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Status of B.C. Pacific Herring (*Clupea pallasii*) in 2013 and forecasts for 2014

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This document presents stock assessments for Pacific Herring (*Clupea pallasii*) in British Columbia waters using data current to 2013. Results of the work are intended to serve as advice over the short term to fishery managers and stakeholders on current stock status and likely impacts of different harvest options. As in previous work, an integrated combined-sex statistical catch-at-age model (ISCAM) was applied independently to each of seven stock areas and tuned to fishery-independent spawn index data, annual estimates of commercial catch since 1951, and age composition data from the commercial fishery and from the test fishery charter program. Assessments were done for five major stock areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), and West Coast of Vancouver Island (WCVI), and two minor herring stock management areas: Haida Gwaii Area 2W, and WCVI Area 27. Results are summarized as stock reconstructions, status of spawning stock in 2013, and projected spawning biomass in 2014.

The model estimated stock-recruitment parameters, time-varying natural mortality, catchability coefficients for the survey time series, and selectivity parameters for the commercial fishery and those survey series for which age data are available. Estimates of unfished equilibrium spawning biomass (SB_0) arose from Beverton-Holt stock-recruitment relationships (within the assessment model), calculated using average trends in weight-at-age, natural mortality and recruitment. All calculations were made using the Bayesian Markov Chain Monte Carlo (MCMC) method to quantify the uncertainty associated with parameter estimation. Estimates of various quantities were calculated from these samples, and are presented as the 5 and 95% credible quantiles, with median values in parentheses. Calculated probabilities are based on joint posterior distributions. One-year spawning biomass projections for 2014 were performed for each major and minor stock area over a range of constant catches to estimate probabilities that spawning biomass and harvest rate metrics are below and above control points historically used in the management of Pacific Herring, as specified in the herring harvest control rule.

The assessment shows current status of major stocks to have increased in 2013 over 2012 and the 2013 median posterior spawning biomass (SB_{2013}) is estimated to be a greater proportion of estimated unfished equilibrium level (SB_0) compared to previous years**.** Ratio estimates (and 90% credibility intervals) of SB_{2013} / SB_0 by major stock area are as follows: HG = 0.80 (0.42-1.49); PRD = 0.49 (0.25-0.90); CC = 0.48 (0.29-0.78); SOG = 0.97 (0.62-1.48), and WCVI= 0.40 (0.23-0.66). For HG, CC and WCVI stocks, where there have been no commercial removals in recent years, the model predicted increases in spawning biomass and recruitment, and decreases in natural mortality in order to explain observed increases in herring spawn index. Common observations across all five major herring stocks include: increases in the spawn index and spawning biomass, most significantly for HG, SOG and CC; declining weight-at-age from mid-1980s to 2010, and apparent decreases in the instantaneous natural mortality rate. For the minor areas, the assessment shows that Area 2W spawning stock biomass has been decreasing since 2011, driven by a declining spawn index since 2010 and apparent increases in the instantaneous natural mortality. For Area 27, the assessment shows that the spawning stock biomass has been at a constant level over the past 10-years but instantaneous natural mortality has been decreasing. Ratio estimates (and 90% credibility intervals) of SB_{2013} / SB_0 by minor stock area are: Area 2W =1.10 (0.45-2.33) and Area 27 = 0.55 (0.31-0.98).

Uncertainty associated with truncated catch data (1972 – present) and an adjustment in the spawn index to account for lead-line changes (2003-2013) was explored through sensitivity runs of the major areas. Fitting the model to a truncated time series had varying effects between stock areas whereas adjustments to spawn widths had negligible influence on model output.

État du hareng du Pacifique (*Clupea pallasii*) de la Colombie-Britannique en 2013 et prévisions pour 2014

RÉSUMÉ

Ce document contient une évaluation des stocks de hareng du Pacifique (*Clupea pallasii*) dans les eaux de la Colombie-Britannique, réalisée à partir de données de 2013. Les résultats de ces travaux serviront à prodiguer des conseils à court terme aux gestionnaires des pêches et aux intervenants relativement à l'état des stocks et aux effets probables sur les diverses options de capture. Comme pour les travaux précédents, un modèle statistique intégré fondé sur les prises des deux sexes selon l'âge a été appliqué de façon indépendante à chacune des sept zones de stock et rempli avec les données sur les indices de frai indépendants des pêches, des estimations annuelles des prises commerciales depuis 1951 et des données de la structure selon l'âge dérivées des pêches commerciales et de la charte du programme de la pêche d'essai. Des évaluations ont été réalisées dans les cinq principales zones de stocks : Haida Gwaii, district de Prince Rupert, côte centrale, détroit de Georgie et côte ouest de l'île de Vancouver (COIV). On compte aussi deux zones secondaires de gestion des stocks de hareng : la zone 2W d'Haida Gwaii et la zone 27 de la COIV. Les résultats sont résumés sous forme de reconstitution du stock, d'état du stock reproducteur en 2013, et de projection de la biomasse du stock reproducteur en 2014.

Le modèle présente une estimation des paramètres stock-recrutement, de la mortalité naturelle en fonction du temps, des coefficients de capturabilité associés aux séries chronologiques de relevés, ainsi que des paramètres de sélectivité afférents aux pêches commerciales et aux séries de relevés pour lesquelles on dispose de données sur les âges. L'estimation de la biomasse d'équilibre non exploitée du stock reproducteur (BSR_0) a été produite en fonction des rapports stock-recrutement de type Beverton-Holt (à l'intérieur du modèle d'évaluation), qui ont été calculés au moyen des tendances moyennes de poids selon l'âge, de mortalité naturelle et de recrutement. Tous les calculs ont été effectués au moyen de la méthode bayésienne de Monte Carlo par chaîne de Markov, qui permet de quantifier l'incertitude entourant l'estimation des paramètres. Les estimations des différentes quantités ont été calculées à partir de ces échantillons et sont présentées en tant qu'intervalles de crédibilité de 5 et de 95 %, avec la valeur médiane entre parenthèses. Les probabilités calculées sont basées sur des distributions combinées a posteriori. Les projections annuelles de biomasse du stock reproducteur pour 2014 sont réalisées pour chaque zone de stock principale et secondaire selon une fourchette de prises constantes afin d'estimer les probabilités que la biomasse du stock reproducteur et les valeurs des taux de récolte soient inférieures et supérieures aux points de contrôle habituellement utilisés pour la gestion du hareng du Pacifique, comme on le précise dans la règle de contrôle des prises de hareng.

L'évaluation démontre que l'état actuel des principaux stocks s'est amélioré entre 2012 et 2013, et on estime que la médiane a posteriori de la biomasse du stock reproducteur (BSR_{2013}) pour 2013 représente une plus grande proportion de la biomasse d'équilibre non exploitée du stock reproducteur (BSR_0) qu'aux années précédentes. Les estimations par ratio (et un intervalle de crédibilité de 90 %) de la BSR_{2013}/BSR_0 pour chacune des principales zones de stock sont les suivantes : Haida Gwaii = 0,80 (0,42-1,49); district de Prince Rupert = 0,49 (0,25-0,90); côte centrale = 0,48 (0,29-0,78); détroit de Georgie = 0,97 (0,62-1,48), et COIV = 0,40 (0,23-0,66). Pour les stocks de Haida Gwaii, de la côte centrale et de la COIV, qui n'ont connu aucune pêche commerciale au cours des quelques dernières années, le modèle prévoit une augmentation de la biomasse du stock reproducteur et du recrutement, ainsi qu'une diminution de la mortalité naturelle, ce qui permet d'expliquer les augmentations de l'indice du frai du hareng. Les observations suivantes ont communément été rapportées pour les

cinq principaux stocks de hareng : augmentation de l'indice du frai et de la biomasse du stock reproducteur, surtout à Haida Gwaii, dans le détroit de Georgie et le long de la côte centrale; baisse du poids selon l'âge entre la seconde moitié des années 80 à 2010; et diminution apparente du taux de mortalité naturelle instantané. Dans les zones secondaires, l'évaluation démontre que la biomasse du stock reproducteur de la zone 2W est en déclin depuis 2011, en raison d'une diminution de l'indice du frai depuis 2010 et d'une augmentation apparente du taux de mortalité naturelle instantané. Dans la zone 27, l'évaluation démontre que la biomasse du stock reproducteur est constante depuis 10 ans, mais que le taux de mortalité naturelle instantané diminue. Les estimations par ratio (et un intervalle de crédibilité de 90 %) de la BSR_{2013}/BSR_0 par chacune des zones secondaires sont les suivantes :
zone 2W =1,10 (0,45-2,33) et zone 27 = 0,55 (0,31-0,98).

L'incertitude associée aux données sur les prises tronquées (de 1972 à aujourd'hui) et une modification de l'indice du frai pour tenir compte des principaux changements (2003-2013) ont été étudiées au moyen de modélisations de la sensibilité dans les zones principales. L'ajustement du modèle selon une série chronologique tronquée a eu différents effets sur les zones de stock, alors que l'ajustement selon la largeur des frayères a eu une incidence négligeable sur les extrants du modèle.

1 INTRODUCTION

1.1 CONTEXT FOR 2013 ASSESSMENT

Assessments of herring stocks in British Columbia (B.C.) waters were done for five major stock management areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), and West Coast of Vancouver Island (WCVI), and two minor herring stock management areas: Haida Gwaii Area 2W, and WCVI Area 27. Assessments for the five major herring stocks areas are reported in the main body of this report, whereas assessments for the two minor stock areas are reported in Appendix E.

There are several key components to the management procedures of B.C. Pacific Herring (*Clupea pallasii*). Here we define a management procedure as the suite of activities that leads to catches in any given year. These components include: which, and how much data are collected; what is assumed about stock structure, the stock assessment model used; and the harvest control rule (HCR) that mathematically converts some estimate of current stock status to a total allowable catch (TAC) (de la Mare 1998). How well a particular management procedure performs depends on what objectives are defined for the management of the stock, including the probability of achieving target biomass level, and the probability of avoiding limit biomass levels. Accordingly, the performance of any given management procedure, or changes to existing ones, cannot be viewed without understanding management objectives.

Many components of Herring management procedures are changing now, or are going to change soon. Some of these changes are required specifically by DFO's policy on the Fisheries Decision-making Framework incorporating the Precautionary Approach, hereafter called the DMF policy; these changes include the requirement to characterize uncertainty and risk as well as develop reference points. Another anticipated change is that with the withdrawal of Larocque funds, DFO will no longer be paying for the collection of survey and biological data that have historically supported stock assessment and management. Yet another change is how to adopt management procedures to deal with apparent time-varying changes in natural mortality and growth. All the above changes cannot be dealt with quickly as they will require both extensive analyses and consultation. We plan more extensive simulation analyses to examine reference points for December 2013 and a preliminary examination of the effects of survey frequency to be reported at a Technical Experts in Stock Assessment workshop in October of 2013. Plans for more comprehensive analyses and consultations from beyond December 2013 are not yet solidified but there are some problems with the current management procedure that can be considered immediately. For this work to be done, a technical working group (TWG) examined some of the rudimentary elements of the existing management procedures, such as the forecasting methodology, as well as some technical aspects of the assessment. The TWG consisted of the Authors of this report as well A.K. Kronlund and J.L. Boldt, who are lead Authors of the working paper titled "*Review of the forecasting methodologies for Pacific herring (Clupea pallasii*)", referred to as the "Kronlund et al. working paper", which was also part of the September 4-6, 2013 Pacific Regional Advisory Process (DFO 2014).

The main technical aspects of the assessment that the TWG reviewed and that are reported herein, relate to the stock assessment model code, input data, and model outputs. With respect to the stock assessment model code, we found some errors that produced errors in the weight-at-age used by the model in the terminal year. With respect to data input, we found two main errors: the assumed length of the lead line used for estimating the spawn survey width was marked with increments larger than required; and inconsistencies between what was assumed to be the maturity-at-age ogive and the values used as input in the model. Criteria for inclusion/exclusion of biological samples used in the calculation of proportion-at-age were also revised.

With respect to model output, we identified an error in the estimation of F_{MSY} quantities previously reported (Martell et al 2012) and the calculation of the discrete harvest rate on the spawning stock biomass. Readers should refer to **Sections 2.4** and **3.1** for a detailed account of these problems, and the measures taken (or not) to deal with them. Finally **Section 3.2** includes a list of issues previously identified issues (2012 Proceedings) and a table listing concerns and whether they were considered or ignored for this assessment.

1.2 LIFE HISTORY

Pacific Herring is a pelagic species migrating between inshore spawning and offshore feeding areas of the North Pacific. In the eastern Pacific, herring distribution ranges from California to the Beaufort Sea. In southern B.C. herring recruit to the spawning stock and are sexually mature predominantly at age 3 with some precocious 2 year olds joining the spawning population while in northern B.C. herring tend to spawn for the first time at ages 3 and 4 with few or no two year old recruits (Taylor 1964). It is believed that in the Strait of Georgia the young-of-year herring overwinter in their first year before joining the immature and adult populations in the offshore feeding grounds whereas in other areas of the coast young-of-year herring appear to begin migration offshore at the end of their first summer (Hourston and Haegele 1980). Herring mature and recruit to the spawning stock predominantly at age 3 within British Columbia but age-at-recruitment tends to increase with latitude within this range.

Herring are iteroparous and return to spawn each year following recruitment until they die naturally or are intercepted in fisheries. Based on many years of tagging data it is evident that while herring usually return to the same large geographical region each year they do not home to the same spawning beach or bay each year (Flostrand et al. 2009). Each female produces about 20-40,000 eggs and quite consistently about 100 eggs/g of female weight with larger females producing more eggs than smaller and younger fish (Hourston and Haegele 1980, Hay 1985).

The age of maturity is difficult to assess in Herring since few surveys of maturing fish have been conducted in the offshore areas. Indications from histological assessments of developing ovaries show that about 25 percent of fish mature at age 2 and at least 90 percent are mature at age 3 (Doug Hay, Fisheries and Oceans Canada, Science, Stock Assessment, Nanaimo, BC, unpublished data). This is consistent with observations for southern B.C stocks, as described above.

All major stocks exhibit seasonal migratory behavior. The main Haida Gwaii (HG) and Prince Rupert District (PRD) stocks feed in Hecate Strait during the summer and fall months, remaining in the offshore areas of Hecate Strait prior to inshore spawning migration in February before spawning in March through May. The main Central Coast (CC) stock feeds in southern Hecate Strait and Queen Charlotte Sound during the summer and early fall months, remaining in offshore areas prior to inshore migration in February to the CC before spawning in March and April. The main Strait of Georgia (SOG) stock feeds off the west coast of Vancouver Island during the summer and early fall months, reentering the SOG beginning in October before spawning in March and April. The main west coast of Vancouver Island (WCVI) stock feeds in offshore areas of southern Vancouver Island during the summer and early fall months (mixing with the migratory SOG stock), returning inshore in late fall prior to spawning in March and April.

1.3 STOCK STRUCTURE

Research examining stock structure of Pacific Herring includes studies using genetics and a variety of tagging methods. Beacham et al. (2008) examined genetic population structure of Pacific Herring in B.C. and adjacent regions using microsatellite variation. This research identified four stocks of Pacific Herring in B.C, as well as stocks in southeast Alaska, Washington, and California. In B.C., differences in timing of spawning were identified as the main isolating mechanisms among stocks, although it is also recognized that geographic isolation of spawning populations may also have some effect in maintaining genetic distinctiveness among stocks. The genetic research concludes that the limited genetic differentiation observed among Pacific Herring populations in B.C. is consistent with among-population straying rates that are sufficient to homogenize allele frequencies over broad areas.

Beginning in the 1930s, B.C. Pacific Herring have been the subject of three tag-recovery programs. The first study employed internal belly tags (1936–1967), the second external anchor tags (1979–1992), and the third internal coded wire tags (1999–2006). The most recent analysis of data collected from the coded wire tag program indicates a wide range in fidelity across regions, from 53 to 90% (Flostrand et al. 2009), consistent with previous findings (Stevenson 1954; Hourston 1982; Ware et al. 2000; Hay et al. 2001; Ware and Schweigert 2001).

For the purposes of fisheries management, B.C. Pacific Herring stocks are managed as five major and two minor stock areas (**Figure 1**). Each stock assessment region (SAR) is comprised of several-to-many herring Statistical Areas that are further broken down into herring Sections and then Locations. Maps identifying stock boundaries and Statistical Areas for each SAR can be found on the Fisheries and Oceans Canada (DFO) website. For the purposes of fisheries management, stock boundaries attempt to capture the habitat range of each discrete "migratory herring stock", defined by historic records of commercial catch and spawning locations.

1.4 ECOSYSTEM CONSIDERATIONS

As a forage species, herring play a key role in the marine ecosystem and are a food source for a variety of species (Schweigert et al. 2010). Herring are an important prey species to many piscivores including Pacific Salmon (Coho and Chinook), Pacific Hake, Pacific Halibut, Arrowtooth Flounder, and Spiny Dogfish. They are also believed to be important in the diet of marine mammal predators such as Steller and California Sea Lions, Harbour and Northern Fur Seals, Harbour Porpoises, Pacific White-Sided Dolphins, Humpback and Grey Whales. Over the time series depicted in the Pacific Herring assessment (1951-2012), population sizes of Seals and Sea Lions and Baleen Whales, which forage on herring, have increased (DFO 2003; DFO 2010; Carretta et al. 2011; Crawford and Irvine 2011).

Research continues to develop a fuller understanding of ecosystem processes and the role that herring play in maintaining ecosystem integrity and function. Little information is available to develop ecosystem-based conservation limits for herring, however, because there is no targeted commercial harvest of immature herring and the current maximum harvest rate of 20% is believed to be conservative, most juveniles and a significant proportion of the adult population should remain available to support ecosystem processes. An equally germane and difficult problem is to determine how to respond to ecosystem processes that are apparently affecting herring stocks, in particular the recent changes in natural mortality and growth. Accordingly, developing management procedure to accommodate such ecosystem changes for B.C. herring stocks is a priority area of research for DFO.

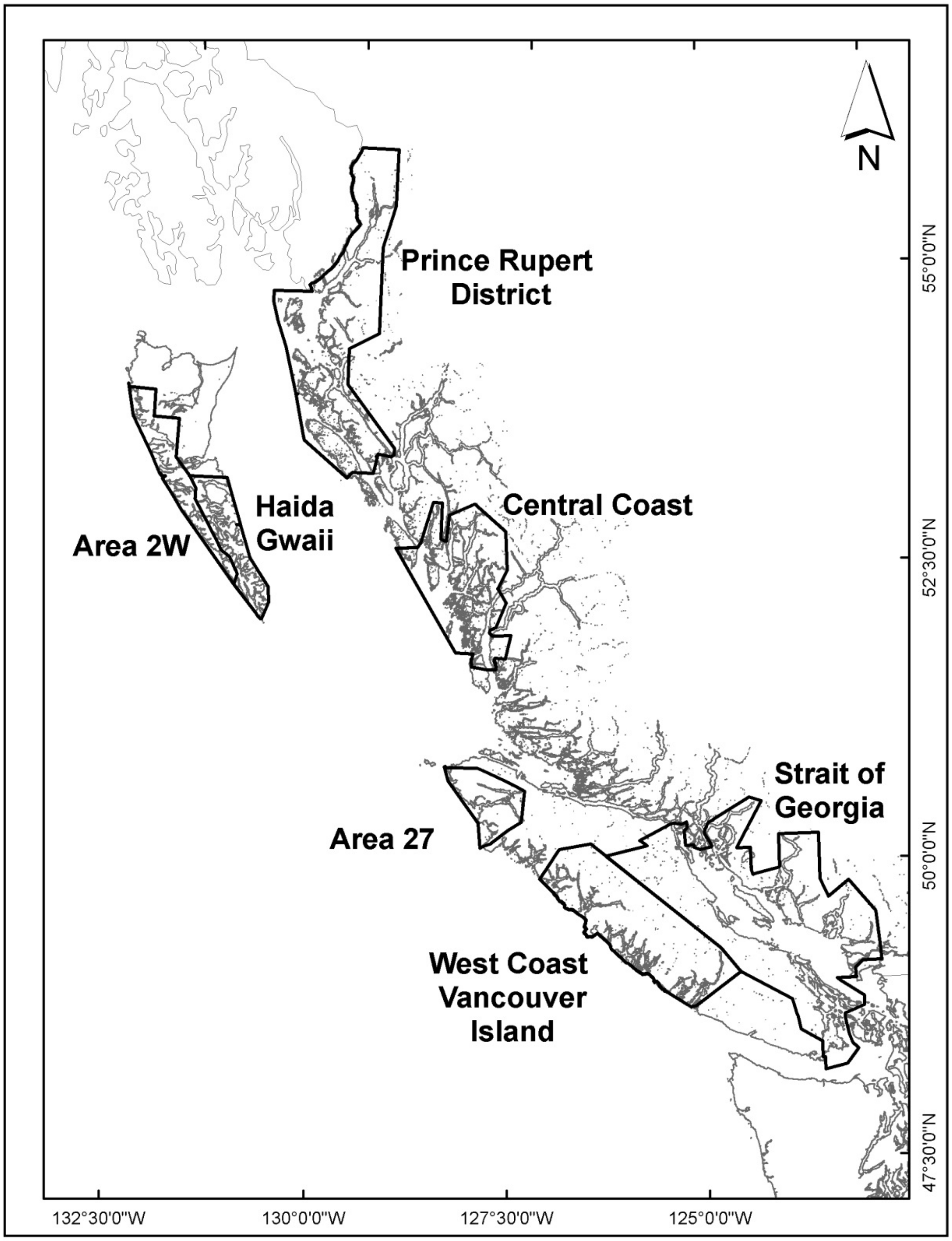

Figure 1. B.C. herring major stock areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), west coast of Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27.

1.5 HERRING FISHERIES

Pacific Herring have been harvested for many years to provide a variety of food products. First Nations have traditionally harvested whole herring and herring spawn for food, social and ceremonial (FSC) purposes.

The commercial Pacific Herring fishery started in British Columbia in the 19th century for the local food market, and quickly expanded into a dry salt fishery for the orient. In 1937 a reduction fishery was also established to produce fishmeal and fish oil (Hourston and Haegele 1980). After the collapse of the Pacific sardine in the late 1940s, Pacific herring became the major fishery off Canada's Pacific coast, and catches steadily increased to over 200,000 tonnes in the early 1960s (Beamish et al. 2004).

From the early 1930s to the late 1960s, herring were commercially harvested and processed (reduced) into relatively low-value products such as fishmeal and oil. Commercial catches increased dramatically in the early 1960s, but were unsustainable. By 1965, most of the older fish had been removed from the spawning population by a combination of overfishing and a sequence of weak year-classes attributed to unfavourable environmental conditions and low spawning biomass. As a result, the commercial fishery collapsed and was closed by the federal government in 1967 to rebuild the resource. During the closure from 1967-1971, limited fishing activity occurred at low levels (Hourston 1980). At this time, there was a growing interest in harvesting roe herring for export to Japan, where herring stocks had been decimated. A small experimental roe harvest began in 1971 and expanded rapidly until 1983, when a fixed harvest rate was introduced to regulate catch. A series of above average year-classes occurred in the early 1970s, rapidly rebuilding stocks and permitting the re-opening of areas for commercial fishing.

1.5.1 Overview of recent fisheries

In addition to First Nations FSC fisheries and recreational opportunities, there are currently five commercial herring fisheries operating on the B.C. coast:

1. Food and bait herring (F&B), usingseine gear, operates November – February;
2. Seine roe (SN), using seine gear, operates February – April;
3. Gillnet roe (GN), using gillnet gear, operates February – April;
4. Spawn on kelp (SOK): open or closed ponding operations where seine gear is permitted for filling closed ponds, operates February – May; and
5. Special use (SU) herring: multiple gear types permitted, operates year round although mainly in fall/ winter.

Commercial licenses for the SN roe and GN roe fisheries are coast-wide licenses, but each year SN and GN licensees select a fishing area from the open areas for that year. Commercial licenses for SOK fisheries are area-specific licenses; meaning fishing opportunities under these licenses exist only if the area is open for fishing. Commercial F&B license eligibility is established by way of an annual lottery draw and SU commercial licenses are open access for areas that are open in that year. **Table 1** provides an overview of herring harvesting activities that have “typically” occurred over the past 10-years in each stock area. Commercial fisheries are prefaced as ‘yes, if open’. A ten-year summary of CSAS recommended maximum available yield, commercial TAC, and total commercial landings are presented for each major SAR in **Table 2.**

Commercial fisheries for B.C. herring stocks were permitted in 2012/13 in the following stock areas: HG 2W (SOK only), PRD (roe SN, roe GN, SOK, winter SN (F&B), SU), SOG (winter SN (F&B), roe SN, roe GN), and WCVI Area 27 (SOK). Commercial fishing opportunities were not permitted in HG 2E, CC, WCVI, or Area 10. Detailed quota allocation for all license categories appears in the 2012/13 Pacific Herring Integrated Fisheries Management Plan (DFO 2012*a*).

Table 1. Overview of harvesting activities for B.C. Pacific Herring stocks over the past 10 years.

	HG	PRD	CC	SOG	WCVI
Commercial					
Food and bait	No	Yes, if open	No	Yes, if open	No
Roe seine	Yes, if open	Yes, if open	Yes, if open	Yes, if open	Yes, if open
Roe gillnet	Yes, if open	Yes, if open	Yes, if open	Yes, if open	Yes, if open
Spawn on	Yes, if open	Yes, if open	Yes, if open	No	Yes, if open
Special use	No	Yes, if open	No	Yes, if open	No
FSC	SOK (harvest of wild SOK, closed ponds)	Whole herring, SOK, spawn-on-boughs	SOK (closed and open ponds), spawn-on-boughs	Whole herring and spawn-on-boughs	Whole herring, SOK (closed and open ponds), spawn-on-boughs
Recreational	Yes	Yes	Yes	Yes	Yes

Table 2. Recent trends in management decisions and landings for major stocks of Pacific Herring for commercial food and bait, special use and roe fisheries (excludes spawn on kelp) Values in metric tonnes.

SAR	HG			PRD			CC		
Year	CSAS	TAC	Total landings	CSAS	TAC	Total landings	CSAS	TAC	Total landings
*2003/04	2,040	0	0	8,140	4,863	4,112	7,310	2,898	2,988
*2004/05	0	0	0	5,480	4,029	3,800	6,780	4,442	3,778
*2005/06	0	0	0	6,410	4,783	2,618	6,330	3,715	3,072
2006/07	0	0	0	3,825	1,070	969	4,083	562	398
2007/08	0	0	0	4,014	1,796	1,662	0	0	0
2008/09	0	0	0	3,468	1,978	2,000	0	0	0
2009/10	0	0	0	3,100	1,558	1,484	0	0	0
2010/11	0	0	0	3,834	2,292	2,147	0	0	0
2011/12	0	0	0	5,498	1,533	1,383	0	0	0
2012/13	43	0	0	5,234	2,068	2,027	0	0	0

CSAS= recommended maximum available yield
*Total landings include Test Fishery program for Use-Fish
** Total Landings (CC 2012/13) does not include 32 t (35 tons) GN catch lost at sea

Table 2 continued.

SAR	SOG			WCVI		
Year	CSAS	TAC	Total landings	CSAS	TAC	Total landings
*2003/04	31,270	18,783	13,601	6,750	4,858	4,454
*2004/05	19,480	18,937	18,871	5,800	5,008	4,269
*2005/06	19,460	18,903	18,762	0	0	0
2006/07	18,294	13,200	10,222	0	0	0
2007/08	13,470	11,485	9,999	0	0	0
2008/09	11,797	9,845	10,169	0	0	0
2009/10	9,000	8,711	8,324	0	0	0
2010/11	13,777	13,247	5,128	0	0	0
2011/12	27,690	16,603	11,339	427	0	0
**2012/13	16,590	**16,558	16,534	0	0	0

CSAS= recommended maximum available yield
*Total landings include Test Fishery program for Use-Fish
** Total SOG Landings (2012/13) does not include 32 t (35 tons) GN catch lost at sea

1.6 MANAGEMENT OF MAJOR HERRING STOCKS

Kronlund et al.[1] describe the current harvest control rule (HCR) for major herring stocks in some detail. Readers should note that in present document we have used *SB* to denote spawning stock biomass instead of *B*, as used by Kronlund et al.. The HCR was stated as follows (after Martell et. al 2012):

$$(1) \qquad U'_{T+1} = \begin{cases} 0 & B_{T+1} \le 0.25SB_0 \\ \dfrac{B_{T+1} - 0.25SB_0}{B_{T+1}} & B_{T+1} > 0.25SB_0 \text{ and } 0.8B_{T+1} \le 0.25SB_0 \\ 0.2 & B_{T+1} > 0.25SB_0 \text{ and } 0.8B_{T+1} > 0.25SB_0 \end{cases}$$

where T is the terminal year for the stock assessment, B_{T+1} is the prefishery forecast biomass in year $T+1$, and SB_0 is the unfished equilibrium spawning stock biomass. Equivalently the rule can be stated as

$$(2) \qquad U'_{T+1} = \begin{cases} 0 & B_{T+1} \le 0.25SB_0 \\ \min\left(\dfrac{B_{T+1} - 0.25SB_0}{B_{T+1}}, 0.2\right) & B_{T+1} > 0.25SB_0 \end{cases}$$

[1] Kronlund, A.R., Boldt, J., Taylor, N., and Cleary, J. Review of Recruitment Forecasting Methodologies for British Columbia Herring Stocks. CSAP WP2013-P71. In review

The output from the HCR is the intended annual harvest rate, which is reduced to zero as the spawning stock is depleted to the level of $0.25SB_0$.

2 DATA

2.1 FISHERY-DEPENDENT DATA

2.1.1 Total catch

Catch data are obtained from landing slips or dockside monitoring. Historically, landing slip data were summed by fishery season with seasons running from July 1 to June 30. Beginning in the 1997/98 season, roe catch data switched to verified plant offload weights, a result of the introduction of the pool quota system for all fisheries except the Strait of Georgia and Prince Rupert gillnet fisheries which remained open fisheries. Beginning in the 1998/99 season, verified plant offload weights became available for all food and roe fisheries coast-wide. Landings from the minor herring fisheries (SU and SOK) are based on landing slip data or more recently also from verified plant offload weights.

For the purposes of stock assessment, catch data are summarized by gear type and fishing category as follows.

Gear 1 (Winter fishery): Commercial catch from the historic reduction fishery (1951-1967), winter seine fishery (F&B, 1968-2013), and the SU fishery (up to 2013).

Gear 2 (Roe seine): Commercial catch and test fishery catch from the roe seine fishery (1972-2013)

Gear 3 (Roe gillnet): Commercial catch and test fishery catch from the roe gillnet fishery (1972-2013)

Currently, catch input to the stock assessment model does not include mortality from the commercial SOK fishery, nor any recreational or FSC fisheries. The commercial SOK fishery is licensed based on pounds of validated SOK product, not tonnes of fish used/ spawned, and there is currently no basis for verifying mortality imposed on the population by this fishery.

A summary of recent fishing activity is described below by major SAR. For areas where commercial food and bait, special use and roe fisheries have occurred, catches by fishery are summarized in **Figure 2**. Raw catch data for each stock area from 1951 to 2013 are included in Appendix B.

Haida Gwaii (HG): The HG has been closed to commercial roe fisheries since 2002 and commercial spawn-on-kelp (SOK) fisheries since 2004. First Nations FSC fisheries operate within traditional territories of individual Nations, harvesting wild SOK and through closed-ponding for SOK.

Prince Rupert District (PRD): There are currently five commercial fisheries operating in the PRD. They are: the Winter fishery – food and bait herring (F&B) that operates November – February; Seine Roe (SN) that operates February – March; Gillnet Roe (GN) that operates February – March; Spawn-on-kelp (SOK) that operates March – May; and Special Use (SU) that uses multiple gear types and operates year round, although mainly in fall/ winter period. First Nations FSC fisheries operate within traditional territories of individual Nations, fishing both whole herring (year round), SOK, and spawn-on-boughs (March-May).

Central Coast (CC): The CC has been closed to commercial roe fisheries and commercial SOK since 2007. First Nations FSC fisheries operate within traditional territories of individual Nations, fishing spawn-on-boughs (March – April) and SOK (open and closed ponding).

Strait of Georgia (SOG): There are currently four commercial fisheries operating in the SOG. They are: the Winter fishery – food and bait herring (F&B) that operates November – February; Seine Roe (SN) that operates February – March; Gillnet Roe (GN) that operates February – March; and Special Use (SU) that uses multiple gear types and operates year round, although mainly in fall/ winter period. First Nations FSC fisheries operate within traditional territories of individual Nations, fishing both whole herring (year round) and spawn-on-boughs (February – March).

West Coast Vancouver Island (WCVI): The WCVI has been closed to commercial roe and spawn-on-kelp (SOK) fisheries since 2006 (with SOK permitted in 2011). First Nations FSC fisheries operate within traditional territories of individual Nations, fishing whole herring (year round), spawn-on-boughs (March – April), and SOK (closed and open ponding).

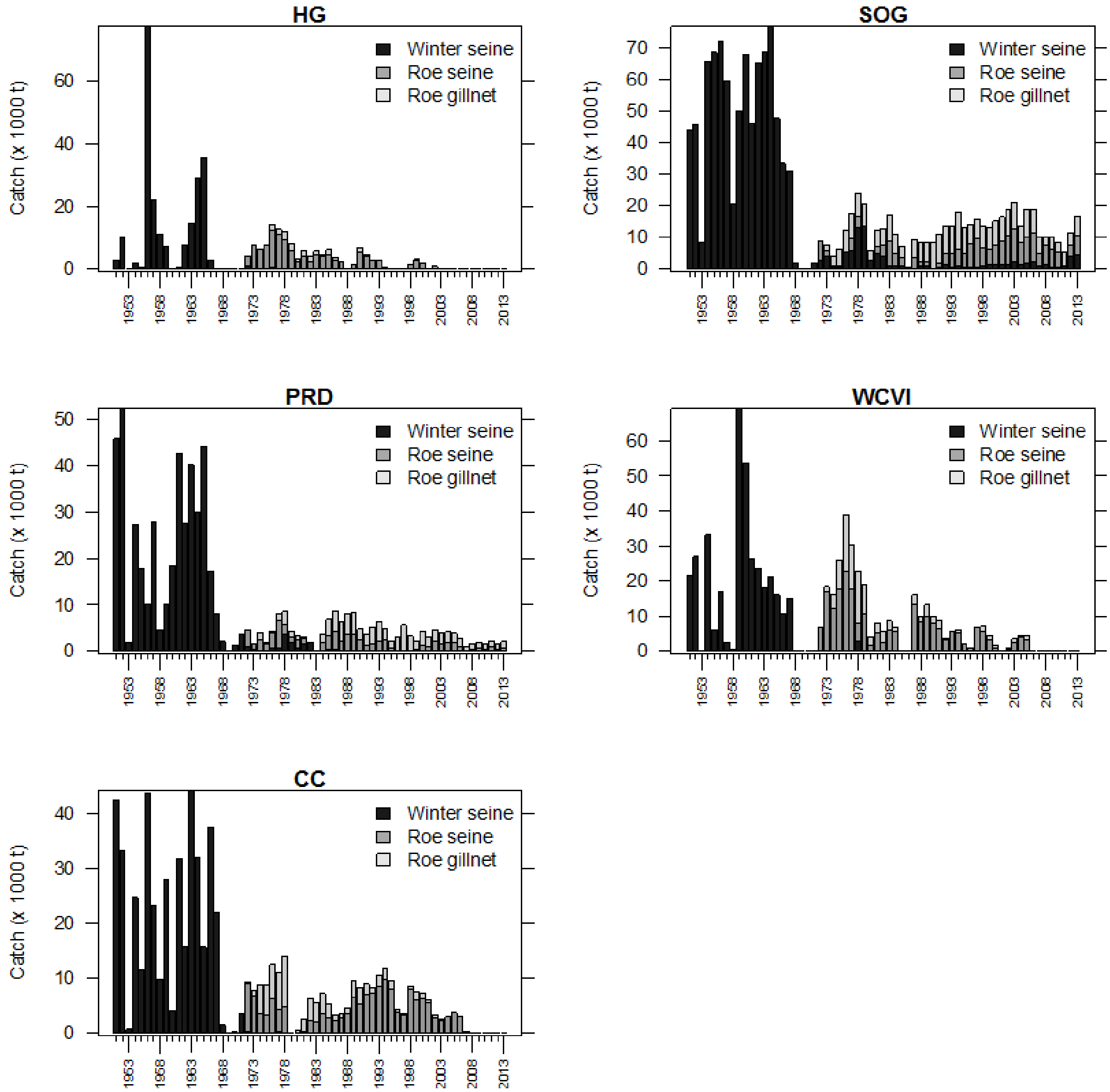

Figure 2. Historic time series of Pacific Herring commercial food and bait, special use and roe fisheries (excludes Spawn On Kelp) used in the assessment of the five major stock areas. Black bars denote winter seine (reduction period: 1951-1967; food & bait 1968-2013), grey bars denote roe seine (1972-2013), light grey bars denote gillnet roe fishery (1972-2013). Units of catch are in thousands of metric tonnes.

2.1.2 Biological data

Biological samples are collected from the major commercial herring fisheries and through the test fishery program. The test fishery charter program began in 1975. One objective of this program is to collect supplementary biological samples in areas where catch sampling was not considered to be representative of mature fish in that stock area (because roe fisheries target large spawning aggregations), and to collect biological samples in areas closed to commercial fishing (providing the sole source of biological data for these areas). Attempts are made to collect 15-20 herring samples from each of the roe seine and roe gillnet fisheries (during validation). In addition, dock-side catch sampling occurs for the F&B fishery, and a small number of samples are collected from the commercial SOK and SU fisheries.

In all sampling events, one “herring sample” (one bucket) is roughly 100 individual herring, from which the following data are collected: fish length, weight, sex, gonad length, gonad weight, and maturity. All fish within a sample are treated as independent observations, that is, there is no weighting of the biological samples by catch or spawn. Biological data from the commercial catch and test fishery sampling programs are pooled for each stock area. These pooled data are used to populate matrices of proportions-at-age and weight-at-age used as input data for the assessment model. Proportions-at-age are summarized by gear type into three fishing categories:

Gear 1 (Winter fishery): Commercial catch samples from the historic reduction fishery (1951-1967) – all gear types, winter seine fishery (F&B, 1968-2013), and the SU fishery (up to 2013).

Gear 2 (Roe seine and SOK): Roe seine catch samples, seine test fishery catch samples, and commercial SOK samples (1972-2013)

Gear 3 (Roe gillnet): Roe gillnet catch samples (1972-2013)

Weight-at-age is averaged over all fishing categories (Gear 1,2,3) into a single matrix of weight-at-age by year for each stock area. The number of biological samples used in the calculation of proportions-at-age and weight-at-age by year and SAR is summarized in **Table 3.**

Herring are aged by the DFO Sclerochronology Lab at the Pacific Biological Station, Nanaimo, B.C. Since 1985, ageing convention for aged finfish species is to use a January-1 birthday. Prior to this change herring were aged with a July-1 birthday coinciding with their biological birthday ranging from mid March (southern stocks) to early June (northern stocks).

Herring ageing data arising from catch samples collected July-1 to Dec-31 are “+1 age-incremented”. That is, during data import, +1 ages are added to the ages of fish collected from July-1 to Dec-31 (e.g., age-2 fish → age-3 fish).

This protocol has been in place since 1985, recognizing that these summer-fall collected fish would be 1-year older had they been removed from the population during roe season (March-April). Herring aged prior to 1985 have been age-adjusted for consistency across all years.

Table 3. Number of biological samples used in the calculation of proportions-at-age and weight-at-age by year, gear (category) and SAR. Note: each sample represents ~100 fish. Gear 1= Reduction, Food & Bait and Special Use; Gear 2= Seine roe, seine test and SOK; Gear 3= Gillnet roe.Seasons span two calendar years, e.g., 19501 is the 1950-51 season.

	Haida Gwaii			Prince Rupert District			Central Coast			Strait of Georgia			West Coast Vancouver Island		
Season	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3
19501	16	-	-	53	-	-	60	-	-	83	-	-	42	-	-
19512	24	-	-	70	-	-	55	-	-	93	-	-	54	-	-
19523	-	-	-	19	-	-	31	-	-	67	-	-	40	-	-
19534	-	-	-	30	-	-	36	-	-	142	-	-	67	-	-
19545	-	-	-	14	-	-	27	-	-	59	-	-	30	-	-
19556	23	-	-	21	-	-	69	-	-	101	-	-	49	-	-
19567	103	-	-	100	-	-	99	-	-	138	-	-	12	-	-
19578	58	-	-	17	-	-	77	-	-	164	-	-	25	-	-
19589	2	-	-	55	-	-	103	-	-	210	-	-	78	-	-
19590	-	-	-	92	-	-	30	-	-	81	-	-	59	-	-
19601	-	-	-	92	-	-	59	-	-	115	-	-	15	-	-
19612	12	-	-	57	-	-	20	-	-	90	-	-	27	-	-
19623	17	-	-	74	-	-	23	-	-	62	-	-	51	-	-
19634	11	-	-	71	-	-	24	-	-	109	-	-	25	-	-
19645	22	-	-	77	-	-	36	-	-	80	-	-	18	-	-
19656	-	-	-	10	-	-	-	-	-	19	-	-	7	-	-
19667	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19678	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19689	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19690	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19701	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19712	-	16	-	-	10	-	-	29	12	47	74	16	-	25	-
19723	-	22	-	2	9	-	-	18	4	58	4	4	-	31	11
19734	-	24	2	-	9	2	-	24	10	1	-	17	-	74	3
19745	-	74	1	1	39	1	-	104	12	5	60	4	-	121	6
19756	-	50	2	2	9	1	-	61	17	51	12	14	-	106	19
19767	-	44	-	8	16	4	-	32	7	31	27	23	-	81	6
19778	-	17	3	11	12	2	-	17	19	23	38	9	31	67	12
19789	-	18	4	13	17	5	-	-	-	35	17	11	-	52	13
19790	-	41	21	15	33	11	-	31	6	54	50	17	-	39	8
19801	-	62	15	44	39	8	-	38	24	51	100	19	-	58	5

	Haida Gwaii			Prince Rupert District			Central Coast			Strait of Georgia			West Coast Vancouver Island		
Season	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3
19812	-	49	8	18	19	-	-	42	21	34	80	16	-	74	16
19823	-	22	12	-	55	-	-	61	24	23	135	6	-	37	7
19834	2	38	6	6	34	7	-	72	18	23	86	12	1	40	8
19845	-	40	3	7	48	7	-	60	17	28	103	14	-	36	-
19856	-	55	7	-	62	16	-	67	15	10	73	-	-	46	-
19867	-	36	-	-	51	20	-	58	12	11	86	24	-	52	8
19878	-	19	-	-	50	10	-	60	9	12	70	11	-	89	8
19889	-	40	-	-	41	7	-	63	11	13	75	11	-	65	6
19890	-	54	7	-	55	7	-	77	12	9	64	19	-	76	6
19901	-	37	6	-	46	12	-	79	10	11	61	15	-	85	5
19912	-	34	-	-	45	11	-	78	10	9	56	15	-	67	7
19923	-	39	-	-	43	9	-	93	10	12	63	12	-	61	-
19934	-	13	-	-	70	10	-	78	23	6	64	15	-	66	8
19945	-	6	-	-	47	10	-	106	16	14	64	11	-	54	-
19956	-	14	-	-	28	6	-	60	7	20	93	7	-	79	-
19967	-	18	-	-	28	7	-	72	6	7	80	8	-	63	-
19978	-	29	-	-	22	12	-	69	13	17	90	16	-	56	12
19989	-	26	7	-	18	8	-	53	12	17	43	11	-	47	11
19990	-	24	-	-	42	9	-	48	8	19	71	13	-	51	8
20001	-	14	-	-	41	12	-	47	10	13	69	12	-	25	-
20012	-	35	-	-	46	10	-	62	6	20	56	11	-	56	7
20023	-	24	-	-	42	11	-	48	12	9	97	19	-	60	12
20034	-	11	-	-	26	13	-	35	-	12	52	16	-	61	9
20045	-	14	-	-	32	10	-	69	-	8	51	11	-	42	10
20056	-	9	-	-	22	7	-	64	-	7	57	15	-	13	-
20067	-	6	-	-	8	16	-	26	-	15	58	44	-	7	-
20078	-	10	-	-	41	16	-	17	-	26	45	27	-	12	-
20089	-	11	-	-	43	12	-	33	-	11	48	12	-	22	-
20090	-	12	-	-	35	12	-	26	-	14	56	13	-	23	-
20101	-	13	-	-	38	18	-	30	-	20	60	28	-	14	-
20112	-	8	-	-	35	13	-	24	-	57	55	32	-	10	-
20123	-	12	-	-	32	12	-	15	-	39	52	20	-	5	-

[./Herring Assessment (2013)/Data stream/2013 input data.xls]

2.2 FISHERY-INDEPENDENT DATA

2.2.1 Spawn survey data

Herring spawn surveys have been conducted throughout the B.C. coast beginning in the 1930s. Prior to 1988, spawn surveys were conducted from the surface either by walking the beach at low tide or using a drag from a skiff to estimate the shoreline length and width of spawn. Beginning in 1988, herring spawn surveys using SCUBA methods were introduced and were implemented coastwide within a couple of years. These surveys were initially conducted by DFO staff and eventually by contract divers hired through the test fishery program. Prior to the 2006 Larocque ruling, the test fishery program was funded through an allocation of fish, and from 2007-2013 this data collection program has been funded directly by DFO. In 2013, dive surveys were conducted in all major and minor assessment regions, with the exception of Area 2W, where a combination of snorkeling and surface survey methods was used.

Both survey methods (surface or dive) involve collecting information on spawn length (parallel to shore), spawn width (perpendicular to shore), and number of egg layers by vegetation type. These data are used to calculate egg densities per spawning bed, with the ultimate goal of estimating spawning biomass, following the methods of Schweigert (2001). Trends in estimates of spawn length, spawn width, and average number of egg layers are presented in Appendix B for all major stock areas. Changes to the calculation of the spawn index are described in **Section 2.4.2.**

Spawn survey data are represented as two independent indices in Herring stock assessments:

1. a surface survey index from 1951-1987; and,
2. a dive survey index from 1988-2013

Spawn indices are an output of the Herring Stock Assessment Database, in units of metric tonnes of herring spawning biomass. **Figure 3** summarizes the time series of spawn index for all major stock areas, from 1951-1987 and 1988-2013. Since 1988, some early and late season surface observations have been collected (Appendix D, Figure D1) but these observations represent a small proportion of total spawn survey in a given area; therefore indices for 1988-2013 shown in **Figure 3** are only represented as being from dive surveys. In all major stock areas, numeric estimates of spawning biomass (spawn index values) increased in 2013 over 2012. Execution of the 2013 spawn survey followed all standard protocols as described in the 2013 version of the Herring Spawn Survey Manual and there were no in-season or post-season concerns raised by the HCRS (contractor) or the DFO Area Managers about the quality of spawn survey data from the 2013 season.

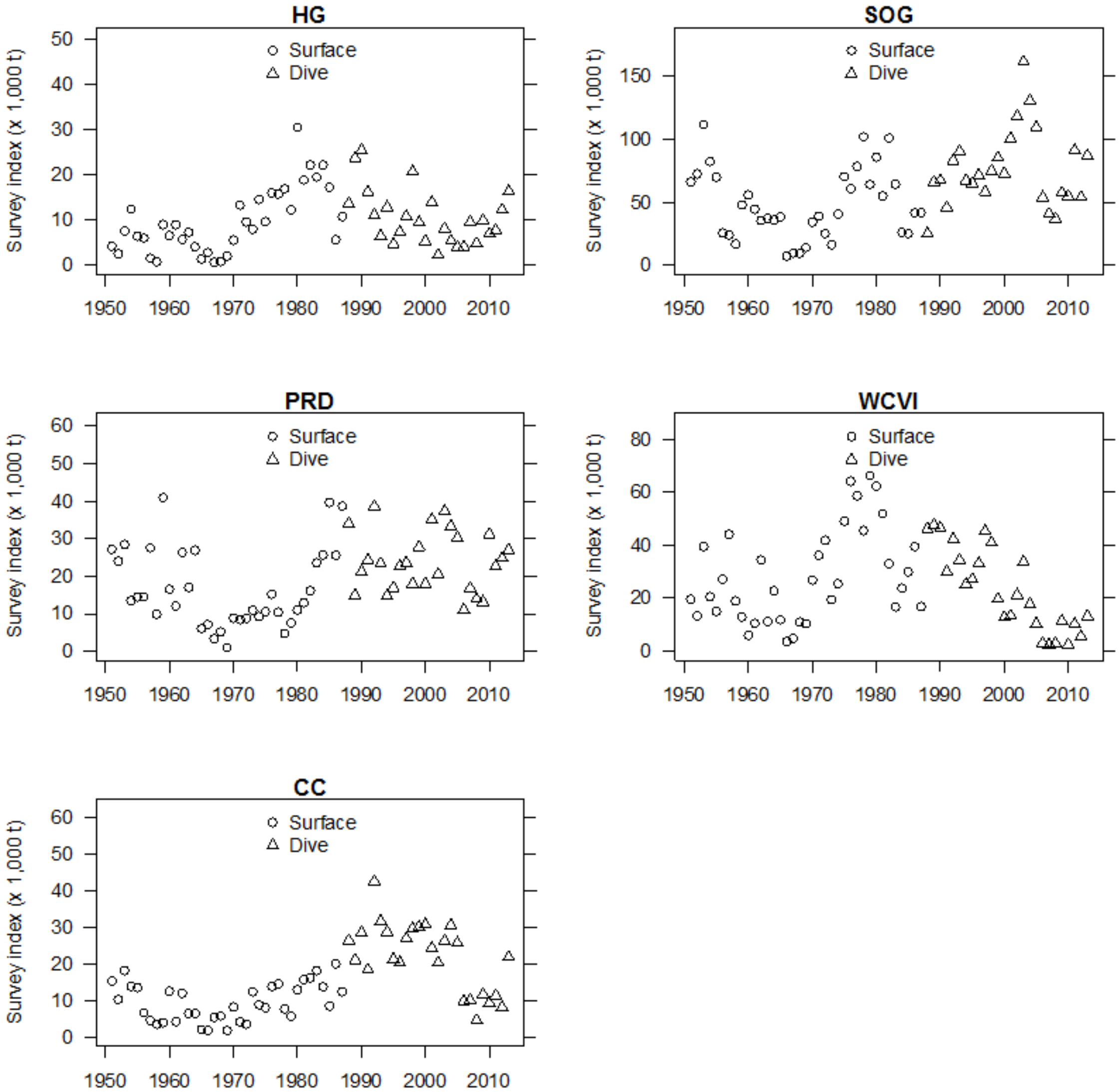

Figure 3. Spawn survey index or index of relative abundance for all major stock areas, 1951-2013. Indices are in units of metric tonnes (x 1,000). "Surface" (circles) represents the time series of surface survey observations (1951 – 1987); and "Dive" (triangles) represents the time series of primarily SCUBA dive survey observations (1988 – 2013). Note: y-axes differ among figures.

2.3 EXTERNALLY ANALYZED DATA

2.3.1 Maturity

As described in **Section 1.2**, data from histological assessment of developing ovaries show that about 25 percent of fish mature at age 2 and at least 90 percent are mature at age 3 (Hay, Unpublished data)[2]. For the assessment, a fixed maturity schedule is used for all herring stocks **Figure 4**.

[2] Doug Hay, Fisheries and Oceans Canada, Science, Stock Assessment, Nanaimo, BC, Unpublished data

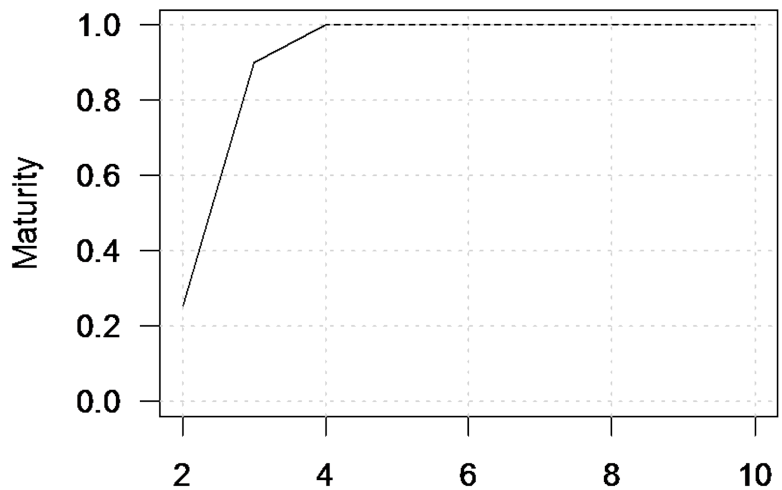

Figure 4. Fixed maturity schedule for B.C. herring stocks.

2.3.2 Weight-at-age

A matrix of empirically derived population weight-at-age data is required as input for the current assessment model. Mean weight-at-age was calculated from samples pooled from all fisheries (commercial and seine test) within a SAR and for the years 1951-2013. Missing years in weight-at-age matrix were interpolated using recent 5-year averages.

Measurable declines in weight-at-age are evident for all major herring stocks, from the mid-1980s to 2010 (**Figure 5**). Declining weight-at-age may be attributed to any number of factors, including: fishing effects (i.e., gear selectivity), environmental effects (changes in ocean productivity), or it may be attributed to by changes in sampling protocols (shorter time frame over which samples are collected). Declining weight-at-age is observed in all five of the major stocks, and despite area closures over the last 10-years, has continued to occur in the HG and WCVI stocks. This trend has been observed in B.C. and U.S. waters, from California to Alaska (Schweigert et al. 2002), however the direct cause and influence of this decline should be investigated in the context of the assessment framework.

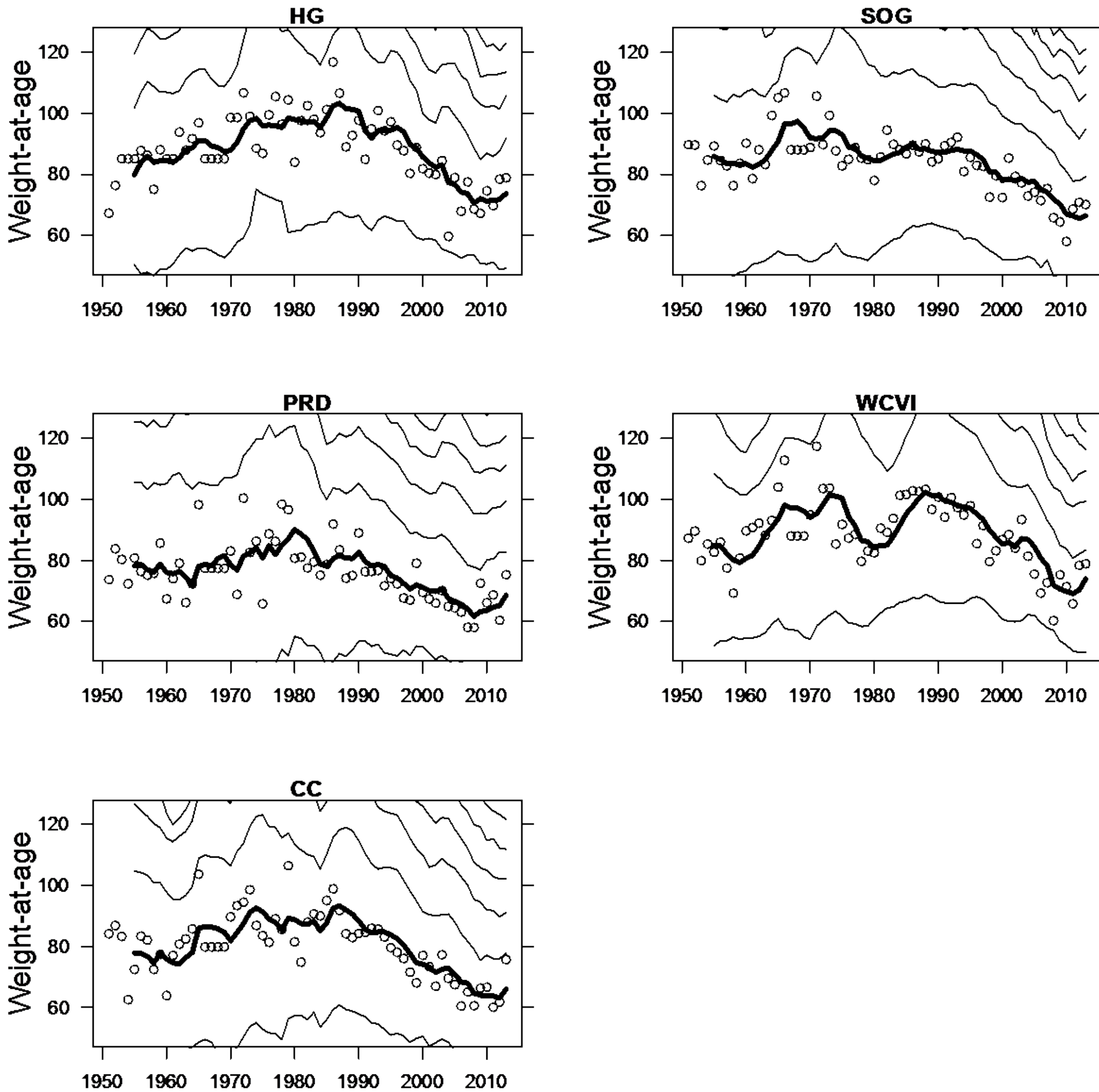

Figure 5. The time series of observed weight-at-age3 (circles) and five-year running mean weight-at-age3 (thick black line) for major herring stocks. Thinner black lines represent five-year running mean weight-at-age2 (lowest) and ages 4-7 (incrementing higher from age3).

2.4 CHANGES TO DATA FROM 2012

2.4.1 Age composition data

Biological samples collected from commercial and test fisheries are used to estimate proportions-at-age and weight-at-age for each stock area. For the purposes of stock assessment, proportions-at-age are summarized by gear type into three fishing categories (Gear 1, Gear 2, Gear 3):

Gear 1 (Winter fishery) – Commercial catch samples from the historic reduction fishery (1951-1967) – all gear types, winter seine fishery (F&B, 1968-2013), and the SU fishery (up to 2013).

Gear 2 (Roe seine and SOK) – Roe seine catch samples, seine test fishery catch samples, and commercial SOK samples (1972-2013)

Gear 3 (Roe gillnet) – Roe gillnet catch samples (1972-2013)

In reviewing past assessments, the TWG identified inconsistencies in the criteria used to define representative samples for each stock area. These inconsistencies arose largely from the lack of stock-specific queries for extracting biological data, resulting in year-to-year changes in the total number of samples used to populate matrices of proportions-at-age for each fishing category. Following the September 2012 CSAS meeting, DFO developed stock-specific queries for extracting biological data to populate matrices of proportions-at-age (by fishing category). These queries will ensure consistency in input data used to represent each stock area.

The TWG recognizes that these modifications also need to extend to the calculation of mean weight-at-age, however time did not permit these additional changes for the 2013 assessment. Therefore, matrices of mean weight-at-age for each stock area reflect data used in 2012, updated with relevant 2013 data.

Matrices of numbers-at-age, used to calculate proportions-at-age, appear for each stock area in Appendix B (#Number aged). **Table 3** summarizes the number of samples by year, gear, and stock area used to produce input data matrices. Main differences in samples selected for the 2013 assessment (vs. the 2012 assessment) are presented in terms of years with representative samples, **Table 4**. Differences are most significant for WCVI because research samples from the summer offshore trawl survey were included for Gear 1, 1988-2012. Given that there is no commercial catch corresponding to this time frame for Gear 1, sensitivity analyses were not conducted.

Table 4. Comparisons of years with/ without representative samples (2012 vs 2013) for each fishing category. Gear 1= Reduction, Food & Bait and Special Use; Gear 2= Seine roe, seine test and SOK; Gear 3= Gillnet roe.

	Haida Gwaii						Prince Rupert District						Central Coast					
	Gear 1		Gear 2		Gear 3		Gear 1		Gear 2		Gear 3		Gear 1		Gear 2		Gear 3	
Season	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input
19501	✔	✔					✔	✔					✔	✔				
19512	✔	✔					✔	✔					✔	✔				
19523							✔	✔					✔	✔				
19534							✔	✔					✔	✔				
19545							✔	✔					✔	✔				
19556	✔	✔					✔	✔					✔	✔				
19567	✔	✔					✔	✔					✔	✔				
19578	✔	✔					✔	✔					✔	✔				
19589	✔	✔					✔	✔					✔	✔				
19590							✔	✔					✔	✔				
19601							✔	✔					✔	✔				
19612	✔	✔					✔	✔					✔	✔				
19623	✔	✔					✔	✔					✔	✔				
19634	✔	✔					✔	✔					✔	✔				
19645	✔	✔					✔	✔					✔	✔				
19656							✔	✔										
19667																		
19678																		
19689																		
19690																		
19701							✔						✔					
19712			✔	✔					✔	✔					✔	✔	✔	✔
19723			✔	✔				✔	✔	✔					✔	✔	✔	✔
19734			✔	✔	✔	✔			✔	✔	✔	✔			✔	✔	✔	✔
19745			✔	✔	✔	✔		✔	✔	✔	✔	✔			✔	✔	✔	✔
19756			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19767			✔	✔			✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19778			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19789			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔						
19790			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔
19801			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19812			✔	✔	✔	✔	✔	✔	✔	✔			✔		✔	✔	✔	✔
19823	✔		✔	✔	✔	✔			✔	✔					✔	✔	✔	✔
19834		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔

	Haida Gwaii						Prince Rupert District						Central Coast					
	Gear 1		Gear 2		Gear 3		Gear 1		Gear 2		Gear 3		Gear 1		Gear 2		Gear 3	
Season	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input
19845			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19856	✔		✔	✔	✔	✔	✔		✔	✔	✔	✔			✔	✔	✔	✔
19867			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
19878	✔		✔	✔			✔		✔	✔	✔	✔			✔	✔	✔	✔
19889			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
19890			✔	✔	✔	✔			✔	✔	✔	✔			✔	✔	✔	✔
19901	✔		✔	✔	✔	✔			✔	✔	✔	✔			✔	✔	✔	✔
19912	✔		✔	✔			✔		✔	✔	✔	✔			✔	✔	✔	✔
19923	✔		✔	✔			✔		✔	✔	✔	✔			✔	✔	✔	✔
19934	✔		✔	✔			✔		✔	✔	✔	✔			✔	✔	✔	✔
19945			✔	✔			✔		✔	✔	✔	✔			✔	✔	✔	✔
19956			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
19967			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
19978			✔	✔			✔		✔	✔	✔	✔			✔	✔	✔	✔
19989			✔	✔	✔	✔			✔	✔	✔	✔			✔	✔	✔	✔
19990			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
20001			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
20012			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
20023			✔	✔					✔	✔	✔	✔			✔	✔	✔	✔
20034			✔	✔					✔	✔	✔	✔			✔	✔		
20045			✔	✔					✔	✔	✔	✔			✔	✔		
20056			✔	✔					✔	✔	✔	✔			✔	✔		
20067			✔	✔					✔	✔	✔	✔			✔	✔		
20078			✔	✔					✔	✔	✔	✔			✔	✔		
20089			✔	✔					✔	✔	✔	✔			✔	✔		
20090			✔	✔					✔	✔	✔	✔			✔	✔		
20101			✔	✔					✔	✔	✔	✔			✔	✔		
20112			✔	✔					✔	✔	✔	✔			✔	✔		
20123				✔						✔		✔				✔		

Table 4 continued.

	Strait of Georgia						West Coast Vancouver Island					
	Gear 1		Gear 2		Gear 3		Gear 1		Gear 2		Gear 3	
Season	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input
19501	✔	✔					✔	✔				
19512	✔	✔					✔	✔				
19523	✔	✔					✔	✔				
19534	✔	✔					✔	✔				
19545	✔	✔					✔	✔				
19556	✔	✔					✔	✔				
19567	✔	✔					✔	✔				
19578	✔	✔					✔	✔				
19589	✔	✔					✔	✔				
19590	✔	✔					✔	✔				
19601	✔	✔					✔	✔				
19612	✔	✔					✔	✔				
19623	✔	✔					✔	✔				
19634	✔	✔					✔	✔				
19645	✔	✔					✔	✔				
19656	✔	✔					✔	✔				
19667												
19678												
19689												
19690												
19701	✔											
19712	✔	✔	✔	✔	✔	✔			✔	✔		
19723	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19734		✔	✔		✔	✔			✔	✔	✔	✔
19745		✔	✔	✔	✔	✔			✔	✔	✔	✔
19756	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔
19767	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19778	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
19789	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19790	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19801	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔
19812	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19823	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔
19834	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
19845	✔	✔	✔	✔	✔	✔			✔	✔		

	Strait of Georgia						West Coast Vancouver Island					
	Gear 1		Gear 2		Gear 3		Gear 1		Gear 2		Gear 3	
Season	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input	2012 input	2013 input
19856	✓	✓	✔	✔					✓	✓		
19867	✓	✓	✔	✔	✓	✓			✓	✓	✔	✔
19878	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19889	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19890	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19901	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19912	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19923	✓	✓	✔	✔	✓	✓	✔		✓	✓		
19934	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19945	✓	✓	✔	✔	✓	✓	✔		✓	✓		
19956	✓	✓	✔	✔	✓	✓	✔		✓	✓		
19967	✓	✓	✔	✔	✓	✓	✔		✓	✓		
19978	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19989	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
19990	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
20001	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20012	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
20023	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
20034	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
20045	✓	✓	✔	✔	✓	✓	✔		✓	✓	✔	✔
20056	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20067	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20078	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20089	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20090	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20101	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20112	✓	✓	✔	✔	✓	✓	✔		✓	✓		
20123		✓		✔		✓			✓	✓		

2.4.2 Spawn survey data

One component of the herring spawn survey methodology involves laying out lead lines along transects perpendicular to the shore to get multiple measurements of spawn width. Transects are spaced every 350-m along a spawning bed and each lead line is marked with 1.0-m increments visible underwater. Marked increments allow divers to estimate spawn width (along each transect) and determine placement of quadrats (for measuring egg layers and collecting substrate information) along each transect.

Sometime in the mid to late 1990s survey crews measured the lengths of the lead lines and observed that lead lines shrank by approximately 1.0m during their first season of use. Over the next few years, lead lines were re-measured each season and the problem was determined to be occurring coastwide. Starting in 1997 the protocol for marking lead lines was changed to account for lead line shrinkage – lead line increments were increased to 1.15m. This 15% increase was derived from measuring and remarking lead lines each year while trying to understand the shrinkage problem. Lead lines are made of a mix of polypropylene and nylon. Nylon tightens up under repeated use, which is thought to explain the shrinkage. Lead line increments re-measured in the mid 2000s were still found to be shrinking from 1.15m to 1.0m, thus supporting continued use of the modified protocol.

During the 2013 spawning season, a contract diver measured lead line increments and found increments to consistently measure 1.15m. Following this observation, additional lead lines used in other stock areas were re-measured by DFO staff and lead lines used coastwide were found to be made up of a combination of 1.0 and 1.15m increments. The combination of observed increment lengths within the same lead line is explained by the lifespan of lead lines. Lead lines are replaced every 5-10 years, with some segments of the lead line being replaced more frequently (inner most ~60m replaced more frequently than seaward sections).

Observations by stock area include:

HG

- Lead line replaced for 2012 spawn season
- Life span of HG lead lines are 8+ years

PRD

- Lead line replaced for 2013 spawn season – measures 1.15m increments
- Lead lines (2) used prior to 2013 are at PBS and have a mix of 1 and 1.15m increments
- Life span of PRD lead lines are 5-8 years

CC, WCVI, SOG

- Lead lines are interchanged for these 3 areas each year – there is no way of tracing a particular lead line to a particular area.
- 90-95% of lead lines used in these 3 areas are new since 2008 and all measure oversized (1.15m increments)

The oldest set of written instructions for describing the modified protocol of painting 1.15m increments is from 2003 and this protocol has continued through 2013. The practice of annually re-measuring lead line increments ceased in the early 2000s, thus we have been unable to determine when lead lines ceased shrinking. Given available written instructions from 2003, and the observations summarized above, we suggest adjusting the spawn width estimates based on the most recent written instructions for the marking protocol. Accordingly, our best estimate of years impacted by the marking of lead lines at 1.15m increments (when shrinking was no longer occurring) is 2003-present. **Table 5** compares the original spawn index (non-width-adjusted, units: metric tonnes of spawners) and the “width-adjusted spawn index” where the latter is created by incrementing each bed-level dive survey observation of spawn width by 15%. The spawn index is calculated as:

(3) $$I_t\ (tonnes) = L(m) \times W(m) \times EggDensity(1000\ eggs \times m^{-2}) \times 10^{-5}\ (eggs \times tonne^{-1})$$

where 10^{-5} = 100 eggs/g x 1,000,000 g/tonne assuming a 50:50 sex ratio.

We have been unable to determine whether there has been a change to materials used for manufacturing lead lines that could explain the absence of lead line shrinkage (e.g., changes to Nylon core). Consequently we recommend proceeding with use of width-adjusted spawn index for all stock areas for the period of 2003-2013. Decisions on how to mark lead lines for the 2014 survey will be discussed in the fall of 2013, as well as a protocol to resume annual measuring of lead line increments.

Table 5. Comparisons by area of original spawn index (non-width-adjusted) and width-adjusted spawn index from 2003-2013.

	HG		PRD		CC	
Year	Original	Width-adjusted	Original	Width-adjusted	Original	Width-adjusted
2003	7,398	8,089	32,389	37,248	22,887	26,320
2004	4,906	5,387	28,961	33,275	26,619	30,612
2005	3,614	4,067	26,247	30,184	22,360	25,714
2006	4,097	4,097	9,567	11,003	8,533	9,813
2007	9,436	9,585	14,632	16,826	8,770	10,086
2008	4,213	4,845	12,071	13,882	3,971	4,566
2009	8,935	9,944	11,368	13,073	10,183	11,710
2010	6,113	6,962	27,073	31,134	8,121	9,339
2011	6,792	7,707	19,644	22,591	9,906	11,392
2012	10,924	12,283	21,559	24,793	7,107	8,173
2013	14,469	16,304	24,219	26,981	19,028	21,879

	SOG		WCVI	
Year	Original	Width-adjusted	Original	Width-adjusted
2003	141,651	160,996	29,279	33,671
2004	114,351	130,151	15,368	17,673
2005	95,643	109,196	8,997	10,347
2006	46,752	53,764	2,705	3,045
2007	35,863	40,788	2,089	2,403
2008	32,103	36,852	2,548	2,930
2009	49,909	57,395	9,876	11,358
2010	47,480	54,602	2,373	2,554
2011	79,070	90,931	9,196	10,204
2012	49,124	53,860	5,243	5,573
2013	78,031	86,812	11,499	13,224

For the current assessment, we use only the width-adjusted index. We include a sensitivity case in **Section 3.4.7** to show the differences between historical spawning stock biomass reconstructions done using the width-adjusted and the non-width-adjusted spawn index. Differences and implications are discussed in **Section 3.4.7.**

2.5 UNRESOLVED PROBLEMS/ISSUES WITH DATA

This year DFO developed stock-specific queries for extracting biological data to populate matrices of proportions-at-age (by fishing category). These queries now ensure consistency in input data used to represent each stock area. The TWG also recognizes that these modifications need to extend to the calculation of mean weight-at-age, however time did not permit these additional changes for the 2013 assessment and instead the TWG used matrices of mean weight-at-age for each stock used in 2012 (with relevant 2013 data). Future work should test these queries to populate matrices of mean weight-at-age. Given the catch-age model cannot accommodate missing values in weight-at-age matrices, this work will need to include consideration of how to populate missing years (e.g., using recent 5-year averages, fitting growth curves, or other forms of interpolation).

3 ASSESSMENT

This assessment reports a single base-case model representing the collective work of the TWG. The catch-age model is fitted to three sources of data: commercial catch, spawn survey biomass index, and proportions-at-age. The assessment depends primarily upon the spawn survey biomass index (surface: 1951 – 1987, dive: 1988 – 2013) for information on the scale of biomass in the major herring stocks. Fishery and seine test fishery age-composition data (1951-2013) are combined for each of the three gear types, contributing to the assessment model's ability to resolve strong and weak cohorts, and to forecast recruitment. The assessment uses Bayesian methods to incorporate prior information and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty is not limited to parameter uncertainty as structural uncertainty is investigated through sensitivity analyses (**Section 3.4.7**).

3.1 CHANGES TO MODEL FROM 2012

In the course of doing a detailed review of the stock assessment model we uncovered several errors and inconsistencies. There were problems with the input of the maturity ogive used in the projection year, the calculations of the instantaneous fishing mortality that produces maximum sustained yield (Fmsy), and finally the calculation of the discrete harvest rate.

In 2011 and 2012 assessments, the ISCAM used a logistic function to describe maturity-at-age while most of the documentation indicated that the proportions of age 2 and age 3 fish were 0.25 and 0.90, respectively, and unity for all ages four and older. The logistic function used in 2011-2012 defined the proportions mature at age 2 to nearly exactly 0.25, but it predicted that 100% of age 3 fish were mature. We illustrate the difference between the 2012 and 2013 maturity ogives in **Figure 6**. For the 2013 assessment, we have changed the parameterization of maturity to be an input vector that is consistent with assumed herring maturity at age specified above (**Section 2.3.1**).

We fixed a source code error that affected how fecundity at age was defined in the stock assessment model. The ISCAM has the option to either define coefficients that convert length-at-age to weight-at-age or to input a matrix of observed weights-at-age. These values fill a third matrix of weight-at-age from model's start year to the projection year. The default setting is to use the former method to define weight-at-age, and then, if there are empirical weight-at-age data, to overwrite the matrix of weight-at-age used by the model. The model then uses the mean of the last five years for the projection year. The model's accounting for weight-at-age was correct; the error in the code was that the fecundity matrix, which is defined in terms of maturity and weight-at-age was not updated with mean weight in the projection year; this row of the fecundity matrix remained incorrectly defined by the coefficients used to convert length-at-age to weight-at-age. Since the spawning stock biomass is also defined in terms of the fecundity matrix, it was also calculated incorrectly for the projection year. This problem is fixed so that fecundity and spawning stock biomass in the terminal year are defined correctly with the mean weight-at-age.

In the course of discussing the fecundity-at-age error with the original ISCAM programmer (Dr. Steve Martell), he mentioned that he had discovered an additional mistake in the calculation of Fmsy and Bmsy values. There was a linear algebra error in the computer code that resulted in Fmsy, and a downward bias in Bmsy. This problem does not affect current herring stock assessment and management because MSY-based reference points are not used. They were however, reported in the 2011 assessment (Martell et al. 2012) and readers should be aware that those values are unreliable.

Finally, we will no longer be presenting forecasts depending on anticipated Poor, Average, and Good recruitments. The reasons why are discussed at some length by Kronlund et al.[1].

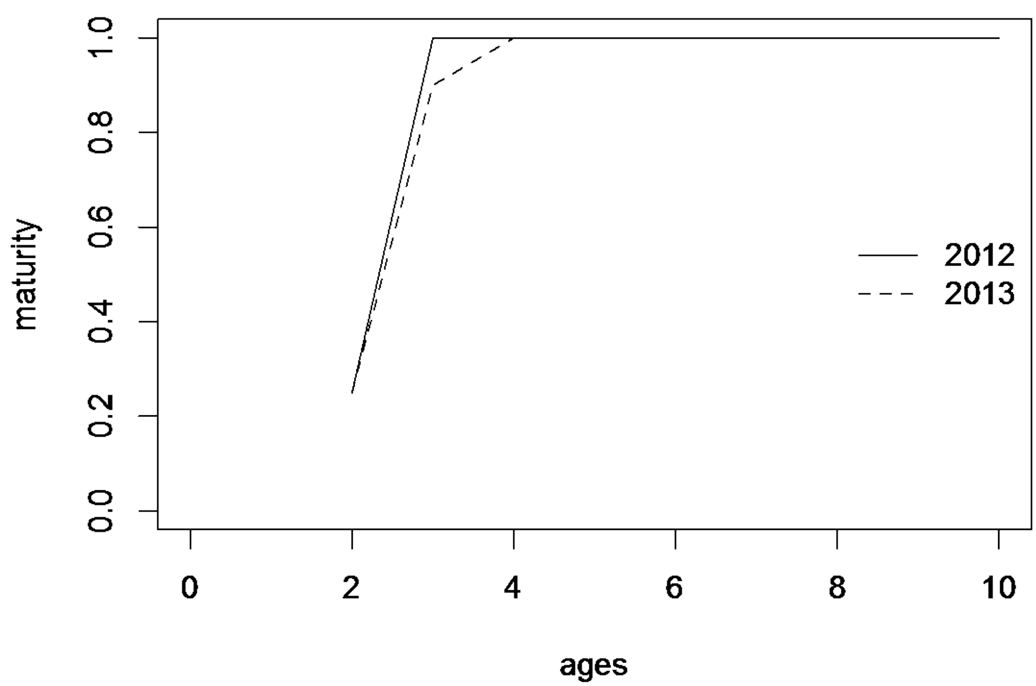

Figure 6. Comparison of maturity ogives used in the 2012 and 2013 assessments of B.C herring stocks.

In addition, the TWG made changes to how the discrete harvest rate U'_{T+1} is calculated in model predictions of the harvest rate on the pre-fishery biomass, given a catch level of C_{T+1}. In the 2011 assessment (Martell et al. 2012) and the 2012 assessment (DFO 2012*b*), the discrete harvest rate was calculated as:

(4) $$U'_{T+1} = C_{T+1} \Big/ \sum_{a=3}^{10+} N_{a,T+1} e^{-\bar{M}_{t+1}} w_{a,T+1}$$

where $N_{a,T+1}$ is the number of fish at age *a* in year *T*+1, $w_{a,T+1}$ is the assumed weight of fish at age *a* in year *T*+1, and $\bar{M}_{T+1}$ is the assumed instantaneous natural mortality rate in year *T*+1.

This calculation was an attempt to capture the expected discrete harvest rate given some future C_{T+1}, and the inconsistency in the model stock reconstruction dynamics with (primarily) end-of-year fisheries.

This formulation of the discrete harvest rate is unsatisfactory because the stock projections assume that all natural mortality occurs prior to the fisheries, whereas the stock reconstruction component of the model assumes that fishing and natural mortality occur simultaneously throughout the year. We have adopted an alternative calculation that is more consistent with the formulation of the stock reconstruction dynamics:

(5) $$U'_{T+1} = C_{T+1} \Big/ \left(C_{T+1} + SB_{T+1}\right)$$

where SB_{T+1} is the predicted spawning biomass in year T+1, calculated based on a catch level, C_{T+1} and assuming simultaneous fishing and natural mortality.

Given the current model formulation there is no satisfactory representation for discrete mid- or end-of-year harvest rates. If the model's representation of continuous fishing mortality is accurate, then target instantaneous fishing mortality rates or exploitation fraction defined in terms of spawners potential per recruit, are needed.

3.2 RECENT REVIEW RECOMMENDATIONS

The following recommendations were identified as priority areas of research during the 2012 assessment review (DFO 2012*c*):

Table 6. Summary of recommendations from September 5 and 6, 2012 Regional Peer Review of the Stock Assessment and Management Advice for the British Columbia Pacific Herring Stocks: 2012 Status and 2013 Forecasts.

No.	Issue/ Recommendation	Comment	In-scope for Sept 2013
1.0	**Subcommittee recommendation: reference points** Recommended that biologically based, limit reference points be developed to inform management and rebuilding strategies	-High priority -Requires feedback simulation	deferred to 2013/14
1.1	**Subcommittee recommendation: recruitment forecasting methodology** Given the significance of recruitment to herring stock productivity, an evaluation of current recruitment forecasting methods and comparisons with other sources	-High priority	yes (see Kronlund et al. draft

No.	Issue/ Recommendation	Comment	In-scope for Sept 2013
	of data (e.g., Strait of Georgia and Central Coast juvenile herring inshore purse seine surveys) and modeling approaches warrants further research.		WP)[1]
1.2	**Subcommittee recommendation: PRD data** It was recommended that the time series prior to 1970 (winter fishery data etc) be excluded from the Base model due to uncertainty in catch locations.	-Medium priority -useful sensitivity analysis for all 5 stocks – start 1972	yes (sensitivity analysis, this WP)
1.3	**Subcommittee recommendation: PRD data** Future work is recommended to explore treating Areas 3 and 4 versus Area 5 as separate stock units because separating PRD by gear and area (Areas 3 and 4 for gillnet versus Area 5 for seine) greatly reduced the retrospective pattern in the time series before 2007.	-Low priority	deferred
1.4	**Subcommittee recommendation: GN selectivity** Sensitivity analysis presented here supports continued use of the age based, weight covariate parameterization for gillnet fishery selectivity that was used and implemented in 2011.	TWG decided to return to age-based logistic form for GN selectivity – consistency among all fishing gears.	yes
1.5	**Subcommittee recommendation: GN selectivity, 2-sex model** While not considered a priority for further model development at this time, suggestions were made to explore alternate treatment of the data including: a. Considering time-varying selectivity (potentially caused by changes in weight data quality, fishing methods, and gear types, changes in ovary size). b. Treating males and females separately	-Medium priority -Requires time varying selectivity for GN fishery and 2-sex model	deferred
1.6	**Subcommittee recommendation**: **pmin** Future work is recommended to evaluate (through simulation) statistical properties against alternate age class modeling options.	-Low priority	deferred
1.7	**Subcommittee recommendation: decision tables** For consideration for the September 2012 assessment, dialog between science and management prior to that meeting needs to occur to discuss the role of the three decision table metrics thought to be most relevant: P(SB decline), P(SB < 0.25Bo) and P(U > 20%).	-High priority	yes
1.8	**Issue: PRD data** It was pointed out that there has been difficulty getting seine test samples from parts of the PRD because the fish stay deep until they move shallower to spawn,	-Low priority	deferred

No.	Issue/ Recommendation	Comment	In-scope for Sept 2013
	therefore test fishery data may be biased. Future work could examine the effect of excluding test fishery data from this area.		
1.9	**Issue: unaccounted for catch- SOK mortality** Currently, the assessment model does not assign any mortality from SOK fisheries, thus, the model may be accounting for SOK induced mortality by adjusting (increasing) natural mortality. Past stock assessments have allocated rough estimates of SOK-induced mortality. Both modelling approaches are subject to bias that would affect model parameters and potentially reference points. The committee agrees that future modelling work should explore effects from varying SOK mortality estimates, ideally in association with acquiring accurate SOK fishery data.	-High priority	deferred
2.0	**Issue**: **pmin** Several commentators noted that binning might be a more appropriate approach for longer lived species with many age classes. For species like herring with fewer age classes, think about whether it makes sense to bin age classes. Are herring like hake, where spawning populations can be maintained by very strong but rare cohorts? Binning may reduce the ability to detect strong cohorts. Consideration of multinomial likelihood was also discussed.	-Low priority	deferred
2.1	**Issue: q** Q values greater than 1 were questioned by a reviewer last year and it was explained as a ratio and consequently could be greater than 1. However, that being true it is not possible for a q to be greater than one so is it bounded for input as more than 1 for estimations? If not it could represent a bias for the amount greater than 1.00.	-Medium priority	deferred
2.2	**Issue: HCR** The forecast is however premised on an estimate of SSB and recruitment to provide advice on harvest amount and rates. No estimates of error or risk is associated with the advice. Unfortunately given the recent increase in SSB associate with the change in assessment models there is real concern as to where the stock is in absolute biomass terms and what will be the impact of increased catches based on the revised SSB, especially on the low level stocks, HG, CC, and WCVI.	-High priority	partially addressed though use of decision tables
2.3	**Issue: test vs commercial samples** Currently charter fishery age-compositions are combined	-High priority	deferred

No.	Issue/ Recommendation	Comment	In-scope for Sept 2013
	with the SN fishery age-compositions to represent the age structure of the SN catch. The validity of this approach was discussed and it was suggested that the data should be disaggregated and the charter fishery data treated as a separate fishery. It may be possible to select years where the charter samples are representative of the spawning populations (ie. spatial and temporal coverage consistent with spawning) and treat these data as reflecting the mature component of the populations. However, additional work investigating the differences between these two sets of data is warranted.	-Ties into post-Larocque "alternate science program scenarios"	until fall 2013
2.4	**Issue: Ageing error** Has there has been a shift in ageing standards? This could be investigated by having a sample of ageing structures from the past (e.g., 10-15 years ago) aged by readers currently conducting the ageing. Additionally, data from dual-aged structures could be used to include ageing error in the model.	-Medium priority -Re-ageing of 2,000+ samples from recent-most 20-year has occurred -Analysis pending	deferred
2.5	**Recommendations: data** -Analyze spawn survey data to determine if the assumptions of constant (time-invariant) location-specific spawn widths for surface surveys and equivalent vegetation type/layers observations for surface and dive surveys are appropriate - Investigate if there has been a shift in ageing - Update steepness prior using current Myer's database (done)	-Low priority	deferred

3.3 MODEL DESCRIPTION

Marginal posterior distributions for estimated model parameters were constructed using the AD Model Builder built in Metropolis-Hastings algorithm (Gelman et al. 2004). For each major assessment area, a systematic sample of 5,000 points were taken from a chain of length of 5,000,000, intended to represent a random sample from the joint posterior distribution. All areas with the exception of the SOG used the inverse Hessian matrix as the jumping distribution. In the case of SOG, the hessian matrix had to be re-scaled (using the -mcmult 9.0 option in ADMB) in order to invert the Hessian matrix. These analytical steps (Bayesian methods) are the same as were applied in September 2011 (Martell et al. 2012) and September 2012 (DFO 2012*b*), and are consistent with assessments from previous years using the HCAM (Cleary and Schweigert 2010; Schweigert et al. 2009). This procedure integrates over the full range of uncertainty producing a posterior distribution for each parameter estimated in the model. Then, these samples are used to construct marginal distributions for derived quantities (e.g., SB_0). Final estimates of spawning stock biomass (SB_t), projected spawning biomass (SB_{T+1}) and estimates of unfished biomass (SB_0) reflect median values of these marginal posterior distributions.

See Appendix F for technical description of model and applications.

3.4 ASSESSMENT MODEL RESULTS

The following sections present median posterior distributions characterizing the major Herring stocks for the following estimates: biomass reconstructions, stock depletion, recruitment and instantaneous natural mortality**.** A comparison of total and spawning stock biomass, selectivity**,** and total instantaneous mortality are presented as maximum posterior density (MPD) estimates.

3.4.1 Biomass and stock status

The assessment shows current status of major B.C. Pacific Herring stocks increased in 2013 relative to 2012 and the 2013 median posterior spawning biomass (SB_{2013}) is estimated to be a greater proportion of estimated unfished equilibrium level (SB_0) compared to previous years **Table 6, Figure 7**, **Figure 8, Figure 9**). For the HG, CC and WCVI stocks, where there have been no commercial removals in recent years (last roe fishery in HG was in 2002, last SOK fishery in HG was in 2004, last roe fishery in CC was in 2007, and last roe fishery in WCVI was in 2006), the model predicts increases in spawning biomass and recruitment, and decreases in natural mortality in order to explain observed increases in the Herring spawn index. Similar tradeoffs are observed for all five major stocks in 2013.

Common observations across all five major herring stocks include:

- Increases in spawn index (Figure 3) and spawning biomass (Table 6**,** Figure 7,Figure 8), most significantly for HG, SOG and CC;
- Declining weight-at-age from mid-1980s to 2010 (Figure 5).
- Years of relatively strong recruitment: CC (2008, 2010, 2012), PRD and SOG (2010, 2012), WCVI (2009) (Figure 10);
- Apparent decreases in instantaneous natural mortality rate (Figure 12).

Summary observations by major stock assessment region are as follows:

- HG
  The assessment shows that the spawning stock biomass has been increasing since 2009 (**Figure 8**). The increased spawning stock biomass is driven by increases in spawn index (2011-2013, **Figure 3**) as well as apparent decreases in instantaneous natural mortality (**Figure 12)**. The 2013 median posterior spawning biomass is estimated to be 80% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 42% to 149% (**Table 6**).
- PRD
  The assessment shows that the spawning stock biomass has been increasing since 2010 (**Figure 8**). The increased spawning stock biomass is driven by increases in spawn index (2010-2013, **Figure 3**), relatively strong recruitments in 2010 and 2012 (**Figure 10**) as well as decreases in estimated instantaneous natural mortality **(Figure 12**).The 2013 median posterior spawning biomass is estimated to be 49% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 25% to 90% (**Table 6).**
- CC
  The assessment shows that the spawning stock biomass to have increased in 2012 and 2013 (**Figure 8**). The increased spawning stock biomass is being driven by relatively strong

recruitments in 2008, 2010 and 2012 **(Figure 10**) as well as apparent decreases in instantaneous natural mortality (**Figure 12**). The 2013 median posterior spawning biomass is estimated to be 48% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 29% to 78% **Table 6**).

- SOG
  The assessment shows that the spawning stock biomass has been increasing since 2010 (**Figure 8**). The increased spawning stock biomass is being driven by relatively strong recruitments in 2010 and 2011 **(Figure 10**) as well as decreases in instantaneous natural mortality (**Figure 12).** The 2013 median posterior spawning biomass is estimated to be 97% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 62% to 148% (**Table 6**).

- WCVI
  The assessment shows that the spawning stock biomass has been increasing since 2009 (**Figure 8**). The increased spawning stock biomass is being driven by relatively strong recruitment in 2009 (**Figure 10)** as well as decreases in instantaneous natural mortality **(Figure 12**). The 2013 median posterior spawning biomass is estimated to be 40% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 23% to 66% (**Table 6**).

Table 7. Recent estimated Pacific Herring spawning biomass (SB_t, metric tonnes) and depletion level relative to estimated unfished equilibrium spawning biomass (SB_0).

	Year	Spawning biomass (tonnes)			Depletion (SB_t/SB_0)		
		5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
HG	2003	7,759	11,693	17,792	0.22	0.33	0.50
	2004	6,213	9,265	13,885	0.17	0.27	0.39
	2005	6,329	9,546	14,502	0.18	0.27	0.41
	2006	5,632	8,524	12,758	0.16	0.24	0.36
	2007	7,066	10,700	16,167	0.20	0.31	0.46
	2008	6,758	10,151	15,123	0.19	0.29	0.43
	2009	7,625	11,609	17,667	0.22	0.33	0.50
	2010	7,665	11,757	17,972	0.22	0.33	0.50
	2011	8,126	12,681	19,884	0.23	0.36	0.55
	2012	10,607	17,990	29,697	0.31	0.51	0.83
	2013	14,357	28,294	54,537	0.42	0.80	1.49
PRD	2003	22,794	32,477	47,794	0.31	0.50	0.75
	2004	17,834	25,041	36,213	0.24	0.39	0.57
	2005	13,303	18,899	27,552	0.18	0.29	0.44
	2006	13,037	18,776	28,057	0.17	0.29	0.44
	2007	14,627	20,998	31,082	0.20	0.32	0.49
	2008	14,851	20,886	30,444	0.20	0.32	0.49
	2009	14,162	19,980	29,373	0.19	0.31	0.46
	2010	14,937	21,292	31,800	0.20	0.33	0.50
	2011	15,246	22,799	35,138	0.21	0.35	0.54
	2012	13,610	22,301	36,189	0.20	0.34	0.55

	Year	Spawning biomass (tonnes)			Depletion (SB_t/SB_0)		
		5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
	2013	16,762	32,568	60,283	0.25	0.49	0.90
CC	2003	29,452	41,936	59,978	0.46	0.68	0.96
	2004	23,268	33,220	47,055	0.37	0.54	0.76
	2005	18,331	26,492	38,349	0.29	0.43	0.61
	2006	11,143	16,646	24,599	0.17	0.27	0.40
	2007	9,003	13,368	19,796	0.14	0.22	0.32
	2008	8,736	12,777	18,602	0.14	0.21	0.30
	2009	11,208	16,218	23,642	0.17	0.26	0.38
	2010	11,170	16,106	23,182	0.17	0.26	0.38
	2011	11,035	16,003	23,272	0.17	0.26	0.37
	2012	12,971	19,177	28,569	0.21	0.31	0.46
	2013	17,844	29,597	48,974	0.29	0.48	0.78
SOG	2003	122,935	170,798	238,978	0.91	1.22	1.58
	2004	101,984	139,602	193,726	0.75	1.00	1.28
	2005	87,289	120,055	167,888	0.64	0.86	1.11
	2006	76,971	108,758	154,394	0.57	0.78	1.03
	2007	79,269	111,277	157,119	0.59	0.79	1.04
	2008	52,894	74,103	103,887	0.39	0.53	0.69
	2009	56,569	80,129	112,736	0.42	0.57	0.76
	2010	50,338	72,887	104,331	0.38	0.52	0.70
	2011	76,283	108,906	157,742	0.57	0.78	1.04
	2012	86,124	125,030	182,816	0.64	0.89	1.22
	2013	83,196	136,258	220,752	0.62	0.97	1.48
WCVI	2003	21,580	30,620	43,772	0.39	0.54	0.74
	2004	12,153	17,595	25,977	0.22	0.31	0.44
	2005	6,532	10,320	16,314	0.12	0.18	0.27
	2006	6,132	9,396	14,537	0.11	0.17	0.25
	2007	5,767	8,715	13,477	0.10	0.15	0.23
	2008	5,153	7,779	12,005	0.09	0.14	0.21
	2009	5,611	8,521	13,302	0.10	0.15	0.23
	2010	7,582	11,599	18,017	0.13	0.20	0.31
	2011	11,005	16,682	25,785	0.19	0.29	0.44
	2012	12,371	19,335	30,591	0.22	0.34	0.52
	2013	12,782	22,464	38,799	0.23	0.40	0.66

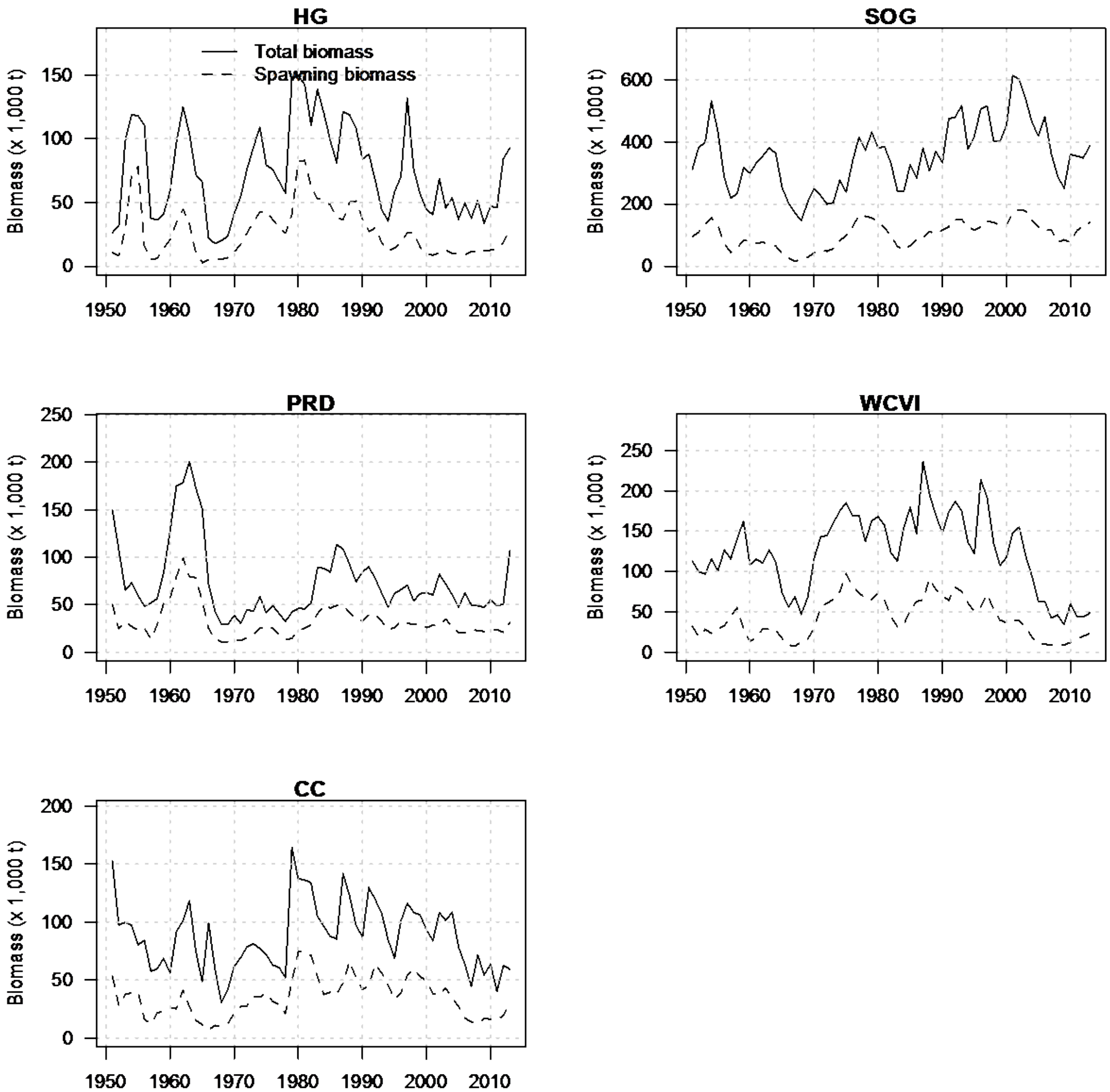

Figure 7. Maximum posterior density (MPD) estimates of total biomass (solid lines) and spawning biomass (dashed lines) through 2013 for the major stock areas. Total biomass is defined as total at beginning of a year (e.g., July-1st), whereas spawning biomass is defined as for the end of year (June 30th).

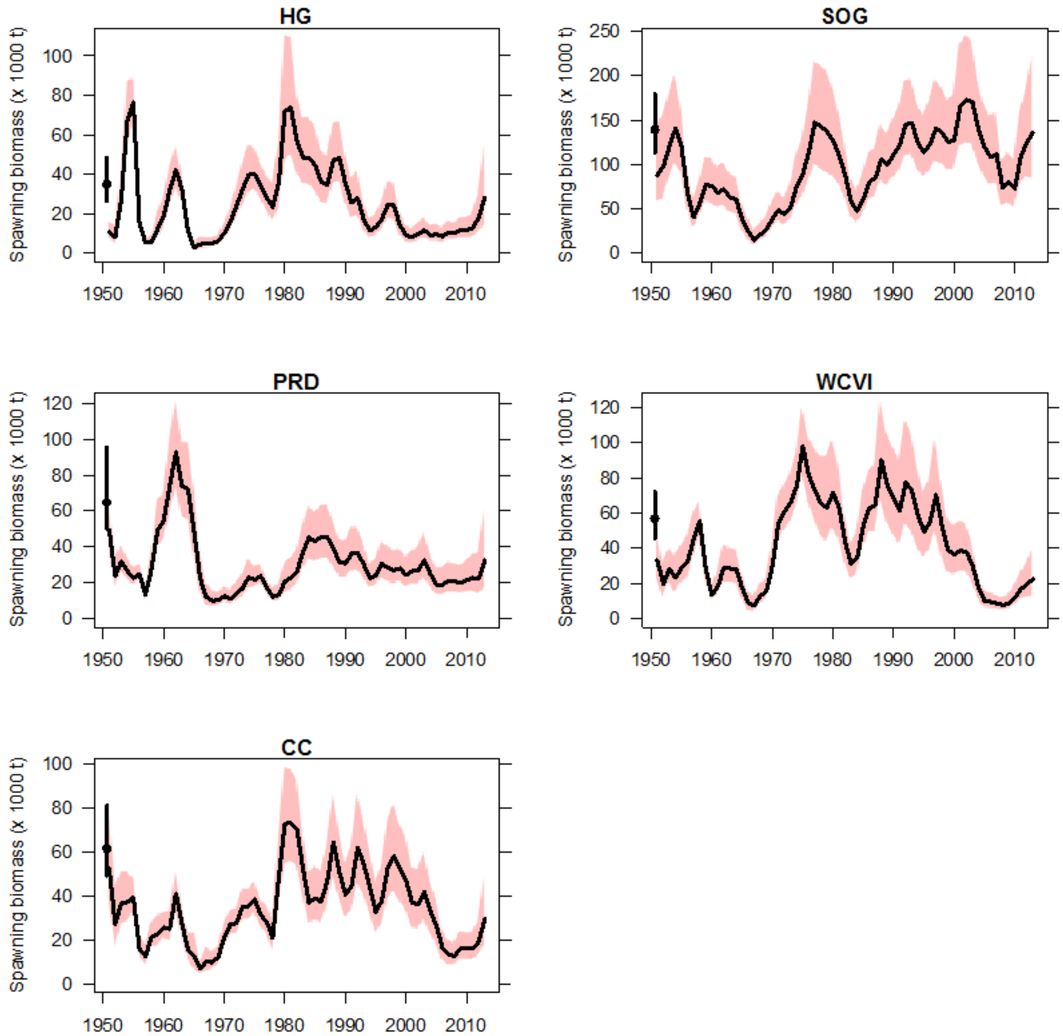

Figure 8. Median of the posterior distribution for spawning biomass through 2013 (solid line) with 90% posterior credibility intervals (shaded area). Solid circle represents the estimated unfished equilibrium spawning biomass, SB_0, with 90% posterior credibility intervals (vertical lines).

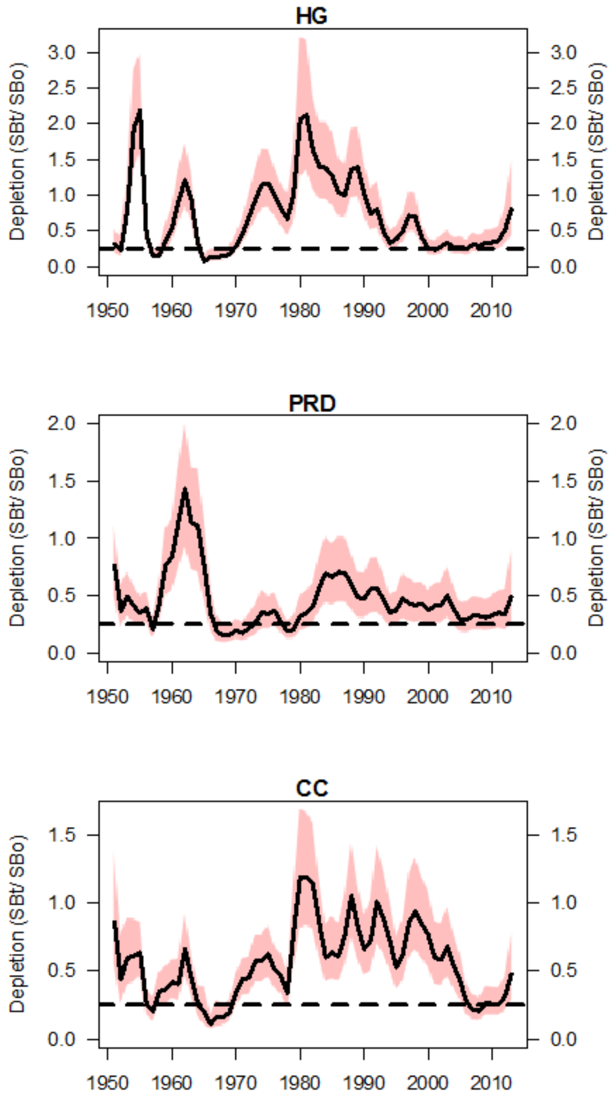

Figure 9. Median of the posterior distribution for spawning depletion (SB_t/SB_0) through 2013 with (solid line) 90% posterior credibility intervals (shaded area). The dashed horizontal line denotes the 25% depletion level.

3.4.2 Recruitment

Recruitment to each stock is defined as the number of age-2 fish entering the population at the beginning of each year, defined as July-1st based on ageing conventions (Section 2.1.2). Trends in estimates of age-2 fish are presented in Table 7, Figure 10. Age-2 recruitment is estimated as a free parameter within the model, subject to the constraint that annual estimates vary around a Beverton-Holt stock recruitment relationship with an estimated unknown standard deviation (Figure 11).

Table 8. Estimates of recent Pacific Herring recruitment (millions of age-2 fish).

	HG			PRD			CC		
Year	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
SAR	HG			PRD			CC		
2003	113	188	315	72	130	230	233	374	595
2004	356	577	935	129	230	412	578	908	1443
2005	99	166	280	115	206	360	212	342	550
2006	372	606	972	322	558	955	350	560	902
2007	84	144	239	125	211	362	150	244	387
2008	386	631	1,034	113	192	328	721	1112	1698
2009	64	111	192	162	276	480	210	327	503
2010	254	424	713	209	362	634	433	678	1042
2011	191	340	610	89	165	302	138	216	341
2012	478	972	1,836	166	414	886	418	665	1064
2013	116	614	2,484	129	814	3,440	141	253	449

SAR	SOG			WCVI		
Year	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
2003	1,883	2,955	4,609	347	554	887
2004	1,968	3,082	4,764	403	654	1,063
2005	1,771	2,804	4,331	288	477	789
2006	3,105	4,838	7,533	442	716	1,162
2007	789	1,249	1,957	180	291	478
2008	2,770	4,385	6,775	318	494	797
2009	510	815	1,276	170	269	434
2010	3,112	4,988	7,726	517	816	1,308
2011	2,041	3,248	5,117	139	224	373
2012	1,169	1,934	3,139	128	209	353
2013	1,455	2,475	4,180	149	267	486

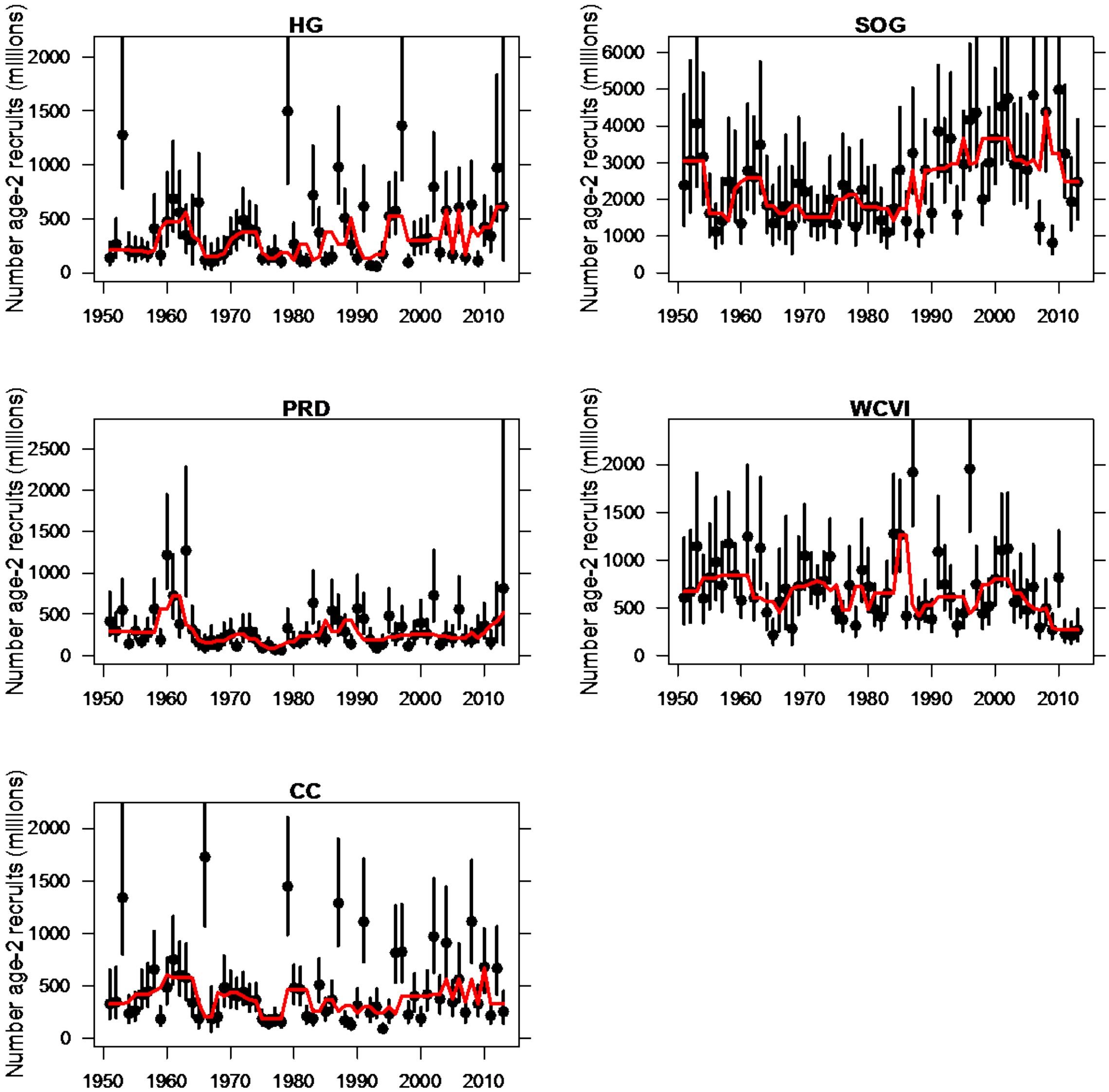

Figure 10. Median posterior estimates (solid circles) of recruitment (millions of age-2 fish) with 90% posterior credibility intervals (vertical lines). Red trend line denotes 5-year running average.

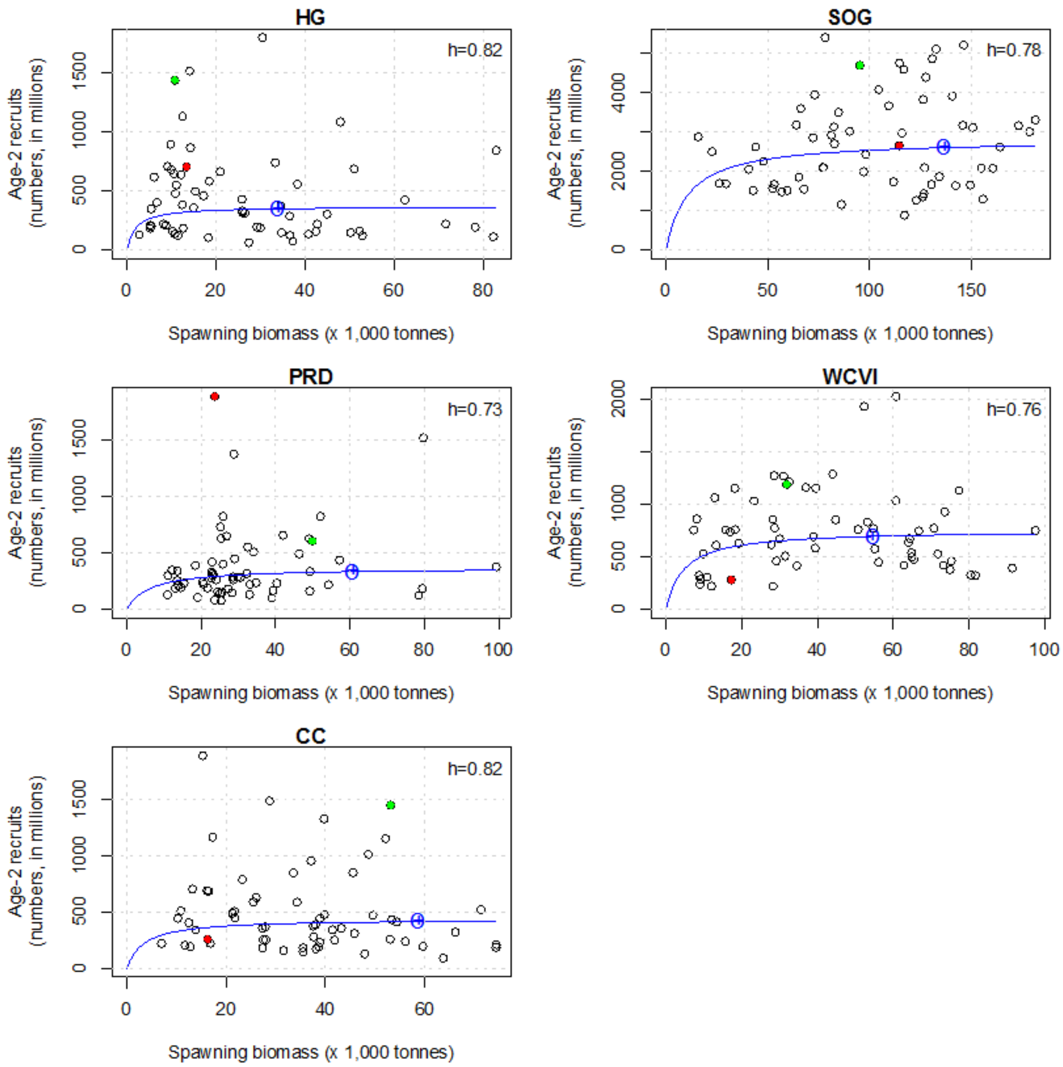

Figure 11. Maximum posterior density (MPD) estimates of age-2 recruits versus estimated spawning stock biomass for each of the major stock areas. The green and red circles indicate the start (recruits in 1951) and end (recruits in 2013) of the series. The circle plus (blue) corresponds to the MPD estimate of unfished spawning biomass (SB_0) and unfished age-2 recruitment $R_{0;}$ the blue curve is the Beverton-Holt stock recruitment model fitted to these data and h is the steepness parameter. Units are in 1,000 tonnes spawning biomass (x-axis) and millions of recruits (y-axis).

3.4.3 Mortality and gear selectivity

Natural mortality is modelled as a time variant instantaneous rate that is constant across ages (**Figure 12)** and instantaneous fishing mortality rates are age-specific (**Figure 13).** Note that fishing mortality rates are not comparable across gear types (fisheries) due to differences in gear selectivity (**Figure 14).**

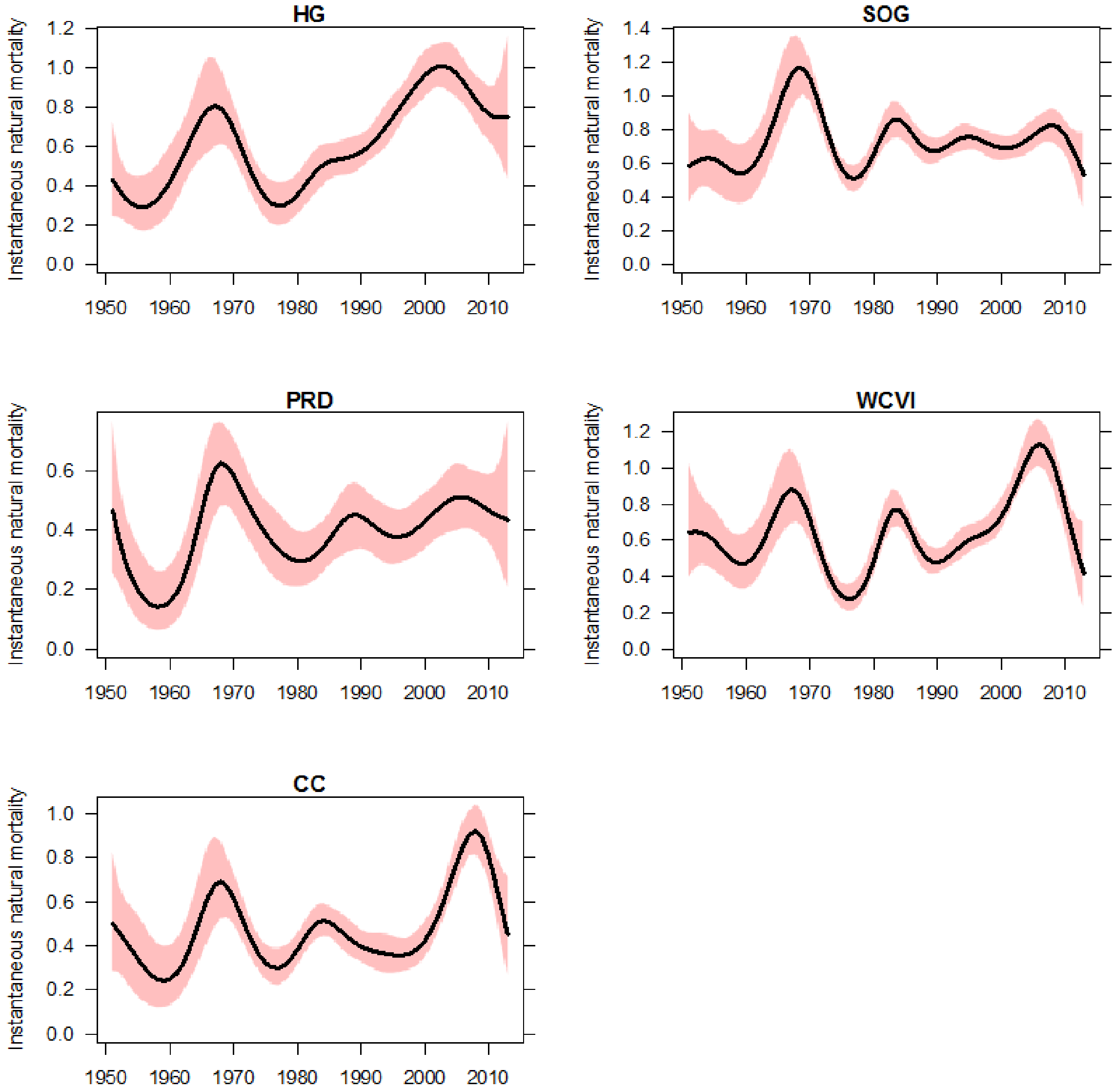

Figure 12. Median (solid line) of the posterior distribution for instantaneous natural mortality rate with 90% posterior credibility intervals (shaded area).

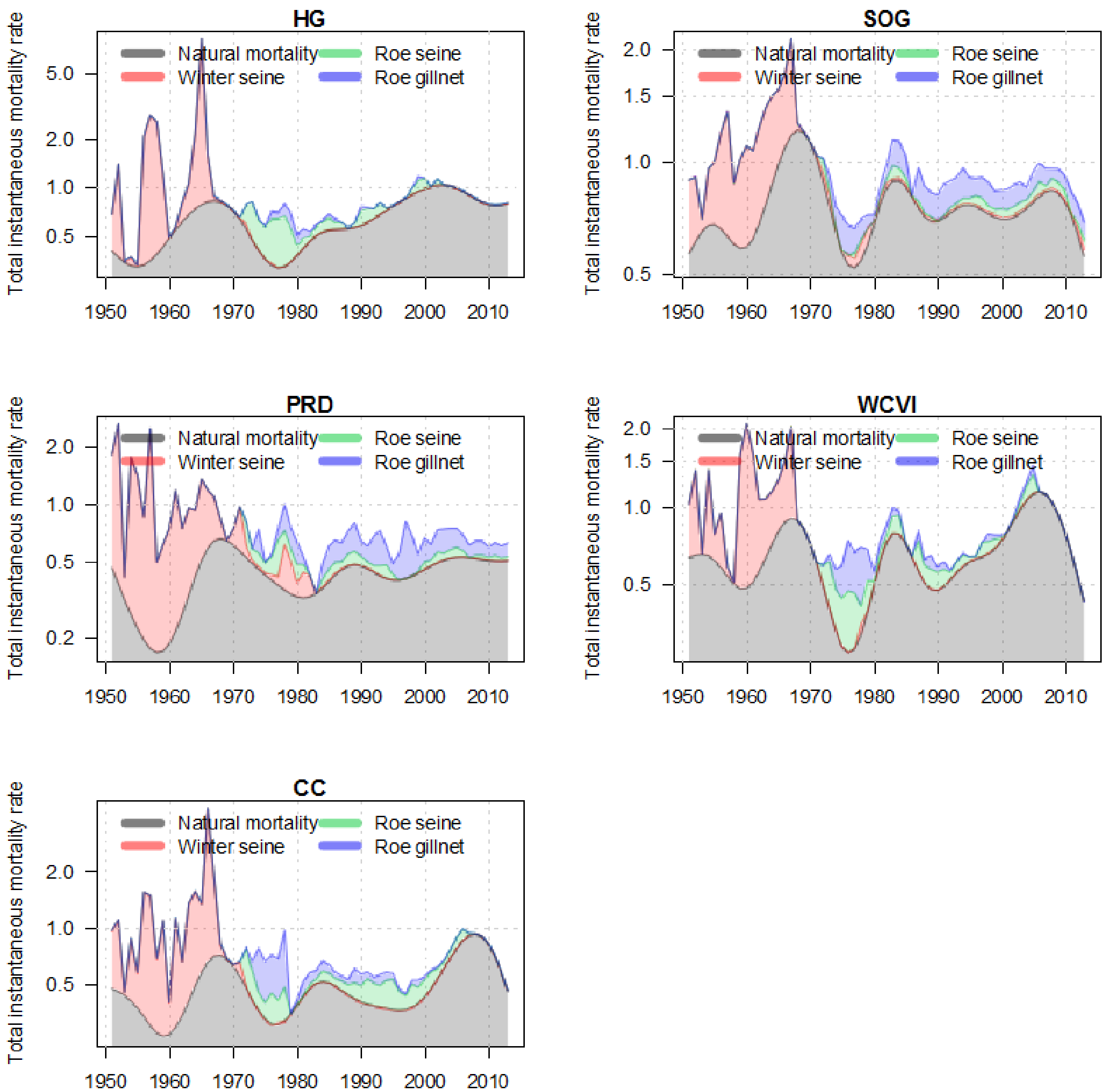

Figure 13. Maximum posterior density (MPD) estimates of total instantaneous mortality rates. Grey shaded region represents the average instantaneous natural mortality rate and red, green and blue regions represent instantaneous fishing mortality rates for the winter, roe seine and roe gillnet fisheries.

Fishery selectivity is estimated for each of the 3 gear types using a logistic function with age-specific selectivity coefficients **(Appendix F**). **Figure 14** presents maximum likelihood estimates of age-specific selectivity coefficients for the all fishing categories (gear types) for each of the major stock areas (scaled to 1.0).

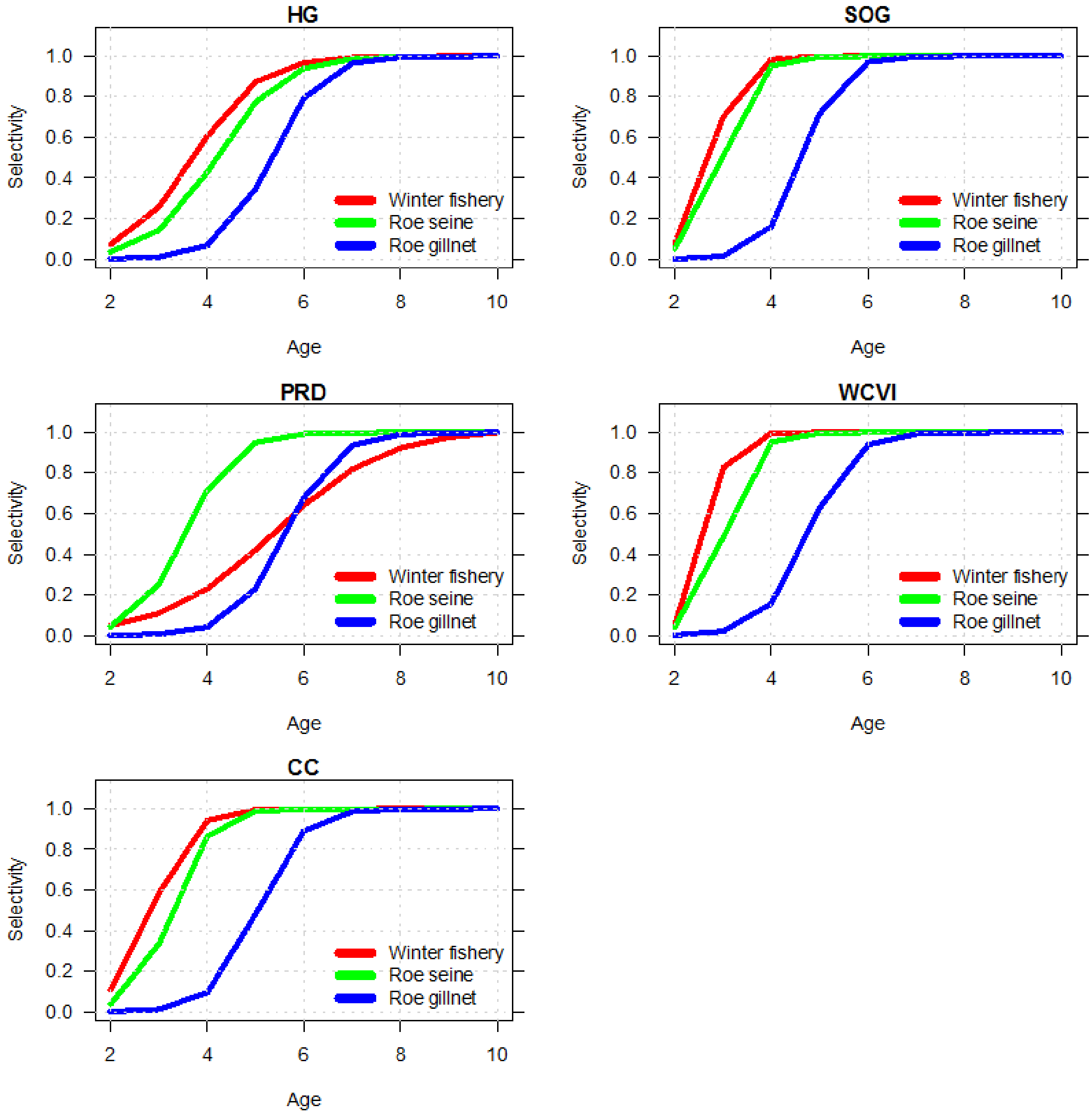

Figure 14. Maximum likelihood estimates of age-specific selectivity coefficients for the all fishing categories (gear types) for each of the major stock areas. To facilitate comparisons amongst gear types, all selectivity values were scaled to a maximum of 1.0.

3.4.4 Model uncertainty

Measures of uncertainty in this assessment underestimate the true uncertainty in current stock status and future projections because they do not account for alternative structural models for Herring population dynamics (e.g., natural mortality) and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distribution choices.

The base case assessment model integrates over substantial uncertainty associated with several important model parameters including: spawn survey catchability (q), the productivity of the stock (via the steepness parameter, h, of the stock-recruitment relationship), natural mortality rate (M), and recruitment deviations. Although the Bayesian results presented include estimation uncertainty, this within-model uncertainty is likely an underestimate of the true uncertainty in current stock status and future projections, since it does not include structural modeling choices, data-weighting uncertainty and scientific uncertainty in selection of prior probability distributions.

The only way to develop a management procedure that is robust to the true range of uncertainty in current stock status and future projections is through feedback simulations.

3.4.5 Reference points

Currently, the assessment of B.C. Herring stocks is limited to a single reference point - unfished equilibrium spawning biomass (SB_0). Estimates of SB_0 arise from the Beverton-Holt stock-recruitment relationship (within the assessment model), calculated using long-term average trends in weight-at-age, natural mortality, and recruitment.

The use of long-term averages to estimate SB_0 is consistent with the DFO decision-making framework which specifies that, in general as long a time series as possible should be used in establishing reference points for fish stocks. The decision-making framework recognizes that many stocks show substantial variation in productivity over a long time series, but suggests that reference points should not be estimated using only information from a period of low productivity unless there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management (DFO 2009). The reasons for recent low Herring productivity (high natural mortality and reduced weight-at-age) are unknown, and do not warrant changes to reference points at this time. However, for comparative purposes, the following section includes estimates of "dynamic unfished biomass, $SB^*_{0,T}$ calculated using recent 5-year averages of weight-at-age and natural mortality, to account for changes in growth and natural mortality, i.e., dynamic SB_0 accounts for changes in productivity over time whereas an equilibrium estimate of SB_0 does not.

For all stock assessment regions, estimates of unfished equilibrium spawning biomass are numerically lower when calculated using recent 5-year averages (dynamic unfished biomass, $SB^*_{0,T}$) compared with long-term averages (SB_0) as shown in **Table 8**. Whereas corresponding estimates of depletion are higher when calculated using recent 5-year averages ($SB_T / SB^*_{0,T}$). Declines in weight-at-age, evident for all major Herring stocks, from the mid-1980s to 2010 (**Figure 5).**

Table 9. Estimates of unfished spawning biomass and depletion for Pacific Herring stocks.

	Spawning biomass (SB_{2013})			Unfished biomass (SB_0)			"Dynamic" unfished biomass ($SB^*_{0,T}$)		
Stock	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
HG	14,357	28,294	54,537	26,336	34,962	48,390	10,411	18,113	32,760
PRD	16,762	32,568	60,283	50,000	64,928	95,558	22,607	41,423	82,891
CC	17,844	29,597	48,974	49,194	61,618	81,250	15,057	23,565	38,678
SOG	83,196	136,258	220,752	113,653	139,511	180,183	84,837	124,520	186,743
WCVI	12,782	22,464	38,799	45,591	56,885	72,047	25,932	41,597	69,339

	Depletion (SB_{2013}/ SB_0)			"Dynamic" Depletion (SB_{2013}/ $SB^*_{0,T}$)		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
HG	0.42	0.80	1.49	1.01	1.55	2.35
PRD	0.25	0.49	0.90	0.47	0.77	1.19
CC	0.29	0.48	0.78	0.87	1.25	1.74
SOG	0.62	0.97	1.48	0.81	1.09	1.46
WCVI	0.23	0.40	0.66	0.37	0.54	0.76

3.4.6 Model projections

One-year model projections are used to forecast herring spawning biomass (SB_{T+1}) under alternate catch assumptions (decision based target fishing levels). Included is a set of performance metrics that were identified as relevant by the TWG and Fisheries Management, relating directly to the performance of the HCR historically used for the management of Pacific Herring **(Section 1.6).** Operational reference points are translated into decision table metrics to evaluate the probability of various outcomes given each potential catch (**Table 9**). Projected spawning biomasses assuming zero catch in 2014 and the relative contribution of fish of age-3 and of fish ages 4-10 are presented in **Table 10**. The operational reference points historically used in the management of Pacific Herring are a commercial fishing threshold of $0.25SB_0$ (cutoff) and a target harvest rate of 20%. Predicted status of spawning biomass (SB_{T+1}) for the major herring stocks in 2014 relative to target fishing levels are presented as probabilistic decision tables (**Table 11**). For each column in a decision table, probabilities are computed for each posterior value in the MCMC chain (length 5,000), summing across all values. Decision tables are only presented for base assessment model runs.

Forecasted spawning biomass is calculated using mean fecundity-at-age for the last 5 years ($\bar{f}_a$) and mean natural mortality for the last 5 years ($\bar{M}$):

$$SB_{T+1} = \sum_a N_a e^{-\bar{M}} \ \bar{f}_a \tag{6}$$

These assumptions reflect recent declines in growth and changes in natural mortality and are consistent with previous herring assessments.

Table 10. Probabilistic decision table metrics.

Metric	Description
P(SB_{2014} < 0.25SB_0)	Probability the forecast spawning biomass (for a given catch level) is below cutoff (0.25SB_0)
Median ratio (SB_{2014} / 0.25SB_0)	Median ratio of forecast spawning biomass (for a given catch level) to 0.25SB_0. When ratio=1, SB_{2014} = 0.25SB_0; when ratio=2, SB_{2014} = 2* (0.25SB_0); when ratio=0.5, SB_{2014} = ½ (0.25SB_0)
P(U'_{2014} > 20%)	Probability the realized harvest rate (for a given catch level) is greater than the target harvest rate of 20% (major stocks)
P(U'_{2014} > 10%)	Probability the realized harvest rate (for a given catch level) is greater than the target harvest rate of 10% (minor stocks)
Median (U'_{2014})	Median realized harvest rate for a given catch level (magnitude of U'_{2014})

Table 11. Estimates of projected spawning biomass in 2014 given zero catch, and predicted proportions of fish of age-3 and of ages 4-10 for the major BC herring stocks.

	Projected proportion age-3 fish in 2014			Projected proportion ages 4-10 fish in 2014			Projected spawning biomass (SB_{2014}) given zero catch		
Stock	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
HG	0.09	0.36	0.74	0.19	0.53	0.83	12,270	26,260	58,540
PRD	0.11	0.49	0.82	0.15	0.45	0.82	19,750	44,840	109,500
CC	0.13	0.20	0.29	0.53	0.68	0.78	13,230	23,370	41,210
SOG	0.27	0.35	0.43	0.42	0.52	0.60	73,260	123,300	206,000
WCVI	0.19	0.28	0.38	0.37	0.52	0.64	11,880	21,770	39,360

Table 12. Probabilistic decision tables for the major Pacific herring stocks.

TAC (metric tonnes)	Biomass metrics		Harvest metrics	
	Prob (below 0.25 SB_0 in 2014) P(SB_{2014} < 0.25 SB_0)	Median ratio of forecast biomass to 0.25 SB_0 Med (SB_{2014} / 0.25 SB_0)	Prob (removal rate > target HR) P(U'_{2014} > 20%)	Median removal rate Med (U'_{2014})
HG				
0	0.01	3.02	0	0
2,000	0.01	2.88	0.01	0.07
3,000	0.02	2.81	0.08	0.11
4,000	0.03	2.73	0.23	0.14
5,000	0.03	2.66	0.39	0.18
5,750	0.04	2.61	0.50	0.20
6,000	0.04	2.59	0.55	0.21
7,000	0.05	2.52	0.66	0.24
8,000	0.07	2.45	0.75	0.27
9,000	0.08	2.38	0.82	0.30

TAC (metric tonnes)	Biomass metrics		Harvest metrics	
	Prob (below 0.25 SB_0 in 2014) $P(SB_{2014} < 0.25\ SB_0)$	Median ratio of forecast biomass to 0.25 SB_0 Med $(SB_{2014} / 0.25\ SB_0)$	Prob (removal rate > target HR) $P(U'_{2014} > 20\%)$	Median removal rate Med (U'_{2014})
PRD				
0	0.02	2.71	0	0
2,500	0.03	2.60	0.00	0.06
5,000	0.05	2.48	0.10	0.11
7,500	0.07	2.37	0.33	0.16
9,500	0.09	2.28	0.50	0.20
10,000	0.10	2.26	0.54	0.21
12,500	0.12	2.15	0.70	0.26
15,000	0.15	2.04	0.81	0.31
17,500	0.18	1.94	0.87	0.35
CC				
0	0.11	1.51	0	0
1,000	0.13	1.46	0.00	0.04
2,000	0.16	1.42	0.01	0.08
3,000	0.19	1.38	0.07	0.12
4,000	0.22	1.33	0.25	0.16
5,000	0.25	1.29	0.50	0.20
6,000	0.29	1.25	0.71	0.24
7,000	0.32	1.20	0.84	0.27
8,000	0.36	1.16	0.92	0.31
9,000	0.40	1.12	0.96	0.34
SOG				
0	0.000	3.50	0	0
10,000	0.000	3.31	0.00	0.08
15,000	0.001	3.22	0.03	0.12
20,000	0.001	3.13	0.19	0.15
25,000	0.002	3.04	0.42	0.19
26,500	0.002	3.01	0.50	0.20
30,000	0.003	2.95	0.66	0.22
35,000	0.005	2.85	0.82	0.26
40,000	0.008	2.76	0.91	0.29
WCVI				
0	0.11	1.55	0	0
2,000	0.16	1.46	0.01	0.09
3,000	0.19	1.41	0.11	0.13
4,000	0.22	1.37	0.32	0.17
4,700	0.25	1.33	0.51	0.20
5,000	0.25	1.32	0.57	0.21
6,000	0.29	1.27	0.75	0.25
7,000	0.32	1.23	0.87	0.29
8,000	0.36	1.19	0.93	0.32

3.4.7 Sensitivity cases

Two sensitivity cases were explored to investigate changes in input data: spawn survey data (width estimates), and truncated time series (1972-2013).

3.4.7.1 Spawn survey data (width estimates)

Following from **Section 2.4.2**, a sensitivity analyses comparing model reconstructions, depletion estimates, and reference points from model fits to width-adjusted spawn index (base case) and non-width-adjusted spawn index (sensitivity case) are included. We conclude that the implications of adjustments to the calculation of spawn width have a negligible influence on model reconstructions (**Figure 15**) and estimates of stock depletion (**Figure 16, Table 12**).

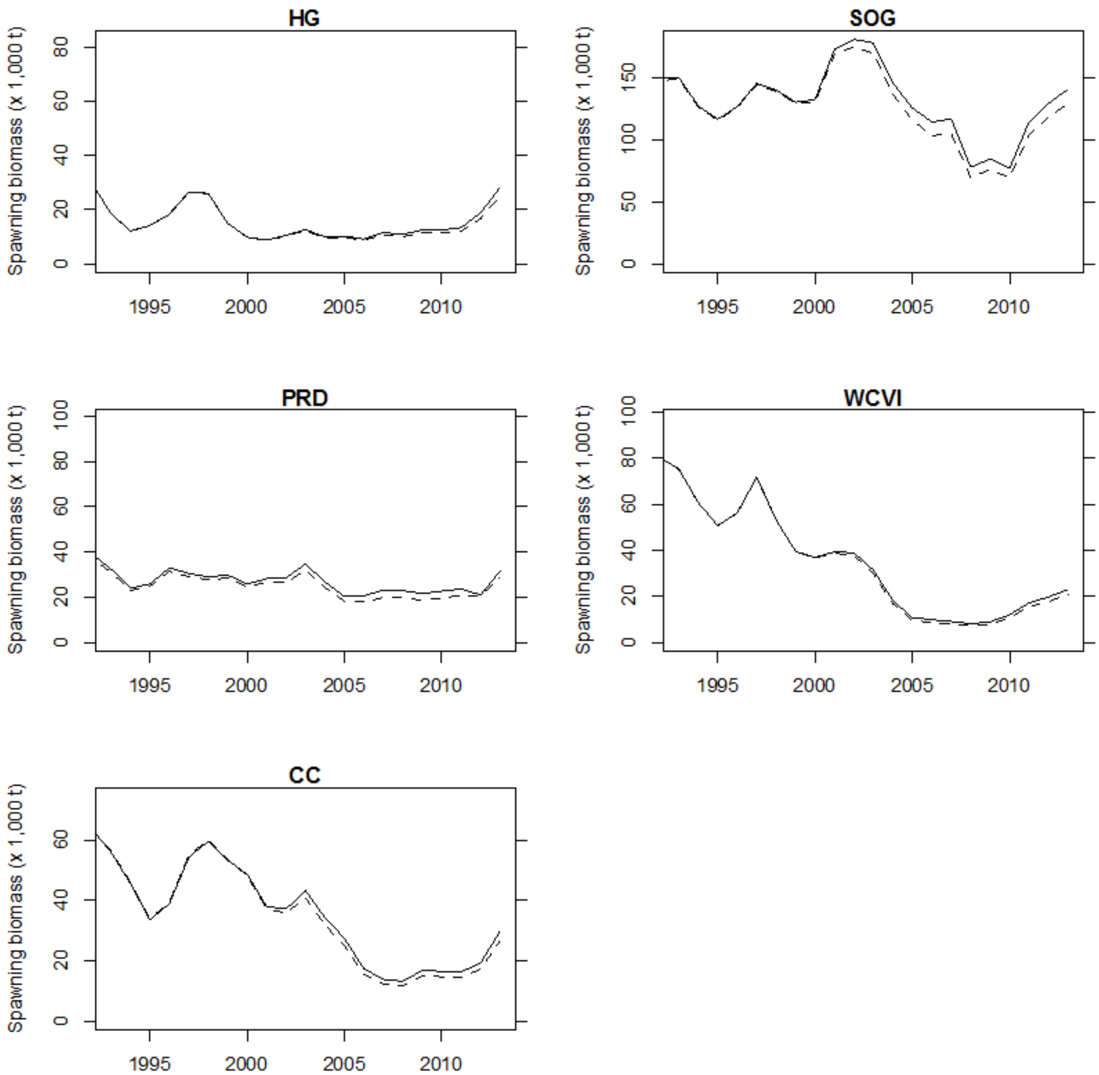

Figure 15. Maximum posterior density (MPD) estimates of spawning biomass derived by fitting the assessment model (independently) to the width-adjusted spawn index (base, solid line) and non-width-adjusted index (sensitivity case, dashed line). The assessment model was fitted to the entire time series (1951-2013), however figures show 1993-2013 only.

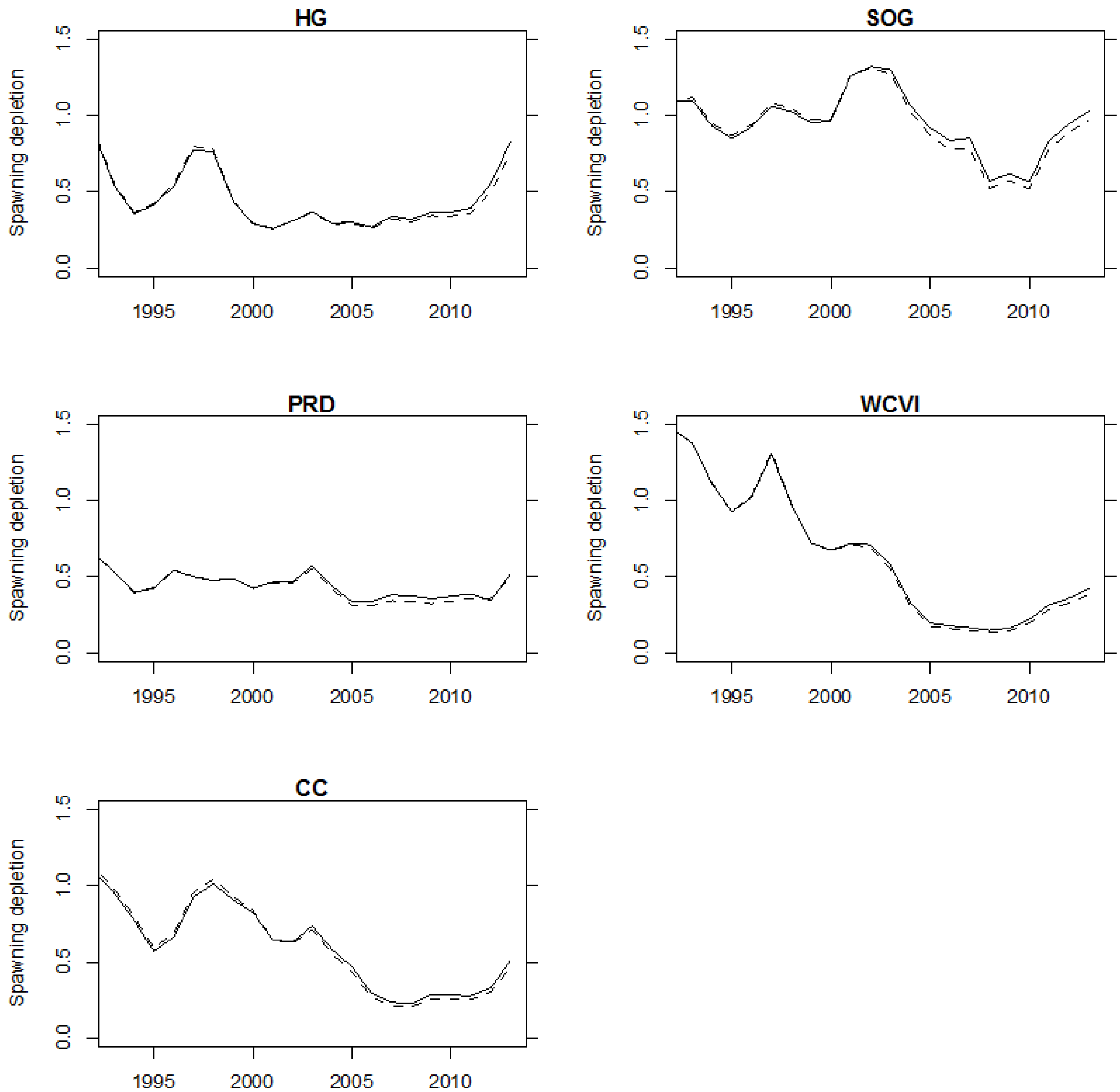

Figure 16. Maximum posterior density (MPD) estimates of spawning depletion (SB_t/SB_0) derived by fitting the assessment model (independently) to the width-adjusted spawn index (base, solid line) and non-width-adjusted index (sensitivity case, dashed line). The assessment model was fitted to the entire time series (1951-2013), however figures show 1993-2013 only.

Table 13. Current estimates of Pacific Herring spawning biomass (SB_{2013}, metric tonnes) and depletion level relative to estimated unfished equilibrium spawning biomass (SB_0) derived by fitting the assessment model (independently) to the width-adjusted spawn index (base) and non-width-adjusted spawn index (sensitivity case).

	Spawning biomass (SB_{2013})			Depletion (SB_{2013}/SB_0)		
2013	5th	Median	95th	5th	Median	95th
HG - width-adjusted (base)	14,357	28,294	54,537	0.42	0.80	1.49
HG - non-width-adjusted	12,476	25,309	47,514	0.37	0.73	1.34
PRD - width-adjusted (base)	16,762	32,568	60,283	0.25	0.49	0.90
PRD - non-width-adjusted	15,428	29,439	53,582	0.23	0.45	0.82
CC - width-adjusted (base)	17,844	29,597	48,974	0.29	0.48	0.78
CC - non-width-adjusted	15,587	26,084	42,662	0.25	0.43	0.71
SOG - width-adjusted (base)	83,196	136,258	220,752	0.62	0.97	1.48
SOG - non-width-adjusted	76,289	125,712	199,621	0.58	0.92	1.39
WCVI - width-adjusted (base)	12,782	22,464	38,799	0.23	0.40	0.66
WCVI - non-width-adjusted	11,409	20,507	35,765	0.21	0.36	0.61

3.4.7.2 Truncated time series, 1972-2013

Section 3.2 describes concerns around inappropriate allocation of the reduction fishery catch to specific stock assessment regions. The reduction fishery operated largely in the fall/ winter months, harvesting Herring from large feeding grounds such as Hecate Strait or Queen Charlotte Sound. These catches are allocated to a given stock assessment region based on landing reports in the Herring database, however it has been noted on many occasions that this procedure may incorrectly allocate large historic catches. See for example the large reduction fishery catches for Haida Gwaii in 1956 and 1965 **(Figure 2**).

The implications of fitting the assessment model to the truncated time series, 1972-2013, has the largest impact on SOG, and a negligible influence on CC ***(*Figure 17, Figure 18 and Table 13).**

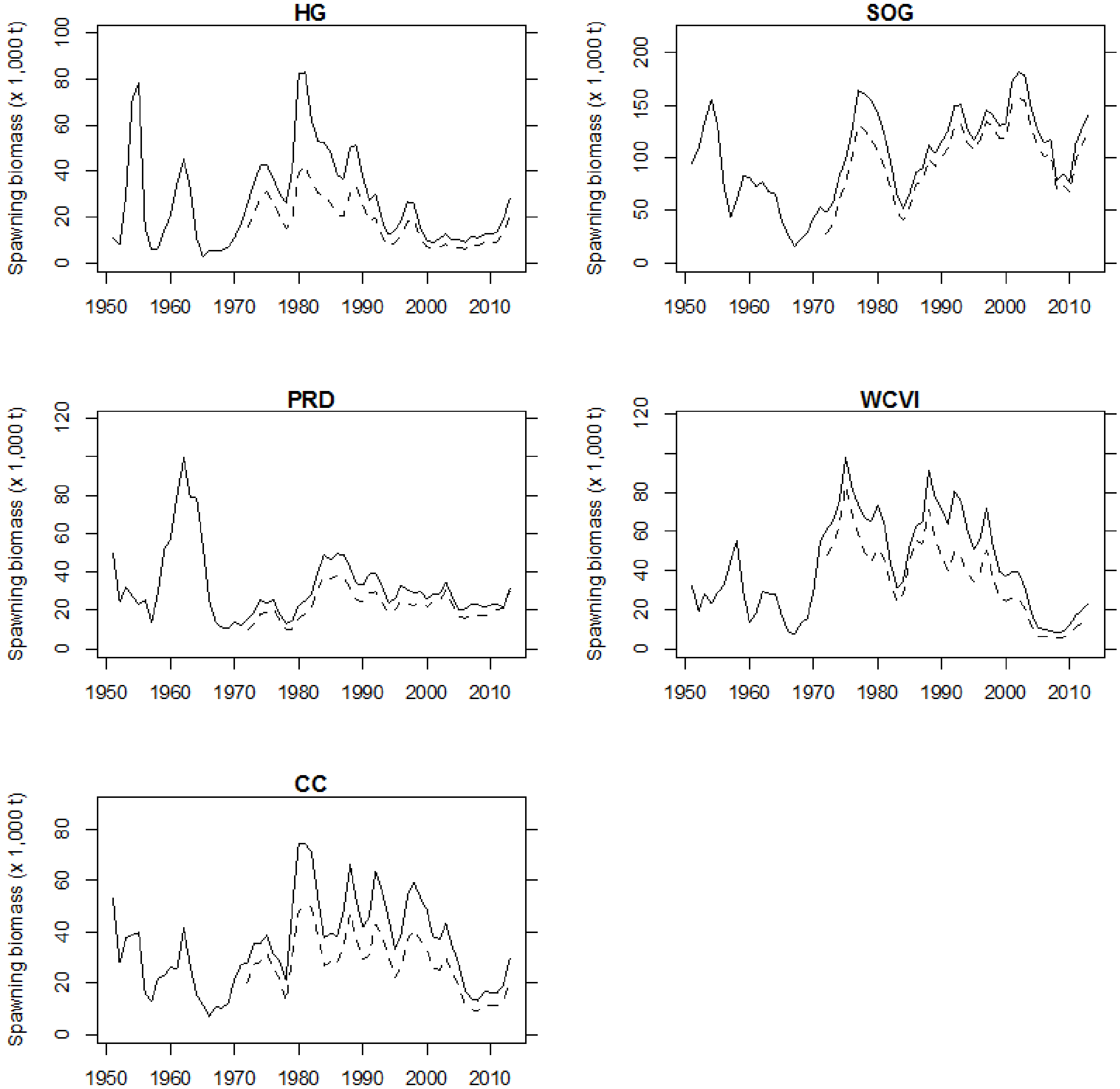

Figure 17. Maximum posterior density (MPD) estimates of spawning biomass derived by fitting the assessment model (independently) to the time series of data from 1951-2013 (base, solid line) and a truncated data time series from 1972-2013 (sensitivity case, dashed line).

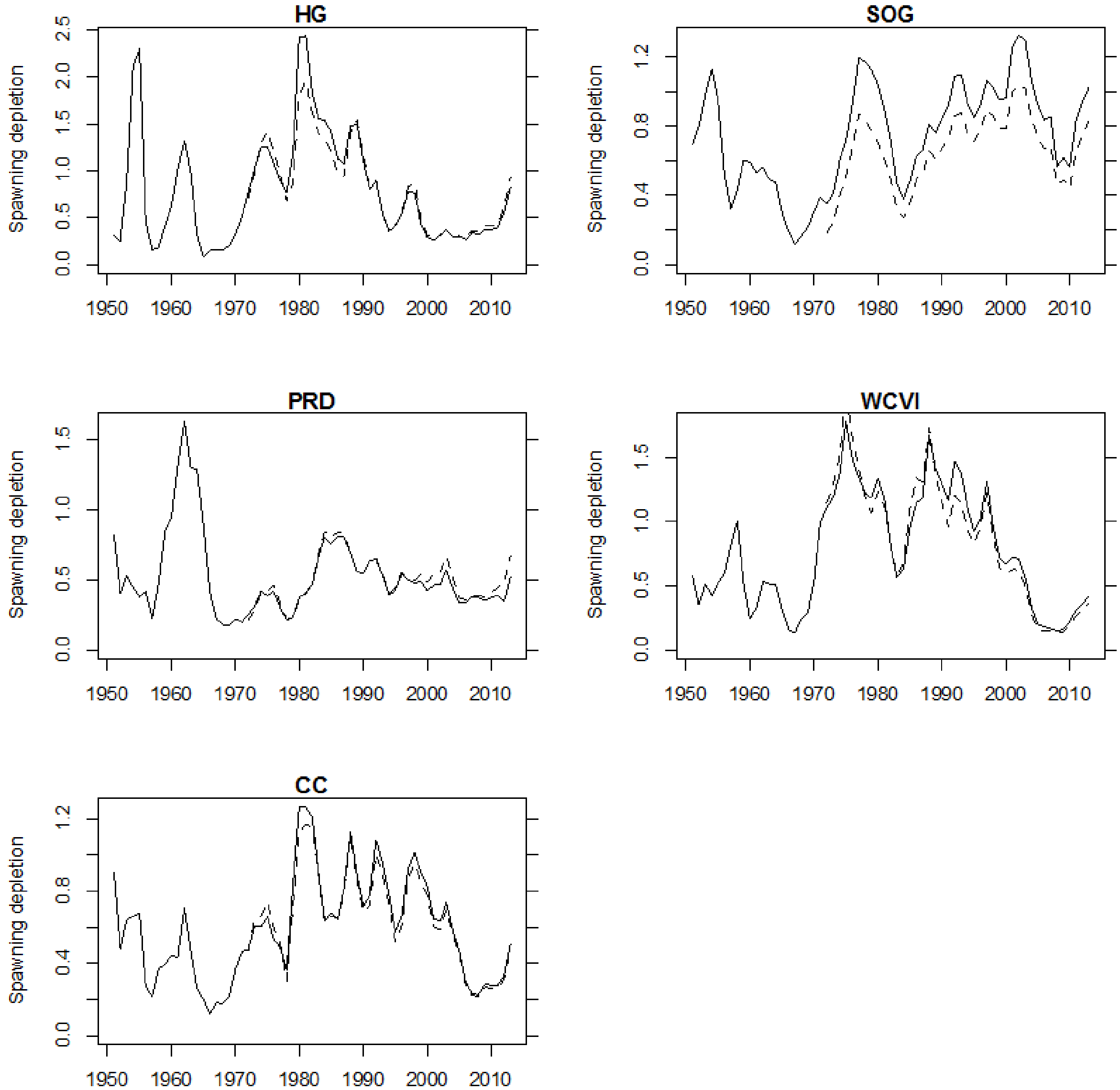

Figure 18. Maximum posterior density (MPD) estimates of spawning depletion (SB_t/SB_0) derived by fitting the assessment model (independently) to the time series of data from 1951-2013 (base, solid line) and a truncated data time series from 1972-2013 (sensitivity case, dashed line).

Table 14. Current estimates (median posterior values) of Pacific Herring spawning biomass (SB_{2013}, metric tonnes) and depletion level relative to estimated unfished equilibrium spawning biomass (SB_0) derived by fitting the assessment model (independently) to the time series of data from 1951-2013 (base) and a truncated data time series from 1972-2013 (sensitivity case). Note: percentiles for sensitivity case based on chain length 2,000 (mcmc 1,000,000 mcsave 500) as opposed to a chain length of 5,000 for the base run (mcmc 5,000,000 mcsave 1,000).

	Spawning biomass (SB_{2013})			Depletion (SB_{2013}/SB_0)		
2013	5th	Median	95th	5th	Median	95th
HG - 1951-2013 (base)	14,357	28,294	54,537	0.42	0.80	1.49
HG - truncated (1972-2013)	23,479	27,968	35,275	0.87	1.04	1.22
PRD - 1951-2013 (base)	16,762	32,568	60,283	0.25	0.49	0.90
PRD - truncated (1972-2013)	16,173	26,465	43,087	0.26	0.50	0.86
CC - 1951-2013 (base)	17,844	29,597	48,974	0.29	0.48	0.78
CC - truncated (1972-2013)	18,961	25,350	28,977	0.45	0.67	0.77
SOG - 1951-2013 (base)	83,196	136,258	220,752	0.62	0.97	1.48
SOG - truncated (1972-2013)	64,795	116,799	202,824	0.41	0.74	1.22
WCVI - 1951-2013 (base)	12,782	22,464	38,799	0.23	0.40	0.66
WCVI - truncated (1972-2013)	8,509	15,510	28,554	0.21	0.36	0.61

3.4.8 Retrospective analyses

Changes in estimates of current spawning biomass (SB_t) and unfished equilibrium spawning biomass (SB_0) were examined retrospectively by successively removing the last 10-years of data. Maximum posterior density (MPD) values for each major stock area are presented in **Figure 19** and **Table 14**.

Retrospective analyses reveal declining trends in MPD estimates of SB_0 over the past 10-years for CC and WCVI stocks, with more gradual declines evident for HG and PRD. Fluctuations in estimates of SB_0 for SOG are minor relative to large fluctuations in retrospective MPD estimates of spawning biomass.

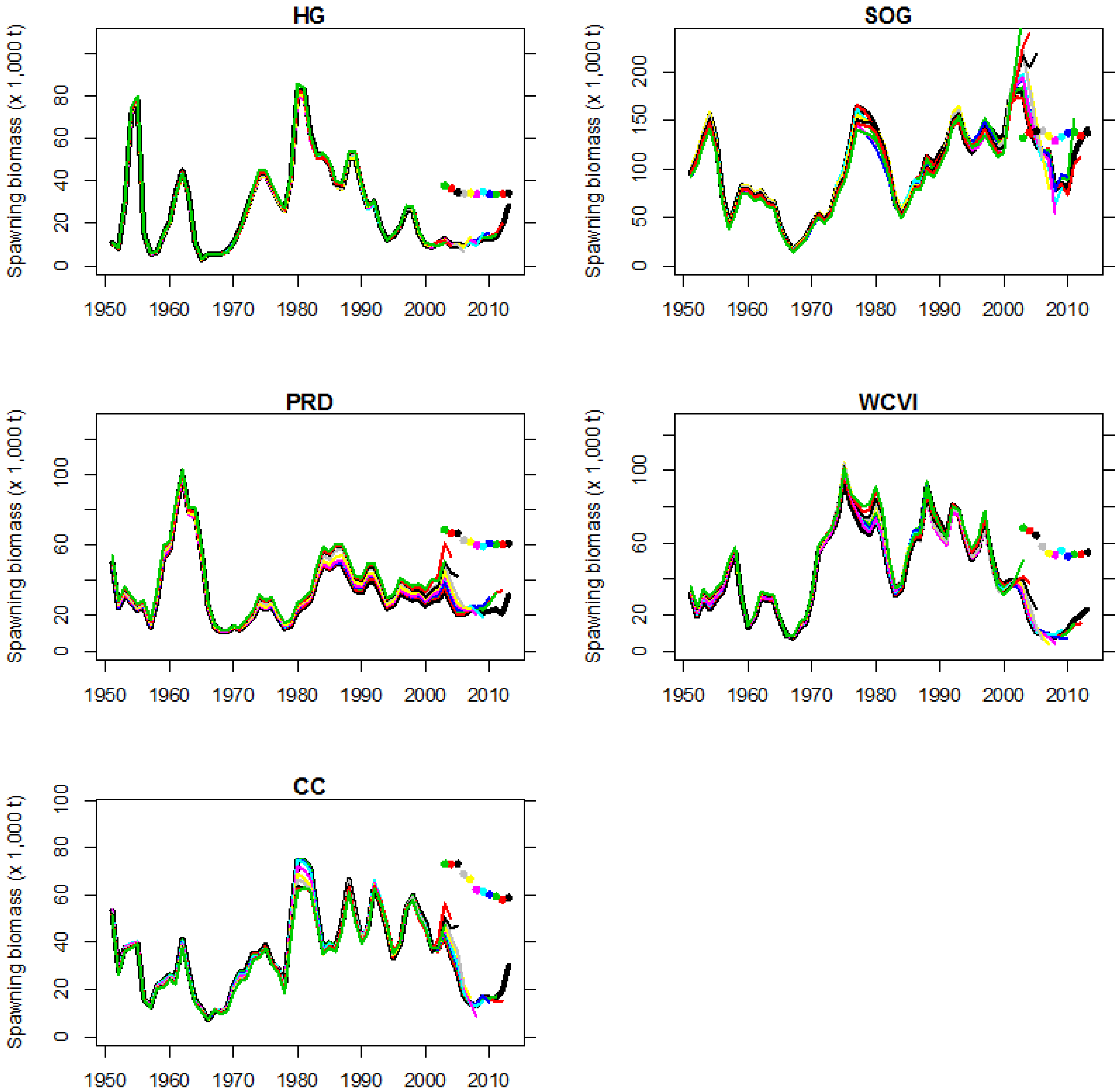

Figure 19. Retrospective maximum posterior density (MPD) estimates of spawning biomass (SB_t) for each of the five major stock areas. Coloured circles represent retrospective estimates of unfished biomass, SB_0.

Table 15. Retrospective maximum posterior density (MPD) estimates of current spawning biomass, SB_t, and unfished spawning biomass, SB_0, for each of the five major stock areas. Units are in metric tonnes.

	HG			PRD			CC		
Year	SB_0	SB_t	SB_t/SB_0	SB_0	SB_t	SB_t/SB_0	SB_0	SB_t	SB_t/SB_0
2003	37,740	10,940	0.29	68,727	50,701	0.74	73,111	47,252	0.65
2004	36,478	9,145	0.25	66,713	53,248	0.80	73,008	49,822	0.68
2005	34,582	8,454	0.24	66,610	42,536	0.64	73,151	46,626	0.64
2006	33,959	6,785	0.20	62,685	25,104	0.40	68,653	21,386	0.31
2007	34,236	13,349	0.39	61,949	23,749	0.38	66,645	16,753	0.25
2008	33,796	10,594	0.31	59,956	20,757	0.35	62,177	8,262	0.13

	HG			PRD			CC		
Year	SB_0	SB_t	SB_t/SB_0	SB_0	SB_t	SB_t/SB_0	SB_0	SB_t	SB_t/SB_0
2009	34,779	15,647	0.45	59,096	19,077	0.32	61,486	14,968	0.24
2010	33,772	15,323	0.45	60,935	30,171	0.50	60,209	14,526	0.24
2011	33,572	14,553	0.43	60,408	32,965	0.55	59,485	17,117	0.29
2012	33,903	19,764	0.58	60,399	34,406	0.57	57,965	15,131	0.26
2013	34,069	28,206	0.83	60,799	31,540	0.52	58,816	29,920	0.51

	SOG			WCVI		
Year	SB_0	SB_t	SB_t/SB_0	SB_0	SB_t	SB_t/SB_0
2003	131,889	264,578	2.01	68,513	50,259	0.73
2004	137,060	239,735	1.75	66,947	37,876	0.57
2005	139,075	217,911	1.57	64,283	23,389	0.36
2006	139,571	110,797	0.79	58,118	6,492	0.11
2007	133,910	80,111	0.60	54,258	3,896	0.07
2008	129,160	53,618	0.42	53,366	4,122	0.08
2009	132,868	79,373	0.60	55,794	11,935	0.21
2010	136,785	91,565	0.67	52,684	7,259	0.14
2011	138,163	151,793	1.10	53,817	15,298	0.28
2012	134,241	111,796	0.83	53,688	15,527	0.29
2013	137,112	141,088	1.03	54,755	23,005	0.42

3.5 UNRESOLVED PROBLEMS/ISSUES WITH THE ASSESSMENT MODEL

Below is a list of unresolved issues with the current assessment model:

- Selectivity – occurrence of selectivity values greater than 1.0 due to simultaneous estimation of F_{msy}.
- Maturity – consideration of fixed maturity schedules for northern vs. southern herring stocks given biological differences in maturity-at-age.
- Natural mortality – stock projections assume that all natural mortality occurs prior to the fisheries, whereas the stock reconstruction component of the model assumes that fishing and natural mortality occur simultaneously throughout the year
- Fishing mortality and harvest rates – with the current model formulation there is no satisfactory representation for discrete mid- or end-of-year harvest rates. If the model's representation of continuous fishing mortality is accurate, then target instantaneous fishing mortality rates, or exploitation fraction defined in terms of spawners potential per recruit, are needed. An alternative is to move to a discrete fishing mortality parameterization (as has been historically used).

4 RESEARCH NEEDS

High priority issues identified in **Section 1.1** and **3.2** research issues discussion within DFO Science, DFO FM, and with herring stakeholders fall into 3 categories: Management Procedure, Science Program, and Data.

Management procedure:

- The only way to develop a management procedure that is robust to the true range of uncertainty in current stock status and future projections is through feedback simulations.

Candidate procedures can then be evaluated against conservation and yield objectives. Feedback simulation can address:

- o Evaluating the current management procedure against the DFO decision-making framework under the Sustainable Fisheries Framework;
- o Development of biologically based, limit reference points to inform management and rebuilding strategies; and
- o Evaluation of management procedures to deal with apparent time-varying changes in natural mortality and growth.

Science program (post-Larocque):

- With the withdrawal of Larocque funds, DFO will no longer pay to collect survey and biological data that have historically supported stock assessment and management;
- Evaluating alternative program structures and the effects of changes in the monitoring and assessment frequency is priority. For example, assess implications of using biennial survey information for assessment of abundance and stock projections in major stock areas; and
- Preliminary examination of the effects of reductions in survey frequency will occur for a Technical Experts in Stock Assessment workshop in October of 2013.

Data: SOK mortality

- Currently, catch input to the stock assessment model does not include mortality from the commercial SOK fishery, nor any recreational or FSC fisheries. The commercial SOK fishery is licensed based on pounds of validated SOK product, not tonnes of fish used/ spawned, thus there is currently no basis for verifying mortality imposed on the population by this fishery; and
- Future modelling work should explore effects from varying SOK mortality estimates, ideally in association with acquiring accurate SOK fishery data.

5 ACKNOWLEGEMENTS

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APPENDIX A. LIST OF TERMS AND ACRONYMS USED IN THIS DOCUMENT

Many of these definitions are relevant to the historical management of Pacific Herring and the CSAS process, and are included here only to improve interpretability of background documents.

CSAS: Canadian Science Advisory Secretariat

Catchability (*q*): The parameter defining the proportionality between a relative index of stock abundance (e.g., spawn survey) and the estimated stock abundance available to that survey (as modified by selectivity) in the assessment model.

Cohort: A group of fish born in the same year. Also see recruitment and year-class.

CV: Coefficient of variation. A measure of uncertainty defined as the standard deviation (SD, see below) divided by the mean.

Depletion: Abbreviated term for relative depletion (see below).

DFO: Fisheries and Oceans Canada. Federal organization which delivers programs and services that support sustainable use and development of Canada's waterways and aquatic resources.

F: Instantaneous rate of fishing mortality (or fishing mortality rate, see below).

Fishing mortality rate, or instantaneous rate of fishing mortality (*F*): A metric of fishing intensity that is usually reported in relation to the most highly selected ages(s) or length(s), or occasionally as an average over an age range that is vulnerable to the fishery. Because it is an instantaneous rate operating simultaneously with natural mortality, it is *not* equivalent to exploitation fraction (or percent annual removal; see above) or the Spawning Potential Ratio (*SPR*, see below).

F_{MSY}: The rate of fishing mortality estimated to produce the maximum sustainable yield from the stock.

HCRS: Herring Conservation Research Society

Maximum sustainable yield (*MSY*): An estimate of the largest average annual catch that can be continuously taken over a long period of time from a stock under prevailing ecological and environmental conditions.

MCMC: Markov-Chain Monte-Carlo. A numerical method used to sample from the posterior distribution (see below) of parameters and derived quantities in a Bayesian analysis. It is more computationally intensive than the maximum likelihood estimate (MLE, see below), but provides a more accurate depiction of parameter uncertainty.

MLE: Maximum likelihood estimate. A method for estimating the values of parameters that maximize the probability that the actual observations would have occurred if the parameter values were true. In stock assessment, when fitting the models to data observations, the maximum likelihood parameter-estimates are those values for which the probability of the actual data observations is highest.

MPD: Estimate of the maximum of the posterior density function. The maximum value (mode of the distribution) of the estimated probability function resulting from a Bayesian estimation procedure, whereby parameter values are estimated as random variables (within associated distributions) conditional on the data. Bayesian estimation can also include explicit incorporation of prior information for the estimated parameters.

MSE: Management Strategy Evaluation. A simulation procedure that simulates a population using an operating model, generates data from that population and passes it to an estimation model, uses the estimation model and a management strategy to provide management advice, which then feeds back into the operating model to simulate an additional fixed set of time before repeating this process.

MSY: Maximum sustainable yield. See above.

Operating Model: A model used to simulate data for use in the MSE (see above). The operating model includes components for the stock and fishery dynamics, as well as the simulation of the data sampling process, potentially including observation error. Cases in the MSE (see above) represent alternative configurations of the operating model.

PBS: Pacific Biological Station of Fisheries and Oceans Canada (DFO, see above).

Posterior distribution: The probability distribution for parameters or derived quantities from a Bayesian model representing the prior probability distributions (see below) updated by the observed data via the likelihood equation. For stock assessments posterior distributions are approximated via numerical methods; one frequently employed method is MCMC (see above).

Prior distribution: Probability distribution for a parameter in a Bayesian analysis that represents the information available before evaluating the observed data via the likelihood equation. For some parameters noninformative priors can be constructed which allow the data to dominate the posterior distribution (see above). For others, informative priors can be constructed based on auxiliary information and/or expert knowledge or opinions.

R_0: Estimated average level of annual recruitment occurring at SB_0 (see below).

Recruits/recruitment: A group of fish born in the same year or the estimated production of new members to a fish population of the same age. Recruitment is reported at a specific life stage, for herring age-2, but sometimes corresponding to the age at which the fish first become vulnerable to the fishery. See also cohort and year-class.

Recruitment deviation: The offset of the recruitment in a given year relative to the stock-recruit function; values occur on a log scale and are relative to the expected recruitment at a given spawning biomass (see below).

Relative depletion: The ratio of the estimated beginning of the year female spawning biomass to estimated average unfished equilibrium female spawning biomass (SB_0, see below). Thus, lower values of relative depletion are associated with fewer mature female fish.

SB_0: The estimated average unfished equilibrium female spawning biomass or spawning output if not directly proportional to spawning biomass.

SD: Standard deviation. A measure of variability within a sample.

Steepness (*h*): A stock-recruit relationship parameter representing the proportion of R_0 expected (on average) when the female spawning biomass is reduced to 20% of SB_0 (i.e., when relative depletion is equal to 20%). This parameter can be thought of one important component to the productivity of the stock.

Technical Working Group (TWG): Consisting of authors of the two working papers from the September 4-6, 2013 Pacific Regional Science Advisory Process, Pacific Biological Station, Nanaimo, B.C. (J.S Cleary; N.G. Taylor; V. Haist; A.R. Kronlund; J. Boldt)

Total Allowable Catch (TAC): The maximum fishery removal.

Vulnerable biomass: The demographic portion of the stock available for harvest by the fishery.

Year-class: A group of fish born in the same year. See also cohort and recruitment.

APPENDIX B. INPUT DATA

Haida Gwaii

```
#JSC: Data updating was finalized Jul 16, 2013.
## ________________________
## ____Model Dimensions____
1951            #first year of data
2013            #last year of data
2                       #age of youngest age class
10                      #age of plus group
5                       #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1      1       1       0       0
0.000   0.951   0.049   0       0               #20-year average catch values (2012)
## NEW: Catch type
## 1 = biomass
## 2 = catch in numbers
## 3 = roe removed (expressed as tons of spawning biomass equivalents)
1   1   1   1   1
## ________________________
## ________________________
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to)  (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage)-input maturity vector
0.24974 0.90 1 1 1 1 1 1
## ________________________
#Time series data
#Observed catch (1951-2013, 1000s metric t)
#Year P1 P2 P3 S1 S2
1951    2.847   0       0       0       0
1952    10.147  0       0       0       0
1953    0       0       0       0       0
1954    1.786   0       0       0       0
1955    0.498   0       0       0       0
1956    77.461  0       0       0       0
1957    21.803  0       0       0       0
1958    11.147  0       0       0       0
1959    6.828   0       0       0       0
1960    0       0       0       0       0
1961    0.576   0       0       0       0
1962    7.632   0       0       0       0
1963    14.705  0       0       0       0
1964    28.772  0       0       0       0
1965    35.448  0       0       0       0
1966    2.746   0       0       0       0
1967    0.213   0       0       0       0
```

1968	0.080	0	0	0	0
1969	0	0	0	0	0
1970	0	0	0	0	0
1971	0.102	0	0	0	0
1972	0.849	3.124	0	0	0
1973	0	7.520	0	0	0
1974	0	6.191	0.127	0	0
1975	0.017	7.602	0.105	0	0
1976	0.374	11.939	1.802	0	0
1977	0.021	11.125	1.489	0	0
1978	0	9.172	2.553	0	0
1979	0.0503	5.817	2.086	0	0
1980	0	2.106	1.210	0	0
1981	0.043	3.884	1.705	0	0
1982	0.018	2.353	1.407	0	0
1983	0.067	4.601	0.929	0	0
1984	0.096	4.016	0.535	0	0
1985	0.044	4.571	1.493	0	0
1986	0	2.613	0.890	0	0
1987	0.033	2.028	0	0	0
1988	0.032	0	0	0	0
1989	0.042	1.419	0	0	0
1990	0.008	5.534	1.170	0	0
1991	0.001	3.898	0.543	0	0
1992	0	2.524	0	0	0
1993	0	2.699	0.0003	0	0
1994	0	0.299	0	0	0
1995	0	0	0	0	0
1996	0	0	0	0	0
1997	0	0	0	0	0
1998	0	1.371	0	0	0
1999	0	2.493	0.485	0	0
2000	0	1.765	0	0	0
2001	0	0	0	0	0
2002	0	0.706	0	0	0
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0

#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37 26
#survey type
1 = survey is proportional to vulnerable numbers
2 = survey is proportional to vulnerable biomass
3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3

#iyr	it	gear	wt	survey timing
1951	4.213	4	1	1
1952	2.578	4	1	1
1953	7.555	4	1	1
1954	12.408	4	1	1
1955	6.437	4	1	1
1956	6.042	4	1	1
1957	1.592	4	1	1
1958	0.815	4	1	1
1959	8.981	4	1	1
1960	6.599	4	1	1
1961	8.981	4	1	1
1962	5.730	4	1	1
1963	7.297	4	1	1
1964	4.104	4	1	1
1965	1.378	4	1	1
1966	2.824	4	1	1
1967	0.710	4	1	1
1968	0.833	4	1	1
1969	2.075	4	1	1
1970	5.552	4	1	1
1971	13.291	4	1	1
1972	9.542	4	1	1
1973	7.960	4	1	1
1974	14.510	4	1	1
1975	9.686	4	1	1
1976	15.986	4	1	1
1977	15.717	4	1	1
1978	16.885	4	1	1
1979	12.236	4	1	1
1980	30.455	4	1	1
1981	18.823	4	1	1
1982	22.159	4	1	1
1983	19.470	4	1	1
1984	22.120	4	1	1
1985	17.232	4	1	1
1986	5.679	4	1	1
1987	10.751	4	1	1
1988	13.631	5	1.1666	1
1989	23.638	5	1.1666	1
1990	25.404	5	1.1666	1
1991	16.204	5	1.1666	1
1992	11.068	5	1.1666	1
1993	6.462	5	1.1666	1
1994	12.807	5	1.1666	1
1995	4.701	5	1.1666	1
1996	7.374	5	1.1666	1
1997	10.778	5	1.1666	1
1998	20.681	5	1.1666	1
1999	9.472	5	1.1666	1
2000	5.341	5	1.1666	1
2001	13.859	5	1.1666	1
2002	2.286	5	1.1666	1
2003	8.089	5	1.1666	1
2004	5.387	5	1.1666	1
2005	4.067	5	1.1666	1

2006	4.097	5	1.1666	1
2007	9.585	5	1.1666	1
2008	4.845	5	1.1666	1
2009	9.944	5	1.1666	1
2010	6.962	5	1.1666	1
2011	7.707	5	1.1666	1
2012	12.283	5	1.1666	1
2013	16.304	5	1.1666	1

#Age composition data by year, gear (ages 2-15+)

#na_gears

3

#na_nobs

11 42 15

#a_sage

2 2 2

#a_page

10 10 10

#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.

1951	1	1	226	781	226	170	62	9	1	0
1952	1	381	485	760	479	92	25	2	0	0
1956	1	2	216	130	838	113	37	10	0	2
1957	1	983	1142	746	454	1265	116	21	6	0
1958	1	2324	466	35	5	4	4	0	0	0
1959	1	1	60	27	7	0	0	0	0	0
1962	1	13	161	177	41	28	7	1	0	0
1963	1	3	402	218	146	17	16	0	1	1
1964	1	5	81	314	94	28	6	0	0	0
1965	1	17	840	116	46	22	10	2	0	0
1984	1	11	68	4	8	16	73	4	1	1
1972	2	36	386	454	190	72	29	11	5	1
1973	2	3	700	372	471	138	29	13	0	0
1974	2	2	493	653	286	147	30	5	1	0
1975	2	38	1521	2056	1677	573	117	22	6	0
1976	2	18	116	1557	1225	948	263	40	3	0
1977	2	3	630	258	947	739	486	144	13	0
1978	2	2	323	214	117	323	174	65	12	4
1979	2	57	45	322	191	217	154	29	4	1
1980	2	17	2821	151	182	94	64	39	19	3
1981	2	9	175	4201	267	151	90	35	9	6
1982	2	30	166	160	3075	87	59	36	19	5
1983	2	96	103	69	135	1434	77	31	18	5
1984	2	72	1148	152	90	331	1358	34	11	5
1985	2	47	531	1132	144	160	404	1119	16	3
1986	2	109	135	1041	1902	191	155	380	905	15
1987	2	57	342	192	799	1239	126	142	190	194
1988	2	61	855	126	80	197	249	23	28	57
1989	2	175	625	2364	143	56	139	99	22	37
1990	2	11	487	918	3033	199	93	193	86	33
1991	2	227	140	361	972	1303	125	61	135	63
1992	2	23	1243	159	270	402	992	77	19	43
1993	2	12	128	2240	165	225	448	436	43	15
1994	2	75	52	61	590	129	133	132	39	8
1995	2	119	96	12	24	193	49	40	26	12
1996	2	351	560	92	35	43	165	26	12	4
1997	2	465	435	550	86	25	73	88	14	6
1998	2	7	1356	710	293	70	18	32	28	9

1999	2	86	53	1446	381	178	58	16	10	13
2000	2	183	415	85	1271	171	97	9	10	4
2001	2	199	302	209	48	201	32	14	2	1
2002	2	785	664	647	329	81	342	40	13	2
2003	2	2	1484	372	123	72	25	48	10	3
2004	2	394	43	442	77	32	22	11	5	3
2005	2	17	606	205	374	51	31	16	6	3
2006	2	139	72	318	70	111	21	3	0	2
2007	2	6	247	78	114	32	56	12	1	0
2008	2	86	66	553	65	75	17	15	0	1
2009	2	1	645	76	222	20	29	4	5	1
2010	2	92	95	658	62	171	19	15	3	2
2011	2	21	521	90	370	65	100	9	4	0
2012	2	137	117	284	27	132	12	22	2	2
2013	2	0	739	136	140	21	45	6	4	0
1974	3	0	9	76	40	26	5	0	0	1
1975	3	0	0	9	16	12	2	1	0	0
1976	3	0	0	1	29	81	19	3	0	0
1978	3	0	1	8	19	32	65	33	6	1
1979	3	0	0	50	50	50	40	7	1	1
1980	3	0	35	42	376	195	209	65	15	1
1981	3	0	2	677	75	85	44	17	5	0
1982	3	0	1	18	464	18	14	6	4	1
1983	3	0	0	10	21	665	23	19	5	4
1984	3	0	11	5	18	35	313	7	1	1
1985	3	0	0	22	3	6	16	96	1	0
1986	3	0	0	48	205	22	21	42	65	2
1990	3	0	2	36	189	44	37	74	37	14
1991	3	0	0	10	85	175	36	27	41	20
1999	3	0	4	185	137	175	60	16	8	16

#n_wt_obs
63
#Mean weight-at-age in kilograms (see "input data 2013.xls")

#A$yr	V1	V2	V3	V4	V5	V6	V7	V8	V9
1951	0.058	0.0673	0.0849	0.0986	0.114	0.1257	0.1419	0.096	0.184
1952	0.0386	0.0764	0.1009	0.1161	0.1364	0.1524	0.143	0.1513	0.184
1953	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1954	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1955	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1956	0.043	0.0878	0.1099	0.1211	0.1474	0.1604	0.1663	0.1513	0.184
1957	0.0413	0.0863	0.1191	0.1347	0.1433	0.1649	0.1661	0.185	0.184
1958	0.0461	0.0751	0.0995	0.1218	0.1475	0.1613	0.1736	0.1513	0.184
1959	0.062	0.088	0.0984	0.1171	0.1501	0.1632	0.1736	0.1513	0.184
1960	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1961	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1962	0.056	0.0938	0.1235	0.1414	0.1534	0.1765	0.168	0.1513	0.184
1963	0.058	0.0879	0.1185	0.1436	0.1659	0.1619	0.1736	0.173	0.184
1964	0.057	0.0917	0.1096	0.1347	0.1605	0.1827	0.1736	0.1513	0.184
1965	0.0565	0.0969	0.1128	0.1475	0.1822	0.183	0.2565	0.1513	0.184
1966	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1967	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1968	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1969	0.0517	0.0851	0.1077	0.1277	0.1501	0.1632	0.1736	0.1513	0.184
1970	0.0668	0.0986	0.1273	0.1513	0.1734	0.1897	0.2035	0.2158	0.2135
1971	0.0668	0.0986	0.1273	0.1513	0.1734	0.1897	0.2035	0.2158	0.2135
1972	0.059	0.1067	0.1505	0.1709	0.2125	0.231	0.2425	0.2496	0.25

1973	0.0733	0.099	0.145	0.1799	0.2128	0.2357	0.2395	0.2158	0.2135
1974	0.1095	0.0885	0.1266	0.1553	0.1913	0.2129	0.2438	0.254	0.2135
1975	0.0589	0.0869	0.1197	0.1558	0.1885	0.2062	0.2086	0.2295	0.2135
1976	0.0628	0.0995	0.1237	0.1523	0.1846	0.2073	0.2369	0.2397	0.2135
1977	0.054	0.1055	0.1335	0.1503	0.177	0.2023	0.2176	0.2428	0.2135
1978	0.0695	0.0964	0.1305	0.1551	0.1697	0.1887	0.2072	0.237	0.2655
1979	0.0593	0.1044	0.13	0.1604	0.173	0.1891	0.2105	0.2028	0.2135
1980	0.0616	0.084	0.1054	0.1478	0.1742	0.1881	0.1983	0.2257	0.2263
1981	0.0636	0.0976	0.1135	0.1321	0.1604	0.1773	0.1838	0.1952	0.1953
1982	0.0639	0.1025	0.1198	0.1283	0.1416	0.1655	0.1743	0.1927	0.203
1983	0.0688	0.0981	0.1249	0.1409	0.1546	0.1666	0.1788	0.2003	0.202
1984	0.0642	0.0936	0.1155	0.1355	0.1411	0.1519	0.172	0.1842	0.1953
1985	0.0622	0.1012	0.1276	0.1468	0.1611	0.1657	0.1858	0.2057	0.193
1986	0.0773	0.1168	0.1409	0.1589	0.1712	0.1804	0.1882	0.2023	0.2258
1987	0.0667	0.1066	0.1318	0.1511	0.1676	0.1742	0.1798	0.1882	0.1991
1988	0.061	0.089	0.1249	0.15	0.1658	0.1817	0.1916	0.2032	0.1937
1989	0.062	0.0928	0.119	0.1451	0.1589	0.1781	0.1923	0.1932	0.2033
1990	0.0661	0.0977	0.1159	0.139	0.1537	0.1668	0.1838	0.1926	0.1804
1991	0.0607	0.0849	0.1131	0.1273	0.1419	0.1564	0.1633	0.1765	0.1809
1992	0.0586	0.0949	0.12	0.1431	0.1477	0.1745	0.1789	0.1742	0.191
1993	0.0771	0.1009	0.1155	0.1281	0.1476	0.1534	0.161	0.1828	0.181
1994	0.0692	0.0943	0.1191	0.125	0.138	0.1482	0.1469	0.155	0.1846
1995	0.0626	0.0972	0.1349	0.1398	0.1519	0.1595	0.1823	0.1758	0.186
1996	0.0552	0.0896	0.1103	0.1308	0.139	0.1512	0.153	0.1603	0.1325
1997	0.0591	0.0877	0.1053	0.1217	0.151	0.152	0.1605	0.1632	0.171
1998	0.0621	0.0803	0.0841	0.1091	0.1204	0.136	0.1397	0.1478	0.1504
1999	0.0573	0.0888	0.1032	0.1106	0.1275	0.137	0.1483	0.1413	0.1701
2000	0.0589	0.0818	0.0969	0.1145	0.1288	0.1366	0.1443	0.1428	0.1577
2001	0.0575	0.0804	0.0999	0.1149	0.1311	0.1422	0.1605	0.167	0.211
2002	0.0556	0.0799	0.0998	0.1172	0.1281	0.1392	0.1501	0.1638	0.159
2003	0.0485	0.0845	0.1109	0.1226	0.1457	0.1559	0.1673	0.1549	0.1787
2004	0.0529	0.0597	0.1031	0.1121	0.1358	0.1375	0.1473	0.166	0.1705
2005	0.0548	0.0789	0.0824	0.1147	0.122	0.1438	0.1468	0.1618	0.1463
2006	0.0506	0.0679	0.0858	0.0956	0.1112	0.1168	0.139	0.1599	0.141
2007	0.061	0.0775	0.0826	0.1075	0.1143	0.1336	0.1312	0.105	0.1684
2008	0.0484	0.0686	0.089	0.0948	0.1124	0.1139	0.1367	0.1599	0.132
2009	0.039	0.0672	0.0848	0.102	0.0995	0.118	0.1148	0.1342	0.144
2010	0.0538	0.0746	0.0925	0.1099	0.125	0.1271	0.1622	0.139	0.166
2011	0.0536	0.0697	0.0803	0.0985	0.1116	0.1206	0.1287	0.1288	0.15
2012	0.0495	0.0784	0.0915	0.1017	0.1156	0.1233	0.1177	0.1605	0.138
2013	0.0498	0.0789	0.1099	0.1161	0.1159	0.1255	0.1432	0.1353	0.1410

#eof
999

Prince Rupert District

#JSC: Data updating was finalized Jul 18, 2013.
____
____Model Dimensions____
1951 #first year of data
2013 #last year of data
2 #age of youngest age class
10 #age of plus group
5 #number of gears (ngear)
flags for fishery (1) or survey (0) in ngears
#1 1 1 0 0

```
0.000   0.301   0.699   0       0               #20-year average catch values (2012)
#0.00137145     0.2850014       0.71362715      0  0            #20-year average catch values (2011)
#0.04   0.32    0.64    0       0                               #2011/12 IFMP allocation
## NEW: Catch type
## 1 = biomass
## 2 = catch in numbers
## 3 = roe removed (expressed as tons of spawning biomass equivalents)
1    1    1    1    1
## ________________________
## ________________________
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to)  (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage)-input maturity vector
0.24974 0.90 1 1 1 1 1 1 1
## ________________________
#Time series data
#Observed catch (1951-2013, 1000s metric t)
#Year P1 P2 P3 S1 S2
1951    45.865  0       0       0       0
1952    52.379  0       0       0       0
1953    1.865   0       0       0       0
1954    27.277  0       0       0       0
1955    17.806  0       0       0       0
1956    10.182  0       0       0       0
1957    28.035  0       0       0       0
1958    4.523   0       0       0       0
1959    10.224  0       0       0       0
1960    18.476  0       0       0       0
1961    42.746  0       0       0       0
1962    27.660  0       0       0       0
1963    40.228  0       0       0       0
1964    29.930  0       0       0       0
1965    44.211  0       0       0       0
1966    17.295  0       0       0       0
1967    7.998   0       0       0       0
1968    2.068   0       0       0       0
1969    0.000   0       0       0       0
1970    1.330   0       0       0       0
1971    3.500   0       0       0       0
1972    0.877   3.613   0.004   0       0
1973    0.218   1.388   0.000   0       0
1974    0.182   2.122   1.515   0       0
1975    0.155   1.536   0.011   0       0
1976    0.564   3.466   0.276   0       0
1977    0.792   5.856   1.494   0       0
1978    3.519   2.038   3.031   0       0
1979    1.810   1.271   1.236   0       0
1980    0.738   1.641   1.046   0       0
1981    1.682   1.051   0.356   0       0
```

1982	1.815	0.170	0.000	0	0
1983	0.000	0.000	0.000	0	0
1984	0.173	1.653	1.880	0	0
1985	0.253	3.018	3.476	0	0
1986	0.375	3.732	4.573	0	0
1987	0.122	2.077	4.071	0	0
1988	0.079	3.550	4.340	0	0
1989	0.071	3.657	4.745	0	0
1990	0.043	2.285	2.361	0	0
1991	0.019	1.348	2.143	0	0
1992	0.142	1.238	3.797	0	0
1993	0.008	2.200	4.112	0	0
1994	0	2.363	2.324	0	0
1995	0	0.706	1.355	0	0
1996	0	0	3.086	0	0
1997	0	0	5.541	0	0
1998	0	0	3.217	0	0
1999	0	0.256	1.859	0	0
2000	0	1.239	3.076	0	0
2001	0	1.012	1.906	0	0
2002	0.001	2.061	2.432	0	0
2003	0.005	1.446	2.562	0	0
2004	0.011	1.909	2.192	0	0
2005	0	1.750	2.050	0	0
2006	0	0.957	1.661	0	0
2007	0	0.000	0.969	0	0
2008	0	0.513	1.148	0	0
2009	0	0.713	1.286	0	0
2010	0	0.475	1.010	0	0
2011	0	0.883	1.264	0	0
2012	0	0.466	0.917	0	0
2013	0	0.743	1.284	0	0

#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37 26
#survey type
1 = survey is proportional to vulnerable numbers
2 = survey is proportional to vulnerable biomass
3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3

#iyr	it	gear	wt	survey timing
1951	27.149	4	1	1
1952	24.047	4	1	1
1953	28.468	4	1	1
1954	13.535	4	1	1
1955	14.482	4	1	1
1956	14.533	4	1	1
1957	27.518	4	1	1
1958	9.882	4	1	1
1959	40.961	4	1	1
1960	16.545	4	1	1
1961	12.059	4	1	1
1962	26.329	4	1	1
1963	16.981	4	1	1

1964	26.919	4	1	1
1965	6.055	4	1	1
1966	7.105	4	1	1
1967	3.386	4	1	1
1968	5.197	4	1	1
1969	0.965	4	1	1
1970	8.814	4	1	1
1971	8.480	4	1	1
1972	8.774	4	1	1
1973	10.959	4	1	1
1974	9.244	4	1	1
1975	10.565	4	1	1
1976	15.199	4	1	1
1977	10.425	4	1	1
1978	4.734	4	1	1
1979	7.600	4	1	1
1980	11.001	4	1	1
1981	12.939	4	1	1
1982	16.108	4	1	1
1983	23.575	4	1	1
1984	25.702	4	1	1
1985	39.606	4	1	1
1986	25.580	4	1	1
1987	38.673	4	1	1
1988	33.957	5	1.1666	1
1989	14.876	5	1.1666	1
1990	21.177	5	1.1666	1
1991	24.305	5	1.1666	1
1992	38.585	5	1.1666	1
1993	23.328	5	1.1666	1
1994	14.683	5	1.1666	1
1995	16.879	5	1.1666	1
1996	22.664	5	1.1666	1
1997	23.565	5	1.1666	1
1998	17.997	5	1.1666	1
1999	27.742	5	1.1666	1
2000	17.943	5	1.1666	1
2001	35.070	5	1.1666	1
2002	20.503	5	1.1666	1
2003	37.248	5	1.1666	1
2004	33.275	5	1.1666	1
2005	30.184	5	1.1666	1
2006	11.003	5	1.1666	1
2007	16.826	5	1.1666	1
2008	13.882	5	1.1666	1
2009	13.073	5	1.1666	1
2010	31.134	5	1.1666	1
2011	22.591	5	1.1666	1
2012	24.793	5	1.1666	1
2013	26.981	5	1.1666	1

#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
27 42 38 #use me for 2013
#a_sage

2 2 2
#a_page
10 10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.

1951	1	203	852	2739	486	263	124	12	2	1
1952	1	282	522	1994	2679	364	61	18	2	0
1953	1	17	541	327	361	158	14	1	0	0
1954	1	56	753	772	638	351	69	16	1	0
1955	1	31	55	795	177	59	12	2	0	0
1956	1	169	978	160	319	43	9	3	2	0
1957	1	397	666	1767	817	658	78	19	2	0
1958	1	388	302	78	106	17	20	0	0	0
1959	1	54	1000	785	216	205	53	39	5	0
1960	1	2067	263	1186	374	174	106	28	8	0
1961	1	419	2508	313	774	187	69	25	5	0
1962	1	53	535	789	119	171	55	17	8	5
1963	1	1342	454	621	753	123	101	17	2	2
1964	1	126	2208	344	372	301	24	20	4	1
1965	1	201	457	1723	365	401	345	70	18	7
1966	1	0	23	93	102	71	83	42	14	7
1973	1	35	73	12	20	7	4	2	0	0
1975	1	1	9	13	37	12	10	2	2	0
1976	1	0	8	11	16	27	29	57	14	0
1977	1	2	120	80	117	85	55	38	12	2
1978	1	12	90	247	140	130	101	48	15	9
1979	1	11	72	76	182	144	121	62	34	17
1980	1	13	673	67	82	78	61	44	20	11
1981	1	30	238	1623	294	302	260	123	64	33
1982	1	7	144	280	520	130	78	44	22	7
1984	1	9	168	76	75	50	97	15	1	2
1985	1	97	52	163	178	74	34	26	5	2
1972	2	0	38	128	460	42	27	17	1	1
1973	2	2	263	35	242	212	27	10	6	0
1974	2	1	113	336	47	104	28	2	1	0
1975	2	172	366	690	1329	345	299	77	18	5
1976	2	0	6	49	226	357	52	17	6	0
1977	2	1	210	49	297	495	197	43	12	6
1978	2	9	93	261	76	168	162	19	5	2
1979	2	26	177	115	303	115	183	64	15	8
1980	2	18	2228	205	145	110	99	36	11	3
1981	2	15	367	2670	110	56	49	12	5	2
1982	2	100	296	115	1025	44	21	6	3	0
1983	2	437	1016	822	242	2256	171	52	27	10
1984	2	15	1071	420	303	431	695	29	9	3
1985	2	127	311	2124	477	246	410	314	6	6
1986	2	99	778	534	2616	611	298	401	313	5
1987	2	42	1865	485	326	1420	280	165	136	60
1988	2	19	1306	1646	251	352	488	82	61	16
1989	2	22	784	1307	1001	178	162	129	23	10
1990	2	33	920	1143	1431	1040	203	168	109	21
1991	2	113	1990	391	519	649	391	68	36	48
1992	2	15	1699	1587	251	228	287	146	26	26
1993	2	5	432	1783	1216	162	177	175	63	14
1994	2	44	325	885	3246	1487	276	248	96	36
1995	2	140	673	297	495	1898	692	107	56	35
1996	2	21	1438	213	63	100	249	120	8	6

1997	2	30	502	1322	197	67	126	116	48	6
1998	2	4	702	465	768	94	30	23	27	3
1999	2	17	95	706	350	425	76	18	15	18
2000	2	75	1101	374	1114	492	641	89	20	17
2001	2	79	1354	848	229	681	307	253	38	6
2002	2	227	820	1467	817	184	416	163	80	13
2003	2	11	2185	493	585	309	88	126	46	22
2004	2	22	50	1663	268	236	97	19	28	3
2005	2	20	768	241	1187	241	153	57	13	13
2006	2	29	327	887	176	460	78	32	9	3
2007	2	27	355	161	78	22	72	9	7	1
2008	2	62	522	1882	412	280	56	130	28	9
2009	2	11	783	657	1607	269	184	41	53	3
2010	2	31	1030	866	364	653	100	52	10	13
2011	2	15	1160	1015	515	204	285	48	19	6
2012	2	97	301	1452	717	312	164	123	13	4
2013	2	19	1136	476	586	314	88	60	25	1
1974	3	0	1	41	22	36	3	1	0	0
1975	3	0	0	15	28	4	0	0	0	0
1976	3	0	0	9	33	13	2	0	0	0
1977	3	0	3	6	56	152	41	19	4	0
1978	3	0	0	31	9	49	50	10	2	0
1979	3	3	3	21	108	41	58	21	5	1
1980	3	0	17	43	154	110	104	45	17	3
1981	3	0	2	166	66	98	63	24	8	0
1984	3	0	5	10	65	108	290	17	6	4
1985	3	0	2	90	82	87	120	164	2	3
1986	3	0	5	55	686	242	111	99	73	3
1987	3	0	10	53	122	973	283	155	105	60
1988	3	0	3	46	51	153	318	83	36	20
1989	3	0	0	22	145	65	112	104	16	12
1990	3	0	0	34	116	231	56	63	33	11
1991	3	0	0	39	171	288	287	61	40	30
1992	3	0	3	112	80	195	225	164	34	43
1993	3	0	0	62	302	71	138	99	61	12
1994	3	0	0	24	160	434	110	101	54	16
1995	3	0	1	10	144	295	334	35	16	13
1996	3	0	4	21	29	132	167	135	16	7
1997	3	0	1	123	73	88	128	130	70	18
1998	3	0	7	33	466	222	107	122	76	49
1999	3	0	0	78	119	357	97	33	14	23
2000	3	0	1	17	187	166	342	76	9	13
2001	3	0	3	58	97	337	215	266	55	9
2002	3	0	1	62	178	103	241	139	135	20
2003	3	0	3	40	323	226	92	107	46	33
2004	3	0	1	244	151	412	172	55	53	29
2005	3	0	0	6	350	136	195	44	10	13
2006	3	0	0	14	36	303	77	69	7	0
2007	3	1	11	40	208	108	630	150	65	15
2008	3	0	1	126	102	224	108	519	77	40
2009	3	0	1	20	406	187	144	53	92	11
2010	3	0	0	19	72	492	145	78	31	30
2011	3	0	2	49	138	282	601	108	45	19
2012	3	0	0	35	110	150	225	370	54	28
2013	3	1	47	18	209	242	100	102	54	9

#n_wt_obs

63

#Mean weight-at-age in kilograms (see "input data 2013.xls")

#A$yr	V1	V2	V3	V4	V5	V6	V7	V8	V9
1951	0.0383	0.0737	0.094	0.1128	0.1229	0.1316	0.142	0.138	0.132
1952	0.0467	0.0838	0.1158	0.1308	0.1496	0.1657	0.1672	0.2215	0.17
1953	0.0388	0.0803	0.1108	0.1307	0.1433	0.1572	0.169	0.1871	0.17
1954	0.0405	0.0724	0.1057	0.1308	0.1453	0.1617	0.1826	0.193	0.17
1955	0.0458	0.0808	0.1013	0.1215	0.1429	0.1593	0.154	0.1871	0.17
1956	0.0373	0.0764	0.0944	0.1136	0.1405	0.1518	0.17	0.199	0.17
1957	0.0287	0.0752	0.1041	0.1225	0.1368	0.1654	0.1887	0.2	0.17
1958	0.0348	0.0758	0.1216	0.1414	0.1393	0.1679	0.169	0.1871	0.17
1959	0.0436	0.0857	0.1022	0.1205	0.1494	0.1547	0.1659	0.148	0.17
1960	0.038	0.0674	0.1038	0.1211	0.1396	0.1545	0.1689	0.17	0.17
1961	0.0395	0.074	0.1074	0.1306	0.1443	0.1594	0.1554	0.193	0.17
1962	0.0439	0.0791	0.1086	0.1388	0.1641	0.1797	0.1807	0.202	0.17
1963	0.0393	0.0662	0.1042	0.1281	0.1545	0.1664	0.1902	0.225	0.17
1964	0.0442	0.0724	0.0932	0.1224	0.1333	0.159	0.152	0.156	0.148
1965	0.0527	0.0983	0.1143	0.14	0.1566	0.1637	0.1797	0.2001	0.23
1966	0.0408	0.0774	0.1054	0.127	0.1442	0.1599	0.169	0.1871	0.17
1967	0.0408	0.0774	0.1054	0.127	0.1442	0.1599	0.169	0.1871	0.17
1968	0.0408	0.0774	0.1054	0.127	0.1442	0.1599	0.169	0.1871	0.17
1969	0.0408	0.0774	0.1054	0.127	0.1442	0.1599	0.169	0.1871	0.17
1970	0.0485	0.0831	0.1134	0.1382	0.1571	0.1734	0.1836	0.1913	0.2042
1971	0.0362	0.0688	0.1104	0.1317	0.1445	0.1766	0.172	0.102	0.2042
1972	0.0485	0.1004	0.137	0.1628	0.1991	0.2247	0.2331	0.249	0.259
1973	0.0326	0.0826	0.1172	0.1641	0.1791	0.1976	0.2103	0.2158	0.2042
1974	0.067	0.0863	0.1212	0.1655	0.1845	0.1947	0.204	0.175	0.2042
1975	0.0288	0.0658	0.1138	0.1375	0.1648	0.1673	0.1827	0.1786	0.2063
1976	0.0485	0.0887	0.1325	0.1583	0.1734	0.2029	0.2106	0.227	0.2042
1977	0.054	0.0862	0.1178	0.151	0.1688	0.1838	0.1955	0.1956	0.2242
1978	0.0554	0.0984	0.1249	0.1491	0.1701	0.1856	0.2022	0.2323	0.2304
1979	0.0566	0.0966	0.1289	0.1483	0.1661	0.1844	0.1911	0.2136	0.2129
1980	0.0609	0.0807	0.1165	0.1471	0.1697	0.1792	0.1879	0.2094	0.2241
1981	0.0452	0.0811	0.0999	0.1306	0.1551	0.1692	0.1827	0.2014	0.2028
1982	0.0421	0.0775	0.1083	0.1162	0.1483	0.1703	0.1778	0.1833	0.1978
1983	0.0556	0.0795	0.1042	0.1222	0.1349	0.1536	0.1697	0.1914	0.1961
1984	0.0457	0.0752	0.0897	0.1112	0.1237	0.1351	0.1568	0.1769	0.187
1985	0.0356	0.0787	0.0975	0.1095	0.1219	0.1336	0.149	0.1766	0.159
1986	0.0555	0.0919	0.1185	0.1369	0.1472	0.1578	0.1685	0.1795	0.1963
1987	0.0549	0.0835	0.107	0.1283	0.1418	0.1526	0.1596	0.1719	0.1746
1988	0.0507	0.0742	0.0967	0.1165	0.1351	0.1514	0.1519	0.1642	0.1887
1989	0.0565	0.0751	0.0964	0.1156	0.1361	0.1471	0.1659	0.1596	0.1906
1990	0.0504	0.089	0.1078	0.1222	0.1379	0.1524	0.1655	0.1763	0.185
1991	0.0548	0.0763	0.1056	0.1205	0.129	0.1413	0.1483	0.1601	0.1711
1992	0.047	0.0764	0.0935	0.1201	0.1334	0.1405	0.1486	0.1671	0.1732
1993	0.0538	0.0767	0.0964	0.1093	0.1264	0.1367	0.1417	0.1514	0.1543
1994	0.0425	0.0717	0.0935	0.1061	0.116	0.134	0.1375	0.1413	0.1594
1995	0.048	0.0741	0.092	0.1123	0.1207	0.1309	0.1487	0.1577	0.1589
1996	0.0524	0.0723	0.0947	0.1111	0.129	0.1343	0.1429	0.1485	0.1608
1997	0.0565	0.0677	0.0839	0.1039	0.119	0.1308	0.1377	0.1454	0.1496
1998	0.0448	0.067	0.0799	0.0924	0.1018	0.1204	0.1303	0.1462	0.1505
1999	0.0579	0.0791	0.0956	0.104	0.1155	0.1189	0.1363	0.139	0.1443
2000	0.0465	0.0695	0.0852	0.1042	0.1099	0.1185	0.1303	0.1308	0.1416
2001	0.0424	0.0674	0.0917	0.1051	0.1245	0.1264	0.1368	0.1376	0.1513
2002	0.0466	0.066	0.0847	0.1047	0.1176	0.1287	0.1334	0.1476	0.1532
2003	0.0505	0.0701	0.0853	0.1096	0.1262	0.14	0.1457	0.1521	0.1588

```
2004	0.05	0.0649	0.0865	0.1003	0.1148	0.1312	0.1432	0.1524	0.134
2005	0.0382	0.0644	0.0709	0.1	0.1059	0.1194	0.1376	0.1392	0.147
2006	0.0479	0.0631	0.0796	0.0908	0.1097	0.1213	0.1309	0.1434	0.1205
2007	0.0399	0.0581	0.0702	0.0902	0.1069	0.1104	0.1196	0.1274	0.144
2008	0.0442	0.058	0.0816	0.0947	0.1078	0.1175	0.1316	0.1323	0.1516
2009	0.0322	0.0725	0.0823	0.1017	0.1134	0.1198	0.1292	0.1374	0.154
2010	0.0449	0.0661	0.0869	0.0985	0.1121	0.118	0.1266	0.1068	0.1464
2011	0.0402	0.0687	0.0817	0.1015	0.1111	0.1254	0.1377	0.1447	0.1383
2012	0.0541	0.0604	0.0809	0.0906	0.1019	0.1126	0.1183	0.1365	0.1263
2013	0.0360	0.0753	0.0814	0.1053	0.1171	0.1283	0.1331	0.1427	0.1420
#eof
999
```

Central Coast

```
#JSC: Data updating was finalized Jul 16, 2013.
## ________________________
## ____Model Dimensions____
1951		#first year of data
2013		#last year of data
2			#age of youngest age class
10			#age of plus group
5			#number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1	1	1	0	0
0.000	0.875	0.125	0	0	#20-year average catch values (2012)
#0.00065774	0.90120814	0.09813412	0  0	##20-year average catch values (2011)
## NEW: Catch type
## 1 = biomass
## 2 = catch in numbers
## 3 = roe removed (expressed as tons of spawning biomass equivalents)
1	1	1	1	1
## ________________________
## ________________________
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to)  (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage)-input maturity vector
0.24974 0.90 1 1 1 1 1 1 1
## ________________________
#Time series data
#Observed catch (1951-2013, 1000s metric t)
#Year P1 P2 P3 S1 S2
1951	42.458	0	0	0	0
1952	33.195	0	0	0	0
1953	0.768	0	0	0	0
1954	24.616	0	0	0	0
1955	11.594	0	0	0	0
1956	43.627	0	0	0	0
1957	23.261	0	0	0	0
```

1958	9.849	0	0	0	0
1959	27.870	0	0	0	0
1960	4.037	0	0	0	0
1961	31.704	0	0	0	0
1962	15.709	0	0	0	0
1963	44.054	0	0	0	0
1964	31.895	0	0	0	0
1965	15.670	0	0	0	0
1966	37.482	0	0	0	0
1967	21.890	0	0	0	0
1968	1.528	0	0	0	0
1969	0	0	0	0	0
1970	0.209	0	0	0	0
1971	3.614	0	0	0	0
1972	0.388	8.755	0.137	0	0
1973	0.035	6.653	1.112	0	0
1974	0	3.621	5.267	0	0
1975	0	3.343	5.395	0	0
1976	0	6.198	6.213	0	0
1977	0.320	3.881	6.904	0	0
1978	0	4.769	9.277	0	0
1979	0.005	0	0	0	0
1980	0.010	0	0.528	0	0
1981	0.006	0.263	2.304	0	0
1982	0.041	2.258	4.071	0	0
1983	0	2.061	3.579	0	0
1984	0.002	3.588	3.582	0	0
1985	0	2.915	2.294	0	0
1986	0.038	2.173	1.176	0	0
1987	0	2.695	0.920	0	0
1988	0.028	3.529	0.970	0	0
1989	0	6.531	2.911	0	0
1990	0	5.305	3.046	0	0
1991	0	7.097	1.806	0	0
1992	0.088	7.163	1.111	0	0
1993	0	8.478	2.038	0	0
1994	0	9.757	2.122	0	0
1995	0	8.131	1.451	0	0
1996	0	3.897	0.402	0	0
1997	0	3.276	0.344	0	0
1998	0	7.976	0.646	0	0
1999	0	6.013	1.511	0	0
2000	0	6.394	0.972	0	0
2001	0	5.613	0.517	0	0
2002	0	2.894	0.399	0	0
2003	0	2.299	0.289	0	0
2004	0	2.988	0	0	0
2005	0	3.778	0	0	0
2006	0	3.072	0	0	0
2007	0	0.398	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0

```
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37              26
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3       3
#iyr    it gear wt      survey timing
1951    15.390  4       1       1
1952    10.295  4       1       1
1953    18.237  4       1       1
1954    13.967  4       1       1
1955    13.564  4       1       1
1956    6.626   4       1       1
1957    4.607   4       1       1
1958    3.549   4       1       1
1959    3.904   4       1       1
1960    12.615  4       1       1
1961    4.265   4       1       1
1962    11.948  4       1       1
1963    6.485   4       1       1
1964    6.464   4       1       1
1965    2.097   4       1       1
1966    1.863   4       1       1
1967    5.434   4       1       1
1968    5.790   4       1       1
1969    1.837   4       1       1
1970    8.230   4       1       1
1971    4.156   4       1       1
1972    3.572   4       1       1
1973    12.434  4       1       1
1974    8.852   4       1       1
1975    8.037   4       1       1
1976    13.849  4       1       1
1977    14.613  4       1       1
1978    7.747   4       1       1
1979    5.669   4       1       1
1980    12.957  4       1       1
1981    15.811  4       1       1
1982    16.238  4       1       1
1983    18.214  4       1       1
1984    13.788  4       1       1
1985    8.483   4       1       1
1986    20.056  4       1       1
1987    12.431  4       1       1
1988    26.467  5       1.1666  1
1989    21.098  5       1.1666  1
1990    28.551  5       1.1666  1
1991    18.429  5       1.1666  1
1992    42.594  5       1.1666  1
1993    31.717  5       1.1666  1
1994    28.790  5       1.1666  1
1995    21.343  5       1.1666  1
```

1996	20.344	5	1.1666	1
1997	27.016	5	1.1666	1
1998	29.738	5	1.1666	1
1999	30.208	5	1.1666	1
2000	30.810	5	1.1666	1
2001	24.334	5	1.1666	1
2002	20.318	5	1.1666	1
2003	26.320	5	1.1666	1
2004	30.612	5	1.1666	1
2005	25.714	5	1.1666	1
2006	9.813	5	1.1666	1
2007	10.086	5	1.1666	1
2008	4.566	5	1.1666	1
2009	11.710	5	1.1666	1
2010	9.339	5	1.1666	1
2011	11.392	5	1.1666	1
2012	8.173	5	1.1666	1
2013	21.879	5	1.1666	1

#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
16 41 31 #use me for 2013
#a_sage
2 2 2
#a_page
10 10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.

1951	1	129	1518	2693	638	269	66	3	0	0
1952	1	267	1035	1551	1966	232	79	23	2	1
1953	1	274	822	702	779	297	39	13	0	0
1954	1	126	2222	646	147	41	5	0	2	0
1955	1	156	181	1749	213	36	9	0	0	0
1956	1	853	688	465	2880	146	17	2	0	1
1957	1	785	2377	506	292	693	34	1	0	0
1958	1	880	2298	474	48	22	21	0	0	0
1959	1	189	2463	1835	403	40	22	21	1	0
1960	1	616	328	375	79	16	1	1	0	0
1961	1	450	902	302	831	282	26	3	2	1
1962	1	78	464	145	21	80	19	1	0	0
1963	1	4	329	630	59	31	32	2	0	0
1964	1	164	549	320	118	17	1	0	0	0
1965	1	143	637	591	277	95	6	1	0	0
1977	1	2	65	37	59	16	13	6	0	0
1972	2	80	548	508	472	127	80	21	1	0
1973	2	16	670	247	206	156	25	6	2	0
1974	2	44	281	613	313	212	105	15	4	0
1975	2	103	2932	2269	2477	764	283	60	6	2
1976	2	163	637	2234	1132	912	246	80	13	1
1977	2	17	435	565	793	414	213	48	10	1
1978	2	3	359	212	278	323	152	49	15	5
1980	2	97	1911	168	235	104	68	18	10	3
1981	2	85	392	2057	254	218	82	20	10	3
1982	2	59	548	376	2112	182	160	51	17	3
1983	2	29	381	840	589	3109	274	169	40	14
1984	2	274	460	637	1143	1016	2563	142	52	6

1985	2	143	1999	397	449	687	625	964	23	5
1986	2	322	963	2359	509	374	397	361	680	32
1987	2	518	1181	748	1629	295	231	294	236	291
1988	2	59	3528	606	326	370	87	76	78	64
1989	2	72	260	4300	517	202	158	42	45	46
1990	2	121	402	337	4920	508	257	200	50	52
1991	2	226	1348	480	440	3947	453	166	105	33
1992	2	146	4241	828	199	250	1362	155	44	39
1993	2	314	593	5600	846	175	221	912	98	41
1994	2	85	1538	620	3888	549	148	199	257	24
1995	2	98	575	2196	888	4538	599	191	216	165
1996	2	644	1072	319	907	375	1665	321	80	77
1997	2	146	3892	1161	249	422	274	583	106	38
1998	2	34	2372	2769	551	154	202	197	192	51
1999	2	36	431	2103	1676	319	81	105	95	65
2000	2	16	865	490	1572	1186	263	53	41	41
2001	2	107	335	1176	511	1129	816	181	37	28
2002	2	337	1849	569	956	333	1094	469	77	15
2003	2	21	2018	1059	326	378	173	312	114	24
2004	2	37	225	2085	542	112	147	75	70	18
2005	2	42	2311	1037	2101	566	125	112	60	40
2006	2	53	697	3226	573	958	197	44	31	8
2007	2	32	688	440	717	188	181	37	10	3
2008	2	224	162	659	184	246	44	43	8	2
2009	2	130	2104	308	238	67	63	8	10	2
2010	2	41	387	1597	133	189	51	52	2	6
2011	2	124	1359	427	671	85	63	18	16	4
2012	2	171	236	1082	267	373	53	35	11	7
2013	2	36	659	177	333	77	78	6	4	2
1972	3	0	3	49	214	35	26	2	0	0
1973	3	0	4	40	71	33	7	2	1	0
1974	3	0	2	113	187	123	61	9	1	0
1975	3	0	17	133	240	85	33	11	0	0
1976	3	0	10	230	364	431	144	37	5	1
1977	3	0	5	59	161	143	61	18	6	0
1978	3	0	14	96	318	410	190	41	5	1
1980	3	0	9	7	68	65	72	31	18	4
1981	3	4	23	779	209	236	163	84	28	10
1982	3	0	32	79	1016	89	79	31	10	1
1983	3	0	9	129	234	1245	90	70	11	5
1984	3	0	3	34	152	200	696	55	13	6
1985	3	0	41	70	121	251	290	492	13	10
1986	3	0	19	256	128	107	171	141	238	9
1987	3	0	8	76	440	115	77	97	80	88
1988	3	0	24	58	84	154	86	42	57	61
1989	3	0	2	196	178	123	117	41	26	27
1990	3	0	0	10	551	143	53	66	9	15
1991	3	0	3	14	41	417	60	44	19	5
1992	3	0	54	54	33	51	475	76	26	11
1993	3	0	2	342	112	44	45	211	17	8
1994	3	0	30	94	1287	237	69	83	135	16
1995	3	0	3	112	101	823	135	23	29	41
1996	3	0	2	8	102	65	306	59	12	12
1997	3	0	7	15	32	117	99	197	37	10
1998	3	0	5	149	142	90	183	164	217	81
1999	3	0	1	132	416	166	62	51	57	42

2000	3	0	3	14	277	285	71	11	6	18
2001	3	0	0	39	46	422	225	57	9	2
2002	3	0	3	30	105	38	237	83	7	1
2003	3	0	4	33	103	238	104	306	114	23

#n_wt_obs
63
#Mean weight-at-age in kilograms (see "input data 2013.xls")

#A$yr	V1	V2	V3	V4	V5	V6	V7	V8	V9
1951	0.048	0.0842	0.1138	0.1371	0.1465	0.1559	0.161	0.1352	0.18
1952	0.0466	0.0869	0.1121	0.1311	0.1476	0.1578	0.1636	0.173	0.18
1953	0.0358	0.0833	0.1078	0.1273	0.1474	0.1616	0.1699	0.1352	0.18
1954	0.026	0.0626	0.0937	0.1167	0.1378	0.133	0.1545	0.131	0.18
1955	0.038	0.0725	0.0966	0.1204	0.1429	0.1347	0.1545	0.1352	0.18
1956	0.0406	0.0834	0.1107	0.1269	0.1436	0.1581	0.122	0.1352	0.18
1957	0.04	0.0821	0.1082	0.1222	0.1322	0.1487	0.173	0.1352	0.18
1958	0.0374	0.0725	0.0956	0.1157	0.1282	0.1465	0.1545	0.1352	0.18
1959	0.0391	0.0774	0.0938	0.1098	0.1069	0.1316	0.1345	0.127	0.18
1960	0.0447	0.0639	0.081	0.1034	0.1078	0.147	0.124	0.1352	0.18
1961	0.0379	0.0771	0.0985	0.1206	0.1241	0.1317	0.1223	0.11	0.18
1962	0.047	0.0808	0.1074	0.1314	0.1436	0.1554	0.122	0.1352	0.18
1963	0.0598	0.0825	0.1035	0.1236	0.1425	0.1543	0.1655	0.1352	0.18
1964	0.0457	0.0858	0.108	0.1271	0.1282	0.154	0.1545	0.1352	0.18
1965	0.0525	0.1037	0.1271	0.1474	0.1675	0.1757	0.242	0.1352	0.18
1966	0.0426	0.0799	0.1039	0.124	0.1365	0.1497	0.1545	0.1352	0.18
1967	0.0426	0.0799	0.1039	0.124	0.1365	0.1497	0.1545	0.1352	0.18
1968	0.0426	0.0799	0.1039	0.124	0.1365	0.1497	0.1545	0.1352	0.18
1969	0.0426	0.0799	0.1039	0.124	0.1365	0.1497	0.1545	0.1352	0.18
1970	0.0559	0.0897	0.1165	0.1386	0.1573	0.1713	0.185	0.1978	0.2077
1971	0.0502	0.0934	0.1275	0.1576	0.1712	0.1819	0.176	0.178	0.2077
1972	0.0605	0.0945	0.1172	0.1418	0.1576	0.1654	0.1973	0.193	0.2077
1973	0.0594	0.0986	0.1312	0.156	0.173	0.1834	0.1972	0.234	0.2077
1974	0.0492	0.0869	0.1209	0.1416	0.1658	0.1788	0.1974	0.2167	0.2077
1975	0.0448	0.0836	0.1187	0.1444	0.1662	0.1862	0.1989	0.2037	0.2205
1976	0.0445	0.0814	0.1081	0.1356	0.1553	0.1754	0.1913	0.2004	0.21
1977	0.0598	0.0891	0.1164	0.1382	0.166	0.1839	0.1987	0.2219	0.225
1978	0.049	0.0856	0.1142	0.1338	0.1612	0.1864	0.216	0.2269	0.2442
1979	0.0832	0.1065	0.1286	0.1534	0.1755	0.1913	0.2116	0.235	0.2077
1980	0.0504	0.0815	0.0998	0.1244	0.144	0.1614	0.1688	0.1981	0.212
1981	0.0452	0.0749	0.099	0.1156	0.1338	0.15	0.1755	0.1747	0.204
1982	0.0521	0.088	0.1094	0.13	0.1392	0.1519	0.1683	0.1824	0.2077
1983	0.0614	0.0907	0.1107	0.1292	0.1424	0.1493	0.1567	0.1727	0.1855
1984	0.059	0.09	0.1082	0.1223	0.1352	0.1419	0.1556	0.1761	0.1782
1985	0.062	0.0951	0.1234	0.1399	0.1502	0.1653	0.1734	0.1753	0.2029
1986	0.0623	0.0989	0.1268	0.1422	0.1551	0.1667	0.1734	0.1802	0.1992
1987	0.0594	0.0918	0.1221	0.1491	0.1683	0.179	0.1845	0.1957	0.2077
1988	0.0541	0.0842	0.1143	0.139	0.1711	0.1844	0.1889	0.1957	0.2031
1989	0.0563	0.083	0.1032	0.1301	0.1465	0.1728	0.1797	0.1804	0.1936
1990	0.0572	0.0843	0.1065	0.1262	0.1476	0.1685	0.1787	0.1877	0.1916
1991	0.0577	0.0846	0.1062	0.1288	0.1447	0.165	0.1784	0.1868	0.1992
1992	0.05	0.086	0.1055	0.1236	0.1362	0.1511	0.1683	0.1874	0.1932
1993	0.0517	0.0858	0.1052	0.1201	0.133	0.1404	0.1538	0.1674	0.1716
1994	0.0476	0.0831	0.1066	0.1225	0.1339	0.1481	0.1581	0.163	0.175
1995	0.0478	0.0796	0.1057	0.1233	0.1348	0.1438	0.1522	0.1561	0.1624
1996	0.0607	0.0781	0.1025	0.1258	0.1397	0.1476	0.1581	0.1655	0.1617
1997	0.0456	0.0761	0.0888	0.1054	0.132	0.1432	0.1493	0.1596	0.1607
1998	0.0415	0.0716	0.0874	0.1006	0.1173	0.1404	0.1462	0.154	0.1629

1999	0.0538	0.0681	0.0902	0.1054	0.1138	0.1292	0.1478	0.1545	0.1582
2000	0.0514	0.0771	0.0881	0.1127	0.1268	0.1377	0.145	0.166	0.1756
2001	0.0445	0.0734	0.0974	0.1061	0.1255	0.1358	0.1468	0.1569	0.1631
2002	0.0512	0.067	0.0878	0.1084	0.1187	0.1295	0.1366	0.1414	0.1507
2003	0.0478	0.0773	0.0885	0.1111	0.1264	0.1371	0.1433	0.1508	0.1629
2004	0.0481	0.0696	0.0912	0.0962	0.1125	0.1248	0.1362	0.1365	0.1461
2005	0.0378	0.0675	0.0752	0.1062	0.1091	0.1259	0.136	0.1404	0.1521
2006	0.0388	0.0605	0.0786	0.0919	0.1106	0.1147	0.1281	0.1347	0.1447
2007	0.041	0.0651	0.075	0.0955	0.1025	0.1184	0.1202	0.1397	0.143
2008	0.043	0.0606	0.0757	0.0873	0.1034	0.1153	0.126	0.1344	0.167
2009	0.0405	0.0664	0.0727	0.0921	0.1035	0.1219	0.1346	0.1315	0.135
2010	0.0481	0.0667	0.0841	0.0928	0.1046	0.1034	0.1228	0.154	0.132
2011	0.0325	0.0601	0.0724	0.0912	0.1	0.1177	0.1185	0.1342	0.1563
2012	0.0530	0.0618	0.0752	0.0851	0.0989	0.1032	0.1144	0.1347	0.1304
2013	0.0459	0.0757	0.0845	0.0946	0.1038	0.1131	0.1180	0.1280	0.1395

```
#eof
999
```

Strait of Georgia

```
#JSC: Data updating was finalized Jul 18, 2013.
## ________________________
## ____Model Dimensions____
1951		#first year of data
2013		#last year of data
2			#age of youngest age class
10			#age of plus group
5			#number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1	1	1	0	0
0.083	0.442	0.474	0	0	#20-year average catch values (2012)
#0.07449536	0.42846497	0.49703967 0  0		#20-year average catch values (2011)
#0.34	0.38	0.28 0  0		#2011/12 IFMP values
## NEW: Catch type
## 1 = biomass
## 2 = catch in numbers
## 3 = roe removed (expressed as tons of spawning biomass equivalents)
1	1	1	1	1
## ________________________
##
## ________________________
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to)  (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage)-input maturity vector
0.24974 0.90 1 1 1 1 1 1 1
## ________________________
##
#Time series data
#Observed catch (1951-2013, 1000s metric t)
```

#yr		p1	p2	p3	survey
1951	43.798	0	0	0	0
1952	45.885	0	0	0	0
1953	8.425	0	0	0	0
1954	65.767	0	0	0	0
1955	68.641	0	0	0	0
1956	72.062	0	0	0	0
1957	59.608	0	0	0	0
1958	20.628	0	0	0	0
1959	50.025	0	0	0	0
1960	68.037	0	0	0	0
1961	46.215	0	0	0	0
1962	65.303	0	0	0	0
1963	68.847	0	0	0	0
1964	76.881	0	0	0	0
1965	47.819	0	0	0	0
1966	33.338	0	0	0	0
1967	31.043	0	0	0	0
1968	1.893	0	0	0	0
1969	0.194	0	0	0	0
1970	0.244	0	0	0	0
1971	1.700	0	0	0	0
1972	2.753	5.921	0.137	0	0
1973	4.005	1.604	2.040	0	0
1974	0.485	0.439	3.093	0	0
1975	0.405	0.469	5.305	0	0
1976	5.069	0.202	6.966	0	0
1977	5.676	4.098	7.735	0	0
1978	13.049	3.723	7.230	0	0
1979	13.576	0	6.762	0	0
1980	2.472	0.169	3.177	0	0
1981	4.907	2.081	5.065	0	0
1982	3.938	3.312	5.583	0	0
1983	0.824	7.780	8.613	0	0
1984	0.870	4.126	6.039	0	0
1985	0.773	2.762	3.495	0	0
1986	0.432	0.162	0.000	0	0
1987	0.244	3.111	5.998	0	0
1988	0.756	1.471	5.988	0	0
1989	1.033	1.417	5.919	0	0
1990	0.233	0	7.886	0	0
1991	0.562	1.131	9.410	0	0
1992	1.216	3.610	8.870	0	0
1993	0.617	4.391	8.733	0	0
1994	1.032	5.134	11.572	0	0
1995	0.643	4.359	8.190	0	0
1996	0.541	7.338	6.233	0	0
1997	0.402	9.274	6.148	0	0
1998	0.954	5.754	6.896	0	0
1999	1.471	4.887	6.838	0	0
2000	1.156	6.454	7.594	0	0
2001	1.423	7.276	7.683	0	0
2002	1.328	9.299	7.986	0	0
2003	2.194	10.600	8.083	0	0
2004	1.356	7.019	5.226	0	0
2005	1.988	7.929	8.954	0	0

```
2006	2.177	9.308	7.277	0	0
2007	1.071	3.865	5.286	0	0
2008	1.201	6.046	2.752	0	0
2009	0.547	5.685	3.937	0	0
2010	0.539	4.540	3.244	0	0
2011	0.713	0	4.415	0	0
2012	4.090	3.170	4.079	0	0
2013	4.530	6.099	5.937	0	0
#2013 catch includes 35 short tons GN catch (lost at sea)
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37		26
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3	3
#iyr	it gear wt	survey timing
1951	66.14254761	4	1	1
1952	72.37610017	4	1	1
1953	111.3071376	4	1	1
1954	82.14114707	4	1	1
1955	69.85431989	4	1	1
1956	25.66699081	4	1	1
1957	24.12574519	4	1	1
1958	16.91140035	4	1	1
1959	47.86418108	4	1	1
1960	55.7089546	4	1	1
1961	44.32558862	4	1	1
1962	35.57407763	4	1	1
1963	37.38082032	4	1	1
1964	35.9537142	4	1	1
1965	38.38960359	4	1	1
1966	7.211082615	4	1	1
1967	9.647054038	4	1	1
1968	9.44191253	4	1	1
1969	14.03855383	4	1	1
1970	34.1629108	4	1	1
1971	38.92110056	4	1	1
1972	25.13862176	4	1	1
1973	16.19138805	4	1	1
1974	40.57052594	4	1	1
1975	70.20784122	4	1	1
1976	60.51102467	4	1	1
1977	78.1125697	4	1	1
1978	101.7843457	4	1	1
1979	63.97261809	4	1	1
1980	85.67881239	4	1	1
1981	54.75383738	4	1	1
1982	100.6113706	4	1	1
1983	64.24272161	4	1	1
1984	26.05416724	4	1	1
1985	25.02373461	4	1	1
1986	41.57526481	4	1	1
```

1987	41.73660802	4	1	1
1988	24.97625851	5	1.1666	1
1989	66.05176087	5	1.1666	1
1990	67.14965711	5	1.1666	1
1991	45.82728504	5	1.1666	1
1992	82.71019088	5	1.1666	1
1993	90.19666959	5	1.1666	1
1994	67.13774404	5	1.1666	1
1995	64.8981324	5	1.1666	1
1996	71.32511657	5	1.1666	1
1997	58.2245486	5	1.1666	1
1998	74.61631326	5	1.1666	1
1999	85.09361473	5	1.1666	1
2000	72.68835912	5	1.1666	1
2001	100.2479625	5	1.1666	1
2002	117.862116	5	1.1666	1
2003	160.9962119	5	1.1666	1
2004	130.1509693	5	1.1666	1
2005	109.1964005	5	1.1666	1
2006	53.76434777	5	1.1666	1
2007	40.788072	5	1.1666	1
2008	36.85238668	5	1.1666	1
2009	57.39548512	5	1.1666	1
2010	54.60215958	5	1.1666	1
2011	90.93094724	5	1.1666	1
2012	53.86033788	5	1.1666	1
2013	86.81247442	5	1.1666	1

#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
58 41 41
#a_sage
2 2 2
#a_page
10 10 10

#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged. #updated (Sept 2012 values were incorrect)

1951	1	326	4413	2371	556	110	27	8	2	0
1952	1	1008	4900	2191	589	114	23	6	1	0
1953	1	763	3509	1897	285	96	15	4	0	0
1954	1	200	6011	4845	1520	432	124	27	3	0
1955	1	227	2533	2048	350	57	6	0	0	0
1956	1	280	2550	2628	2307	529	86	26	5	3
1957	1	84	3829	1566	761	333	38	3	1	1
1958	1	588	3548	1528	428	363	212	29	5	0
1959	1	1616	6073	1455	251	55	24	12	2	1
1960	1	288	1921	1368	135	20	6	3	0	1
1961	1	1292	1252	1191	765	263	39	4	0	0
1962	1	317	2348	608	212	114	30	9	0	0
1963	1	427	1388	734	113	33	14	2	0	0
1964	1	259	2650	1507	172	36	11	5	0	0
1965	1	555	1870	891	95	36	8	5	0	0
1966	1	184	274	191	114	18	9	0	0	0
1972	1	394	1313	1337	696	143	51	5	1	0
1973	1	47	1294	1432	1188	585	82	14	2	0

1974	1	15	63	7	1	0	0	0	0	0
1975	1	97	265	54	9	6	2	0	1	0
1976	1	272	872	1723	914	272	117	41	18	2
1977	1	110	1349	584	439	118	33	13	4	3
1978	1	42	695	815	207	145	59	10	7	2
1979	1	44	437	1002	703	213	121	30	7	3
1980	1	121	1753	969	777	346	92	52	15	4
1981	1	176	1521	1554	715	391	135	21	5	0
1982	1	80	839	711	349	133	92	19	2	1
1983	1	60	336	507	392	211	77	91	44	9
1984	1	279	598	435	321	153	63	19	8	6
1985	1	681	993	464	188	77	25	8	2	0
1986	1	116	501	177	50	15	3	1	0	0
1987	1	192	306	273	88	17	4	2	0	0
1988	1	32	550	158	140	25	6	2	1	0
1989	1	278	174	450	74	62	9	2	0	0
1990	1	37	427	102	144	16	19	0	0	0
1991	1	162	286	313	57	56	7	2	0	0
1992	1	31	526	92	56	4	1	1	0	0
1993	1	253	302	316	67	26	3	6	1	0
1994	1	42	287	134	81	9	5	0	0	0
1995	1	294	329	413	125	54	8	2	0	1
1996	1	421	821	199	157	41	18	3	0	0
1997	1	112	304	70	16	4	1	2	1	0
1998	1	60	699	596	99	19	8	2	0	0
1999	1	175	416	619	217	46	9	2	0	0
2000	1	422	736	259	210	65	18	2	2	0
2001	1	91	560	326	85	56	22	6	2	0
2002	1	131	949	369	93	16	5	2	0	1
2003	1	28	377	303	75	21	5	2	2	0
2004	1	80	288	402	153	30	9	0	1	0
2005	1	42	207	134	134	43	17	3	1	0
2006	1	87	154	142	64	46	14	2	1	0
2007	1	57	510	309	104	25	14	2	0	0
2008	1	320	234	1134	276	69	22	15	1	0
2009	1	8	692	150	52	10	2	0	0	0
2010	1	272	103	705	50	29	10	2	3	0
2011	1	354	1011	126	114	10	6	0	0	0
2012	1	246	2382	1917	172	143	9	4	0	0
2013	1	452	1295	935	503	35	29	3	0	0
1972	2	428	1819	1655	903	174	50	6	1	0
1973	2	16	208	81	49	23	2	0	0	0
1975	2	191	2852	1452	408	174	83	25	9	0
1976	2	135	279	456	166	38	26	17	5	1
1977	2	79	1315	474	341	91	30	18	6	3
1978	2	29	1209	1477	396	253	47	10	1	2
1979	2	23	282	461	394	132	73	29	9	6
1980	2	103	2062	658	733	408	108	51	11	5
1981	2	617	2993	2428	890	758	293	52	23	2
1982	2	371	1875	1354	1127	253	282	135	30	4
1983	2	358	3759	3407	2134	1372	381	366	150	35
1984	2	894	2869	2101	935	515	242	81	35	11
1985	2	2818	3815	1558	651	276	108	47	5	1
1986	2	818	3603	1423	396	123	48	9	5	0
1987	2	855	2584	2861	1176	273	82	29	10	5
1988	2	327	3568	883	900	242	61	13	4	0

1989	2	643	1157	3435	607	456	102	20	2	1
1990	2	496	3251	607	1070	170	97	23	3	1
1991	2	701	1191	2125	473	770	118	74	10	1
1992	2	260	2762	691	843	176	260	30	16	1
1993	2	963	2138	1747	379	326	76	84	8	2
1994	2	279	2518	1594	1120	238	168	42	9	0
1995	2	664	1317	2080	1010	627	155	62	20	6
1996	2	1125	4051	1170	1198	481	280	57	19	7
1997	2	805	3810	1667	428	464	185	107	9	5
1998	2	349	3992	2608	1005	216	166	62	16	2
1999	2	231	898	1553	687	245	67	26	6	2
2000	2	692	2444	1237	1432	570	137	19	13	1
2001	2	499	2856	1847	564	531	169	39	6	2
2002	2	413	2536	1325	607	127	108	21	4	0
2003	2	387	3835	3248	1060	310	77	33	7	0
2004	2	398	1274	1805	902	225	67	14	8	1
2005	2	337	1313	1390	1093	362	85	30	10	4
2006	2	1438	1334	1095	734	442	98	35	8	1
2007	2	89	2469	1384	647	324	174	40	10	1
2008	2	75	445	2531	562	215	89	27	8	2
2009	2	16	2644	564	559	173	58	25	10	1
2010	2	566	164	3428	269	300	70	26	7	4
2011	2	319	3243	576	1031	105	57	22	4	1
2012	2	82	1757	2391	208	391	36	11	4	0
2013	2	245	1190	1457	1311	102	160	13	2	2
1972	3	46	119	481	300	71	15	2	1	0
1973	3	0	39	68	84	25	7	1	0	0
1974	3	0	48	418	310	165	40	9	0	0
1975	3	0	9	78	65	22	6	1	0	0
1976	3	0	5	349	385	112	26	6	1	0
1977	3	0	54	456	755	263	60	8	2	0
1978	3	0	4	115	170	202	65	8	2	0
1979	3	0	7	141	332	82	35	9	0	1
1980	3	0	15	69	336	252	66	14	2	0
1981	3	1	25	207	262	426	183	32	3	1
1982	3	0	37	128	237	123	173	118	14	3
1983	3	0	2	113	120	96	38	30	7	1
1984	3	0	54	231	238	147	71	13	5	7
1985	3	1	34	286	356	259	101	41	9	9
1987	3	0	48	684	642	317	163	50	11	5
1988	3	0	75	122	395	160	45	19	3	2
1989	3	0	13	331	181	213	64	18	3	0
1990	3	0	115	160	771	167	133	20	4	1
1991	3	0	14	306	187	436	79	51	13	1
1992	3	0	74	174	510	137	221	31	17	5
1993	3	0	104	363	154	196	37	49	2	2
1994	3	1	45	300	537	183	95	30	8	2
1995	3	0	21	243	341	242	52	22	4	2
1996	3	0	21	86	247	119	56	10	4	1
1997	3	0	30	113	104	202	108	54	16	6
1998	3	0	45	450	438	185	191	57	26	6
1999	3	0	18	245	307	176	56	28	5	1
2000	3	0	12	161	488	309	99	24	4	0
2001	3	0	31	190	263	345	154	34	7	3
2002	3	0	45	206	285	149	178	45	5	2
2003	3	0	32	293	452	316	139	87	29	6

2004	3	0	25	278	451	276	116	25	13	1
2005	3	0	5	91	352	207	80	28	9	1
2006	3	0	7	119	315	322	160	40	11	1
2007	3	0	144	397	801	802	551	146	42	7
2008	3	1	32	857	468	318	159	56	18	1
2009	3	0	42	63	466	166	99	29	11	1
2010	3	0	1	222	67	428	114	60	23	8
2011	3	0	103	77	1171	205	260	61	18	8
2012	3	1	247	1306	154	398	50	28	4	2
2013	3	0	27	286	689	84	160	8	4	2

#n_wt_obs
63
#Mean weight-at-age in kilograms (see "input data 2013.xls")

#A$yr	V1	V2	V3	V4	V5	V6	V7	V8	V9
1951	0.0417	0.0897	0.1126	0.1376	0.1586	0.1706	0.2001	0.1865	0.1865
1952	0.0432	0.0896	0.1133	0.1385	0.1599	0.1756	0.1677	0.178	0.1865
1953	0.0329	0.0763	0.0958	0.1255	0.1498	0.1599	0.1335	0.1784	0.1865
1954	0.0447	0.0847	0.1036	0.1278	0.1571	0.1721	0.1751	0.186	0.1865
1955	0.0499	0.0893	0.1043	0.1262	0.1448	0.1738	0.172	0.1784	0.1865
1956	0.0471	0.0845	0.106	0.1205	0.141	0.1587	0.1785	0.1733	0.1865
1957	0.0481	0.0828	0.1089	0.1371	0.1506	0.164	0.21	0.1784	0.1865
1958	0.0438	0.0763	0.1081	0.1421	0.1535	0.1647	0.1762	0.1885	0.1865
1959	0.0502	0.0836	0.0993	0.1314	0.1596	0.1677	0.1523	0.158	0.1865
1960	0.053	0.0902	0.1125	0.1279	0.1597	0.129	0.177	0.1784	0.1865
1961	0.0576	0.0786	0.1111	0.117	0.1372	0.165	0.172	0.1784	0.1865
1962	0.0501	0.088	0.0993	0.1366	0.1449	0.153	0.202	0.1784	0.1865
1963	0.0477	0.0832	0.1049	0.1116	0.1494	0.1778	0.179	0.1784	0.1865
1964	0.0576	0.0993	0.1159	0.1378	0.1586	0.185	0.14	0.1784	0.1865
1965	0.0611	0.1051	0.1224	0.1451	0.1452	0.177	0.144	0.1784	0.1865
1966	0.052	0.1067	0.1487	0.1681	0.1783	0.1888	0.172	0.1784	0.1865
1967	0.0488	0.088	0.1104	0.1332	0.153	0.1677	0.172	0.1784	0.1865
1968	0.0488	0.088	0.1104	0.1332	0.153	0.1677	0.172	0.1784	0.1865
1969	0.0488	0.088	0.1104	0.1332	0.153	0.1677	0.172	0.1784	0.1865
1970	0.0578	0.0888	0.1175	0.1399	0.1608	0.1733	0.1871	0.1927	0.2096
1971	0.0553	0.1056	0.1319	0.1537	0.1742	0.1895	0.169	0.1927	0.2096
1972	0.0586	0.0897	0.129	0.1478	0.1671	0.1778	0.1973	0.185	0.2096
1973	0.0525	0.0993	0.1274	0.1588	0.1749	0.1928	0.1977	0.201	0.2096
1974	0.063	0.0877	0.1392	0.1653	0.2093	0.1733	0.242	0.1927	0.2096
1975	0.0421	0.0828	0.1115	0.1423	0.1694	0.1934	0.1995	0.2122	0.2096
1976	0.0498	0.0849	0.1234	0.1455	0.1743	0.1914	0.2033	0.2248	0.2133
1977	0.0571	0.0888	0.1173	0.1389	0.1616	0.191	0.201	0.2027	0.2418
1978	0.0501	0.0853	0.1099	0.1321	0.1513	0.1672	0.1683	0.1999	0.2095
1979	0.0597	0.0848	0.1178	0.1405	0.1604	0.1754	0.199	0.2051	0.2174
1980	0.0522	0.078	0.1083	0.1352	0.1584	0.1718	0.1831	0.1984	0.2172
1981	0.0602	0.0857	0.1085	0.1348	0.1561	0.1706	0.1873	0.1802	0.2022
1982	0.0635	0.0945	0.1153	0.1292	0.1531	0.1618	0.1696	0.1688	0.195
1983	0.0576	0.0898	0.1174	0.1349	0.1431	0.158	0.1707	0.1851	0.1941
1984	0.0624	0.0881	0.1146	0.1388	0.1569	0.159	0.1666	0.1762	0.201
1985	0.0647	0.0867	0.1141	0.1345	0.1564	0.1703	0.1869	0.1926	0.232
1986	0.067	0.0895	0.1108	0.1324	0.1495	0.17	0.1971	0.1954	0.2096
1987	0.0628	0.0874	0.1056	0.1226	0.1366	0.1522	0.166	0.155	0.1823
1988	0.0609	0.09	0.1138	0.1302	0.1423	0.1547	0.1642	0.2006	0.2096
1989	0.0644	0.0841	0.1068	0.1273	0.139	0.1474	0.1561	0.158	0.182
1990	0.0604	0.0851	0.106	0.1283	0.1468	0.1572	0.1609	0.1453	0.226
1991	0.0642	0.0894	0.1101	0.128	0.1426	0.1553	0.1634	0.1508	0.185
1992	0.0598	0.0905	0.1118	0.1319	0.1494	0.1592	0.1738	0.1739	0.1563

1993	0.0579	0.0922	0.1118	0.1286	0.1411	0.1529	0.1565	0.16	0.1475
1994	0.0522	0.0809	0.1047	0.1207	0.135	0.1405	0.1512	0.1609	0.1563
1995	0.0612	0.0856	0.1106	0.1314	0.1446	0.1617	0.1631	0.1791	0.1753
1996	0.0619	0.0829	0.1061	0.1264	0.1457	0.1557	0.1719	0.1694	0.183
1997	0.0497	0.0826	0.1017	0.1197	0.1368	0.1463	0.1541	0.167	0.1817
1998	0.0504	0.0725	0.0939	0.1086	0.1194	0.1331	0.1438	0.1559	0.1485
1999	0.046	0.0795	0.0991	0.1134	0.1255	0.1341	0.1434	0.1508	0.139
2000	0.0523	0.0724	0.0948	0.111	0.1291	0.1387	0.153	0.1599	0.163
2001	0.0622	0.0853	0.099	0.1197	0.1332	0.1483	0.1552	0.1454	0.144
2002	0.0494	0.0793	0.0959	0.1076	0.1254	0.1324	0.1413	0.164	0.059
2003	0.0518	0.0772	0.093	0.105	0.1113	0.1282	0.1401	0.128	0.1563
2004	0.0498	0.0729	0.0888	0.0993	0.1091	0.1125	0.1241	0.1219	0.132
2005	0.0476	0.0741	0.091	0.1064	0.1175	0.1257	0.1305	0.1215	0.1373
2006	0.0483	0.0714	0.0882	0.1023	0.1113	0.1208	0.1279	0.1394	0.178
2007	0.062	0.0753	0.0831	0.0994	0.1154	0.123	0.1301	0.1432	0.134
2008	0.0257	0.0658	0.0858	0.0936	0.103	0.1105	0.1155	0.1331	0.135
2009	0.0453	0.0644	0.0688	0.1033	0.1156	0.1251	0.1347	0.1542	0.178
2010	0.0435	0.058	0.079	0.085	0.1118	0.1189	0.1158	0.1119	0.1413
2011	0.0362	0.0686	0.0725	0.0906	0.0948	0.1083	0.1194	0.143	0.122
2012	0.0483	0.0708	0.0832	0.0857	0.0947	0.1012	0.1113	0.1243	0.14206
2013	0.0557	0.0701	0.0926	0.1092	0.1145	0.1235	0.1240	0.1340	0.1208

#eof
999

West Coast Vancouver Island

```
#JSC: Data updating was finalized Jul 16, 2013.
## ________________________
## ____Model Dimensions____
1951            #first year of data
2013            #last year of data
2                       #age of youngest age class
10                      #age of plus group
5                       #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
0.000   0.857   0.143   0       0       #20-year average catch values (2012)
#0      0.828   0.172   0  0            #20-year average catch values (2011)
## NEW: Catch type
## 1 = biomass
## 2 = catch in numbers
## 3 = roe removed (expressed as tons of spawning biomass equivalents)
1    1    1    1    1
## ________________________
##
## ________________________
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to)  (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage)-input maturity vector
0.24974 0.90 1 1 1 1 1 1 1
```

____
##
#Time series data
#Observed catch (1951-2013, metric t)

#yr		p1	p2	p3	survey
1951	21.821	0	0	0	0
1952	27.008	0	0	0	0
1953	0.020	0	0	0	0
1954	33.209	0	0	0	0
1955	6.123	0	0	0	0
1956	17.098	0	0	0	0
1957	2.612	0	0	0	0
1958	0.556	0	0	0	0
1959	69.223	0	0	0	0
1960	53.911	0	0	0	0
1961	26.435	0	0	0	0
1962	23.684	0	0	0	0
1963	18.206	0	0	0	0
1964	21.266	0	0	0	0
1965	16.046	0	0	0	0
1966	10.843	0	0	0	0
1967	15.145	0	0	0	0
1968	0	0	0	0	0
1969	0	0	0	0	0
1970	0	0	0	0	0
1971	0	0	0	0	0
1972	0	6.894	0	0	0
1973	0	16.766	1.537	0	0
1974	0	12.394	3.940	0	0
1975	0.001	17.798	8.309	0	0
1976	0	22.820	16.005	0	0
1977	0.029	17.458	12.556	0	0
1978	2.839	5.151	14.755	0	0
1979	0.084	10.472	8.138	0	0
1980	0	1.682	2.300	0	0
1981	0.002	5.008	3.079	0	0
1982	0.002	2.370	3.115	0	0
1983	0	6.141	2.434	0	0
1984	0	5.718	0.858	0	0
1985	0.001	0.177	0.000	0	0
1986	0.001	0.203	0.000	0	0
1987	0	13.463	2.471	0	0
1988	0	8.276	1.448	0	0
1989	0	9.774	3.515	0	0
1990	0	7.890	1.959	0	0
1991	0	6.299	2.336	0	0
1992	0	3.086	0.627	0	0
1993	0	5.612	0.000	0	0
1994	0.001	5.332	0.706	0	0
1995	0.004	1.947	0.000	0	0
1996	0.001	0.790	0.000	0	0
1997	0	6.656	0.000	0	0
1998	0	5.450	1.534	0	0
1999	0	3.405	0.968	0	0
2000	0	0.926	0.700	0	0
2001	0	0.000	0.000	0	0

```
2002    0    0.433    0.388    0    0
2003    0    2.571    0.945    0    0
2004    0    3.861    0.593    0    0
2005    0    3.373    0.896    0    0
2006    0    0    0    0    0
2007    0    0    0    0    0
2008    0    0    0    0    0
2009    0    0    0    0    0
2010    0    0    0    0    0
2011    0    0    0    0    0
2012    0    0    0    0    0
2013    0    0    0    0    0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37        26
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3    3
#iyr    it gear wt        survey timing
1951    19.597    4    1    1
1952    13.310    4    1    1
1953    39.571    4    1    1
1954    20.648    4    1    1
1955    15.112    4    1    1
1956    27.183    4    1    1
1957    44.114    4    1    1
1958    18.986    4    1    1
1959    12.979    4    1    1
1960    6.015    4    1    1
1961    10.556    4    1    1
1962    34.470    4    1    1
1963    11.245    4    1    1
1964    22.761    4    1    1
1965    11.891    4    1    1
1966    3.722    4    1    1
1967    4.813    4    1    1
1968    11.029    4    1    1
1969    10.465    4    1    1
1970    26.912    4    1    1
1971    36.206    4    1    1
1972    41.857    4    1    1
1973    19.481    4    1    1
1974    25.540    4    1    1
1975    49.149    4    1    1
1976    64.200    4    1    1
1977    58.679    4    1    1
1978    45.607    4    1    1
1979    66.397    4    1    1
1980    62.308    4    1    1
1981    52.014    4    1    1
1982    33.047    4    1    1
1983    16.771    4    1    1
```

1984	23.872	4	1	1
1985	30.010	4	1	1
1986	39.514	4	1	1
1987	16.858	4	1	1
1988	46.242	5	1	1
1989	47.718	5	1	1
1990	46.464	5	1	1
1991	29.996	5	1	1
1992	42.366	5	1	1
1993	34.408	5	1	1
1994	25.249	5	1	1
1995	27.128	5	1	1
1996	33.121	5	1	1
1997	45.362	5	1	1
1998	41.011	5	1	1
1999	19.734	5	1	1
2000	12.799	5	1	1
2001	13.414	5	1	1
2002	21.242	5	1	1
2003	33.671	5	1	1
2004	17.673	5	1	1
2005	10.347	5	1	1
2006	3.045	5	1	1
2007	2.403	5	1	1
2008	2.930	5	1	1
2009	11.358	5	1	1
2010	2.554	5	1	1
2011	10.204	5	1	1
2012	5.573	5	1	1
2013	13.224	5	1	1

#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
18 42 26
#a_sage
2 2 2
#a_page
10 10 10
#

#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.

1951	1	508	1519	1666	272	58	12	1	1	0
1952	1	97	1435	1230	1824	245	72	16	2	0
1953	1	565	2220	1086	65	19	2	0	0	0
1954	1	163	3852	1681	338	42	9	5	1	1
1955	1	422	1490	494	86	16	1	0	0	0
1956	1	575	2990	743	282	52	7	2	2	0
1957	1	16	423	146	2	1	0	0	0	0
1958	1	154	579	322	75	34	20	5	1	0
1959	1	155	1650	1004	528	141	88	74	21	4
1960	1	255	1575	671	252	81	27	10	4	2
1961	1	274	248	118	26	1	0	0	0	0
1962	1	59	1031	130	31	10	0	0	0	0
1963	1	39	985	1110	106	14	4	0	0	0
1964	1	30	713	305	123	10	3	0	0	0
1965	1	18	283	411	82	27	3	0	0	0

1966	1	1	124	100	64	8	3	0	0	0
1978	1	29	935	479	259	311	45	19	7	5
1984	1	2	42	10	2	1	3	0	0	0
1972	2	51	291	756	387	55	18	12	1	0
1973	2	18	784	625	823	277	40	7	2	0
1974	2	436	2333	1298	738	480	120	12	2	1
1975	2	60	5437	2005	1153	806	505	130	17	1
1976	2	19	818	4332	1828	1196	746	251	40	0
1977	2	35	838	2097	2507	834	301	112	19	3
1978	2	41	2396	1066	1000	1104	264	77	11	4
1979	2	30	530	1966	554	414	306	60	20	5
1980	2	86	1317	449	661	218	182	73	14	3
1981	2	135	1362	1137	420	500	221	93	20	0
1982	2	160	1210	1401	1316	275	466	132	71	15
1983	2	135	723	701	702	566	142	173	34	29
1984	2	888	1231	425	286	316	191	35	33	8
1985	2	753	1695	446	114	83	99	53	4	7
1986	2	157	2094	1233	344	130	93	73	24	3
1987	2	760	803	1624	1011	346	120	65	51	18
1988	2	191	4548	571	1100	736	209	55	33	16
1989	2	146	903	3482	376	495	259	39	10	2
1990	2	33	1856	849	3233	307	406	125	16	6
1991	2	482	1565	1543	780	2420	220	251	48	2
1992	2	97	2860	630	803	360	1017	126	73	13
1993	2	214	1517	2233	375	411	225	420	51	31
1994	2	182	1361	1449	1862	491	311	330	97	15
1995	2	40	645	1183	1003	1266	333	220	155	35
1996	2	1030	1439	864	1292	878	911	200	84	60
1997	2	144	4003	468	261	387	287	194	32	20
1998	2	118	1119	3110	332	146	166	94	58	16
1999	2	69	943	1011	1610	320	112	59	30	15
2000	2	278	1072	904	817	1249	171	56	30	9
2001	2	162	1027	452	185	174	221	29	5	4
2002	2	368	2662	1136	371	140	157	131	15	1
2003	2	96	2169	2023	700	134	62	41	33	4
2004	2	391	1316	2450	1004	286	64	21	11	1
2005	2	157	1655	939	680	237	71	12	2	3
2006	2	174	430	387	91	62	9	1	0	0
2007	2	7	303	211	66	11	4	0	0	0
2008	2	54	255	559	119	32	8	6	1	1
2009	2	44	1204	284	230	41	10	0	0	0
2010	2	356	597	859	105	91	14	2	0	0
2011	2	62	806	270	123	12	6	0	0	0
2012	2	19	168	561	93	53	6	3	0	0
2013	2	15	106	66	209	22	20	2	0	0
1973	3	0	49	143	323	84	18	6	1	0
1974	3	0	46	54	46	24	6	0	0	0
1975	3	0	8	82	102	57	19	1	0	0
1976	3	0	9	529	445	206	87	33	4	1
1977	3	2	12	59	153	63	44	19	5	1
1978	3	0	7	27	125	284	116	40	4	2
1979	3	0	7	148	152	143	108	11	2	0
1980	3	0	0	24	213	102	65	44	3	1
1981	3	0	5	59	42	102	53	20	0	0
1982	3	0	5	103	374	101	234	35	10	1
1983	3	0	2	81	136	256	37	56	2	1

1984	3	0	10	40	107	194	190	32	20	2
1987	3	0	10	135	340	30	12	16	5	2
1988	3	0	27	35	204	147	64	15	6	2
1989	3	0	1	208	42	85	36	6	4	0
1990	3	0	6	35	307	37	46	11	3	0
1991	3	0	1	25	41	223	28	28	2	1
1992	3	0	35	75	171	77	166	16	14	2
1994	3	1	35	199	340	33	7	4	1	0
1998	3	0	5	344	99	87	181	111	51	21
1999	3	0	8	106	527	159	44	31	12	1
2000	3	0	8	47	169	330	39	16	14	2
2002	3	0	0	55	154	82	110	120	12	2
2003	3	0	15	99	203	142	77	103	57	4
2004	3	0	5	179	154	158	92	24	14	5
2005	3	0	4	54	294	143	61	22	1	2

#n_wt_obs
63
#Mean weight-at-age in kilograms (see "input data 2013.xls")

#A$yr	V1	V2	V3	V4	V5	V6	V7	V8	V9
1951	0.0503	0.0873	0.1144	0.1339	0.1489	0.16	0.205	0.196	0.1586
1952	0.0536	0.0896	0.1144	0.1386	0.1569	0.1699	0.1781	0.19	0.1586
1953	0.0446	0.0799	0.1001	0.121	0.1473	0.1455	0.1594	0.1656	0.1586
1954	0.0542	0.0854	0.1056	0.1258	0.1474	0.1658	0.155	0.1656	0.1586
1955	0.0579	0.0827	0.107	0.1249	0.1514	0.131	0.1594	0.1656	0.1586
1956	0.0577	0.086	0.1064	0.1192	0.1389	0.144	0.1594	0.14	0.1586
1957	0.0543	0.0775	0.1016	0.1139	0.136	0.144	0.142	0.14	0.1586
1958	0.0503	0.0693	0.0965	0.1093	0.1248	0.1281	0.1383	0.169	0.1586
1959	0.0508	0.0808	0.097	0.113	0.1241	0.1332	0.1371	0.1499	0.1527
1960	0.0594	0.0897	0.106	0.1212	0.1336	0.1446	0.1604	0.1745	0.1645
1961	0.0583	0.0908	0.1159	0.141	0.173	0.1484	0.1594	0.1656	0.1586
1962	0.0567	0.0922	0.1093	0.1241	0.1282	0.1484	0.1594	0.1656	0.1586
1963	0.0562	0.0883	0.1116	0.1222	0.1366	0.1448	0.1594	0.1656	0.1586
1964	0.065	0.0931	0.1145	0.1362	0.1452	0.13	0.1594	0.1656	0.1586
1965	0.0683	0.104	0.1292	0.1474	0.1733	0.158	0.1594	0.1656	0.1586
1966	0.042	0.1128	0.1351	0.1489	0.1627	0.1793	0.1594	0.1656	0.1586
1967	0.0549	0.088	0.1102	0.1275	0.1455	0.1484	0.1594	0.1656	0.1586
1968	0.0549	0.088	0.1102	0.1275	0.1455	0.1484	0.1594	0.1656	0.1586
1969	0.0549	0.088	0.1102	0.1275	0.1455	0.1484	0.1594	0.1656	0.1586
1970	0.0639	0.0949	0.1248	0.1501	0.1697	0.1844	0.1957	0.2034	0.2082
1971	0.064	0.1174	0.1485	0.166	0.1689	0.1991	0.2175	0.2034	0.2082
1972	0.0642	0.1036	0.1382	0.1596	0.1737	0.1807	0.2032	0.16	0.2082
1973	0.0633	0.1037	0.1349	0.1598	0.1836	0.1924	0.1903	0.254	0.2082
1974	0.0617	0.0854	0.1234	0.1487	0.1717	0.1856	0.1836	0.2175	0.231
1975	0.0547	0.0918	0.1279	0.1652	0.1893	0.2071	0.2202	0.2406	0.207
1976	0.0536	0.0873	0.1202	0.1518	0.1811	0.1951	0.2112	0.2223	0.2082
1977	0.0628	0.0885	0.1253	0.1435	0.1695	0.1828	0.1918	0.1962	0.2153
1978	0.0591	0.0797	0.1082	0.1341	0.1539	0.1736	0.1883	0.2038	0.2244
1979	0.0621	0.0831	0.1104	0.1412	0.1672	0.1835	0.2003	0.2034	0.1995
1980	0.0669	0.0825	0.1079	0.1314	0.159	0.1789	0.1928	0.2083	0.218
1981	0.063	0.0906	0.1104	0.1377	0.1527	0.1755	0.183	0.1879	0.1891
1982	0.0708	0.0892	0.1094	0.1251	0.1423	0.15	0.1712	0.1795	0.1774
1983	0.0611	0.0938	0.119	0.1405	0.1552	0.166	0.1737	0.1954	0.1936
1984	0.0692	0.1013	0.1306	0.1535	0.1662	0.1767	0.1863	0.1891	0.2112
1985	0.0694	0.1016	0.1351	0.1609	0.1818	0.1857	0.2076	0.1848	0.1997
1986	0.0683	0.1028	0.1311	0.1601	0.1809	0.1919	0.1984	0.2045	0.2217
1987	0.0695	0.1026	0.1367	0.1634	0.181	0.2001	0.203	0.205	0.2139

1988	0.0679	0.1033	0.1302	0.1597	0.1775	0.1952	0.2019	0.2062	0.2138
1989	0.0649	0.0967	0.1268	0.1476	0.17	0.1869	0.1936	0.1966	0.205
1990	0.062	0.1008	0.1295	0.1542	0.1721	0.1881	0.1993	0.2148	0.1963
1991	0.0662	0.0942	0.1235	0.1412	0.1608	0.1773	0.1858	0.1978	0.2065
1992	0.0687	0.1006	0.1256	0.1493	0.1638	0.1773	0.1879	0.1973	0.2082
1993	0.0685	0.0973	0.1217	0.1406	0.1593	0.1694	0.1784	0.1873	0.1979
1994	0.0648	0.0949	0.1194	0.1358	0.1498	0.1605	0.1642	0.1748	0.1779
1995	0.0693	0.0979	0.1216	0.1432	0.1599	0.1749	0.1823	0.1888	0.1874
1996	0.0695	0.0855	0.116	0.1363	0.152	0.1646	0.1766	0.1814	0.1921
1997	0.0641	0.0914	0.1055	0.1316	0.1492	0.161	0.1756	0.1729	0.1794
1998	0.0589	0.0796	0.1037	0.1133	0.1321	0.1424	0.1494	0.1557	0.1575
1999	0.0536	0.0832	0.0991	0.1195	0.1257	0.144	0.1521	0.1634	0.1562
2000	0.0578	0.0868	0.1074	0.1301	0.1468	0.1584	0.1609	0.1681	0.1771
2001	0.0659	0.0885	0.1074	0.1242	0.1408	0.1564	0.1563	0.1478	0.1983
2002	0.0634	0.084	0.1032	0.1249	0.144	0.1566	0.1704	0.1868	0.218
2003	0.0609	0.0934	0.1031	0.1207	0.1387	0.1544	0.1763	0.167	0.192
2004	0.0635	0.0814	0.1028	0.11	0.1242	0.134	0.1557	0.1657	0.1852
2005	0.0559	0.0755	0.0913	0.1122	0.1204	0.1332	0.1375	0.1525	0.137
2006	0.0548	0.0693	0.0877	0.102	0.1169	0.1103	0.128	0.1754	0.1852
2007	0.0546	0.0727	0.0805	0.0924	0.0981	0.1313	0.1642	0.1754	0.1852
2008	0.0565	0.0603	0.0877	0.1034	0.1156	0.1315	0.145	0.139	0.162
2009	0.0461	0.0753	0.0777	0.1038	0.1101	0.1138	0.1642	0.1754	0.1852
2010	0.049	0.0714	0.0855	0.0923	0.1069	0.117	0.1095	0.1754	0.1852
2011	0.0457	0.0658	0.0721	0.0963	0.0987	0.1123	0.0818	0.1754	0.1852
2012	0.0518	0.0784	0.0875	0.0989	0.1102	0.1167	0.1223	0.1681	0.1806
2013	0.0564	0.0789	0.0939	0.1050	0.1207	0.1225	0.1340	0.1667	0.1796

#eof
999

Minor Stock Area 2W

```
#JSC: All data were updated Aug 11, 2013.
## _________________________
## ____Model Dimensions____
1978       #first year of data
2013       #last year of data
2          #age of youngest age class
10         #age of plus group
4          #number of gears (ngear) - 4 (not 5) bc assume only 1 survey time series
## flags for fishery (1) or survey (0) in ngears
#1  1   1   0
0.100 0.405 0.495 0.0              #2011 allocation used for 2012
## NEW: Catch type
## 1 = biomass
## 2 = catch in numbers
## 3 = roe removed (expressed as tons of spawning biomass equivalents - for SOK "catch")
1    1    1    1                   #4 "gears" to match line 8
## _________________________
## _________________________
## _________________________
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to)  (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
```

```
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage)                          input maturity vector
0.24974 0.90 1 1 1 1 1 1
## ________________________
#Time series data
#Observed catch (1951-2012, 1000s metric t)
#Year P1 P2 P3 S1
1978  0 0.575  0  0
1979  0 0.691  0  0
1980  0 0.000  0  0
1981  0 0.770  0  0
1982  0 1.225  0  0
1983  0 2.518  0  0
1984  0 0.000  0  0
1985  0 0.199  0  0
1986  0 0.000  0  0
1987  0 0.000  0  0
1988  0 0.000  0  0
1989  0 0.000  0  0
1990  0 2.272  0  0
1991  0 2.558  0  0
1992  0 1.284  0  0
1993  0 1.306  0  0
1994  0 0.000  0  0
1995  0 0.000  0  0
1996  0 0.000  0  0
1997  0 0.000  0  0
1998  0 0.180  0  0
1999  0 0.000  0  0
2000  0 0.000  0  0
2001  0 0.000  0  0
2002  0 0.000  0  0
2003  0 0.000  0  0
2004  0 0.000  0  0
2005  0 0.000  0  0
2006  0 0.000  0  0
2007  0 0.000  0  0
2008  0 0.000  0  0
2009  0 0.000  0  0
2010  0 0.000  0  0
2011  0 0.000  0  0
2012  0 0.000  0  0
2013  0 0.000  0  0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit (not 2 b/c all surface observations)
1
#nit_nobs       (1978-2013)
#31
32
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3
```

```
#iyr     it gear wt     survey timing
1978  0.832  4  1  1
1979  0.494  4  1  1
1980  2.114  4  1  1
1981  1.894  4  1  1
1982  4.781  4  1  1
1983  4.869  4  1  1
1984  2.522  4  1  1
1985  1.719  4  1  1
1986  0.684  4  1  1
1987  0.989  4  1  1
1988  3.380  4  1  1
1989  2.719  4  1  1
1990 10.946  4  1  1
1991  2.985  4  1  1
1992  3.909  4  1  1
1993  0.089  4  1  1
1994  0.248  4  1  1
1998  0.469  4  1  1
2000  0.288  4  1  1
2001  0.035  4  1  1
2002  0.149  4  1  1
2003  1.462  4  1  1
2004  2.996  4  1  1
2005  1.111  4  1  1
2006  1.791  4  1  1
2007  1.960  4  1  1
2008  2.349  4  1  1
2009  2.860  4  1  1
2010  2.921  4  1  1
2011  2.353  4  1  1
2012  2.412  4  1  1
2013  2.076  4  1  1
#Age composition data by year, gear (ages 2-15+)
#na_gears
1
#na_nobs
#32
33
#a_sage
2
#a_page
10
#yr gear        V2   V3   V4   V5  V6  V7  V8 V9 V10  #Number aged.
1978 2   0   11   43   16   80   12   10   6  0
1979 2   8  101  123   87  123   74   10   6  3
1980 2   1  203   35   12    9    5    0   2  0
1981 2 246   71 1071  186  102   68   29  11  4
1982 2  31  648   25  887   71   37   20   6  1
1983 2  23   45 1893  101 1111   98   42  25 14
1984 2  32    8    3  175   12  253    9   3  1
1985 2   5   29   52   28  218   28  631   7  1
1986 2   3    1   42   43   20   76   27 152  2
1987 2  87  241    1    5    5    5   32   4 13
1988 2  27 1119  292    4    8   10   12  25  9
1989 2   6   42  934  195    6    6   12  10  9
```

```
1990 2   5   36   42 1901  412   11    5  14 10
1991 2  17  415   54   80 2163  501   26  15  8
1992 2  31  184  268   31   55 1181  243  11  6
1993 2  27  367  449  386   55  125 1097 140  9
1994 2  10   23   82   28   18    4   11  10  2
1998 2 205  385  256  207   29    7   17   2  0
1999 2 120  249  216  110   56   12    4   2  0
2000 2  13   56   16    0    2    0    1   0  0
2001 2  17   33  158   95   47   27    8   2  0
2002 2 301  250   50  227  102   72   28  16  2
2003 2  17 1214  253   56   61   19   22   6  3
2004 2  55   74  545   57   13   12    2   0  2
2005 2   4  297   96  654   45    6    9   0  2
2006 2  50   65   82   32  209   16    8   3  0
2007 2   2  374   73   42   21  120   10   3  1
2008 2  61    3   75   15    5    4   15   0  0
2009 2  21  590   20   99   18   20   18  24  4
2010 2  55  210  240   18   63   14   36  17 12
2011 2  20  455  167  212   15   32   10   1  0
2012 2  34   91  176   70   75    7   14   2  4
2013 2  2   392   51  109   38   28    0   4  1
#n_wt_obs
#35
36
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$yr     V1     V2     V3     V4     V5     V6     V7     V8     V9
1978 0.0693 0.0966 0.1424 0.1688 0.1813 0.1960 0.2207 0.2303 0.2174
1979 0.0528 0.1004 0.1373 0.1557 0.1809 0.1903 0.2110 0.2030 0.1870
1980 0.0600 0.0955 0.1197 0.1686 0.1987 0.2200 0.2124 0.2465 0.2174
1981 0.0680 0.0934 0.1256 0.1572 0.1822 0.1901 0.2018 0.1900 0.2255
1982 0.0657 0.1132 0.1233 0.1559 0.1814 0.1889 0.2145 0.2100 0.2220
1983 0.0751 0.1076 0.1415 0.1579 0.1783 0.1951 0.2025 0.1962 0.2136
1984 0.0729 0.1073 0.1307 0.1563 0.1886 0.1851 0.1841 0.1867 0.2140
1985 0.0850 0.1178 0.1531 0.1791 0.2042 0.2102 0.2188 0.2191 0.2260
1986 0.0800 0.1160 0.1490 0.1623 0.1843 0.2116 0.2270 0.2315 0.2070
1987 0.0628 0.1030 0.1270 0.1702 0.2018 0.1864 0.2227 0.1958 0.2245
1988 0.0707 0.1005 0.1429 0.1583 0.1818 0.2066 0.2209 0.2391 0.2370
1989 0.0620 0.1011 0.1317 0.1579 0.1808 0.1912 0.2033 0.2161 0.2163
1990 0.0584 0.0942 0.1414 0.1638 0.1868 0.1917 0.2304 0.2070 0.2344
1991 0.0622 0.0959 0.1270 0.1676 0.1756 0.1892 0.2002 0.2123 0.2049
1992 0.0695 0.1073 0.1342 0.1460 0.1777 0.1965 0.2098 0.2066 0.2168
1993 0.0685 0.1045 0.1283 0.1460 0.1691 0.1771 0.1892 0.1979 0.1922
1994 0.0748 0.1147 0.1393 0.1514 0.1738 0.1530 0.1999 0.1985 0.1960
1995 0.0655 0.0959 0.1209 0.1482 0.1725 0.1767 0.1877 0.1996 0.2081
1996 0.0655 0.0959 0.1209 0.1482 0.1725 0.1767 0.1877 0.1996 0.2081
1997 0.0655 0.0959 0.1209 0.1482 0.1725 0.1767 0.1877 0.1996 0.2081
1998 0.0703 0.1053 0.1334 0.1677 0.1759 0.1714 0.1973 0.1940 0.2081
1999 0.0713 0.1069 0.1209 0.1476 0.1682 0.1658 0.1340 0.1870 0.2081
2000 0.0693 0.0830 0.0881 0.1482 0.2045 0.1767 0.1110 0.1996 0.2081
2001 0.0698 0.1038 0.1478 0.1717 0.1769 0.1769 0.1784 0.2155 0.2081
2002 0.0655 0.1075 0.1254 0.1747 0.1969 0.2039 0.2041 0.2041 0.2405
2003 0.0742 0.1030 0.1144 0.1337 0.1828 0.1994 0.1965 0.1922 0.1917
2004 0.0621 0.0952 0.1294 0.1437 0.1622 0.1992 0.2460 0.1996 0.2235
2005 0.0590 0.0842 0.1093 0.1392 0.1554 0.1477 0.1738 0.1996 0.1900
2006 0.0594 0.0773 0.1037 0.1374 0.1693 0.1844 0.2096 0.2113 0.2081
2007 0.0800 0.0822 0.0879 0.1174 0.1406 0.1585 0.1550 0.1753 0.2000
```

2008 0.0555 0.0753 0.1102 0.1286 0.1558 0.1448 0.1643 0.1996 0.2081
2009 0.0560 0.0877 0.1015 0.1393 0.1563 0.1613 0.1922 0.1903 0.1923
2010 0.0559 0.0923 0.1227 0.1347 0.1684 0.1691 0.1722 0.1852 0.2062
2011 0.0564 0.0941 0.1172 0.1411 0.1277 0.1554 0.1608 0.1570 0.2000
2012 0.0567 0.0923 0.1230 0.1453 0.1724 0.1776 0.1790 0.1805 0.1750
2013 0.0740 0.0852 0.1136 0.1544 0.1817 0.1846 0.1790 0.1963 0.1560
#eof
999

Minor Stock Area 27

#JSC: All data were updated Aug 11, 2013.
____
____Model Dimensions____
1978 #first year of data
2013 #last year of data
2 #age of youngest age class
10 #age of plus group
5 #number of gears (ngear)
flags for fishery (1) or survey (0) in ngears
#1 1 1 0 0
0.100 0.405 0.495 0.0 0.0 #2011 allocation used for 2012
NEW: Catch type
1 = biomass
2 = catch in numbers
3 = roe removed (expressed as tons of spawning biomass equivalents - for SOK "catch")
1 1 1 1 1 #5 "gears" to match line 8
____
____
#Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to) (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
#init_vector mat(sage,nage) input maturity vector
0.24974 0.90 1 1 1 1 1 1 1
____
#Time series data
#Observed catch (1951-2010, 1000s metric t)
#Year P1 P2 P3 S1 S2
1978 0 0.075 0.075 0 0
1979 0 0.422 0.270 0 0
1980 0 0.000 0.520 0 0
1981 0 0.000 0.671 0 0
1982 0 0.238 0.332 0 0
1983 0 0.000 0.163 0 0
1984 0 0.000 0.171 0 0
1985 0 0.000 0.000 0 0
1986 0 0.000 0.000 0 0
1987 0 0.000 0.000 0 0
1988 0 0.000 0.000 0 0
1989 0 0.000 0.000 0 0

```
1990    0 0.000 0.000    0    0
1991    0 0.091 0.000    0    0
1992    0 0.335 0.000    0    0
1993    0 0.000 0.367    0    0
1994    0 0.000 0.345    0    0
1995    0 0.088 0.000    0    0
1996    0 0.000 0.000    0    0
1997    0 0.000 0.000    0    0
1998    0 0.000 0.000    0    0
1999    0 0.000 0.000    0    0
2000    0 0.000 0.000    0    0
2001    0 0.000 0.000    0    0
2002    0 0.000 0.000    0    0
2003    0 0.000 0.000    0    0
2004    0 0.000 0.000    0    0
2005    0 0.000 0.000    0    0
2006    0 0.000 0.000    0    0
2007    0 0.000 0.000    0    0
2008    0 0.000 0.000    0    0
2009    0 0.000 0.000    0    0
2010    0 0.000 0.000    0    0
2011    0 0.000 0.000    0    0
2012    0 0.000 0.000    0    0
2013    0 0.000 0.000    0    0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
#10      25
10      26
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3   3
#iyr     it gear wt     survey timing
1978  3.595    4    1    1
1979  6.909    4    1    1
1980 14.419    4    1    1
1981  1.828    4    1    1
1982  4.137    4    1    1
1983  2.500    4    1    1
1984  3.004    4    1    1
1985  1.382    4    1    1
1986  3.803    4    1    1
1987  0.952    4    1    1
1988  1.612    5    1.1666    1
1989  4.612    5    1.1666    1
1990  5.212    5    1.1666    1
1991  3.214    5    1.1666    1
1992  2.778    5    1.1666    1
1993  5.576    5    1.1666    1
1994  5.229    5    1.1666    1
1995  2.484    5    1.1666    1
1996  1.333    5    1.1666    1
1997  1.963    5    1.1666    1
```

1998 2.553 5 1.1666 1
1999 0.657 5 1.1666 1
2000 1.301 5 1.1666 1
2001 0.544 5 1.1666 1
2002 0.917 5 1.1666 1
2003 0.906 5 1.1666 1
2004 1.154 5 1.1666 1
2005 1.797 5 1.1666 1
2006 1.936 5 1.1666 1
2007 2.154 5 1.1666 1
2008 0.750 5 1.1666 1
2009 1.146 5 1.1666 1
2010 0.806 5 1.1666 1
2011 0.547 5 1.1666 1
#2012 0.963 5 1.1666 1 -incorrect (Aug11,2013)
2012 0.706 5 1.1666 1
2013 0.914 5 1.1666 1
#Age composition data by year, gear (ages 2-15+)
#na_gears
2
#na_nobs
#32 6
33 6
#a_sage
2 2
#a_page
10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.
1978 2 1 38 4 14 12 2 0 0 0
1979 2 1 10 55 10 2 1 1 0 0
1980 2 20 229 25 4 0 0 1 0 0
1981 2 15 99 435 63 98 11 0 0 0
1982 2 7 370 105 439 43 84 8 1 0
1983 2 4 21 32 11 29 0 4 0 0
1986 2 6 64 172 7 4 5 7 6 0
1987 2 48 78 45 100 3 0 3 1 4
1988 2 8 232 41 23 57 6 3 0 1
1989 2 1 59 268 38 39 53 6 2 0
1990 2 17 210 132 367 54 66 72 6 2
1991 2 33 145 33 38 83 10 18 8 0
1992 2 49 1004 158 48 41 71 14 18 6
1993 2 72 228 248 32 10 9 32 2 3
1994 2 14 300 232 292 52 20 27 5 2
1995 2 24 91 504 348 352 59 19 23 6
1996 2 107 172 49 123 104 86 18 2 2
1997 2 23 441 42 9 23 27 9 0 0
1998 2 4 112 140 14 1 8 7 2 0
1999 2 59 213 257 189 31 4 4 2 1
2000 2 15 355 158 63 49 8 1 3 0
2001 2 13 41 70 25 24 19 2 1 0
2002 2 35 293 73 47 3 11 4 1 0
2003 2 3 295 214 36 23 1 4 1 0
2004 2 5 83 209 76 4 6 3 0 0
2005 2 1 97 43 23 13 1 1 0 0
2007 2 5 209 140 72 16 10 1 0 0
2008 2 6 12 218 80 44 5 1 0 0

2009 2 9 448 73 143 23 18 0 1 0
2010 2 15 35 154 25 36 6 7 0 0
2011 2 6 105 64 74 8 10 2 1 0
2012 2 25 109 318 76 85 10 8 0 1
2013 2 20 120 27 64 16 20 1 0 1
1979 3 0 0 29 12 12 7 0 0 0
1982 3 0 0 5 30 8 18 2 0 0
1983 3 0 0 7 12 50 2 9 0 0
1984 3 0 0 18 182 72 144 11 5 0
1993 3 0 17 276 73 41 39 60 5 6
1994 3 0 6 91 287 46 16 18 2 3
#n_wt_obs
36
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$yr V1 V2 V3 V4 V5 V6 V7 V8 V9
1978 0.0550 0.0778 0.1035 0.1311 0.1539 0.1520 0.1768 0.2015 0.2289
1979 0.0350 0.0827 0.1028 0.1254 0.1360 0.1510 0.1780 0.2015 0.2289
1980 0.0679 0.0833 0.0977 0.1218 0.1559 0.1657 0.1610 0.2015 0.2289
1981 0.0643 0.0928 0.1115 0.1288 0.1379 0.1498 0.1768 0.2015 0.2289
1982 0.0561 0.0929 0.1096 0.1263 0.1358 0.1469 0.1661 0.1450 0.2289
1983 0.0508 0.0884 0.1060 0.1141 0.1275 0.1657 0.1365 0.2015 0.2289
1984 0.0585 0.0932 0.1173 0.1357 0.1559 0.1657 0.1768 0.2015 0.2289
1985 0.0585 0.0932 0.1173 0.1357 0.1559 0.1657 0.1768 0.2015 0.2289
1986 0.0678 0.1139 0.1375 0.1560 0.1958 0.2048 0.1987 0.2267 0.2289
1987 0.0671 0.1072 0.1508 0.1645 0.1827 0.1657 0.2113 0.2330 0.1958
1988 0.0625 0.1002 0.1368 0.1537 0.1782 0.1897 0.1863 0.2015 0.2620
1989 0.0430 0.1039 0.1376 0.1770 0.1994 0.2127 0.1977 0.2495 0.2034
1990 0.0628 0.1014 0.1380 0.1705 0.1969 0.2162 0.2264 0.2417 0.2345
1991 0.0649 0.0944 0.1192 0.1528 0.1738 0.2005 0.2063 0.2045 0.2034
1992 0.0605 0.1020 0.1328 0.1538 0.1821 0.2035 0.2212 0.2344 0.2518
1993 0.0583 0.0894 0.1190 0.1277 0.1747 0.1848 0.1971 0.1560 0.2130
1994 0.0699 0.0948 0.1112 0.1361 0.1547 0.1680 0.1857 0.1882 0.1830
1995 0.0601 0.0998 0.1167 0.1309 0.1514 0.1682 0.1748 0.2007 0.1853
1996 0.0526 0.0907 0.1126 0.1344 0.1425 0.1643 0.1688 0.1910 0.1835
1997 0.0476 0.0820 0.1092 0.1328 0.1336 0.1494 0.1579 0.1808 0.2034
1998 0.0435 0.0751 0.0972 0.0993 0.1240 0.1328 0.1530 0.1490 0.2034
1999 0.0487 0.0720 0.0891 0.1064 0.1054 0.1390 0.1243 0.1750 0.1730
2000 0.0531 0.0798 0.0888 0.1130 0.1342 0.1356 0.1500 0.1343 0.2034
2001 0.0509 0.0743 0.0911 0.1024 0.1108 0.1142 0.1135 0.1210 0.2034
2002 0.0845 0.0917 0.0989 0.1230 0.0963 0.1192 0.1450 0.1650 0.2034
2003 0.0567 0.0995 0.1070 0.1149 0.1328 0.1490 0.1628 0.1490 0.2034
2004 0.0546 0.0816 0.1013 0.1052 0.1288 0.1277 0.1163 0.1808 0.2034
2005 0.0340 0.0684 0.0775 0.1084 0.1340 0.1300 0.1540 0.1808 0.2034
2006 0.0544 0.0845 0.1026 0.1217 0.1369 0.1505 0.1594 0.1808 0.2034
2007 0.0556 0.0675 0.0744 0.0903 0.1003 0.1171 0.1290 0.1808 0.2034
2008 0.0472 0.0660 0.0791 0.0882 0.0960 0.1114 0.1060 0.1808 0.2034
2009 0.0446 0.0735 0.0729 0.1005 0.1131 0.1141 0.1594 0.1540 0.2034
2010 0.0507 0.0677 0.0821 0.0882 0.0919 0.1037 0.0999 0.1808 0.2034
2011 0.0452 0.0642 0.0741 0.0916 0.1000 0.1020 0.1235 0.0580 0.2034
2012 0.0460 0.0684 0.0870 0.0840 0.0914 0.0986 0.1040 0.1808 0.1140
2013 0.0534 0.0769 0.0863 0.1067 0.1171 0.1169 0.1470 0.1808 0.1210

#eof
999

APPENDIX C. CONTROL AND PROJECTION CONTROL FILES

CONTROL FILE FOR ALL MAJOR HERRING STOCKS (HG, PRD, CC, SOG, WCVI)

```
## _________________________________________________________________________ ##
##                            GENERIC HERRING CONTROLS
##                            BASE SCENARIO FOR JULY2013
## ____________________CONTROLS FOR ESTIMATED PARAMETERS________________________
##
## Prior descriptions:
##            -0 uniform (0,0)
##            -1 normal (p1=mu,p2=sig)
##            -2 lognormal (p1=log(mu),p2=sig)
##            -3 beta (p1=alpha,p2=beta)
##            -4 gamma(p1=alpha,p2=beta)
## _________________________________________________________________________ ##
7  ## npar
## ival    lb    ub    phz   prior   p1    p2     parameter name
## _________________________________________________________________________ ##
  7.60     -5.0   15    4     0     -5.0   15     #log_ro
  0.67     0.2    1.0   4     3     10.0   4.925373  #steepness
  -0.7985077  -5.0   5.0   3    1     -0.7985077 0.4   #log.m
  7.40     -5.0   15    1     0     -5.0   15     #log_avgrec
  7.20     -5.0   15    1     0     -5.0   15     #log_recinit
  0.3043478  0.001  0.999  3    3     17.08696   39.0559   #rho
  0.8695652  0.01   5.0    3    4     25.0  28.75   #kappa (precision)
## _________________________________________________________________________ ##
## __________________________SELECTIVITY PARAMETERS_____________________________ ##
## OPTIONS FOR SELECTIVITY:
##     1) logistic selectivity parameters
##     2) selectivity coefficients
##     3) a constant cubic spline with age-nodes
##     4) a time varying cubic spline with age-nodes
##     5) a time varying bicubic spline with age & year nodes.
##     6) fixed logistic (set isel_type=6, and estimation phase to -1)
##     7) logistic function of body weight.
##     sig=0.05 0.10 0.15 0.20 0.30 0.40 0.50
##     wt =200. 50.0 22.2 12.5 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
  1    1                 1            6            6
## Age at 50% selectivity (logistic)
  3.0    3.0        4.0          2.055   2.055
## STD at 50% selectivity (logistic)
  0.25    0.25       0.25    0.05    0.05
## No. of age nodes for each gear (0 to ignore).
  5    5                 5            0            0
## No. of year nodes for each gear (0 to ignore).
  12   3                 10           0            0
## Estimation phase
  2    2                 2            -2           -2
## Penalty weight for 2nd differences w=1/(2*sig^2)
  125.0   125.0          12.5    12.5    12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
  50.0   50.0       200.0   200.0   200.0
## _________________________________________________________________________ ##
##                 Priors for Survey q                  ##
```

```
## ________________________________________________________________________________ ##
## nits  #number of surveys
         2
## priors 0=uniform density                    1=normal density
         1                    1
## prior log(mean)
   -0.569   -0.569
## prior sd
   0.274    0.274
## ________________________________________________________________________________ ##
## ________________________OTHER MISCELLANEOUS CONTROLS_________________________
##
0                          ## 1 verbose ADMB output (0=off, 1=on)
1                          ## 2 recruitment model (1=beverton-holt, 2=ricker)
0.100           ## 3 std in observed catches in first phase.
0.0707          ## 4 std in observed catches in last phase.
0                          ## 5 Assume unfished in first year (0=FALSE, 1=TRUE)
0.02            ## 6 Minimum proportion to consider in age-proportions for dmvlogistic
0.20            ## 7 Mean fishing mortality for regularizing the estimates of Ft
0.01            ## 8 std in mean fishing mortality in first phase
2.00            ## 9 std in mean fishing mortality in last phase
3                          ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.1                        ## 11 std in deviations for natural mortality
12                         ## 12 number of estimated nodes for deviations in natural mortality
1.00       ## 13 fraction of total mortality that takes place prior to spawning
1         ## 14 switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
## ________________________________________________________________________________ ##
## operational control points for harvest control rule
0.25            ## cutoff_fraction - prop prefishery biomass to unfished biomass used to calculate cutoff
0.20            ## target_hr

## eofc
999
```

CONTROL FILES FOR MINOR HERRING STOCKS

```
## ________________________________________________________________________________ ##
##                                  AREA 2W
## ____________________CONTROLS FOR ESTIMATED PARAMETERS_________________________
##
##  Prior descriptions:
##              -0 uniform (0,0)
##              -1 normal (p1=mu,p2=sig)
##              -2 lognormal (p1=log(mu),p2=sig)
##              -3 beta (p1=alpha,p2=beta)
##              -4 gamma(p1=alpha,p2=beta)
## ________________________________________________________________________________ ##
7  ## npar
##  ival      lb     ub     phz    prior   p1     p2     parameter name
## ________________________________________________________________________________ ##
##    2.60       -5.0    15      4      0      -5.0    15       #log_ro
   2.60       -5.0    15      1      0      -5.0    15       #log_ro
   0.67       0.2     1.0     4      3      10.0    4.925373  #steepness
   -0.7985077  -5.0    5.0      3      1      -0.7985077 0.4    #log.m
   2.40       -5.0    15      1      0      -5.0    15       #log_avgrec
   2.20       -5.0    15      1      0      -5.0    15       #log_recinit
```

```
   0.3043478   0.001   0.999    3       3       17.08696    39.0559    #rho
   0.8695652   0.01    5.0      3       4       25.0  28.75   #kappa (precision)
## ______________________________________________________________________________ ##
## __________________________SELECTIVITY PARAMETERS______________________________ ##
## OPTIONS FOR SELECTIVITY:
##      1) logistic selectivity parameters
##      2) selectivity coefficients
##      3) a constant cubic spline with age-nodes
##      4) a time varying cubic spline with age-nodes
##      5) a time varying bicubic spline with age & year nodes.
##      6) fixed logistic (set isel_type=6, and estimation phase to -1)
##      7) logistic function of body weight.
##      sig=0.05 0.10 0.15 0.20 0.30 0.40 0.50
##      wt =200. 50.0 22.2 12.5 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4 survey
## isel_type
   1       1         1       6
## Age at 50% selectivity (logistic)
   2.0      3.0        3.6     2.055
## STD at 50% selectivity (logistic)
   0.25      0.25      0.25    0.05
## No. of age nodes for each gear (0 to ignore).
   5       5         5       0
## No. of year nodes for each gear (0 to ignore).
   12      3         10      0
## Estimation phase
   -2       2         -2      -1
## Penalty weight for 2nd differences w=1/(2*sig^2)
   125.     125.       12.5    12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
   50.0     50.0      200.0   200.0
## ______________________________________________________________________________ ##
##                         Priors for Survey q                          ##
## ______________________________________________________________________________ ##
## nits  #number of surveys
   1
## priors 0=uniform density     1=normal density
   1
## prior log(mean)
   -0.569
## prior sd
   0.274
## ______________________________________________________________________________ ##
## ________________________OTHER MISCELLANEOUS CONTROLS__________________________
##
0          ## 1  verbose ADMB output (0=off, 1=on)
1          ## 2  recruitment model (1=beverton-holt, 2=ricker)
0.100       ## 3  std in observed catches in first phase.
0.0707      ## 4  std in observed catches in last phase.
0          ## 5  Assume unfished in first year (0=FALSE, 1=TRUE)
0.02        ## 6  Minimum proportion to consider in age-proportions for dmvlogistic
0.20        ## 7  Mean fishing mortality for regularizing the estimates of Ft
0.01        ## 8  std in mean fishing mortality in first phase
2.00        ## 9  std in mean fishing mortality in last phase
3          ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.1         ## 11 std in deviations for natural mortality
```

```
12                              ## 12 number of estimated nodes for deviations in natural mortality
1.00        ## 13 fraction of total mortality that takes place prior to spawning
1          ## 14 switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
## ____________________________________________________________________________ ##

## operational control points for harvest control rule
0.25                ## cutoff_fraction - prop prefishery biomass to unfished biomass used to calculate cutoff
0.20                ## target_hr
## eofc
999

## ____________________________________________________________________________ ##
##                                    AREA 27
## ___________________CONTROLS FOR ESTIMATED PARAMETERS________________________
##
##  Prior descriptions:
##                  -0 uniform (0,0)
##                  -1 normal (p1=mu,p2=sig)
##                  -2 lognormal (p1=log(mu),p2=sig)
##                  -3 beta (p1=alpha,p2=beta)
##                  -4 gamma(p1=alpha,p2=beta)
## ____________________________________________________________________________ ##
7   ## npar
##  ival       lb      ub      phz     prior    p1      p2      parameter name
## ____________________________________________________________________________ ##
   3.60       -5.0    15       4       0       -5.0    15       #log_ro
   0.67       0.2     1.0      4       3       10.0    4.925373  #steepness
   -0.7985077  -5.0     5.0      3       1       -0.7985077 0.4    #log.m
   2.40       -5.0    15       1       0       -5.0    15       #log_avgrec
   2.20       -5.0    15       1       0       -5.0    15       #log_recinit
   0.3043478   0.001   0.999   3       3       17.08696    39.0559   #rho
   0.8695652   0.01    5.0     3       4       25.0  28.75   #kappa (precision)
## ____________________________________________________________________________ ##
## _________________________SELECTIVITY PARAMETERS_____________________________ ##
## OPTIONS FOR SELECTIVITY:
##      1) logistic selectivity parameters
##      2) selectivity coefficients
##      3) a constant cubic spline with age-nodes
##      4) a time varying cubic spline with age-nodes
##      5) a time varying bicubic spline with age & year nodes.
##      6) fixed logistic (set isel_type=6, and estimation phase to -1)
##      7) logistic function of body weight.
##      sig=0.05 0.10 0.15 0.20 0.30 0.40 0.50
##      wt =200. 50.0 22.2 12.5 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
   1       1         1       6       6
## Age at 50% selectivity (logistic)
   2.0      3.0       3.6     2.055   2.055
## STD at 50% selectivity (logistic)
   0.25      0.25      0.25    0.05    0.05
## No. of age nodes for each gear (0 to ignore).
   5       5         5       0       0
## No. of year nodes for each gear (0 to ignore).
   12      3         10      0       0
## Estimation phase
```

```
   -2       2         2      -1      -1
## Penalty weight for 2nd differences w=1/(2*sig^2)
   125.     50.       12.5    12.5    12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
   50.0     50.0      200.0   200.0   200.0
## ________________________________________________________________________ ##
##                          Priors for Survey q                            ##
## ________________________________________________________________________ ##
## nits  #number of surveys
   2
## priors 0=uniform density     1=normal density
   1      1
## prior log(mean)
   -0.569  -0.569
## prior sd
   0.274   0.274
## ________________________________________________________________________ ##
## ______________________OTHER MISCELLANEOUS CONTROLS________________________
##
0          ## 1  verbose ADMB output (0=off, 1=on)
1          ## 2  recruitment model (1=beverton-holt, 2=ricker)
0.100       ## 3  std in observed catches in first phase.
0.0707      ## 4  std in observed catches in last phase.
0          ## 5  Assume unfished in first year (0=FALSE, 1=TRUE)
0.02        ## 6  Minimum proportion to consider in age-proportions for dmvlogistic
0.20        ## 7  Mean fishing mortality for regularizing the estimates of Ft
0.01        ## 8  std in mean fishing mortality in first phase
2.00        ## 9  std in mean fishing mortality in last phase
3          ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.1         ## 11 std in deviations for natural mortality
12                           ## 12 number of estimated nodes for deviations in natural mortality
1.00        ## 13 fraction of total mortality that takes place prior to spawning
1          ## 14 switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
## ________________________________________________________________________ ##

## operational control points for harvest control rule
0.25              ## cutoff_fraction - prop prefishery biomass to unfished biomass used to calculate cutoff
0.20              ## target_hr

## eofc
999
```

PROJECTION CONTROL FILES BY HERRING STOCK

Projection control file for HG

```
## ______________________________ ##
## Projection file control (pfc) ##
## ______________________________ ##
##
## n_tac  length of catch vector.
12
## tac vector (1000 mt)
0 1.0 2.0 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0
##
```

```
## ________________________________ ##
## Control options              ##
## ________________________________ ##
8   ## Length of control options vector

## ________________________________ ##
## Consider 3 scenarios:
##  Scenario A: longterm average
##        Scenario B: recent average
##        Scenario C: longterm + average
## ________________________________ ##

## This is Scenario B

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2)  Last year for mean natural mortality rate

2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4)  Last year for average fecundity/weight-at-age in projections

##not currently used
1951 ## - 5) Start year for average recruitment period in projections.
2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

## eof
-999
```

Projection control file for PRD

```
## ________________________________ ##
## Projection file control (pfc) ##
## ________________________________ ##
##
## n_tac  length of catch vector.
11
## tac vector (1000 mt)
0  1  2  3  4  5  6  7  8  9  10
##
## ________________________________ ##
## Control options              ##
## ________________________________ ##
8   ## Length of control options vector
## ________________________________ ##
## Consider 3 scenarios:
##  Scenario A: longterm average
##        Scenario B: recent average
##        Scenario C: longterm + average
## ________________________________ ##

## This is Scenario B (5-year means)

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2)  Last year for mean natural mortality rate
```

2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4) Last year for average fecundity/weight-at-age in projections

##not currently used
1951 ## - 5) Start year for average recruitment period in projections.
2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

eof
-999

Projection control file for CC

```
## _________________________________ ##
## Projection file control (pfc) ##
## _________________________________ ##
##
## n_tac  length of catch vector.
7
## tac vector (1000 mt)
0  0.5 1  2  3  4  5
##
## _________________________________ ##
## Control options              ##
## _________________________________ ##
8    ## Length of control options vector
## _________________________________ ##
## Consider 3 scenarios:
##  Scenario A: longterm average
##        Scenario B: recent average
##        Scenario C: longterm + average
## _________________________________ ##

## This is Scenario B

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2)  Last year for mean natural mortality rate

2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4)  Last year for average fecundity/weight-at-age in projections

##not currently used
1951 ## - 5) Start year for average recruitment period in projections.
2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

## eof
-999
```

Projection control file for SOG

```
## _________________________________ ##
## Projection file control (pfc) ##
## _________________________________ ##
##
## n_tac  length of catch vector.
8
## tac vector (1000 mt)
0  10 15 20 25 30 35 40
##
## _________________________________ ##
## Control options              ##
## _________________________________ ##
8    ## Length of control options vector
## _________________________________ ##
## Consider 3 scenarios:
##  Scenario A: longterm average
##        Scenario B: recent average
##        Scenario C: longterm + average
## _________________________________ ##

## This is Scenario B

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2)  Last year for mean natural mortality rate

2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4)  Last year for average fecundity/weight-at-age in projections

##not currently used
1951 ## - 5) Start year for average recruitment period in projections.
2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

## eof
-999
```

Projection control file for WCVI

```
## _________________________________ ##
## Projection file control (pfc) ##
## _________________________________ ##
##
## n_tac  length of catch vector.
8
## tac vector (1000 mt)
0  2  3  3.5 4  4.5 5  6
##
## _________________________________ ##
## Control options              ##
## _________________________________ ##
8    ## Length of control options vector
## _________________________________ ##
## Consider 3 scenarios:
```

```
##  Scenario A: longterm average
##        Scenario B: recent average
##        Scenario C: longterm + average
## _________________________________ ##

## This is Scenario B

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2)  Last year for mean natural mortality rate

2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4)  Last year for average fecundity/weight-at-age in projections

##not currently used
1951 ## - 5) Start year for average recruitment period in projections.
2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

## eof
-999
```

Projection control file for Area 2W

```
## _________________________________ ##
## Projection file control (pfc) ##
## _________________________________ ##
##
## n_tac  length of catch vector.
6
## tac vector (1000 mt)
0  0.2 0.3 0.4 0.5 0.6
##
## _________________________________ ##
## Control options              ##
## _________________________________ ##
8    ## Length of control options vector

## _________________________________ ##
## Consider 3 scenarios:
##  Scenario A: longterm average
##        Scenario B: recent average
##        Scenario C: longterm + average
## _________________________________ ##

## This is Scenario B

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2)  Last year for mean natural mortality rate

2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4)  Last year for average fecundity/weight-at-age in projections

##not currently used
1978 ## - 5) Start year for average recruitment period in projections.
```

2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

eof
-999

Projection control file for Area 27

____
Projection file control (pfc)
____
##
n_tac length of catch vector.
7
tac vector (1000 mt)
0 0.025 0.05 0.75 0.1 0.125 0.15
##
____
Control options
____
8   ## Length of control options vector

____
Consider 3 scenarios:
Scenario A: longterm average
Scenario B: recent average
Scenario C: longterm + average
____

This is Scenario B

2009 ## - 1) Start year for mean natural mortality rate
2013 ## - 2) Last year for mean natural mortality rate

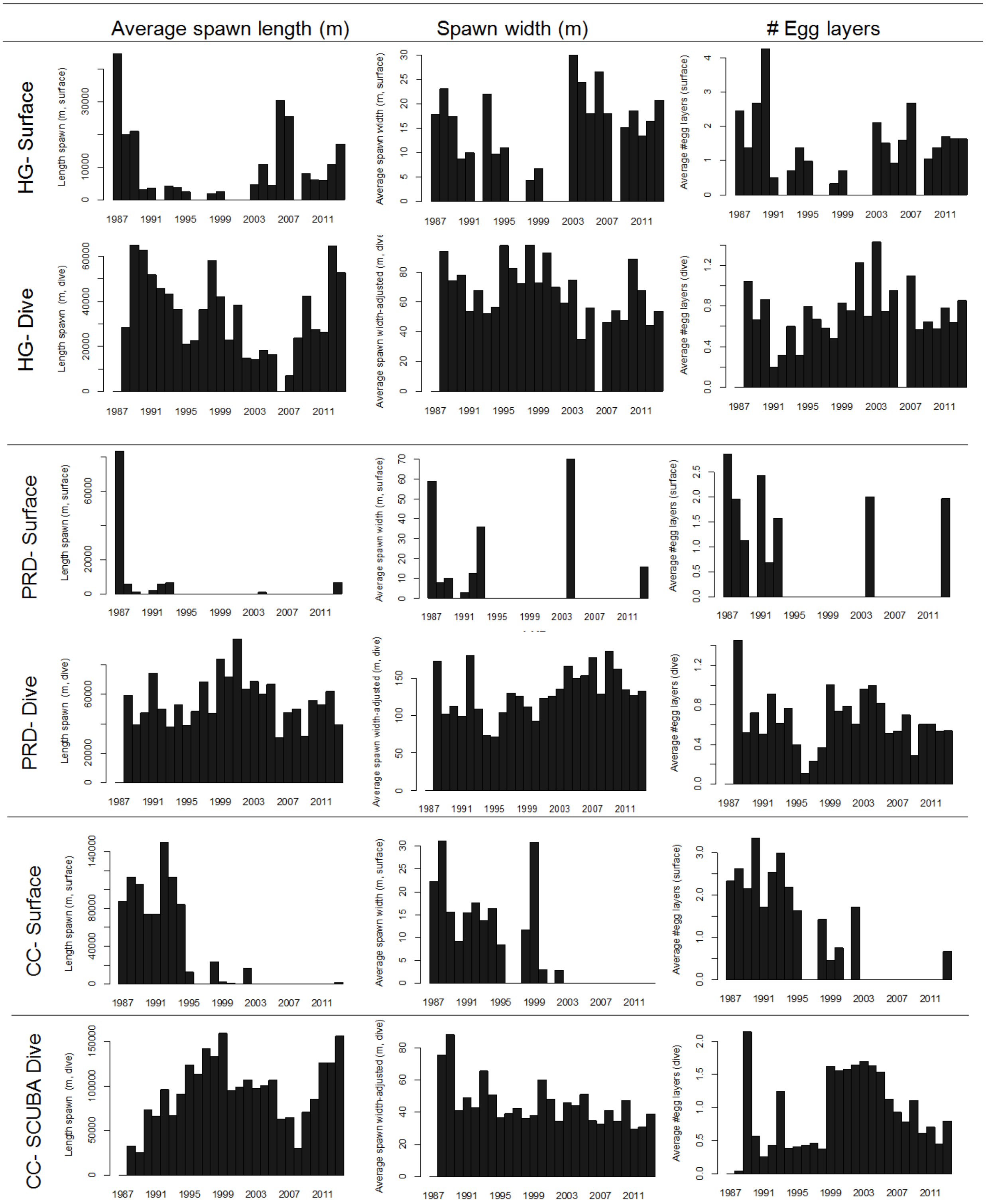
2009 ## - 3) Start year for average fecundity/weight-at-age in projections
2013 ## - 4) Last year for average fecundity/weight-at-age in projections

##not currently used
1978 ## - 5) Start year for average recruitment period in projections.
2012 ## - 6)   End year for average recruitment period in projections.

##reference_period_years
2000 ## - 7) start of reference period
2006 ## - 8) end of reference period

eof
-999

APPENDIX D. ADDITIONAL MODEL OUTPUTS



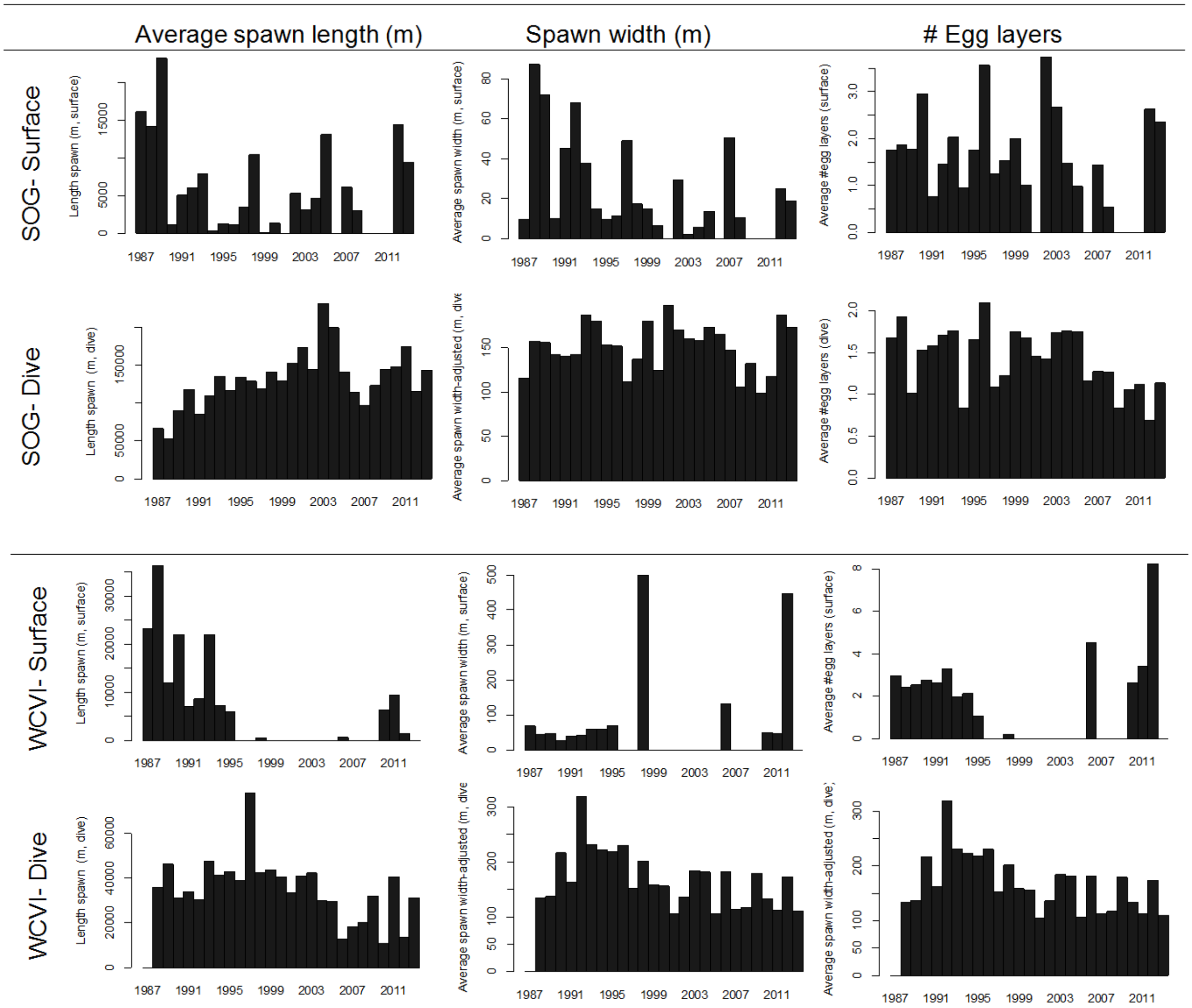


Figure D 1. Spawn survey observations contributing to major herring stock spawn survey indices, as reported in Figure 3 (Section 2.2.1).

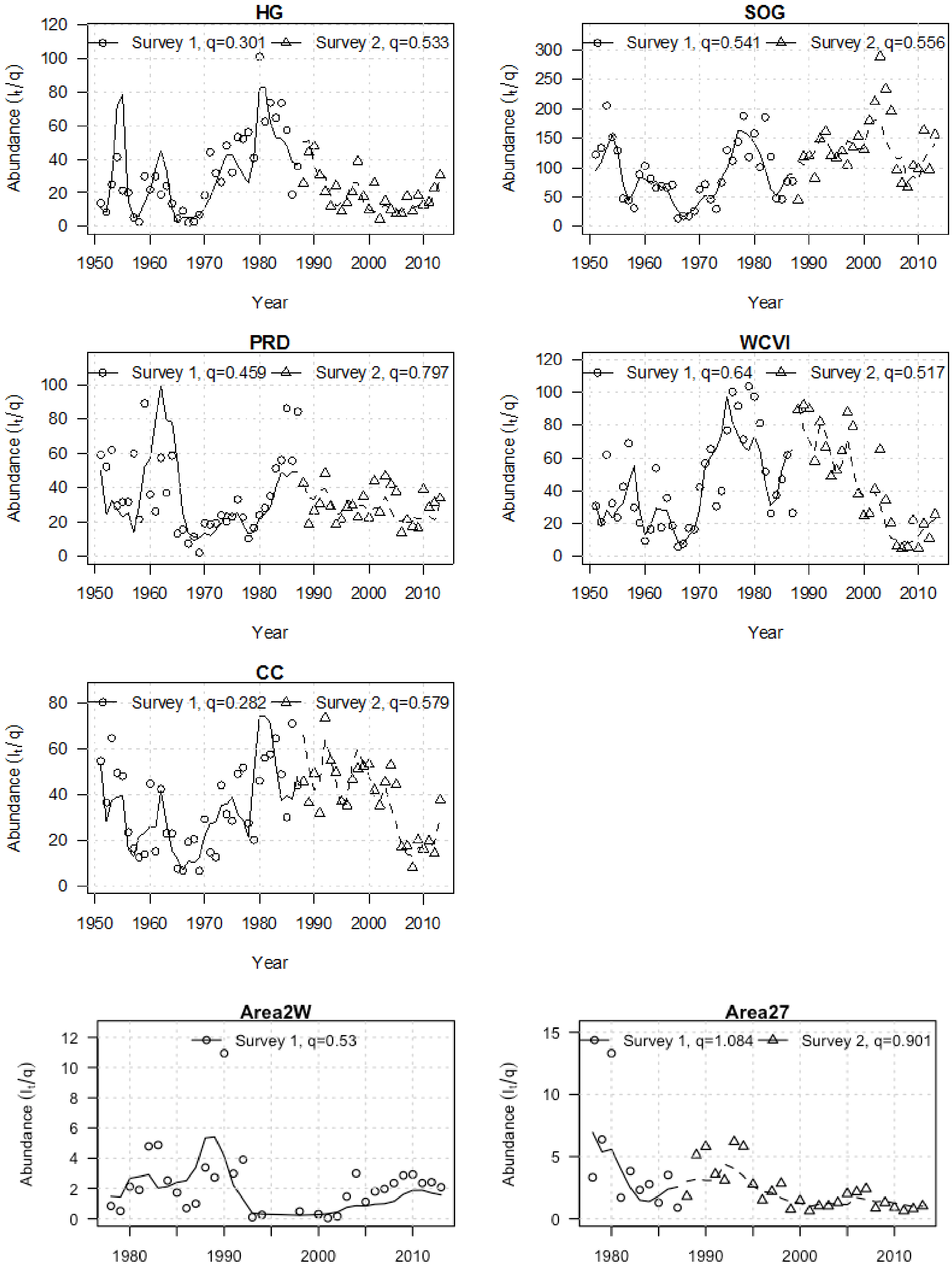


Figure D 2. Observed (points) and predicted (lines) spawn survey abundance data scaled by the MLE estimate of q by herring stock. In each panel, the corresponding scalar (q) is presented for each type of survey (circles for surface; triangles for dive).

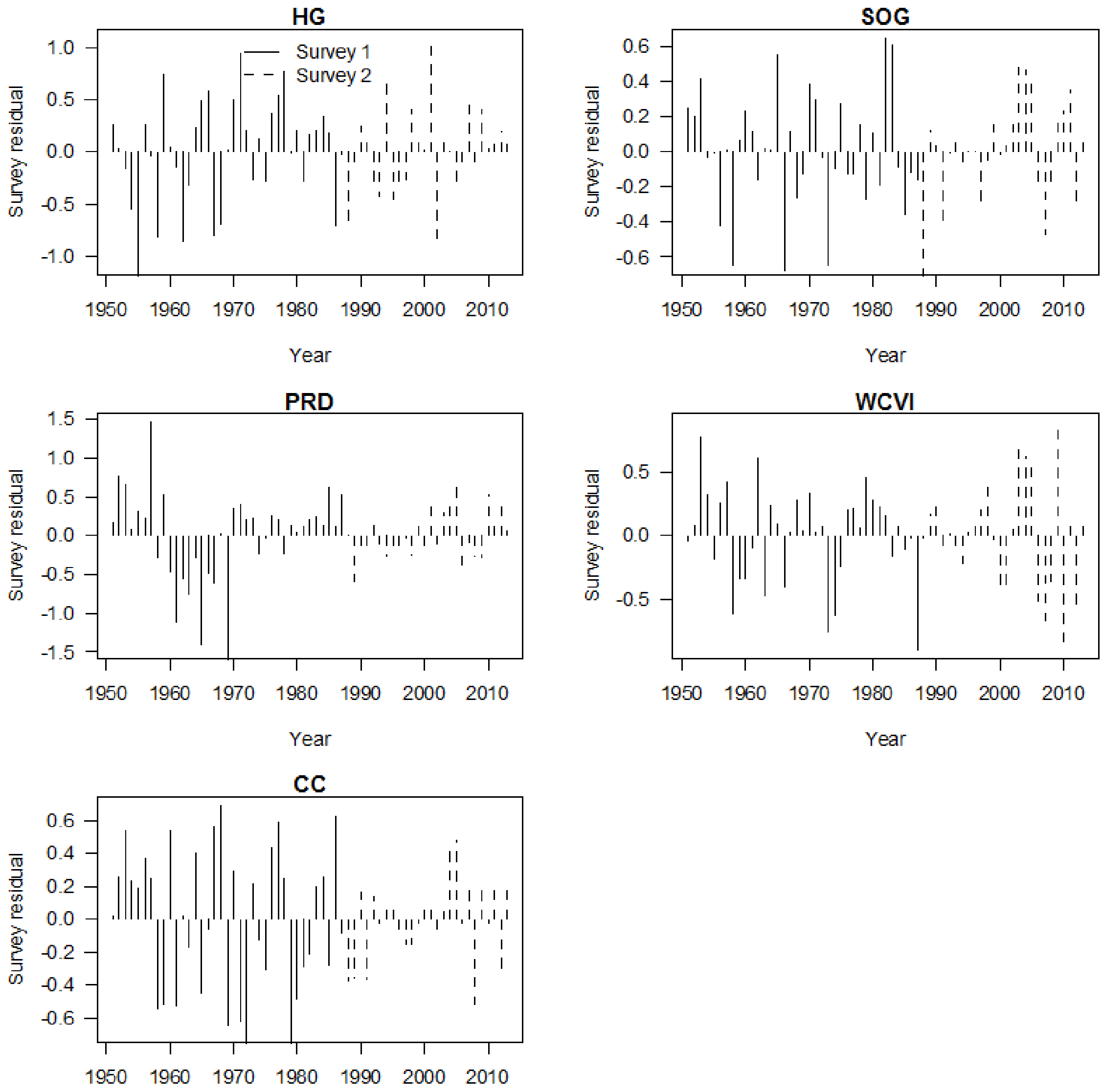


Figure D 3. Residual patterns for the log difference between observed and predicted spawn survey abundance for the five major stock areas. Spawn survey data based on surface estimates are show as solid lines and data based on diver surveys is shown as dashed lines (major stocks).

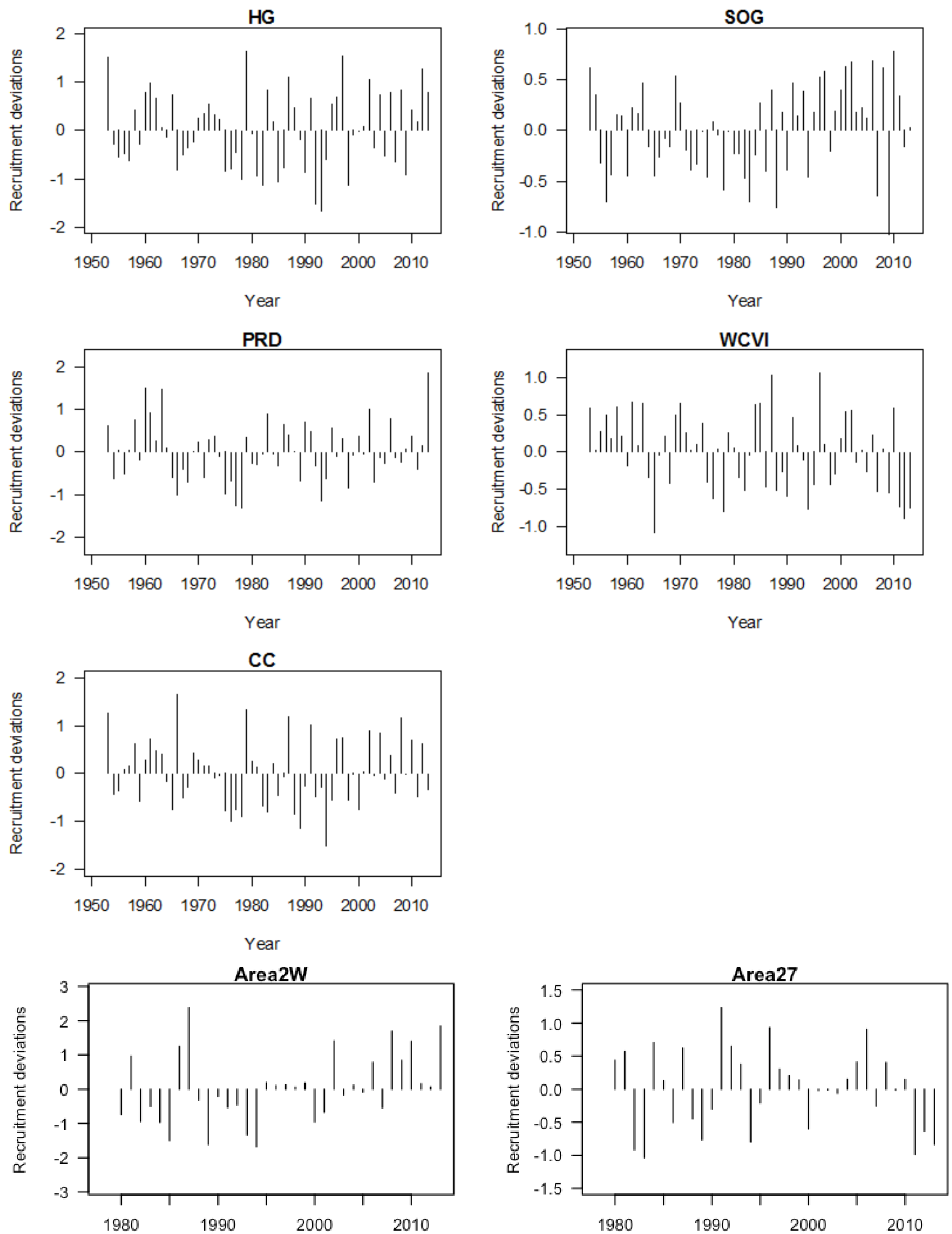


Figure D 4. Log residual differences between estimated age-2 recruits and the recruitment predicted by the Beverton-Holt model and estimated spawning stock biomass (major and minor stocks).

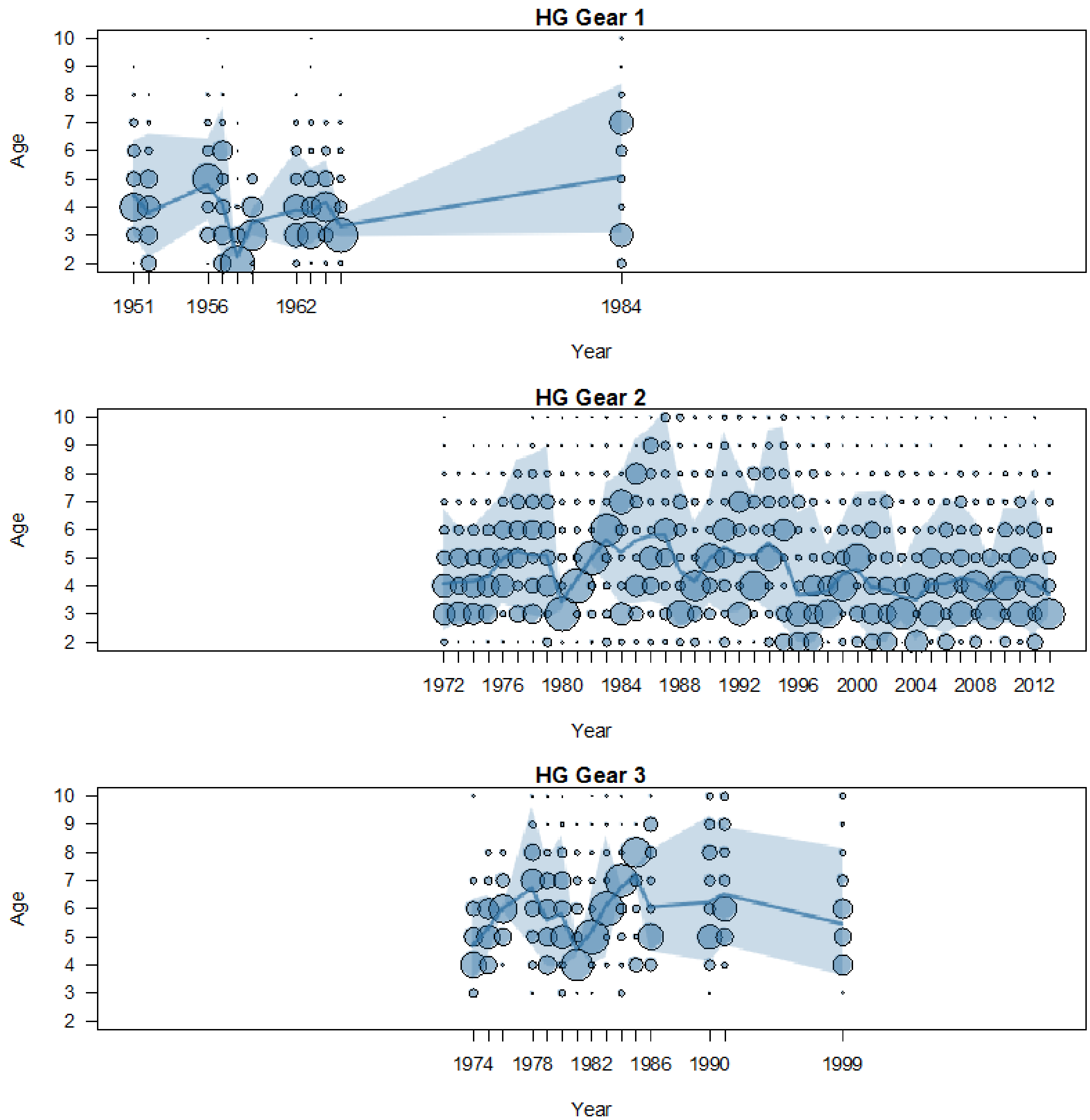


Figure D 5. Proportion-at-age versus time for winter (top), roe seine (middle), and roe gillnet fisheries (bottom) for Haida Gwaii. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

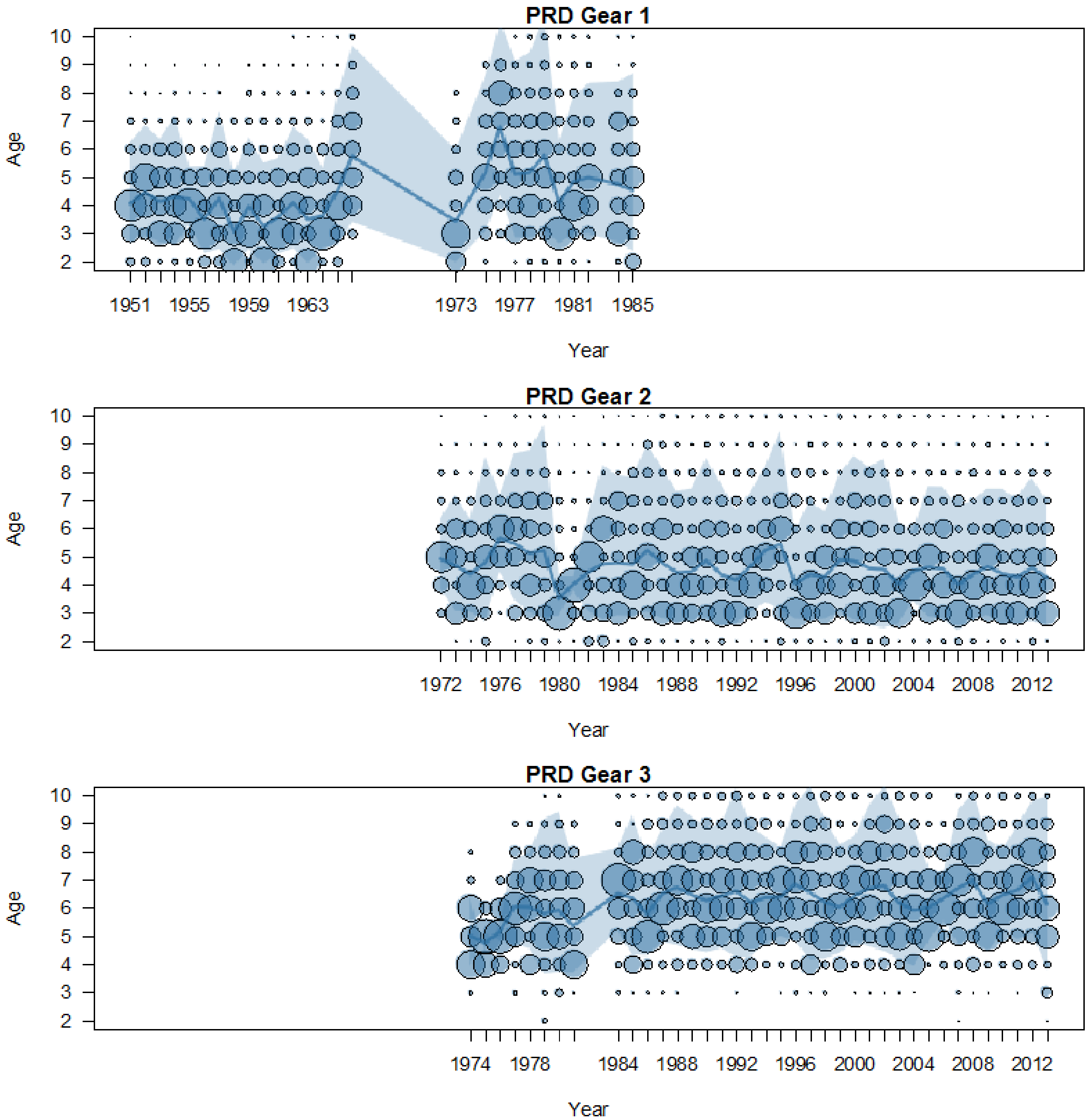


Figure D 6. Proportion-at-age versus time for winter (top), roe seine (middle), and roe gillnet fisheries (bottom) for Prince Rupert District. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

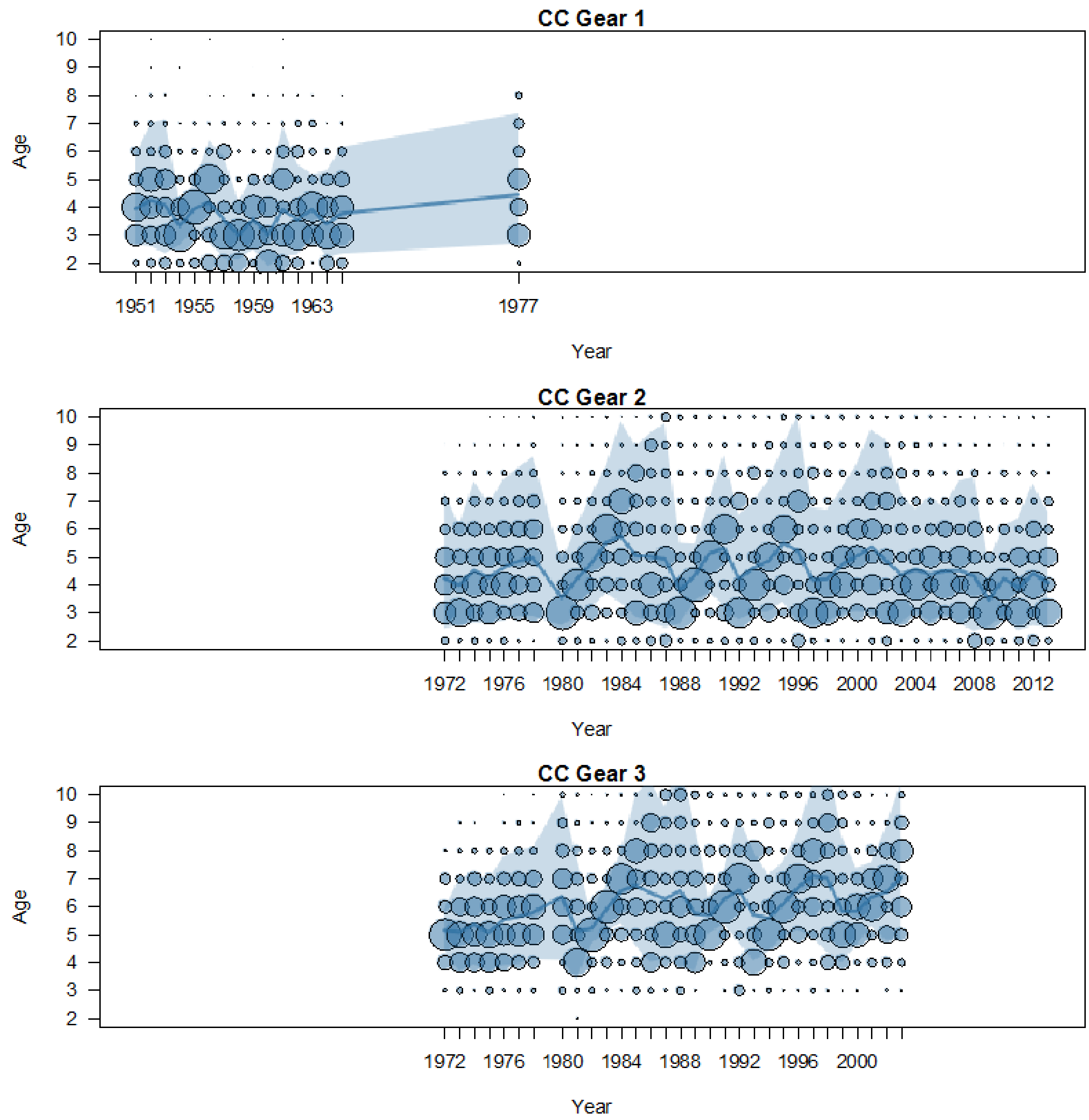


Figure D 7. Proportion-at-age versus time for winter (top), roe seine (middle), and roe gillnet fisheries (bottom) for Central Coast. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

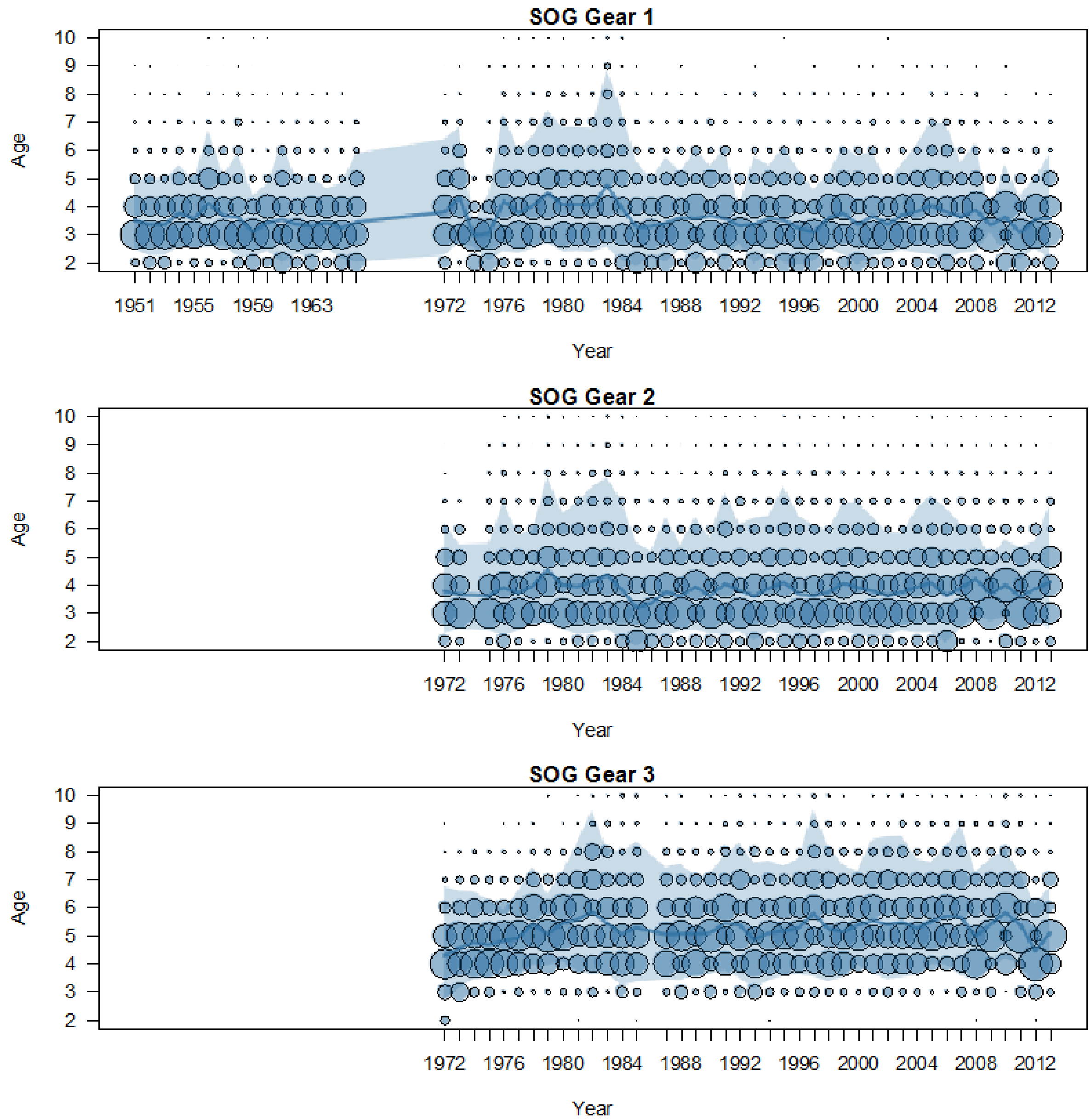


Figure D 8. Proportion-at-age versus time for winter (top), roe seine (middle), and roe gillnet fisheries (bottom) for Strait of Georgia. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

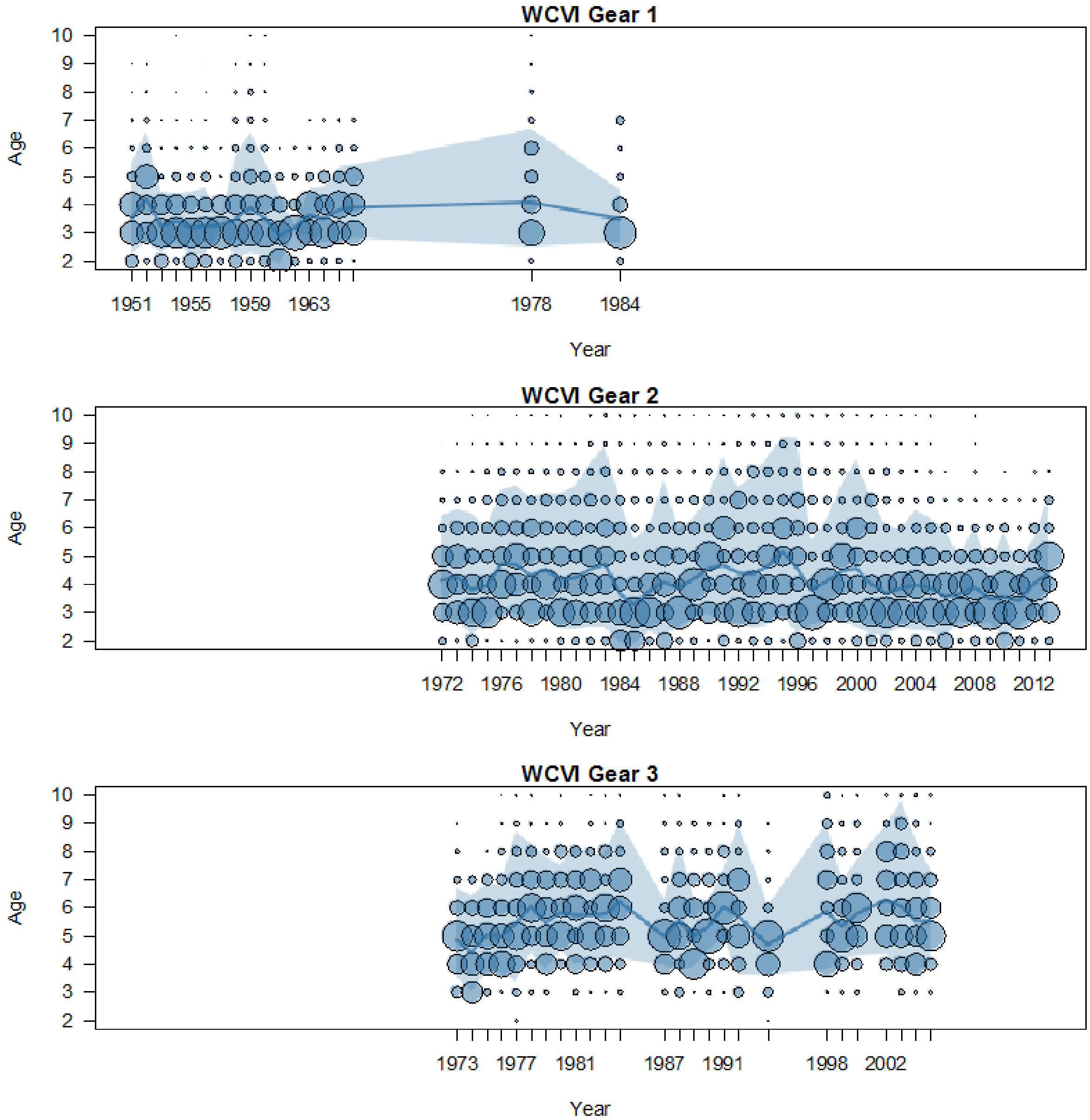


Figure D 9. Proportion-at-age versus time for winter (top), roe seine (middle), and roe gillnet fisheries (bottom) for West Coast Vancouver Island. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

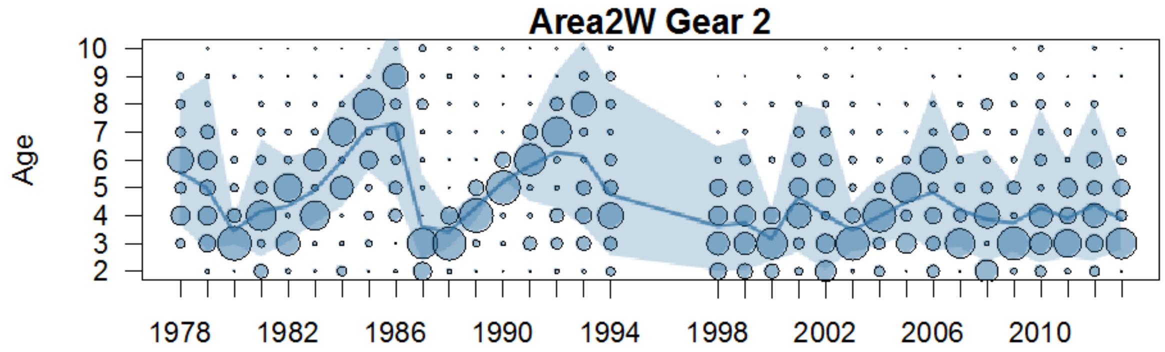


Figure D 10. Proportion-at-age versus time for roe seine for Area 2W. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

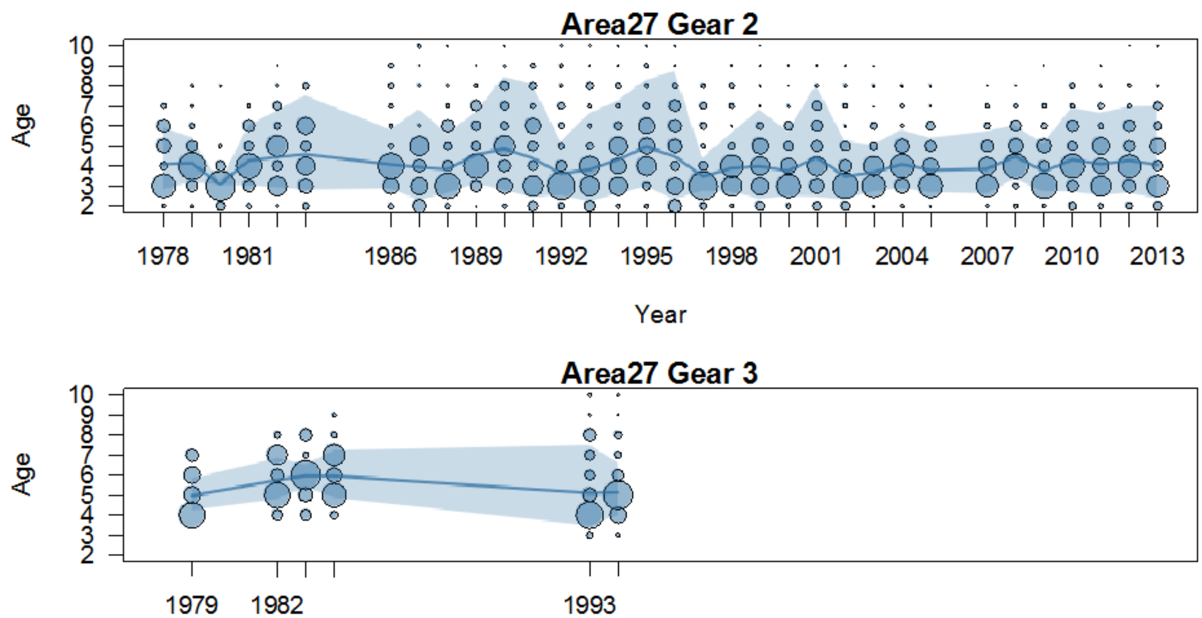


Figure D 11. Proportion-at-age versus time for roe seine (middle) and roe gillnet fisheries (bottom) for Area 27. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10. Mean age of all samples (line) and approximate 90% distribution of ages by year is represented by the shaded polygon.

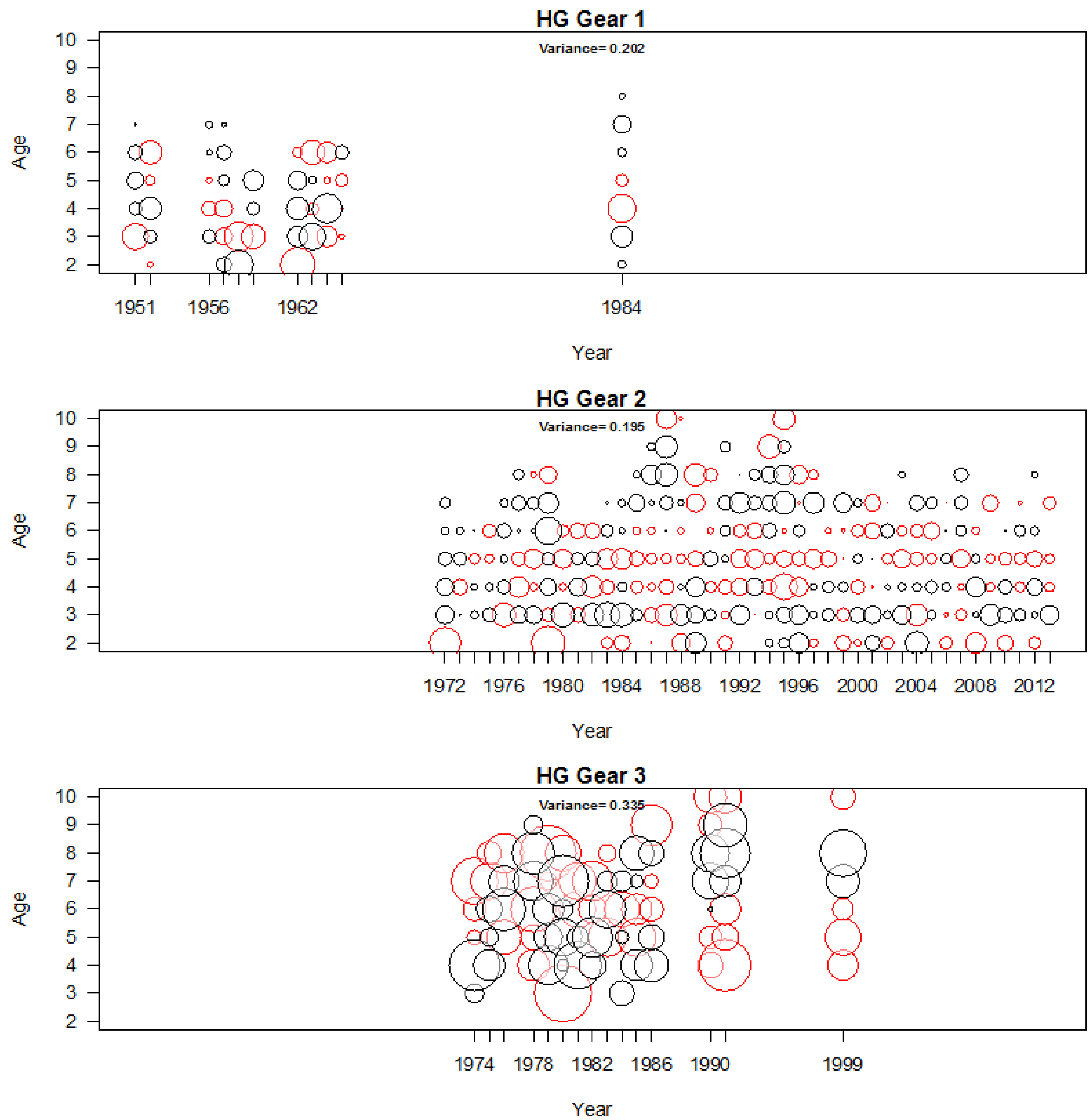


Figure D 12. Residual difference between the observed and predicted proportions-at-age for Haida Gwaii for each of the three gear types (Gear 1 = winter, Gear 2 = roe seine, Gear 3 = roe gillnet). The area of each circle is proportional to the residual, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

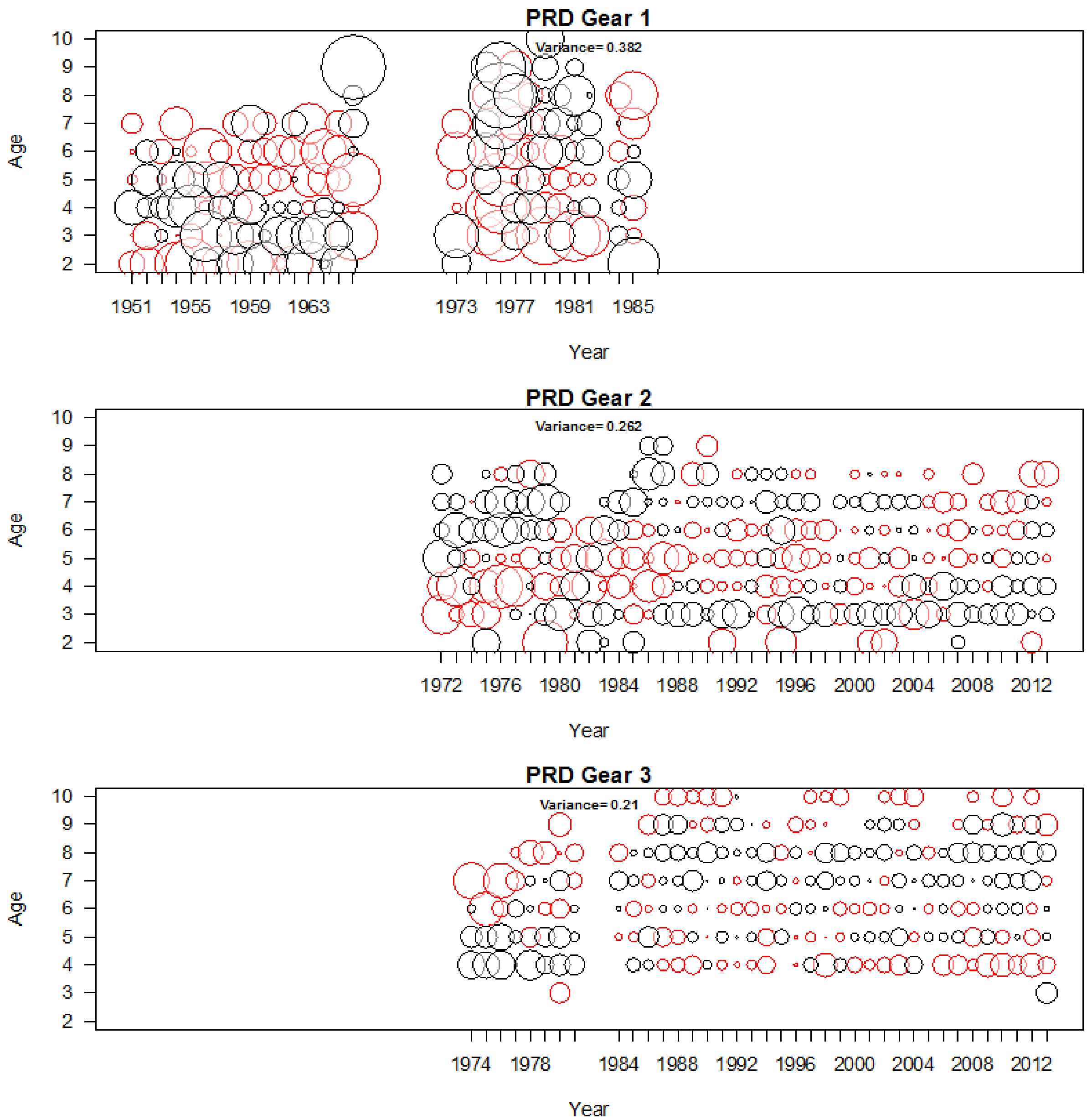


Figure D 13. Residual difference between the observed and predicted proportions-at-age for Prince Rupert District for each of the three gear types (Gear 1 = winter, Gear 2 = roe seine, Gear 3 = roe gillnet). The area of each circle is proportional to the residual, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

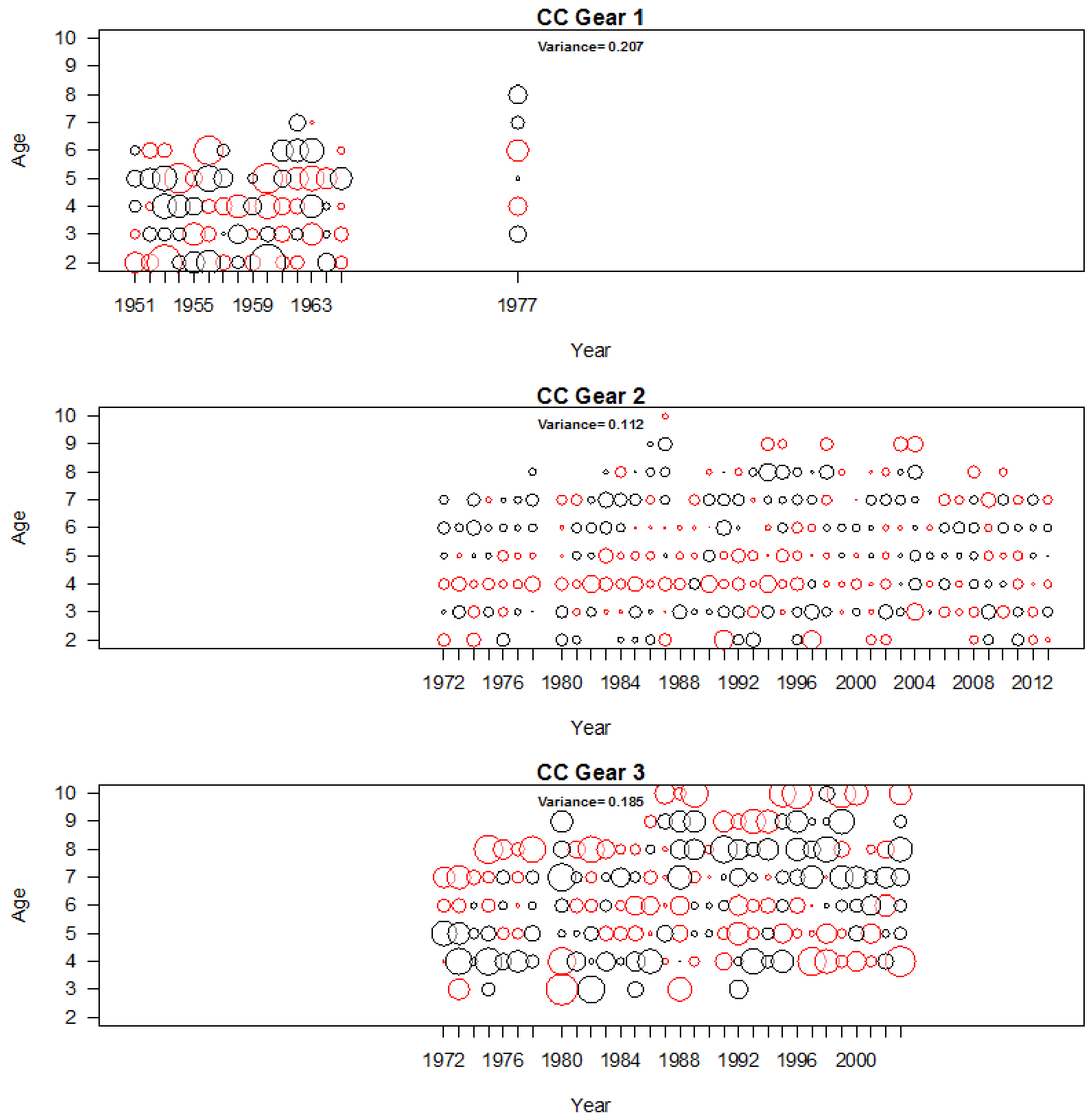


Figure D 14. Residual difference between the observed and predicted proportions-at-age for Central Coast for each of the three gear types (Gear 1 = winter, Gear 2 = roe seine, Gear 3 = roe gillnet). The area of each circle is proportional to the residual, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

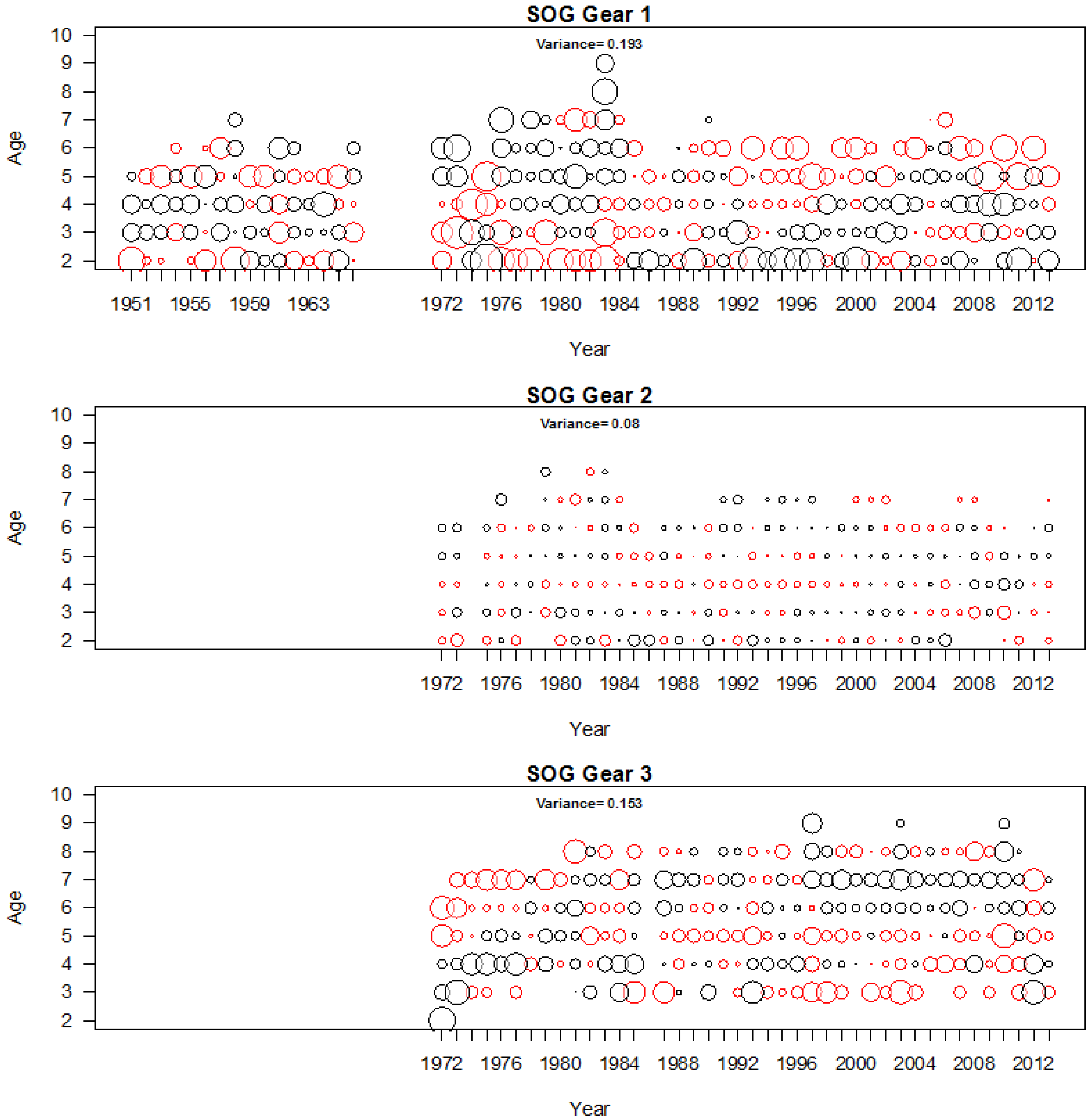


Figure D 15. Residual difference between the observed and predicted proportions-at-age for Strait of Georgia for each of the three gear types (Gear 1 = winter, Gear 2 = roe seine, Gear 3 = roe gillnet). The area of each circle is proportional to the residual, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

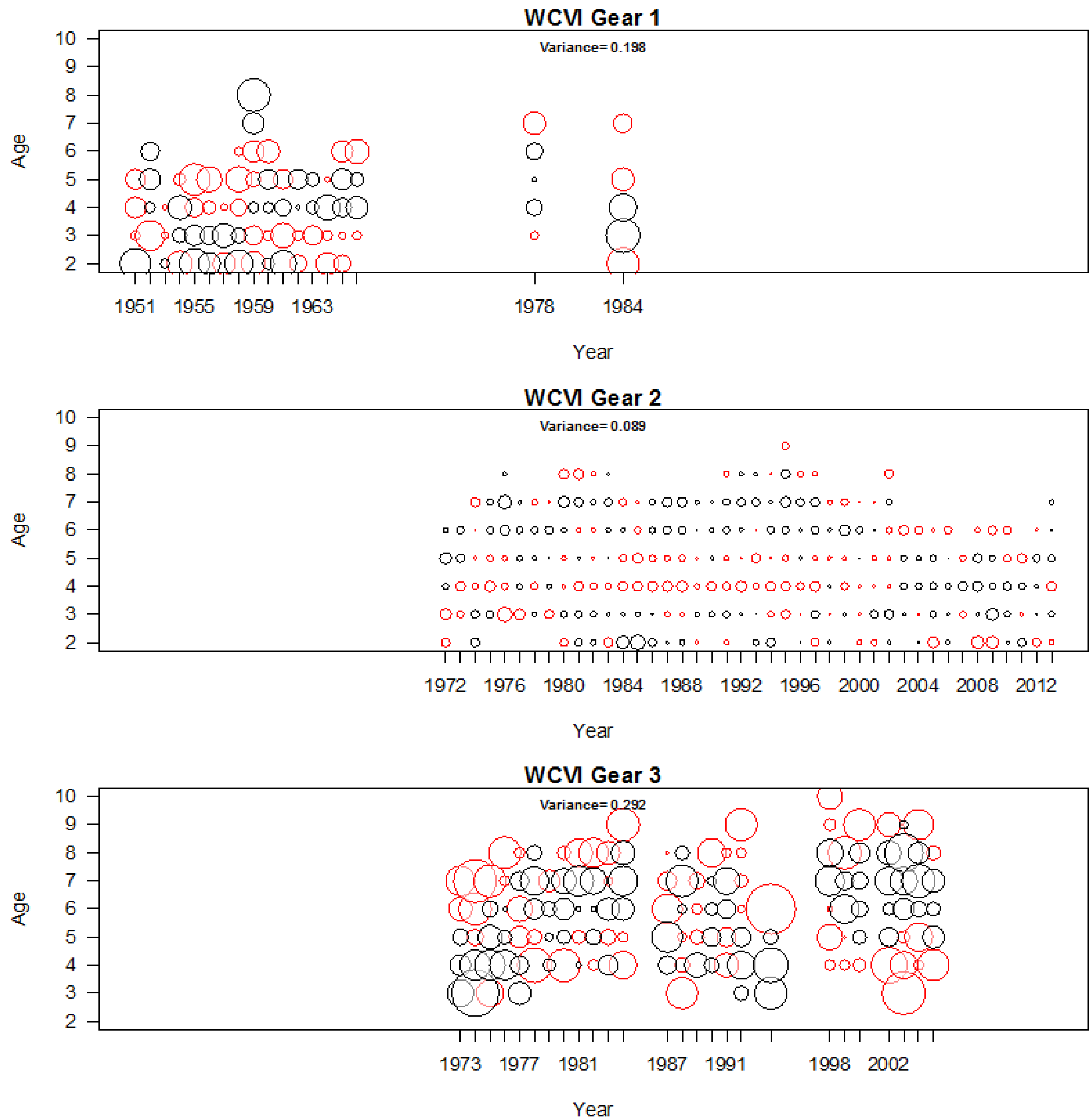


Figure D 16. Residual difference between the observed and predicted proportions-at-age for West Coast Vancouver Island for each of the three gear types (Gear 1 = winter, Gear 2 = roe seine, Gear 3 = roe gillnet). The area of each circle is proportional to the residual, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

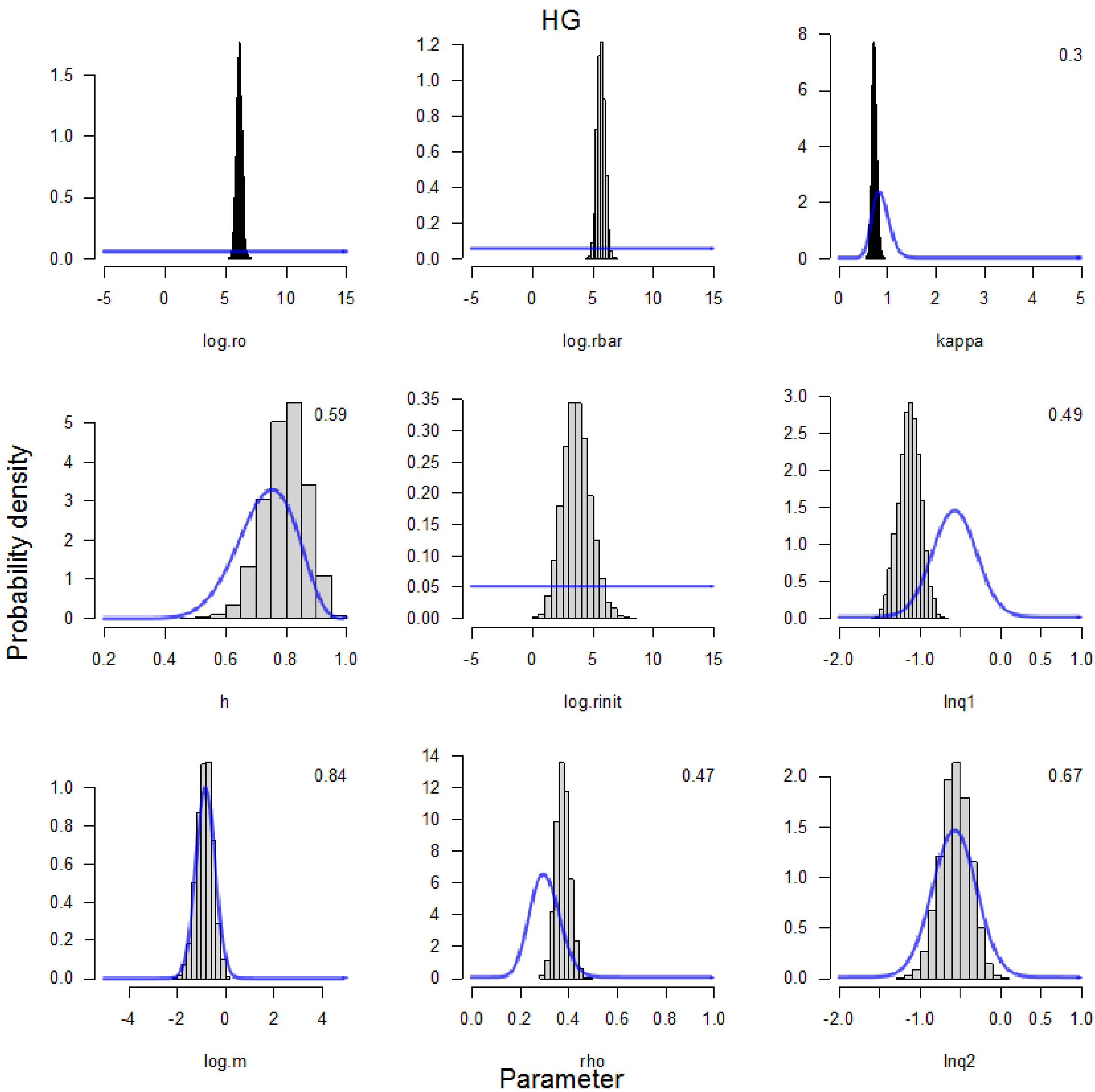


Figure D 17. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 and lnq2) for the Haida Gwaii stock. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

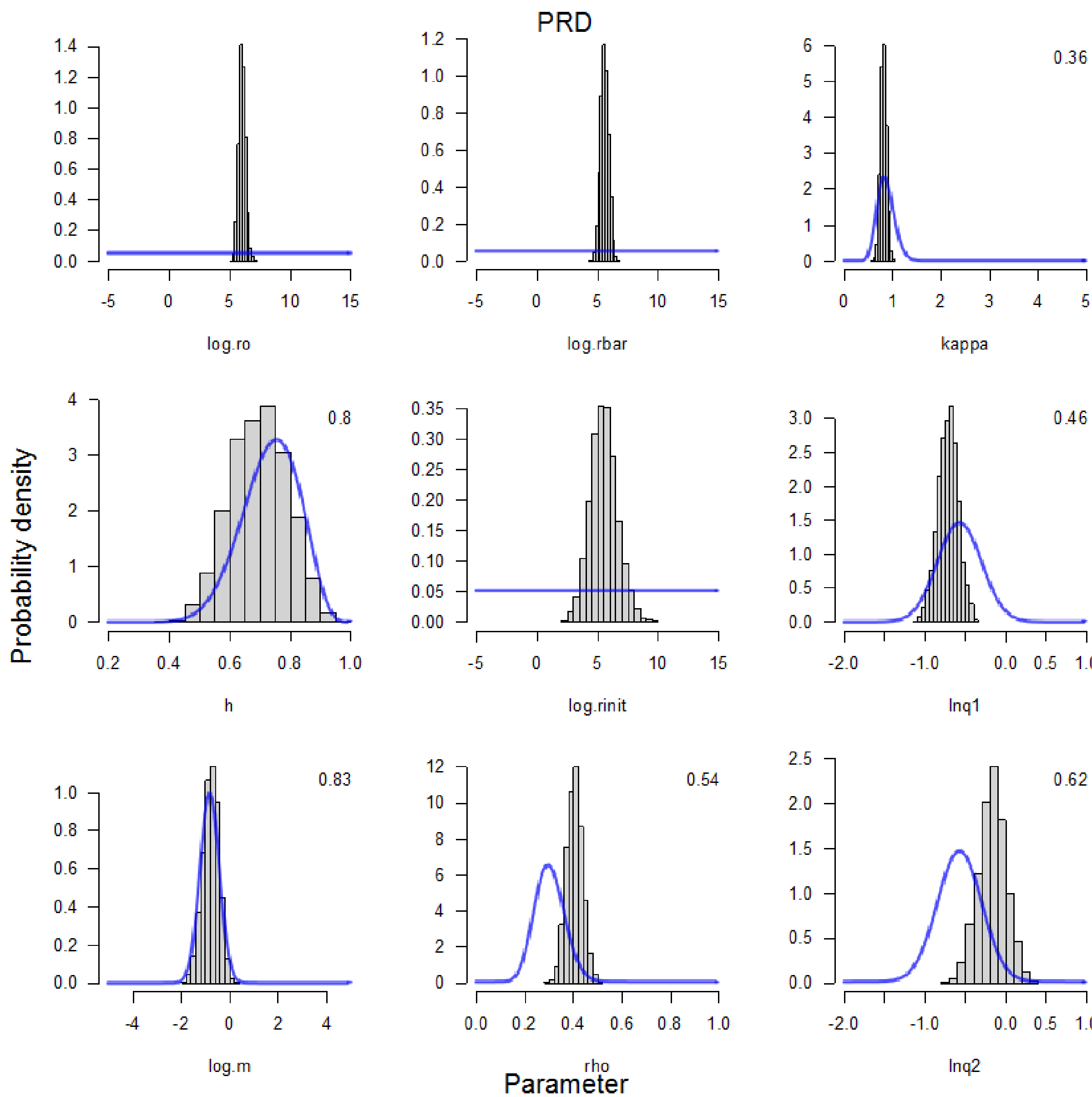


Figure D 18. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 and lnq2) for the Prince Rupert District stock. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

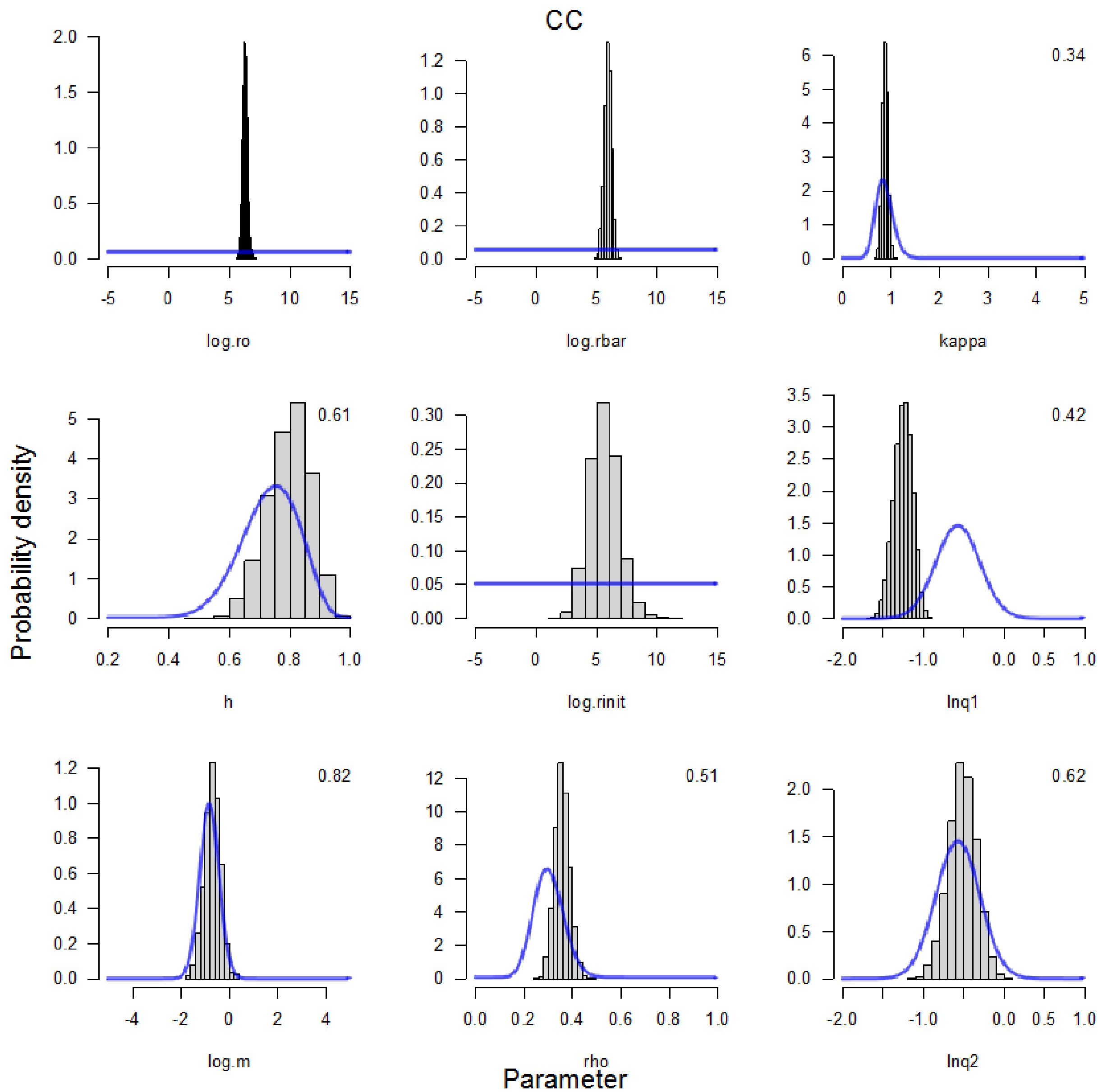


Figure D 19. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 and lnq2) for the Central Coast stock. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

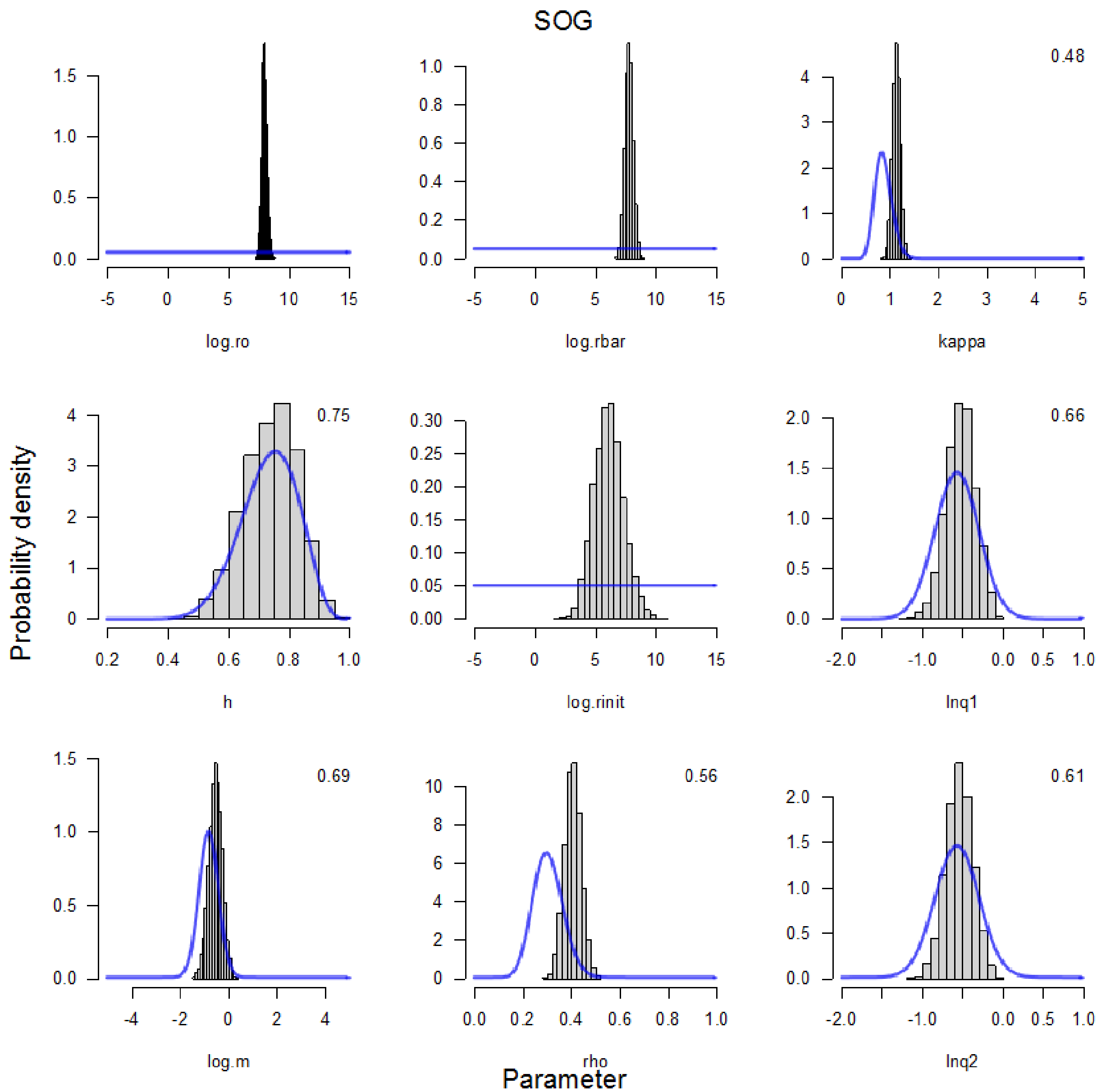


Figure D 20. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 and lnq2) for the Strait of Georgia stock. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

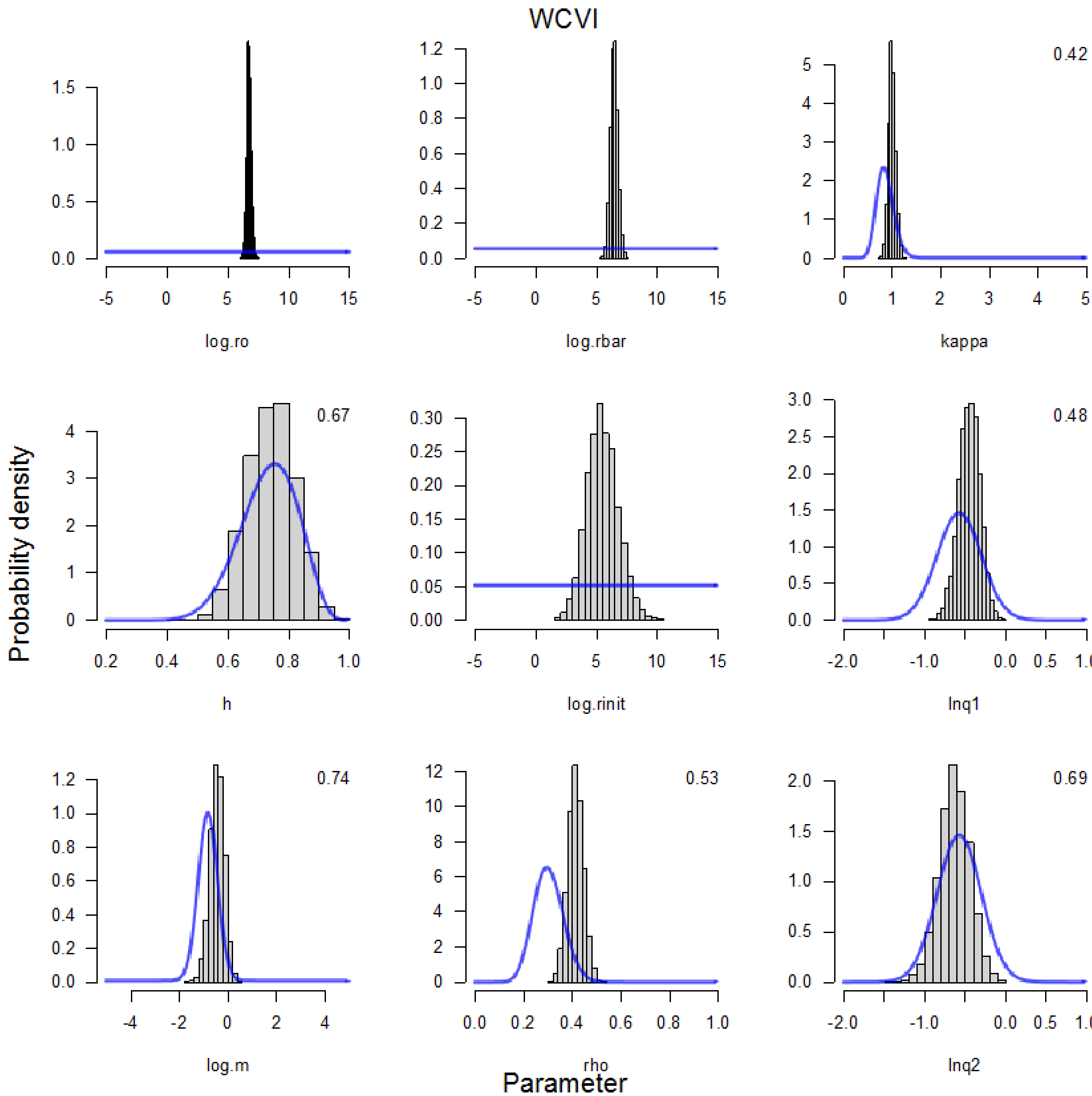


Figure D 21. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 and lnq2) for the West Coast Vancouver Island stock. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

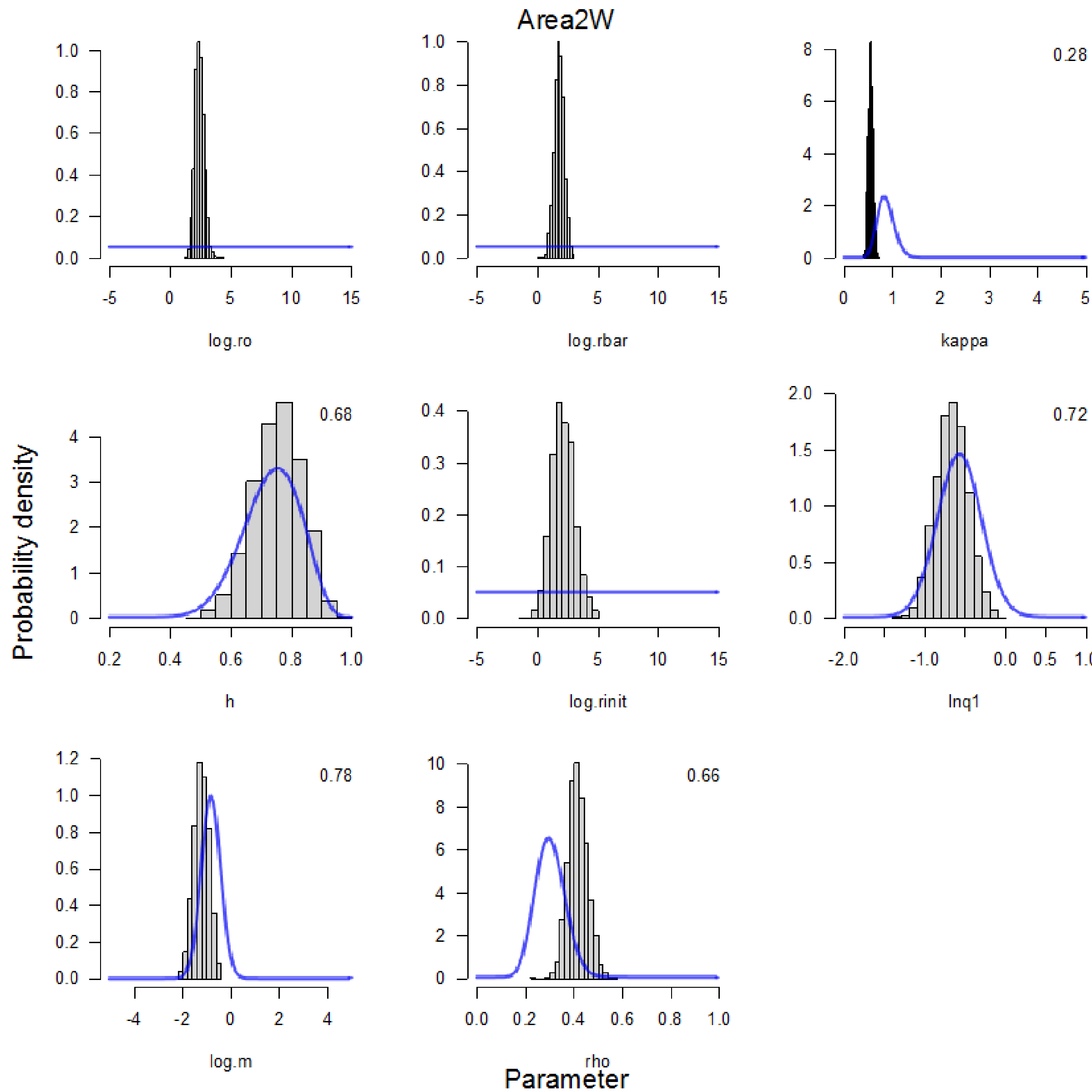


Figure D 22. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 only) for Area 2W. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

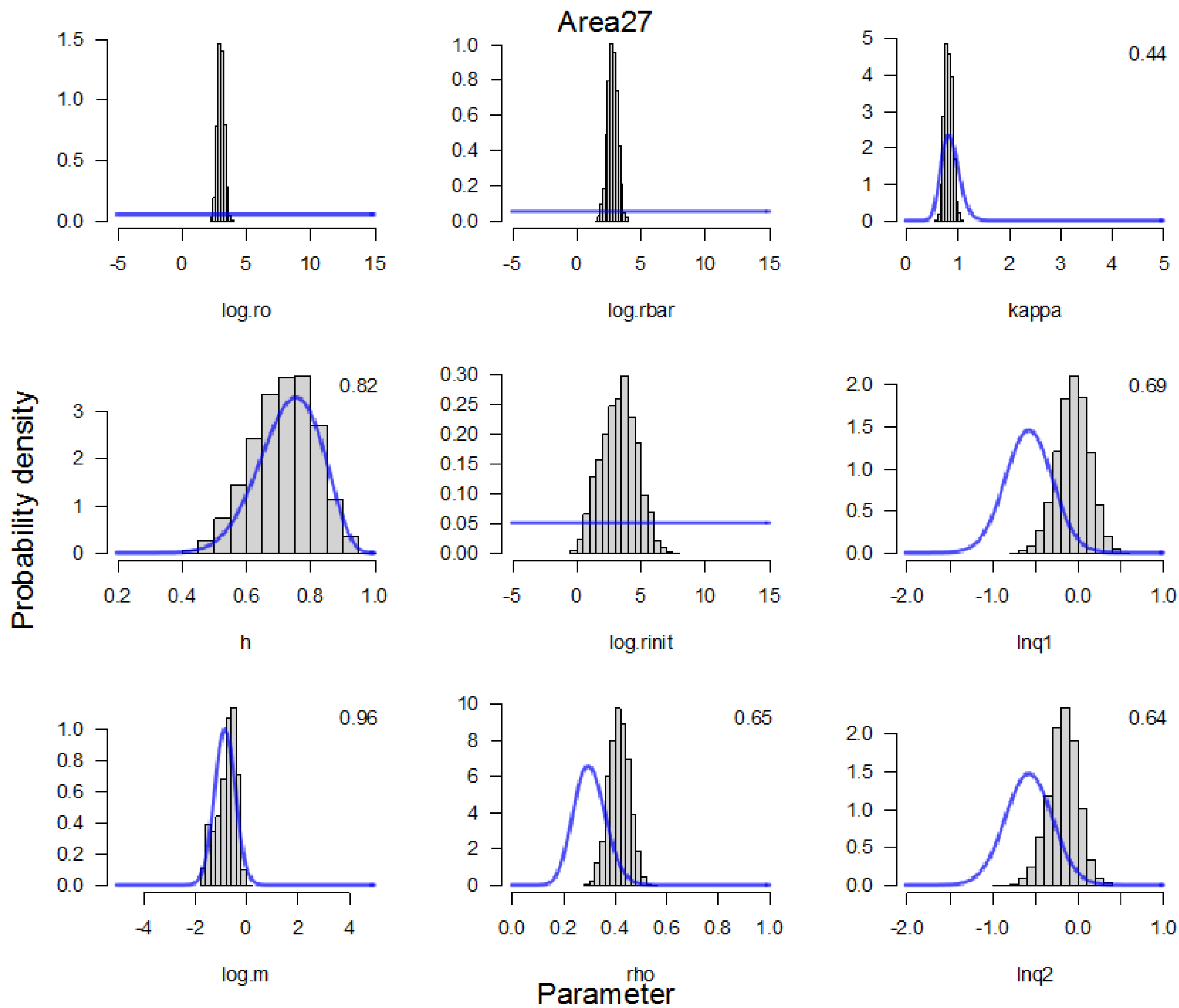


Figure D 23. Marginal posterior densities (histograms) and prior densities (blue lines) for the seven leading parameters and for the spawn survey scalar (lnq1 and lnq2) for Area 27. Note the x-axis range corresponds to the lower and upper bounds of each model parameter and, where applicable, the number in the top right corner is the ratio of posterior standard deviation to prior standard deviation (a ratio close to one implies no information in the data to estimate the parameter).

Table D 1. Leading parameters: MPD and marginal posterior density estimates by herring stock area.

	Posterior estimates			
	MPD	Median	5th percentile	95th percentile
HG				
R_0 (millions)	481.59	455.78	314.74	622.53
steepness (*h*)	0.82	0.80	0.68	0.88
Natural mortality (*M*)	0.41	0.43	0.24	0.64
R_bar (average recruitment)	324.78	284.10	171.27	426.83
R̈ (initial recruitment)	41.34	36.12	6.40	166.20
rho (ρ)	0.37	0.37	0.33	0.41
kappa ( )	0.78	0.73	0.65	0.80
q1	0.30	0.32	0.26	0.38
q2	0.53	0.57	0.42	0.71
PRD				
R_0 (millions)	426.73	404.58	263.93	589.48
steepness (*h*)	0.73	0.70	0.54	0.82
Natural mortality (*M*)	0.46	0.46	0.26	0.69
R_bar (average recruitment)	297.11	257.84	149.38	402.88
R̈ (initial recruitment)	291.89	236.25	43.59	1,050.44
rho (ρ)	0.41	0.40	0.35	0.45
kappa ( )	0.84	0.81	0.71	0.90
q1	0.46	0.49	0.39	0.57
q2	0.80	0.84	0.63	1.05
CC				
R_0 (millions)	532.49	534.89	391.75	716.44
steepness (*h*)	0.82	0.80	0.67	0.88
Natural mortality (*M*)	0.48	0.50	0.28	0.74
R_bar (average recruitment)	391.93	380.65	228.02	557.21
R̈ (initial recruitment)	332.66	257.91	41.65	1,252.75
rho (ρ)	0.35	0.36	0.31	0.40
kappa ( )	0.93	0.88	0.78	0.95
q1	0.28	0.29	0.23	0.33
q2	0.58	0.60	0.45	0.74
SOG				
R_0 (millions)	2,921.96	2,781.04	1,901.67	3,758.48
steepness (*h*)	0.78	0.74	0.59	0.85
Natural mortality (*M*)	0.57	0.58	0.36	0.82
R_bar (average recruitment)	2,488.59	2,243.30	1,293.58	3,495.79
R̈ (initial recruitment)	735.35	413.30	60.09	2,030.86
rho (ρ)	0.41	0.40	0.35	0.45
kappa ( )	1.23	1.13	0.99	1.24
q1	0.54	0.59	0.44	0.74
q2	0.56	0.58	0.44	0.72
WCVI				
steepness (*h*)	0.76	0.74	0.61	0.84

	Posterior estimates			
	MPD	Median	5th percentile	95th percentile
Natural mortality (*M*)	0.64	0.64	0.39	0.93
R_bar (average recruitment)	643.80	617.10	378.79	917.70
R ̈(initial recruitment)	384.22	222.99	32.14	1,272.75
rho (ρ)	0.42	0.41	0.36	0.45
kappa ( )	1.07	0.99	0.88	1.09
q1	0.64	0.64	0.51	0.75
q2	0.52	0.53	0.39	0.67
Area 2W				
R_0 (millions)	9.79	10.72	6.11	18.07
steepness (*h*)	0.78	0.76	0.62	0.86
Natural mortality (*M*)	0.29	0.29	0.17	0.44
R_bar (average recruitment)	5.69	5.84	3.03	9.61
R ̈(initial recruitment)	7.48	7.73	1.91	26.44
rho (ρ)	0.41	0.41	0.35	0.47
kappa ( )	0.57	0.55	0.47	0.61
q	0.53	0.51	0.37	6.59
Area 27				
R_0 (millions)	15.34	20.15	13.52	28.19
steepness (*h*)	0.83	0.72	0.55	0.84
Natural mortality (*M*)	0.54	0.50	0.22	0.71
R_bar (average recruitment)	15.11	16.13	8.70	26.55
R ̈(initial recruitment)	45.90	27.91	2.79	147.77
rho (ρ)	0.45	0.41	0.35	0.47
kappa ( )	0.86	0.81	0.69	0.91
q1	1.12	0.95	0.69	1.20
q2	1.00	0.85	0.62	1.04

APPENDIX E. MINOR HERRING STOCKS

This assessment reports the status of the minor Pacific Herring (*Clupea pallasii*) stocks: Area 2W (west coast of Haida Gwaii) and Area 27 (north west coast of Vancouver Island), B.C., Canada (see Figure 1).

DATA AND ASSESSMENT

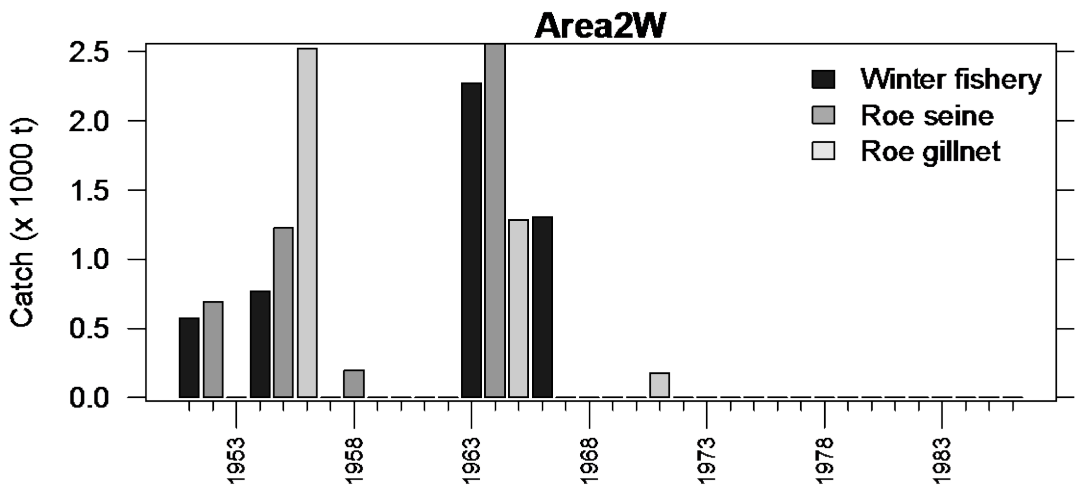
This assessment reports a single base-case model representing the collective work of the Technical Working Group (TWG). The catch-age model is fitted to three sources of data: commercial catch, spawn survey biomass index, and proportions-at-age. The assessment depends primarily upon the spawn survey biomass index for information on the scale of the minor herring stocks. For Area 2W, surface survey data are available from 1978-2013 and for Area 27, a combination of surface (1978-1987) and dive (1988-2013) survey data are available. A limited number of commercial SOK samples and seine test fishery age-composition data (1978-2013) are combined for each of the three gear types (where applicable), contributing to the assessment model's ability to resolve strong and weak cohorts, and to forecast recruitment.

The assessment uses Bayesian methods to incorporate prior information and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. Marginal posterior distributions for estimated model parameters were constructed using the AD Model Builder built in Metropolis-Hastings algorithm (Gelman et al. 2004). For each minor assessment area, a systematic sample of 2,000 points were taken from a chain of length 1,000,000, intended to represent a random sample from the joint posterior distribution.

Assessment results include median posterior distributions for the following: biomass reconstructions, stock depletion, recruitment, and instantaneous natural mortality. A comparison of total and spawning stock biomass, selectivity, and total instantaneous mortality are presented as maximum posterior density (MPD) estimates.

Total catch

The recent 10-years have seen both minor stocks open for commercial spawn-on-kelp (SOK) opportunities only. Commercial landings from the spawn-on-kelp (SOK) fishery are available only as pounds of product validated and not tonnes of fish used/ spawned. Thus, commercial landings for this fishery are not included as inputs to the assessment model because there is no basis for verifying mortality imposed on the population by the fishery. Catch time series (**Figure E 1)** excludes SOK.



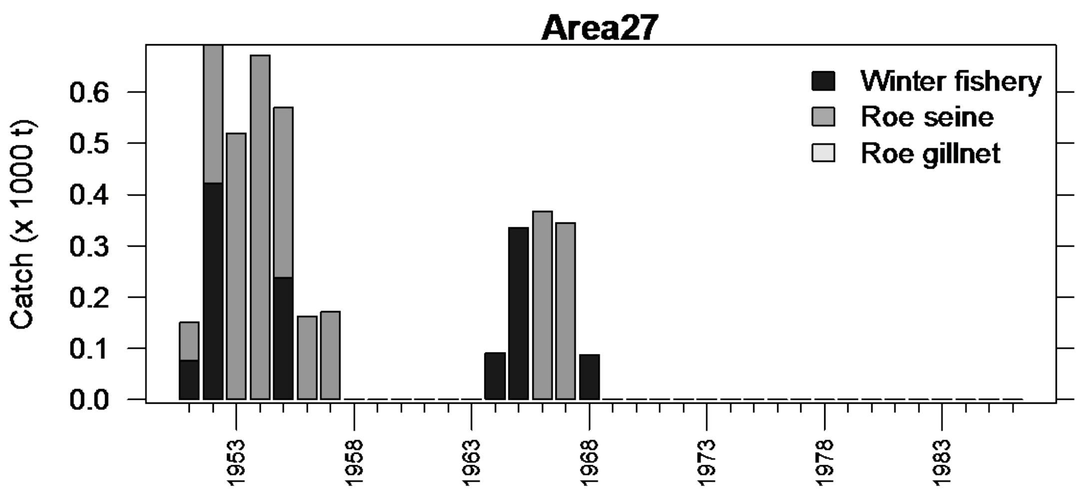


Figure E 1. Total Pacific Herring catch used in the assessment by gear type/ fishing period, 1978-2013, for the minor herring stocks. Black bars denote winter fishery (reduction period: 1978 – 1967, F&B: 1978 – 2013), grey bars denote seine roe fishery (1978 – 2013) and light grey bars denote gillnet roe fishery (1978 – 2013). Units: x 1,000 metric tonnes (t).

Spawn survey data

Time series of spawn survey biomass indices are shown on **Figure E 2** for the two minor stocks (1978-2013). Note that an error in input data for the 2012 spawn index in Area 27, was discovered (replaced 963 tonnes with 706 tonnes).

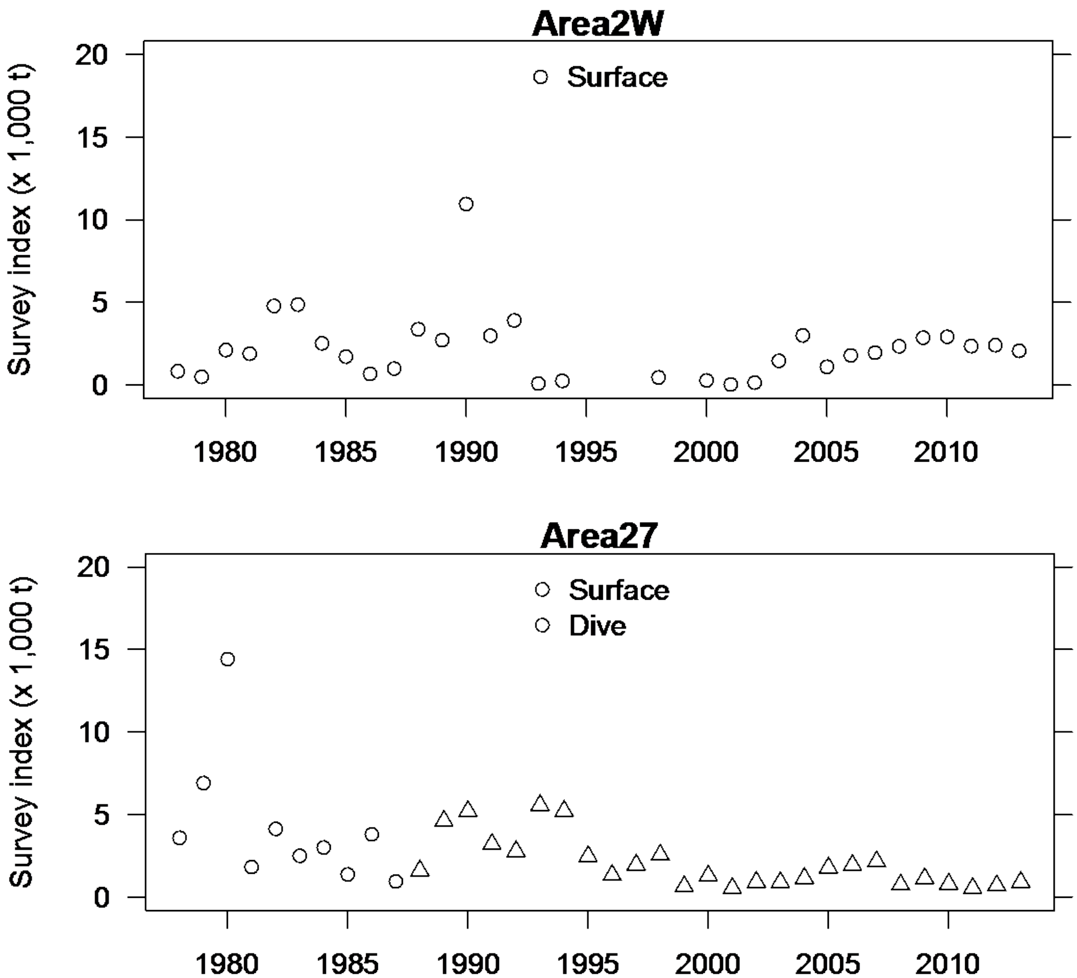


Figure E 2 . Survey biomass index for the minor herring stocks from 1978 – 2013, resulting from annual spawn deposition surveys. Survey index is in biomass units of x 1,000 metric tonnes. "Surface" represents the time series of surface survey observations and "Dive" represents the time series of primarily SCUBA dive survey observations.

Biomass and stock status

Area 2W: The assessment shows that the spawning stock biomass has been declining since 2011 (**Table E 1, Figure E 3**). The decreasing spawning stock biomass is being driven by declining spawn index since 2010 (**Figure E 2**) and increases in instantaneous natural mortality (**Figure E 8).**The current (2013) median posterior spawning biomass is estimated to be 110% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 45% to 233% (**Table E 1**).

Area 27: The assessment shows that the spawning stock biomass has been at a constant level over the past 10-years (**Table E 1, Figure E 3**). Instantaneous natural mortality is apparently decreasing (**Figure E 8).**The current (2013) median posterior spawning biomass is estimated to be 55% of the estimated unfished equilibrium level (SB_0) with 90% posterior credibility intervals ranging from 31% to 98% **(Table E 2**).

Table E 1. Area 2W: Recent estimated Pacific Herring spawning biomass (SB_t, metric tonnes) and depletion level relative to estimated unfished equilibrium spawning biomass (SB_0).

	Spawning biomass (t)			Depletion (SB_t/SB_0)		
Year	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
2003	760	1,287	2,111	0.18	0.36	0.66
2004	865	1,476	2,447	0.21	0.41	0.75
2005	831	1,430	2,364	0.20	0.40	0.72
2006	954	1,640	2,720	0.23	0.46	0.82
2007	1,001	1,734	2,880	0.25	0.48	0.85
2008	1,196	2,046	3,391	0.29	0.57	0.98
2009	1,730	3,016	4,988	0.44	0.83	1.42
2010	2,125	3,692	6,190	0.56	1.02	1.72
2011	2,179	3,994	7,080	0.60	1.11	1.88
2012	1,944	3,910	7,681	0.55	1.09	2.01
2013	1,557	3,938	9,171	0.45	1.10	2.33

Table E 2. Area 27: Recent estimated Pacific Herring spawning biomass (SB_t, metric tonnes) and depletion level relative to estimated unfished equilibrium spawning biomass (SB_0).

	Spawning biomass (t)			Depletion (SB_t/SB_0)		
Year	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
2003	915	1,398	2,107	0.44	0.66	0.97
2004	878	1,329	1,988	0.42	0.63	0.91
2005	863	1,299	1,940	0.41	0.61	0.89
2006	1,276	1,911	2,834	0.60	0.90	1.30
2007	1,158	1,727	2,576	0.55	0.82	1.19
2008	1,026	1,531	2,292	0.48	0.72	1.06
2009	1,074	1,621	2,482	0.50	0.77	1.14
2010	937	1,427	2,191	0.44	0.67	1.01
2011	846	1,301	2,030	0.40	0.61	0.92
2012	709	1,134	1,882	0.34	0.54	0.83
2013	645	1,185	2,239	0.31	0.55	0.98

Figure E 3. Maximum posterior density (MPD) estimates of total biomass (solid lines) and spawning biomass (dashed lines) through 2013 for the major stock areas.

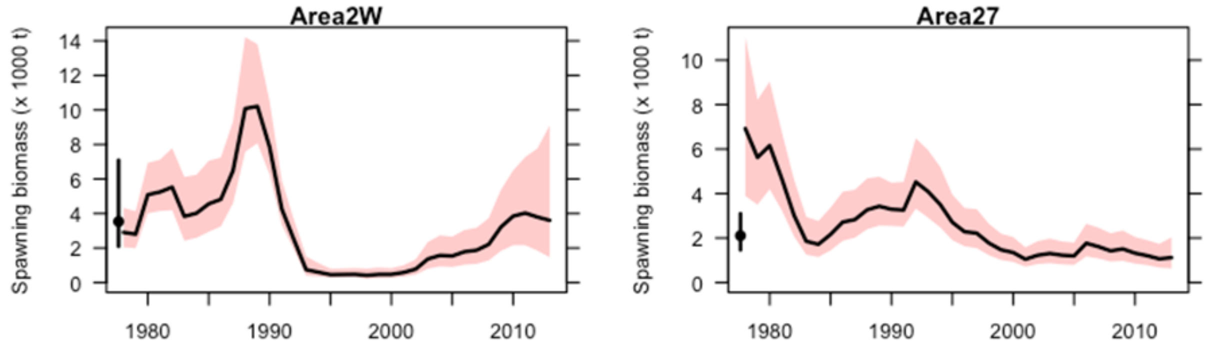


Figure E 4. Median of the posterior distribution for spawning biomass through 2013 (solid line) with 90% posterior credibility intervals (shaded area). Solid circle represents the estimated unfished equilibrium spawning biomass, SB_0, with 90% posterior credibility intervals (vertical lines).

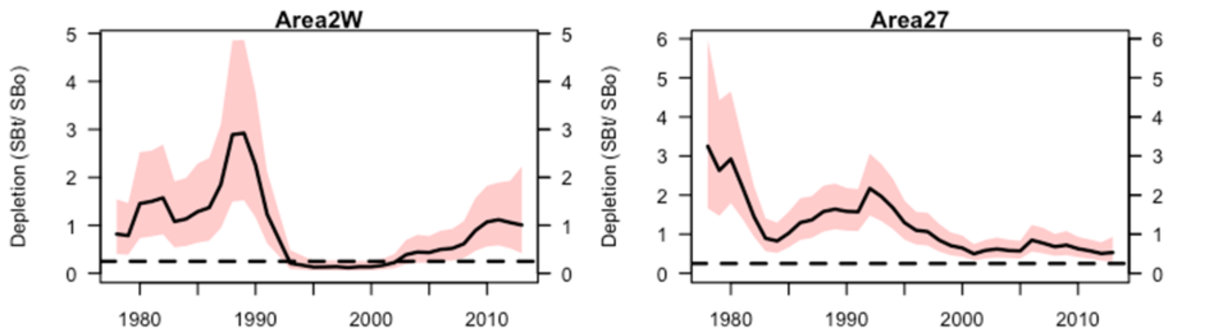


Figure E 5. Median of the posterior distribution for spawning depletion (SB_t/SB_0) through 2013 with (solid line) 90% posterior credibility intervals (shaded area). The dashed horizontal line denotes the 25% depletion level.

Recruitment

Recruitment to each stock is defined as the number of age-2 fish entering the population at the beginning of each year, defined as July-1st based on ageing conventions (**Section** 2.1.2**)**. Trends in estimates of age-2 fish are presented in **Table E 3**, **Figure E 6**. Age-2 recruitment is estimated as a free parameter within the model, subject to the constraint that annual estimates vary around a Beverton-Holt stock recruitment relationship with an estimated unknown standard deviation (**Figure E 7**).

Table E 3. Area 2W and Area 27: Estimates of recent Pacific Herring recruitment (millions of age-2 fish).

	Area 2W			Area 27		
Year	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
2003	2	4	7	7	13	25
2004	3	5	10	8	17	33
2005	3	5	9	12	22	40
2006	6	11	22	21	36	63
2007	1	3	6	6	11	20
2008	15	29	53	12	23	40
2009	7	12	23	8	14	25
2010	12	22	42	9	16	29
2011	3	7	14	3	5	10
2012	3	8	22	4	7	15
2013	7	32	93	3	6	14

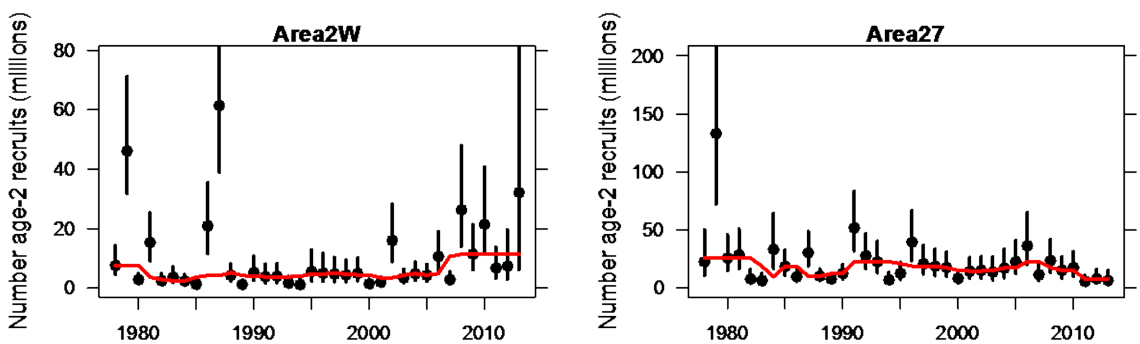


Figure E 6. Median posterior estimates (solid circles) of recruitment (millions of age-2 fish) with 90% posterior credibility intervals (vertical lines). Red trend line denotes 5-year running average.

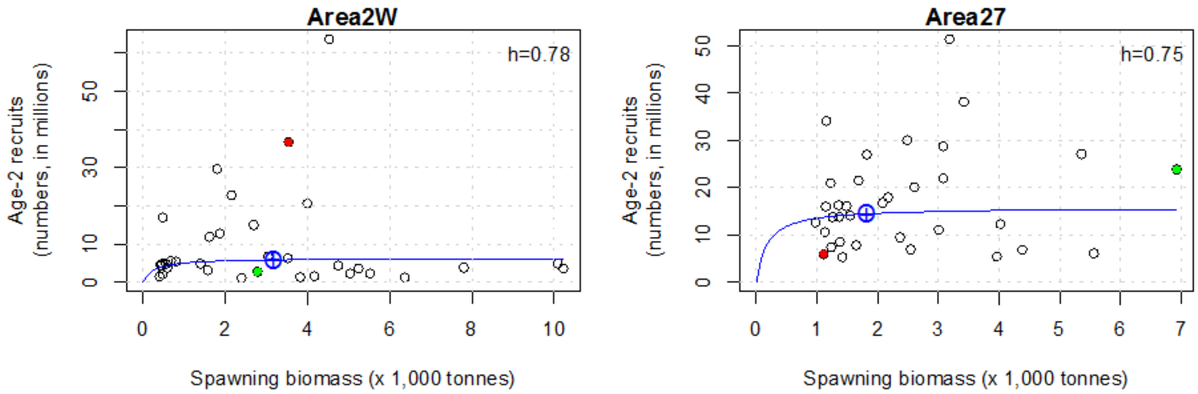


Figure E 7. Maximum posterior density (MPD) estimates of age-2 recruits versus estimated spawning stock biomass for each of the major stock areas. The green and red circles indicate the start (recruits in 1951) and end (recruits in 2013) of the series. The circle plus (blue) corresponds to the MPD estimate of unfished spawning biomass (SB_0) and unfished age-2 recruitment $R_{0;}$ the blue curve is the Beverton-Holt stock recruitment model fitted to these data and h is the steepness parameter. Units are in 1,000 tonnes spawning biomass (x-axis) and millions of recruits (y-axis).

Mortality and gear selectivity

Natural mortality is modelled as a time variant instantaneous rate that is constant across ages (**Figure E 8**) and instantaneous fishing mortality rate is age-specific (not shown). Note that fishing mortality rates are not comparable across gear types (fisheries) due to differences in gear selectivity (Figure E 9).

Fishery selectivity is estimated for each of the 3 gear types using a logistic function with age-specific selectivity coefficients (Appendix F). presents maximum likelihood estimates of age-specific selectivity coefficients for the all fishing categories (gear types) for each of the minor stock areas (scaled to 1.0).

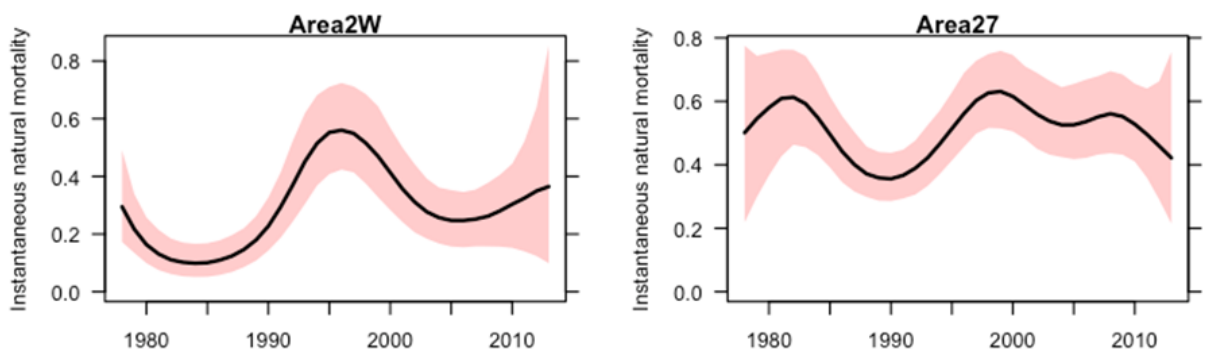


Figure E 8. Median (solid line) of the posterior distribution for instantaneous natural mortality rate with 90% posterior credibility intervals (shaded area).

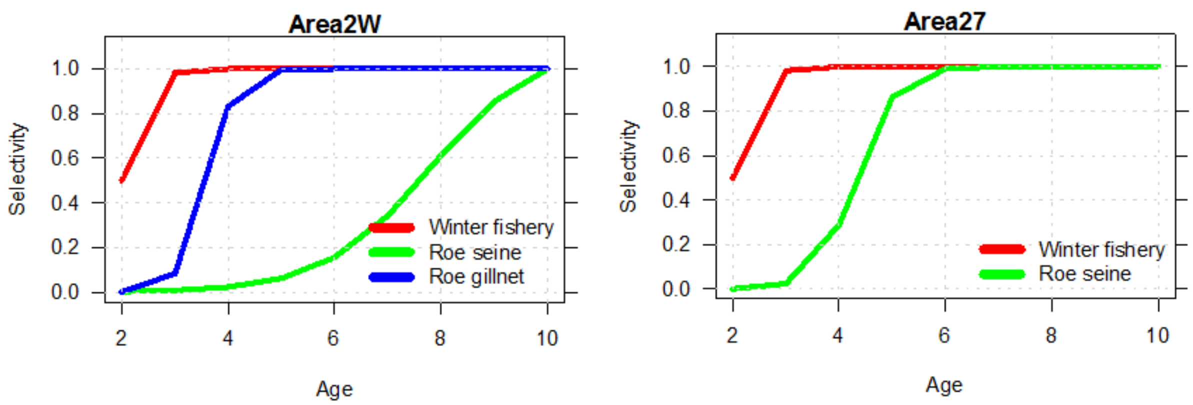


Figure E 9. Maximum likelihood estimates of age-specific selectivity coefficients for the all fishing periods (gear types) for each of the major stock areas. Roe gillnet selectivity is not presented for Area27 due to insufficient data from this type of fishing in this area.

MANAGEMENT

Recent fisheries

Total allowable catch (TAC) since the 2003/04 fishing year is presented in **Table E 4**; amounts were equal to the CSAS recommended maximum available yield for the period. Since 2008, the CSAS recommended maximum available yield has arisen from a 10% harvest rate applied to median posterior estimates of prefishery forecast biomass (total forecast biomass ages 3 and older). Prior to 2008, 10% harvest rate was applied to maximum posterior density estimates only.

Table E 4. Recent trends in Pacific Herring management decisions for the minor stocks.

	Area 2W	Area 27
	CSAS-recommended maximum available yield	CSAS-recommended maximum available yield
2003/04	146	86
2004/05	274	114
2005/06	54	160
2006/07	386	265
2007/08	244	274
2008/09	165	132
2009/10	413	135
2010/11	253	94
2011/12	540	112
2012/13	533	115

* 2004, 2005, 2006 - Total landings include allocation to Test Fishery program for Use-Fish.

Model projections

We present a decision table showing predicted status for Area 2W and Area 27 minor herring stocks in 2014 relative to target fishing levels and include a set of performance metrics that were identified as relevant by the TWG and Fisheries Management, relating directly to a harvest rate of 10%. One-year model projections are used to forecast herring spawning biomass (SB_{T+1}) under alternate catch assumptions (target fishing levels). Projected spawning biomasses assuming zero catch in 2014 and the relative contribution of fish of age-3 and of ages 4-10 are presented in **Table E 5**. Predicted status of spawning biomass (SB_{T+1}) for Area 2W and Area 27 minor herring stocks in 2014 relative to target fishing levels are presented as probabilistic decision tables (**Table E 6**).

Table E 5. Estimates of projected spawning biomass in 2014 given zero catch, and predicted proportions of fish of age-3 and of ages 4-10 for the minor BC herring stocks.

	Projected proportion age-3 fish in 2014			Projected proportion ages 4-10 fish in 2014			Projected spawning biomass (SB_{2014}) given zero catch		
Stock	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
Area 2W	0.08	0.33	0.56	0.41	0.64	0.89	1,520	4,427	11,761
Area 27	0.08	0.16	0.28	0.52	0.71	0.84	533	1,020	2,090

Table E 6. Area 2W: Probabilities of various performance metrics given different catch alternatives.

Minor Stock Areas	Harvest Metrics	
TAC (metric tonnes)	Prob (removal rate > target HR) P(U'_{2014} > 10%)	Median removal rate Med (U'_{2014})
Area 2W		
0	0	0
200	0.10	0.04
300	0.27	0.07
400	0.43	0.09
450	0.50	0.10
500	0.57	0.11
600	0.68	0.13
700	0.77	0.16
Area 27		
0	0	0
50	0.03	0.05
100	0.47	0.10
105	0.51	0.10
110	0.56	0.11
115	0.60	0.11
200	0.94	0.19

UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

Key unresolved problems and major uncertainties associated with the minor stocks for further consideration and research are listed below:

- Causes for changes in model estimates of instantaneous natural mortality
- Causes for the change in size at age (data or ecological)
- Poor predictive capacity of the assessment model to forecast changes (in growth, natural mortality) and impacts of these changes on reference points.
- Appropriate definition of a fishing mortality/exploitation rate for herring fisheries (discrete, continuous, F-targets)

APPENDIX F. DESCRIPTION OF CATCH-AT-AGE MODEL

We begin by defining the model symbols and then describe the dynamic and equilibrium models used by the assessment. These models determine the time series of state dynamics, as well as the equilibrium conditions for the unfished and projected states, respectively. The dynamic model propagates fish in each age class recursively: at each time step new recruits are added to the population, individuals become one year older, grow and if applicable spawn; or they die from natural or fishing mortality. The equilibrium conditions are used for both initialization of the model and to define the initial conditions at $t = t'$. Because of the apparent non-stationarity in weight at age and natural mortality, the expected unfished spawning stock biomass SB_0 is given as $SB_0 = R_0\phi_E$ and so will change with weight at age and natural mortality (see eq. F.22 below) used to calculate it.

MODEL NOTATION AND EQUATIONS

ISCAM is an age-structured model that is parameterized with initial recruitment R_0 (defined as fish numbers at age 2) and steepness *h*. However, it does not assume that the population is at unfished equilibrium R_0, in the first model year. Instead, recruitment in years before year $\acute{t}$ are given by eq. F.4. Subsequent recruitments are given by eq. F.4 and constrained according to eq. F.36 so that R_t's are given by a Beverton-Holt stock recruitment relationship. The estimated parameter vector in ISCAM is defined in (F.1), where R_0, $\ddot{R}$, *h* and *M* are the leading unknown population parameters that define the overall population scale in the form of unfished recruitment and productivity in the form of steepness *h* and natural mortality, *M*.

Table F.1. List of symbols, constants and description for variables used in ISCAM.

Symbol	Constant Value	Description
Indexes		
a		index for age
t		index for year
k		index for gear
n_k		number of non-zero catch observations in gear k
Model Dimensions		
$\acute{a}$, *A*	2, 10	youngest and oldest age class (*A* is a plus group)
$\acute{t}$, *T*	1951, 2014	first and last year of catch data
K	5	Number of gears including survey gears
Observations (data)		
$\omega_{t,a}$		observed weight at age a in year *t* (kg)
$C_{k,t}$		catch in weight by gear *k* in year *t* (kg)
$I_{k,t}$		relative abundance index for gear *k* in year *t* (kg)
$p_{k,t,a}$		observed proportion-at-age a in year *t* for gear *k*
m_a		maturity at age a

Symbol	Constant Value	Description
Initial States		
υ_a		unfished survivorship at age a
$\hat{\upsilon}_a$		fished survivorship at age a
ϕ_E		spawning biomass per recruit in the unfished state
ϕ_e		spawning biomass per recruit in the fished state
ϕ_B		vulnerable biomass per recruit in the unfished state
ϕ_b		vulnerable biomass per recruit in the fished state
s_0		maximum juvenile survival rate
$\ddot{\omega}_a$		age-$\acute{\alpha}$ deviates from $\ddot{R}$ for year $\acute{t}$
Estimated Parameters		
R_0		Age-$\acute{\alpha}$ recruits in unfished conditions
SB_0		spawning stock biomass in unfished conditions
h		recruitment steepness
M		constant natural mortality rate used in steady state equations
M_t		instantaneous natural mortality rate, used in year t
$\lambda_{k,t}$		coefficient to correct numbers-at-age for survey timing
$\ddot{R}$		average age-$\acute{\alpha}$ recruitment in the first model year $\acute{t}$ - 1
$\bar{R}_t$		recruitment and time t
ρ		fraction of the total variance associated with observation error
ϑ		total precision (inverse of variance) of the total error
γ_k		steepness of logistic selectivity function for gear k
a_k		age at 50 % selectivity for gear k
$\gamma_{k,t}$		logarithm of the instantaneous fishing mortality
$\ddot{\omega}_a$		age- $\acute{\alpha}$ deviates from $\ddot{R}$ for year $\acute{t}$
ω_t		age- $\acute{\alpha}$ deviates from $\bar{R}$ for years $\acute{t}$ to T
φ_t		logarithm of annual change in natural mortality rate
Standard deviations		
σM	0.1	standard deviation in random walk for natural mortality
σ		standard deviation for observation errors in survey index
$\mathcal{T}$		standard deviation in process errors (recruitment deviations)
σC	0.0707	standard deviation in observed catch by gear
State Variables		
B_0		unfished biomass
$N_{t,a}$		numbers at age a and time t
$\bar{M}$		mean natural mortality of last 5 years
SB_t		spawning stock biomass
$V_{k,t}$		vulnerable biomass in gear k at time t
B_t		total biomass for ages 2-10
$F_{k,t}$		instantaneous fishing mortality for gear k in year t
Fek		equilibrium fishing mortality for gear k in year
$f_{t,a}$		fecundity at age a in year t
Residuals		
ℓ		objective function vector
δ_t		annual recruitment residual
n_t		residual error in predicted catch

The total standard deviation ϑ^2 and the proportion of the total standard deviation that is associated with observation errors ρ are also estimated, then the total is partitioned into observation errors (σ^2) and process errors (τ^2) using eq. (F.2).

The unobserved state variables (F.3) include the numbers-at-age year year t ($N_{t,a}$), the total biomass B_t, the spawning stock biomass (SB_t) and the total age-specific total mortality rate ($Z_{t,a}$).

The initial numbers-at-age in the first year (F.4) and the annual recruits (F.5) are treated as estimated parameters and used to initialize the numbers-at-age matrix. Age-specific selectivity for gear type k is asymptotic with the age at 50 % selectivity given by γ_k and with $\widehat{a_k}$ as the parameter that influences the slope of the ogive, respectively (F.6). The vector of log fishing mortality rate parameters $F_{k,t}$ is a bounded vector with a minimum value of -30 and an upper bound of 3.0. In arithmetic space this corresponds to a minimum value of 9.36e-14 and a maximum value of 20.01 for annual fishing mortality rates F_t. In years where there are no reported catches for a given fleet, F_t is assumed to be zero.

For Pacific herring, we assume natural mortality is a random walk process (F.7), where the natural mortality rate, M in the first year is the estimated leading parameter (F.1). In subsequent years the mortality rate deviates from the previous year based on the estimated deviation parameter φ_t. In last year's assessment some concern was expressed that the random walk formulation used in the model would result in increasing M_t estimates: we performed some simulations and showed that over the modeling time frames considered for the assessment model, there was no upward trend in M so no bias correction required (positive biases do appear as $T \to \infty$). Moreover, the estimates were constrained each year by the data through the annual estimation procedure.

State variables in each year are updated using equations F.10–F.14. Spawning biomass is the product of the numbers-at-age and the fecundity at age $f_{a,t}$ (F.10); $f_{a,t}$ is assumed to be function of maturity at age m_a and weight at age in year t, $\omega_{a,t}$. The total mortality rate is given by (F.12), and the total catch (in weight) for each gear is given by (F.13) assuming that both natural and fishing mortality occur simultaneously throughout the year. The numbers-at-age are propagated over time using (F.14), where members of the plus group (age A) are all assumed to have the same total mortality rate.

Recruitment to age two is defined by a Beverton-Holt model (F.16) where the maximum juvenile survival rate (s_0) is defined as $s_0 = k / \phi_e$. For the Beverton-Holt model, β is derived by solving (F.16) for β conditional on estimates of k and R_0:

$$\beta = \frac{k-1}{R_0 \phi_E} \tag{F.18}$$

where $k = 4h/(1 - h)$ and $k = 5h^{5/4}$ for the Beverton-Holt and Ricker models, respectively. Note that only the Beverton-Holt formulation is used in the current Pacific herring assessment.

Analytic Methods

This section contains technical documentation of the underlying age-structured model, its steady state version used to calculate reference points, the observation models used in predicting observations, and the components of the objective function that formulate the statistical criterion used to estimate model parameters. Model equations are presented in tables intended to represent the order of operations, or pseudocode, in which to implement the model. ISCAM was implemented in AD Model Builder version 10.1.

For Pacific herring, weight at age $\omega_{a,t}$ is given by the empirical weight-at-age data and the age-specific vulnerability is given by eq. (F.6). Mean fecundity-at-age is assumed to be proportional to the mean weight-at-age of mature fish, where maturity at age, m_a is specified for age 2 to 10 as 0:24974; 0:9; 1; 1; 1; 1; 1; 1; 1.

Table F.2. Statistical catch-age model using the Baranov catch equation

Estimated Parameters

$$\Theta = \left(R_0, h, M, \bar{R}, \ddot{R}, \rho, \vartheta, \gamma_k, \hat{a_h}, F_{k,t}, \{\ddot{\omega}_a\}_{a=\acute{a}+1}^{a=A}, \{\omega_t\}_{t=t'}^{t=T}, \{\varphi_t\}_{t=\acute{t}+1}^{T}\right) \quad \text{(F.1)}$$

$$\sigma = \rho/\vartheta, \quad \tau = (1-\rho)/\vartheta \quad \text{(F.2)}$$

Unobserved states

$$N_{t,a}, B_t, SB_t, R_t, Z_{t,a} \quad \text{(F.3)}$$

Initial states

$$N_{t,a} = \ddot{R}e^{\ddot{\omega}_a}\exp(-M_t)^{(a-\acute{a})}; \quad t = \acute{t}; \acute{a} \le a \le A \quad \text{(F.4)}$$

$$N_{t,a} = \bar{R}e^{\omega_t}; \quad \acute{t} \le t \le T; a = \acute{a} \quad \text{(F.5)}$$

$$v_{k,a} = (1 + \exp(-(\hat{a_k} - a)/\gamma_k))^{-1} \quad \text{(F.6)}$$

$$M_t = M_{t-1}\exp(\varphi_t), \quad t > \acute{t}, \varphi_t \sim N(0, \sigma_M) \quad \text{(F.7)}$$

$$F_{k,t} = \exp(F_{k,t}) \quad \text{(F.8)}$$

State dynamics

$$B_t = \sum_a N_{t,a} w_{a,t} \quad \text{(F.9)}$$

$$f_{a,t} = m_a w_{a,t} \quad \text{(F.10)}$$

$$SB_t = \sum_a N_{t,a} f_{a,t} \quad \text{(F.11)}$$

$$Z_{t,a} = M_t + \sum_k F_{k,t} v_{k,t,a} \quad \text{(F.12)}$$

$$\hat{C}_{k,t} = \sum_a \frac{N_{t,a} w_a F_{k,t} v_{k,t,a}\left(1 - e^{-Z_{t,a}}\right)}{Z_{t,a}} e^{\eta_t} \quad \text{(F.13)}$$

$$N_{t,a} = \begin{cases} N_{t-1,a-1}\exp(-Z_{t-1,a-1}) & a > \acute{a} \\ N_{t-1,A}\exp(-Z_{t-1,A}) + Nt - 1, A - 1exp(-Z_{t-1,A-1}) & a = A \end{cases} \quad \text{(F.14)}$$

Discrete harvest rate approximation

$$U' = \frac{C_{T+1}}{C_{T+1} + \sum_a N_{t,a} f_{a,t} e^{-\bar{M}}} \quad \text{(F.15)}$$

Recruitment models

$$R_t = \frac{s_o SB_{t-k}}{1 + \beta SB_{t-k}} e^{\delta_t - 0.5\tau^2} \quad \text{Beverton-Holt} \quad \text{(F.16)}$$

$$N_{t,\acute{a}} = R_t \quad \text{(F.17)}$$

Table F.3. Steady-state age-structured model assuming age-specific vulnerability, age-specific natural mortality, age-specific fecundity and Beverton-Holt type recruitment. Note that average natural mortality M and weight at age ω_a are specified differently, depending the time period specified (i.e., reconstructions or projections)

Parameters

$$\Theta = (B_o, \kappa, M, \hat{a_k}, \hat{\gamma}_k, F_e) \tag{F.19}$$

$B_0 > 0$; $k > 1$; $M > 0$; $F_e \geq 0$

Survivorship

$$\iota_a = \begin{cases} 1, & a = 1 \\ \iota_{a-1}e^{-M}, & a > 1 \\ \iota_{a-1}/(1-e^{-M}), & a = A \end{cases} \tag{F.20}$$

$$\hat{\iota}_a = \begin{cases} 1, & a = 1 \\ \hat{\iota}_{a-1}e^{-M-F_e v_{a-1}}, & a > 1 \\ \hat{\iota}_{a-1}e^{-M-F_e v_{a-1}}/(1-e^{-M-F_e v_a}), & a = A \end{cases} \tag{F.21}$$

Incidence functions

$$\phi_E = \sum_{a=1}^{\infty} \iota_a f_a, \quad \phi_e = \sum_{a=1}^{\infty} \hat{\iota}_a f_a \tag{F.22}$$

$$\phi_B = \sum_{a=1}^{\infty} \iota_a w_a v_{a,k}, \quad \phi_b = \sum_{a=1}^{\infty} \hat{\iota}_a w_a v_a \tag{F.23}$$

$$\phi_q = \sum_{a=1}^{\infty} \frac{\hat{\iota}_a w_a v_a}{M + F_e v_a}\left(1 - e^{(-M-F_e v_a)}\right) \tag{F.24}$$

Steady-state conditions

$$B_o = R_o \phi_B \tag{F.25}$$

$$SB_0 = R_o \phi_E \tag{F.26}$$

$$R_e = R_o \frac{\kappa - \phi_E/\phi_e}{\kappa - 1} \tag{F.27}$$

$$C_e = F_e R_e \phi_q \tag{F.28}$$

Survivorship for unfished and fished populations is defined by (F.20) and (F.21), respectively. It is assumed that all individuals ages *A* and older (i.e., the plus group) have the same total mortality rate. The incidence functions refer to life-time or per-recruit quantities such as spawning biomass per recruit (ϕ_E) or vulnerable biomass per recruit (ϕ_b). Note that upper and lower case subscripts denote unfished and fished conditions, respectively. Spawning biomass per recruit is given by (F.22), the vulnerable biomass per recruit is given by (F.23) and the per recruit yield to the fishery is given by (F.24). Unfished recruitment is estimated as a leading parameter and the steady-state equilibrium recruitment for a given fishing mortality rate F_e is given by (F.27). Note that in (F.27) recruitment is assumed to follow a Beverton-Holt model of the form:

$$R_e = \frac{s_o R_e \phi_e}{1 + \beta R_e \phi_e}$$

where

$$s_o = \kappa/\phi_E,$$
$$\beta = \frac{(\kappa - 1)}{R_o \phi_E},$$
$$\kappa = 4h/(1-h),$$

which simplifies to (F.27).

For this herring assessment, the average catch over the past 20 years was used to determine the allocation scheme for each of the stock assessment regions. For the Strait of Georgia this corresponds to 6.9% for the winter seine fishery, 41.4% for the seine roe fishery, and 51.8% for the gill net fishery. We further assume that 100% of the total mortality takes place prior to spawning, and that the start of each biological year is the month of April.

RESIDUALS, LIKELIHOODS & OBJECTIVE FUNCTION VALUE COMPONENTS

There are three components to the overall objective function that is minimized as part of the statistical fitting procedure. These components consist of the likelihood of the data, prior distributions, and penalty functions that are invoked to regularize the solution during intermediate phases of the non-linear parameter estimation. This section discusses each component in turn, starting first with the residuals between observed and predicted states followed by the negative loglikelihood that is minimized for the catch data, relative abundance data, age-composition, and stock-recruitment relationships.

Catch Data

It is assumed that the measurement errors in the non-zero catch observations are log-normally distributed, and the residuals are given by:

$$\eta_{k,t} = \ln(C_{k,t}) - \ln(\hat{C}_{k,t}), \tag{F.29}$$

The residuals are assumed to be normally distributed with a user specified standard deviation σ_C. At present, observed catches for each gear *k* are assumed to have the same standard deviation. To aid in parameter estimation, two separate standard deviations are specified in the control file: the first is the assumed standard deviation used in the first, second, to *N*-1 phases, and the second is the assumed standard deviation in the last phase. The negative loglikelihood (ignoring the scaling constant) for the catch data is given by:

$$\ell_C = \sum_k \left[T_k \ln(\sigma_C) + \frac{\sum_{t \in \hat{C}_{k,t} \neq 0} (\eta_{k,t})^2}{2\sigma_C^2} \right], \tag{F.30}$$

where n_k is the total number of non-zero catch observations for gear type *k*.

Survey Data

For Pacific Herring the relative abundance data are assumed to be proportional to the spawning biomass so the vulnerable biomass available to the *k*th survey is given by

$$V_{k,t} = \sum_a SB_{t,a} e^{-\lambda_{k,t} M_t} f_{a,t}, \tag{F.31}$$

A user specified fraction of the total mortality $\lambda_{k,t}$ adjusts the numbers-at-age to correct for survey timing. The residuals between the observed and predicted relative abundance index are given by:

$$\epsilon_{k,t} = \ln(I_{k,t}) - \ln(q_k) - \ln(V_{k,t}), \qquad \text{(F.32)}$$

where $I_{k,t}$ is the observed relative abundance index, q_k is the catchability coefficient for index *k*, and $V_{k,t}$ is the predicted vulnerable biomass at the time of sampling. Following Walters and Punt (1996), the catchability coefficient q_k is evaluated at its conditional maximum likelihood estimate:

$$q_k = \frac{1}{N_k} \sum_{t \in I_{k,t}} \ln(I_{k,t}) - \ln(V_{k,t}),$$

where N_k is the number of relative abundance observations for index *k*. The negative loglikelihood for relative abundance data is given by:

$$\ell_I = \sum_k \sum_{t \in I_{k,t}} \ln(\sigma_{k,t}) + \frac{\epsilon_{k,t}^2}{2\sigma_{k,t}^2} \qquad \text{(F.33)}$$

Where

$$\sigma_{k,t} = \frac{\rho\vartheta}{\omega_{k,t}},$$

where $\rho\upsilon$ is the proportion of the total error that is associated with observation errors, and $\omega_{k,t}$ is a user specified relative weight for observation *t* from gear *k*. The $\omega_{k,t}$ terms allow each observation to be weighted relative to the total error $\rho\upsilon$; for example, to omit a particular observation, set $\omega_{k,t}$ = 0, or to give 2 times the weight, then set $\omega_{k,t}$ = 2:0. To assume all observations have the same variance, then simply set $\omega_{k,t}$ = 1. Note that if $\omega_{k,t}$ = 0, then equation (F.33) is undefined; therefore, ISCAM adds a small constant to $\omega_{k,t}$ (1.e-10, which is equivalent to assuming an extremely large variance) to ensure the likelihood can be evaluated.

In the case of the Pacific Herring assessment, the spawn survey data post-1988 were assumed to be 1.166 time as precise as the pre-dive survey data (1951-1987). To implement this assumption, the objective function weights for the 1951-1987 data were set equal to unity and the contemporary data were assigned a relative weight of 1.166. The standard deviation in the observation errors is conditional on estimated values of *ρ* and φ^2.

Age Composition Data

Based on sampling theory the age composition data are assumed to be derived from a multinomial distribution. However, the ISCAM assumes that age-proportions are obtained from a multivariate logistic distribution. The multinomial distribution, used in many stock assessments, requires the specification of an effective sample size. In cases where there are very large numbers of observations, the age composition data may be too heavily weighted in the objective function, i.e., the assumed effective sample size can have a large impact on the overall model results.

In the multivariate logistic distribution, the age-proportion data can be weighted based on the conditional maximum likelihood estimate of the variance in the age-proportions (Richards and Schnute, 1995). Therefore, the contribution of the age-composition data to the overall objective function is “self-weighting” and is conditional on other components in the model.

Ignoring the subscript for gear type for clarity, the observed and predicted proportions-at-age must satisfy the constraint

$$\sum_{a=1}^{A} p_{t,a} = 1$$

for each year. The multivariate logistic residuals between the observed ($p_{t,a}$) and predicted proportions ($\widehat{p_{t,a}}$) is given by:

$$\eta_{t,a} = \ln(p_{t,a}) - \ln(\widehat{p_{t,a}}) - \frac{1}{A}\sum_{a=1}^{A}\left[\ln(p_{t,a}) - \ln(\widehat{p_{t,a}})\right]. \tag{F.34}$$

The conditional maximum posterior density estimate of the variance is given by

$$\widehat{\tau}^2 = \frac{1}{(A-1)T}\sum_{t=1}^{T}\sum_{a=1}^{A}\eta_{t,a}^2,$$

and the negative log posterior density evaluated at the conditional maximum posterior density estimate of the variance is given by:

$$\ell_A = (A-1)T\ln(\widehat{\tau}^2). \tag{F.35}$$

In short, the multivariate logistic likelihood for age-composition data is the log of the residual variance weighted by the number observations over years and ages.

Examination of (F.34) reveals that observed and predicted proportions-at-age must be greater than zero. It is not uncommon in catch-age data sets to observe zero proportions for older, or young, age classes or weak year classes. In the ISCAM the definition of age-classes is altered to require that $p_{t,a} \geq \dot{p}$ for every age in each year, where $\dot{p}$ is the minimum percentage specified by the user (e.g., $\dot{p}$ = 0:02 corresponds to 2%). This is accomplished by grouping consecutive ages, where $p_{t,a} < \dot{p}$, into a single age-class and reducing the effective number of age-classes in the variance calculation ($\hat{T}^2$) by the number of groups created. In the current Pacific herring assessment, the $\dot{p}$ is set to be 0.02.

Stock-Recruitment

There are two alternative stock-recruitment models available in ISCAM: the Beverton-Holt model and the Ricker model. Annual recruitment and the initial age-composition are treated as latent variables in ISCAM, and the residuals between estimated recruits and the deterministic stock-recruitment models are used to estimate unfished spawning stock biomass and recruitment compensation. The residuals between the estimated and predicted recruits is given by

$$\delta_t = \ln(\bar{R}e^{w_t}) - \ln((R_t)) \tag{F.36}$$

where $f(SB_{t-k})$ is given by (F.16) , and ά is the age at recruitment. Note that a bias correction term for the lognormal process errors is included in (F.16).

The negative log likelihood for the recruitment deviations is given by the normal density (ignoring the scaling constant):

$$\ell_\delta = n\ln(\tau) + \frac{\sum_{t=1+k}^{T}\delta_t^2}{2\tau^2} \tag{F.37}$$

Equations (F.36) and (F.37) are key for estimating unfished spawning stock biomass and recruitment compensation via the recruitment models. The relationship between (s_0, β) and (B_0, k) is defined as:

$$s_o = \kappa/\phi_E \tag{F.38}$$

$$\beta = \begin{cases} \frac{\kappa-1}{B_0} & \text{Beverton-Holt} \end{cases} \tag{F.39}$$

where s_0 is the maximum juvenile survival rate, β is the density effect on recruitment, and B_0 is the unfished spawning stock biomass. Unfished steady-state spawning stock biomass per recruit is given by ϕ_E, which is the sum of products between age-specific survivorship and relative fecundity. In cases where the natural mortality rate is allowed to vary over time, the calculation of ϕ_E, and the corresponding unfished spawning stock biomass (B_0) is based on the average natural mortality rate over the entire time period. This subtle calculation has implications for reference point calculations in cases where there are increasing or decreasing trends in natural mortality rates over time; as estimates of natural mortality rates trend upwards, estimates of B_0 decrease.

Note that for this Pacific Herring assessment, only the Beverton-Holt recruitment model was considered.

PARAMETER ESTIMATION AND UNCERTAINTY

Parameter estimation and quantifying uncertainty was carried out using the tools available in AD Model Builder. AD Model Builder (ADMB) is a software for creating computer programs to estimate the parameters and associated probability distributions for nonlinear statistical models. The software is freely available. This software was used to develop ISCAM, and the source code and documentation for the open source ISCAM project (on which the herring assessment model variant is based) is freely available from a GitHub subversion repository. There are five distinct components that make up the objective function, f that ADMB is minimizing:

f = negative loglikelihoods+constraints+priors for parameters+survey priors+convergence penalties.

The purpose of this section is to completely document all of the components that make up the objective function.

Negative Loglikelihoods

The negative loglikelihoods pertain specifically to elements that deal with the data and variance partitioning and have already been described in detail in section F.1. There are four specific elements that make up the vector of the objective function:

$$\ell = \ell_C, \ell_I, \ell_A, \ell_\delta \tag{F.40}$$

These are the likelihood of the catch data ℓ_C likelihood of the survey data ℓ_I the likelihood of the age-composition data ℓ_A and the likelihood of the stock-recruitment residuals ℓ_δ. Each of these elements are expressed in negative log-space, and ADMB estimates these model parameters by minimizing the sum of these elements.

Constraints

There are two specific constraints that are described here:

1. parameter bounds, and
2. constraints to ensure that parameter vectors for catch and recruitment deviations sum to zero.

In ISCAM the user must specify the lower and upper bounds for the leading parameters defined in the control file. All estimated selectivity parameters in eq.F.6 are estimated in log space and have minimum and maximum values -5 and 5, respectively. These constraints are written into the source code, but should be sufficiently large or small enough to capture a wide range of selectivities. Estimated log fishing mortality rates are constrained to have a minimum value of -30, and a maximum value of 3.0. Log annual recruitment deviations are constrained to have minimum and maximum values of -15.0 and 15.0, respectively, and there is an additional constraint to ensure the vector of deviations sums to 0. This summation constraint is necessary in order to be able to estimate the average recruitment $\bar{R}$. Finally, the annual log deviations in natural mortality rates are constrained to lie between -5.0 and 5.0.

Priors for Parameters

Each of the seven leading parameters specified in the control file (ln(R_0),h,ln(M),ln($\bar{R}$),ln($\ddot{R}$),ρ,ϑ) are declared as bounded parameters and in addition the user can also specify an informative prior distribution for each of these parameters. Five distinct prior distributions can be implemented: uniform, normal, lognormal, beta and gamma.

For the Pacific Herring assessment, a bounded recruitment uniform prior was specified for the log of unfished recruitment U(-5,15), a beta prior was assumed for steepness Beta(10.0,4.92), a normal prior was specified for the log of natural mortality rate N(-0.79,0.4), a bounded uniform prior for both the log of initial recruitment and average recruitment U(-5.0,15.0), a beta prior for the variance partitioning parameter $\rho\tilde{\beta}$(17:086; 39:0559), and a gamma prior for the inverse total standard deviation parameter $\vartheta\tilde{T}$(25; 28:75). The scaling parameter ***q*** for each of the surveys is not treated as an unknown parameter within the code; rather, the maximum posterior density estimate for ln*(q)* conditional on all other parameters is used to scale the predicted spawning biomass to the observed biomass indices (Walters and Punt 1994). For all stock areas, we specified an informative normal prior on ln(q) with a mean of -0.569, and a standard deviation of 0.274 for the contemporary data (1988-2014) and also for pre-1988 spawn survey data.