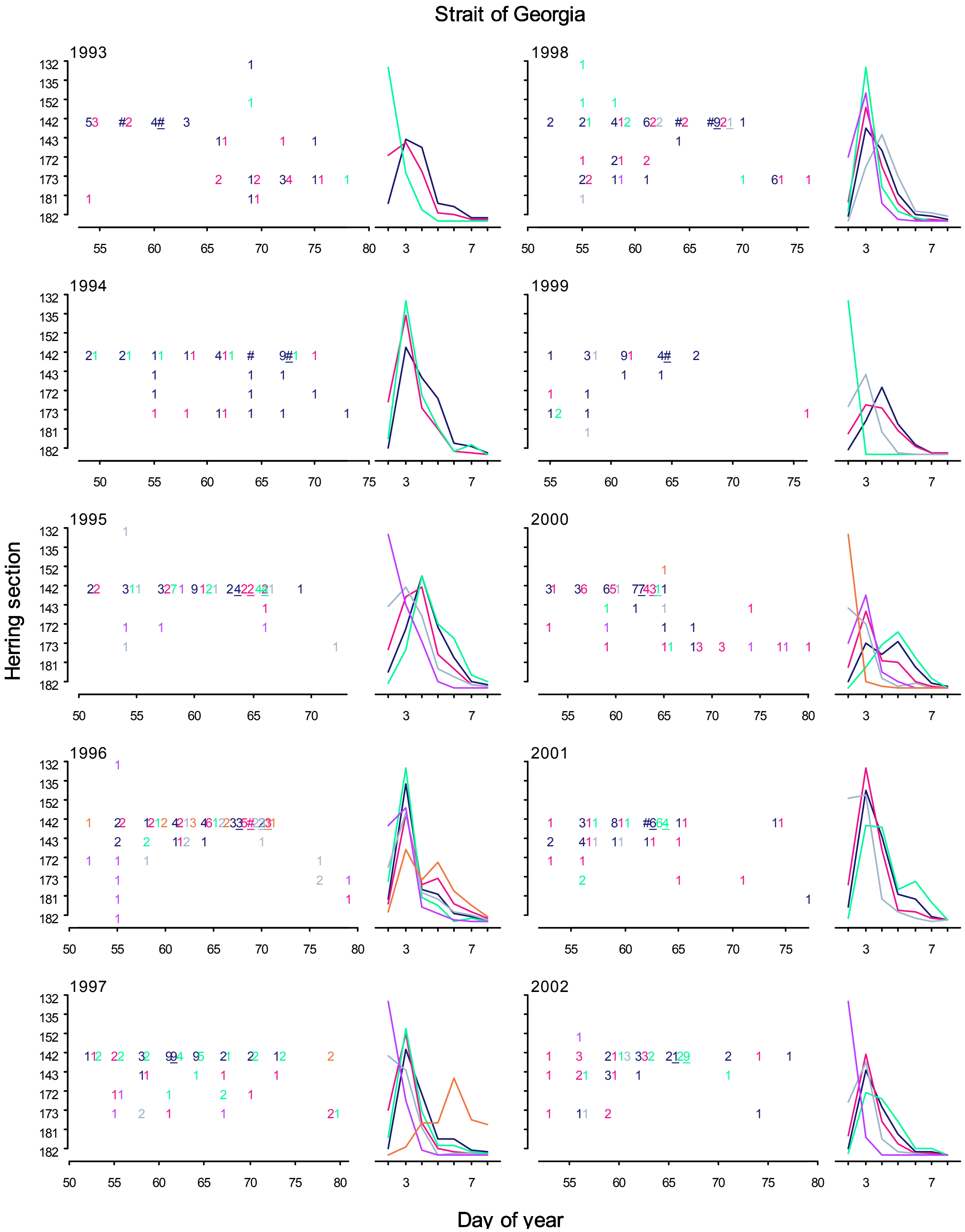
Appendix Figure 1 (cont). Age-composition clusters for the Central Coast SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



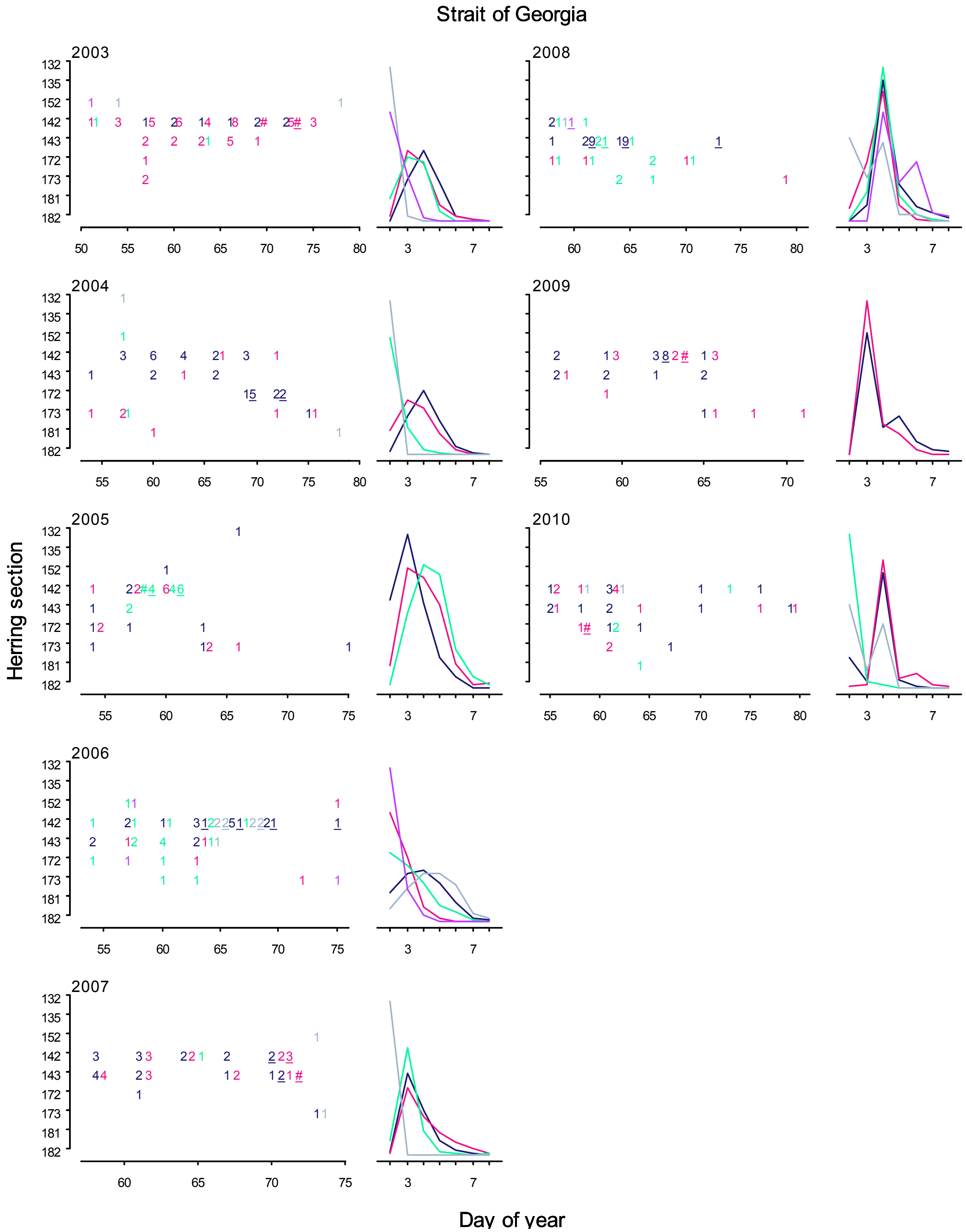
Appendix Figure 1 (cont). Age-composition clusters for the Strait of Georgia SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



Appendix Figure 1 (cont). Age-composition clusters for the Strait of Georgia SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

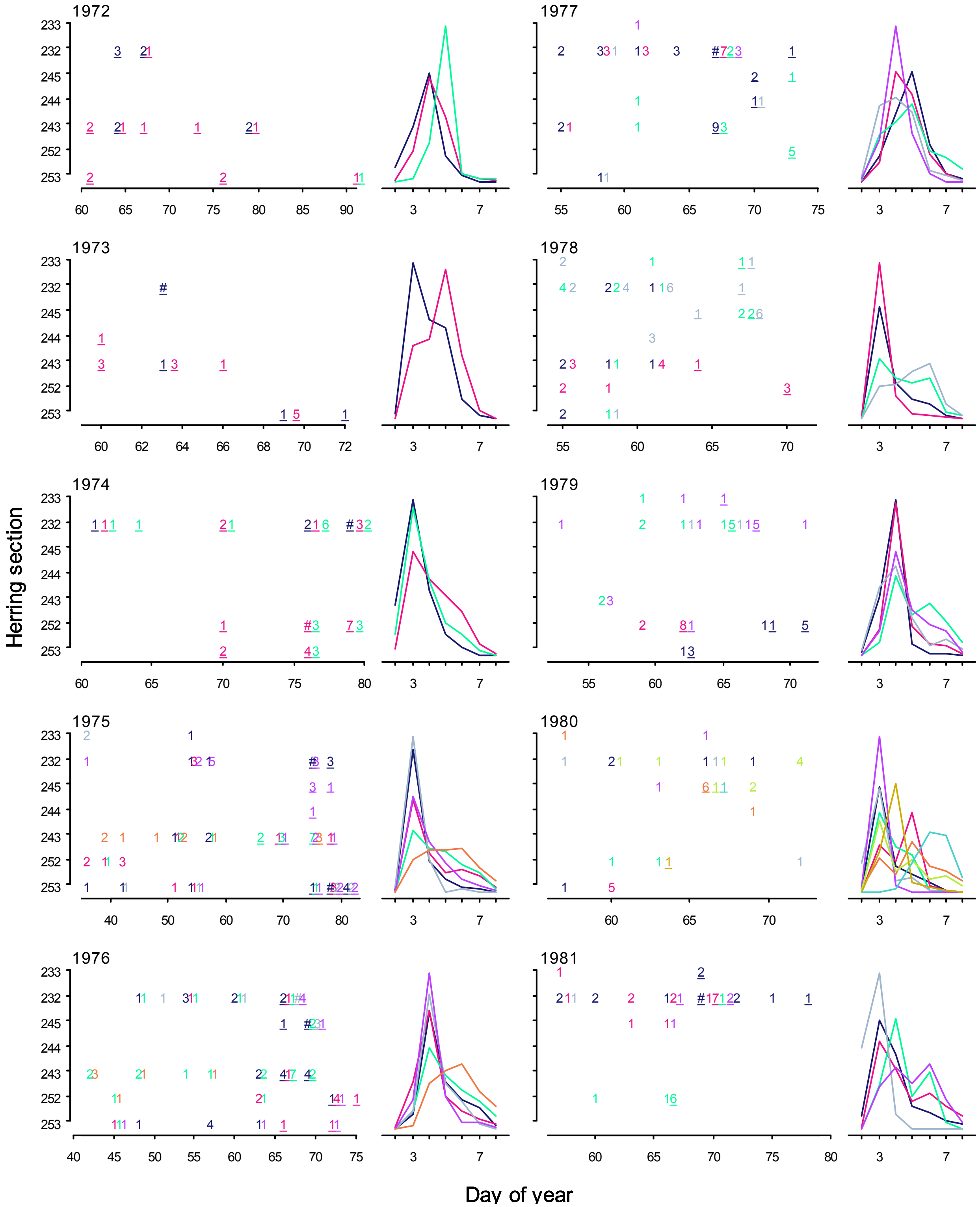


Appendix Figure 1 (cont). Age-composition clusters for the Strait of Georgia SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

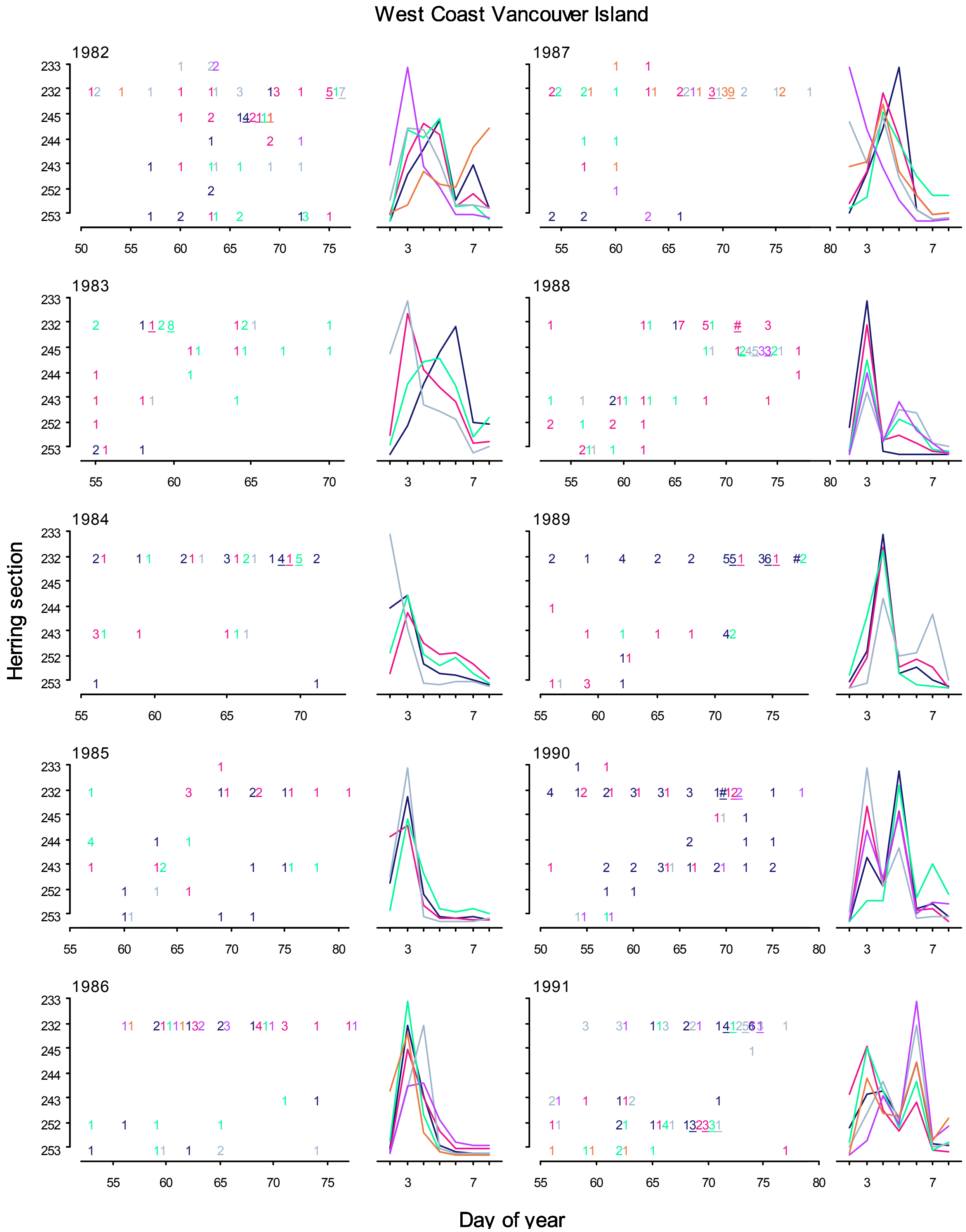


Appendix Figure 1 (cont). Age-composition clusters for the Strait of Georgia SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

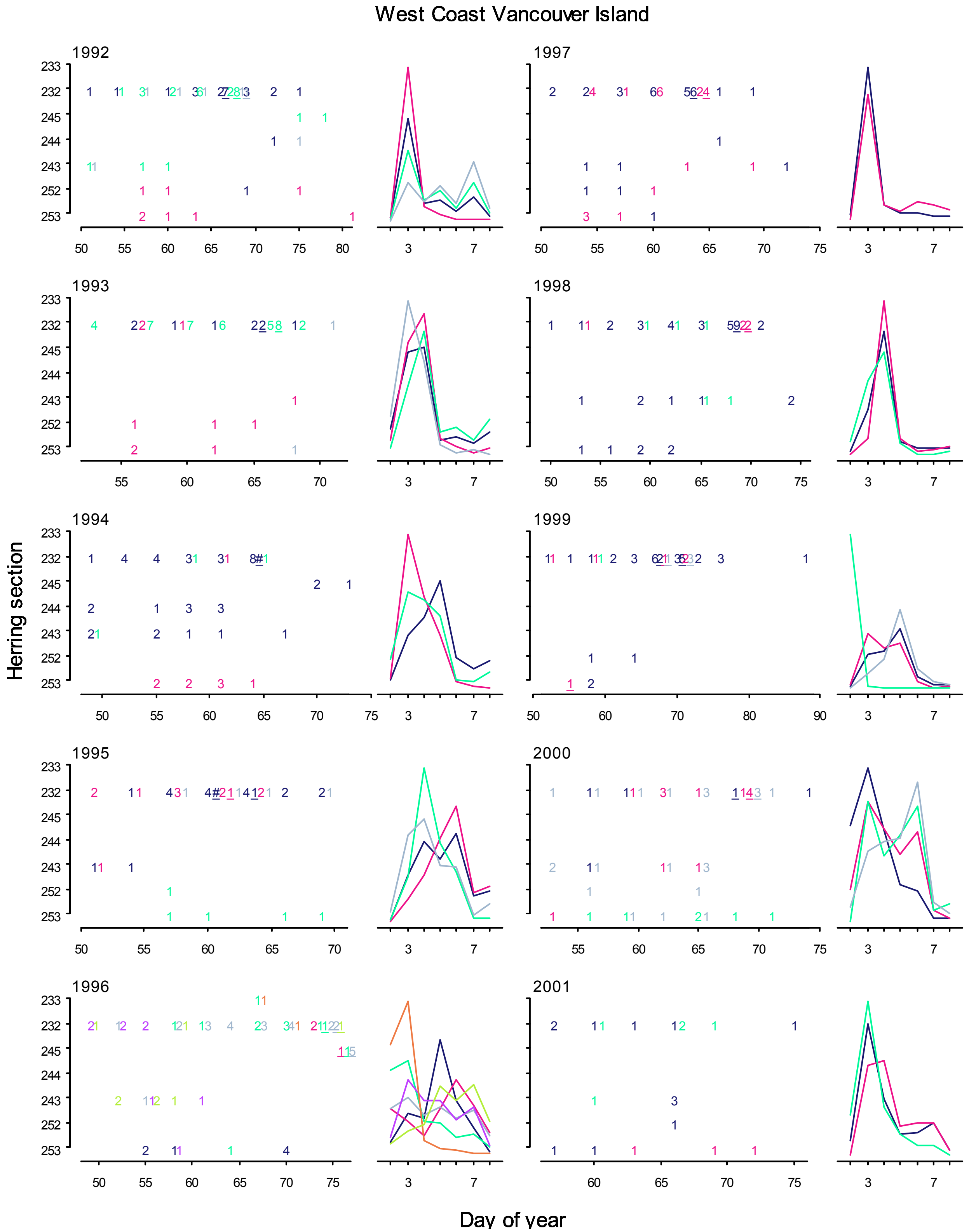
West Coast Vancouver Island



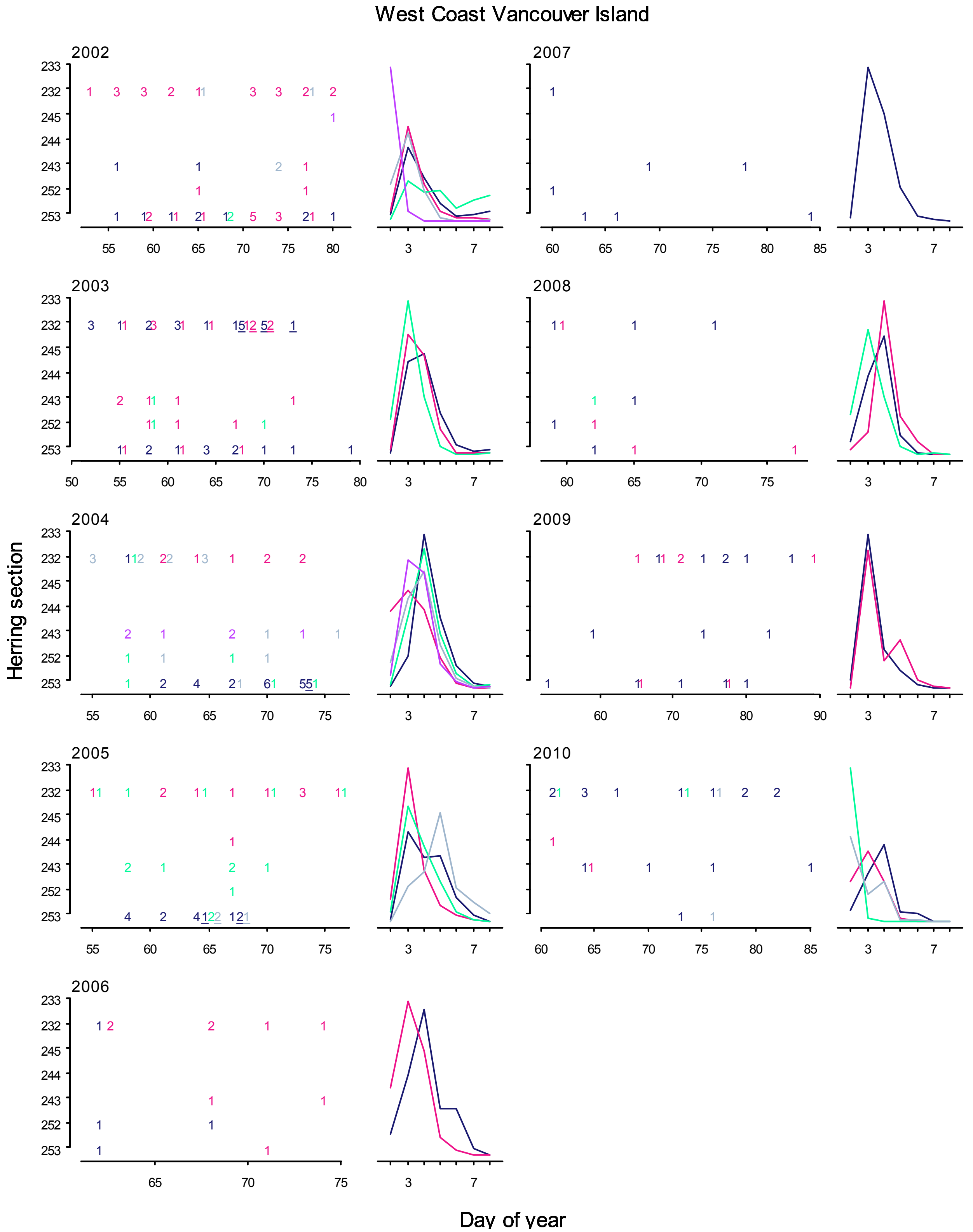
Appendix Figure 1 (cont). Age-composition clusters for the West coast Vancouver Island SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



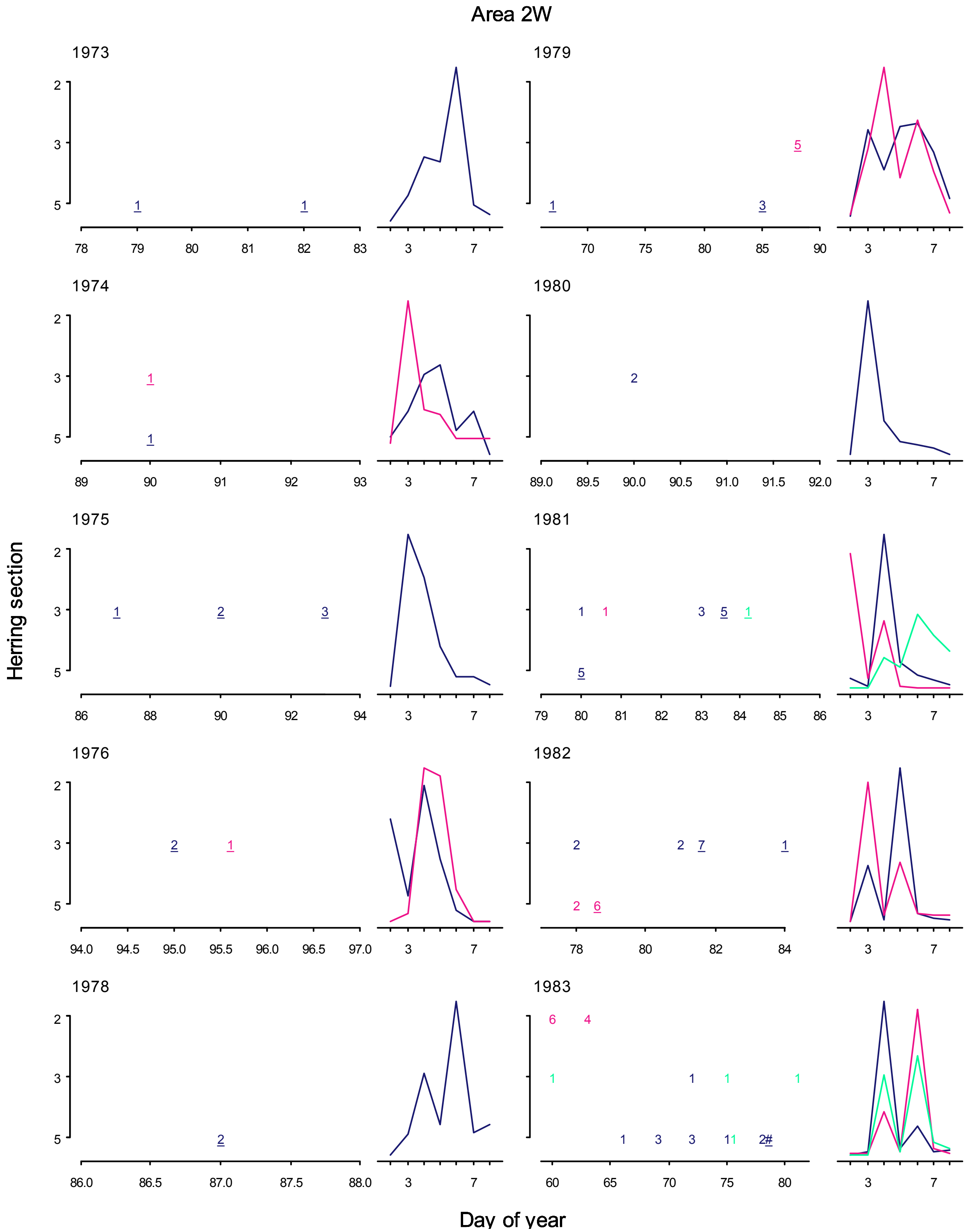
Appendix Figure 1 (cont). Age-composition clusters for the West coast Vancouver Island SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



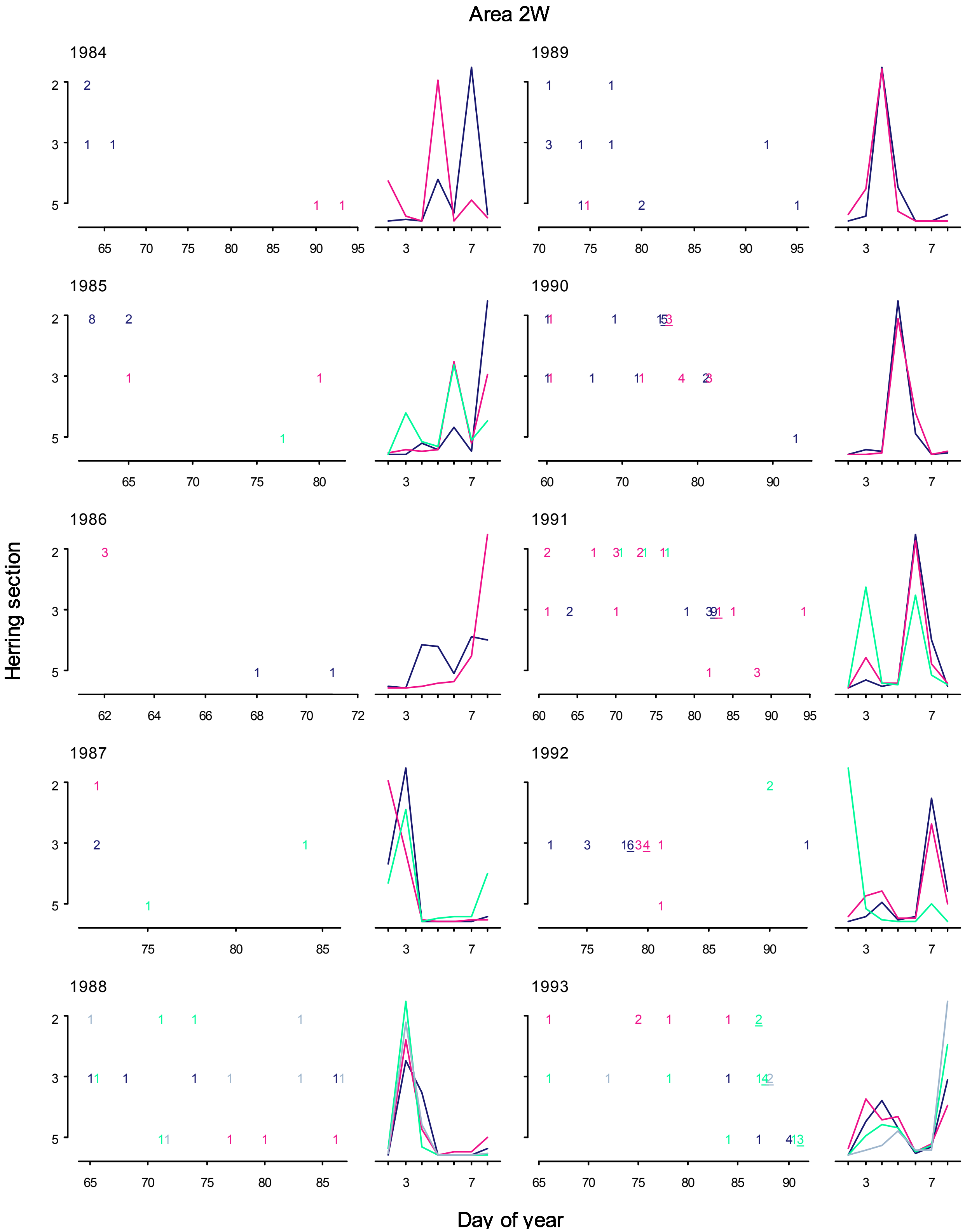
Appendix Figure 1 (cont). Age-composition clusters for the West coast Vancouver Island SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



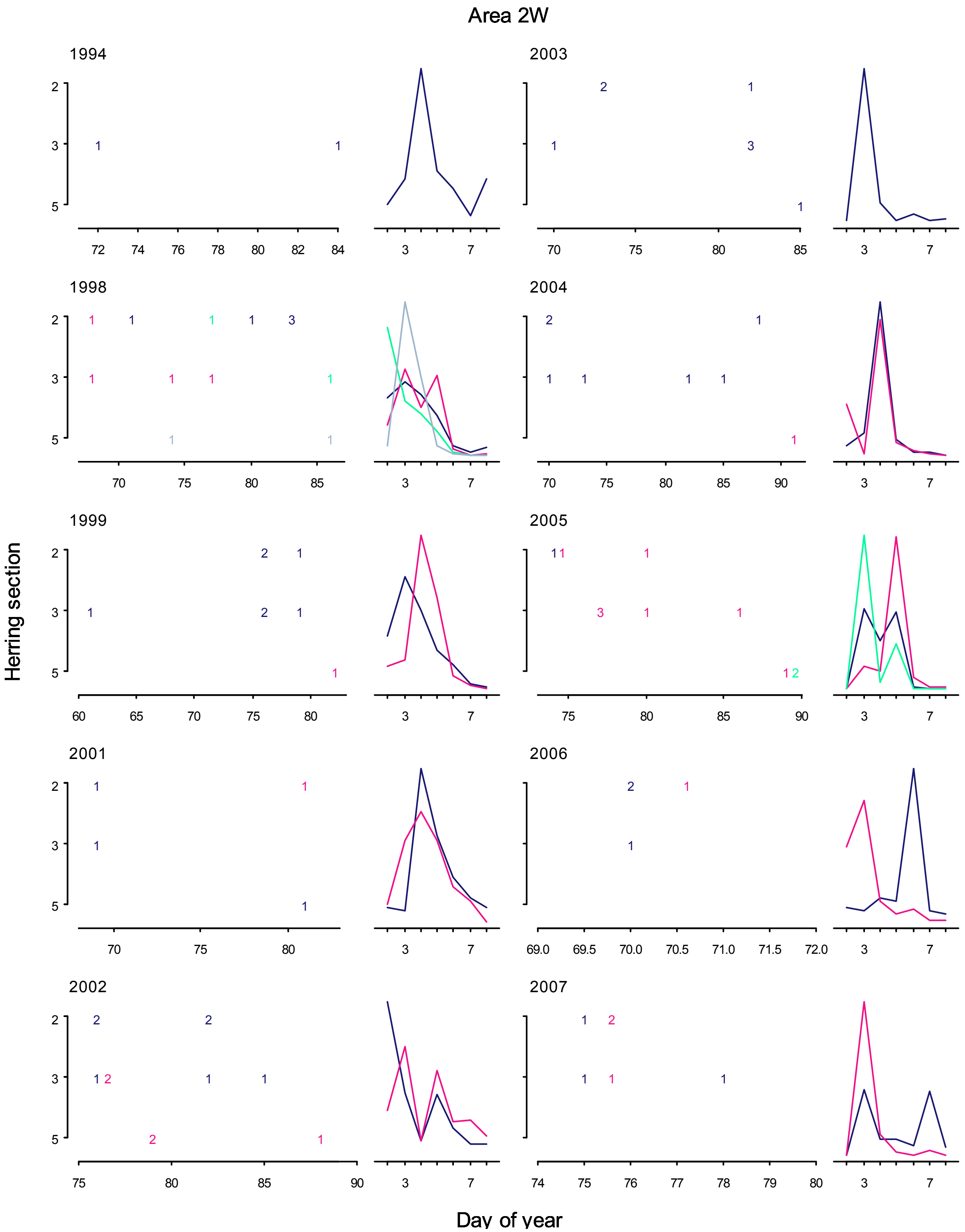
Appendix Figure 1 (cont). Age-composition clusters for the West coast Vancouver Island SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



Appendix Figure 1 (cont). Age-composition clusters for the A2W SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

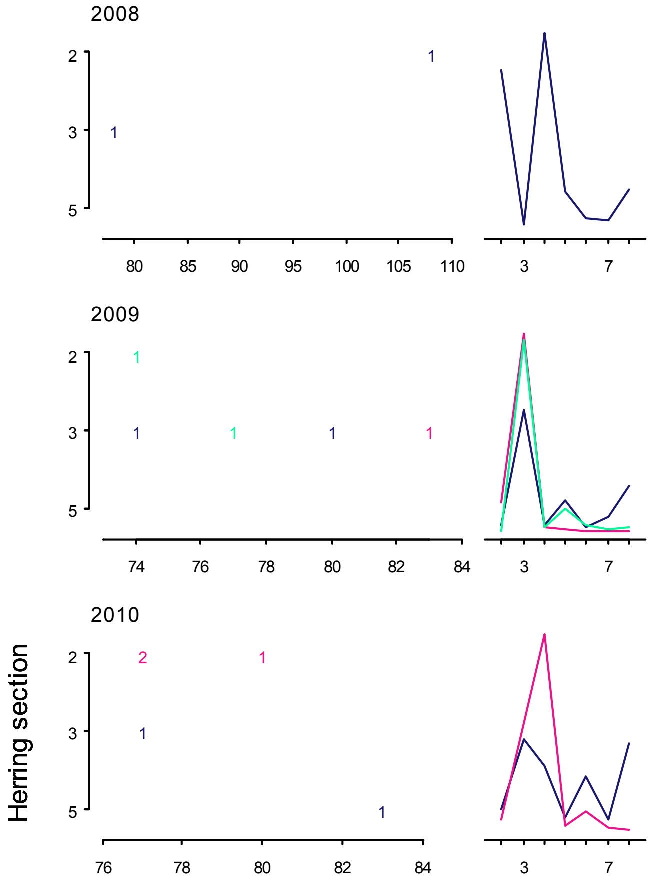


Appendix Figure 1 (cont). Age-composition clusters for the A2W SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



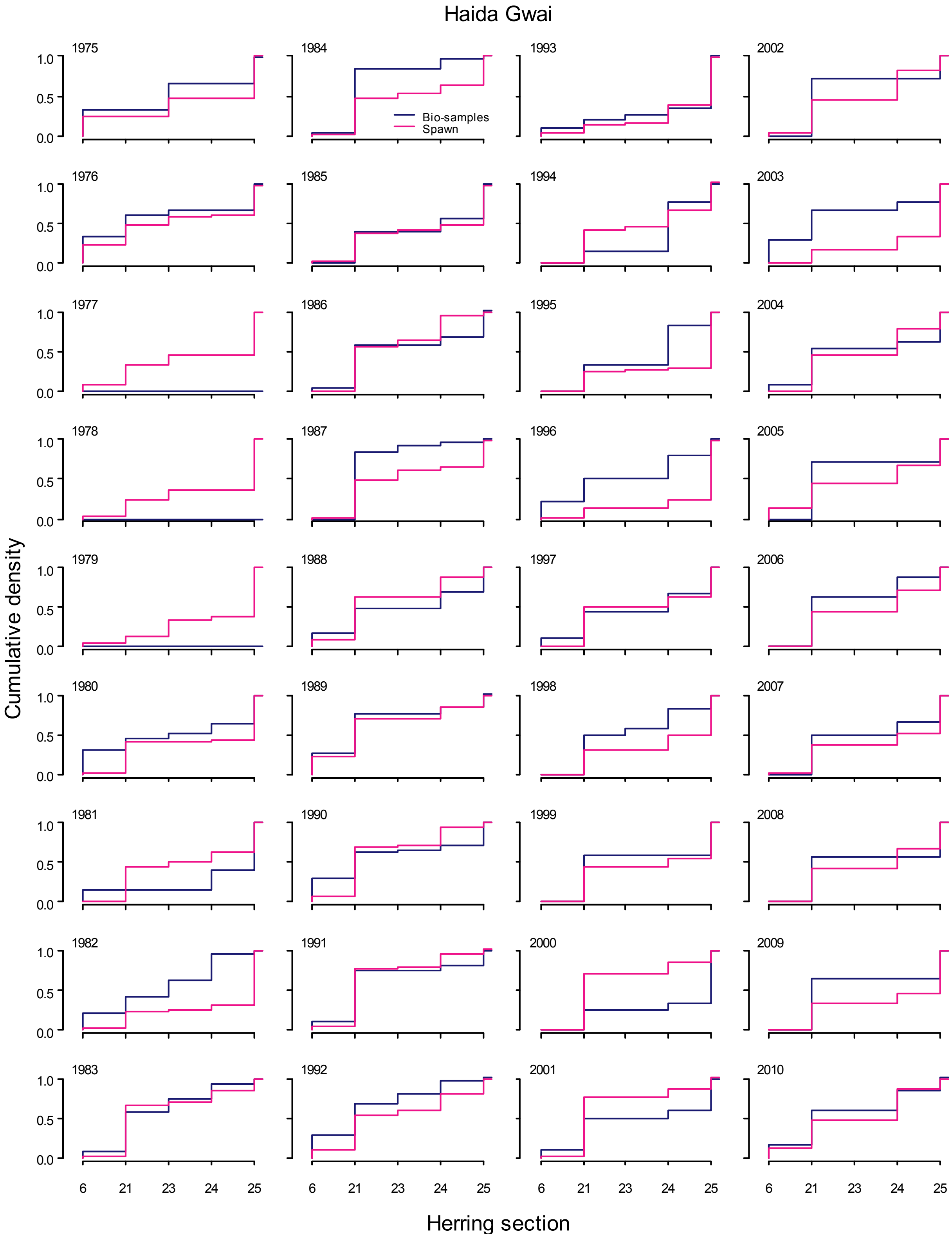
Appendix Figure 1 (cont). Age-composition clusters for the A2W SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.

Area 2W

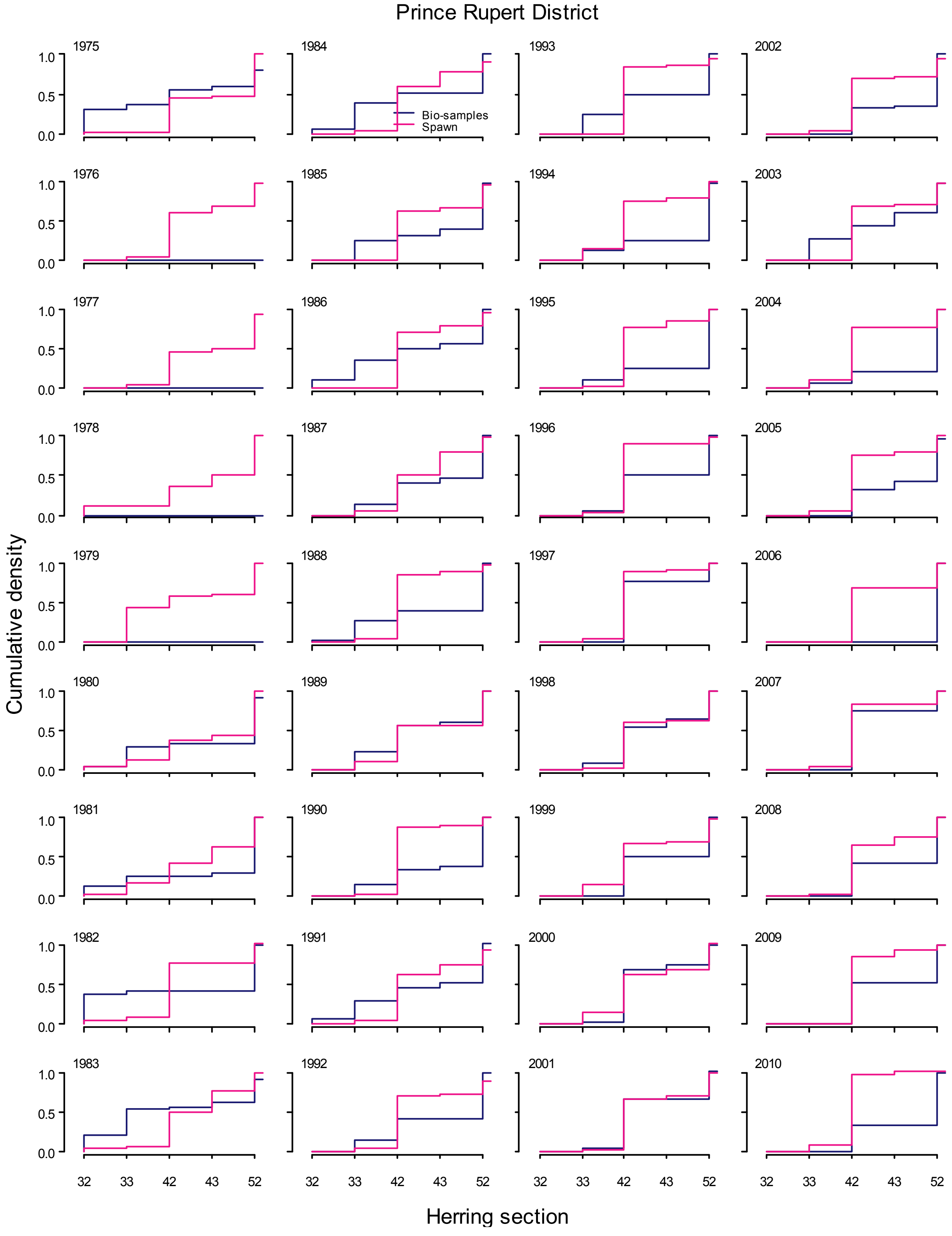


Day of year

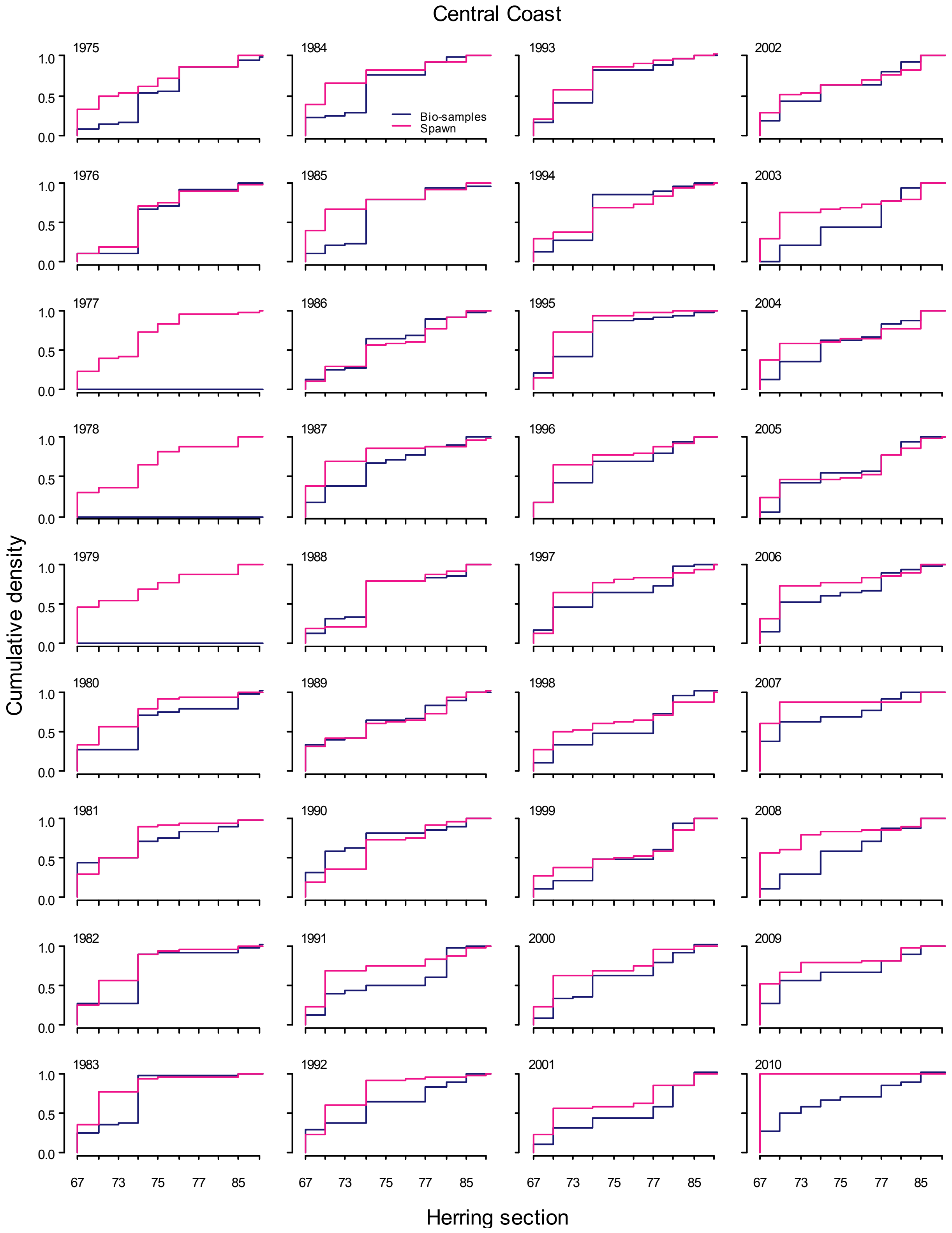
Appendix Figure 1 (cont). Age-composition clusters for the A2W SAR by herring section and day of year: each cluster is plotted with a distinct colour, Sn-roe fishery samples are underlined, and the number plotted indicates the number of samples. Results are amalgamated over 3 day intervals and the proportion-at-age for each cluster is plotted using the same colour scheme to indicate cluster.



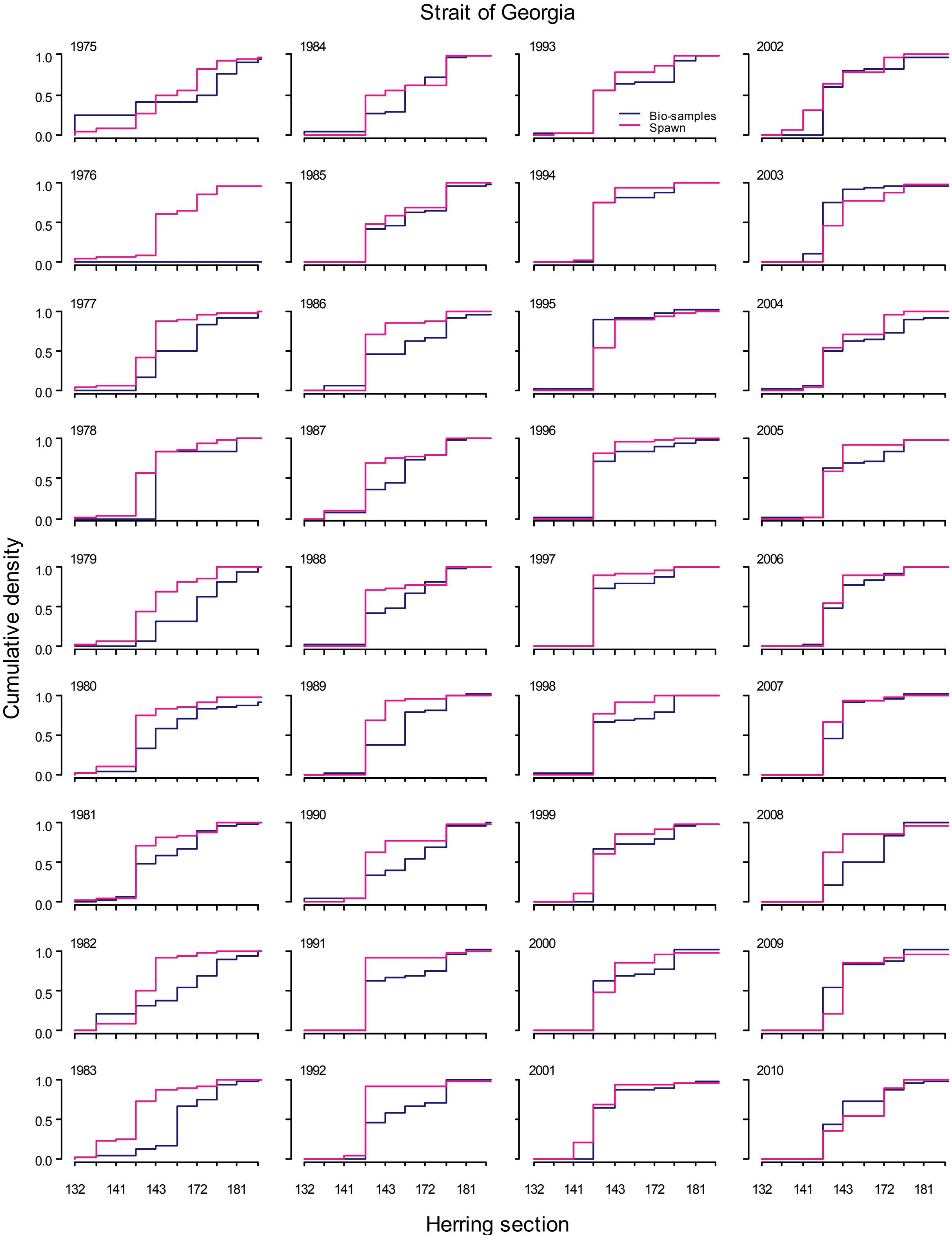
Appendix Figure 2. Annual cumulative density functions for spawn deposition and test fishery bio-samples across sections for the Haida Gwai SAR.



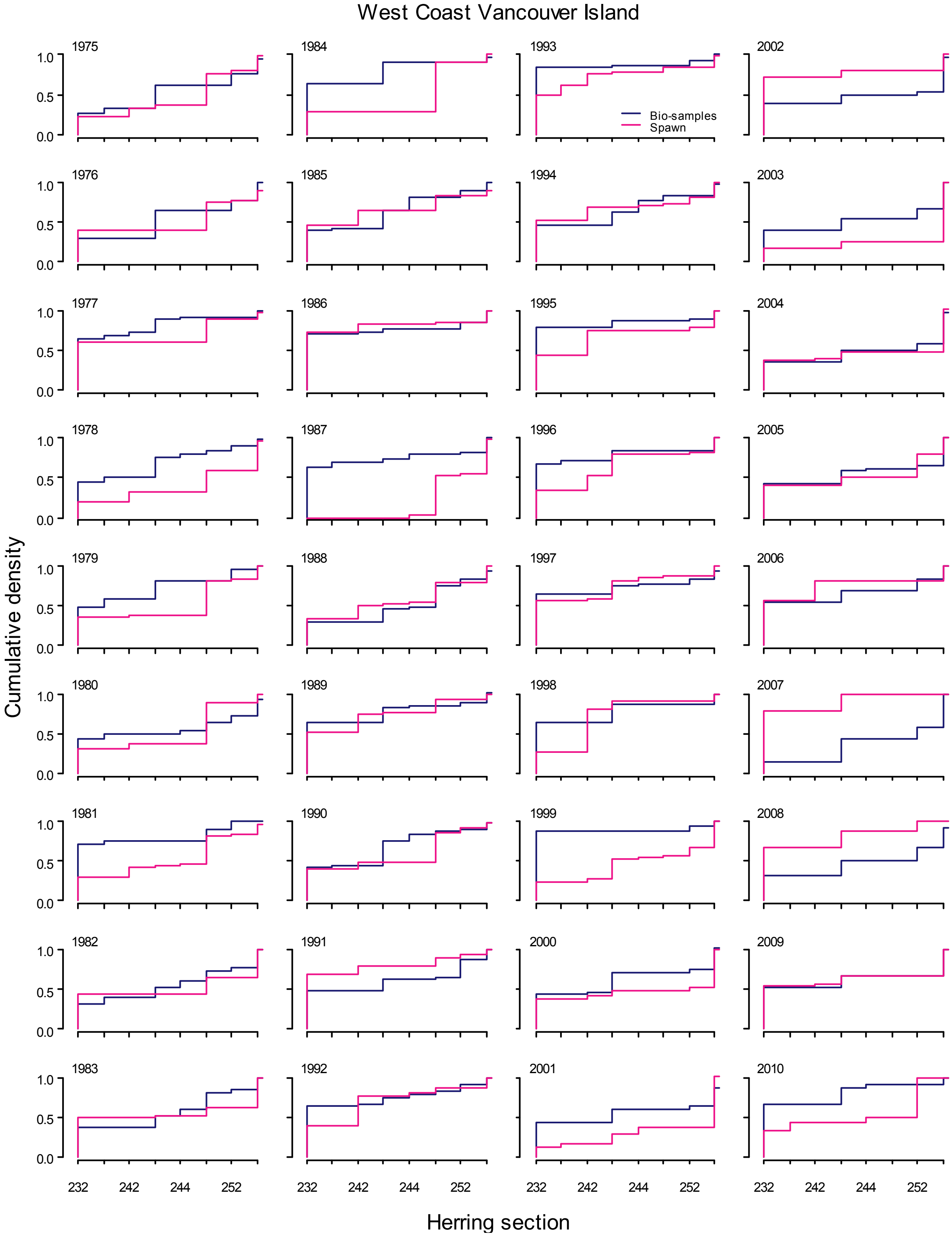
Appendix Figure 2 (cont). Annual cumulative density functions for spawn deposition and test fishery bio-samples across sections for the Prince Rupert District SAR.



Appendix Figure 2 (cont). Annual cumulative density functions for spawn deposition and test fishery bio-samples across sections for the Central Coast SAR.



Appendix Figure 2 (cont). Annual cumulative density functions for spawn deposition and test fishery bio-samples across sections for the Strait of Georgia SAR.



Appendix Figure 2 (cont). Annual cumulative density functions for spawn deposition and test fishery bio-samples across sections for the West Coast Vancouver Island SAR.