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Stock Assessment and Harvest Advice for Rock Sole *(Lepidopsetta spp.)* in British Columbia

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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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ABSTRACT

Rock Sole (*Lepidopsetta* spp.) occur along the entire coast of British Columbia (BC), Canada, with abundance highest in Hecate Strait and Queen Charlotte Sound. The majority of Rock Sole catch is taken by the groundfish trawl fishery. Two species of Rock Sole occur in BC: Southern Rock Sole (*L. bilineata*) and Northern Rock Sole (*L. polyxystra*). Rock Sole encountered in BC fisheries and research surveys are almost exclusively Southern Rock Sole. Rock Sole stocks in BC are assessed and managed as five separate areas based on DFO Statistical Areas. This assessment provides harvest advice for Areas 5AB (Queen Charlotte Sound) and 5CD (Hecate Strait). Limited fishery and survey data from the other three management areas (3CD, 4B, 5E) preclude the provision of quantitative harvest advice. Summaries of available data for these areas are provided.

A female-only statistical catch-at-age model in a Bayesian estimation framework was used to assess Rock Sole in Areas 5AB and 5CD. The model was fit to catch data, two or more indices of abundance, and age composition data from commercial trawl fisheries and research surveys. Indices of abundance included fishery-dependent catch-per-unit effort time series as well as fishery-independent trawl survey indices. Stock status in Areas 5AB and 5CD is evaluated relative to two types of reference points: MSY-based and historical. The MSY-based reference points are consistent with the provisional reference points contained in the DFO Fishery Decision-making Framework Incorporating the Precautionary Approach. These include a limit reference point (LRP = $0.4B_{\mathrm{MSY}}$, where B_{MSY} is the female spawning biomass associated with maximum sustainable yield), an upper stock reference point (USR = $0.8B_{\mathrm{MSY}}$), B_{MSY}, and the harvest rate associated with MSY (u_{MSY}). The historical reference points were previously developed and applied to BC Rock Sole stocks in 2006, and include a limit biomass (B_{LIM}), a target biomass (B_{TAR}), current biomass (B_{2014}), and a target harvest rate (u_{TAR}).

Results show that in Area 5AB, female spawning biomass in 2014, B_{2014}, is estimated to be 0.37 (0.27 – 0.49) of unfished female spawning biomass, B_0 (where numbers are given as posterior medians with 5th and 95th percentiles shown in brackets), and at $1.52B_{\mathrm{MSY}}$ (0.98 – 2.26). There is a high probability that B_{2014} in Area 5AB is above B_{MSY}, $0.8B_{\mathrm{MSY}}$, $0.4B_{\mathrm{MSY}}$, and B_{LIM}, with B_{2014} most likely just below B_{TAR}. In Area 5CD, B_{2014} is estimated to be at $0.80B_0$ (0.58 – 1.07) and $3.22B_{\mathrm{MSY}}$ (2.10 – 4.64). There is a high probability that B_{2014} in Area 5CD is above all biomass-based reference points. Exploitation rates in 2013 are estimated to be below u_{TAR} and u_{MSY} in both management areas. In Area 5AB, the ratio of u_{2013} / u_{TAR} is 0.59 (0.46-0.75) and the ratio of u_{2013} / u_{MSY} is 0.46 (0.30-0.72). In 5CD, the ratio of u_{2013} / u_{TAR} is 0.32 (0.24-0.42) and the ratio of u_{2013} / u_{MSY} is 0.08 (0.04 -0.16). In both areas, there is a 100% percent probability that the exploitation rate in 2013 is less than u_{TAR} and u_{MSY}.

Advice to management is presented in the form of decision tables using five-year projections for a range of constant catches. For each level of constant harvest, decision tables show the probability that projected stock status in each year will be greater than specified reference points.

Évaluation du stock et avis sur les prélèvements de fausse limande (*Lepidopsetta* sp.) en Colombie-Britannique

RÉSUMÉ

La fausse limande (*Lepidopsetta* spp.) est présente sur toute la côte de la Colombie-Britannique, au Canada, et particulièrement dans le détroit d'Hécate et le détroit de la Reine-Charlotte. La majorité des prises de fausse limande proviennent de la pêche au chalut du poisson de fond. Deux espèces sont présentes en Colombie-Britannique : la fausse limande du Pacifique sud (*L. bilineata*) et la fausse limande du Pacifique nord (*L. polyxystra*). Les fausses limandes prises dans le cadre des pêches et des relevés de recherche en Colombie-Britannique sont presque uniquement des fausses limandes du Pacifique sud. En Colombie-Britannique, les stocks de fausse limande sont évalués et gérés selon cinq zones distinctes fondées sur les secteurs statistiques du MPO. La présente évaluation fournit un avis sur les prélèvements dans les zones 5AB (détroit de la Reine-Charlotte) et 5CD (détroit d'Hécate). Le caractère limité des données de la pêche et des données d'enquête disponibles pour les trois autres zones de gestion (3CD, 4B et 5E) empêche de formuler un avis quantitatif sur les prélèvements dans ces zones. Le sommaire des données disponibles pour ces zones est fourni.

Un modèle statistique fondé sur les prises selon l'âge des femelles seulement et utilisé dans un cadre d'évaluation bayésienne a servi à évaluer la fausse limande dans les zones 5AB et 5CD. Le modèle a été adapté aux données sur les prises, à deux indices d'abondance au moins et aux données sur la composition selon l'âge des pêches commerciales au chalut et des relevés de recherche. Les indices d'abondance incluaient une série chronologique des prises par unité d'effort dépendant de la pêche, ainsi qu'un indice tiré des relevés au chalut, indépendant de la pêche. L'état du stock dans les zones 5AB et 5CD a été évalué relativement à deux types de points de référence : les points de référence fondés sur le rendement maximal soutenu (RMS) et les points de référence historiques. Les points de référence fondés sur le RMS sont conformes aux points de référence provisoires du Cadre décisionnel pour les pêches intégrant l'approche de précaution du MPO. Ces points comprennent un point de référence limite (PRL = 0.4B_{RMS}, où B_{RMS} désigne le stock reproducteur femelle associé au rendement maximal soutenu), un point de référence supérieur du stock (PRS = 0.8B_{RMS}), B_{RMS}, et le taux de récolte associé au rendement maximal soutenu (u_{RMS}). Les points de référence historiques avaient déjà été définis et appliqués au stock de fausse limande de la Colombie-Britannique en 2006, et comprenaient une biomasse limite (B_{LIM}), une biomasse cible(B_{CIB}), la biomasse actuelle(B_{2014}) et un taux de récolte cible (u_{CIB}).

Les résultats montrent que dans la zone 5AB en 2014, la biomasse des femelles reproductrices, B_{2014}, était estimée à 0,37 (0,27 – 0,49) de la biomasse reproductrice non exploitée, B_0 (où les chiffres entre parenthèses indiquent les médianes a posteriori aux 5^{e} et 95^{e} centiles), et la biomasse des femelles reproductrices associée à un rendement maximal soutenu estimée à 1,52B_{RMS} (0,98 – 2,26). Il y a de fortes probabilités que B_{2014} dans la zone 5AB soit supérieure à B_{RMS}, 0,8B_{RMS}, 0,4B_{RMS} et B_{LIM}, et à peine inférieure à B_{CIB}. Dans la zone 5CD, B_{2014} est estimée à 0,80B_0 (0,58 – 1,07) et 3,22B_{RMS} (2,10 – 4,64). Il y a de fortes probabilités que B_{2014} dans la zone 5CD se situe au-dessus de tous les points de référence basés sur la biomasse. Les taux d'exploitation de 2013 ont été estimés inférieurs à u_{CIB} et u_{RMS} dans les deux zones de gestion. Dans la zone 5AB, le rapport u_{2013}/u_{CIB} était de 0,59 (0,46-0,75), et le rapport u_{2013}/u_{RMS} était de 0,46 (0,30-0,72). Dans la zone 5CD, le rapport u_{2013}/u_{CIB} était de 0,32 (0,24-0,42), et le rapport u_{2013}/u_{RMS} était de 0,08 (0,04-0,16). Dans les deux zones, la probabilité que le taux d'exploitation de 2013 soit inférieur à u_{CIB} et u_{RMS} était de 100 %.

Les avis concernant la gestion des pêches sont présentés sous la forme de tables de décision et reposent sur des projections quinquennales réalisées en fonction d’un éventail de prises constantes. Pour chaque niveau de capture constant, les tables de décision indiquent la probabilité que l’état du stock projeté chaque année soit supérieur aux points de référence établis.

INTRODUCTION

Rock Sole (*Lepidopsetta* spp.) is a commercially important species of flatfish that occurs along the entire coast of British Columbia (BC), Canada (Figure 1). Rock Sole are primarily taken by the groundfish trawl fishery, although very small numbers are also encountered by hook and line fisheries. The purpose of this stock assessment is to update management advice for Rock Sole stocks in British Columbia, as requested by the Groundfish Management Unit (GMU). This assessment identifies reference points for Rock Sole that are consistent with the DFO Decision-making Framework Incorporating the Precautionary Approach (DFO 2009) and characterizes stock status relative to these reference points. Management advice takes the form of decision tables which forecast the impacts of varying harvest levels on Rock Sole stock status relative to these reference points.

Rock Sole in BC are managed as five separate areas based on DFO Statistical Areas: Areas 3CD (West Coast Vancouver Island), 4B (Strait of Georgia), 5AB (Queen Charlotte Sound), 5CD (Hecate Strait), and 5E (West Coast Haida Gwaii), where two letters combined (e.g., 3CD) denote the combination of two separate statistical areas (e.g., 3C and 3D) into one management area (Figure 2). Trawl fishery catch rates indicate that abundance is highest in Hecate Strait and Queen Charlotte Sound (Figure 3), which is where the majority of catches are taken. A statistical catch-at-age stock assessment model is fit to data for management areas 5AB and 5CD. Limited fishery and survey data from the other three management areas (3CD, 4B, 5E) are inadequate for informing assessment models, precluding the provision of quantitative harvest advice. Available data from these three management areas are reported.

BIOLOGY

Species and Stock Delineation in British Columbia

Two species of Rock Sole (genus *Lepidopsetta*) occur in BC: Southern Rock Sole (*L. bilineata*) and Northern Rock Sole (*L. polyxystra*). Northern Rock Sole occur from the Bering Sea and Aleutian Islands to Puget Sound in Washington State, while Southern Rock Sole occur from the southeastern Bering Sea and eastern edges of the Aleutian Islands to California (Orr and Matarese 2000). Before 2000, these two species were thought to be a single species (Orr and Matarese 2000).

The majority of Rock Sole encountered in BC fisheries and research surveys are believed to be Southern Rock Sole. While similar in appearance, Northern and Southern Rock Sole can be visually differentiated by trained observers. Since 1996, catches from biennial bottom trawl surveys in BC have been examined for the presence of Northern Rock Sole, with this species reported from a handful of samples. Orr and Matarese (2000) found only a small number of Northern Rock Sole adults in BC and no evidence of Northern Rock Sole larvae. A Northern Rock Sole stock does exist in Puget Sound, Washington and the species has been observed in nearby Juan de Fuca Strait and southern Strait of Georgia (Orr and Matarese 2000). Occasional samples of Northern Rock Sole have also been reported in the inlets of Haida Gwaii and the northern BC mainland (Orr and Matarese 2000). All observations of Northern Rock Sole in BC have been from nearshore waters, which are not typically fished by the commercial trawl fishery or groundfish trawl surveys. Studies in the Gulf of Alaska, where Northern Rock Sole are more abundant, also show that Northern Rock Sole are captured primarily in bays and coastal areas while Southern Rock Sole are predominantly found farther off shore (Stark and Somerton 2002). While this combined evidence suggests that the large majority of the data used in this assessment are Southern Rock Sole, we refer to these stocks at the genus level

(*Lepidopsetta* spp.) to allow for the possibility that some Northern Rock Sole occur in commercial catches and survey samples.

While the five management areas for Rock Sole in BC have been established based on management considerations, tagging studies have shown that adult Rock Sole do not appear to move between these areas. Ketchen (1982) and Fargo and Westrheim (1987) suggested that separate adult stocks exist in Hecate Strait, Queen Charlotte Sound, and off the west coast of Vancouver Island based on several decades of tagging data. Low (or zero) rates of tag exchange at finer scales within Queen Charlotte Sound and Hecate Strait led these studies to suggest that multiple sub-stocks may exist within each area. All stock structure information in BC was developed assuming there was a single species since this work pre-dated the taxonomic distinction of Rock Sole into northern and southern species.

Spawning Migrations

Both Northern and Southern Rock Sole are determinate synchronous spawners, with one annual spawning event per year (Stark and Somerton 2002). Spawning occurs in BC during late winter, primarily between January and March. BC Rock Sole undergo small seasonal migrations between separate spawning (winter) and feeding (summer) areas. In Hecate Strait, one main spawning area is off Cumshewa Inlet on the east coast of Moresby Island (Starr et al. 2006, unpublished manuscript[1]). Rock sole in this area undergo a movement to shallower spawning grounds in Cumshewa Inlet each winter, and an easterly post-spawning migration to summer feeding grounds in the central portion of the Strait (Starr et al. 2006, unpublished manuscript[1]). Studies of Northern Rock Sole in Alaska have shown evidence of multiple spawning locales within an area (Lanksbury et al. 2007).

Recruitment

Rock sole recruitment is influenced by both spawning biomass and environmental factors. In the eastern Bering Sea, Ricker stock recruitment models incorporating environmental factors fit to Northern Rock Sole data have shown evidence of density-dependence, with variability in productivity linked to decadal patterns in the ocean environment (Wilderbuer et al. 2002). Wilderbuer et al. (2002) suggested that decadal-scale climate variability influenced marine survival during the early life history period since years with above average recruitment coincided with wind-driven advection of flatfish larvae to favourable nursery grounds.

An earlier study examining the influence of environmental factors (ocean temperature) and spawning stock biomass on Rock Sole recruitment in the Bering Sea (presumably Northern Rock Sole) and Hecate Strait (presumably Southern Rock Sole) showed that while both factors affected recruitment for the Hecate Strait stock, they were less pronounced than the effects seen for the Bering Sea stock (Fargo and Wilderbuer 2000). The authors of this study concluded that, while temperature had a moderating influence on Rock Sole recruitment in Hecate Strait, it could not be considered a controlling factor.

Growth and Maturity

Rock Sole exhibit strong sexual dimorphism, with females growing faster, larger, and older than males (Appendix D). In 5AB, the estimated maximum length for females is 53 cm, while that for

[1] Starr, P.J., Kronlund, A.R., Workman, G., Olsen, N., and Fargo, J. 2006. *Rock sole (Lepidopsetta spp.) in BC, Canada: Stock Assessment for 2005 and Advice to Managers for 2006/2007*. Fisheries and Oceans Canada Pacific Scientific Advice Review Committee (PSARC) Working Paper, unpublished manuscript, available from P.J. Starr or K.R. Holt.

males is 43 cm. In 5CD, the estimated maximum length for females is 46 cm, while that for males is 39 cm. The maximum Rock Sole age observed in B.C. is 20 years for females and 14 years for males. Both males and females reach 50% maturity at 5.6 years.

Habitat

Adult Rock Sole show little preference for a particular sediment type. They are found over sand, gravel, shell, cobble and rocky bottoms (Garrison and Miller 1982). Juvenile Rock Sole prefer coarse sand or gravel substrate (Garrison and Miller 1982). Rock sole eggs in Puget Sound, Washington (either Northern, Southern, or both species) have been identified in sandy gravel of upper intertidal beaches (Penttila 1995 cited in Orr and Matarese 2000).

FISHERY & MANAGEMENT HISTORY

Trawl fishery landings for Rock Sole are available from 1945 to present. Coastwide catch generally increased though the late 1940's and 1950's, with annual peaks of over 2000 tonnes occurring in the 1950's (Figure 4). Prior to 1955, the majority of this catch came from Hecate Strait in Area 5CD, which accounted for an average of 81% of coastwide catch. Landings in Area 5AB rose sharply during the late-1950's, with catches in this area peaking at 1100 tonnes in 1966. Catches in Area 3CD showed an overall increase between 1945 and the 1960's, with catches peaking at 226 tonnes in 1967. Catches in Area 4B varied between around 40 and 70 tonnes throughout the 1960's, while no landings were reported in Area 5E prior to 1977. United States (US) trawlers began to fish in Canadian waters in the 1940's; however, US trawl catch was not recorded until 1954. US trawl catches in Canadian waters dwindled and ceased completely by 1982, following the declaration of Canada's 200 mile Canadian Fishing Zone in 1977. Landings in all areas showed steep declines starting in the early 1980's, followed by increases in the late-1980's and early 1990's to catch levels comparable to the 1960's (Figure 4). Catch levels in 3CD, 5AB, and 5CD once again began to decline in the late 1990's after fleet rationalisation, the imposition of annual catch limits and the implementation of Individual Vessel Quotas (IVQs). In Areas 3CD and 5CD, catches have remained at a relatively constant level since the mid-1990's, with catches nearly reaching the TAC in 5CD and well below the TAC in 3CD. In Area 5AB, catches have fluctuated since the late-1990's, but have generally remained below the TAC.

Management of the BC Rock Sole fishery has used a range of tactics, including trip limits and annual quotas. There were no catch or trip limits for Rock Sole before 1982. A trip limit of 11 tonnes was introduced for management region 5CD in 1982 (Appendix A). By 1986, trip limits of 14 tonnes were in place for each of Areas 5CD and 5AB. Trip limits continued to be applied until 1992, at which time area-specific management by Total Allowable Catch (TAC) was introduced for management areas 5AB and 5CD. These initial quota levels were set at 800 tonnes in 5AB and 1150 tonnes in 5CD based on a review of catch and effort trends. A TAC of 102 tonnes was introduced to region 3CD for the 1997/1998 fishing year and has remained at this level since then. The TACs were reduced for areas 5AB and 5CD in the early 2000's, as shown in Figure 4. Areas 4B and 5E have never been assigned TACs as they represent a minor component of total coastwide landings (Figure 1; Figure 4).

There is no legal size limit for Rock Sole; however, an effective minimum size in the landings is driven by market preference. Typically a preferred fish is at least 33 cm total length to ensure a worthwhile fillet yield. This effective size limit results in a fishery that is primarily made up of females, with the majority of males being below 33 cm.

In addition to the trip limits and TACs, there have been other significant management tactics applied to the trawl fishery in the last decade that may affect fishery-dependent data:

1. Mesh size of trawl nets has changes through time due to regulatory changes. The following table shows the history of codend mesh size regulations in Hecate Strait:

Years of implementation	Codend mesh size	Type of regulation
before 1989	not regulated	–
1989–1993	127 mm (5 inches)	Voluntary compliance
1994	140 mm (5.5 inches)	Voluntary compliance
1995–present	140 mm (5.5 inches)	DFO regulation

   The objective of the increased codend mesh size was to allow greater escapement of small fish. Mesh selection studies (Stanley and Davenport 1982) indicated that a 15 cm codend is 50 percent selective for Rock Sole of 34 cm (about age 3 and older) while an 11.4 cm codend was 50 percent selective for Rock Sole of 25 cm (age 2 and older). These regulation changes were intended to reduce discard mortality on undersize flatfish and ensure that commercial catches more closely approximated the market preference for fish greater than 33 cm;

2. Independent dockside validation of landings was introduced in 1994;

3. One hundred percent coverage by at-sea observers was introduced for the majority of the bottom trawl fleet (excluding the Strait of Georgia) in 1996. At-sea observers provide a tool for independent estimation of catch composition, both retained and discarded, verification of fishing location and biological samples of un-graded fish;

4. An Individual Vessel Quota (IVQ) program was adopted in 1997 and remains the management tool used to ensure that the TAC is not exceeded. The IVQ “species cap” for Rock Sole is 5% on a coastwide basis, i.e., any one licensed vessel may only accumulate a maximum of 5% of the total coastwide Rock Sole quota;

5. Since 1996, a seasonal closure to trawl gear to protect Dungeness Crab (*Cancer magister*) has been in place annually between June 1 and July 15. This closed area covers approximately 40% of the area in the shallows on the western side of Hecate Strait (region 5CD), which included a portion of the historical fishing grounds for Rock Sole. The closed area accounted for approximately 4% of the catch over the 1991 to 1995 period before implementation of the closure;

6. Substantial reductions in the Pacific Cod (*Gadus macrocephalus*) TAC, starting with the 2000/2001 fishing season, likely affected Rock Sole catch patterns, as Rock Sole are often caught concurrently with Pacific Cod. In Area 5CD, the reduction in Pacific Cod TAC was from 1000 tonnes to 200 tonnes within a single year (2000/2001). Pacific Cod TACs have risen in recent years and are now at 1,200 tonnes in Area 5CDE and 590 tonnes in Area 5AB.

7. A seasonal closure for Pacific Cod spawning aggregations has been in place since 1996. The following table shows the timing of bottom trawl regulatory closures in most of Hecate Strait (5CD) for the protection of Pacific Cod:

Year(s) of implementation	Closed period
1996	16 February–15 April
1997	1 January–31 March
1998–2001	1 January–15 April
2002–present	1 January–30 April

DEFINITION OF REFERENCE POINTS

Two approaches to setting stock reference points for Areas 5AB and 5CD are presented in decision tables for this assessment: (i) reference points based on maximum sustainable yield (MSY) and (ii) historical reference points based on reconstructed biomass and exploitation rate trajectories. Both types of reference points were estimated based on assessment model fits. As only the female portion of the population was modelled for stock assessment (see next section), all reference points are based on female-only spawning biomass and exploitation rates.

The MSY-based reference points are consistent with the provisional recommendations contained in the DFO Fishery Decision-making Framework Incorporating the Precautionary Approach (PA policy; DFO 2009). The policy requires stock status to be characterized using three reference points: (i) a reference removal rate, (ii) an upper stock reference point (USR), and (iii) a limit reference point (LRP). Provisional values of USR = $0.8B_{\mathrm{MSY}}$ and LRP = $0.4B_{\mathrm{MSY}}$ are suggested when there is insufficient information to estimate stock-specific MSY-based reference points, where B_{MSY} is the spawning biomass associated with MSY. A reference removal rate is not directly identified in this policy scheme; however, the framework specifies that the reference removal rate should not exceed the rate of fishing mortality associated with MSY, F_{MSY}, which implies a maximum reference removal rate of F_{MSY} and a target biomass level of B_{MSY}. We therefore use four reference points linked to the DFO PA Policy in decision tables:

- Limit Reference Point: $0.4B_{\mathrm{MSY}}$
- Upper Stock Reference: $0.8B_{\mathrm{MSY}}$
- B_{MSY}
- u_{MSY}

Note that we use a discrete exploitation rate (u) rather than the continuous fishing mortality rate (F) used in the DFO PA policy to describe fishery removals because our assessment model is a discrete model.

Historical reference points were previously developed and applied to Area 5CD and 5AB Rock Sole in 2006 (Starr et al. 2006, unpublished manuscript[1]). They include (i) a limit biomass level set at the minimum female spawning biomass estimate between 1966 and 2005, (ii) a target biomass level set at the average female spawning biomass estimate during a period of average biomass levels (1977-1985 for 5AB; 1971-1980 for 5CD), and (iii) a target harvest rate based on the average female harvest rate between 1966 and 2005. Female spawning biomass in the current year, B_{2014}, was also included in decision tables in 2006 as a reference point to help inform decision-making based on objectives related to the probability of stock increase or decline. We therefore also use four reference points based on the approach developed in 2006:

- Limit Biomass: minimum ($B_{1966\text{-}2005}$)
- Target Biomass: mean ($B_{1977\text{-}1985}$) for 5AB; mean ($B_{1971\text{-}1980}$) for 5CD
- Target Exploitation Rate: mean ($u_{1966\text{-}2005}$)
- B_{2014}

STOCK ASSESSMENT MODELLING

We applied a female-only statistical catch-at-age model in a Bayesian estimation framework to assess Rock Sole in Areas 5AB and 5CD. For both areas, the model was fit to catch data, two or more indices of abundance with associated coefficients of variation, and age composition data from commercial trawl fisheries and research surveys. Biological parameters used in the model, including weight-at-age and maturity schedules, were estimated independently and then input to the assessment model as fixed parameters that remained constant over time.

Quantities related to MSY, including B_{MSY} and u_{MSY}, were estimated by projecting assessment model fits forward across a range of constant harvest rates until equilibrium was reached.

Harvest decision tables for Areas 5AB and 5CD were created by projecting each assessment model 5 years into the future under a range of constant catch levels without feedback control. For each level of constant harvest, decision tables show the probability that projected stock status in each year will be greater than specified reference points.

DATA INPUTS

Four types of data inputs were used for the assessment models, each of which is described in the following four sections: 1) historical records on annual catch, 2) one or more indices of relative abundance, 3) age composition data, and 4) biological data on growth and maturity schedules. We provide a brief overview of these four data inputs here, and then elaborate on them in the referenced appendices.

Catch Data

As only the female portion of the population was modelled, all catch data were scaled to represent female-only catch (including estimated discards) before input into the model (Appendix A).

Trawl fishery landing data were available from 1945 to 2012 for input into Area 5AB and 5CD stock assessment models. Catch records from both areas come from a variety of sources due to the long time period involved (Appendix A). Landings from 1945-1955 include only Canadian fishery landings. While some catches were likely taken by US fisheries during this period, US catch information prior to 1956 is unavailable. As an indication of how much catch may be missing before 1956, the average annual contribution to total catch taken by US fisheries between 1956 and 1960 (the first five years with US data) was 16% in Area 5AB and 6% in Area 5CD. Catches from 1956-1981 include landings from both Canadian and US fisheries. US landings ended in 1981, so all landing records from 1982 onwards come from Canadian vessels.

Discarded trawl fishery catch was included in catch summaries used for stock assessment model fits. Discard estimates are available from 1996-2012. Estimates of discards before the implementation of 100% observer coverage in 1996 are considered unreliable. For the purposes of consistent model input, discards before 1996 were estimated by applying the average discard rate by region between 1996 and 2012 to landed catch values in each year (Appendix A).

Catch of Rock Sole by groundfish fisheries other than bottom trawl are negligible and are not included as catch in our stock assessment modeling (Appendix A).

Research survey catches for 5AB and 5CD stocks were included in catch summaries used to fit stock assessment models (Appendix A).

Abundance Indices

Fishery-dependent abundance indices were derived from commercial trawl fishery catch rates (catch-per-unit effort; CPUE). CPUE indices were standardized using a stepwise generalised linear model (GLM) procedure (Appendix B). For Area 5AB, a single GLM analysis was performed for the entire time period of available catch and effort data (1966 – 2012). For Area 5CD, GLM analyses were performed for two time periods: (1) 1954 – 1995 and (2) 1996 – 2012. The series were separated between 1995 and 1996 to reflect the substantial changes that took place in the BC bottom trawl fishery between those years. These changes include the implementation of Individual Vessel Quota (IVQ) management, and the introduction of 100% observer coverage corresponding with a full accounting for all catch, including discards. Over time, these management changes resulted in the rationalisation of the fleet and an overall reduction in the number of vessels fishing. It seems unlikely that the two time periods would share the same catchability coefficient. While the approach taken in Area 5CD of splitting the time series at 1996 was originally deemed preferable to using a single CPUE series in Area 5AB, model runs that uncoupled the CPUE series in 5AB led to high estimates of survey catchability (e.g., q = 0.82; Appendix G) which lacked credibility given the much lower values of survey q seen for the more data-rich Area 5CD assessment (q=0.19 for Hecate Strait assemblage survey and q=0.20 for Hecate Strait synoptic survey). Furthermore, when the two series were separated, the estimate of catchability for the recent CPUE series (1996-2012) was more than twice the estimate for the early CPUE series (1966-1995), which did not seem credible in the context of recent management changes and dissimilar results in the 5CD assessment. We therefore used a single CPUE time series for our base case model run in Area 5AB and provide the 2 CPUE model as a sensitivity run (Appendix G).

Fishery-independent indices were derived from bottom trawl research surveys (Appendix C). For Area 5CD, two survey series were used: (1) the Hecate Strait multi-species assemblage survey, which occurred 11 times between 1984 and 2003, and (2) the Hecate Strait synoptic survey, which occurred biennially between 2005 and 2013. For Area 5AB, a single survey series was used: the Queen Charlotte Sound synoptic survey, which occurred in 2003, 2004, and biennially between 2005 and 2013. Descriptions of survey design and analysis methods, as well as the final survey series used as input to assessment models, are given in Appendix C.

Age Data

Age composition data were available from the commercial bottom trawl fishery as well as from the three research surveys described above. In Area 5CD, fishery age data were available for most years between 1978 and 2011, while for area 5AB, fishery age data were only available for 16 years between 1986 and 2011. Survey age data for each area were available for most survey years up to, and including, 2011.

Age composition data were input to the assessment models as weighted proportions-at-age. Weighting was based on a stratified weighting scheme that adjusted for unequal sampling effort across spatial or temporal strata. For commercial data, these strata comprised quarterly periods within a year, while, for survey samples, the strata were defined by the survey design. A description of the methods used to calculate weighted age frequencies is given in Appendix D.

Biological Parameters

Schedules describing weight-at-age and proportion mature-at-age were calculated independent of the assessment model and were then input into the model as fixed values that were held constant over time. Descriptions of the data and models used to develop these schedules are provided in Appendix D.

The stock assessment for Area 5AB required a fixed value to be assumed for natural mortality (M) because there were insufficient data available to estimate this parameter. A value of 0.2 was used based on a review of flatfish life history literature, as described below for the development of a prior distribution for *M*. A sensitivity model run with a fixed *M* of 0.2 was also conducted for the Area 5CD stock (Appendix G).

STATISTICAL CATCH-AT-AGE MODEL

Overview

The statistical catch-at-age software "Awatea" was used for stock assessment modelling (A. Hicks, NOAA, pers. comm.). Awatea is a modified version of the Coleraine statistical catch-at-age software (Hilborn et al. 2003) that accommodates Bayesian estimation using the Markov Chain Monte Carlo (MCMC) method. The model structure is similar to that used previously in BC for Yellowmouth Rockfish (Edwards et al. 2012a) and Pacific Ocean Perch (Edwards et al. 2014a, Edwards et al. 2014b), except that only one sex was modelled. We followed a data weighting scheme suggested by Francis (2011) to assign relative weights to multiple indices of abundance and age composition data. Under this scheme, observed coefficients of variation (CVs) for abundance indices were reweighted by adding process error to the observation error CVs, with different process error CVs used for each abundance index. A description of the stock assessment model structure, including model equations and the reweighting scheme used, is provided in Appendix E.

Estimated parameters for the Area 5AB assessment included unfished equilibrium recruitment of age-1 fish (R_0), steepness for the Beverton-Holt stock recruitment curve (h), catchability coefficients for both the Queen Charlotte Sound (QCS) synoptic survey and the long-term CPUE series (1954-2012), and two selectivity parameters (age at full selectivity, μ, and variance of the left arm of the selectivity curve, v) for the commercial trawl fishery and the QCS synoptic survey. Selectivity for the CPUE series was assumed to be the same as for the commercial fishery. The rate of natural mortality, M, was held fixed at 0.2. Estimating M (with an informed prior distribution) is preferable to holding the parameter fixed because it allows the introduction of additional variability associated with this parameter. However, it was not possible to achieve MCMC convergence when this parameter was estimated for Area 5AB, thus requiring us to fix it at M=0.2 for the base case 5AB assessment.

Estimated parameters for the Area 5CD assessment included R_0, h, M, catchability coefficients for all four abundance series (1954-1995 CPUE, 1996-2012 CPUE, Hecate Strait multispecies assemblage survey, and Hecate Strait synoptic survey), and two selectivity parameters (μ and v) for each of the commercial trawl fishery, the assemblage survey, and the synoptic survey. As with Area 5AB, selectivity for both CPUE series was assumed to be the same as for the commercial fishery. An attempt was made to exclude CPUE data when fitting the Area 5CD model; however, MCMC posterior distributions were unable to reach convergence when this was done (Appendix G).

Development of Prior Distributions

Informative Bayesian prior distributions were used for steepness, h, and when estimated, natural mortality, M. For Area 5AB, informative prior distributions on selectivity parameters were also necessary, which were parameterized based on Area 5CD model results. Uninformative prior distributions were used for all other estimated parameters (Table 1).

Informative prior distributions for h and M were developed through a review of published literature and stock assessments. A normal distribution with a mean of 0.2 and a CV of 20% (N(0.2, 0.04)) was used as a prior distribution on M. A mean value of 0.2 is in line with female-specific estimates from the literature. The 2012 stock assessment for Northern Rock Sole in the Bering Sea estimated M=0.19 for females (Wilderbuer and Nichol 2013), while the 2013 stock assessment for Rock Sole in the Gulf of Alaska assumed M=0.2 for females and estimated

M=0.267 and M=0.275 for male Southern and Northern Rock Sole, respectively (A'mar et al. 2012). Both previous Rock Sole assessments in BC have assumed a fixed M=0.2 for females (Fargo et al. 2000, Starr et al. 2006, unpublished manuscript[1]). Application of the Hoenig (1983) life history approximation to a maximum female Rock Sole age of 20 years results in an approximation of M = 0.21.

A beta distribution with a mode of 0.9, a mean of 0.85, and a CV of 10% (Beta(13.4, 2.4)) was used as a prior distribution on h. This distribution is in line with published flatfish estimates of Beverton-Holt steepness which range from 0.798 to 1.0. A Bayesian stock assessment model fit to West Coast U.S. English Sole data produced a posterior distribution with an estimate of h=0.798 (CV = 19%; Stewart 2007). A review of steepness estimates for flatfish species by Maunder (2012) suggested that flatfish steepness using a Beverton-Holt curve is usually close to 1.0 (where, h = 1.0 means recruitment is independent of spawning biomass). A meta-analysis of steepness by Myers et al. (1999) estimated steepness using a Ricker stock recruitment relationship as h = 0.80 ($h_{20\%}$ = 0.71, $h_{80\%}$ = 0.87) for Family Pleuronectidae (right-eyed flounders). However, Maunder (2012) suggested that the Myers et al. (1999) median estimate may be closer to h=0.94 based on the 15% negative bias in estimates of h when the underlying stock recruitment curve is a Beverton-Holt curve rather than a Ricker curve, as described for Atlantic cod in Appendix 2 of Myers et al. (1999).

SENSITIVITY ANALYSES

Sensitivity analyses were used to investigate how choices made during stock assessment model formulation affected results. Sensitivity analyses for the Area 5AB stock assessment explored the effect on stock assessment results of splitting the CPUE time series into two separate series (before 1996 and since 1996) and estimating natural mortality. Sensitivity analyses for the Area 5CD stock assessment explored the effect on stock assessment results of excluding various combinations of CPUE indices when fitting the model to data, the magnitude of process error added to survey indices, and the prior distribution specified for the stock recruitment steepness parameter h. Summaries of all sensitivity model runs and results are provided in Appendix G.

ASSESSMENT RESULTS

A detailed summary of stock assessment model fits (including an evaluation of MCMC convergence) is presented in Appendix F. In this section, we provide an overview of the results and refer readers to Appendix F for more information.

MCMC chains were slow to converge for both management areas due to confounding among estimated parameters. Large thinning intervals were needed to achieve acceptable convergence in both base runs (1 in 10,000 runs for Area 5AB and 1 in 50,000 runs for Area 5CD). Parameter estimates of h and R_0 were confounded in the Area 5AB MCMC estimation procedure (correlation coefficient = 0.68; Figure F.11 in Appendix F). For the Area 5CD base run, in which M was estimated, parameter estimates of M were highly correlated with R_0 (correlation coefficient = 0.90; Figure F.33 in Appendix F), while neither R_0 nor M were correlated with h.

Area 5AB

The posterior median estimate of steepness in Area 5AB was 0.876, with associated 5th and 95th percentiles of 0.730 and 0.966, respectively (Table 2). This posterior distribution showed almost no updating from the prior distribution (Appendix F).

Estimated catchability, q, for the Queen Charlotte Sound synoptic survey was higher than expected for a multi-species survey such as this. The posterior median estimate was 0.628, which means the model predicts that 63% of female Rock Sole in areas swept by the trawl survey net were captured (Table 2). We consider this result to be unlikely, and provide a more detailed discussion of this result in the Discussion section.

Female spawning biomass in Area 5AB at the start of 2014 is estimated to be at 0.37 of unfished female biomass in 1945, B_0, based on posterior median values (Table 2). The predicted time series of female vulnerable biomass shows a steep decline from unfished levels between the late 1950's and 1970 (Figure 5). Female biomass levels stabilized between 1970 and 1990, a period of reduced catch compared to the 1960's, before once again beginning to decline in the early 1990s with increased catches. Female biomass reached a low point for the time series in 1997-1998, before steadily increasing after 2000 to current levels.

The median estimate of B_{2014} / B_{MSY} is 1.52, which places it above all three of the B_{MSY}-based reference points presented in this assessment (B_{MSY}, USR = 0.8B_{MSY}, and LRP = 0.4B_{MSY}; Table 2, Figure 6). The probability that B_{2014} was greater than both the LRP and USR was 100% (Figure 9). B_{2014} was also substantially above the historical limit reference point (defined as B_{Lim} = min($B_{1977\text{-}1985}$)), with a median B_{2014} / B_{Lim} ratio of 2.45. The lower 5$^{\text{th}}$ percentile of this ratio was 1.86, allowing us to conclude that current female spawning biomass is above the historical limit reference point. B_{2014} was just below the historical target reference point (defined as B_{Tar} = mean($B_{1966\text{-}2005}$)), with a median B_{2014} / B_{Tar} ratio of 0.96.

The posterior median estimate of MSY for the 5AB stock is 524 tonnes (females only). The exploitation rate in 2013 was below both u_{MSY} and the historical target exploitation rate, u_{Tar}. The median ratios of u_{2013} / u_{MSY} and u_{2013} / u_{Tar} were 0.46 and 0.59, respectively, and the 95th percentiles for these posterior distributions were 0.72 and 0.75, allowing us to conclude that current fishing rates are below target levels.

Decision tables for Area 5AB are shown in Table 4 and Appendix F. The condensed decision table shown in Table 4 is limited to a summary of stock status in 2019 (i.e., 5 years from now), while a series of decision tables and figures in Appendix F summarize stock status in each of the five years between 2014 and 2019.

Area 5CD

The posterior median estimate of steepness in Area 5CD was 0.862, with associated 5$^{\text{th}}$ and 95$^{\text{th}}$ percentiles of 0.698 and 0.962, respectively (Table 3). As with Area 5AB, the posterior distribution for steepness in Area 5CD showed almost no updating from the prior distribution (Appendix F).

The posterior median estimate of M was 0.251, with associated 5$^{\text{th}}$ and 95$^{\text{th}}$ percentiles of 0.208 and 0.292, respectively. The posterior distribution for M was shifted upwards from the prior distribution, which had a mean of 0.2, but lies within the range of the prior distribution (Appendix F).

Estimates of survey catchability were considerably lower in Area 5CD than in Area 5AB; the Hecate Strait multispecies assemblage survey had a median posterior q of 0.2165, while that of the Hecate Strait synoptic survey was 0.1869 (Table 3).

Female spawning biomass in Area 5CD at the start of 2014 is estimated to be at 0.80 of unfished female biomass in 1945, B_0, based on posterior median values (Table 3). The predicted time series of female spawning biomass shows an initial increase in biomass to levels greater than unfished equilibrium biomass during the early 1950's followed by a continuous decline during the 1960's (Figure 7). The steepest decline occurred in the late-1960s, a time during which catches doubled compared to the previous decade. Female biomass levels experienced occasional minor fluctuations between 1970 and 2000. Female biomass in Area 5CD has shown a general increasing trend after 2000, with the greatest rate of increase occurring between 2000 and 2005. The most recent 4 years of the time series (2010 to 2014) showed a constant increasing trend.

The median estimate of B_{2014} / B_{MSY} is 3.22, which places it well above all three of the B_{MSY}-based reference points presented in this assessment (B_{MSY}, USR = 0.8B_{MSY}, and *L*RP = 0.4B_{MSY}; Table 3, Figure 8). The probability that B_{2014} was greater than both the LRP and USR was 100% (Figure 9). B_{2014} was also substantially above the historical limit reference point, (defined as B_{Lim} = min($B_{1966\text{-}2005}$)) with a median B_{2014} / $\mathrm{B}_{\mathrm{Lim}}$ ratio of 2.00. The lower 5th percentile of this ratio was 1.53, allowing us to conclude that current biomass is above the historical limit reference point. B_{2014} was also above the historical target reference point (defined as B_{Tar} = mean($B_{1971\text{-}1980}$)), with a median B_{2014} / B_{Tar} ratio of 1.40.

The posterior median estimate of MSY for the 5CD stock is 1,895 tonnes (females only). The exploitation rate in 2013 was below both u_{MSY} and the historical target exploitation rate, u_{Tar}. The median ratios of u_{2013} / u_{MSY} and u_{2013} / u_{Tar} were 0.08 and 0.32, respectively, and the 95th percentiles for these posterior distributions were 0.16 and 0.42, allowing us to conclude that current fishing rates are below target levels.

Decision tables for Area 5CD are shown in Table 5 and Appendix F. The condensed decision table shown in Table 5 is limited to a summary of stock status in 2019 (i.e., 5 years from now), while a series of decision tables and figures in Appendix F summarize stock status in each of the five years between 2014 and 2019.

Sensitivity Analyses

Area 5AB

Sensitivity analysis results for Area 5AB indicated that splitting the CPUE series into two independent time series (pre-1996 and post-1996), as opposed to using a single CPUE series as was done in the base case, had little effect on the trend in biomass trajectories or on posterior distributions for MSY-based and historical reference points (Appendix G).

Natural mortality (*M*) was estimated to be 0.14 for two sensitivity runs that estimated *M* in Area 5AB, which is lower than the fixed value of *M*=0.2 that was used in the 5AB base case and considerably lower than the equivalent values estimated for the 5CD assessment. We did not estimate *M* in the base case model for Area 5AB because we were unable to achieve convergence in MCMC posterior distributions.

Area 5CD

In Area 5CD, estimates of current stock status relative to B_0 showed low sensitivity to the inclusion or exclusion of the CPUE data (with the exception of a model run that eliminated only the 1996-2013 CPUE seriesand showed moderate sensitivity). There was some sensitivity to the inclusion of CPUE series in the estimates of overall stock size and the amount of available yield (Appendix G).

Applying a constant process error CV of 0.2 to all abundance indices in Area 5CD, compared to using different values for each index as was done in the 5CD base case (Appendix E), increased the estimated scale of predicted stock biomass throughout the time series by about 4-5%. Estimates of B_{2014} / B_0 were very similar between the two runs, leading to similar conclusions regarding stock status. This result shows that there was not much sensitivity to the process error choice we used in the base case compared to applying a constant process error CV of 0.2.

Fixing the value of M at the prior mean 0.2 in Area 5CD resulted in a smaller predicted scale of the Rock Sole stock compared to the base run. This result is unsurprising, given that M was estimated about 25% higher than 0.2 in the base case. Ratios of B_{2014} / B_0, and B_{2014} / B_{MSY} were also lower when M was fixed. However, the ratios of B_{2014} to reference points based on historical biomass levels (i.e., B_{2014} / B_{Lim} and B_{2014} / B_{Tar}) were comparable or slightly higher than for the base case, demonstrating that the use of historical periods as reference levels provide greater stability for interpretation because they are less sensitive to shifts in model assumptions. We selected the run which estimates M to be our base case because this run adds variability to the estimates of derived parameters compared to the fixed M run.

Using a prior distribution of h with a lower prior mean (h=0.72) and a wider CV (15%) than the base case prior had little effect on the estimated biomass levels or on biomass relative to B_0; however, the lower value of h reduced the estimated productivity of the stock, with lower estimates for productivity-based reference points such as MSY and u_{MSY} and a larger estimate of B_{MSY}. As a result, the posterior of B_{2014} / B_{MSY} was shifted lower when the h prior was lower, while the posterior for u_{2013} / u_{MSY} was shifted upwards. As seen when investigating the effect of fixing M, current stock status relative to historical reference levels was relatively insensitive to assumptions about h. Our investigation of the effect of the prior distribution on h showed that the data used to fit this stock assessment model contained very little information about this parameter. In both the base run and the low steepness prior sensitivity run, the posterior distribution was not updated from the shape of the prior distribution.

SUMMARY OF NON-ASSESSED AREAS

Rock Sole catch from commercial fisheries were low throughout Areas 3CD (West Coast Vancouver Island), 4B (Strait of Georgia), and 5E (West Coast Haida Gwaii) (Figure 4; Appendix A). Research survey catches of Rock Sole have also been infrequent and / or low for these areas (Appendix C). As a result of these data limitations, we did not attempt to fit stock assessment models or provide harvest advice for these three areas. In this section, we summarize catch trends relative to TACs and available data for each of these three non-assessed areas.

AREA 3CD

Between 1954 and 1995, the average annual landing of Rock Sole in Area 3CD was 133 tonnes. A large reduction in Rock Sole trawl landings occurred in 1996 coincident with the implementation of at-sea observers and just prior to the start of the IVQ program in 1997. This decline in landings was also coincident with a substantial decline in Pacific Cod landings and effort from 2,977 tonnes (36,281 hours trawled) in 1991/1992 to 790 tonnes (25,771 h trawled) in 1994/1995 (Starr et al. 2002). It is possible that the much reduced effort directed at Pacific Cod has also meant less Rock Sole effort, either directed or as bycatch**.**

Rock Sole landings from 1996 to 2012 averaged 17.5 tonnes by calendar year, well below the assigned quota of 102 tonnes (Figure 4). A low of 8.1 tonnes in 1997-98 was followed by a mild increase before falling to 3.6 tonnes in 2008. Since then, landings have increased to 23.1 tonnes by 2012. Discard records since implementation of on-board observers in 1996 indicate that discard rates averaged 5.2 tonnes from 1996-2012. The peak discard rate of 43% occurred in 2005 and declined to 10% by 2012.

Commercial trawl catch rates are the only potential source of a long-term stock abundance index. Fishery-independent data consist of Rock Sole biomass estimates from five West Coast Vancouver Island Synoptic (WCVIS) surveys between 2004 and 2012 plus associated biological data. This survey series showed no overall trend in relative biomass indices over the nine years of coverage (Appendix A).

A quantitative stock assessment was not attempted for this region because of data limitations. Consequently there is no advice to managers for Rock Sole in Area 3CD except to note that, should Pacific cod build to higher levels of abundance, increased landings of Rock Sole may occur. Fishery statistics should be monitored at regular intervals to assess whether Rock Sole catch shows any substantial changes. Similarly, Rock Sole biomass indices from the current West Coast Vancouver Island synoptic survey should continue to be monitored for possible trends in abundance.

AREA 4B

Annual Rock Sole landings have never exceeded 80 tonnes in Area 4B, with cycles of increasing and decreasing catch occurring over the available 1954 to 2012 series (Figure 4). Most recently, landings have declined steadily since 1999 and bottomed out near 0.8 tonnes in 2007 (Figure 4). Discard rates in 2011-2012 averaged 48% of retained catch.

The 2006 Rock Sole assessment (Starr et al. 2006, unpublished manuscript[1]) noted that industry members had cited a decline in Rock Sole price as a possible cause for the reduction in landings leading up to 2006. That assessment also noted that fishing has been focused in a relatively small area of Area 4B on what may be the spawning biomass given the seasonal timing of catches.

There are few surveys in Area 4B and biological data for this region are limited (Appendix C). Available data will not support stock assessment. Consequently no advice to managers on quota is provided. Fishery statistics should be monitored at regular intervals to assess whether Rock Sole catch shows any substantial changes.

AREA 5E

Trawl landings from Area 5E are very low compared with other Rock Sole stocks (Figure 4). Total catch averaged 0.1 tonnes from 1996-2012. Relatively high discard rates and incidental catches in 5E indicate that Rock Sole are not a target species in this area. Commercial fishery catch rates are not considered to represent stock abundance and the only available survey time series is recent (biennial since 2006) and has not encountered Rock Sole in a single year. There is no useable time series of biological data. No assessment is possible, or required, for Area 5E at this time and no advice to managers on quota is provided. Fishery statistics should be monitored at regular intervals to assess whether the catch of Rock Sole in the commercial fishery changes.

DISCUSSION

UPDATES FROM 2006 STOCK ASSESSMENT

This assessment is the first time a statistical catch-at-age model has been used to assess stock status for the Area 5AB stock. A delay-difference model was applied in 2006 because there were insufficient catch-at-age data to adequately inform a statistical catch-at-age model at the time (Starr et al. 2006, unpublished manuscript[1]). Prior to 2006, Rock Sole biomass in Area 5AB was assessed based on an evaluation of CPUE trends rather than on a formal stock assessment model. We chose to apply a catch-at-age model this time due to increased data availability; there have been four additional years of biomass estimates and age composition data from the Queen Charlotte Sound synoptic survey, as well as seven additional years of fishery CPUE and five additional years with adequate sample sizes of commercial fishery age composition data. However, even with these additional years, data for Area 5AB were not sufficiently informative to allow the catch-at-age model to estimate *M* or to estimate separate catchability coefficients for the CPUE series before and after 1996. As a result, we were required to make strong assumptions for this stock for which we have low confidence, particularly with regard to the assumption of constant catchability for CPUE over the entire time period. It seems unlikely that these two time periods would share a single catchability coefficient given the reduction in number of vessels fishing (Appendix B), the introduction of 100% observer coverage, and the introduction of IVQ management in 1996/97. All of these factors will lead to substantial changes in fishing behaviour. However, it should be noted that the assumption of a constant catchability may not be entirely incorrect because the 5CD assessment model estimates nearly identical catchability coefficients for CPUE1 and CPUE2 (Table 3).

The delay-difference model used to assess the 5AB Rock Sole stock in 2006 (Starr et al. 2006, unpublished manuscript[1]) contained an error that invalidated the results. This error was discovered in 2009 and, while a correction was made for two flatfish assessments conducted in the year following the 5AB Rock Sole assessment (Starr 2009a and Starr 2009b), the 2006 5AB stock assessment was never corrected. This error stems from the method by which the mean weight in the initial year was calculated, and resulted in always using the mean weight associated with the unfished biomass (B_0) in the first year of the reconstruction. When the initial level of depletion was estimated as a free parameter (as was the case in the 2006 5AB stock assessment), equilibrium mean weight associated with the level of depletion should have been used rather than the mean weight associated with B_0. This error biased estimates of B_0 and stock status, and invalidates comparisons between results from the 2006 assessment and this assessment in Area 5AB.

The model structure used for the 2006 Rock Sole assessment in Area 5CD was similar to that used for the current 2013 assessment, with both models using the Coleraine software for statistical catch-at-age analysis. However, the two assessments differed in several ways. The 2006 assessment assumed a fixed steepness (*h*) value at 0.75 for all model runs while allowing natural mortality (*M)* to be either estimated or fixed (depending on the model run). In this assessment, we estimated both *M* and *h* using informative prior distributions that were based on a review of the literature. In the case of *h*, the prior we used in this study (a beta distribution with a mode of 0.9 and a mean of 0.85) was higher than the fixed value of 0.75 used in 2006. Our justification for using a higher value was based on a review of flatfish steepness estimates from the literature, as described in the Stock Assessment Modelling section above. In addition, some changes were made to the data sets used to fit the model in 2013, including (i) splitting the CPUE series at 1996 (the 2006 assessment used a single CPUE series extending from 1966 to 2005), (ii) dropping the Hecate Strait Pacific Cod monitoring survey that was used in 2006, and (iii) adding the Hecate Strait synoptic survey. The Pacific Cod monitoring survey was not considered for this assessment because it was only run for three successive years (2003-2005), after which it was discontinued, and strongly targeted Pacific Cod. The Hecate Strait synoptic survey was not considered in 2006 as it did not begin until 2005. Finally, the two models differed in the data weighting scheme used, including how they treated the age composition data. For the 2013 model, we adopted the recommendations of Francis (2011) to substantially reduce the weight associated with the age composition data. The expected effect of this change is that the 2006 model will have placed considerably more weight on the age-composition data than the 2013 model did.

The two different model formulations used for Area 5CD in 2006 and 2013, combined with updated data to 2013, result in quite different model predictions. For the 2006 model run in which natural mortality was estimated and a standardised CPUE series was used, the median posterior estimate of M was 0.35 and the median posterior estimate of unfished recruitment (R_0) was 54,527. In comparison, our current 5CD assessment estimates a posterior median M of 0.25 and a R_0 of 20,280. The higher estimate of M may have been the result of the high relative weight placed on the age-composition data in the 2006 model. Large differences are also seen when comparing estimates of stock status in 2006 relative to reference points. The 2006 assessment model predicted biomass in 2006 to be at 0.74 of the historical target biomass level, while our 2013 model predicted biomass in 2006 to be above the historical target biomass level. Estimates of the historical target harvest rate were also quite different between the two models. The 2006 model had a posterior median estimate of 0.26, while that of the 2013 model was 0.12. We believe these updates, as well as the adoption of the Francis (2011) weighting recommendations, have improved the quality of the 2013 5CD assessment relative to the 5CD assessment conducted in 2006.

The 2013 assessment results in both areas show an increase in stock status since 2006. In Area 5AB, the 2013 model predicts a steep increase in biomass between 2006 (posterior median of B_{2006} = 1,314 tonnes) and 2014 (posterior median of B_{2014} = 2,776 tonnes), driven by decreased catch combined with an overall increase in CPUE in recent years. The Queen Charlotte Sound synoptic survey trend is generally flat over this time period. In Area 5CD, the 2013 model predicts an overall increase in biomass between 2006 (posterior median of B_{2006} = 13,489 tonnes) and 2014 (posterior median of B_{2014} = 15,385 tonnes). This increase is driven by the high 2013 survey index value for the Hecate Strait synoptic survey, recruitment signals in the age composition data from both the commercial fishery and the Hecate Strait synoptic survey, and reduced exploitation rates that are estimated to be well below M (see Figure G.19).

ASSESSMENT LIMITATIONS

A key assumption of both the Area 5AB and Area 5CD assessments is that the commercial CPUE series is proportional to the vulnerable biomass of Rock Sole. While commercial CPUE can track abundance, it can also be influenced by factors that affect fishing behaviour, including management regulations, fishing opportunities for co-occurring species (e.g., Pacific Cod in the case of Rock Sole), and changes in fishing gear efficiency (Hilborn and Walters 1992; Robins et al. 1998). CPUE indices are also prone to hyperstability, in which CPUE remains high despite declining abundance (Hilborn and Walters 1992). As a result, CPUE indices may not accurately reflect underlying stock abundance. While CPUE data are not the preferred source of abundance information for fitting stock assessment models, they are the only long-term index series available for Rock Sole stocks in BC. A sensitivity run in Area 5CD that excluded CPUE data was unable to achieve convergence of the MCMC chain. However, the maximum posterior density (MPD) estimate for depletion in the final year for this run was nearly the same as the equivalent estimate from the base case 5CD run that used CPUE (see Appendix G).

We chose to estimate both h and M when fitting the catch-at-age model to data in Area 5CD, and to estimate h, but not M, in Area 5AB. One or both of these parameters are often assumed known when fitting statistical catch-at-age models to data because estimates for these two parameters are considered unreliable, and also because these two parameters are often too correlated to estimate simultaneously (Magnusson and Hilborn 2007). However, some recent studies have shown that these values can be reliably estimated when data series cover a period of high contrast in biomass (Magnusson and Hilborn 2007; Conn et al. 2010, Lee et al. 2012). We also note that recent BC *Sebastes* assessments (Edwards et al. 2012a, 2012b, 2014a, and 2014b) were able to estimate both of these parameters with almost no correlation. We chose to estimate these values, using informative prior distributions, because we wanted to better represent the uncertainty in estimated biomass and reference points while ensuring that the parameter estimates stayed within acceptable limits. Lee et al. (2012) has suggested that *M* may be more estimable than *h* (i.e., lower bias and higher precision); however, we chose to hold *M* fixed in favour of estimating *h* in Area 5AB. This decision was based on our need to obtain estimates of MSY-based reference points from model fits. Estimates of MSY and MSY-derived reference points are sensitive to assumed values of steepness (Punt et al. 2008, Zhu et al. 2012, Mangel et al. 2013), so fixing *h* would have been equivalent to fixing our reference points. In the end, sensitivity analyses showed that our data contained so little information about steepness that MSY-based reference points were still largely determined by the assumed prior distribution. However, the use of a prior on *h* was still deemed preferable because it allowed for the introduction of some uncertainty into the estimates of the MSY-based reference points compared to the frequent practice of assuming a single value for this parameter. When the prior distribution for steepness was lower in our sensitivity analysis, the estimated productivity of the stock was lower, with lower estimates for productivity-based reference points such as MSY and u_{MSY} and a larger estimate of B_{MSY}. As a result, the posterior of B_{2014} / B_{MSY} was shifted lower when the *h* prior was lower, while the posterior for u_{2013} / u_{MSY} was shifted upwards.

Correlation pairs plots for MCMC chains showed that, for the Area 5CD base run that estimated *M* and R_0 were highly correlated with each other (see Figure F.36), which is usually the case in this type of model because a high *M* implies higher productivity and consequently a larger R_0 (Edwards et al. 2012a, Edwards et al. 2014a, Edwards et al. 2014b). Surprisingly, the correlation of *M* with B_0 was much lower (0.54, see Figure F.39). Estimated reference points were also correlated with *M*, including both historical and MSY-based reference points, but at a lower level (range: 0.35–0.7, see Figure F.39). Given the confounding effects between *M* and key management parameters, future Rock Sole assessments should explore the influence of assumed values of *M* (or *M* priors) on assessment results. We note that the value of *M*=0.2 assumed in the Area 5AB assessment and used as the mean of the prior distribution in the Area 5CD assessment is consistent with the values used for previous Rock Sole stock assessments (Fargo et al. 2000, Starr et al. 2006, unpublished manuscript[1]) and for other flatfish species.

Failure to account for a shift in CPUE catchability in 1996 for the Area 5AB stock assessment may have contributed to the high estimate of survey catchability for the Queen Charlotte Sound synoptic survey, which indicated that 63% of Rock Sole within the area spanned by the trawl doors are captured (q = 0.6280). This value is higher than published estimates in the literature as well as the estimate for the Hecate Strait synoptic survey, which is a similarly designed survey series in Area 5CD operating over the same time period. For example, Somerton et al. (2007) found that trawl efficiency estimates for Arrowtooth Flounder (*Reinhardtius stomias*) Flathead Sole (*Hippoglossoides elassodon*) Rex Sole (*Glyptocephalus zachirus*) increased with increasing fish length, reaching a maximum of 0.45, 0.42, and 0.43 respectively. The catchability estimates of Somerton et al. (2007) are higher than would be expected for the Queen Charlotte Sounds synoptic survey due to different gear types but are still lower than estimated by the 5AB model. Somerton et al. (2007) used a trawl net with 36 cm bobbins which is better suited for catching flatfish than the 45 cm rock hopper gear with fixed discs that is used for the DFO groundfish synoptic surveys (Olsen et al. 2007). We therefore believe that the catchability estimates seen for the Hecate Strait synoptic survey (q = 0.1869) and the Hecate Strait assemblage survey (q = 0.2165) in Area 5CD are more credible than that of the Queen Charlotte Sound survey. The high estimate for survey q in Area 5AB, combined with the assumption of a single q for the entire CPUE time series, leads us to discount the reliability of the Area 5AB assessment model results.

Another explanation for the high survey catchability estimate for Area 5AB is that there has been an increasing trend in natural mortality (*M*). Several groundfish species on the east coast of Canada, including the flatfish species American Plaice (*Hippoglossoides platessoides*), are hypothesized to have experienced increased natural mortality due to unfavourable environmental conditions and increased predation (Chouinard et al. 2005, DFO 2011). Experience in fitting stock assessment models to stocks under conditions of increasing natural mortality has shown that estimates of survey catchability are often negatively correlated with the estimates of natural mortality (Morin et al. 2008, Wang and O'Brien 2012). Furthermore, the MCMC results in the Area 5CD assessment show that the posterior distributions of *M* and the survey *q* parameters were also negatively correlated (for example, see Figure F.36). This reinforces the contention that higher estimates of *M* may imply lower estimates of *q*. The potential for an increased *M* for Rock Sole in Area 5AB was not explored in this assessment because it was considered unlikely that *M* would be increasing in Area 5AB while there was no evidence of change in neighbouring Area 5CD. However, given the east coast experience, future stock assessments should consider whether a constant *M* is a reasonable assumption, given the available data.

The introduction of voluntary and then compulsory regulations between 1989 and 1995 to control the codend mesh size of bottom trawl nets (see discussion under Fishery and Management History) are likely to have changed the commercial fishery selectivity, thus affecting the comparability of the CPUE abundance indices and fishery catch data over time. A potential effect of larger codend mesh sizes would be to reduce the number of small Rock Sole seen on deck, thus potentially changing retention behaviour. For this stock assessment, we assumed that the change in mesh size did not affect selectivity, which is the same assumption made in the 2006 stock assessment. Early attempts by the 2006 assessment to model two separate fisheries divided between 1995 and 1996 were unsuccessful due to a lack of information in the age data used to estimate separate selectivity patterns for these two time periods (Starr et al. 2006, unpublished manuscript[1]). Biological samples are limited in their ability to provide evidence of whether this change occurred because samples before 1996 primarily came from sampling catch at the port of landing. As a result, the potential change in selectivity associated with the change in codend mesh size is confounded with market-driven selection practices. It is possible that the effect of a changing selectivity has been partially accommodated by splitting the CPUE series at 1996 in the present 5CD stock assessment. However, this does not remove the problem for fits to the age composition data in 5CD (which assume a constant selectivity) or for the CPUE and age composition fits in the 5AB assessment. It should be noted that previous investigations of changes in fishery selectivity for Rock Sole have focused on analysing age composition data (Starr et al. 2006, unpublished manuscript[1]); however, length frequency data could also show evidence of changing selectivity over time. Future Rock Sole assessments should include an examination of changes in length frequency distributions due to mesh size regulations, and if detected, use these patterns to inform changes in selectivity within the assessment model.

The mesh size changes after 1995 may also have biased the estimated average discard rate that we applied to landings prior to 1996 to estimate discards. The average discard rate was estimated based on observer data collected between 1996 and 2012, when larger codend mesh sizes were in use. The estimated mean rate was then applied to all years before 1996, during the period when it is likely that smaller codend mesh sizes were commonly used. If discard rates were lower after 1996 due to the larger mesh size, this average discard rate would be an underestimate of the rate before 1996 and consequently discards would be underestimated.

Two types of reference points have been used by this stock assessment (Historical and MSY-based; Tables 4 – 5), requiring decision-makers to choose one or the other for guiding harvest decisions. Simulations which include feedback control rules, sometimes called "Closed-loop" policy simulations, could be used to explore the performance of these reference points across a range of management policies that are tuned to these alternative reference levels. Closed-loop policy simulations provide a means for examining trade-offs between conservation objectives and fishery catch objectives for a set of candidate management procedures (Walters 1986, de la Mare 1998, Cox and Kronlund 2008). This is done by simulating the entire management system by modelling data collection, stock assessment, the application of a harvest control rule based on assessment results, and the responses of fish populations to harvest. The simulation is driven by a mathematical-statistical model (called the “operating” model) that is assumed to represent the “true” state of nature as the system is projected forward in time. Observed monitoring data are generated with measurement error from this “true” fish population, and “current” population status (i.e., for the perceived population) is estimated by applying a stock assessment to observed data. Management decisions throughout the projection period are made based on the “perceived” state of the stock, which results in management actions (e.g., setting catch levels) that affect the “true” population in the underlying operating model. Performance measures that evaluate how the alternative management policies perform under these conditions are then calculated based on how they affect the state of the “true” population. Fishery objectives for Rock Sole management in BC could be incorporated into these performance measures to evaluate existing and alternative management procedures. The development and evaluation of such procedures, which could be applied either on an annual or multi-year basis, should be done in collaboration with fisheries managers and stakeholders. Additional issues that could be addressed within such a simulation framework include evaluating the management implications of alternative assessment frequencies, alternative stock assessment models (e.g., delay-difference versus catch-at-age model), and the effect of violations of model assumptions.

RECOMMENDATIONS FOR FUTURE DATA COLLECTION AND RESEARCH

1. Closed-loop policy simulations should be explored as a means of examining trade-offs between conservation objectives and fishery catch objectives for a set of candidate Rock Sole management procedures. This type of analysis could help address questions regarding the use of historical or MSY-based reference points when making harvest decisions, the frequency of stock assessments, and alternative stock assessment methodologies. Such work requires the development of clearly stated policy objectives for these stocks.

2. Continue with the current suite of fishery-independent synoptic surveys, operated on a biennial frequency, that monitor fish populations in regions 3CD, 5AB, and 5CD. This initiative will reduce the future dependency on fishery CPUE data for Rock Sole.

3. Increased biological sampling of commercial Rock Sole catch is needed to ensure adequate sample sizes of otoliths. Sample sizes were too small in some of the more recent years to characterize proportion-at-age of the commercial catch.

4. If estimates of Queen Charlotte Sound survey catchability remain high, the potential contribution of changes in natural mortality in Area 5AB to this trend should be considered. Initial efforts may wish to focus on using the stock assessment model to examine whether there is support within the data for changes in M; however, the development of plausible hypotheses for factors driving changes in M would also be important.

5. Future Rock Sole assessments that estimate M within an age-structured model should explore the influence of the M prior distribution on the assessment results using likelihood profiles and alternative prior distributions.

6. Given that the weighting scheme of Francis (2011) used in this assessment is a relatively new contribution to a developing area of research, the topic of data-weighting in stock

assessment models should be reviewed prior to the next assessment to ensure that this method is still deemed appropriate for BC Rock Sole.

7. Future assessments of Rock Sole will have to cope with the disappearance of sorted samples (i.e., based on landed catch only) after 2009 to estimate the fraction of the total catch which is female. Either the assessment model will have to explicitly model the male portion of the population, or a more sophisticated estimation procedure will be required to prepare the data for use in the assessment model. This latter approach will require approximating the sorting procedure which occurs when selecting Rock Sole for market while the assessment model will do the same thing inside the model. Regardless of which approach is chosen, such modelling would require observations that describe the sorting process through the collection of additional data.

8. Length frequency data should be investigated in detail for the next Rock Sole assessment to determine whether these data can be used to inform the assessment model regarding changes to selectivity resulting from changes in mesh size regulations.

9. The existence, distribution, and abundance of Northern Rock Sole stocks in B.C. should continue to be investigated through training of survey staff and at-sea-observers in the visual differentiation of Northern and Southern Rock Sole, as well as the collection of genetic samples from suspected Northern Rock Sole specimens to confirm species identification.

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TABLES

Table 1. Prior distributions used for Bayesian estimation procedure. Symbols correspond to the notation used to describe the stock assessment model in Appendix E. Note that the prior distribution for catchability was used for multiple data sets within each management area, while prior distributions for the age at full selectivity and the variance of left arm of the selectivity curve in Area 5CD were used for both surveys in this area (the Hecate Strait multispecies assemblage and the Hecate Strait synoptic).

Parameter	Symbol	Prior Distribution
Unfished equilibrium recruitment	R_0	Uniform (100, 100,000)
Recruitment deviations (log scale)	σ_R	Normal (0. 0.6)
Natural mortality	M	Normal (0.2, 0.04)
Steepness	h	Beta (13.4, 2.4)
Catchability (log-scale)	$\ln(q)$	Uniform (-15, 15)
Age at full selectivity	μ	<u>Fishery:</u> 5AB: Normal (8.2, 2.46) 5CD: Uniform (2, 10) <u>Survey:</u> 5AB: Normal (7.3, 2.19) 5CD: Uniform (1, 10)
Variance parameter for left arm of selectivity curve (log-scale) - surveys	v	<u>Fishery:</u> 5AB: Normal (2, 0.6) 5CD: Uniform (-10, 5) <u>Survey:</u> 5AB: Normal (2.2, 0.66) 5CD: Uniform (-10, 5)

Table 2. The 5th, 50th and 95th percentiles of MCMC posterior distributions for model parameters and associated quantities for the Area 5AB assessment. Parameter definitions are as follows: B_0 = unfished female spawning biomass, V_0 = unfished female vulnerable biomass, R_0 = unfished female recruitment, h = stock recruitment steepness, q_g = catchability for data series g, u_g = age of full female selectivity for data series g, v_{Lg} = variance parameter for the left limb of the female selectivity curve for data series g, B_{2014} = female spawning biomass at the start of 2014, V_{2014} = female vulnerable biomass at the start of 2014, u_{2013} = harvest rate in 2013, MSY = maximum sustainable yield, B_{MSY} = female spawning biomass associated with MSY, u_{MSY} = harvest rate associated with MSY, B_{Lim} = the historical limit biomass, defined for Rock Sole in Area 5AB as the minimum predicted biomass between 1966 and 2005, B_{Tar} = the historical target biomass, defined as the mean predicted biomass level between 1977 and 1985, and u_{Tar} = the historical target exploitation rate, defined as the mean predicted harvest rate between 1966 and 2005.

	Percentile		
Value	5%	50%	95%
B_0	6,765	7,479	8,457
V_0	6,799	7,592	8,680
R_0	3,015	3,333	3,770
h	0.7298	0.8761	0.9663
q_{CPUE}	0.000342	0.000431	0.000542
q_{Synoptic}	0.4343	0.6280	1.020
μ_{fishery}	5.403	5.933	6.614
μ_{Synoptic}	6.563	7.725	9.322
$v_{\mathrm{L\ fishery}}$	0.700	1.353	2.084
$v_{\mathrm{L\ Synoptic}}$	1.725	2.190	2.643
B_{2014}	1,977	2,776	3,779
V_{2014}	2,185	3,122	4,344
B_{2014} / B_0	0.271	0.371	0.492
V_{2014} / V_0	0.298	0.411	0.549
u_{2013}	0.082	0.110	0.150
	MSY-based quantities		
B_{MSY}	1,427	1,833	2,471
B_{2014} / B_{MSY}	0.977	1.521	2.264
$0.4B_{\mathrm{MSY}}$	571	733	988
$0.8B_{\mathrm{MSY}}$	1,142	1,467	1,977
MSY	483	524	580
u_{MSY}	0.176	0.239	0.307
$u_{2013}/u_{\mathrm{MSY}}$	0.299	0.463	0.724
	Historical quantities		
B_{Lim}	863	1,133	1,422
B_{2014} / B_{Lim}	1.862	2.452	3.260
B_{Tar}	2,216	2,879	3,663
B_{2014} / B_{Tar}	0.738	0.959	1.271
u_{Tar}	0.154	0.188	0.229
u_{2013}/ u_{Tar}	0.464	0.590	0.750

Table 3. The 5th, 50th and 95th percentiles of MCMC posterior distributions for model parameters and associated quantities for the Area 5CD assessment. In Area 5CD, B_{Tar} = the historical target biomass, defined as the mean predicted biomass level between 1971 and 1980. All other parameter definitions are the same as those provided in Table 2 caption.

	Percentile		
Value	5%	50%	95%
B_0	16,263	19,329	25,361
V_0	13,952	16,572	21,387
R_0	11,651	20,280	35,686
M	0.2077	0.2514	0.2923
h	0.6978	0.8616	0.9624
q_{CPUE1}	0.0000698	0.000102	0.000144
q_{CPUE2}	0.0000718	0.000118	0.000181
q_{HSmulti}	0.1365	0.2165	0.3191
q_{Synoptic}	0.1110	0.1869	0.3033
μ_{fishery}	7.411	8.063	8.890
μ_{HSmulti}	4.891	5.770	6.897
μ_{Synoptic}	6.366	7.295	8.326
$\text{v}_{\text{L fishery}}$	1.509	1.910	2.331
$\text{v}_{\text{L HSmulti}}$	1.010	1.569	2.051
$\text{v}_{\text{L Synoptic}}$	1.638	2.109	2.507
B_{2014}	9,949	15,385	24,724
V_{2014}	8,399	13,341	21,310
B_{2014} / B_0	0.581	0.802	1.068
V_{2014} / V_0	0.577	0.802	1.078
u_{2013}	0.025	0.039	0.061
	MSY-based quantities		
B_{MSY}	3,613	4,853	6,799
B_{2014} / B_{MSY}	2.100	3.223	4.638
$0.4B_{\text{MSY}}$	1,445	1,941	2,720
$0.8B_{\text{MSY}}$	2,890	3,883	5,439
MSY	1,326	1,895	2,810
u_{MSY}	0.295	0.507	0.800
u_{2013}/u_{MSY}	0.037	0.077	0.163
	Historical quantities		
B_{Lim}	5,223	7,739	11,971
B_{2014} / B_{Lim}	1.528	2.004	2.722
B_{Tar}	7,753	11,135	16,662
B_{2014} / B_{Tar}	1.000	1.401	1.969
u_{Tar}	0.083	0.122	0.168
u_{2013}/ u_{Tar}	0.243	0.319	0.423

Table 4. Decision table for 5-year projections in Area 5AB. Values are the probability that female spawning biomass, B, (or exploitation rate, u), is greater than the specified reference point in 2019 under a given constant annual catch policy. Female catch represents the constant catch (including discards) value used in projections of the female-only model, while total catch represent an adjusted catch value to include males and females (including discards). Total catch was estimated by applying the median estimate of proportion females between 1956–73, 1975–2006, and 2009 (91.04%) to the female catch value. For reference, the average total catch (females and males) over the last 5 years (2008-2012) is 346 tonnes and the maximum annual total catch between 1945 and 2012 is 1102 tonnes (from the year 1966). Decision tables showing probabilities of exceeding reference points for every year between 2014 and 2019 are provided in Appendix F.

Female Catch	Total Catch	$P(B_{2019} > 0.4B_{MSY})$	$P(B_{2019} > 0.8B_{MSY})$	$P(B_{2019} > B_{MSY})$	$P(B_{2019} > B_{2014})$	$P(u_{2019} > u_{MSY})$	$P(B_{2019} > min(B_{1966-2005}))$	$P(B_{2019} > mean(B_{1977-1985}))$	$P(u_{2019} > mean(u_{1966-2005}))$
0	0	1.00	1.00	1.00	1.00	0.00	1.00	0.99	0.00
100	110	1.00	1.00	1.00	1.00	0.00	1.00	0.98	0.00
200	220	1.00	1.00	0.99	0.98	0.00	1.00	0.90	0.00
300	330	1.00	1.00	0.98	0.85	0.00	1.00	0.76	0.00
400	440	1.00	0.97	0.92	0.62	0.03	1.00	0.55	0.07
500	550	1.00	0.91	0.81	0.36	0.20	0.97	0.36	0.40
600	660	0.96	0.77	0.60	0.19	0.53	0.92	0.20	0.77
700	770	0.88	0.56	0.40	0.08	0.79	0.75	0.11	0.94
800	880	0.71	0.38	0.26	0.03	0.92	0.54	0.05	0.98
900	990	0.49	0.22	0.14	0.01	0.97	0.32	0.03	0.99
1000	1100	0.31	0.12	0.07	0.01	0.99	0.18	0.01	1.00
1100	1210	0.19	0.06	0.03	0.01	0.99	0.09	0.01	1.00
1200	1320	0.10	0.03	0.01	0.00	1.00	0.05	0.00	1.00

Table 5. Decision table for 5-year projections in Area 5CD. Values are the probability that biomass, B, (or exploitation rate, u), is greater than the specified reference point in 2019 under a given constant annual catch policy. Female catch represents the constant catch (including discards) value used in projections of the female-only model, while total catch represent an adjusted catch value to include males and females (including discards). Total catch was estimated by applying the median estimate of proportion females between 1956 and 2009 (88.95%) to the female catch value. For reference, the average total catch (females and males) over the last 5 years (2008-2012) is 636 tonnes and the maximum annual total catch between 1945 and 2012 is 2643 tonnes (from the year 1991). Decision tables showing probabilities of exceeding reference points for every year between 2014 and 2019 are provided in Appendix F.

Female Catch	Total Catch	$P(B_{2019} > 0.4B_{\mathrm{MSY}})$	$P(B_{2019} > 0.8B_{\mathrm{MSY}})$	$P(B_{2019} > B_{\mathrm{MSY}})$	$P(B_{2019} > B_{2014})$	$P(u_{2019} > u_{\mathrm{MSY}})$	$P(B_{2019} > min(B_{1966\text{-}2005}))$	$P(B_{2019} > mean(B_{1971\text{-}1980}))$	$P(u_{2019} > mean(u_{1966\text{-}2005}))$
0	0	1.00	1.00	1.00	0.83	0.00	1.00	0.99	0.00
100	110	1.00	1.00	1.00	0.79	0.00	1.00	0.98	0.00
200	220	1.00	1.00	1.00	0.76	0.00	1.00	0.98	0.00
300	340	1.00	1.00	1.00	0.72	0.00	1.00	0.97	0.00
400	450	1.00	1.00	1.00	0.67	0.00	1.00	0.97	0.00
500	560	1.00	1.00	1.00	0.62	0.00	1.00	0.96	0.00
600	670	1.00	1.00	1.00	0.57	0.00	1.00	0.93	0.00
700	790	1.00	1.00	1.00	0.51	0.00	1.00	0.91	0.00
800	900	1.00	1.00	1.00	0.45	0.00	1.00	0.90	0.00
900	1010	1.00	1.00	1.00	0.40	0.00	0.99	0.88	0.02
1000	1120	1.00	1.00	1.00	0.35	0.00	0.99	0.85	0.05
1100	1240	1.00	1.00	1.00	0.31	0.00	0.99	0.83	0.14
1200	1350	1.00	1.00	1.00	0.28	0.00	0.98	0.79	0.25
1300	1460	1.00	1.00	1.00	0.23	0.00	0.97	0.76	0.39
1400	1570	1.00	1.00	1.00	0.19	0.01	0.97	0.72	0.54
1500	1690	1.00	1.00	0.99	0.17	0.01	0.95	0.68	0.67
1750	1970	1.00	0.99	0.98	0.11	0.05	0.90	0.58	0.88
2000	2250	1.00	0.98	0.95	0.07	0.10	0.83	0.49	0.96
2250	2530	1.00	0.95	0.91	0.04	0.18	0.73	0.39	0.99
2500	2810	0.99	0.91	0.87	0.03	0.28	0.64	0.30	1.00
2750	3090	0.97	0.86	0.80	0.02	0.40	0.54	0.23	1.00
3000	3370	0.96	0.81	0.72	0.01	0.50	0.46	0.18	1.00

FIGURES

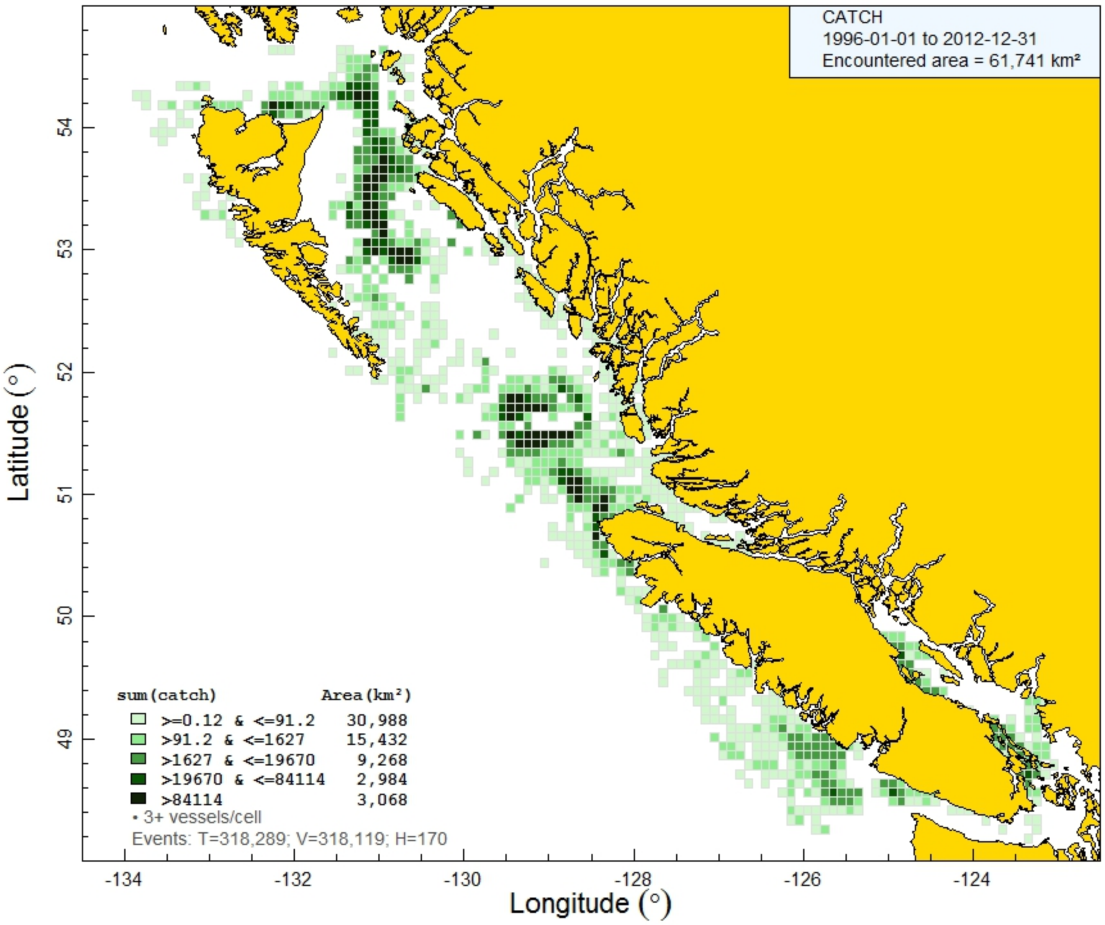

Figure 1. Rock Sole catch (kg) in grid cells 0.075 longitude by 0.055 latitude (roughly 32 km^2), calculated as the total catch from all commercial fisheries between 1996 and 2012. The shaded cells give an approximation of the area where Rock Sole was encountered by fishing events.

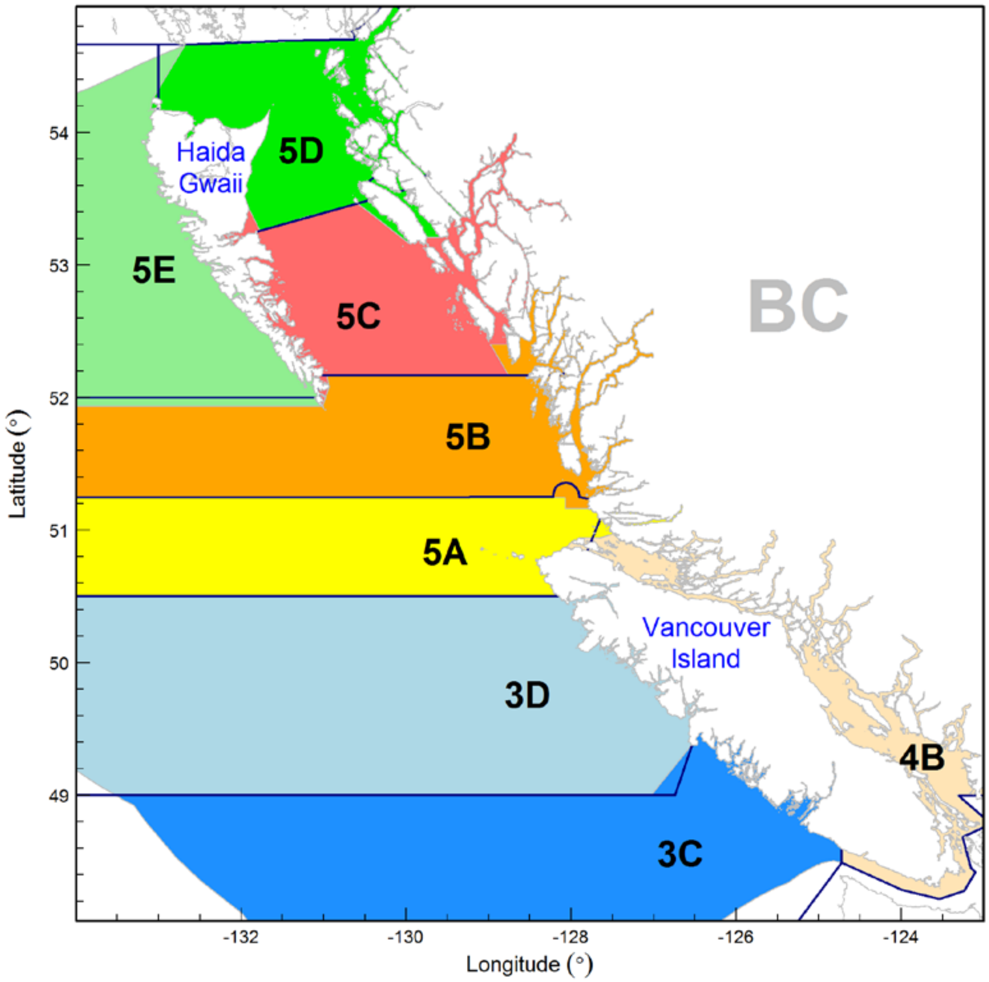

Figure 2. Pacific Marine Fisheries Commission (PMFC) major areas (outlined in dark blue) compared with Groundfish Management Unit areas for Rock Sole (shaded). Areas used in this stock assessment are based on the PMFC major areas.

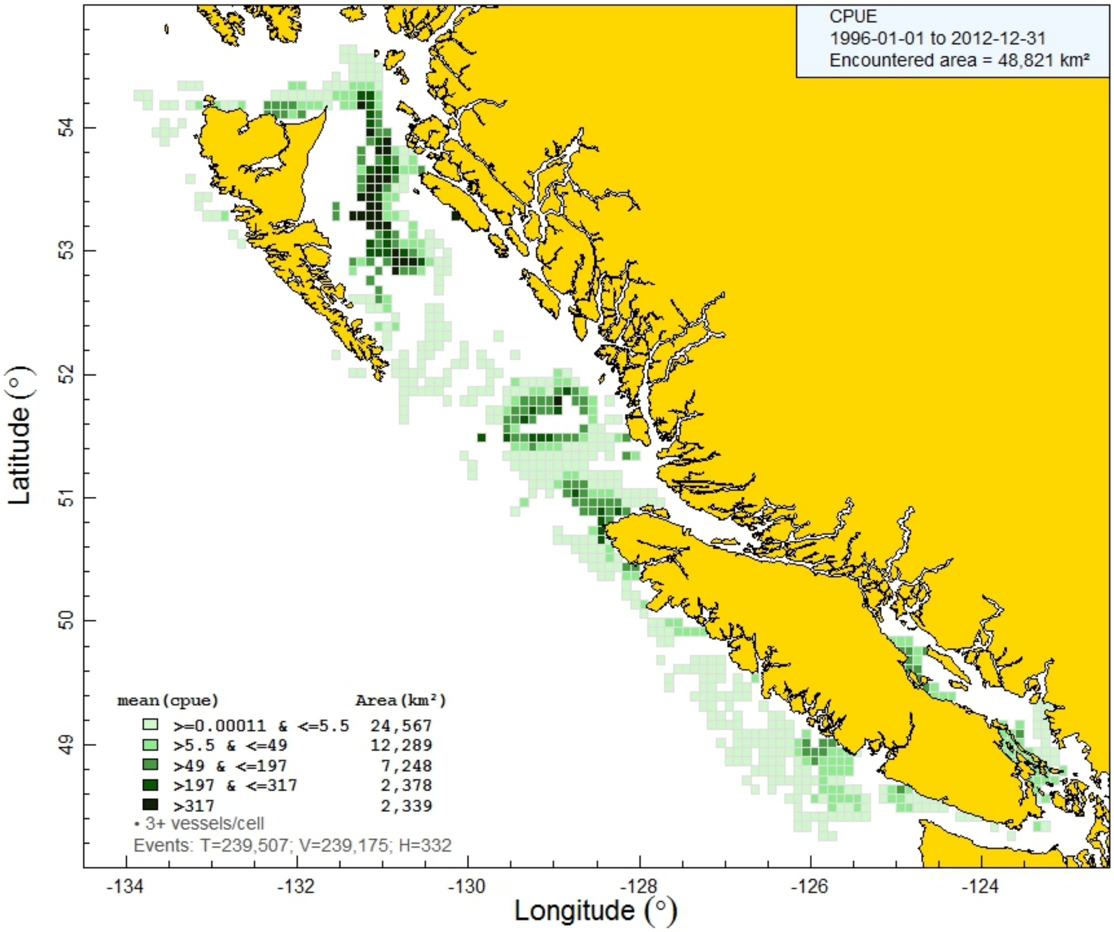

Figure 3. Mean catch-per-unit-effort (CPUE, kg/h) of Rock Sole in grid cells 0.075 longitude by 0.055 latitude (roughly 32 km^2) from the commercial bottom trawl fishery between 1996 and 2012.

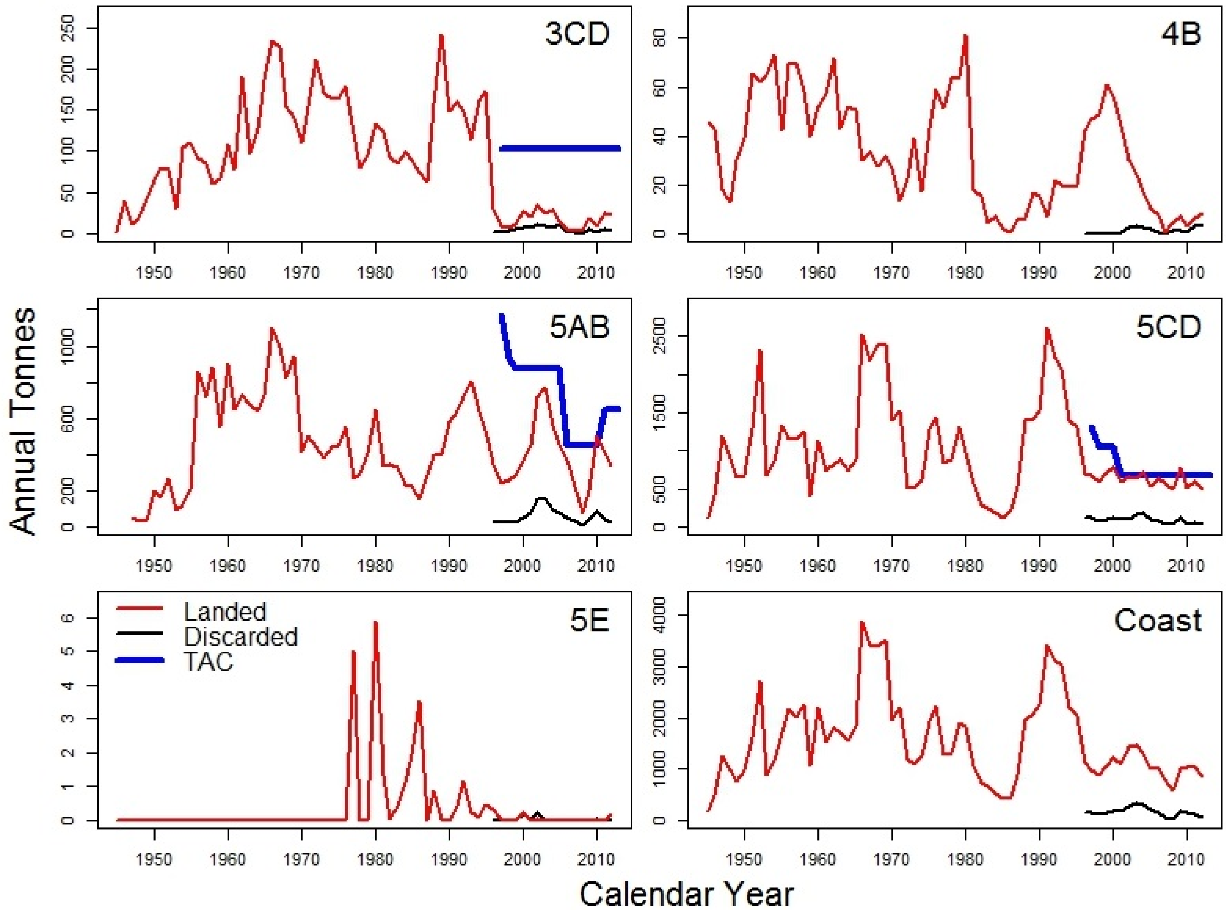

Figure 4. Annual trawl fishery trends in Rock Sole landings, discards and total allowable catch (TAC) by area. All units are in tonnes. Landings from 1945-1955 are limited to Canadian fisheries, landings from 1956-1981 include both Canadian and U.S. fisheries, and landings from 1982-2012 include only Canadian fisheries. Note the scale of the y-axis (Annual Tonnes) differs between areas.

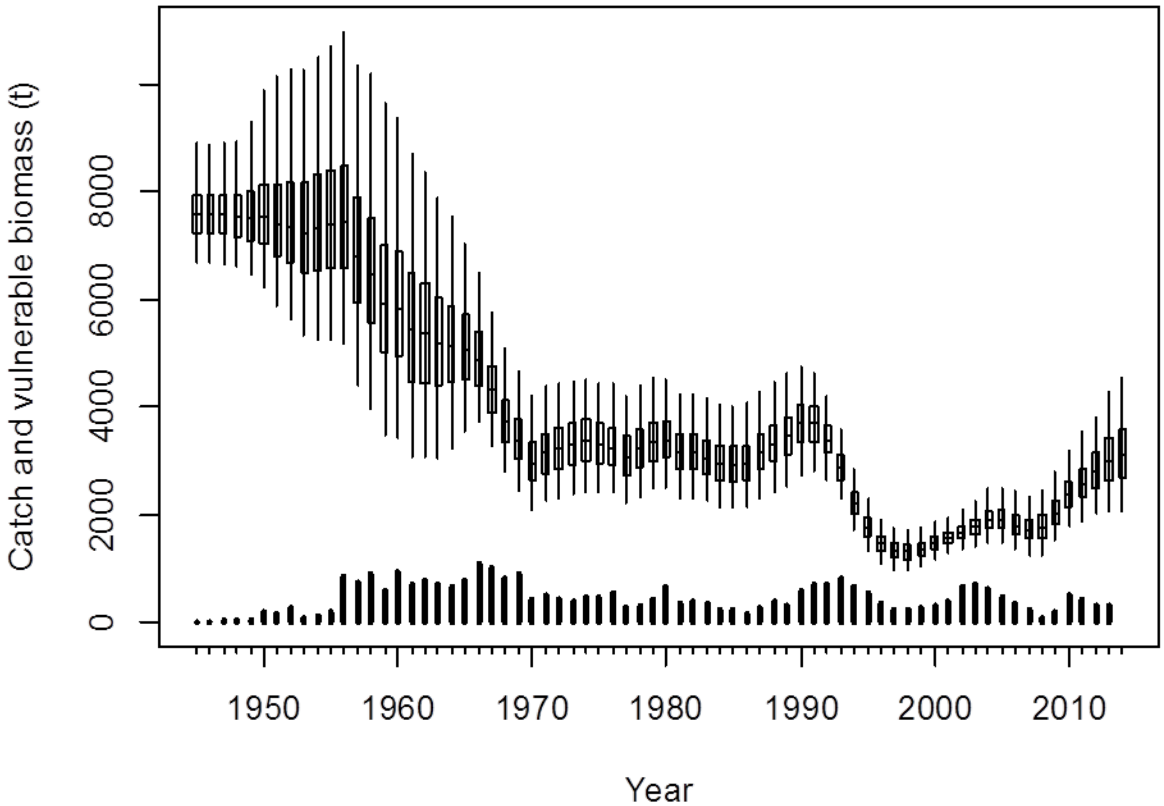

Figure 5. Estimated female vulnerable biomass (boxplots) and female commercial catch (vertical bars), in tonnes, over time in Area 5AB. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from posterior distributions approximated via the MCMC method.

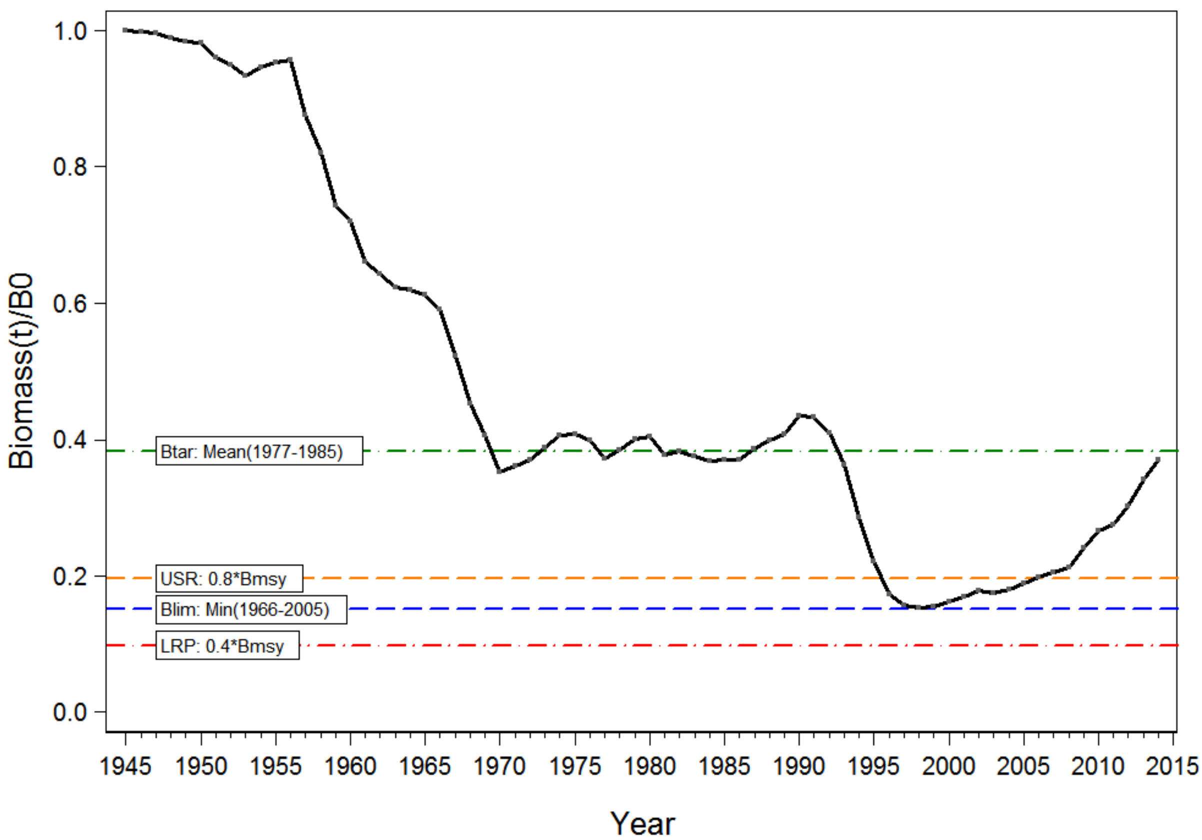

Figure 6. Posterior median estimates of female spawning biomass relative to B_0 by year for the 5AB base case (black line). Also shown are posterior median estimates of MSY-based reference points (Limit Reference Point = $0.4B_{MSY}$; Upper Reference Point = $0.8B_{MSY}$) relative to B_0 and posterior median estimates of historical reference points identified for Rock Sole in 2006 (B_{Lim} = minimum biomass between 1966 and 2005; B_{Tar} = mean biomass between 1977 and 1985) relative to B_0.

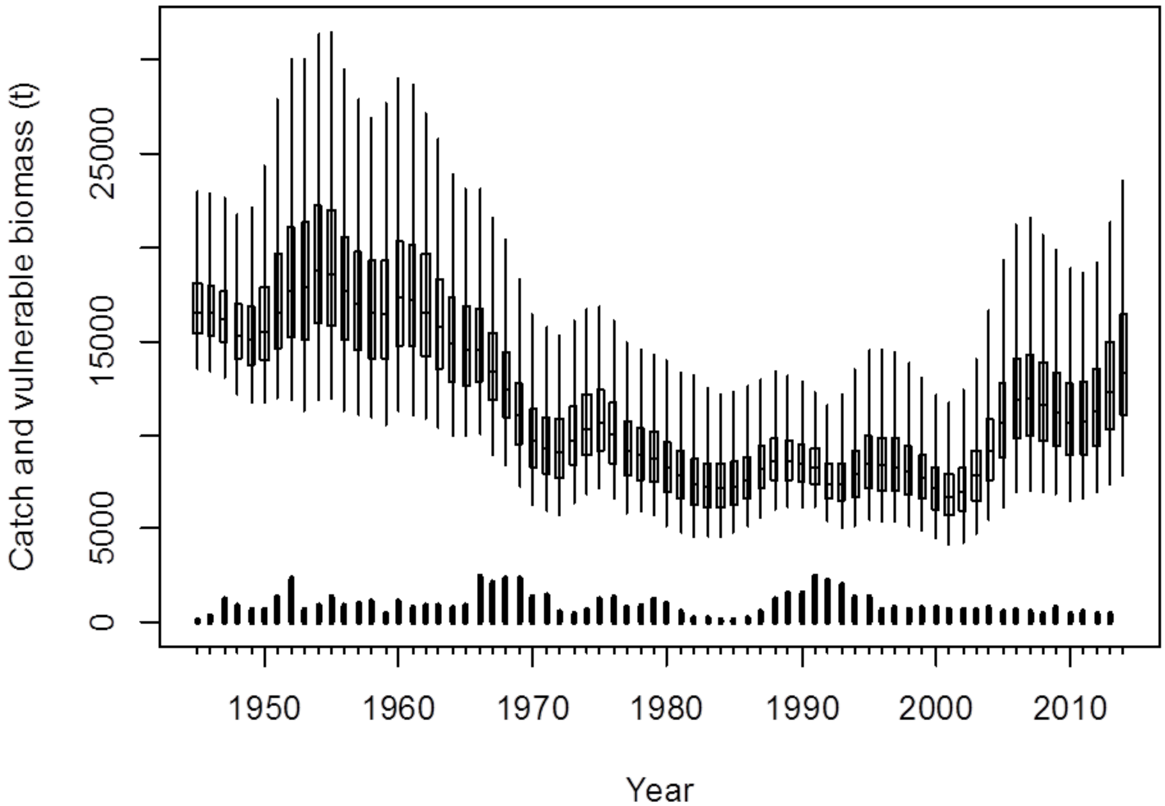

Figure 7. Estimated female vulnerable biomass (boxplots) and female commercial catch (vertical bars), in tonnes, over time in Area 5CD. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from posterior distributions approximated via the MCMC method.

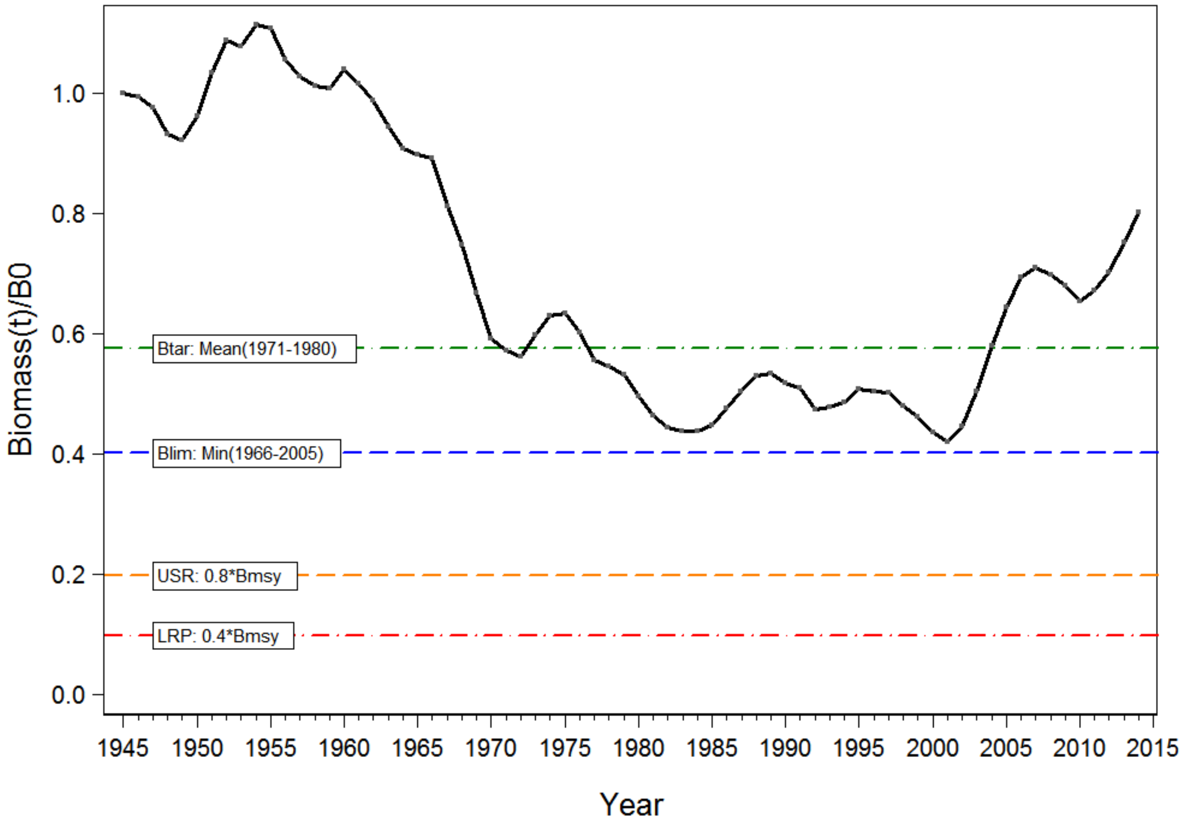

Figure 8. Posterior median estimates of female spawning biomass relative to B_0 by year for the 5CD base case (black line). Also shown are posterior median estimates of MSY-based reference points (Limit Reference Point = $0.4B_{MSY}$; Upper Reference Point = $0.8B_{MSY}$) relative to B_0 and posterior median estimates of historical reference points identified for Rock Sole in 2006 (B_{Lim} = minimum biomass between 1966 and 2005; B_{Tar} = mean biomass between 1971 and 1980) relative to B_0.

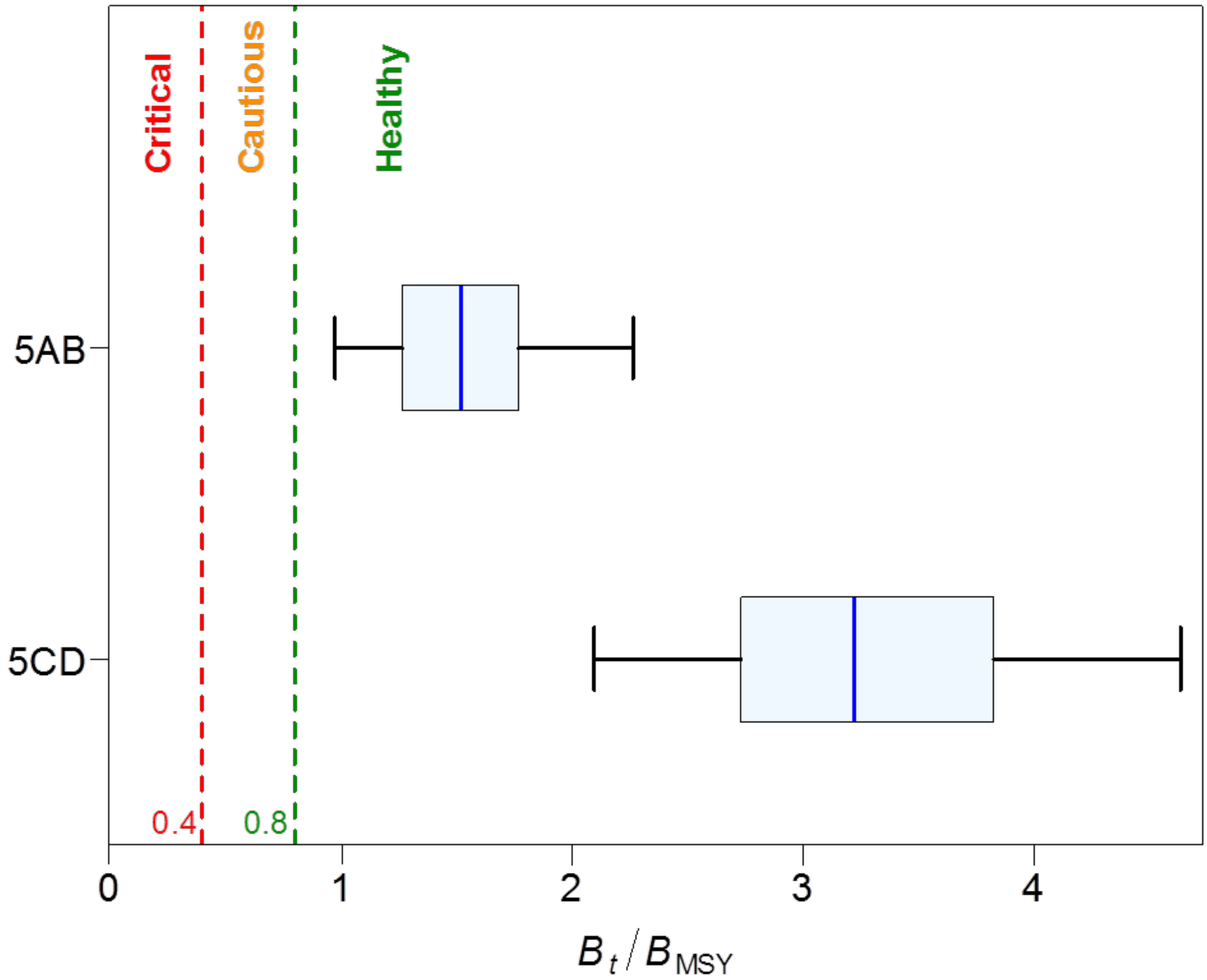

Figure 9. Current stock status (represented as the ratio of B_{2014} to B_{MSY}) of Area 5CD and 5AB stocks relative to the DFO Precautionary Approach provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$. Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

APPENDIX A. CATCH DATA

TRAWL FISHERY LANDINGS

A summary of total Rock Sole landings (females and males) from the commercial bottom trawl fishery between 1945 and 2012 is provided in Table A.1. A map of trawl fishery catch between 1996 and 2012 (Figure A.1) shows the recent distribution of catch in BC.

Trawl fishery catch data come from various databases due to the long time period involved. The database ***GFCatch*** contains commercial catch data from 1945-1995, with catch information consisting of a combination of trip and/or set information that has varied and evolved over time. Table A.1 includes GFCatch data as landings from 1945-1955 and 1982-1995. Catches from 1956-1981 were obtained from a recent summary of historical Canadian and United States (US) trawl fishery catches (Kate Rutherford, pers. comm, DFO Pacific Biological Station, Nanaimo, BC). The ***PacHarvTrawl*** database provided catch data from January 1996 to March 31, 2007, while the remaining period from May 1, 2007 to the end of 2012 came from the ***GFFOS*** database.

Catches from 1956-1981 include landings from both Canadian and US fishers, while landings from 1945-1955 include only Canadian fishery landings. Some catches were likely taken by US fisheries between 1945 and 1956; however, US catch information prior to 1956 is unavailable. As an indication of how much catch may be missing prior to 1956, the average annual contribution to total catch taken by US fisheries between 1956 and 1960 (the first five years with US data) was 16% in Area 5AB and 6% in Area 5CD. US landings ended in 1981, so all landing records from 1982 onwards come from Canadian vessels.

Data retrieval for catch analysis used the 'PBStools' R package plus associated sql code to extract detailed data in a standardized format from all three databases. Key fishing event information included fishery, gear, data source, date, major and minor areas, fishing depth, effort, plus rock sole landed and discarded weights when they were caught.

Table A.1. Trawl fishery landings (tonnes) by area. Values from 1956-1981 include both Canadian and US landings. US landings ceased in 1982 and only Canadian landings were available prior to 1956.

	Area					
Year	**3CD**	**4B**	**5AB**	**5CD**	**5E**	**Coastwide**
1945	1.9	45.6	19.7	120.8	-	187.9
1946	39.3	42.9	-	409.8	-	492.1
1947	11.2	18.2	53.2	1181.2	-	1263.9
1948	19.8	12.8	34.8	901.2	-	968.6
1949	41.6	30.2	32.5	656.9	-	761.1
1950	65.5	38.9	202.7	667.1	-	974.2
1951	79.2	65.2	164.8	1300.2	-	1609.4
1952	77.5	62.5	266.4	2314.3	-	2720.7
1953	30.5	64.7	91.5	685.7	-	872.4
1954	105.6	73.2	119.5	871.0	-	1169.2
1955	110.8	42.3	205.5	1338.5	-	1697.1
1956	91.9	69.2	858.0	1160.1	-	2179.1
1957	85.3	69.9	717.1	1151.2	-	2023.5
1958	61.0	58.3	880.0	1256.2	-	2255.5
1959	66.7	39.7	556.3	416.2	-	1078.9
1960	108.4	51.9	900.6	1127.2	-	2188.2
1961	78.2	57.4	652.7	744.1	-	1532.5
1962	190.1	71.7	727.1	828.7	-	1817.6
1963	97.5	43.1	678.1	879.1	-	1697.8
1964	127.9	52.2	637.8	743.0	-	1560.8

	Area					
Year	**3CD**	**4B**	**5AB**	**5CD**	**5E**	**Coastwide**
1965	186.4	50.8	724.9	879.1	-	1841.2
1966	234.1	30.4	1101.8	2526.6	-	3892.8
1967	226.3	33.6	993.4	2168.7	-	3422.0
1968	154.2	27.7	826.9	2389.6	-	3398.4
1969	140.6	31.3	944.8	2412.7	-	3529.5
1970	109.8	26.8	411.9	1401.2	-	1949.6
1971	154.2	13.6	502.6	1526.8	-	2197.2
1972	210.9	22.7	440.0	506.2	-	1179.8
1973	171.0	39.0	380.6	503.9	-	1094.5
1974	164.2	17.2	444.1	621.0	-	1246.5
1975	163.7	43.1	445.0	1265.5	-	1917.4
1976	178.3	59.0	550.2	1436.1	-	2223.5
1977	122.0	51.3	271.3	845.5	5.0	1295.0
1978	80.3	63.5	296.7	873.6	-	1314.1
1979	95.7	64.0	409.6	1315.0	-	1884.3
1980	132.9	81.6	649.6	975.7	5.9	1845.7
1981	123.8	18.1	332.9	583.8	1.4	1060.1
1982	93.0	15.5	344.5	293.6	0.0	746.7
1983	86.0	4.4	330.0	247.5	0.4	668.3
1984	99.5	7.2	229.6	188.1	1.1	525.5
1985	89.4	1.7	225.2	111.5	1.9	429.7
1986	73.4	0.7	158.0	218.7	3.5	454.4
1987	63.0	5.5	285.7	536.1	0.0	890.3
1988	158.8	6.1	396.1	1401.1	0.9	1963.0
1989	242.3	16.4	393.6	1422.6	0.0	2074.9
1990	148.0	15.1	580.3	1523.7	0.0	2267.1
1991	159.4	6.9	642.2	2614.5	0.4	3423.5
1992	148.2	21.6	718.5	2225.7	1.2	3115.2
1993	114.7	20.1	808.5	2082.1	0.2	3025.7
1994	162.1	19.1	636.6	1390.6	0.1	2208.5
1995	173.2	20.1	536.1	1308.8	0.5	2038.7
1996	29.7	42.4	343.3	706.7	0.3	1122.5
1997	8.7	46.7	241.0	683.9	0.0	980.3
1998	7.6	49.0	255.2	587.9	0.0	899.8
1999	11.0	61.2	283.3	720.7	0.0	1076.3
2000	27.2	56.7	364.8	777.1	0.2	1225.9
2001	20.5	44.6	452.4	589.7	0.0	1107.2
2002	33.5	30.2	716.9	647.3	0.1	1428.1
2003	25.5	24.3	770.0	639.3	0.0	1458.9
2004	28.2	17.6	562.3	713.5	0.0	1321.5
2005	15.6	10.5	455.0	536.1	0.0	1017.2
2006	4.9	7.4	371.5	632.1	0.0	1015.9
2007	4.1	0.8	222.0	570.1	0.0	797.0
2008	3.6	4.1	74.3	488.3	0.0	570.3
2009	19.7	7.3	194.4	785.4	0.0	1006.8
2010	9.5	2.8	498.3	513.7	0.0	1024.3
2011	25.5	6.7	419.1	602.3	0.0	1053.6
2012[1]	23.1	8.0	337.4	500.2	0.2	868.9

[1] GFFOS landings lack the final month of commercial catch since data extraction was done before December information was available in the GFFOS database

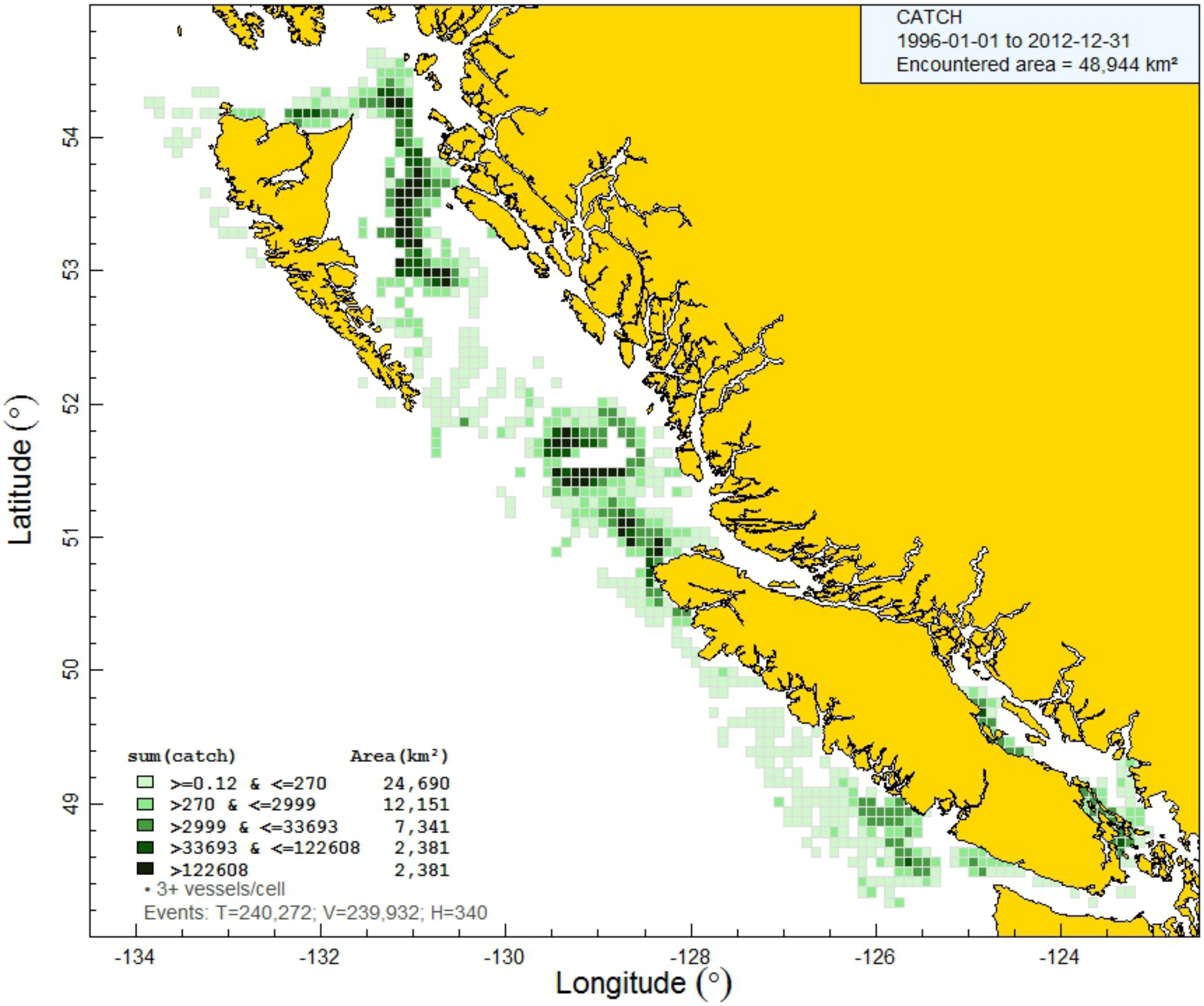

Figure A.1. Total commercial trawl fishery catch (kg) of Rock Sole between 1996 and 2012 in grid cells 0.075 longitude by 0.055 latitude (roughly 32 km^2). Data were compiled from individual fishing events in the PacHarvTrawl and GFFOS databases that had identifiable location information.

TRAWL FISHERY DISCARDS

Reliable information on discards became available starting in 1996 due to the implementation of 100% observer coverage of the trawl fishery. Discard information prior to 1996 is considered incomplete and therefore inaccurate. Trawl discard information (Table A.2) was compiled from two groundfish databases: PacHarvTrawl (January 1, 1996 to March 31, 2007) and GFFOS (April 1, 2007 to December 31, 2012). Discard data were extracted from these databases as described above using PBStools for catch data extraction. The 2007 data are summed from both databases for the annual amount (Jan-Mar/2007 from PacHarvTrawl and Apr-Dec/2007 from GFFOS).

Discards prior to 1996 were estimated by applying the average discard rate between 1996 and 2012 to landed catch values in all earlier years. This procedure is described in more detail below in the “Calculation of female-only catch” section of this appendix.

Table A.2. Trawl fishery discards (tonnes) by year and area.

Year	Area					Coastwide
	3CD	4B	5AB	5CD	5E	
1996	2.3	0.0	33.4	115.0	0.0	150.3
1997	2.0	0.0	21.8	115.8	0.0	139.9
1998	3.1	0.0	25.1	89.1	0.0	117.3
1999	4.6	0.0	24.0	108.3	0.0	136.8
2000	7.1	0.0	50.6	126.2	0.2	184.1
2001	8.0	0.4	74.8	97.6	0.0	180.8
2002	11.0	2.4	157.1	105.1	0.2	275.8
2003	9.8	2.9	154.2	163.0	0.0	329.7
2004	7.5	2.3	97.3	185.5	0.0	292.6
2005	11.8	1.6	73.7	109.2	0.0	196.3
2006	2.5	0.7	47.8	85.3	0.0	136.2
2007	1.1	0.1	30.1	41.0	0.0	72.4
2008	0.5	1.0	7.5	32.3	0.0	41.3
2009	6.2	1.2	43.2	117.9	0.0	168.5
2010	2.7	0.8	86.2	46.8	0.1	136.6
2011	5.7	3.5	46.4	57.7	0.0	113.3
2012	3.3	3.5	23.6	35.7	0.0	66.1

OTHER FISHERIES

Catch of Rock Sole by groundfish fisheries other than bottom trawl are considered negligible and are not included as catch in our stock assessment modelling. Annual coastwide Rock Sole landings from hook and line fisheries have ranged from 148 to 874 kg between 2001 and 2012. Discard information from the hook and line fishery is absent from the Official Catch table in PacHarvHL and GFFOS databases, therefore no official discard weights are available. Unofficial records contain a combination of units with discards reported as weights in some cases and as pieces in other cases. From 2003-2012, the highest annual recorded discard weight from logbooks was 272 kg in Area 5AB in 2005. For records reported in pieces, only 359 pieces have been discarded from all identifiable areas since 2007.

HISTORY OF CATCH MANAGEMENT MEASURES

Historical catch management included a mix of individual trip limits and Total Allowable Catches (TAC) set for selected stocks (Table A.3). Both trip limits and TACs were noted several years. Trip limits were not defined for 3CD/4B/5E stocks but were assumed part of the coastwide trip limits from 1989-1993. TACs have never been applied to Areas 4B or 5E.

Table A.3. Rock Sole TACs (tonnes) and trip limits (tonnes) for groundfish trawl fisheries.

	3CD		**4B**		**5AB**		**5CD**		**5E**		**Coastwide**	
Year	TAC	Trip	TAC	Trip	TAC	Trip	TAC	Trip	TAC	Trip	TAC	Trip
1979	-	-	-	-	150	-	400[1]	-	-	-	-	-
1980	-	-	-	-	300	-	960[1]	-	-	-	-	-
1981	-	-	-	-	300	-	620[1]	-	-	-	-	-
1982	-	-	-	-	-	-	750[1]	11	-	-	-	-
1983	-	-	-	-	-	-	950[1]	23	-	-	-	-
1984	-	-	-	-	-	-	-	14	-	-	-	-
1985	-	-	-	-	-	-	-	14	-	-	-	-
1986	-	-	-	-	-	14	-	14	-	-	-	-
1987	-	-	-	-	-	14	-	14	-	-	-	-
1988	-	-	-	-	-	14	-	14	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-	-	13.6
1990	-	-	-	-	-	-	-	-	-	-	-	13.6
1991	-	-	-	-	-	-	-	-	-	-	-	13.6
1992	-	-	-	-	800	-	1150	-	-	-	-	13.6
1993	-	-	-	-	750	-	1150	-	-	-	-	9.1
1994	-	-	-	-	800	-	1500	-	-	-	-	-
1995	-	-	-	-	800	-	1525	-	-	-	-	-
1996	-	-	-	-	880	-	673	-	-	-	-	-
1997/98	102	-	-	-	935	-	1045	-	-	-	-	-
1998/99	102	-	-	-	935	-	1045	-	-	-	2082	-
1999/00	102	-	-	-	875	-	1045	-	-	-	2022	-
2000/01	102	-	-	-	875	-	1045	-	-	-	2022	-
2001/02	102	-	-	-	875	-	673	-	-	-	1650	-
2002/03	102	-	-	-	875	-	673	-	-	-	1650	-
2003/04	102	-	-	-	875	-	673	-	-	-	1650	-
2004/05	102	-	-	-	875	-	673	-	-	-	1650	-
2005/06	102	-	-	-	875	-	673	-	-	-	1650	-
2006/07	102	-	-	-	450	-	673	-	-	-	1225	-
2007/08	102	-	-	-	450	-	673	-	-	-	1225	-
2008/09	102	-	-	-	450	-	673	-	-	-	1225	-
2009/10	102	-	-	-	450	-	673	-	-	-	1225	-
2010/11	102	-	-	-	450	-	673	-	-	-	1225	-
2011/12	102	-	-	-	650	-	673	-	-	-	1425	-
2012/13	102	-	-	-	650	-	673	-	-	-	1425	-
2013/14	102	-	-	-	650	-	673	-	-	-	1425	-

[1]Annual Commercial Fishing Guides noted these TACs as upper catch limits to consider before lowering trip limits.

SURVEY CATCHES (AREAS 5AB AND 5CD)

Trawl survey catches for 5AB and 5CD stocks come from three fisheries-independent surveys (Table A.4).

Table A.4. Fishery-independent trawl survey catches (tonnes) for Areas 5AB (Queen Charlotte Sound Synoptic survey) and 5CD (Hecate Strait Assemblage surveys to 2003 and Hecate Strait Synoptic surveys since 2005).

	Area	
Year	**5AB**	**5CD**
1984	–	0.97
1985	–	–
1986	–	–
1987	–	0.64
1988	–	–
1989	–	2.50
1990	–	–
1991	–	1.58
1992	–	–
1993	–	1.72
1994	–	–
1995	–	1.58
1996	–	3.79
1997	–	–
1998	–	1.36
1999	–	–
2000	–	2.28
2001	–	–
2002	–	1.58
2003	0.52	3.48
2004	1.72	–
2005	0.91	3.24
2006	–	–
2007	0.64	1.43
2008	–	–
2009	0.78	1.51
2010	–	–
2011	0.78	2.14
2012	–	–
2013	0.54	4.06

CALCULATION OF FEMALE-ONLY CATCH (5AB, 5CD)

Calculation of proportion of female catch

As a first step to calculating female-only catch, annual estimates of the proportion of catch biomass that was female were required. This calculation was done in two ways for Rock Sole catches, with the method used in a given management area (called a region here) and year dependent on the availability of information that linked samples to specific fishing trips. The two algorithms used are described below.

The following criteria were used to extract data for analyses from databases:

Criteria

1.	Select major PMFC areas =5CD or 5AB	as required for the analysis
2.	Select TRIP_SUB_TYPE = 1 or 4	1=Non-observed domestic 4=observed domestic
3.	Select GEAR_CODE = 1	Bottom trawl only
4.	Select SPECIES_CATEGORY_CODE = 1 or 3	1=unsorted; 3=keepers (as required for the analysis)
5.	Select SAMPLE_TYPE_CODE = 1 or 2 or 6 or 7	1=total catch 2=random 6=random from randomly assigned set 7=random from set after randomly assigned set
6.	Calendar years from 1 January1956 to 31 December 2012, separated into three-month quarters: 1=Jan-Mar; 2=Apr-Jun; 3=Jul-Sep; 4=Oct-Dec.	Quarters coded sequentially for the analysis
7.	Select sex code = 1 (male) or =2 (female)	use only valid codes for male and female
8.	Select records where length>0 and IS NOT NULL	use only valid length records

It was realized after the analysis for 2013 was complete that the field SAMPLE_SOURCE_CODE (1 = unsorted; 2 = keepers) should have been used in conjunction with the SPECIES_CATEGORY_CODE to identify sorted and unsorted samples. Application of the corrected criteria resulted in minor changes in Area 5AB (two unsorted samples were re-classified as sorted in 2001 and one unsorted sample was re-classified as sorted in 2005) and no changes in Area 5CD. The analysis was not re-done for the current assessment as these updates were not expected to significantly change estimates of proportion female; however, future assessments should correct for this error. The correct selection criteria for sorted and unsorted samples are as follows:

Unsorted:

- species_category_code = 1 & sample_source_code = 1, or
- species_category_code = 1 & sample_source_code IS NULL

Sorted:

- species_category_code = 1 & sample_source_code = 2, or
- species_category_code = 3 & sample_source_code = 2, or
- species_category_code = 3 & sample_source_code IS NULL

Algorithm #1: Treat every length observation independently

Algorithm #1 weights all samples collected in a given year and region equally when calculating the proportion of female catch. The steps taken are as follows:

1. Sex-specific sampling of commercial catch has more often reported fish length than fish weight, making it first necessary to estimate individual fish weights within each algorithm. Within each region *R* (*R* = 5AB or 5CD), convert each valid length measurement (l_{ijs}) from SampleID *j* and sex *s* to a corresponding weight estimate (w_{ijs}) :

$$w_{ijs} = a^s l_{ijs}^{b^s} \qquad (A.1)$$

where a^s and b^s are constant sex-specific parameters. There are no SampleID (*j*) which include more than one region *r*. Following the practice used for the 2006 Rock Sole Assessment (Starr et al. 2006, unpublished manuscript[1]), length-weight parameters were estimated from all available length-weight observations in the combined 5ABCD region using all available samples (commercial and research) up to 2012 (a parameter = 5.95 x 10^{-6}; b parameter = 3.2161 in Equation A.1).

2. For every year *y*, calculate the unweighted sex-specific mean weight $\left(\overline{W}_{ys}\right)$ (Equation A.2a) or total weight (W_{ys}) (Equation A.2b) over all weight observations:

$$\overline{W}_{ys} = \sum_{i=1}^{N_{ys}} w_{iys} \Big/ N_{ys} \qquad \textit{(A.2a)}$$

$$W_{ys} = \sum_{i=1}^{N_{ys}} w_{ys} \qquad \textit{(A.2b)}$$

where N_{ys} is the number of weight estimates (w_{iys}) from sex *s* in year *y.*

1. The proportion female by weight (P_y) for each year *y* is then calculated, using the total weights calculated in Equation A.2:

$$P_y = W_{s=f,y} \Big/ \left(W_{s=f,y} + W_{s=m,y}\right) \qquad \textit{(A.3)}$$

where *m* and *f* subscripts denote sex = male and female, respectively. Note that this is done by region 5AB or 5CD, based on the available samples.

Algorithm #1 assumes that every observation in a sample is independent of all other observations in that sample, as well as from observations from all other samples. This assumption is unlikely to be true because observations within a sample are likely correlated. Even consecutive samples taken sequentially while on board for the same trip are likely to be correlated by virtue of being on the same vessel with the same skipper. Thus, for years in which sample weights were available and there were adequate trips sampled, algorithm #2 was applied.

Algorithm #2: Weighted calculation procedure

Algorithm #2 calculates a mean weight by sex for each trip, then combines the trips within a quarter to obtain a mean weight that is weighted by the total catch for each trip. It then combines mean weight estimates by sex across quarters using the relative commercial catch within each quarter as weights.

1. Convert all lengths in a sample to a weight, as in the first step of Algorithm #1 and calculate a sex-specific mean weight (Equation A.4a) or total weight (Equation A.4b) for each Sample ID j (W_{js}):

$$\overline{W}_{js} = \sum_{i=1}^{N_{js}} w_{ijs} \Big/ N_{js} \qquad \textit{(A.4a)}$$

$$W_{js} = \sum_{i=1}^{N_{js}} w_{ijs} \qquad \textit{(A.4b)}$$

where N_{js} is the number of weight estimates (w_{ijs}) from sex *s* in Sample ID *j*.

2. Calculate the mean weight and total weight by sex s for trip *n*, (W_{sn}), weighted by the sample weight of each sampleID within the trip (S_{jn}) (this step should not have any effect if it is a dockside or "port" sample because there will only be one sample for the trip):

$$\bar{W}_{sn} = \sum_{j=1}^{K_n} \bar{W}_{sjn} S_{jn} \Bigg/ \sum_{j=1}^{K_n} S_{jn} \qquad (A.5a)$$

$$W_{sn} = \sum_{j=1}^{K_n} W_{sjn} S_{jn} \Bigg/ \sum_{j=1}^{K_n} S_{jn} \qquad (A.5b)$$

where K_n is the number of SampleIDs (j) in trip (n).

3. The mean and total sex-specific weight for each sequential quarter t, (W_{st}), is calculated, weighted by the trip weight of Rock Sole for all sampled trips in quarter t, (R_{nt}):

$$\bar{W}_{st} = \sum_{n=1}^{N} \bar{W}_{snt} R_{nt} \Bigg/ \sum_{n=1}^{T_t} R_{nt} \qquad (A.6a)$$

$$W_{st} = \sum_{n=1}^{N} W_{snt} R_{nt} \Bigg/ \sum_{n=1}^{T_t} R_{nt} \qquad (A.6b)$$

where T_t is the number of sampled trips in sequential quarter t.

1. The mean weight or total weight for a year y is calculated by averaging the quarterly mean weight or total weight weighted by the catch of total rock sole (C_t) in either 5CD or 5AB during sequential quarter t:

$$\bar{W}_y^A = \sum_{t=1}^{4} \bar{W}_t C_t \Bigg/ \sum_{t=1}^{4} C_t \qquad (A.7a)$$

$$W_y^A = \sum_{t=1}^{4} W_t C_t \Bigg/ \sum_{t=1}^{4} C_t \qquad (A.7b)$$

Note that because the quarters (t) are defined sequentially, they can only reference a single year (which is why the year subscript on the right side of the above equations have been left off).

2. The mean proportion female in a year is calculated using Equation A.3.

Sampling considerations

There are two types of samples in the GFBio database: “sorted” (sampled after the catch has been sorted for keepers and discards) and “unsorted” (sampled prior to any sorting). Since we are estimating the proportion of females in the catch, it is straightforward to apply the mean weights from the sorted samples to the catch to estimate the proportion of females. Using the unsorted samples requires applying a selectivity function before the proportion females in the catch can be estimated.

Almost all the samples taken in either 5AB or 5CD before 1996 were “sorted” samples (Table A.5). However, a gradual shift towards collection of “unsorted” samples instead of “sorted” samples has resulted in the three most recent years (2010–2012) having no “sorted” samples.

Database considerations

The trip catch weight (R_{nt}) specified in Equation A.6 should ideally be comprised of the total catch reported by that trip in the commercial catch database. However, practical considerations of data availability preclude the capacity to apply Equation A.6 in this manner consistently over the entire data set. For instance, there are no sample catch weights (S_{jn} in Equation A.5) before 1964, which means it is not possible to use Equations A.5 and A.6 when applying Algorithm #2 before that year.

There are sample catch weights from 1964 to 2012, but the trip identification codes used are unique to the GFBio database and do not cross reference to the GFCatch database. A new field ([`hail_in_number`]) was added to GFBio which links the sampleID to the trip identifier assigned when the vessel lands in port. This works successfully with the PacHarvTrawl database, allowing perfect linkage for this data set between these two databases between 1996 and 2006. Unfortunately, this linking was not available in the version of GFFOS used for this analysis, which affected the years 2007-2012. Subsequent discussions with DFO Groundfish database personnel revealed that this linkage was available in GFFOS; however, this discussion occurred after the catch data were finalized. Future assessments should attempt to correct this discrepancy. However, when the annual sample totals from sampled trips were compared with the reported catches from those same trips (with accurate linking) in the PacHarvTrawl database, the totals were nearly identical between the two sources (Table A.6), implying that most of these trips had been completely sampled. Consequently, the values used for R_{nt} in Equation A.6 from 1964 onwards were the sum of the GFBio reported sampled weights for the trip $\left(S_{jn}\right)$. This approach assumes that the relationship seen between the annual sample totals and trip reported catches between 1996 and 2006 were representative of the entire time period between 1964 and 2012.

In order to apply Algorithm #2 before 1964, it was necessary to assume a nominal weight of one (1) for all samples, effectively assuming that every sample had equal weight. However, it was possible to apply the commercial catch weighting procedure described in Equation A.9 when implementing Algorithm #2.

Results

There is good agreement between the proportion of females calculated using Algorithm #1 and the values used in the 2005 Rock Sole stock assessment (Figure A.2). There are some differences between the proportion females calculated using Algorithm #1 and Algorithm #2, but they are relatively small (Figure A.2; Table A.7). The proportion females in the unsorted samples show a relatively large downwards shift compared to the sorted sample estimates from the 2005 stock assessment (Figure A.3). However, the differences shown in this plot are unsurprising because the unsorted sample should have a larger proportion of male Rock Sole.

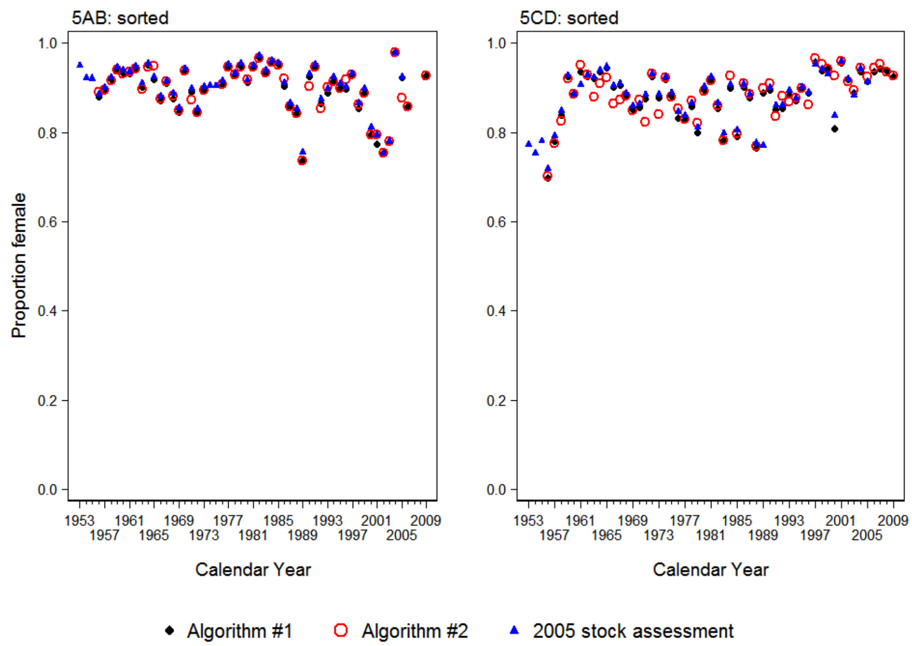

Figure A.2. Comparison plots showing the proportion female estimated by year for 5AB and 5CD from "sorted" samples. The black symbols plot the estimates based on Algorithm #1 and the red open circles plot the estimates based on Algorithm #2. The blue triangles plot the proportion females calculated for the 2005 assessment. Algorithms #1 and #2 use updated length-weight parameters.

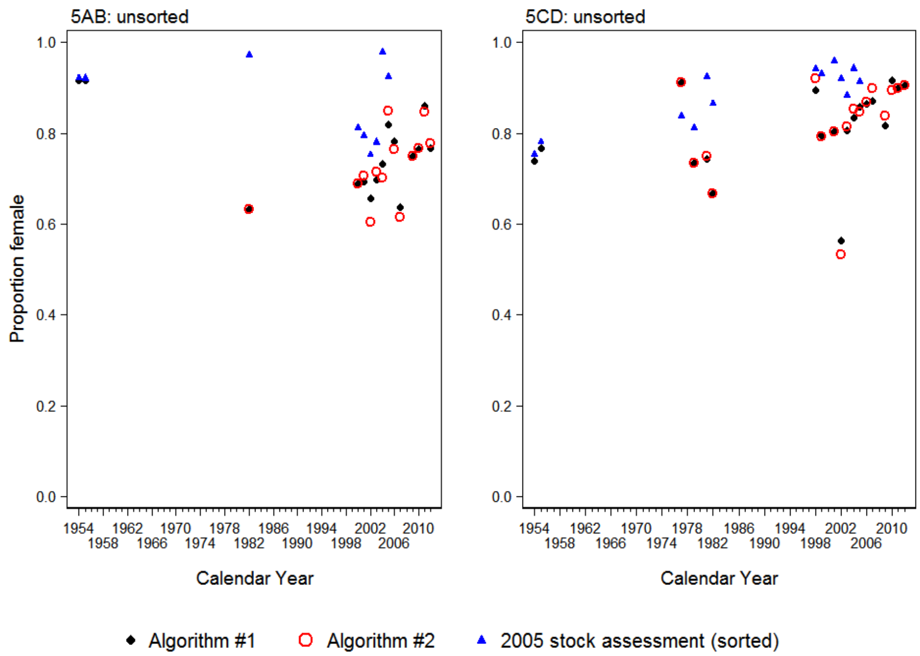

Figure A.3. Comparison plots showing the proportion female estimated by year for each of 5AB and 5CD from "unsorted" samples. The black symbols plot the estimates based on Algorithm #1 and the red open circles plot the estimates based on Algorithm #2. The blue triangles plot the proportion females calculated for the 2005 assessment (reported in Table A.7). Algorithms #1 and #2 use updated length-weight parameters.

Table A.5. Number of sorted and unsorted samples by year and combined major Region, along with number of length observations in those samples.

	Number of Samples			Number of Lengths		
Year	**5AB**	**5CD**	**Total**	**5AB**	**5CD**	**Total**
Sorted samples						
1956	15	15	30	3,181	3,190	6,371
1957	22	33	55	5,910	7,130	13,040
1958	19	41	60	4,546	8,824	13,370
1959	19	11	30	3,985	2,286	6,271
1960	20	18	38	4,138	3,755	7,893
1961	22	11	33	4,731	2,017	6,748
1962	35	13	48	8,659	2,918	11,577
1963	22	11	33	5,710	2,352	8,062
1964	17	22	39	3,991	4,966	8,957
1965	14	14	28	3,345	3,111	6,456
1966	28	49	77	6,569	9,661	16,230
1967	19	37	56	4,382	6,910	11,292
1968	20	34	54	5,221	6,464	11,685
1969	14	22	36	3,826	4,621	8,447
1970	1	12	13	256	2,792	3,048
1971	3	12	15	1,022	2,675	3,697
1972	1	4	5	224	741	965
1973	1	11	12	394	2,882	3,276
1974	–	6	6	–	1,469	1,469
1975	–	4	4	–	1,024	1,024
1976	5	8	13	1,483	1,977	3,460
1977	6	23	29	1,849	6,548	8,397
1978	10	13	23	3,104	3,456	6,560
1979	11	28	39	3,177	7,538	10,715
1980	8	9	17	2,196	2,629	4,825
1981	1	1	2	300	258	558
1982	3	4	7	661	1,060	1,721
1983	1	1	2	299	301	600
1984	1	2	3	300	611	911
1985	2	2	4	600	604	1,204
1986	2	7	9	600	2,020	2,620
1987	1	4	5	303	1,120	1,423
1988	1	7	8	300	2,127	2,427
1989	1	7	8	160	1,851	2,011
1990	6	15	21	304	733	1,037
1991	2	21	23	99	1,009	1,108
1992	5	15	20	245	818	1,063
1993	3	6	9	147	330	477
1994	2	22	24	86	1,188	1,274
1995	4	18	22	208	1,123	1,331
1996	8	19	27	390	1,175	1,565
1997	1	7	8	47	354	401
1998	3	15	18	126	758	884
1999	6	13	19	273	644	917
2000	1	13	14	45	769	814
2001	3	5	8	142	225	367
2002	2	6	8	98	311	409
2003	6	13	19	293	795	1,088

Year	Number of Samples 5AB	5CD	Total	Number of Lengths 5AB	5CD	Total
2004	2	6	8	123	370	493
2005	2	3	5	100	178	278
2006	1	8	9	50	486	536
2007	–	3	3	–	177	177
2008	–	2	2	–	106	106
2009	1	5	6	46	265	311
Total	**403**	**711**	**1114**	**88,244**	**123,702**	**211,946**
Unsorted samples						
1977	–	1	1	–	99	99
1979	–	1	1	–	263	263
1981	–	13	13	–	855	855
1982	6	1	7	401	102	503
1998	–	3	3	–	137	137
1999	–	2	2	–	104	104
2000	1	–	1	52	–	52
2001	9	4	13	443	237	680
2002	10	4	14	493	236	729
2003	15	9	24	776	443	1,219
2004	17	16	33	876	899	1,775
2005	16	12	28	875	601	1,476
2006	5	6	11	271	287	558
2007	3	5	8	157	280	437
2009	1	4	5	46	213	259
2010	5	5	10	247	271	518
2011	2	1	3	105	65	170
2012	4	1	5	207	50	257
Total	**94**	**88**	**182**	**4,949**	**5,142**	**10,091**

Table A.6. Summary of annual catch totals of Rock Sole (in tonnes) obtained when linking sampled trips with the catches from those trips in the PacHarvTrawl database.

Year	Total catch from all samples	Total commercial catch in sampled trips	Total annual commercial catch	% sampled
1996	351.9	328.6	1,642.6	20.0%
1997	70.8	64.0	1,599.2	4.0%
1998	215.8	229.4	1,354.8	16.9%
1999	201.3	208.3	1,658.1	12.6%
2000	171.6	232.9	1,806.5	12.9%
2001	110.8	141.5	1,374.1	10.3%
2002	94.4	98.1	1,504.8	6.5%
2003	162.4	165.4	1,604.6	10.3%
2004	91.6	108.9	1,797.9	6.1%
2005	52.6	61.1	645.2	9.5%
2006	71.3	70.5	717.4	9.8%

Table A.7. Proportion females estimated from sorted and unsorted samples by year and combined major Region. These proportions have been estimated in two ways: A) Algorithm #1; B) Algorithm #2. The values used for the 2005 stock assessment are presented for comparison. The symbol '–' indicates no data.

	5AB			5CD		
Year	**Algorithm #1**	**Algorithm #2**	**2005 values**	**Algorithm #1**	**Algorithm #2**	**2005 values**
Sorted samples						
1953	–	–	0.951	–	–	0.773
1954	–	–	0.922	–	–	0.754
1955	–	–	0.921	–	–	0.780
1956	0.880	0.891	0.886	0.698	0.701	0.719
1957	0.893	0.894	0.900	0.781	0.775	0.793
1958	0.918	0.917	0.923	0.838	0.826	0.849
1959	0.941	0.941	0.945	0.924	0.920	0.928
1960	0.934	0.933	0.939	0.887	0.886	0.885
1961	0.932	0.935	0.936	0.937	0.951	0.907
1962	0.945	0.943	0.949	0.925	0.929	0.929
1963	0.901	0.897	0.912	0.920	0.879	0.925
1964	0.951	0.947	0.955	0.937	0.910	0.939
1965	0.919	0.950	0.925	0.945	0.922	0.947
1966	0.871	0.876	0.880	0.901	0.865	0.906
1967	0.910	0.913	0.917	0.907	0.873	0.910
1968	0.875	0.881	0.887	0.880	0.881	0.887
1969	0.844	0.850	0.856	0.851	0.850	0.859
1970	0.938	0.938	0.943	0.856	0.872	0.863
1971	0.891	0.873	0.899	0.876	0.823	0.885
1972	0.845	0.845	0.854	0.926	0.932	0.931
1973	0.895	0.895	0.902	0.878	0.842	0.884
1974	–	–	0.904	0.918	0.922	0.923
1975	–	–	0.904	0.882	0.879	0.890
1976	0.906	0.907	0.916	0.832	0.853	0.847
1977	0.948	0.947	0.952	0.828	0.830	0.838
1978	0.927	0.930	0.933	0.857	0.872	0.866
1979	0.950	0.947	0.955	0.800	0.822	0.811
1980	0.911	0.919	0.918	0.895	0.892	0.903
1981	0.946	0.946	0.951	0.916	0.916	0.924
1982	0.968	0.967	0.972	0.854	0.861	0.865
1983	0.933	0.933	0.939	0.782	0.782	0.799
1984	0.957	0.957	0.962	0.900	0.928	0.907
1985	0.953	0.952	0.957	0.792	0.797	0.805
1986	0.904	0.922	0.910	0.901	0.909	0.908
1987	0.858	0.858	0.866	0.878	0.887	0.886
1988	0.843	0.843	0.853	0.766	0.770	0.776
1989	0.736	0.736	0.755	0.888	0.898	0.771
1990	0.926	0.903	0.931	0.894	0.910	0.900
1991	0.947	0.946	0.952	0.851	0.836	0.862
1992	0.864	0.854	0.876	0.854	0.883	0.862
1993	0.888	0.901	0.898	0.885	0.870	0.894
1994	0.915	0.913	0.924	0.871	0.877	0.877
1995	0.900	0.898	0.909	0.899	0.899	0.903
1996	0.897	0.919	0.903	0.888	0.863	0.891
1997	0.930	0.930	0.933	0.958	0.965	0.953

Year	5AB Algorithm #1	5AB Algorithm #2	5AB 2005 values	5CD Algorithm #1	5CD Algorithm #2	5CD 2005 values
1998	0.853	0.862	0.866	0.937	0.954	0.942
1999	0.889	0.888	0.898	0.943	0.943	0.931
2000	0.795	0.795	0.813	0.807	0.926	0.837
2001	0.773	0.795	0.794	0.956	0.960	0.959
2002	0.753	0.755	0.753	0.919	0.914	0.921
2003	0.779	0.780	0.780	0.887	0.896	0.883
2004	0.979	0.979	0.979	0.936	0.945	0.943
2005	0.924	0.878	0.924	0.914	0.925	0.914
2006	0.859	0.859	–	0.936	0.945	–
2007	–	–	–	0.942	0.953	–
2008	–	–	–	0.938	0.936	–
2009	0.928	0.928	–	0.926	0.928	–
Unsorted samples						
1977	0.917	–	0.922	0.739	–	0.754
1979	0.916	–	0.921	0.767	–	0.780
1981	–	–	–	0.912	0.912	0.838
1982	–	–	–	0.734	0.734	0.811
1998	–	–	–	0.743	0.750	0.924
1999	0.634	0.634	0.972	0.668	0.668	0.865
2000	–	–	–	0.896	0.922	0.942
2001	–	–	–	0.796	0.792	0.931
2002	0.690	0.690	0.813	–	–	–
2003	0.692	0.706	0.794	0.803	0.803	0.959
2004	0.657	0.605	0.753	0.563	0.533	0.921
2005	0.697	0.715	0.780	0.807	0.815	0.883
2006	0.733	0.702	0.979	0.833	0.854	0.943
2007	0.820	0.849	0.924	0.859	0.848	0.914
2009	0.782	0.765	–	0.865	0.868	–
2010	0.638	0.614	–	0.871	0.898	–
2011	0.750	0.750	–	0.816	0.838	–
2012	0.765	0.768	–	0.917	0.895	–

Estimation of Female Catch

Selection of data:

1. Start with combined trawl databases: GFCatch, PacHarvTrawl and GFFOS (trawl component only)	only trawl data considered here
2. Select major PMFC combined Region =5CD or 5AB	as required for the analysis
3. Calendar years from 1 January 1945 to 31 December 2012.	only complete calendar years; starting year is under discussion

Starting from the total landed catch values provided in Table A.1, the following steps were taken to estimate female-only catch:

1. Create a vector of proportion female by year *y,* P_{Ry}, beginning with the first year of the analysis (start year = 1945) (where *R* subscripts 5AB or 5CD). The value for proportion female by year *y* will be selected using the following rules:

$$\left.\begin{array}{l} P_{Ry} = {}^{t=2}P_{Ry}^{S=0} \text{ if } N_{Ry} \geq 4 \\ P_{Ry} = {}^{t=1}P_{Ry}^{S=0} \text{ if } N_{Ry} < 4 \end{array}\right\} \text{ and } S=0 \text{ is not NULL} \qquad (A.8)$$
$$P_{Ry} = \text{ median}\left(P_R\right) \quad \text{and } S=0 \text{ is NULL}$$

where *S*=0 is a “sorted” sample,

t=1 means that P_{Ry} has been estimated without weights (Algorithm #1);

t=2 means that the estimate for P_{Ry} has been weighted by the available sample weights and quarterly commercial catch (Algorithm #2); and,

N_{Ry} = number of available samples in region *R* and year *y* (Table A.5).

The rationale for using the number of samples to decide on the algorithm to estimate P_{Ry} is that Algorithm #2 uses quarterly commercial weights which requires a reasonable number of samples to operate effectively. Also, with a small number of samples, it is probably best to use all the available data rather than rely on one or two samples (which is what would happen if one or two samples have a lot of associated sample catch). The suggested value of “4” is arbitrary.

2. Missing proportion female observations were replaced with median value from the appropriate series (Equation A.8). This approach was selected for its simplicity, given the relatively few years to fill (before 1954 and after 2009 for 5CD and a few more intermediate years for 5AB) and the complexity of other potential solutions. Furthermore, any bias introduced through using the series median would be small compared to other uncertainties in the procedure. Accuracy in our current infilling may have been improved by using the median proportion female estimates from only the most recent years to fill in missing values after 2009 given that estimates since the late-1990’s have consistently been above the long-term median in Area 5CD (Figure A.2; Table A.7).
3. Future infilling attempts should use this recommended approach if this trend of increased proportion female estimates in recent years continues into the future.
4. Calculate the ratio $\left(Z_{Ry}\right)$ of discarded catch $\left({}^{D}C_{Ryi}\right)$ relative to landed catch $\left({}^{L}C_{Ryi}\right)$ for each of the years where there are estimates of the discarded catch (beginning in 1996):

$$Z_{Ry} = \sum_{i=1}^{X_{Ry}} {}^{D}C_{Ryi} \Big/ \sum_{i=1}^{W_{Ry}} {}^{L}C_{Ryi} \qquad (A.9)$$

where X_{Ry} indexes the discard observations and W_{Ry} indexes the landing observations.

The mean of these observations will be the value used to estimate discards for the years before 1996:

$$\bar{Z}_R = \sum_{y=1996}^{y=2012} Z_{Ry} \Big/ (2012 - 1996 + 1) \qquad (A.10)$$

5. Add a vector of survey catches (Table A.4) to the commercial catches in the appropriate years from the three surveys used to monitor Rock Sole (Hecate Strait assemblage, Hecate Strait synoptic and Queen Charlotte Sound synoptic) by summing the total survey catch weight of Rock Sole across all tows. Catches from the two Hecate Strait surveys were assigned to 5CD and catches from the Queen Charlotte Sound survey were assigned to 5AB, even though some tows from the latter survey were located in the southern portion of 5C. This was done for simplicity and because the amounts involved were small (on the order of less than a tonne).

6. Calculate a total catch vector by year y of females $\left({}^{T}C_{Ry}^{F}\right)$ for region R using the following equations:

$$ {}^{T}C_{Ry}^{F} = \begin{cases} P_{Ry}\,{}^{L}C_{Ry}\left(1+\bar{Z}_R\right) & \text{if } y < 1996 \\ P_{Ry}\,{}^{T}C_{Ry} & \text{if } y \ge 1996 \end{cases} \qquad (A.11)$$

The catch totals from 1996 onwards already include the estimates of discards. Note that once the survey catches have been added to the commercial catches, Equation A.11 assumes that the sex ratio of the survey catches are the same as the commercial catches and that the pre-1996 HS assemblage survey discarded small Rock Sole. This is clearly incorrect but the amounts of catch involved are very small and this bias was ignored (Table A.8).

Results:

The procedure documented in Equations A.8 to A.11 was used to estimate the total annual female catch in 5AB (Figure A.4 and Table A.8) and 5CD (Figure A.5 and Table A.8). Years with missing observations were filled in with the median of the full series for both regions (Equation A.8).

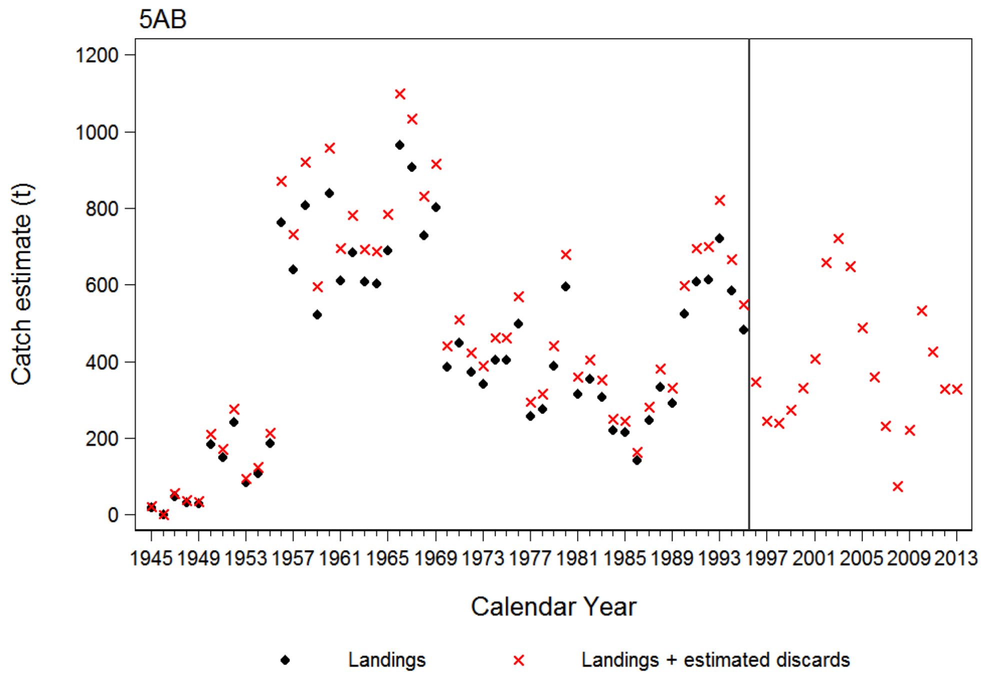

Figure A.4. Plot showing landings and landings+estimated discards for female Rock Sole catches for 5AB. Estimated discards before 1996 are based on the rules given in Equations A.8 to A.11.

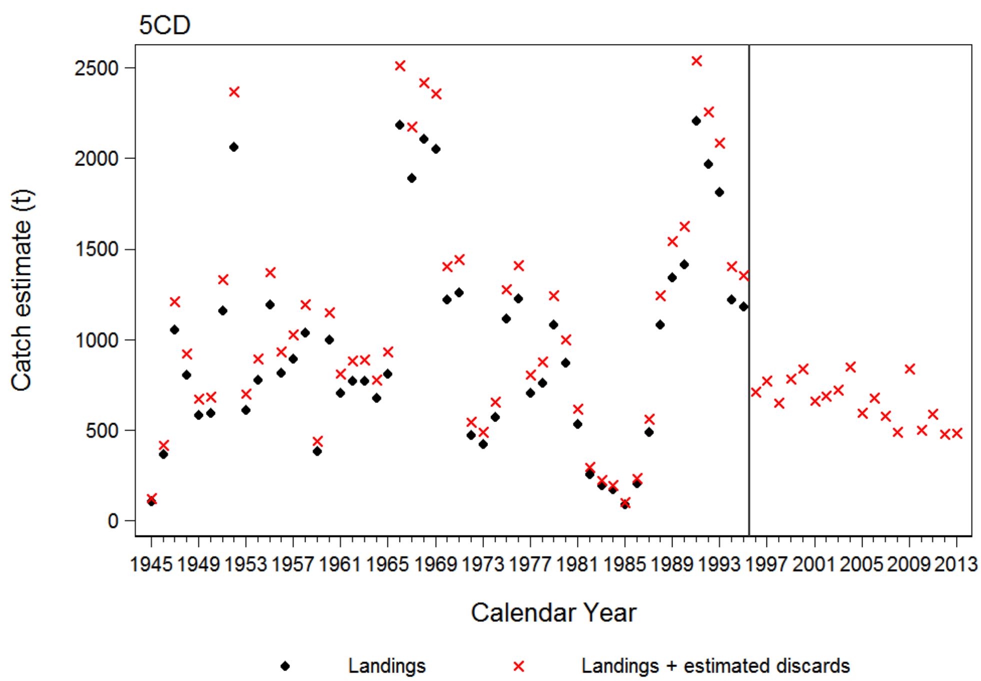

Figure A.5. Plot showing landings and landings+estimated discards for female Rock Sole catches for 5CD. Estimated discards before 1996 are based on the rules given in Equations A.8 to A.11.

Table A.8. Catch estimates (tonnes) for 5AB and 5CD: 2013 estimates include total catch (males plus females) or female only (including discards); also shown are the female catches used in the 2005 Rock Sole stock assessment and the additional component of catch attributed to surveys. The 5AB values are plotted in Figure A.4 and the 5CD values are plotted in Figure A.5.

	5AB				5CD			
Year	**Survey catch[1]**	**2013 total catch[2]**	**2013 female catch[3]**	**2005 female catch[4]**	**Survey catch[1]**	**2013 total catch[2]**	**2013 female catch[3]**	**2005 female catch[4]**
1945	–	20	20	–	–	121	124	–
1946	–	0	0	–	–	410	419	–
1947	–	53	55	–	–	1,182	1,208	–
1948	–	35	36	–	–	902	921	–
1949	–	33	34	–	–	658	672	–
1950	–	203	210	–	–	668	682	–
1951	–	165	171	–	–	1,301	1,330	–
1952	–	267	277	–	–	2,316	2,366	–
1953	–	92	95	–	–	686	701	–
1954	–	120	124	128	–	872	891	777
1955	–	206	213	219	–	1,340	1,369	1,236
1956	–	858	871	880	–	1,160	935	993
1957	–	717	731	747	–	1,151	1,025	1,107
1958	–	880	920	940	–	1,256	1,192	1,260
1959	–	556	596	609	–	416	440	457
1960	–	901	957	979	–	1,127	1,147	1,179
1961	–	653	696	707	–	744	812	837
1962	–	727	782	799	–	829	884	910
1963	–	678	693	716	–	879	888	980
1964	–	638	688	705	–	743	776	870
1965	–	725	785	776	–	879	931	984
1966	–	1,102	1,100	1,122	–	2,527	2,511	2,959
1967	–	993	1,034	1,054	–	2,169	2,174	2,334
1968	–	827	831	849	–	2,390	2,418	2,593
1969	–	945	915	936	–	2,413	2,355	2,462
1970	–	412	440	450	–	1,401	1,404	1,432
1971	–	503	510	523	–	1,527	1,443	1,597
1972	–	440	424	435	–	506	542	567
1973	–	381	388	398	–	504	487	529
1974	–	444	461	465	–	621	658	679
1975	–	445	462	466	–	1,266	1,277	1,331
1976	–	550	569	584	–	1,436	1,407	1,438
1977	–	271	293	299	–	846	806	847
1978	–	297	314	321	–	874	875	937
1979	–	410	442	453	–	1,315	1,241	1,280
1980	–	650	680	710	–	976	1,000	1,064
1981	–	333	359	380	–	584	614	650
1982	–	366	404	412	–	295	292	302
1983	–	330	351	359	–	250	225	237
1984	–	230	250	256	1.0	189	195	202
1985	–	225	244	250	–	111	101	106
1986	–	158	163	167	–	225	235	242
1987	–	287	281	288	0.6	550	560	576
1988	–	396	380	392	–	1,404	1,241	1,289
1989	–	396	332	346	2.5	1,497	1,544	1,364
1990	–	581	598	627	–	1,553	1,624	1,653
1991	–	643	694	709	1.6	2,643	2,537	2,694
1992	–	719	699	729	–	2,229	2,259	2,273

Year	5AB Survey catch[1]	5AB 2013 total catch[2]	5AB 2013 female catch[3]	5AB 2005 female catch[4]	5CD Survey catch[1]	5CD 2013 total catch[2]	5CD 2013 female catch[3]	5CD 2005 female catch[4]
1993	–	812	822	845	1.7	2,085	2,082	2,204
1994	–	638	665	683	–	1,391	1,401	1,443
1995	–	536	549	565	1.6	1,313	1,356	1,401
1996	–	377	346	337	3.8	825	712	720
1997	–	263	244	245	–	800	772	757
1998	–	280	239	240	1.4	678	647	633
1999	–	307	273	273	–	829	782	765
2000	–	415	330	329	2.3	906	839	739
2001	–	527	408	407	–	687	660	655
2002	–	874	659	629	1.6	754	689	685
2003	0.5	925	721	695	3.5	806	722	692
2004	1.7	661	647	644	–	899	849	838
2005	0.9	530	489	507	3.2	648	593	594
2006	–	419	360	–	–	717	678	–
2007	0.6	253	230	–	1.4	613	577	–
2008	–	82	74	–	–	521	488	–
2009	0.8	238	221	–	1.5	905	840	–
2010	–	585	532	–	–	561	499	–
2011	0.8	466	425	–	2.1	662	589	–
2012	–	361	329	–	–	536	477	–
2013	0.5	362	329	–	4.1	540	480	–

[1] unsorted by size or sex
[2] includes males for all years and discard estimates after 1996
[3] includes discards either from observers or estimated using Equation A.11.
[4] from Starr et al. (2006, unpublished manuscript[1])

APPENDIX B. FISHERY CPUE INDICES

INTRODUCTION

Commercial catch and effort data have been used to generate indices of abundance in several ways in this Appendix. The simplest indices were derived from the arithmetic mean or geometric mean of catch divided by an appropriate measure of effort (Catch per Unit Effort or CPUE). We refer to these indices as “arithmetic” and “unstandardised” CPUE, respectively. Such indices make no adjustments for changes in fishing practices or other non-abundance factors that may affect catch rates. Consequently, methods to standardise for changes to vessel configuration, the timing or location of catch and other possible effects using generalised linear models (GLMs) have been developed to remove potential biases to CPUE that may result from such changes. We refer to series that have been standardised using GLMs as “standardised” series. In these models, abundance is represented as a “year effect” and the dependent variable is either an explicitly calculated CPUE represented as catch divided by effort, or an implicit CPUE represented as catch per tow or catch per record. In the latter case, effort terms can be offered as explanatory variables, allowing the model to select the effort term with the greatest explanatory power. It is always preferable to standardise for as many factors as possible when using CPUE as a proxy for abundance. Unfortunately, it is often not possible to adjust for some factors that might affect the behaviour of fishers, particularly economic factors, because adequate data are not available. As a result, CPUE indices may not entirely reflect the underlying stock abundance.

The standardised [`Year`] indices estimated by these models were used as relative abundance indices in the 5AB and 5CD Rock Sole stock assessment models. Short-term (1996–2012) combined models (Equation B.4), fitted to the sum of landings plus discards, were used in 5AB sensitivity analyses (CPUE2 in Appendix H) and in the 5CD base case to index abundance from 1996 to 2012. The 5AB long-term (1966-2012) log-normal model (Equation B.3), fitted to landings, was used in the 5AB base case to index abundance from 1966 to 2012 and as CPUE1 in a 5AB sensitivity run to index abundance from 1966 to 1995. The 5CD long-term (1954-2012) log-normal model (Equation B.3), fitted to landings up to 1995, was used as CPUE1 in the 5CD base case to index abundance from 1954 to 1995.

METHODS

Arithmetic and Unstandardised CPUE

Arithmetic and unstandardised CPUE indices provide potential measures of relative abundance, but are generally considered unreliable because they fail to take into account changes in the fishery, including spatial and temporal changes as well as behavioural and gear changes. They are frequently calculated because they provide a measure of the overall effect of the standardisation procedure.

Arithmetic CPUE $\left(\hat{A}_y\right)$ in year y was calculated as the total catch for the year divided by the total effort in the year using Equation B.1:

$$\hat{A}_y = \frac{\sum_{i=1}^{n_y} C_{i,y}}{\sum_{i=1}^{n_y} E_{i,y}} \qquad (B.\ 1)$$

where $C_{i,y}$ is the [catch], $E_{i,y}= T_{i,y}$ ([*tows*]) or $E_{i,y}= H_{i,y}$ ([*hours_fished*]) for record i in year y, and n_y is the number of records in year y.

Unstandardised (geometric) CPUE assumes a log-normal error distribution. An unstandardised index of CPUE $\left(\hat{G}_y\right)$ in year *y* was calculated as the geometric mean of the ratio of catch to effort for each record *i* in year *y* using Equation B.2:

$$\hat{G}_y = \exp\left[\frac{\sum_{i=1}^{n_y} \ln\left(C_{i,y} / E_{i,y}\right)}{n_y}\right] \qquad (B.\ 2)$$

where C_i , $E_{i,y}$ and n_y are as defined for Equation B.1.

Standardised CPUE

These models are preferred over the unstandardised models described above because they can account for changes in fishing behaviour and other factors which may affect the estimated abundance trend, as long as the models are provided with adequate data. In the models described below, catch per record is used as the dependent variable and the associated effort is treated as an explanatory variable.

Lognormal Model

Standardised CPUE assumes a lognormal error distribution, with explanatory variables used to represent changes in the fishery. A standardised CPUE index (Equation B.3) is calculated from a generalised linear model (GLM) (Quinn and Deriso 1999) using a range of explanatory variables including [*year*], [*month*], [*depth*], [*vessel*] and other available factors:

$$\ln(I_i) = B + Y_{y_i} + \alpha_{a_i} + \beta_{b_i} + ... + f\left(\chi_i\right) + f\left(\delta_i\right) .... + \varepsilon_i \qquad (B.\ 3)$$

where I_i = C_i; B is the intercept; Y_{y_i} is the year coefficient for the year corresponding to the ith record; α_{a_i} *and* β_{b_i} are the coefficients for factorial variables a and b corresponding to the ith record; $f\left(\chi_i\right)$ and $f\left(\delta_i\right)$ are polynomial functions (to the 3rd order) of the continuous variables χ_i and δ_i corresponding to the ith record; and ε_i is an error term.

The actual number of factorial and continuous explanatory variables in each model depends on the model selection criteria. Because each record represents a single tow, C_i has an implicit associated effort of one tow. Hours fished for the tow is represented on the right-hand side of the equation, usually as a continuous (polynomial) variable.

Note that calculating standardised CPUE with Equation B.3 without additional explanatory variables is equivalent to using Equation B.2, provided the same definition for $E_{i,y}$ is used.

Canonical coefficients and standard errors were calculated for each categorical variable (Francis 1999, unpublished manuscript[2]). Standardised analyses typically set one of the coefficients to 1.0 without an error term and estimate the remaining coefficients and the associated error relative to the fixed coefficient. This is required because of parameter confounding. The Francis (1999, unpublished manuscript[2]) procedure rescales all coefficients so that the geometric mean of the coefficients is equal to 1.0 and then calculates a standard error for each coefficient, including the fixed coefficient.

Coefficient-distribution-influence plots (CDI plots) are visual tools to facilitate understanding of patterns which may exist in the combination of coefficient values, distributional changes, and annual influence (Bentley et al. 2012). CDI plots were used to illustrate each explanatory variable added to the model.

Binomial Logit Model

The procedure described by Equation B.3 is necessarily confined to the positive catch observations in the data set because the logarithm of zero is undefined. Observations with zero catch were modelled by fitting a logit regression model based on a binomial distribution and using the presence/absence of Rock Sole as the dependent variable (where 1 is substituted for $\ln(I_i)$ in Equation B.3 if it is a successful catch record and 0 if it is not successful) and using the same data set. Explanatory factors are estimated in the model in the same manner as described in Equation B.3. Such a model provides an alternative series of standardised coefficients of relative annual changes that is analogous to the series estimated from the lognormal regression.

Combined Model

A combined model, integrating the two sets of relative annual changes estimated by the lognormal and binomial models, can be estimated using the delta distribution, which allows zero and positive observations (Vignaux 1994). Such a model provides a single index of abundance which integrates the signals from the positive (lognormal) and binomial series. This approach uses the following equation to calculate an index based on the two contributing indices:

$$ {}^{C}Y_y = \frac{{}^{L}Y_y}{\left(1 - P_0\left[1 - \frac{1}{{}^{B}Y_y}\right]\right)} \qquad \textit{(B. 4)} $$

where ${}^{C}Y_y$ = combined index for year *y*, ${}^{L}Y_y$ = lognormal index for year *I*, ${}^{B}Y_y$ = binomial index for year *I* P_0 = proportion zero for base year *0.*

Francis (2001) suggests that a bootstrap procedure is the appropriate way to estimate the variability of the combined index. Therefore, confidence bounds for the combined model were estimated using a bootstrap procedure based on 1000 replicates, drawn with replacement.

PRELIMINARY INSPECTION OF THE DATA

Two types of analysis are reported based on data from the 5AB or the 5CD trawl fisheries:

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[2] Francis, R.I.C.C. 1999. The impact of correlations on standardised CPUE indices. New Zealand Fishery Assessment Research Document 1999/42. 30 p. (Unpublished report held in NIWA library, Wellington, New Zealand).

A. a tow-by-tow analysis using total catch (landings + discards) confined to the period 1996–2012 when detailed positional data for every tow are available and there is an estimate of discarded catch for the tow because of the presence of an observer on board the vessel. These data are held in the DFO PacHarvestTrawl (PacHarv) and GFFOS databases (Fisheries and Oceans Canada, Pacific Region, Groundfish Data Unit);

B. a coarser analysis covering the period 1966–2012 (5AB) or 1954–2012 (5CD), where the earlier data (pre-1991) are only available amalgamated by depth and DFO reporting locality for a trip. Data after 1 January 1991 were amalgamated to the same level of detail as the pre-1991 data for continuity. These data are entirely held in the GFCatch database (Rutherford 1999). The pre-1996 data do not contain reliable estimates of discards. Consequently, only landings data are used.

Tow-by-tow data (5AB and 5CD: 1996–2012)

Tow-by-tow catch and effort data for Rock Sole from the BC bottom trawl fishery operating in the uppermost part of the Vancouver Island west coast, most of Queen Charlotte Sound, Hecate Strait, plus Dixon Entrance from 1996 to 2012 were selected using the following criteria:

Tow start date between 1 January 1996 and 31 December 2012
Bottom trawl type (includes soft and hard bottom trawl types after 2006) (includes ‘unknown’ gear)
Fished in PMFC regions: 5A or 5B (for the 5AB analysis); 5C or 5D (for the 5CD analysis)
Fishing success code <=1 (code 0= unknown; code 1= useable)
Catch of at least one fish or invertebrate species (no water hauls or inanimate object tows)
Valid depth field
Valid latitude and longitude co-ordinates
Valid estimate of time towed that was greater than 0 hours and less than or equal to 6 hours

Each record represents a single tow, which results in equivalency between the number of records and number of tows. Catch per record can therefore be used to represent CPUE, because each record (tow) has an implicit effort component. The empirical 1% and 99% quantiles of the distribution of successful catch records data ranged from 53 m to 210 m for 5AB (Figure B.1) and from 27 m to 146 m for 5CD (Figure B.2), both areas have sporadic observations at deeper depths. It is possible that the deeper recorded depths are in error or document tows that passed through a wide range of depths. Valid tows were binned by depth in 20 m increments, between 40 and 220 m (5AB) or between 20 and 160 m (5CD).

Selection of core vessel fleet: 5AB

There were a total of 101 trawl vessels in the 5AB data set which recorded a catch of Rock Sole at least once in the 17-year period. Vessel qualification criteria based on number of trips per year and number of years fishing were developed to avoid including vessels which only occasionally fished in 5AB or which did not actively fish Rock Sole (Figure B.3). Qualified vessels were those which had fished at least three trips for a minimum of six years. Once a vessel was selected, all data for the qualifying vessel were included, regardless of the number of trips in a year.

The analysis was based on a core fleet of 30 qualified vessels, responsible for 86% of the total catch in the data set. The vessel overlap across years was good, with a considerable number of vessels operating in most of the available 17 years of data (Figure B.4). Only tows which were less than 6 hours long were used in the analysis. This restriction did not drop much data because over 99% of the tows were less than 5 hours in length. The final data set is large, with nearly 18,000 successful tows and about 6,300 t of Rock Sole catch (Table B.1). Mean catch rates for successful tows in the data set are 357 kg/tow and 136 kg/h.

Selection of core vessel fleet: 5CD

There were a total of 83 trawl vessels in the 5CD data set which recorded a catch of Rock Sole at least once in the 17-year period. Vessel qualification criteria based on number of trips per year and number of years fishing were developed to avoid including vessels which only occasionally fished in 5CD or which did not actively fish Rock Sole (Figure B.5). Qualified vessels were those which had fished at least four trips for a minimum of three years. Once a vessel was selected, all data for the qualifying vessel were included, regardless of the number of trips in a year.

The analysis was based on a core fleet of 24 qualified vessels, responsible for 87% of the total catch in the data set. The vessel overlap across years was good, with a considerable number of vessels operating in most of the available 17 years of data (Figure B.6). Only tows which were less than 6 hours long were used in the analysis. This limitation did not exclude much data because over 99% of the tows were less than 5 hours long. The final data set is large, with over 16,000 successful tows and over 10,000 t of Rock Sole catch (Table B.2). Mean catch rates for successful tows in the data set are 670 kg/tow and 290 kg/h.

Explanatory variables offered to each model based on tow-by-tow data

The following explanatory variables were offered to each 1996–2012 model, based on the tow-by-tow information in each record in 5AB or 5CD:

Year (1 January–31 December)	17 categories
Hours fished	continuous: 3rd order polynomial
Month	12 categories
DFO locality (Rutherford 1999)	5AB: 9 categories plus a final aggregated category; 5CD: 17 categories plus a final aggregated category
Latitude separated in 0.1° bands beginning with 48°N	5AB: 11 categories plus a final aggregated category 5CD: 15 categories plus a final aggregated category
Vessel	5AB: 30 categories 5CD: 24 categories
Depth aggregated into 20 m depth bands	5AB: 9 categories 5CD: 7 categories
DFO Major region (5A or 5B) OR (5C or 5D)	2 categories

Long-term analysis using amalgamated data (5AB: 1966–2012; 5CD: 1954–2012)

Rock Sole amalgamated catch and effort data up to the end of 1990 plus tow-by-tow catch and effort data from 1991 onwards from the BC bottom trawl fishery operating either in the uppermost part of the Vancouver Island west coast and most of Queen Charlotte Sound (5AB), or in Hecate Strait and Dixon Entrance (5CD) were selected using the following criteria:

Tow start date between 1 January 1966 and 31 December 2012 for 5AB, or 1 January 1954 and 21 December 2012 for 5CD
Bottom trawl type (includes soft and hard bottom trawl types after 2006) (includes ‘unknown’ gear)
Fished in PMFC regions: 5A or 5B (for the 5AB analysis); 5C or 5D (for the 5CD analysis)
Fishing success code <=1 (code 0= unknown; code 1= useable)
Catch of at least one fish or invertebrate species (no water hauls or inanimate object tows)
Valid depth field
Valid estimate of time towed that was greater than 0 hours and less than or equal to 48 hours

Each record before 1991 represented an observation from a vessel on a trip operating in a DFO locality at a specified depth. Consequently, information with respect to the general location of capture at a specified depth has been captured, but the individual tow-by-tow variation both in time and space has been lost. For this analysis, the more detailed tow-by-tow data from the post-1990 data were amalgamated to the same level of aggregation: trip, depth, and DFO locality. Unlike in the short-term analysis, where each record represents a single tow, each record in the long-term analysis will represent a variable number of tows. The variable [`Hours fished`] was offered to the model as a continuous variable to represent effort. The empirical 1% and 99% quantiles of the distribution of successful catch records ranged from 53 m to 218 m (5AB) and 27 m to 146 m (5CD), with sporadic observations at deeper depths. Both the 5AB and 5CD long-term analyses used the same depth intervals as were used in the shorter 1996–2012 analyses.

Vessel information was not used in either analysis because there was no expectation that vessel coefficients would remain consistent across the 47 (5AB) or 59 (5CD) years spanned by each analysis. There clearly will be changes in the operating skipper as well as considerable improvements in the fishing power of the vessel.

The 5AB analysis was not started until 1966, while the equivalent 5CD analysis for Hecate Strait and Dixon Entrance was started in 1954. The reason for this difference lies in the nature of the available data for the 5AB analysis, where the codes used for [`DFO locality`] show a clear shift in quality between 1965 and 1966. Figure B.7 shows that all the information for the [`DFO locality`] variable from 1954 to 1965 was coded as “Unknown” (either for 5A or 5B), which were codes that were used only sparingly after 1965 and which clearly have a different definition. From 1966, the [`DFO locality`] variable contains information about the locality of capture and it seems inappropriate to estimate variable coefficients for index values that are dropped from the data and have little explanatory power beyond the [`Major_region`] variable, which was also offered to the model.

The sum of hours fished up to 48 hours was accepted into the long-term analyses because the data were amalgamated and may represent several days of fishing. This criterion accepted about 98% of the available records in both data sets. Each final data set is large, with 54,600 tows in 5AB and 117,000 tows in 5CD in successful strata (note that the number of records [=amalgamated strata] is much less, with only 16,900 records holding the 54,600 tows in 5AB and 24,600 records holding the 117,000 tows in 5CD). There were 14,500 t of Rock Sole catch in 5AB (Table B.3) and 52,000 t caught in 5CD (Table B.4). Mean catch rates in 5AB over the 47 years were 265 kg/tow and 103 kg/h; in 5CD, the mean unstandardised catch rates over 59 years were 445 kg/tow and 241 kg/h.

Explanatory variables offered to each long-term model

The following explanatory variables were offered to each long-term model, based on the amalgamated information in each record in 5AB or 5CD:

Year (1 January–31 December)	5AB: 47 categories 5CD: 59 categories
Hours Fished	continuous: 3rd order polynomial
Month	12 categories
DFO locality (Rutherford 1999)	5AB: 9 categories plus a final aggregated category; 5CD: 21 categories plus a final aggregated category
Depth aggregated into 20 m depth bands	5AB: 9 categories 5CD: 7 categories
DFO Major region (5C or 5D)	2 categories

5AB: RESULTS

5AB: Tow-by-tow data Analysis (1996 – 2012)

5AB: Lognormal Positive Model

A standardised lognormal General Linear Model (GLM) analysis was performed on positive catch records from a tow-by-tow data set generated as described in Section [Tow-by-tow data]. Eight explanatory variables (described in Section [Explanatory variables offered to each model based on tow-by-tow data]) were offered to the model and ln(`catch`) was used as the dependent variable, where `catch` is the total by weight of landed plus discarded Rock Sole in each record (tow) (Equation B.3). The resulting CPUE index series is presented in Table B.5 and Figure B.8.

The `[Year]` categorical variable was forced as the first variable in the model without regard to its effect on the model deviance. The remainder of the variables were offered sequentially, with a stepwise acceptance of the remaining variables with the best AIC. This process was continued until the improvement in the model R^2 was less than 1% (Table B.6). This model selected 5 of the 8 available explanatory variables, including `[Depth bands]`, `[Hours fished]`, `[0.1° Latitude bands]`, and `[Vessel]` as explanatory variables, in addition to `[Year]`. The final lognormal model accounted for 42% of the total model deviance (Table B.6), with the year variable explaining about 3% of the model deviance.

Model residuals appeared to be consistent with the underlying lognormal distributional assumption for the bulk of the data, with some deviation near the peak of the distribution and particularly at the lower tail of the distribution (Figure B.9). A stepwise plot of the year indices as each explanatory variable was introduced into the model shows some minor impact with the addition of the [`Depth bands`] variable, dropping the annual indices somewhat in the mid-2000s (Figure B.10).

CDI plots (Bentley et al. 2012) of the four explanatory variables introduced to the model in addition to [`Year`] show some overall trends (Figure B.11 to Figure B.14). For instance, there was a move to more shallow tows in the mid-2000s, a depth region where the expectation of Rock Sole catch is higher (Figure B.11). Consequently, the model discounts the higher catch rates for these few years. The relationship between [`Hours fished`] and ln(`catch`) is nearly linear over the majority of the observations in the data set and there appears to be little trend in this variable over time (Figure B. 12). The positional variable accepted into the model was not the DFO locality, but the [`0.1° latitude bands`], indicating that there is greater contrast in catch rates from this variable than in the locality variable (Figure B. 12). Most of the data reside in two 0.1° bands on the Goose Island Bank. The vessel variable does not impart a lot of explanatory power; however, unlike in the 5CD analysis, the vessels with the higher average catch rates are staying in the fishery while the lower catch rate vessels are dropping out (Figure B.14). The plot of the year indices shows a cyclical abundance trend to 2008, followed by a sharp increase to a peak in 2010 and a drop to near the initial 2008 level by 2012 (Table B.5 and Figure B.8).

5AB: Binomial Logit Model

The same variables used in the lognormal model were offered sequentially to this model, beginning with the year categorical variable, until the improvement in the model R^2 was less than 1%. The model produced a similar trend of year indices up to 2008. Between 2008 and 2012 there is a gradual increasing trend for the binomial model while the lognormal model increased and then dropped over the same period (Figure B.15).

5AB: Combined Model

Figure B.16 shows that the effect of adding the binomial series to the lognormal series to produce a combined series is small. The resulting series more closely resembles the lognormal series than the binomial series. However, the minimum in 2007 for the combined model is lower than either the lognormal or binomial models, as is the peak in 2010 (Table B.5).

5AB: Comparison with Survey Index

A comparison of the combined GLM series with the scaled biomass indices from the Queen Charlotte Sound synoptic survey shows some agreement between the two series, although there is little contrast over time in the survey series (Figure B.17). The observed drop in the survey biomass series for the 2007 index is mirrored in the CPUE series and the CPUE peak in the commercial series occurred during a year when this biennial survey did not occur (2010).

5AB: Long-term Analysis (1966–2012)

5AB: Lognormal Positive Model

A standardised lognormal General Linear Model (GLM) analysis was performed on positive catch records from a data set generated from amalgamated data described in Section [Long-term analysis using amalgamated data], encompassing the period 1966–2012. Six explanatory variables (described in Section [Explanatory variables offered to each long-term model]) were offered to the model and ln(catch) was used as the dependent variable. The definition of [catch] was the weight of landings. Although estimates of discards were available after 1995, these data were not used in this analysis because this series was intended to be used in the stock assessment model as a continuous series, which required comparability between the periods with and without reliable discard data. The resulting CPUE index series is presented in Figure B.18 and Table B.7.

The [`Year`] categorical variable was forced as the first variable in the model without regard to its contribution to the model deviance. However, in contrast with the equivalent short-term analysis, the [`Year`] categorical variable explained 10% of the deviance, due to the contrast in the indices across the width of the series. The remainder of the variables were offered sequentially, with a stepwise acceptance of the remaining variables with the best AIC. This process was continued until the improvement in the model R2 was less than 1% (Table B.8). This model selected 3 of the 5 remaining explanatory variables, including [`Depth band`], [`Hours fished`] and [`DFO locality`] as explanatory variables. The final lognormal model accounted for 54% of the total model deviance (Table B.8), with the year variable explaining 10% of the model deviance.

Model residuals appeared to be consistent with the underlying lognormal distributional assumption, with some minor deviation near the peak of the distribution and in the lower tail of the distribution (Figure B.19).

A stepwise plot of the year indices as each explanatory variable was introduced into the model shows considerable impact from the standardisation procedure over the entire series, with the indices brought down before 1990 and lifted after the mid-1990s (Figure B.20). Both the [`Depth band`] and the [`Hours fished`] variables had considerable impact on the series.

CDI plots of the three explanatory variables introduced into the model in addition to [`Year`] show some trends (Figure B.21 to Figure B.23). The unstandardised catch rates at the beginning of the series are brought down because the early records tended to fish in shallow waters where catch rates of Rock Sole tend to be higher (Figure B.21). It is difficult to interpret the CDI plot for [`Hours_fished`] because of the overlapping symbols in the bubble plot (Figure B.22).

However, this plot shows that amalgamation of the tow-by-tow data did not result in a distribution of fishing effort that was equivalent to the pre-1991 records. This can be seen in the large white space after 1990 caused by the lack of records with greater than 24 hours of fishing, a region which was more fully populated by the earlier data (Figure B.22). However, the model compensates for the imbalance by lowering the year indices before 1990 and increases the indices somewhat after that year. The contrast in the catch rates in the 8 [`DFO localities`] is not large, with the 4 localities in the Cape Scott Triangle sub-region having slightly lower catch rates than the 4 localities on Goose Island Bank (Table B.9; Figure B.23).

The plot of the year indices shows CPUE maintaining a constant level through the 1970s and 1980s and into the early 1990s, after a rapid decline in the latter half of the 1960s (Figure B.18 and Table B.7). CPUE dropped to a low level from the mid-1990s to 2008, after which the CPUE has shown a strong recovery to a level similar to that seen before the mid-1990s. A binomial series was not attempted because these are amalgamated records, with the data containing implied zeros because it is unlikely that the amalgamation was based on the catch (or lack of catch) of Rock Sole. Consequently, an analysis of Rock Sole presence/absence based on this amalgamation seems unwarranted.

5AB: Comparison with short-term tow-by-tow analysis

A comparison of the long-term and short-term series shows good agreement between the two series (Figure B.24). This result is not surprising considering the short-term and long-term series are based on the same data in the overlapping years. This comparison is really a test of the effect of amalgamatiing tow-by-tow data, which appears to be minor in spite of the observation made for the [`Hours fished`] CDI plot (Figure B.22) that the “roll-up” of the tow-by-tow data did not reproduce the distribution of hours fished seen in the pre-1991 data (see above).

5CD: RESULTS

5CD: Tow-by-tow data Analysis

5CD: Lognormal Positive Model

A standardised lognormal General Linear Model (GLM) analysis was performed on positive catch records from a tow-by-tow data set generated as described in Section [Tow-by-tow data]. Eight explanatory variables (described in Section [Explanatory variables offered to each model based on tow-by-tow data]) were offered to the model and ln(`catch`) was used as the dependent variable, where catch is the total by weight of landed plus discarded Rock Sole in each record (tow) (Equation B.3). The resulting CPUE index series is presented in Table B.10 and Figure B.25.

The [`Year`] categorical variable was forced as the first variable in the model without regard to its effect on the model deviance. The remainder of the variables were offered sequentially, with a stepwise acceptance of the remaining variables with the best AIC. This process was continued until the improvement in the model R2 was less than 1% (Table B.11). This model selected 6 of the 8 available explanatory variables, including [`DFO locality`], [`Depth band`], [`Hours fished`], [`Month`], and [`Vessel`] as explanatory variables, in addition to [`Year`]. The final lognormal model accounted for 67% of the total model deviance (Table B.11), with the year variable explaining less than 1% of the model deviance.

Model residuals appeared to be consistent with the underlying lognormal distributional assumption, with some deviation near the peak of the distribution and at both tails (Figure B.26).

A stepwise plot of the year indices as each explanatory variable was introduced into the model shows some impact from the standardisation procedure, particularly with raising of the more recent index values (Figure B.27).

CDI plots of the five explanatory variables introduced to the model in addition to [`Year`] show some overall trends (Figure B.28 to Figure B.32). For instance, there appears to have been a shift toward the “East Horseshoe” locality (#229), the DFO locality with the highest catch rate, in recent years (Figure B.28). However, two localities with a consistently large number of records (Butterworth [#250] and Two Peaks [#251]) have low relative catch rates for Rock Sole (0.41 and 0.25 respectively). These are known “hot spots” for Pacific Cod, which suggests that much of the Rock Sole catch is bycatch from a target Pacific Cod fishery. Hours fished is nearly linear (Figure B.30) and there is evidence that in the early years of the series, vessels fished in months with lower catch rates (Figure B.31). There is also evidence of a withdrawal of the vessels with the highest catch rates since the mid-2000s (Figure B.32).

The plot of the year indices shows a gradual decreasing trend to 2009, but the most recent two years have recovered to near the mean of the series (about 300 kg/h; Table B.10 and Figure B.25).

5CD: Binomial Logit Model

The same variables used in the lognormal model were offered sequentially to this model, beginning with the year categorical variable, until the improvement in the model R2 was less than 1%. The model produced a variable set of year indices with a dissimilar trend to the trend estimated by the lognormal model (Figure B.33). The index might be affected by the very high proportion of zero tows in 1996. There is a slight declining trend in the proportion of zero tows since then (Table B.10, Figure B.33).

5CD: Combined Model

Figure B.34 shows that the effect of adding the binomial series to the lognormal series to produce a combined series is relatively small because the resulting series more closely resembles the lognormal series. An exception is 1996, where the combined index resembles the binomial index due to the very high proportion of zero tows in that year. All three sets of indices appear to converge after 1999.

5CD: Comparison with Survey Index

A comparison of two GLM indices (combined and lognormal) with the scaled biomass indices from the Hecate Strait synoptic survey (Olsen et al. 2009) shows reasonable agreement between all three series over the four overlapping years, but there is little contrast in these indices (Figure B.35). The strong increase in the Hecate Strait index in 2013 does not have a matching CPUE observation (Table B.10).

5CD: Long-term Analysis (1956–2012)

5CD: Lognormal Positive Model

A standardised lognormal General Linear Model (GLM) analysis was performed on positive catch records from an amalgamated data set generated as described in Section [Long-term analysis using amalgamated data], which encompassed the period 1954–2012. Six explanatory variables were offered to the model and ln(`catch`) was used as the dependent variable. The definition of [`catch`] varied with year: where [`catch`] was the weight of landings before 1996 and was the total of landed plus discarded Rock Sole (Equation B.3). This shift in the definition of [`catch`] in 1996 was done for comparability with the short-term tow-by-tow analysis that used the sum of landed and discarded catch. This change in the definition of [`catch`] had no effect when this series was used in the stock assessment model because the series was truncated at 1995. The resulting CPUE index series is presented in Figure B.36 and Table B.13.

The [`Year`] categorical variable was forced as the first variable in the model without regard to its effect on model deviance. However, in contrast with the equivalent short-term analysis, the [`Year`] categorical variable explained over 13% of the deviance, due to the strong contrast in the indices across the width of the series. The remaining variables were offered sequentially, with a stepwise acceptance of the remaining variables with the best AIC. This process was continued until improvement in the model R^2 was less than 1% This model selected 4 of the 5 remaining explanatory variables, including [`Depth band`], [`Hours fished`], [`DFO locality`] and [`Month`] as explanatory variables. The final lognormal model accounted for 61% of the total model deviance (Table B.14), with the year variable explaining more than 13% of model deviance.

Model residuals appeared to be consistent with the underlying lognormal distributional assumption, with some minor deviation near the peak of the distribution and at both tails (*Figure B.37*).

A stepwise plot of the year indices as each explanatory variable was introduced into the model shows considerable impact from the standardisation procedure in the early years of the series and a small overall increase in the series relative to the unstandardised series beginning in the early 1990s (Figure B.38).

CDI plots of the four explanatory variables introduced to the model in addition to [`Year`] show some trends (Figure B.39 to Figure B.42). The very high unstandardised catch rates at the beginning of the series (>9 in 1954) are brought down because these early records tended to fish in shallow waters where the catch rates of Rock Sole were inclined to be higher (Figure B.39). It is difficult to interpret the CDI plot for [`Hours fished`] because of the overlapping symbols in bubble plots (Figure B.40). However, this plot shows that amalgamation of the tow-by-tow data did not result in a distribution of fishing effort that was equivalent to pre-1991 records. This can be seen in the large white space after 1990 caused by the lack of records with greater than 24 hours of fishing, a region which was more fully populated by the earlier data (Figure B.40). As seen with the short-term tow-by-tow analysis, Butterworth [#250] and Two Peaks [#251] are dominant DFO localities in terms of number of records but each have low relative catch rates for Rock Sole (0.61 and 0.34 respectively; Figure B.41). There seems to be a long-term seasonal shift in this fishery, where tows that take Rock Sole are getting progressively later in more recent years (Figure B.42).

The plot of the year indices shows a long decline to the mid- to late-1990s, with a relatively small increase to the present (Figure B.36 and Table B.13). A binomial series was not attempted because these are amalgamated records from data containing implied zeros. It is unlikely that the amalgamation was based on the catch (or lack of catch) of Rock Sole. Consequently, analysis of Rock Sole presence/absence based on this amalgamation seems unwarranted.

5CD: Comparison with Survey Index

A comparison of the long-term lognormal series with the scaled biomass indices from the Hecate Strait assemblage survey (Sinclair 1999) shows a weak agreement between the two series, with the assemblage survey indices showing a gradually increasing trend which is not present in the years overlapping with the CPUE series (Figure B.43).

5CD: Comparison with short-term tow-by-tow analysis

A comparison of the long-term and short-term series shows good agreement between the two series (Figure B.44). This result is not surprising, considering the short-term and longterm series are based on the same data in the overlapping years. This comparison is really a test of the effect of amalgamating the tow-by-tow data, which appears to be minor in spite of the observation made for the [`Hours fished`] CDI plot (Figure B.40), which noted that the “roll-up” of tow-by-tow data did not reproduce the distribution of hours seen in pre-1991 data (see above).

Table B.1. Summary data for the Rock Sole fishery in 5AB by year for the core data set (after selection of core vessels and applying all data filters).

Year	Number vessels[1]	Number trips[1]	Number tows[1]	Number tows[2]	% zero tows[2]	Total catch (t)[1]	Total hours[1]	CPUE (kg/h) (Eq. C.1)
1996	27	84	460	1,550	70.3	130.6	1,096	119.2
1997	26	120	629	2,525	75.1	139.8	1,421	98.4
1998	25	144	770	2,788	72.4	209.1	2,008	104.1
1999	27	161	1,035	3,372	69.3	273.7	2,723	100.5
2000	29	204	1,306	3,432	61.9	372.3	3,346	111.3
2001	27	194	1,301	3,004	56.7	418.0	3,450	121.2
2002	28	264	1,999	4,099	51.2	742.7	5,337	139.2
2003	28	274	2,183	4,284	49.0	828.0	6,064	136.6
2004	27	216	1,609	3,659	56.0	608.3	4,263	142.7
2005	24	213	1,384	3,453	59.9	503.1	3,634	138.4
2006	24	192	1,204	3,087	61.0	382.7	3,277	116.8
2007	22	152	815	2,698	69.8	222.6	2,296	96.9
2008	19	91	347	1,640	78.8	76.9	843	91.2
2009	21	140	618	1,969	68.6	216.6	1,479	146.4
2010	18	137	774	2,018	61.6	525.3	1,966	267.2
2011	17	135	806	1,779	54.7	410.6	2,052	200.1
2012	16	97	592	1,201	50.7	303.8	1,465	207.3

[1] calculated for tows with Rock Sole catch >0
[2] calculated for all tows

Table B.2. Summary data for the Rock Sole fishery in 5CD by year for the core data set (after selection of core vessels and applying all data filters).

Year	Number vessels[1]	Number trips[1]	Number tows[1]	Number tows[2]	% zero tows[2]	Total catch (t)[1]	Total hours[1]	CPUE (kg/h) (Eq. C.1)
1996	19	108	617	1,544	60.0	287.1	1,450	198.0
1997	19	161	970	2,269	57.2	464.1	2,366	196.1
1998	19	179	1,333	3,125	57.3	577.8	3,401	169.9
1999	20	207	1,532	3,279	53.3	769.5	3,790	203.0
2000	20	216	1,689	3,356	49.7	860.9	4,081	210.9
2001	19	144	948	2,166	56.2	650.8	2,254	288.7
2002	19	168	1,197	2,598	53.9	692.1	2,547	271.7
2003	17	137	979	2,102	53.4	713.3	2,001	356.5
2004	16	134	935	2,219	57.9	836.9	2,000	418.5
2005	15	177	812	2,503	67.6	621.7	1,668	372.8
2006	14	140	802	1,845	56.5	683.8	1,698	402.7
2007	13	121	672	1,597	57.9	559.6	1,513	369.7
2008	13	108	604	1,540	60.8	517.0	1,412	366.1
2009	13	139	953	1,811	47.4	863.5	2,114	408.5
2010	11	116	776	1,590	51.2	558.2	1,637	340.9
2011	12	121	814	2,073	60.7	642.7	1,678	383.0
2012	11	125	825	1,970	58.1	513.0	1,724	297.7

[1] calculated for tows with Rock Sole catch >0
[2] calculated for all tows

Table B.3. Summary data for the Rock Sole fishery in 5AB long-term model by year for the data set after applying all data filters.

Year	Number vessels[1]	Number trips[1]	Number tows[1]	Number records[1]	Number records[2]	% zero records[2]	Total catch (t)[1]	Total hours[1]	CPUE (kg/h) (Eq. C.1)
1966	29	117	1,437	209	356	41.3	488.8	2,767	176.7
1967	27	118	1,315	214	341	37.2	373.1	2,478	150.6
1968	29	129	1,423	226	397	43.1	466.7	2,813	165.9
1969	31	131	1,285	210	409	48.7	300.9	2,902	103.7
1970	24	96	757	165	317	47.9	212.8	1,706	124.8
1971	19	72	747	132	246	46.3	242.2	1,801	134.4
1972	11	53	632	91	214	57.5	195.3	1,689	115.6
1973	18	47	395	70	162	56.8	83.1	1,083	76.7
1974	15	46	425	64	134	52.2	97.3	1,147	84.8
1975	21	74	617	120	262	54.2	153.6	1,576	97.5
1976	24	96	811	151	294	48.6	167.7	2,258	74.3
1977	24	76	794	139	314	55.7	150.0	2,231	67.2
1978	31	116	1,124	163	442	63.1	213.5	2,571	83.0
1979	30	95	1,033	152	451	66.3	218.2	2,445	89.3
1980	33	143	1,451	238	554	57.0	467.2	3,500	133.5
1981	26	89	786	148	396	62.6	190.0	1,893	100.4
1982	25	88	983	169	414	59.2	286.5	2,451	116.9
1983	23	79	809	133	347	61.7	183.3	1,927	95.1
1984	21	57	552	90	282	68.1	112.7	1,373	82.0
1985	17	48	501	61	232	73.7	103.9	1,207	86.1
1986	25	60	525	88	361	75.6	73.1	1,352	54.1
1987	33	125	1,005	161	598	73.1	174.2	2,513	69.3
1988	35	119	928	170	554	69.3	183.7	2,423	75.8
1989	34	111	777	143	568	74.8	180.4	2,155	83.7
1990	33	117	897	177	674	73.7	195.1	2,550	76.5
1991	37	153	1,162	381	1,331	71.4	314.7	3,362	93.6
1992	62	269	1,599	612	2,334	73.8	630.3	4,811	131.0
1993	69	338	1,793	726	2,829	74.3	735.5	5,597	131.4
1994	72	329	2,072	701	2,006	65.1	611.3	6,338	96.4
1995	78	374	1,860	717	2,477	71.1	445.2	5,537	80.4
1996	78	237	1,635	664	2,308	71.2	322.0	3,903	82.5
1997	55	194	1,271	593	2,395	75.2	233.8	2,872	81.4
1998	42	193	1,326	582	2,114	72.5	250.4	3,245	77.2
1999	40	186	1,441	560	2,143	73.9	265.0	3,595	73.7
2000	42	225	1,690	708	2,052	65.5	350.6	4,205	83.4
2001	40	225	1,578	672	1,852	63.7	394.8	4,111	96.0
2002	39	295	2,357	937	2,258	58.5	658.9	6,294	104.7
2003	35	297	2,427	1,032	2,318	55.5	725.3	6,742	107.6
2004	34	237	1,980	887	2,108	57.9	549.4	5,159	106.5
2005	29	229	1,744	703	1,887	62.7	444.5	4,410	100.8
2006	30	209	1,574	655	1,670	60.8	364.1	4,241	85.9
2007	27	159	1,074	457	1,489	69.3	198.0	3,016	65.6
2008	22	95	511	203	877	76.9	71.4	1,234	57.8
2009	25	151	775	351	1,119	68.6	191.7	1,854	103.4
2010	22	146	926	412	1,176	65.0	480.8	2,301	209.0
2011	20	141	1,008	384	925	58.5	414.7	2,498	166.0
2012	21	105	758	310	690	55.1	315.6	1,846	171.0

[1] calculated for tows with Rock Sole catch >0
[2] calculated for all tows

Table B.4. *Summary data for the Rock Sole fishery in 5CD long-term analysis by year for the data set after applying all data filters.*

Year	Number vessels[1]	Number trips[1]	Number tows[1]	Number records[1]	Number records[2]	% zero records[2]	Total catch (t)[1]	Total hours[1]	CPUE (kg/h) (Eq. C.1)
1954	14	57	919	62	178	65.2	791.0	956	827.4
1955	21	120	1,800	143	304	53.0	1,177.4	1,877	627.3
1956	20	76	1,236	104	319	67.4	949.9	1,646	577.3
1957	21	88	1,292	134	308	56.5	843.2	1,914	440.5
1958	22	105	1,480	136	356	61.8	1,041.8	1,785	583.6
1959	19	67	830	77	308	75.0	314.6	1,129	278.6
1960	24	116	1,617	150	400	62.5	879.1	1,970	446.3
1961	19	74	847	92	335	72.5	703.0	1,024	686.6
1962	21	86	1,109	110	340	67.6	689.7	1,467	470.1
1963	17	75	1,145	96	262	63.4	633.5	1,537	412.2
1964	20	133	1,702	168	388	56.7	745.6	2,463	302.7
1965	27	152	2,066	197	483	59.2	792.9	3,276	242.0
1966	41	271	3,453	365	665	45.1	2,450.5	5,609	436.9
1967	45	209	2,573	301	588	48.8	1,856.1	3,957	469.1
1968	35	246	3,559	408	760	46.3	1,938.6	6,049	320.5
1969	34	239	3,475	400	702	43.0	1,914.4	5,829	328.4
1970	28	150	2,482	310	630	50.8	974.8	3,967	245.7
1971	23	174	2,864	338	633	46.6	986.0	4,860	202.9
1972	13	112	1,761	201	402	50.0	366.3	2,828	129.5
1973	19	101	1,298	163	429	62.0	354.5	2,210	160.4
1974	19	108	1,300	200	373	46.4	477.4	2,243	212.8
1975	27	158	2,604	296	558	47.0	931.7	4,031	231.1
1976	32	187	2,682	327	597	45.2	942.8	4,218	223.5
1977	24	186	2,490	292	677	56.9	670.3	4,378	153.1
1978	26	187	2,248	319	673	52.6	840.7	4,319	194.7
1979	36	299	3,284	459	971	52.7	1,070.7	5,870	182.4
1980	36	302	2,836	440	1,029	57.2	684.0	5,406	126.5
1981	22	203	2,333	315	661	52.3	463.9	4,303	107.8
1982	16	136	1,429	184	453	59.4	240.4	2,961	81.2
1983	23	148	1,556	215	472	54.4	220.9	2,738	80.7
1984	20	167	1,860	220	486	54.7	172.4	3,250	53.0
1985	21	128	1,304	148	382	61.3	105.8	2,281	46.4
1986	22	138	1,337	174	393	55.7	221.5	2,130	104.0
1987	31	254	2,212	290	667	56.5	451.2	4,035	111.8
1988	39	306	2,392	382	748	48.9	1,128.3	4,961	227.4
1989	32	303	2,955	446	831	46.3	1,276.5	5,933	215.2
1990	36	307	2,495	449	1,026	56.2	1,104.4	4,900	225.4
1991	40	433	4,153	989	1,854	46.7	1,918.7	8,848	216.8
1992	50	516	4,520	1,247	2,630	52.6	2,033.2	9,334	217.8
1993	67	624	3,898	1,337	3,666	63.5	1,971.6	9,073	217.3
1994	56	460	2,873	1,019	2,489	59.1	1,373.1	6,898	199.0
1995	49	393	2,723	920	2,343	60.7	1,285.9	6,222	206.7
1996	68	252	2,010	812	1,751	53.6	787.7	4,294	183.4
1997	49	250	1,948	918	1,806	49.2	767.2	4,590	167.1
1998	31	208	2,016	835	1,659	49.7	658.9	4,790	137.6
1999	29	237	2,142	917	1,728	46.9	816.5	5,032	162.3
2000	27	230	2,253	996	1,708	41.7	891.9	5,072	175.9
2001	27	159	1,204	482	1,071	55.0	662.0	2,752	240.5

Year	Number vessels[1]	Number trips[1]	Number tows[1]	Number records[1]	Number records[2]	% zero records[2]	Total catch (t)[1]	Total hours[1]	CPUE (kg/h) (Eq. C.1)
2002	23	179	1,611	644	1,265	49.1	727.7	3,264	223.0
2003	23	150	1,266	524	995	47.3	752.3	2,454	306.6
2004	21	141	1,233	452	1,010	55.2	895.9	2,533	353.7
2005	19	188	1,298	471	1,116	57.8	644.3	2,368	272.1
2006	18	145	1,045	459	938	51.1	716.2	2,094	342.0
2007	18	134	942	376	828	54.6	606.4	1,988	305.0
2008	14	109	731	316	757	58.3	517.1	1,625	318.2
2009	17	146	1,203	514	899	42.8	879.0	2,587	339.8
2010	12	118	981	382	751	49.1	569.9	2,021	282.0
2011	12	121	1,040	426	900	52.7	642.7	2,022	317.9
2012	12	128	1,131	462	920	49.8	534.5	2,233	239.4

[1] calculated for tows with Rock Sole catch >0
[2] calculated for all tows

Table B.5. Relative indices of annual CPUE from the arithmetic, unstandardised, lognormal, binomial, and combined models of non-zero catches of Rock Sole in 5AB. All indices are scaled so that their geometric means equal 1.0. Upper and lower 95% confidence bounds and associated standard error (SE) are presented for the lognormal model, while bootstrapped upper and lower 95% confidence bounds are presented for the combined model.

Year	Arithmetic Index	Unstandardised Index	Lognormal				Binomial Index	Combined		
			Index	Lower bound	Upper bound	SE		Index	Lower bound	Upper bound
1996	0.416	0.789	1.159	1.032	1.302	0.059	0.813	1.009	0.839	1.180
1997	0.445	0.628	0.887	0.804	0.979	0.050	1.105	0.962	0.841	1.105
1998	0.665	0.763	0.757	0.693	0.828	0.045	0.904	0.713	0.628	0.796
1999	0.871	0.793	0.697	0.645	0.753	0.039	0.701	0.542	0.482	0.599
2000	1.185	0.784	0.696	0.650	0.746	0.035	0.970	0.689	0.620	0.771
2001	1.330	1.150	0.888	0.829	0.952	0.035	1.248	1.044	0.947	1.164
2002	2.363	1.305	0.968	0.914	1.025	0.029	1.110	1.053	0.963	1.149
2003	2.635	1.296	1.103	1.044	1.166	0.028	1.677	1.559	1.426	1.683
2004	1.935	1.314	1.196	1.123	1.273	0.032	1.261	1.415	1.290	1.541
2005	1.601	1.163	1.170	1.093	1.251	0.034	1.091	1.257	1.143	1.383
2006	1.218	0.981	0.954	0.887	1.025	0.037	0.919	0.908	0.813	1.016
2007	0.708	0.702	0.642	0.589	0.699	0.044	0.547	0.411	0.356	0.475
2008	0.245	0.502	0.687	0.605	0.781	0.065	0.478	0.393	0.323	0.482
2009	0.689	1.029	1.230	1.116	1.355	0.049	0.858	1.114	0.946	1.266
2010	1.671	1.950	2.079	1.903	2.271	0.045	1.234	2.425	2.146	2.749
2011	1.307	1.612	1.600	1.467	1.745	0.044	1.407	2.031	1.767	2.318
2012	0.967	1.280	1.158	1.048	1.280	0.051	1.579	1.578	1.372	1.829

*Table B.6. Order of acceptance of variables into the lognormal model of positive total mortalities (verified landings plus discards) of Rock Sole by core vessels in 5AB (based on the vessel selection criteria of at least three trips in six or more years) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Variable	1	2	3	4	5	6
Year*	**0.0318**	-	-	-	-	-
Depth bands*	0.2883	**0.3189**	-	-	-	-
Hours fished*	0.0938	0.1222	**0.3780**	-	-	-
0.1° Latitude bands*	0.1503	0.1752	0.3548	**0.4033**	-	-
Vessel*	0.0561	0.0846	0.3614	0.4022	**0.4243**	-
Month	0.0180	0.0476	0.3254	0.3831	0.4077	0.4283
DFO locality	0.0692	0.0964	0.3475	0.3957	0.4040	0.4249
Major PMFC area	0.0056	0.0360	0.3393	0.3887	0.4034	0.4243
Improvement in deviance	0.0000	0.2871	0.0591	0.0252	0.0210	0.0040

Table B.7. Relative indices of annual CPUE from the arithmetic, unstandardised and lognormal models of non-zero catches of Rock Sole in the 5AB long-term analysis. All indices are scaled so that their geometric means equal 1.0. Upper and lower 95% confidence bounds and associated standard error (SE) are presented for the lognormal model.

Year	Arithmetic Index	Unstandardised Index	Lognormal			
			Index	Lower bound	Upper bound	SE
1966	1.878	3.184	2.031	1.711	2.410	0.087
1967	1.434	2.208	1.606	1.355	1.903	0.087
1968	1.793	2.658	1.629	1.381	1.922	0.084
1969	1.156	1.939	1.097	0.924	1.302	0.087
1970	0.818	1.558	1.085	0.895	1.316	0.098
1971	0.930	1.830	1.058	0.854	1.311	0.109
1972	0.750	2.973	1.882	1.454	2.436	0.132
1973	0.319	1.360	1.125	0.839	1.508	0.150
1974	0.374	2.030	1.729	1.272	2.351	0.157
1975	0.590	1.367	1.221	0.975	1.528	0.115
1976	0.644	1.319	1.173	0.960	1.434	0.102
1977	0.576	1.450	1.211	0.982	1.492	0.107
1978	0.820	1.271	1.215	1.001	1.475	0.099
1979	0.838	1.359	1.280	1.048	1.564	0.102
1980	1.795	1.678	1.216	1.036	1.429	0.082
1981	0.730	1.370	1.286	1.050	1.575	0.103
1982	1.101	1.883	1.538	1.272	1.860	0.097
1983	0.704	1.856	1.687	1.363	2.089	0.109
1984	0.433	1.343	1.189	0.918	1.541	0.132
1985	0.399	1.575	0.849	0.620	1.163	0.160
1986	0.281	0.971	0.921	0.709	1.196	0.134
1987	0.669	1.212	1.171	0.964	1.423	0.099
1988	0.706	1.264	1.405	1.162	1.698	0.097
1989	0.693	1.529	1.260	1.026	1.549	0.105
1990	0.750	1.087	1.022	0.849	1.231	0.095
1991	1.209	0.747	1.059	0.932	1.204	0.065
1992	2.422	0.936	1.456	1.314	1.614	0.052
1993	2.826	1.159	1.383	1.258	1.521	0.048
1994	2.349	0.945	0.980	0.890	1.079	0.049
1995	1.711	0.524	0.648	0.589	0.713	0.049

Year	Arithmetic Index	Unstandardised Index	Lognormal			
			Index	Lower bound	Upper bound	SE
1996	1.237	0.299	0.484	0.439	0.535	0.051
1997	0.898	0.270	0.501	0.451	0.557	0.054
1998	0.962	0.347	0.543	0.489	0.603	0.054
1999	1.018	0.378	0.434	0.390	0.484	0.055
2000	1.347	0.378	0.491	0.446	0.541	0.049
2001	1.517	0.572	0.608	0.551	0.672	0.051
2002	2.532	0.719	0.693	0.636	0.755	0.044
2003	2.787	0.802	0.823	0.758	0.893	0.042
2004	2.111	0.691	0.797	0.730	0.870	0.045
2005	1.708	0.628	0.732	0.664	0.807	0.050
2006	1.399	0.592	0.719	0.651	0.794	0.051
2007	0.761	0.357	0.442	0.393	0.497	0.060
2008	0.274	0.234	0.426	0.358	0.507	0.089
2009	0.737	0.560	0.856	0.749	0.979	0.069
2010	1.847	1.083	1.588	1.403	1.799	0.063
2011	1.593	1.000	1.304	1.146	1.483	0.066
2012	1.213	0.899	1.022	0.886	1.178	0.073

*Table B.8. Order of acceptance of variables into the 5AB lognormal model of positive total mortalities (verified landings plus discards) of Rock Sole in the 5AB long-term analysis with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Variable	1	2	3	4	5
Year*	**0.0994**	-	-	-	-
Depth bands*	0.2018	**0.3107**	-	-	-
Hours fished*	0.2300	0.2759	**0.5070**	-	-
DFO locality*	0.0449	0.1576	0.3647	**0.5363**	-
Month	0.0201	0.1201	0.3249	0.5127	0.5393
Major PMFC area	0.0127	0.1184	0.3500	0.5290	0.5364
Improvement in deviance	0.0000	0.2113	0.1963	0.0293	0.0030

Table B.9. DFO localities with associated estimated standardised index of 5AB relative catch rate (see upper left graph, Figure B.41). Remaining localities were put into a "plus" group (not reported here) because there were too few positive records to reliably estimate the relative catch rate. The mean Rock Sole catch rate of this series, including the "Plus" group, is 1.0

Major Area	Minor Area	Minor Area Name	Locality Code	Locality Name	Index
5A	11	Cape Scott-Triangle	177	Unknown	1.164
			178	Triangle	0.613
			179	Cape Scott Spit	0.849
			180	Mexicana	0.775
			181	Topknot	0.527
5B	8	Goose Island Bank	192	NE Goose	1.407
			193	SE Goose	1.387
			194	NW Goose	1.397
			195	SW Goose	1.646

Table B.10. Relative indices of annual CPUE from the arithmetic, unstandardised, lognormal, binomial, and combined models of non-zero catches of Rock Sole in 5CD. All indices are scaled so that their geometric means equal 1.0. Upper and lower 95% confidence bounds and associated standard error (SE) are presented for the lognormal model, while bootstrapped upper and lower 95% confidence bounds are presented for the combined model.

Year	Arithmetic Index	Unstandardised Index	Lognormal				Binomial Index	Combined		
			Index	Lower bound	Upper bound	SE		Index	Lower bound	Upper bound
1996	0.466	0.895	0.880	0.797	0.973	0.051	0.850	0.798	0.683	0.920
1997	0.753	0.933	0.887	0.816	0.965	0.043	0.925	0.849	0.760	0.944
1998	0.937	0.841	0.713	0.663	0.766	0.037	0.797	0.620	0.561	0.686
1999	1.248	0.950	0.710	0.664	0.758	0.034	0.929	0.681	0.622	0.747
2000	1.397	1.056	0.818	0.769	0.869	0.031	1.294	0.950	0.872	1.033
2001	1.056	1.123	0.893	0.825	0.966	0.040	1.182	0.987	0.878	1.079
2002	1.123	0.868	0.788	0.734	0.845	0.036	1.065	0.820	0.742	0.894
2003	1.157	1.073	0.944	0.874	1.020	0.039	0.910	0.894	0.809	0.986
2004	1.358	1.227	1.417	1.309	1.535	0.040	1.193	1.575	1.437	1.739
2005	1.008	0.817	1.549	1.423	1.686	0.043	1.365	1.851	1.668	2.046
2006	1.109	1.485	1.338	1.229	1.455	0.043	0.869	1.230	1.082	1.380
2007	0.908	1.041	1.107	1.011	1.213	0.047	0.897	1.039	0.918	1.153
2008	0.839	1.186	1.020	0.926	1.123	0.049	0.927	0.977	0.846	1.103
2009	1.401	1.269	1.450	1.341	1.567	0.040	1.303	1.691	1.531	1.867
2010	0.905	0.877	0.983	0.902	1.072	0.044	0.928	0.943	0.838	1.045
2011	1.043	0.931	1.146	1.053	1.248	0.043	0.832	1.025	0.891	1.139
2012	0.832	0.714	0.861	0.791	0.937	0.043	0.981	0.854	0.758	0.951

*Table B.11. Order of acceptance of variables into the lognormal model of positive total mortalities (verified landings plus discards) of Rock Sole by core vessels in 5CD (based on the vessel selection criteria of at least four trips in three or more years) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Variable	1	2	3	4	5	6	7
Year*	**0.0064**	-	-	-	-	-	-
DFO locality*	0.4269	**0.4426**	-	-	-	-	-
Depth bands*	0.3817	0.3903	**0.5875**	-	-	-	-
Hours fished*	0.2199	0.2328	0.5147	**0.6302**	-	-	-
Month*	0.1363	0.1457	0.4732	0.6105	**0.6593**	-	-
Vessel*	0.0251	0.0321	0.4572	0.5994	0.6417	**0.6706**	-
0.1° Latitude bands	0.4140	0.4304	0.4758	0.5970	0.6386	0.6655	0.6772
Major PMFC area	0.1325	0.1387	0.4455	0.5876	0.6302	0.6593	0.6706
Improvement in deviance	0.0000	0.4362	0.1448	0.0427	0.0291	0.0113	0.0066

Table B.12. DFO localities with associated estimated standardised index of relative catch rate (see upper left graph, Figure B.28). Remaining localities were put into a “plus” group (not reported here) because there were too few positive records to reliably estimate the relative catch rate. The mean Rock Sole catch rate of this series, including the “Plus” group, is 1.0

Major Area	Minor Area	Minor Area Name	Locality Code	Locality Name	Index
5C	2	2B-East	209	West Horseshoe	2.063
			210	Ole Spot	1.755
			214	Cumshewa/Reef Is. Flats	0.903
	6	5-Lower-SE Hecate Strait	219	Unknown	2.277
			220	North Moresby	0.744
			221	South Bonilla	0.537
			229	East Horseshoe	2.491
5D	1	2A-East- Skidegate	236	Unknown	1.488
			241	West Two Peaks	0.309
	3	1 East-Dixon Entrance	243	McIntyre Bay	0.529
			244	West Masset	0.664
	4	4-Two Peaks-Dundas Is.	250	Butterworth	0.413
			251	Two Peaks	0.251
			252	Oval Hill	1.944
	5	White Rocks	263	White Rocks	1.108
			265	Shell Ground	1.972
			266	Venus	2.137

Table B.13. Relative indices of annual CPUE from the arithmetic, unstandardised and lognormal models of non-zero catches of Rock Sole in the 5CD long-term analysis. All indices are scaled so that their geometric means equal 1.0. Upper and lower 95% confidence bounds and associated standard error (SE) are presented for the lognormal model.

Year	Arithmetic Index	Unstandardised Index	Lognormal			
			Index	Lower bound	Upper bound	SE
1954	1.060	9.279	2.691	1.919	3.774	0.173
1955	1.577	6.513	3.082	2.462	3.860	0.115
1956	1.272	7.539	1.954	1.504	2.538	0.134
1957	1.129	4.843	1.415	1.123	1.782	0.118
1958	1.396	3.972	2.220	1.765	2.791	0.117
1959	0.421	1.872	1.487	1.098	2.013	0.155
1960	1.178	1.905	1.850	1.488	2.301	0.111
1961	0.942	3.906	3.908	2.963	5.154	0.141
1962	0.924	2.590	2.437	1.892	3.140	0.129
1963	0.849	2.109	1.553	1.184	2.037	0.138
1964	0.999	2.718	1.567	1.276	1.925	0.105
1965	1.062	2.018	1.134	0.937	1.373	0.097
1966	3.282	3.504	1.698	1.474	1.957	0.072
1967	2.486	3.489	1.927	1.651	2.251	0.079
1968	2.597	3.063	1.618	1.416	1.849	0.068
1969	2.564	2.147	1.282	1.120	1.468	0.069
1970	1.306	1.248	0.978	0.840	1.138	0.078
1971	1.321	1.401	1.014	0.876	1.173	0.074
1972	0.491	0.977	0.903	0.748	1.090	0.096
1973	0.475	1.388	1.281	1.040	1.579	0.107
1974	0.640	1.415	1.512	1.252	1.826	0.096
1975	1.248	2.045	1.473	1.261	1.722	0.079
1976	1.263	1.596	1.241	1.069	1.439	0.076
1977	0.898	1.354	1.148	0.981	1.343	0.080
1978	1.126	1.294	1.099	0.945	1.276	0.077
1979	1.434	0.953	1.036	0.914	1.175	0.064
1980	0.916	0.915	0.990	0.871	1.125	0.066
1981	0.621	0.797	0.964	0.829	1.122	0.077
1982	0.322	0.611	0.592	0.486	0.721	0.101
1983	0.296	0.640	1.045	0.871	1.255	0.093
1984	0.231	0.468	0.823	0.687	0.986	0.092
1985	0.142	0.366	0.525	0.421	0.653	0.112
1986	0.297	0.384	0.696	0.569	0.852	0.103
1987	0.604	0.597	0.718	0.613	0.841	0.080
1988	1.511	1.218	1.017	0.886	1.168	0.070
1989	1.710	1.385	1.004	0.883	1.141	0.065
1990	1.479	1.231	1.009	0.887	1.148	0.066
1991	2.570	1.017	1.074	0.982	1.173	0.045
1992	2.724	0.705	0.856	0.790	0.927	0.041
1993	2.641	0.917	0.965	0.893	1.042	0.039
1994	1.839	0.673	0.803	0.736	0.877	0.045
1995	1.722	0.504	0.608	0.555	0.666	0.047
1996	1.055	0.308	0.461	0.418	0.508	0.050
1997	1.028	0.309	0.612	0.558	0.671	0.047
1998	0.883	0.275	0.411	0.374	0.453	0.049
1999	1.094	0.330	0.456	0.416	0.500	0.047
2000	1.195	0.328	0.559	0.511	0.610	0.045
2001	0.887	0.372	0.581	0.513	0.657	0.063

Year	Arithmetic Index	Unstandardised Index	Lognormal			
			Index	Lower bound	Upper bound	SE
2002	0.975	0.294	0.448	0.402	0.499	0.055
2003	1.008	0.341	0.532	0.472	0.600	0.061
2004	1.200	0.408	0.786	0.692	0.893	0.065
2005	0.863	0.290	0.823	0.726	0.934	0.064
2006	0.959	0.546	0.850	0.748	0.966	0.065
2007	0.812	0.340	0.601	0.523	0.691	0.071
2008	0.693	0.510	0.704	0.605	0.820	0.077
2009	1.178	0.524	0.906	0.803	1.022	0.061
2010	0.763	0.450	0.620	0.540	0.713	0.071
2011	0.861	0.461	0.682	0.598	0.778	0.067
2012	0.716	0.280	0.464	0.409	0.527	0.065

*Table B.14. Order of acceptance of variables into the lognormal model of positive total mortalities (verified landings plus discards) of Rock Sole in the 5CD long-term analysis with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Variable	1	2	3	4	5	6
Year*	**0.1381**	-	-	-	-	-
Depth bands*	0.2467	**0.3617**	-	-	-	-
Hours fished*	0.2132	0.2714	**0.5053**	-	-	-
DFO locality*	0.1611	0.2961	0.4206	**0.5625**	-	-
Month*	0.0625	0.2006	0.4053	0.5531	**0.6101**	-
Major PMFC area	0.0223	0.1620	0.3856	0.5275	0.5630	0.6102
Improvement in deviance	0.0000	0.2236	0.1436	0.0572	0.0476	0.0002

Table B.15. DFO localities with associated estimated standardised index of relative catch rate (see upper left graph, Figure B.41). Remaining localities were put into a "plus" group (not reported here) because there were too few positive records to reliably estimate the relative catch rate. The mean Rock Sole catch rate of this series, including the "Plus" group, is 1.0.

Major Area	Minor Area	Minor Area Name	Locality Code	Locality Name	Index
5C	2	2B-East	209	West Horseshoe	1.3554
			210	Ole Spot	1.4003
			211	Reef Island	1.7091
			214	Cumshewa/Reef Island Flats	1.1529
	6	5-Lower-SE Hecate Strait	220	North Moresby	0.8176
			221	South Bonilla	1.0186
			229	East Horseshoe	2.1185
5D	1	2A-East- Skidegate	236	Unknown	2.0005
			241	West Two Peaks	0.3121
	3	1 East-Dixon Entrance	243	McIntyre Bay	0.7086
			244	West Masset	1.0208
	4	4-Two Peaks-Dundas Is.	250	Butterworth	0.6148
			251	Two Peaks	0.3353
			252	Oval Hill	1.4814
			253	Fingers	0.8546
			254	Dundas	0.5758
	5	White Rocks	262	Unknown	1.1001
			263	White Rocks	0.7824
			264	Bonilla	0.7825
			265	Shell Ground	1.7795
			266	Venus	1.7407

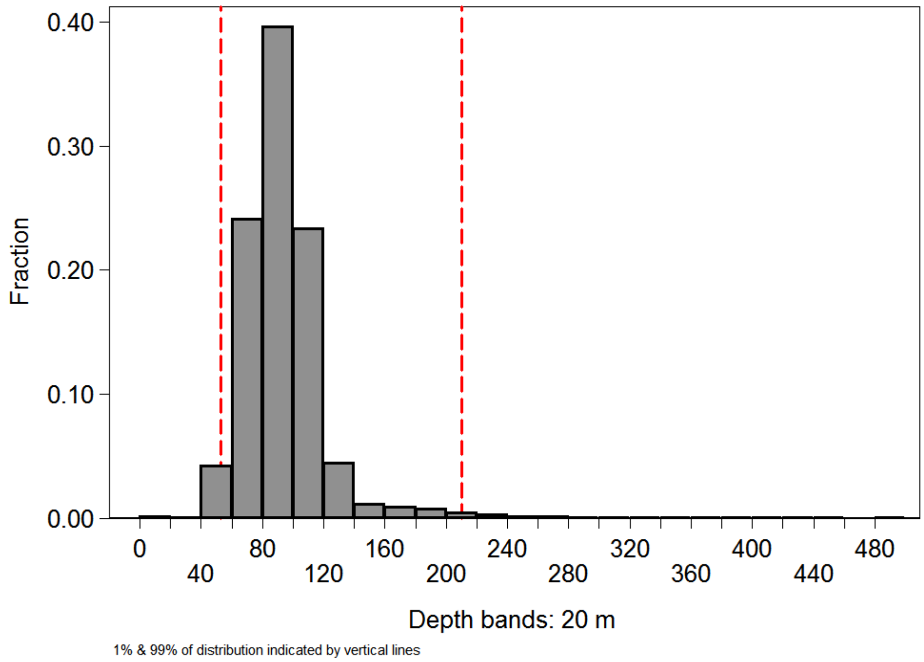


Figure B.1. Depth distribution of Rock Sole for tows with landed plus discarded catch in Areas 5AB from 1996 to 2012 in 20 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines indicate the following quantiles: 1%=53 m; 99%=210 m. Mean depth=94 m; median depth=91 m.

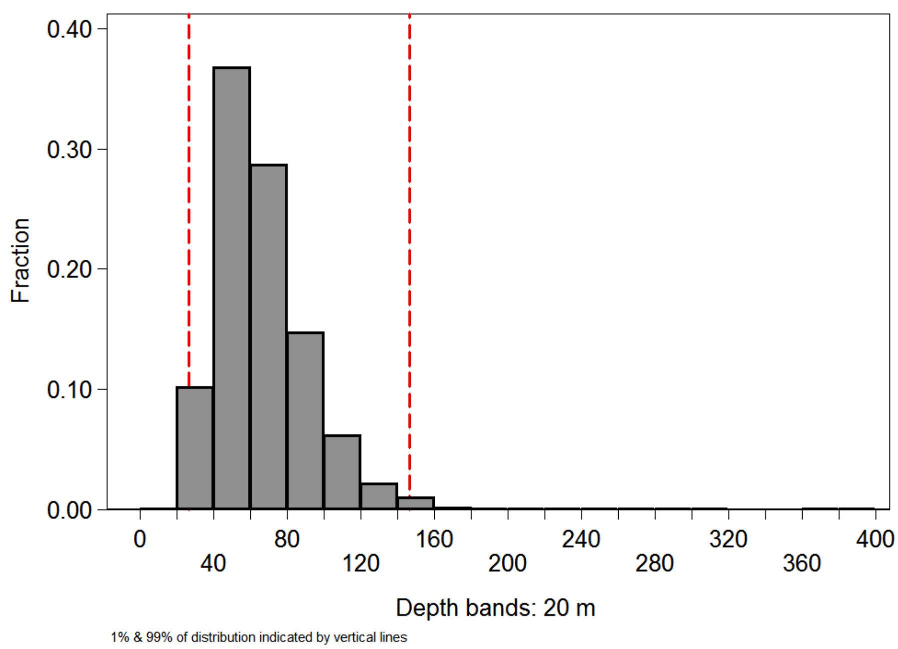


Figure B.2. Depth distribution of Rock Sole for tows with landed plus discarded catch in Areas 5CD from 1996 to 2012 in 20 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines indicate the following quantiles: 1%=27 m; 99%=146 m. Mean depth=67 m; median depth=62 m.

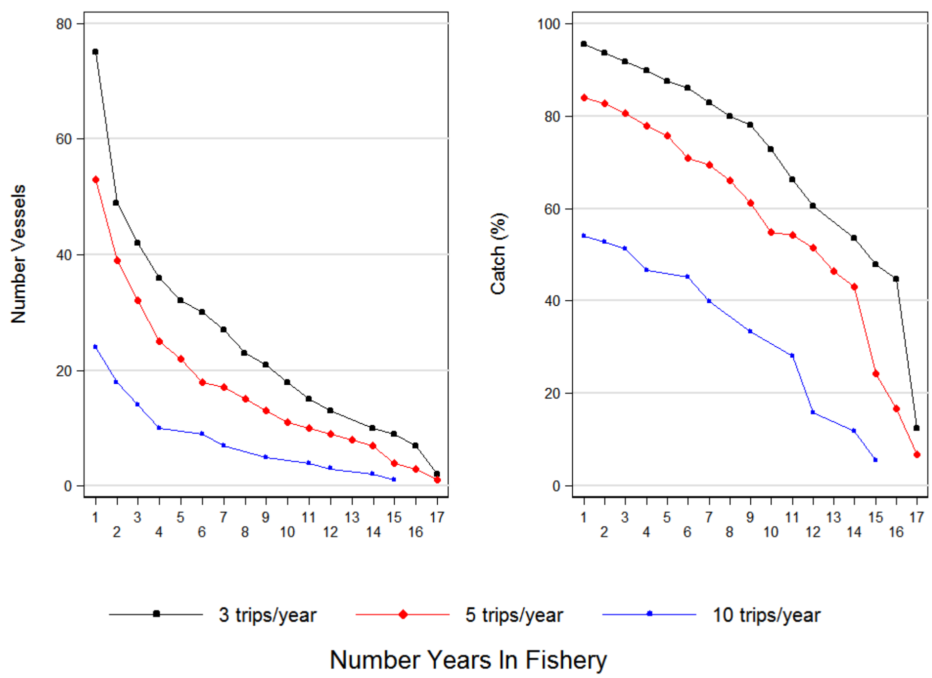


Figure B.3. Plots showing the relationship of number of trawl vessels [left panel] or percentage of total Rock Sole catch [right panel] with the number of trips per year and the number of years in the Areas 5AB fishery from 1996 to 2012. Each plotted point relates the number of years that vessels participated in the fishery while recording at least the indicated minimum number of trips per year.

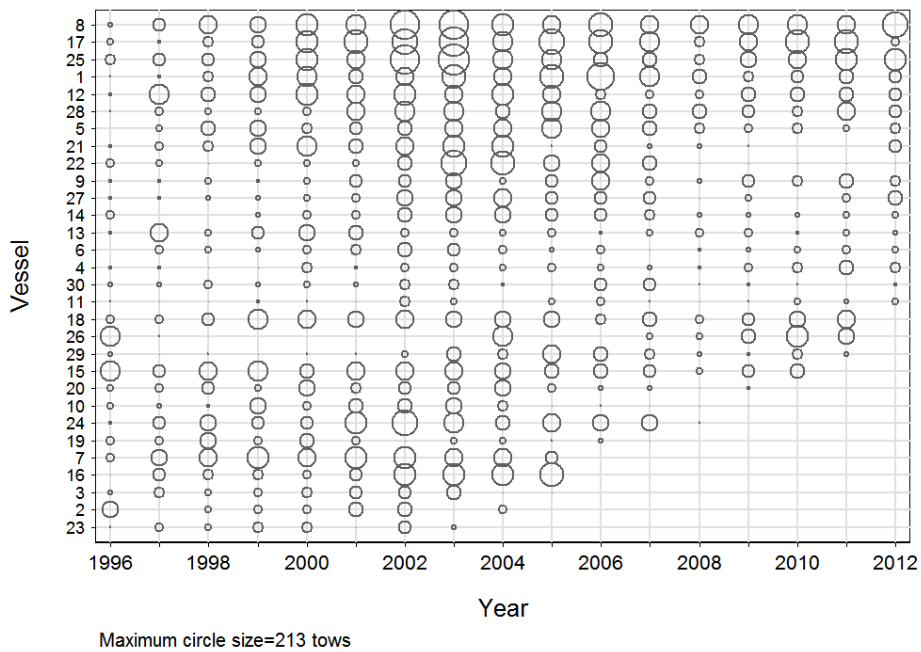


Figure B.4. Bubble plot showing vessel participation (number tows) by the 5AB core fleet in each year.

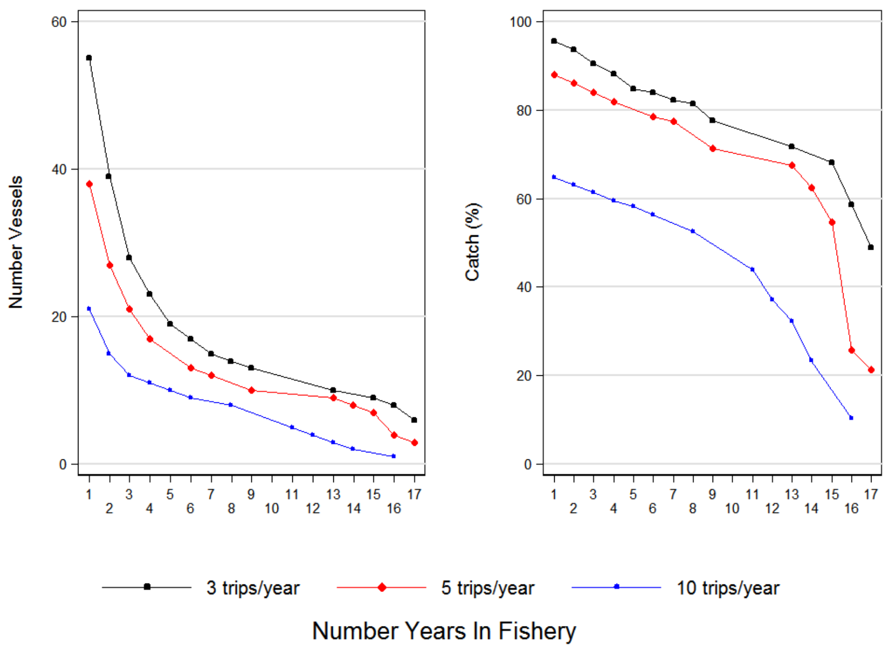


Figure B.5. Plots showing the relationship of number of trawl vessels [left panel] or percentage of total Rock Sole catch [right panel] with the number of trips per year and the number of years in the Areas 5CD fishery from 1996 to 2012. Each plotted point relates the number of years that vessels participated in the fishery while recording at least the indicated minimum number of trips per year.

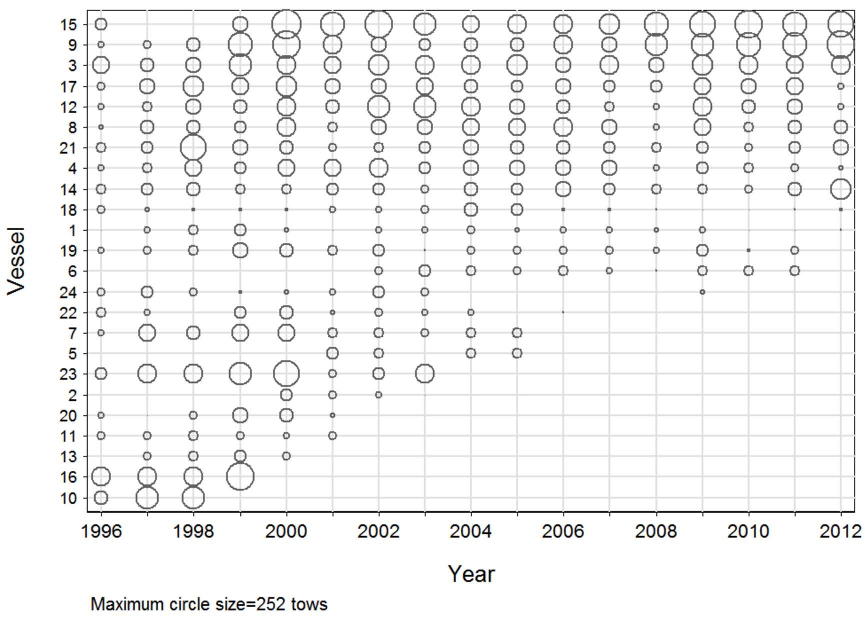


Figure B.6. Bubble plot showing vessel participation (number tows) by the 5CD core fleet in each year.

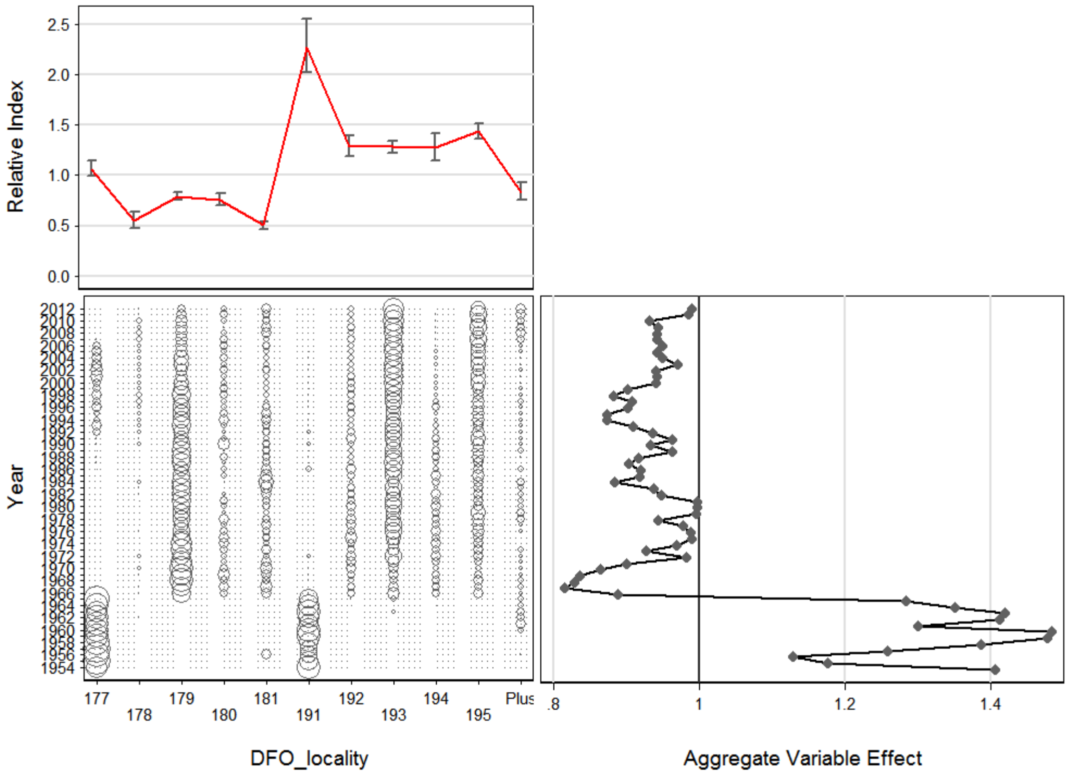


Figure B.7. CDI plot showing the effect of introducing the categorical variable [`DFO locality`] to the lognormal regression model in a 5AB long-term model starting in 1954 (not reported). Note that the left lower sub-graph which shows the annual relative distribution of [`DFO locality`] codes indicates a shift away from code 177 [5A-Unknown] and 191 [5B-Unknown] between 1965 and 1966, with the latter code never reappearing in the data set and the 177 code used sparingly between 1992 and 2006.

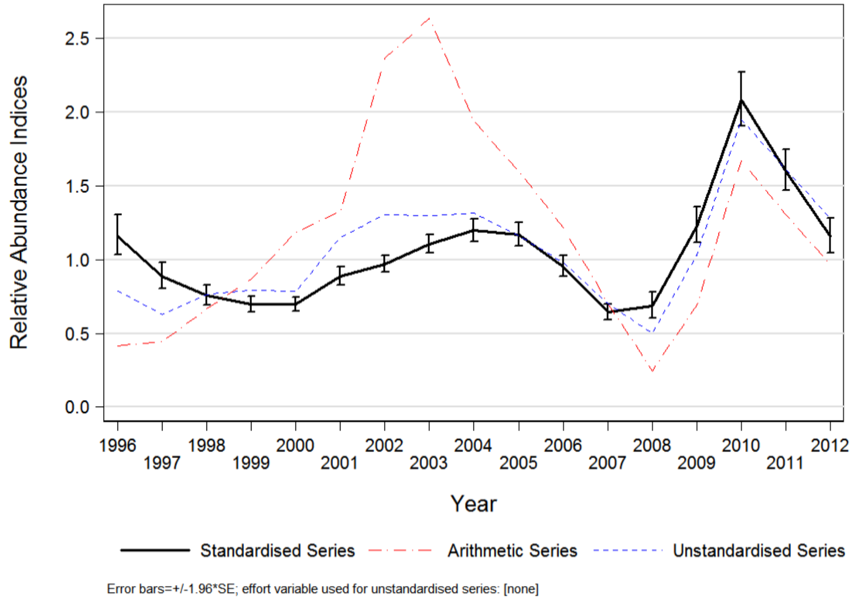


Figure B.8. Three CPUE series from 1996 to 2012 in 5AB. The solid line is the standardised CPUE series from the lognormal model (Equation B.3). The arithmetic series (Equation B.1) and the unstandardised series (Equation B.2) are also presented. All series have a geometric mean equal to 1.0.

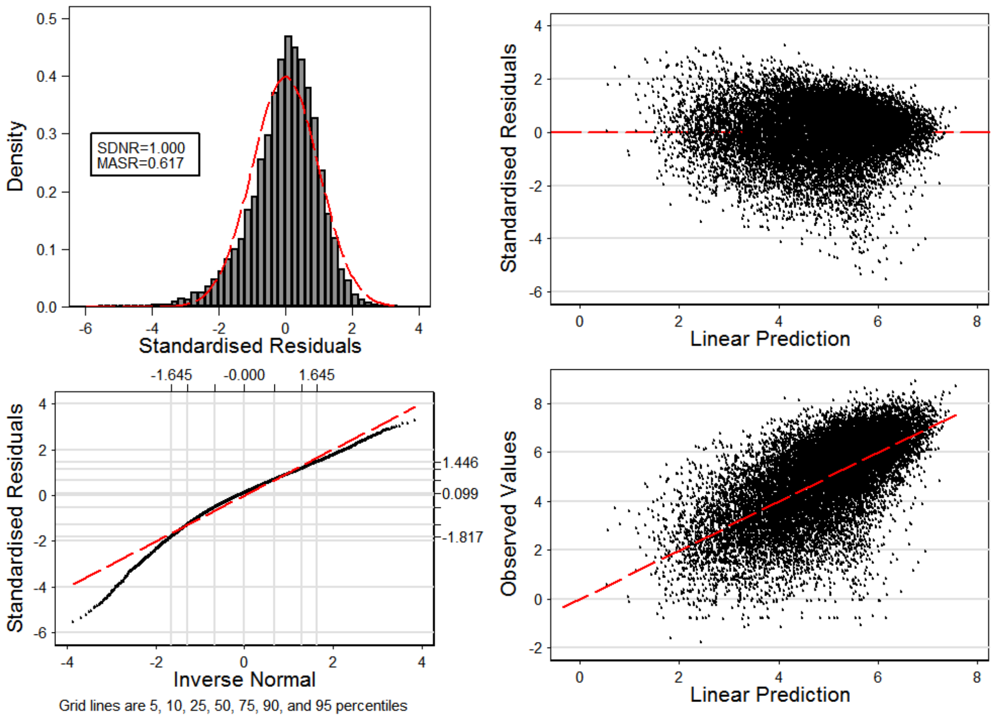


Figure B.9. Residual diagnostic plots for the GLM lognormal analysis for Rock Sole in 5AB. Upper left: histogram of the standardised residuals with overlaid lognormal distribution (SDNR = standard deviation of normalised residuals. MASR = median of absolute standardised residuals). Lower left: Q-Q plot of the standardised residuals with the outside horizontal and vertical lines representing the 5th and 95th percentiles of the theoretical and observed distributions. Upper right: standardised residuals plotted against the predicted CPUE. Lower right: observed CPUE plotted against the predicted CPUE.

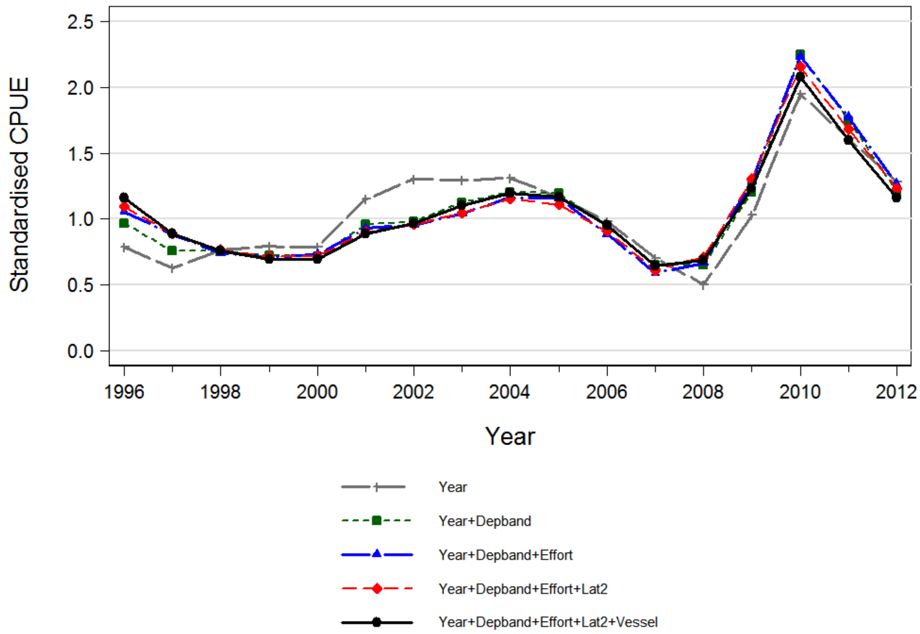


Figure B.10. Plot showing the year coefficients after adding each successive term of the standardised lognormal regression analysis for Rock Sole in 5AB. The final model is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

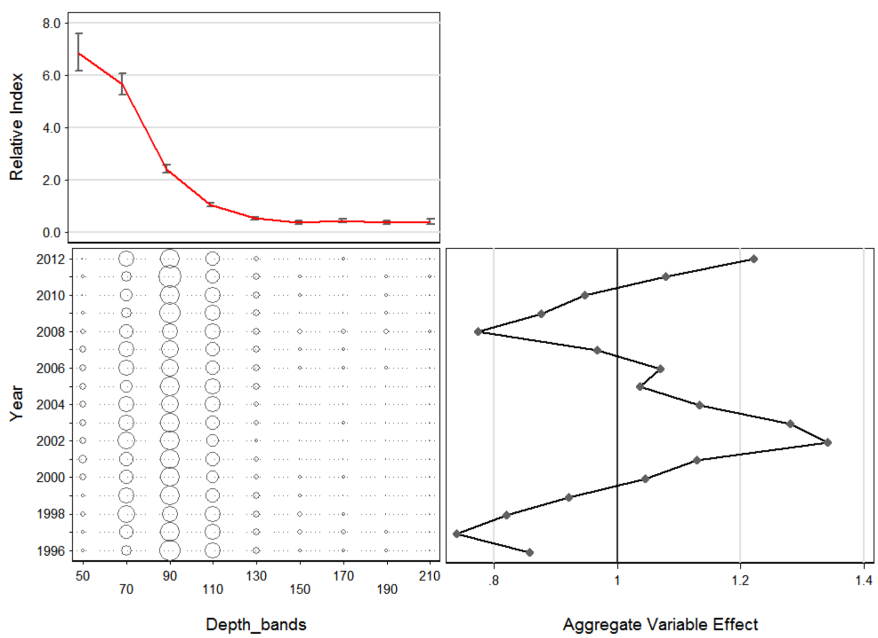


Figure B.11. CDI plot showing the effect of introducing the categorical variable [`depth band`] to the lognormal regression model for Rock Sole in 5AB. Each plot consists of subplots showing the effect by level of variable (top left), the relative distribution by year of variable records (bottom left), and the cumulative effect of variable by year (bottom right).

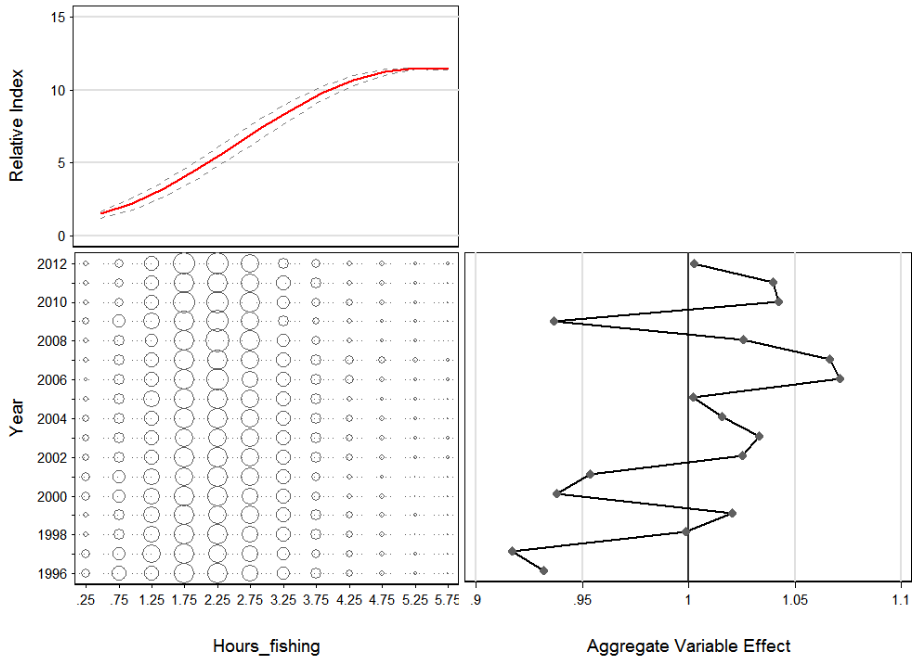


Figure B. 12. CDI plot showing the effect of introducing the categorical variable [`Hours fishing`] to the lognormal regression model for Rock Sole in 5AB. See Figure B.11 for a description of each subplot.

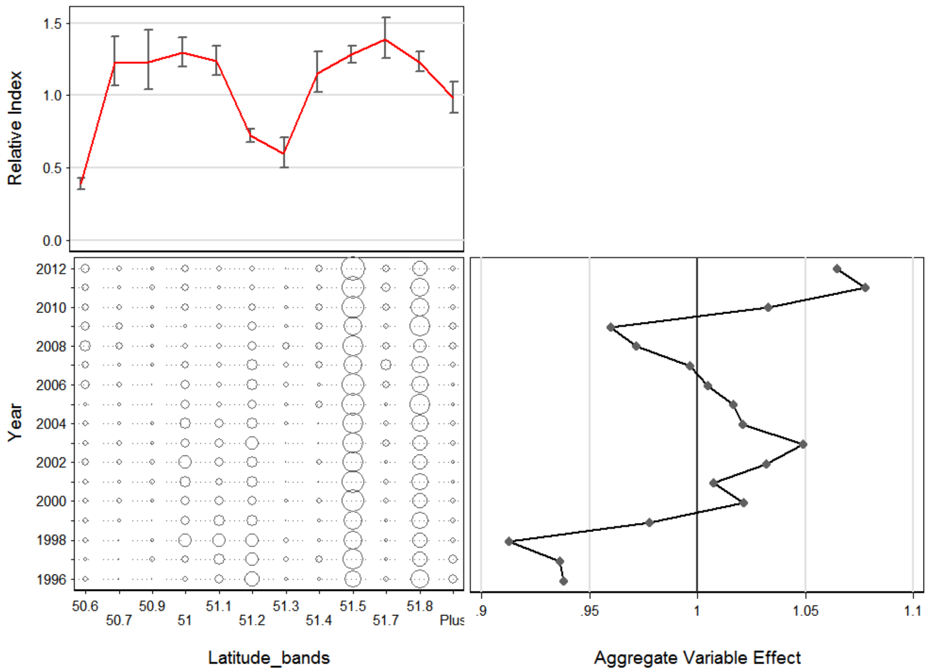


Figure B.13. CDI plot showing the effect of introducing the continuous variable [`Latitude bands`] to the lognormal regression model for Rock Sole in 5AB. See Figure B.11 for a description of each subplot.

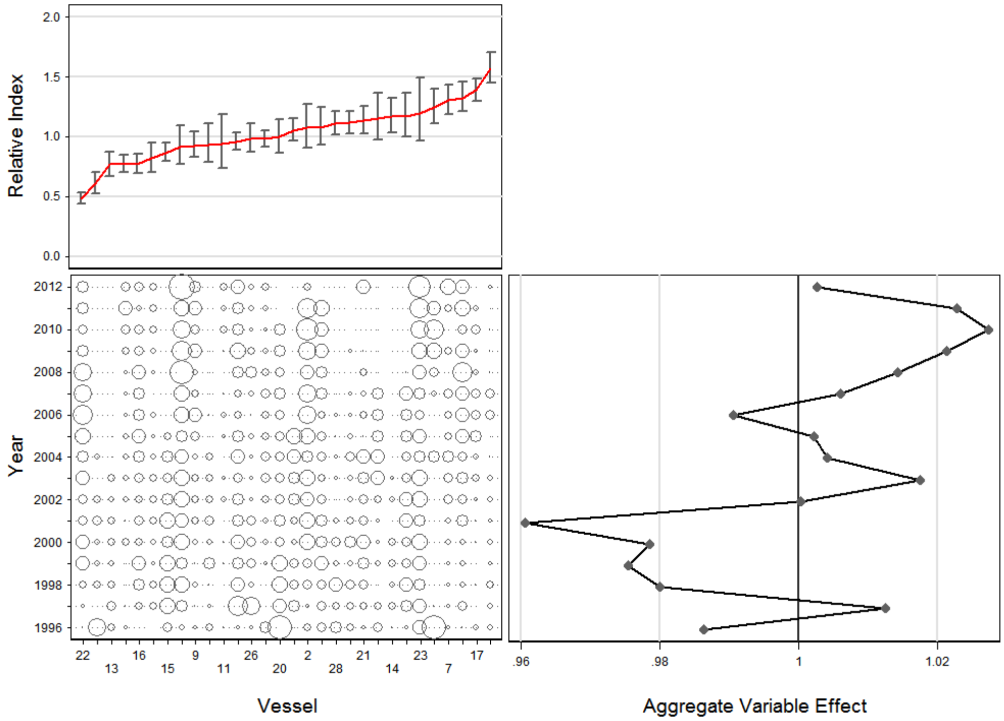


Figure B.14. CDI plot showing the effect of introducing the categorical variable [`Vessel`] to the lognormal regression model for Rock Sole in 5AB. See Figure B.11 for a description of each subplot. Vessel numbers have been coded and are ordered from left to right in terms of the relative index value.

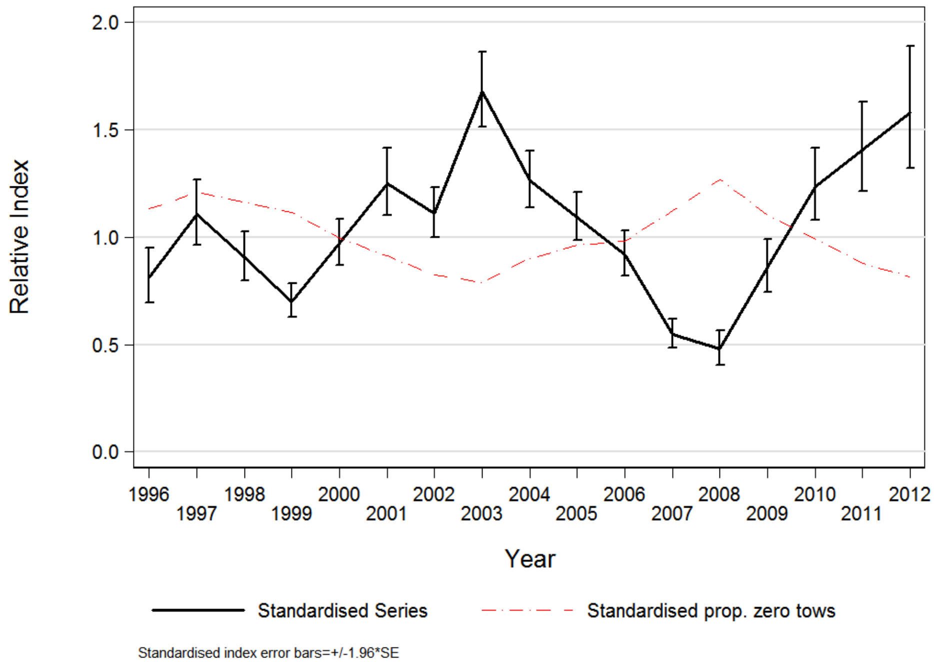


Figure B.15. Year effects from a standardised binomial logit model fit to the presence/absence of Rock Sole in the 5AB trawl fishery, using the same dataset that provided the lognormal regression model. Also shown is the relative proportion of tows with zero Rock Sole by year (mean=0.63). Each series has been normalised so that the geometric mean=1.0.

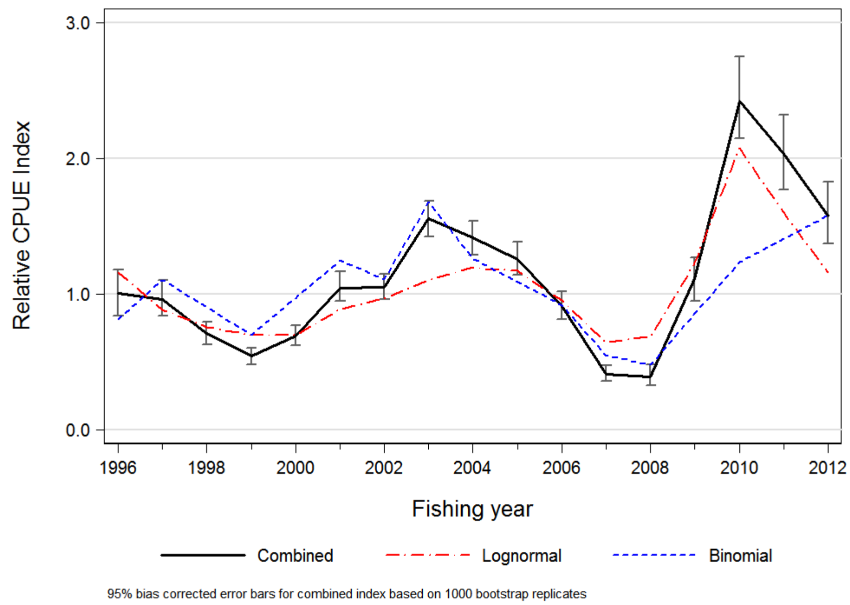


Figure B.16. Combined, lognormal and binomial models for Rock Sole in 5AB, based on commercial trawl catch and effort data. The error bars for the combined model were estimated by a bootstrap procedure replicated 1000 times with replacement.

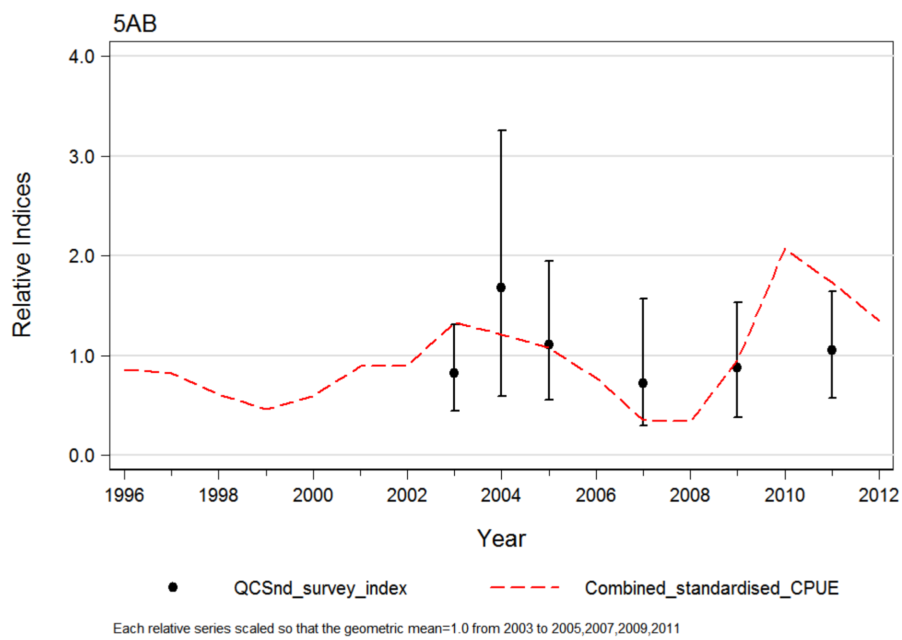


Figure B.17. Comparison of the combined and lognormal GLM models for Rock Sole in 5AB with scaled biomass indices for Rock Sole from the Queen Charlotte Sound synoptic survey (Stanley et al. 2009). The error bars for the survey data points were estimated by a bootstrap procedure replicated 1000 times with replacement.

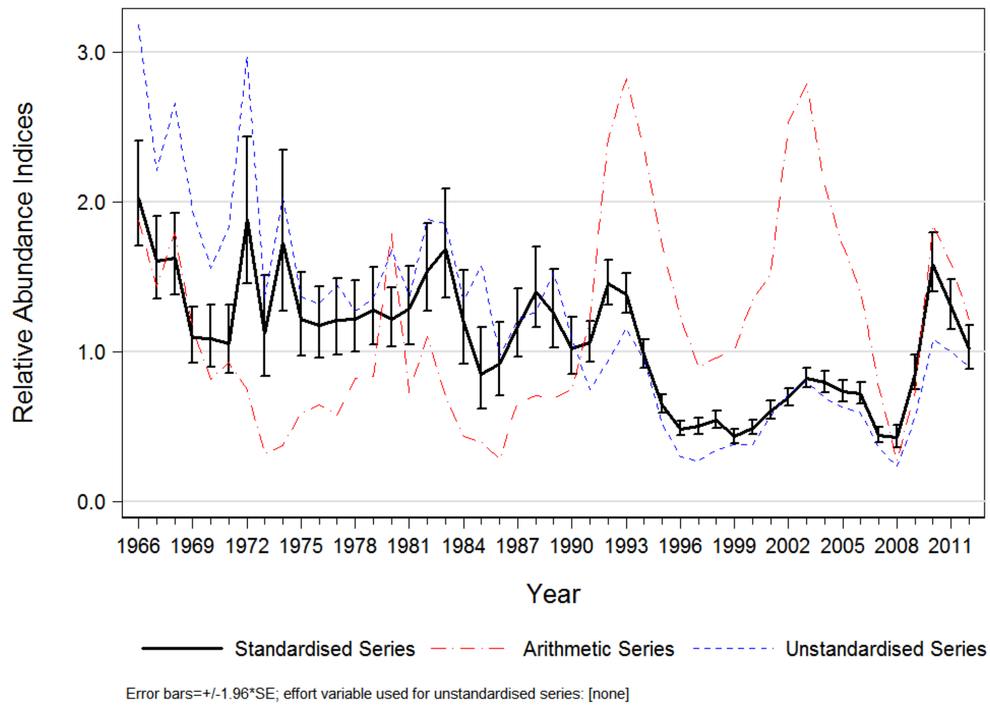


Figure B.18. Three CPUE series for Rock Sole from 1996 to 2012 in the 5AB long-term model. The solid line is the standardised CPUE series from the lognormal model (Equation B.3). The arithmetic series (Equation B.1) and the unstandardised series (Equation B.2) are presented as well. All series have a geometric mean=1.0.

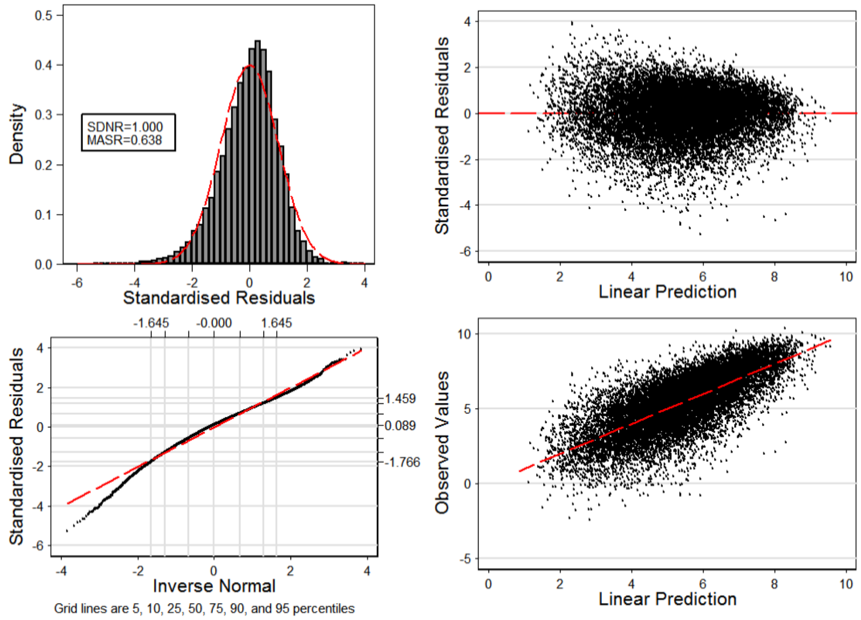


Figure B.19. Residual diagnostic plots for the GLM lognormal analysis for Rock Sole in the 5AB long-term model. Upper left: histogram of the standardised residuals with overlaid lognormal distribution (SDNR = standard deviation of normalised residuals. MASR = median of absolute standardised residuals). Lower left: Q-Q plot of the standardised residuals with the outside horizontal and vertical lines representing the 5th and 95th percentiles of the theoretical and observed distributions. Upper right: standardised residuals plotted against the predicted CPUE. Lower right: observed CPUE plotted against the predicted CPUE.

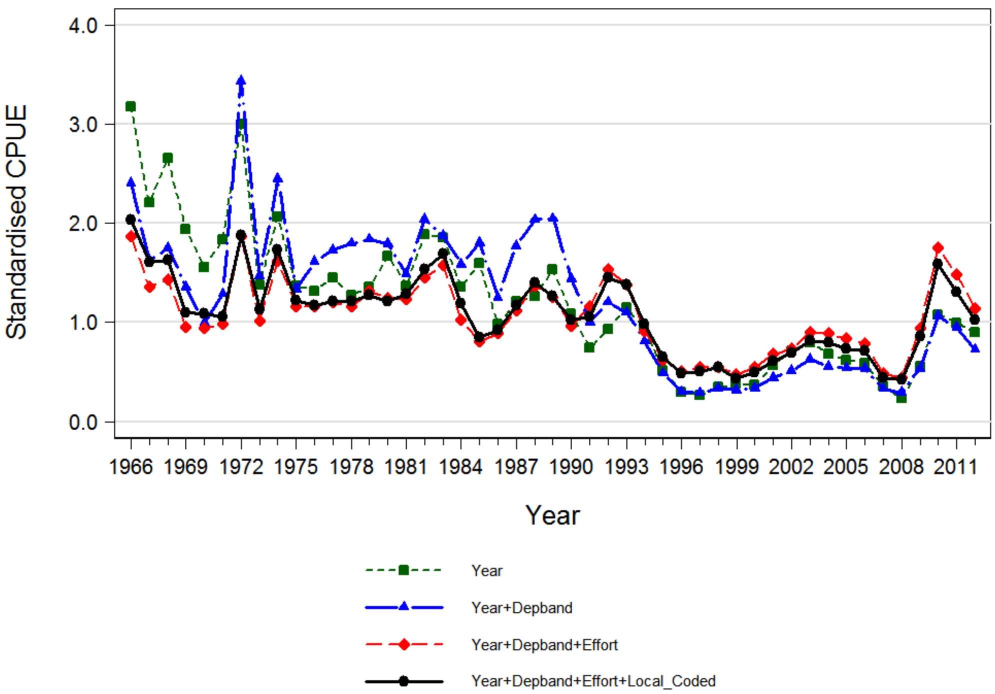


Figure B.20. Plot showing the year coefficients after adding each successive term of the standardised lognormal regression analysis for Rock Sole in the 5AB long-term model. The final model is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

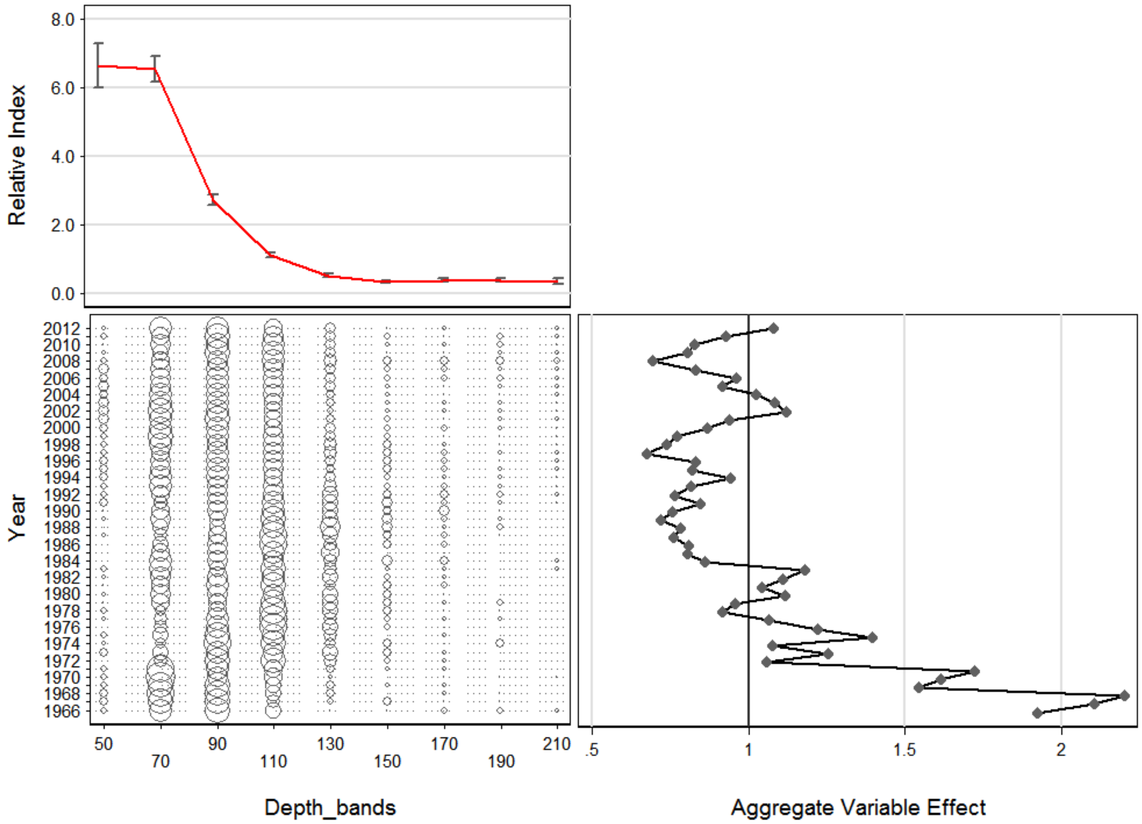


Figure B.21. CDI plot showing the effect of introducing the categorical variable [`depth band`] to the lognormal regression model for Rock Sole in the 5AB long-term model. See Figure B.11 for a description of each subplot.

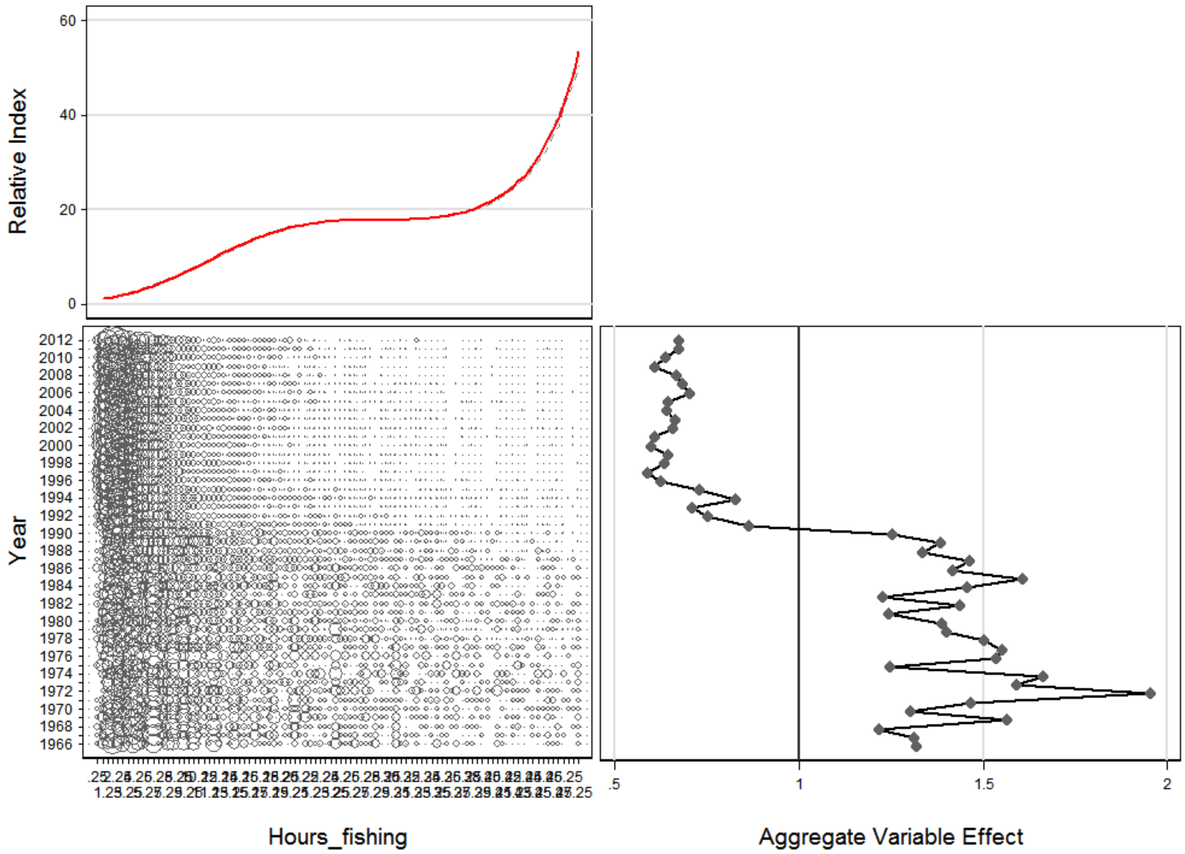


Figure B.22. CDI plot showing the effect of introducing the continuous variable [`Hours fishing`] to the lognormal regression model for Rock Sole in the 5AB long-term model. See Figure B.11 for a description of each subplot.

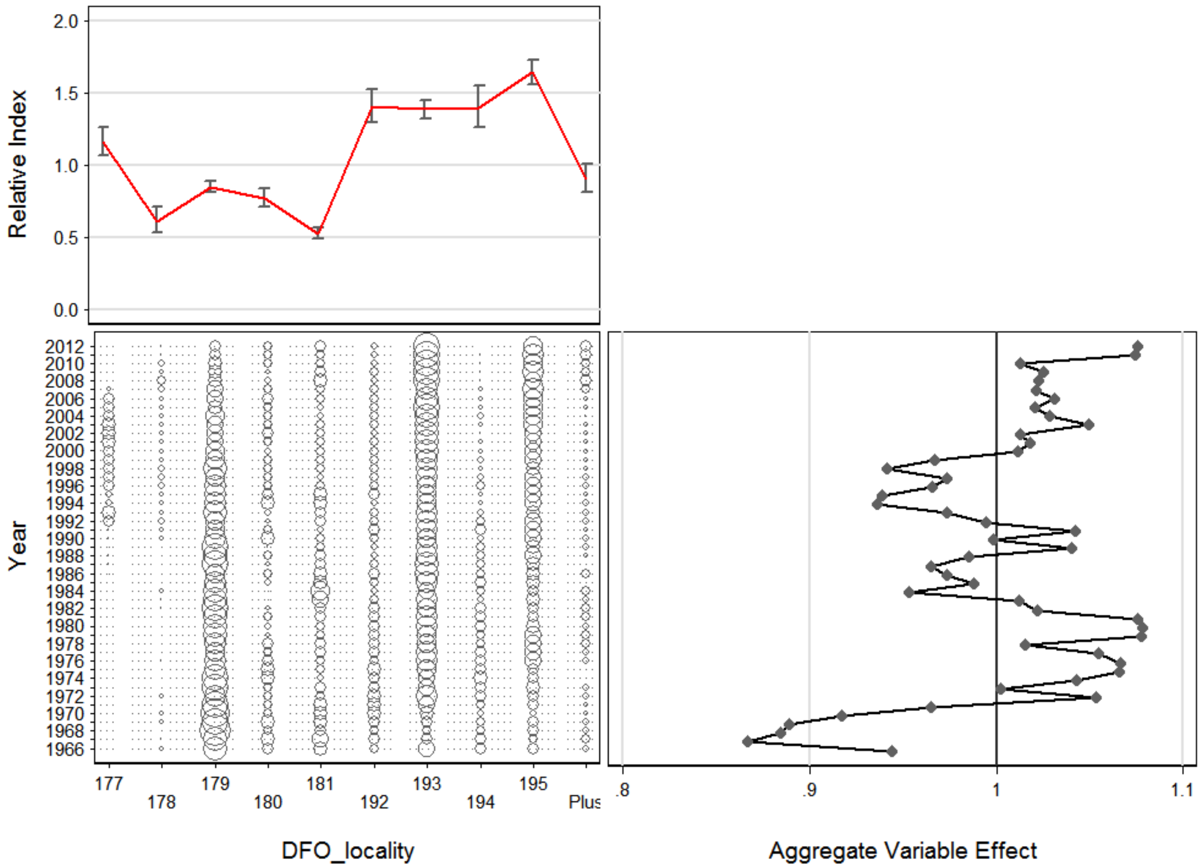


Figure B.23. CDI plot showing the effect of introducing the categorical variable [`DFO locality`] to the lognormal regression model for Rock Sole in the 5AB long-term model. See Figure B.11 for a description of each subplot.

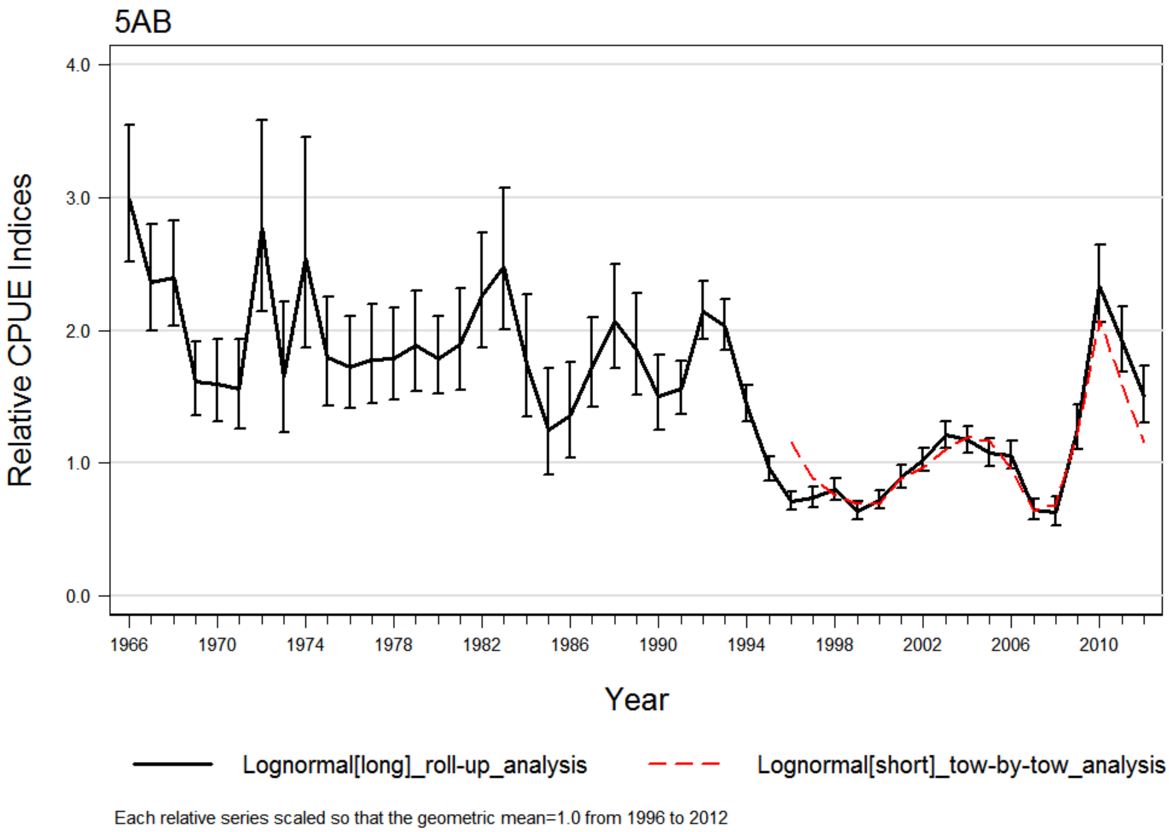


Figure B.24. Comparison of the lognormal GLM model for Rock Sole from the 5AB long-term model with the 1996–2012 combined tow-by-tow model (Table B.10).

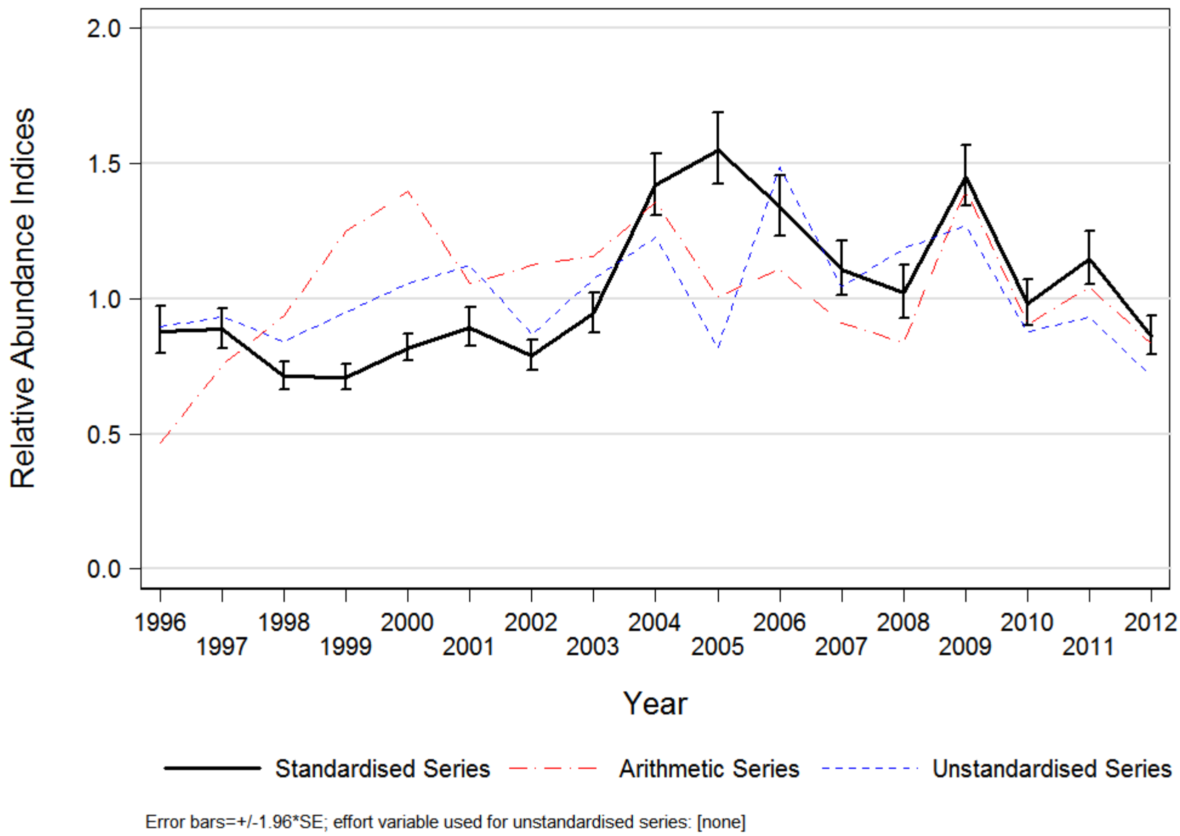


Figure B.25. Three CPUE series for Rock Sole from 1996 to 2012 in 5CD. The solid line is the standardised CPUE series from the lognormal model (Equation B.3). The arithmetic series (Equation B.1) and the unstandardised series (Equation B.2) are also presented. All three series have a geometric mean equal to 1.0.

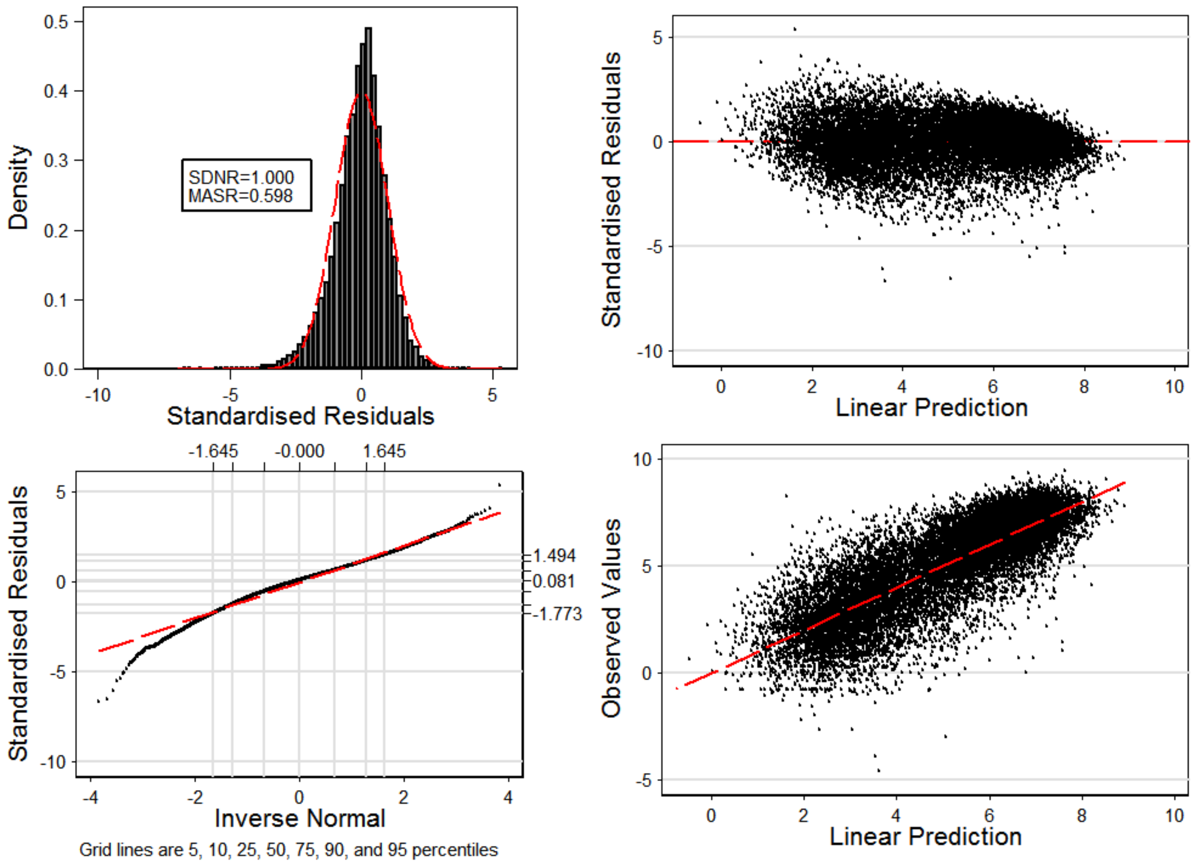


Figure B.26. Residual diagnostic plots for the GLM lognormal analysis for Rock Sole in 5CD. Upper left: histogram of the standardised residuals with overlaid lognormal distribution (SDNR = standard deviation of normalised residuals. MASR = median of absolute standardised residuals). Lower left: Q-Q plot of the standardised residuals with the outside horizontal and vertical lines representing the 5^{th} and 95^{th} percentiles of the theoretical and observed distributions. Upper right: standardised residuals plotted against the predicted CPUE. Lower right: observed CPUE plotted against the predicted CPUE.

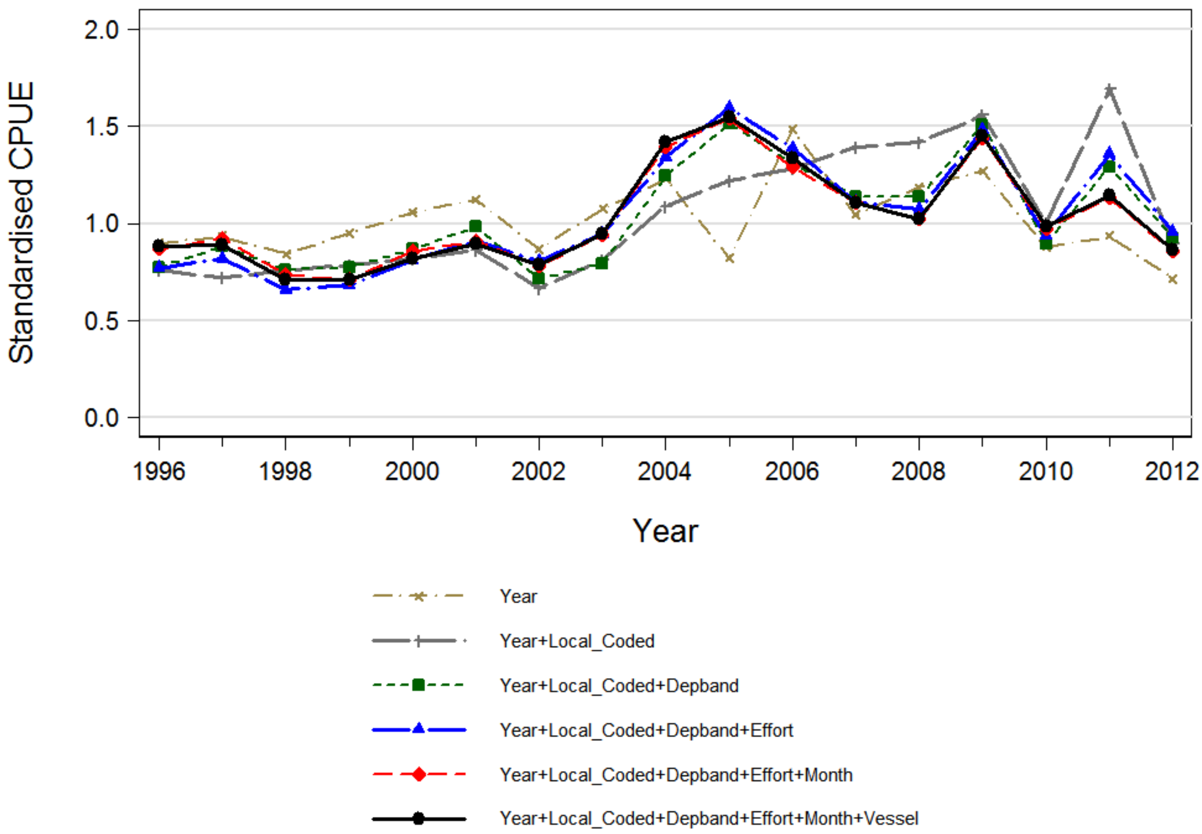


Figure B.27. Plot showing the year coefficients after adding each successive term of the standardised lognormal regression analysis for Rock Sole in 5CD. The final model is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

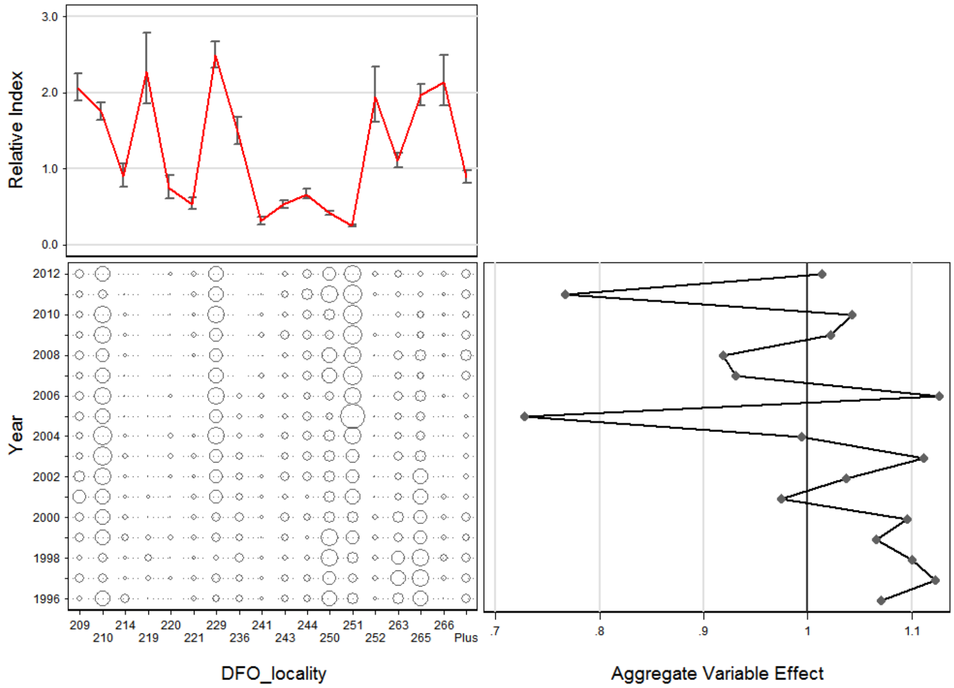


Figure B.28. CDI plot showing the effect of introducing the categorical variable [`DFO locality`] to the lognormal regression model for Rock Sole in 5CD. See Figure B.11 for a description of each subplot.

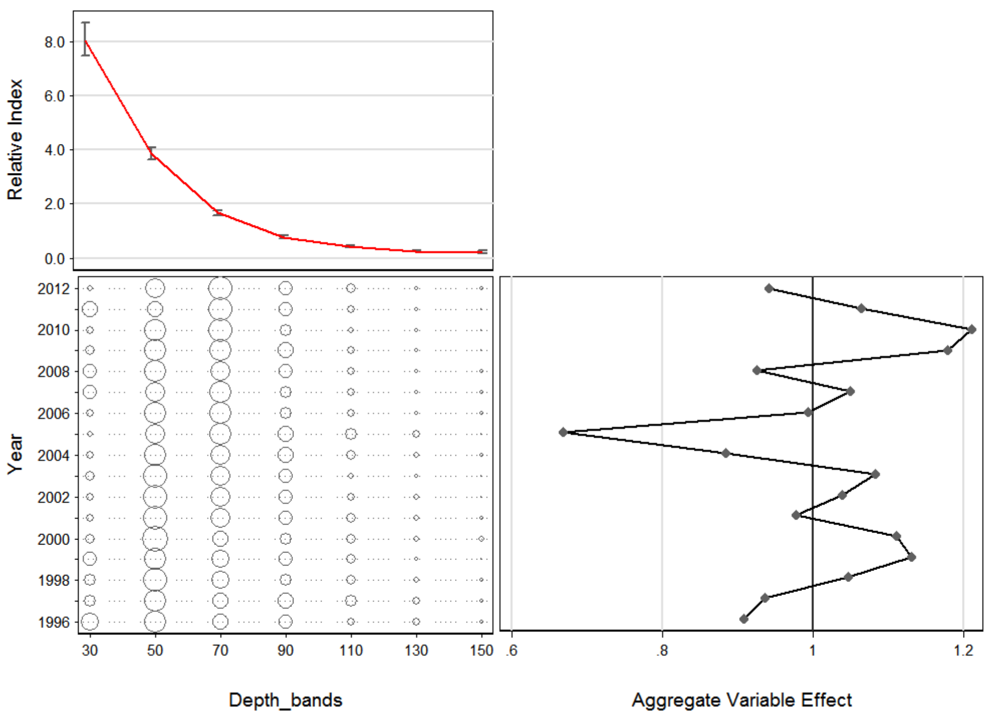


Figure B.29. CDI plot showing the effect of introducing the categorical variable [`depth band`] to the lognormal regression model for Rock Sole in 5CD. See Figure B.11 for a description of each subplot.

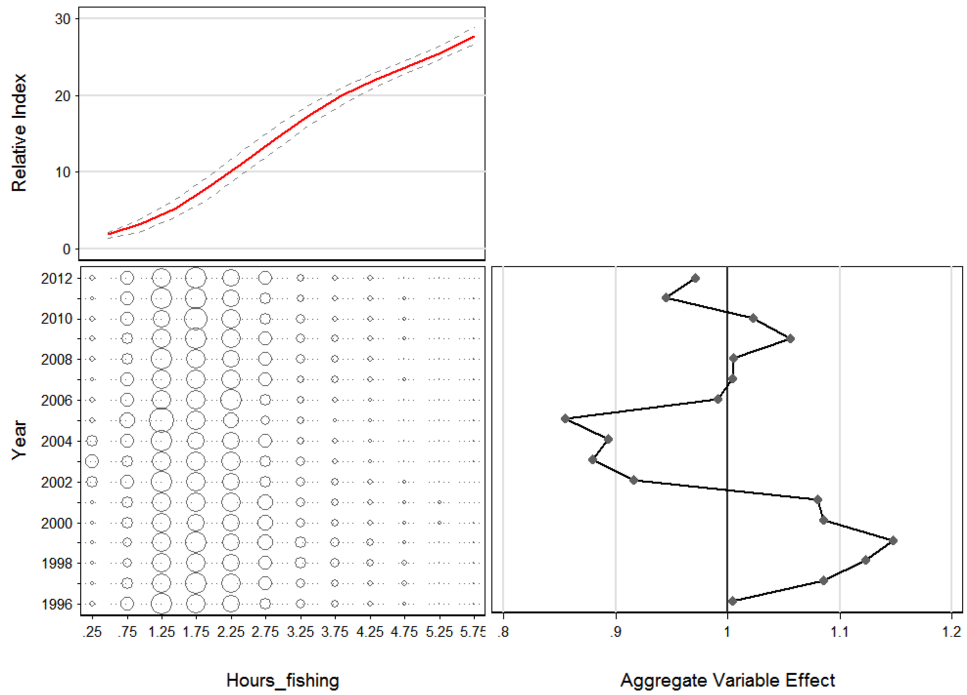


Figure B.30. CDI plot showing the effect of introducing the continuous variable [`Hours fishing`] to the lognormal regression model for Rock Sole in 5CD. See Figure B.11 for a description of each subplot.

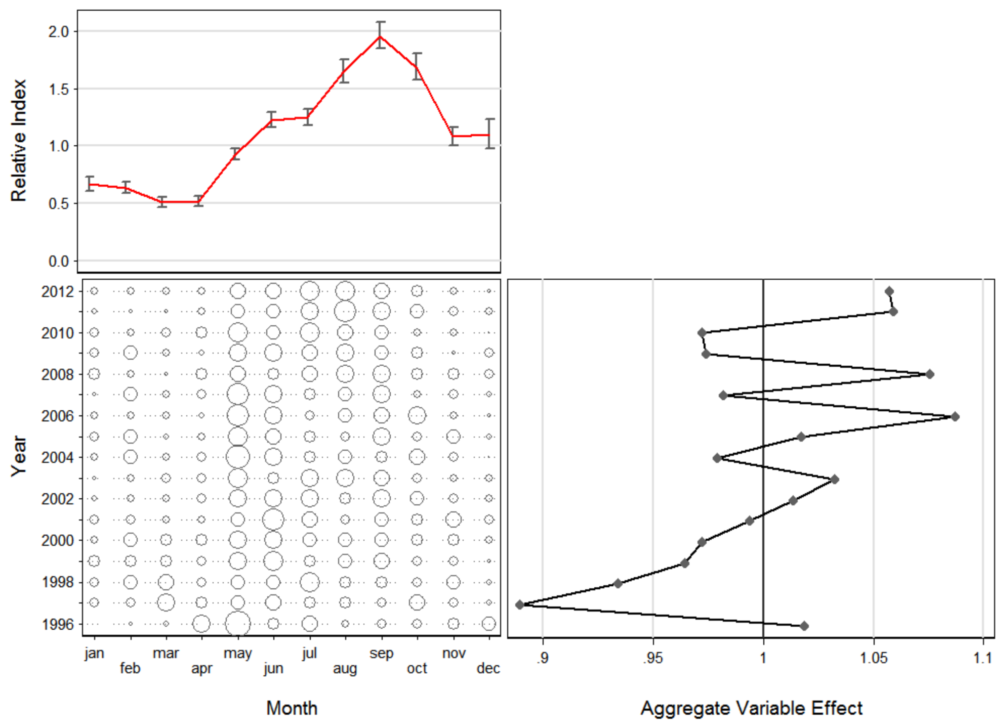


Figure B.31. CDI plot showing the effect of introducing the categorical variable [`Month`] to the lognormal regression model for Rock Sole in 5CD. See Figure B.11 for a description of each subplot.

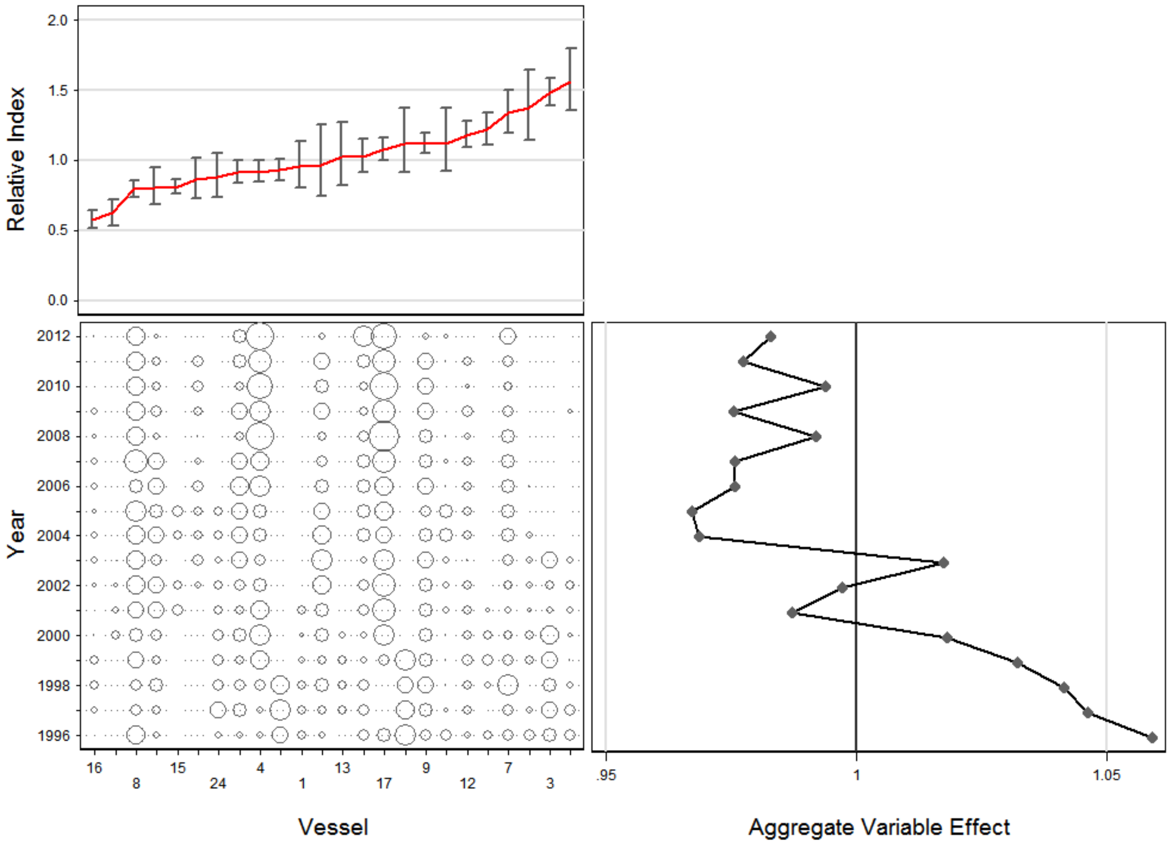


Figure B.32. CDI plot showing the effect of introducing the categorical variable [`Vessel`] to the lognormal regression model for Rock Sole in 5CD. See Figure B.11 for a description of each subplot. Vessel numbers have been coded and are ordered from left to right in terms of the relative index value.

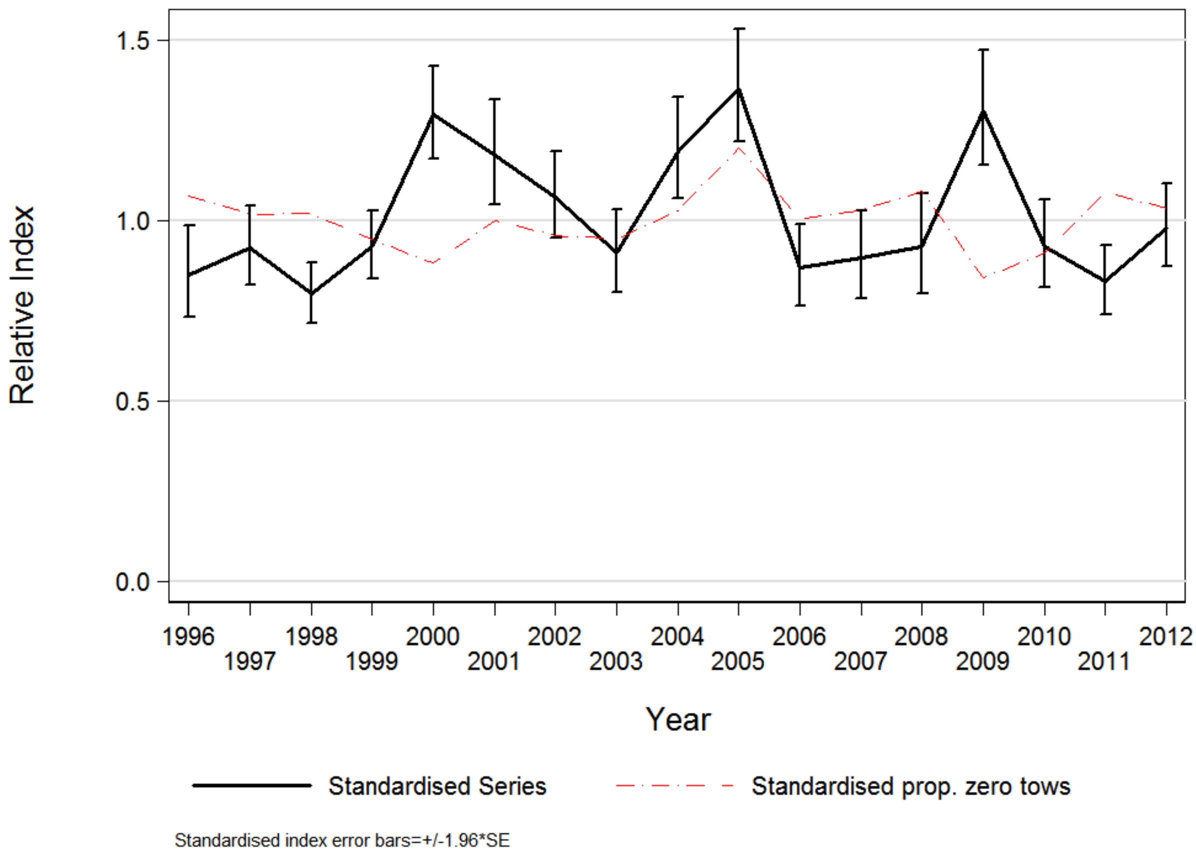


Figure B.33. Year effects from a standardised binomial logit model fit to the presence/absence of Rock Sole in the 5CD trawl fishery, using the same dataset that provided the lognormal regression model. Also shown is the relative proportion of tows with zero Rock Sole by year (mean=0.56). Each series has been normalised so that the geometric mean=1.0.

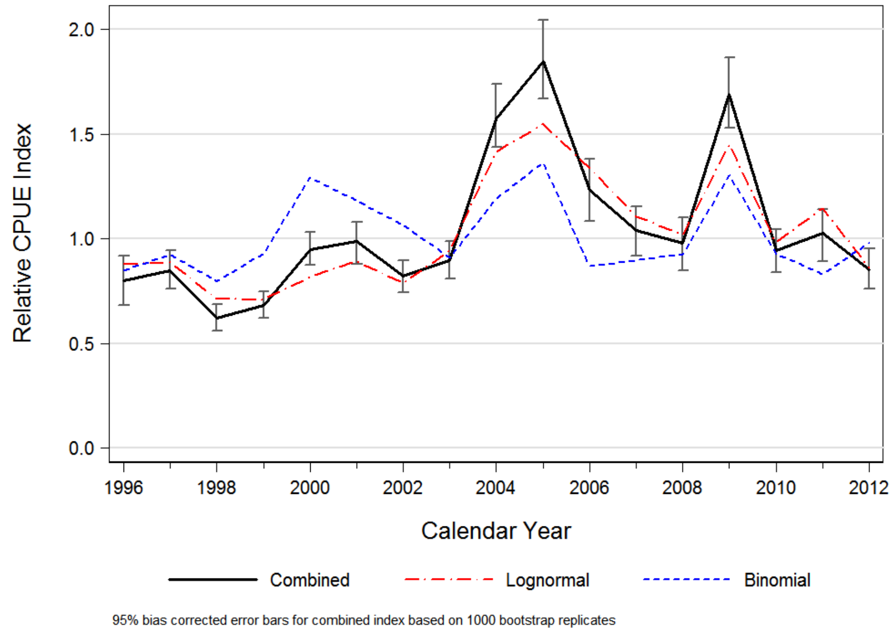


Figure B.34. Combined, lognormal and binomial models for Rock Sole in 5CD, based on commercial trawl catch and effort data. The error bars for the combined model were estimated by a bootstrap procedure replicated 1000 times with replacement.

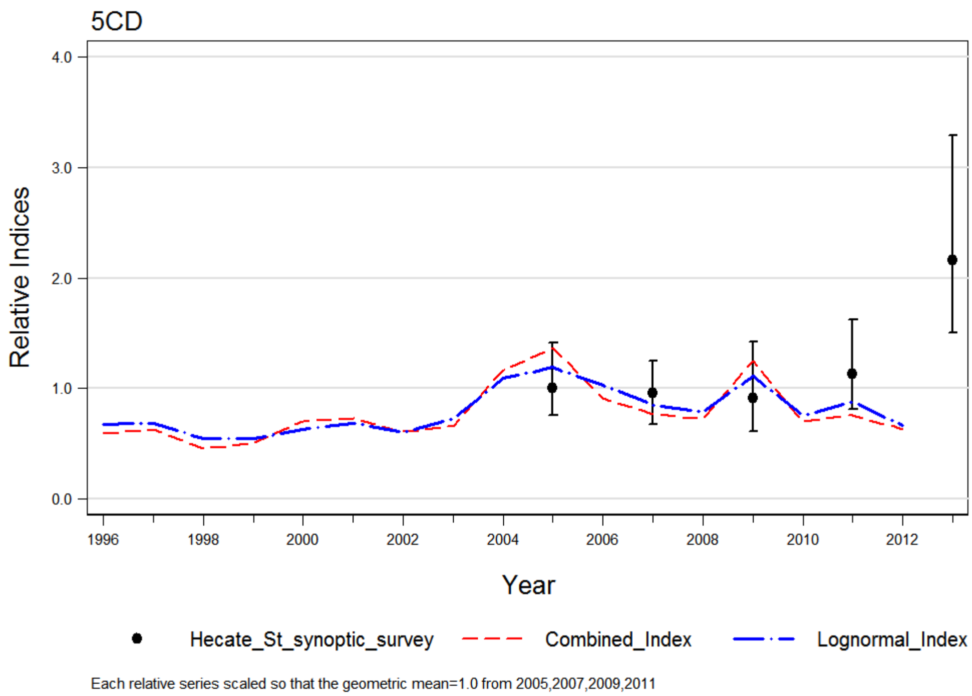


Figure B.35. Comparison of the combined and lognormal GLM models for Rock Sole in 5CD with scaled biomass indices for Rock Sole from the Hecate Strait synoptic survey (Olsen et al. 2009). The error bars for the survey data points were estimated by a bootstrap procedure replicated 1000 times with replacement.

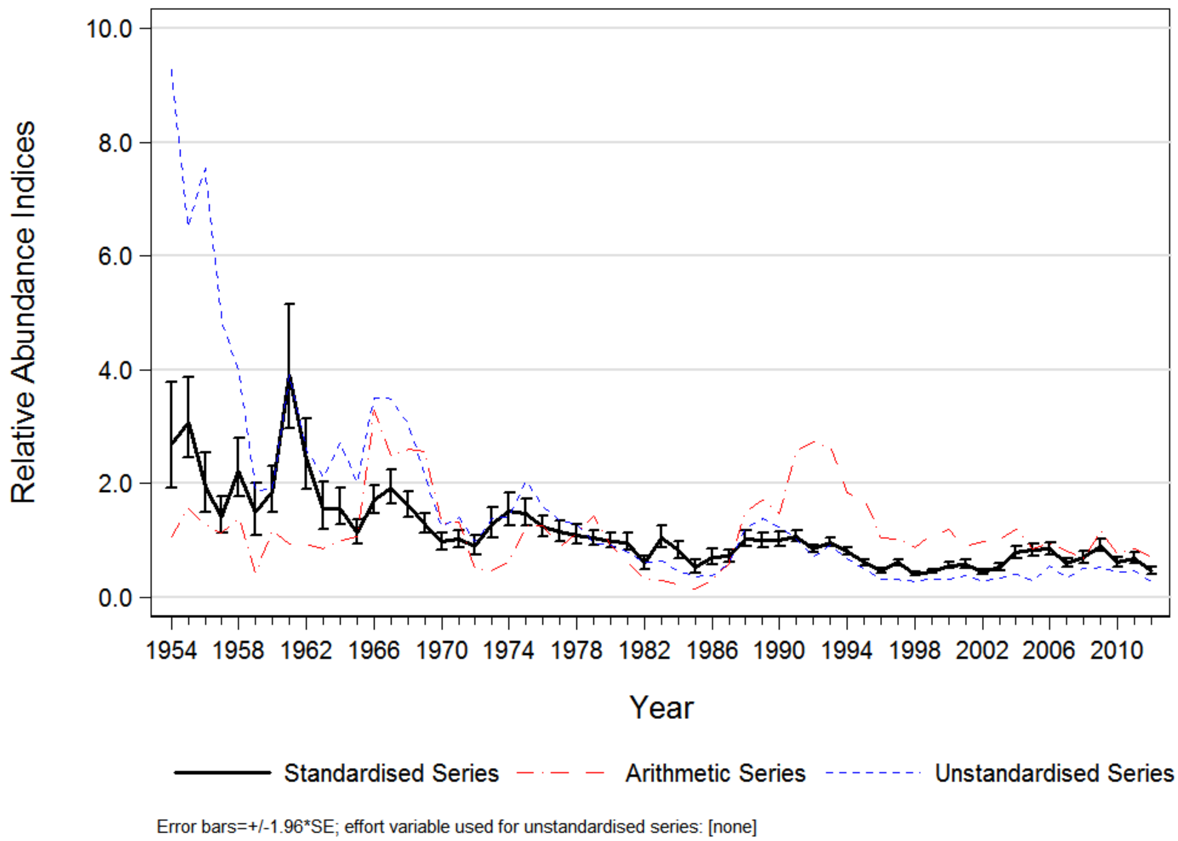


Figure B.36. Three CPUE series for Rock Sole from 1996 to 2012 in the 5CD long-term model. The solid line is the standardised CPUE series from the lognormal model (Equation B.3). The arithmetic series (Equation B.1) and the unstandardised series (Equation B.2) are presented as well.

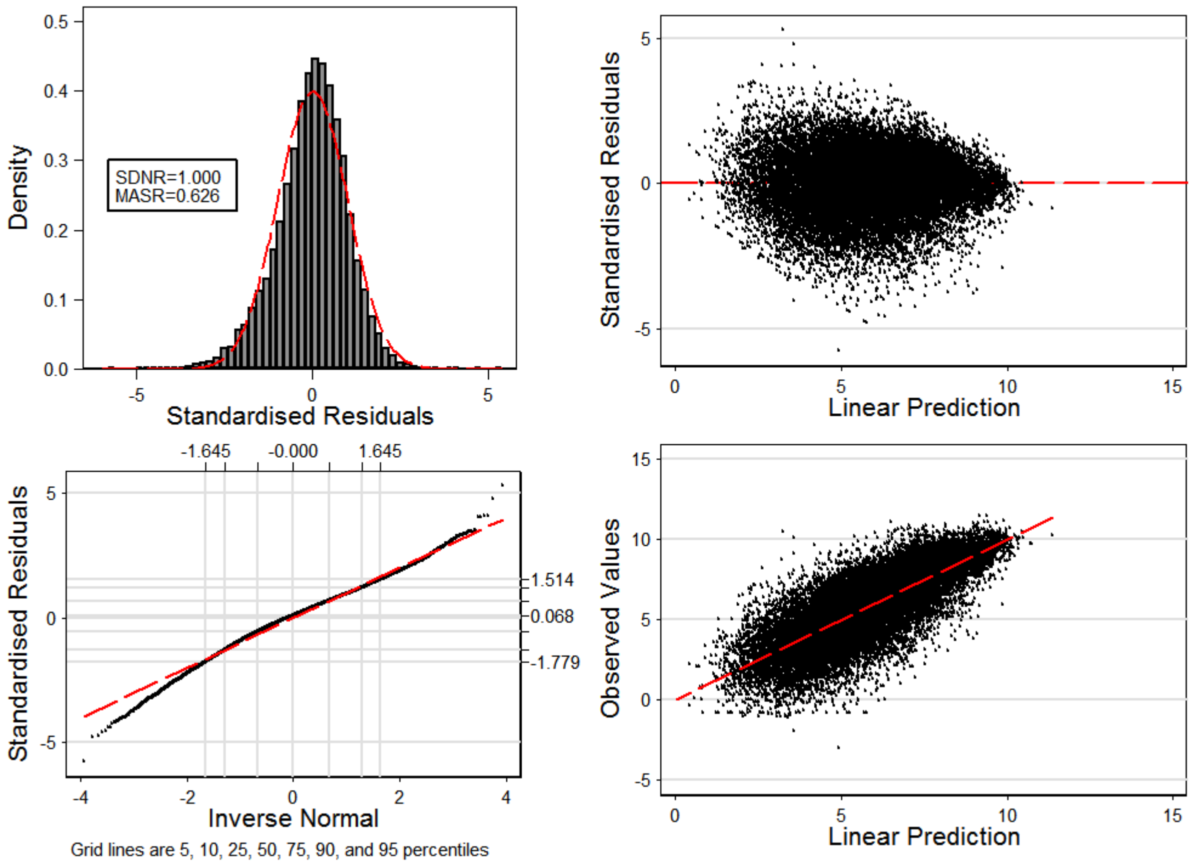


Figure B.37. Residual diagnostic plots for the GLM lognormal analysis for Rock Sole in the 5CD long-term model. Upper left: histogram of the standardised residuals with overlaid lognormal distribution (SDNR = standard deviation of normalised residuals. MASR = median of absolute standardised residuals). Lower left: Q-Q plot of the standardised residuals with the outside horizontal and vertical lines representing the 5th and 95th percentiles of the theoretical and observed distributions. Upper right: standardised residuals plotted against the predicted CPUE. Lower right: observed CPUE plotted against the predicted CPUE.

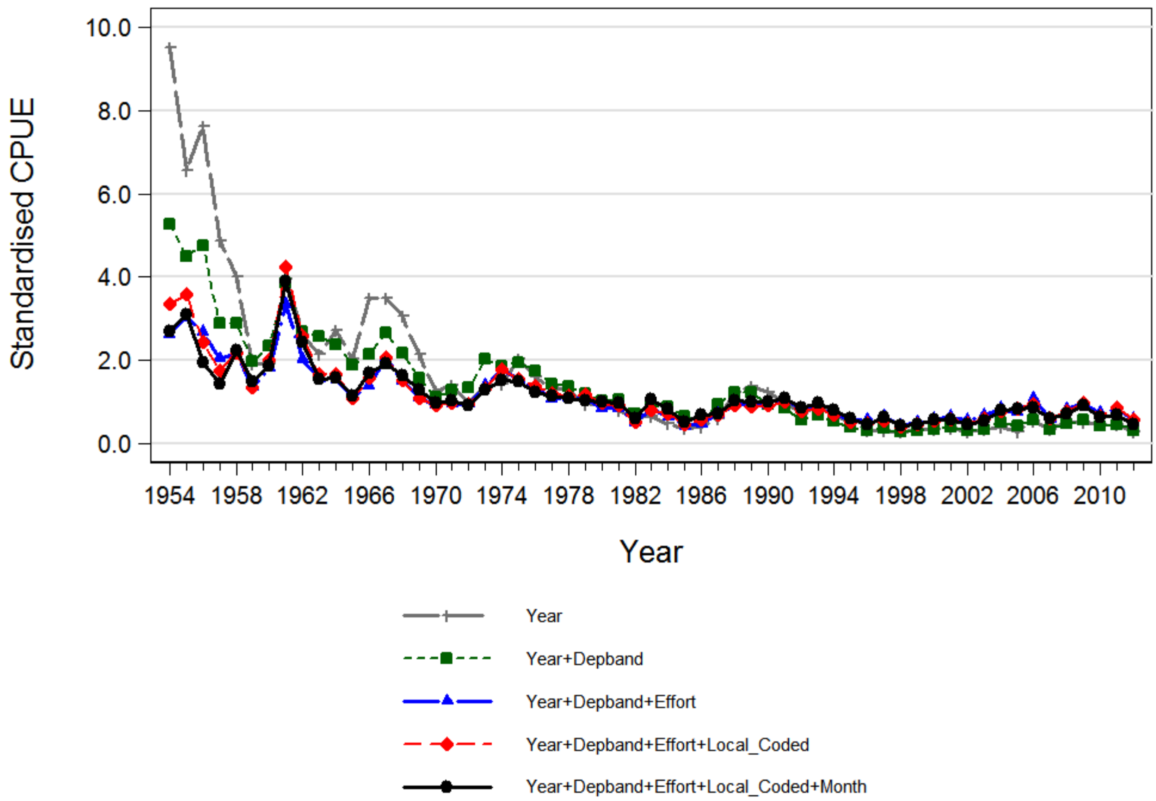


Figure B.38. Plot showing the year coefficients after adding each successive term of the standardised lognormal regression analysis for Rock Sole in the 5CD long-term model. The final model is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

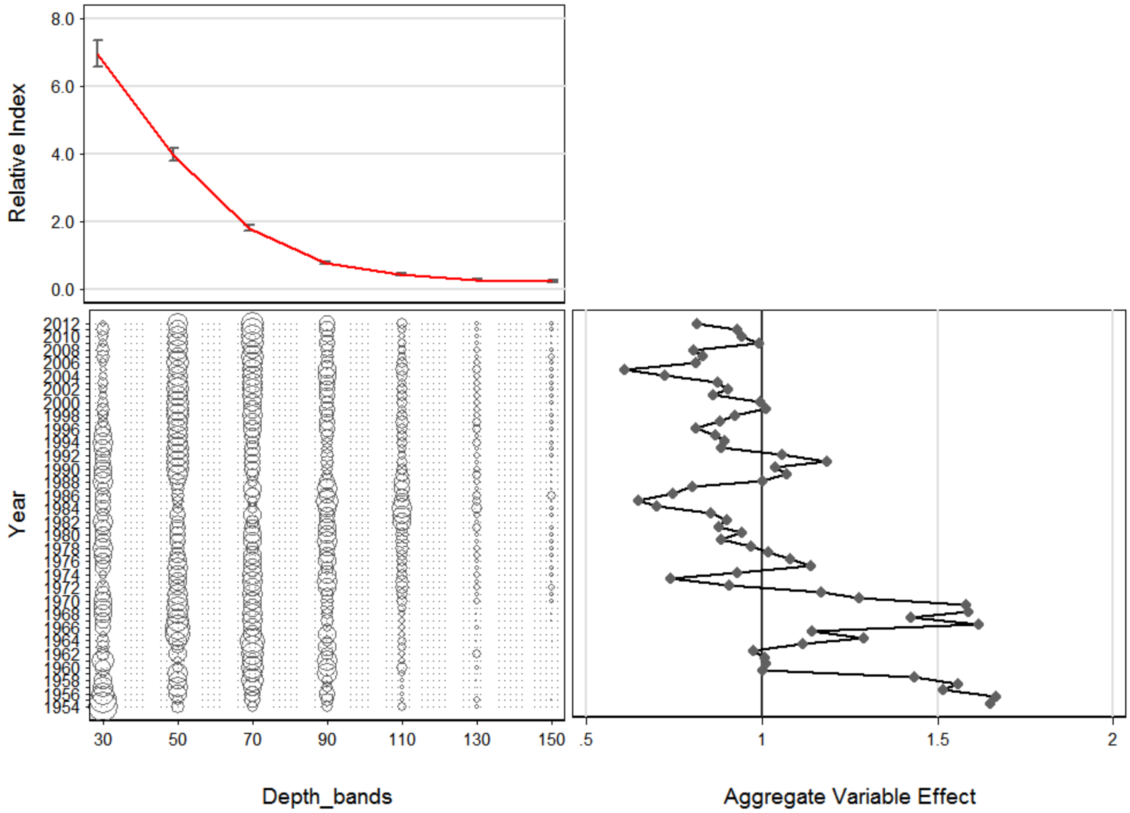


Figure B.39. CDI plot showing the effect of introducing the categorical variable [`depth band`] to the lognormal regression model for Rock Sole in the 5CD long-term model. See Figure B.11 for a description of each subplot.

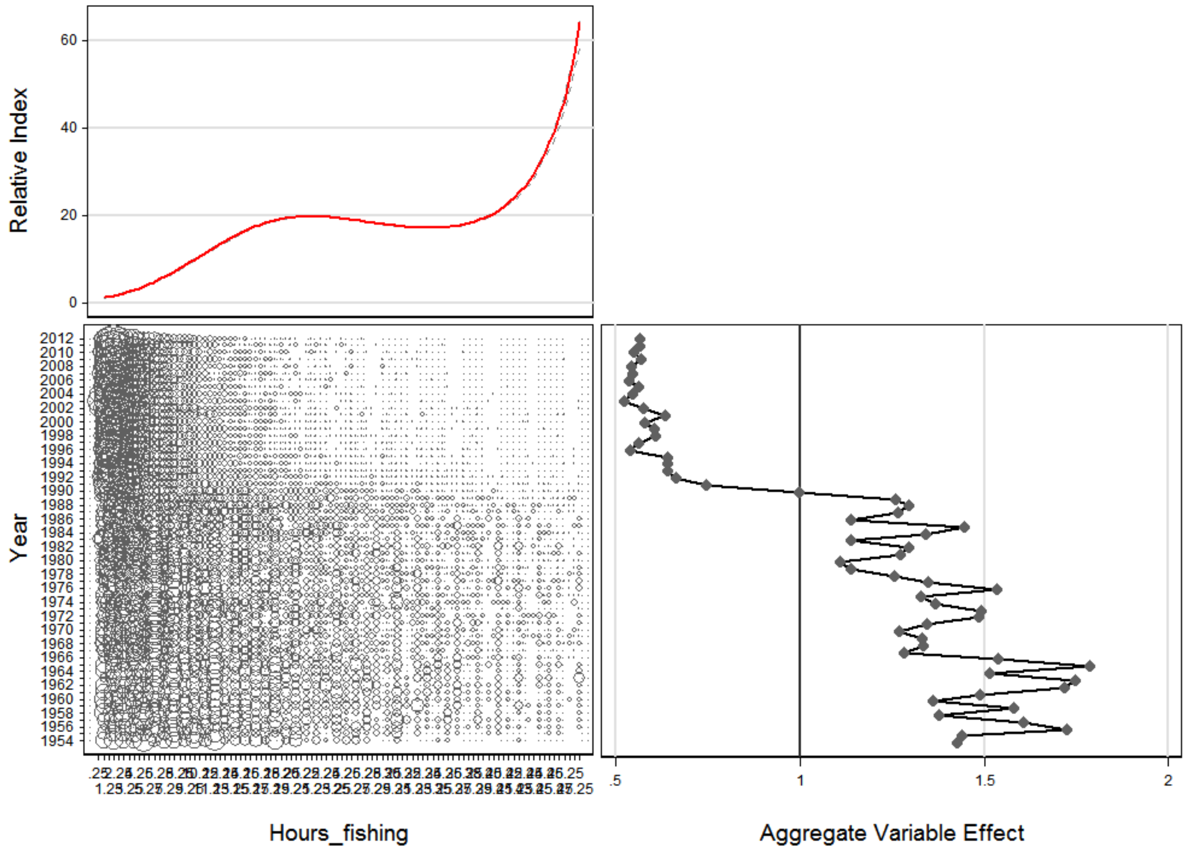


Figure B.40. CDI plot showing the effect of introducing the continuous variable [`Hours fishing`] to the lognormal regression model for Rock Sole in the 5CD long-term model. See Figure B.11 for a description of each subplot.

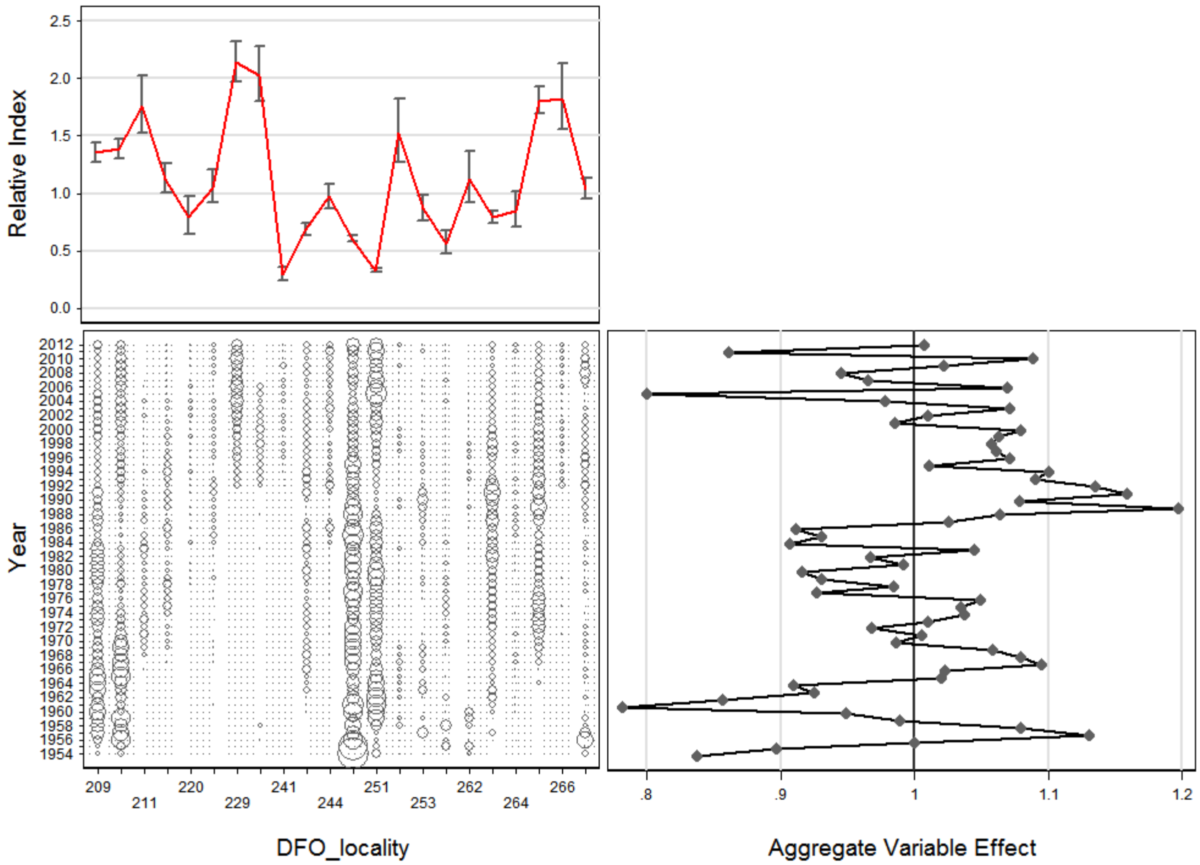


Figure B.41. CDI plot showing the effect of introducing the categorical variable [`DFO locality`] to the lognormal regression model for Rock Sole in the 5CD long-term model. Each plot consists of subplots showing the effect by level of variable (top left), the relative distribution of variable records by year (bottom left), and the cumulative effect of variable by year (bottom right).

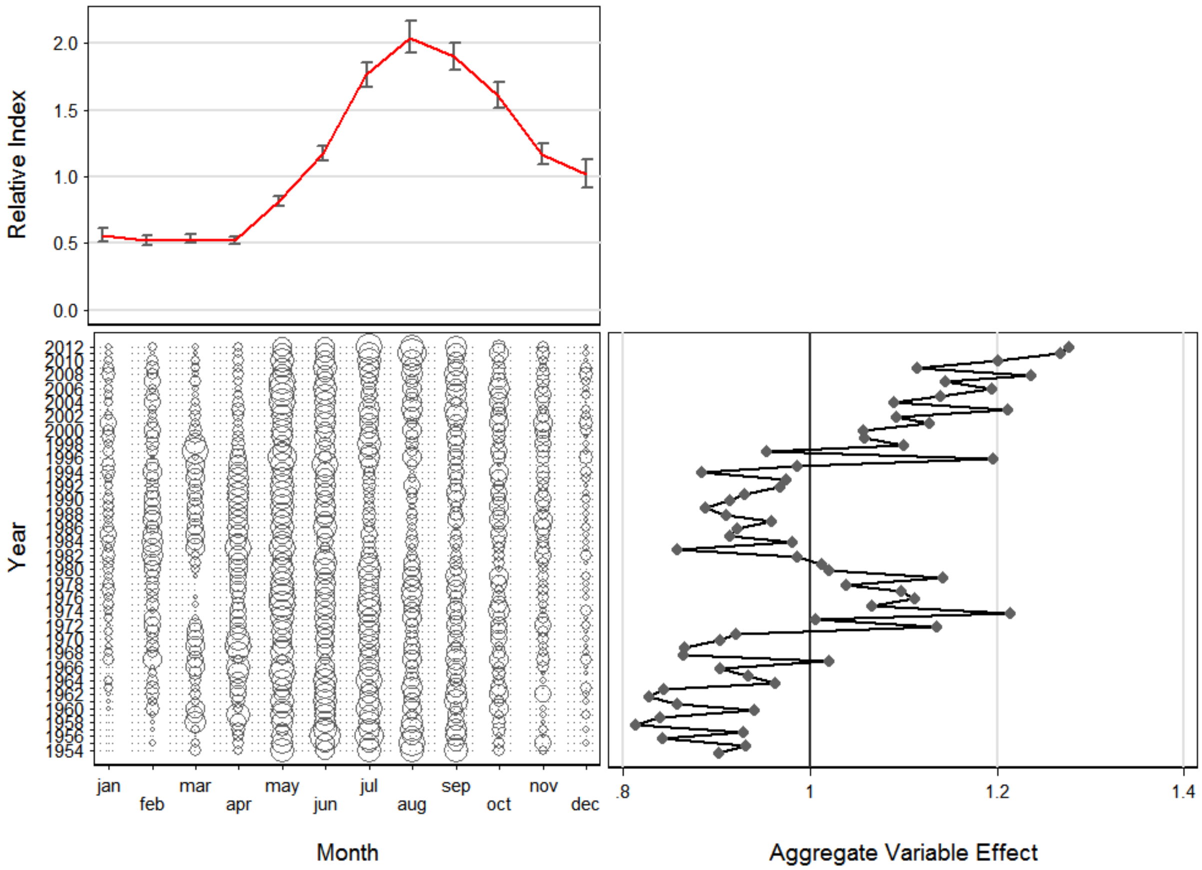


Figure B.42. CDI plot showing the effect of introducing the categorical variable [`Month`] to the lognormal regression model for Rock Sole in the 5CD long-term model. Each plot consists of subplots showing the effect by level of variable (top left), the relative distribution of variable records by year (bottom left), and the cumulative effect of variable by year (bottom right).Vessel numbers have been coded and are ordered from left to right in terms of the relative index value.

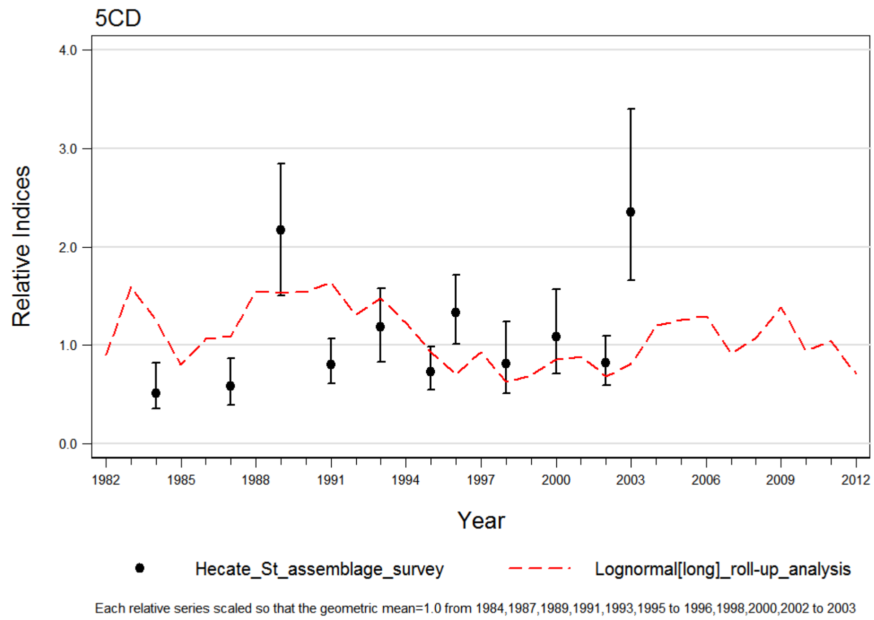


Figure B.43. Comparison of the lognormal GLM model for Rock Sole from the 5CD long-term model with scaled biomass indices from the Hecate Strait assemblage survey (Sinclair 1999). The error bars for the survey data points were estimated by a bootstrap procedure replicated 1000 times with replacement.

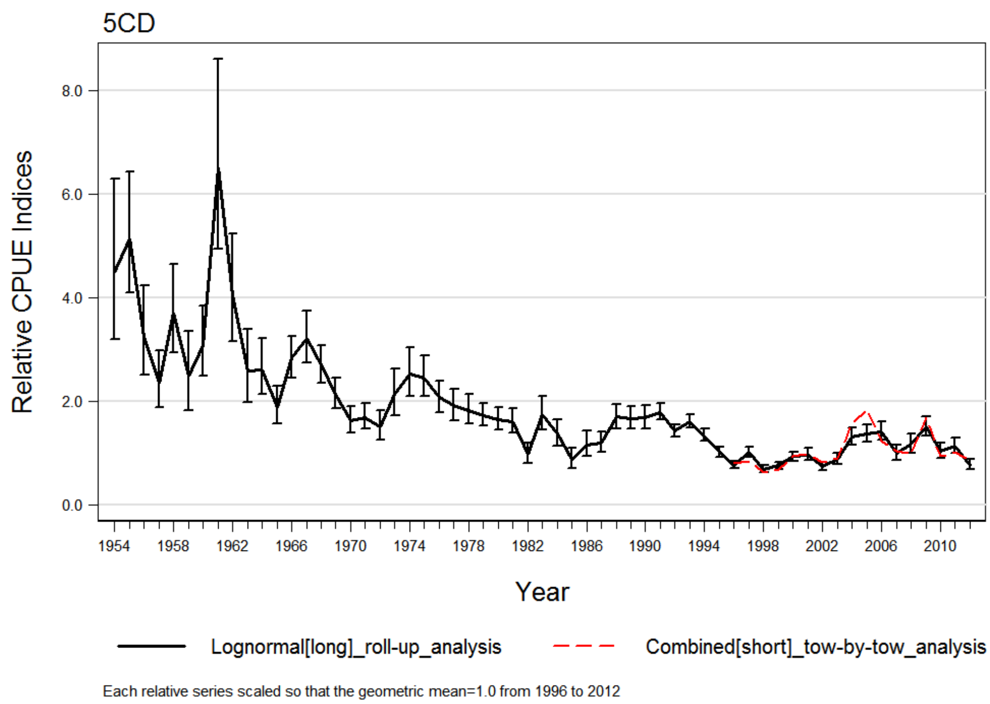


Figure B.44. Comparison of the lognormal GLM model for Rock Sole from the 5CD long-term model with the 1996–2012 combined tow-by-tow model (Table B.10).

APPENDIX C. RESEARCH SURVEYS

INTRODUCTION

This appendix summarizes the derivation of relative Rock Sole abundance indices from the:

- Assemblage survey that operated in Hecate Strait from 1984 to 2003;
- Hecate Strait synoptic survey;
- Queen Charlotte Sound synoptic survey;
- West Coast Vancouver Island synoptic survey

A summary of available Rock Sole data from all groundfish surveys that have been conducted in BC are provided in Table C.1.

ANALYTICAL METHODS

Catch and effort data for strata i in year y yield catch per unit effort (CPUE) values U_{yi}. Given a set of data $\left\{C_{yij}, E_{yij}\right\}$ for tows $j = 1, \ldots, n_{yi}$,

$$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}}, \qquad \text{(C.1)}$$

where C_{yij} = catch (kg) in tow j, stratum i, year y;

E_{yij} = effort (h) in tow j, stratum i, year y;

n_{yi} = number of tows in stratum i, year y.

CPUE values U_{yi} convert to CPUE densities δ_{yi} (kg/km^2) using:

$$\delta_{yi} = \frac{1}{vw} U_{yi}, \qquad \text{(C.2)}$$

where v = average vessel speed (km/h);

w = average net width (km).

Alternatively, if vessel information exists for every tow, CPUE density can be expressed

$$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}}, \qquad \text{(C.3)}$$

where C_{yij} = catch weight (kg) for tow j, stratum i, year y;

D_{yij} = distance travelled (km) for tow j, stratum i, year y;

w_{yij} = net opening (km) for tow j, stratum i, year y;

n_{yi} = number of tows in stratum i, year y.

The annual biomass estimate is then the sum of the product of CPUE densities and bottom areas across m strata:

$$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi}\ , \tag{C.4}$$

where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;

A_i = area (km^2) of stratum i;

B_{yi} = biomass (kg) for stratum i, year y;

m = number of strata.

The variance of the survey biomass estimate V_y (kg^2) follows:

$$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi}\ , \tag{C.5}$$

where σ_{yi}^2 = variance of CPUE density (kg^2/km^4) for stratum i, year y;

V_{yi} = variance of the biomass estimate (kg^2) for stratum i, year y.

The coefficient of variation (CV) of the annual biomass estimate for year y is

$$CV_y = \frac{\sqrt{V_y}}{B_y}. \tag{C.6}$$

Table C.1. Description of available Rock Sole survey data in British Columbia.

Survey Series Description	Gear	Areas	First Year	Last Year	Number of Years	Number of Years with Species	Number of Usable Sets	Number of Sets with Species	Mean Catch/set
West Coast Vancouver Island Synoptic Survey	Trawl	3CD	2004	2012	5	5	701	132	7.9 kg
Queen Charlotte Sound Synoptic Survey	Trawl	5AB 5CD	2003	2013	7	7	1,670	280	19.9 kg
Hecate Strait Synoptic Survey	Trawl	5CD	2005	2013	5	5	854	425	28.0 kg
Hecate Strait Multispecies Assemblage Survey	Trawl	5CD	1984	2003	11	11	1,110	626	34.8 kg
Hecate Strait Pacific Cod Monitoring Survey	Trawl	5CD	2002	2004	3	3	600	312	64.1 kg
Historic GB Reed Goose Island Gully Surveys	Trawl	5AB	1967	1995	9	8	463	17	13.1 kg
Lingcod YOY Trawl Survey	Trawl	4B	1991	2005	4	4	267	252	31.1 kg
Queen Charlotte Sound Shrimp Survey	Shrimp Trawl	5AB	1998	2013	16	16	1,103	57	0.4 kg
West Coast Vancouver Island Shrimp Survey	Shrimp Trawl	3CD	1975	2013	37	13	2,943	31	3.7 kg
IPHC Longline Survey	Longline	3CD 5AB 5CD	2003	2012	10	8	1,696	14	1.3 Pcs
IRF Longline Survey (North)	Longline	4B	2003	2012	6	4	301	14	2.0 Pcs
IRF Longline Survey (South)	Longline	4B	2005	2013	4	4	230	11	1.2 Pcs
PHMA Rockfish Longline Survey (Outside North)	Longline	5AB 5CD 5E	2006	2012	4	4	762	43	1.5 Pcs
PHMA Rockfish Longline Survey (Outside South)	Longline	3CD 5AB 5CD	2007	2011	3	3	530	16	3.8 Pcs

THE HECATE STRAIT ASSEMBLAGE SURVEY

Data selection

This survey was conducted 11 times over the period 1984 to 2003 in Hecate Strait between Moresby and Graham Islands and the mainland (all valid tow starting positions are shown by survey year in Figure C.1 to Figure C.11) (Sinclair 1999). The design overlaid a 10 nm square grid over Hecate Strait and placed one tow per grid square in each 10-fathom depth interval over the range of 10 to 80 fathoms (18 to 146 m). Tow positions were selected non-randomly by substrate type and were fixed after the first survey, although there was some variation in how tow positions were revisited and new tow positions were added over the years. There were 85 to 105 valid tows in each survey year after the initial year, which had over 140 tows (Table C.2). Sinclair (1999) chose to analyse these data using the 10 fathom depth intervals as depth strata, without reference to the overlaid grid pattern by assuming that tow locations had been selected randomly.

Two methods have been used to generate a doorspread density value (Equation C.3) for each survey tow, given that there are no estimates of doorspread or wingspread for this survey and there only exist estimates of [`distance travelled`] and [`speed`] for the final three survey years. The method proposed by Sinclair (1999) was to calculate a CPUE (kg/h) for each tow and to convert this value to biomass per area swept (kg/km^2) by assuming a constant area swept by each tow, with 0.0486 km^2/h as the constant. A second method was proposed by Starr et al. (2006, unpublished manuscript[1]), who assumed a constant doorspread value of 43 m and a constant speed of 5.1 km/h (Equation C.2). There is little practical difference between these methods when the resulting biomass indices are treated as relative, as demonstrated by the plot in Figure C.12. For this assessment we use the method of Starr et al. 2006 (unpublished manuscript[1]).

Table C.2. Number of usable tows for biomass estimation by year and depth stratum for the Hecate Strait assemblage survey over the period 1984 to 2003. Also shown is the area of each depth stratum and the vessel conducting the survey by survey year.

		Depth stratum							Total
Year	**Vessel**	**10-19fm**	**20-29fm**	**30-39fm**	**40-49fm**	**50-59fm**	**60-69fm**	**70-79fm**	**tows**
1984	G.B. Reed/ Arctic Ocean	19	19	23	25	23	23	14	146
1987	Southward Ho	15	12	12	11	16	10	9	85
1989	Southward Ho	17	12	12	15	12	9	13	90
1991	Southward Ho	18	12	15	10	21	15	7	98
1993	W.E. Ricker	16	20	11	15	10	15	7	94
1995	W.E. Ricker	17	19	15	16	14	14	7	102
1996	W.E. Ricker	25	24	21	10	11	10	4	105
1998	W.E. Ricker	14	11	17	13	13	14	4	86
2000	W.E. Ricker	18	22	19	14	15	11	6	105
2002	Viking Storm	17	17	15	16	11	10	6	92
2003	W.E. Ricker	15	17	16	18	15	9	5	95
Area (km^2)		2,657	1,651	908	828	912	792	612	8,360 [1]

[1] total area for survey

Table C.3. Biomass estimates for Rock Sole from the Hecate Strait assemblage trawl survey for the survey years 1984 to 2003, using the method of Starr et al. (2006, unpublished manuscript[1]) (see text for explanation). Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. C.6)
1984	1,052	1,041	732	1,705	0.2213	0.2156
1987	1,205	1,207	809	1,791	0.2073	0.2011
1989	4,510	4,527	3,128	5,904	0.1598	0.1591
1991	1,665	1,656	1,278	2,216	0.1466	0.1489
1993	2,469	2,476	1,729	3,284	0.1668	0.1669
1995	1,520	1,526	1,130	2,046	0.1549	0.1568
1996	2,765	2,775	2,111	3,568	0.1317	0.1331
1998	1,678	1,664	1,060	2,572	0.2226	0.2219
2000	2,247	2,257	1,479	3,261	0.2024	0.2062
2002	1,702	1,707	1,240	2,265	0.1495	0.1478
2003	4,888	4,831	3,440	7,068	0.1798	0.1798

Results

Catch densities of Rock Sole from this survey were generally highest in the central part of Hecate Strait, extending to the top of Graham Island (Figure C.1 to Figure C.11). Rock Sole were mainly taken at depths from 26 to 106 m (5% and 95% quantiles of the empirical depth distribution), with only a few observations at depths greater than 130 m and only one at less than 20 m (Figure C.13).

Estimated Rock Sole biomass indices from this trawl survey showed a slow increasing trend from 1984 to 2002, with large (high) outliers in 1989 and 2003 (Table C.3; Figure C.14). The estimated relative errors were reasonable, ranging from 13 to 22% (Table C.3). These estimates of variability may be biased low, given the non-random selection of tow locations. On average, over half of the survey tows captured Rock Sole (ranging from 0.35 to 0.65) (Figure C.15). Overall, 619 of the 1,098 valid survey tows contained Rock Sole.

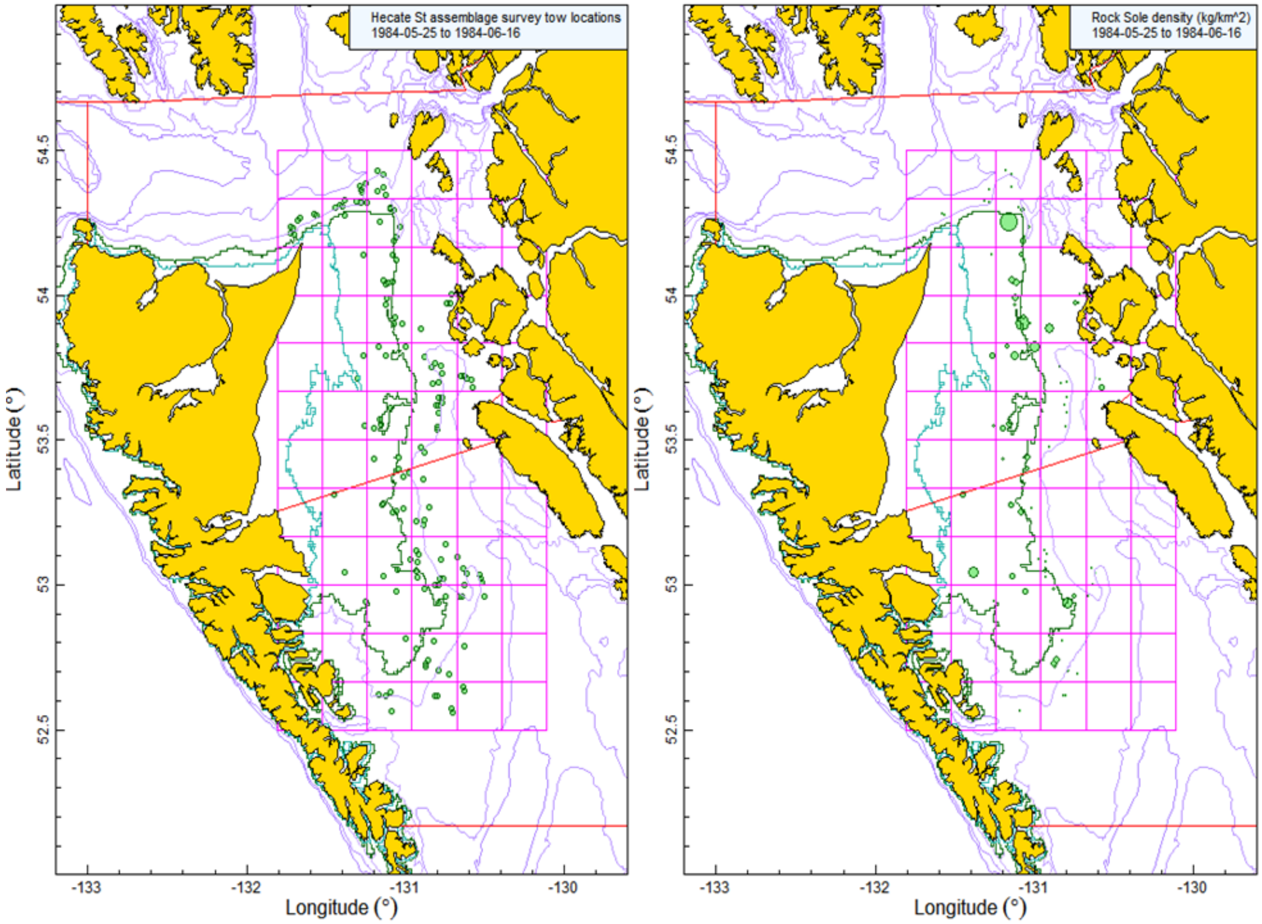


Figure C.1. Valid tow locations and density plots for the 1984 Hecate Strait assemblage survey. Circle sizes in the right-hand density plot scaled across all years (1984, 1987, 1989, 1991, 1993, 1995, 1996, 1998, 2000, 2002, 2003), with the largest circle = 5,805 kg/km^2 in 2003.

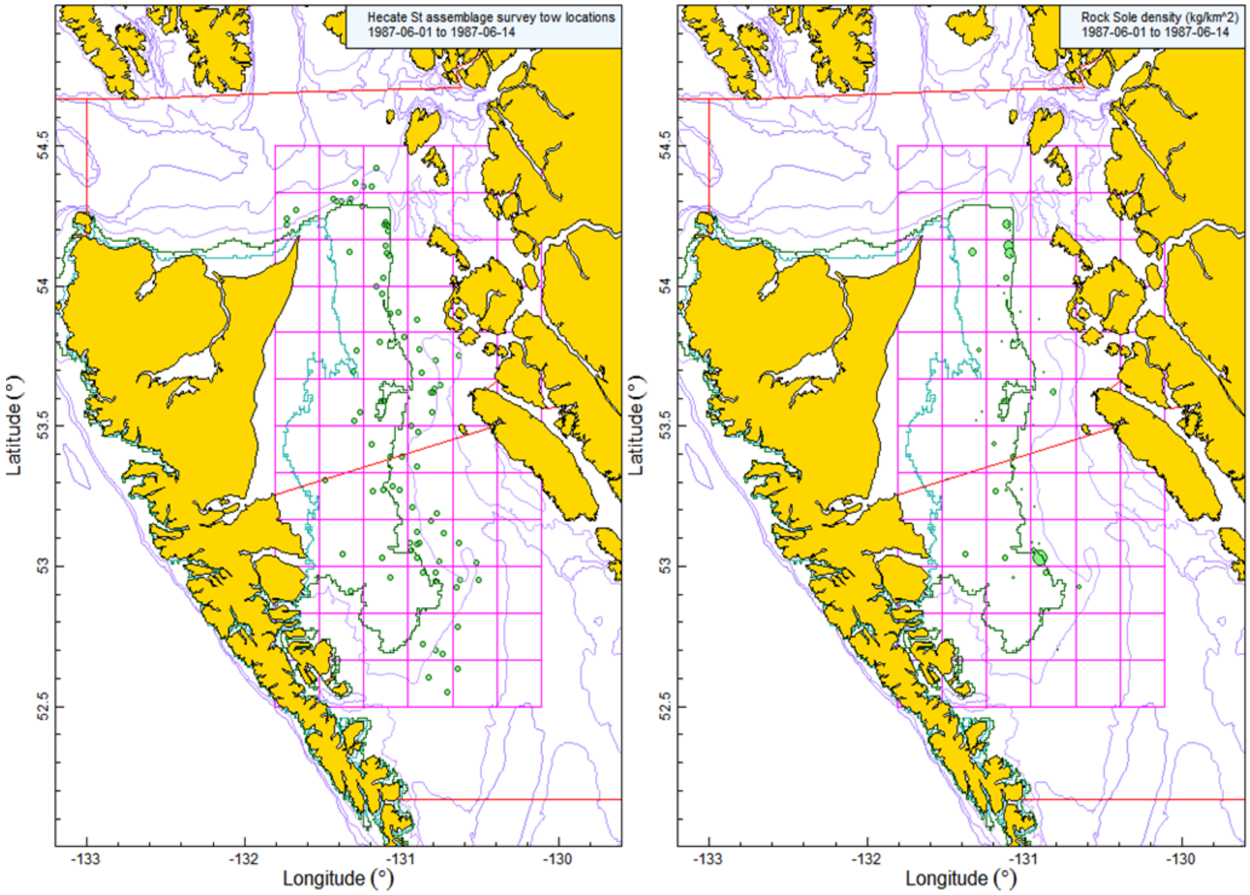


Figure C.2. Tow locations and density plots for the 1987 Hecate Strait assemblage survey (see Figure C.1 caption).

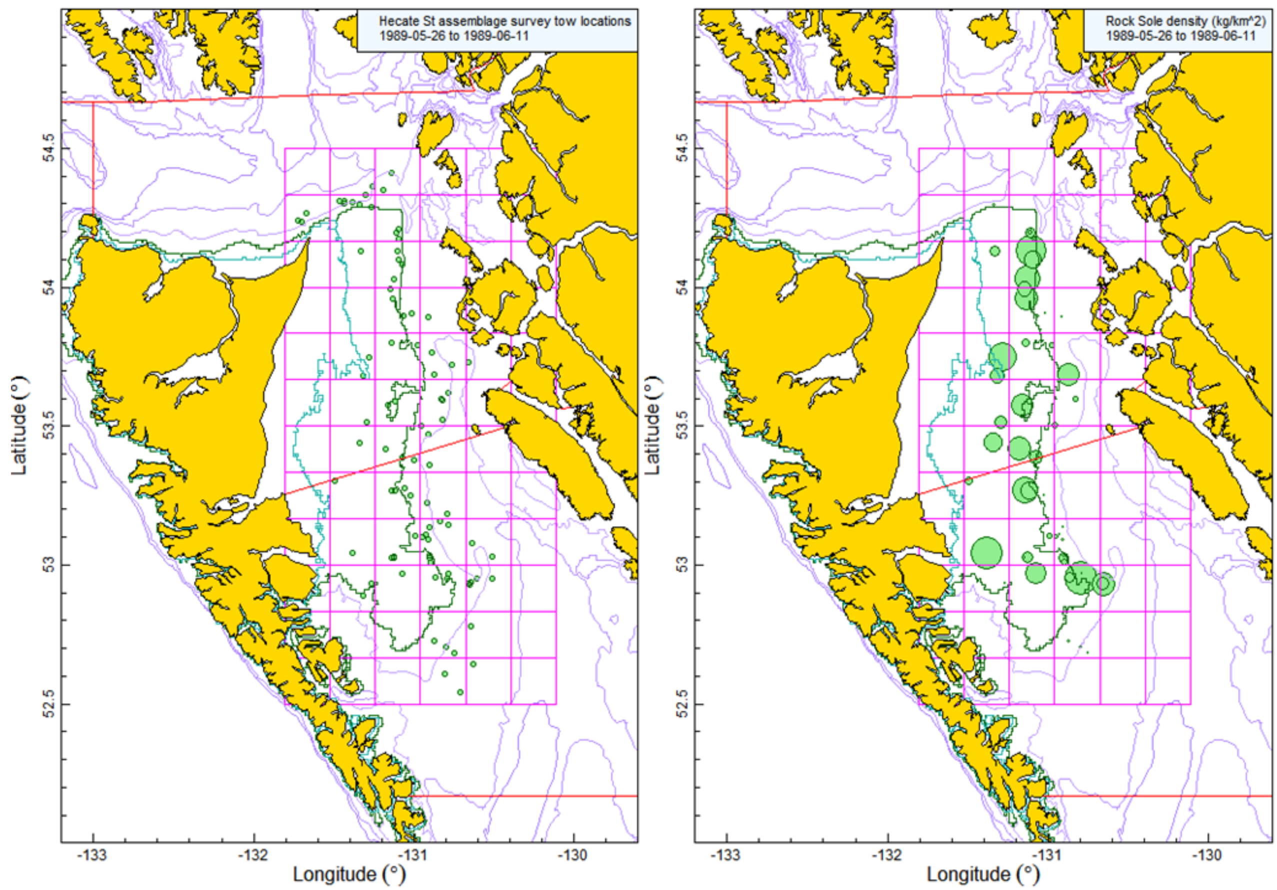


Figure C.3. Tow locations and density plots for the 1989 Hecate Strait assemblage survey (see Figure C.1 caption).

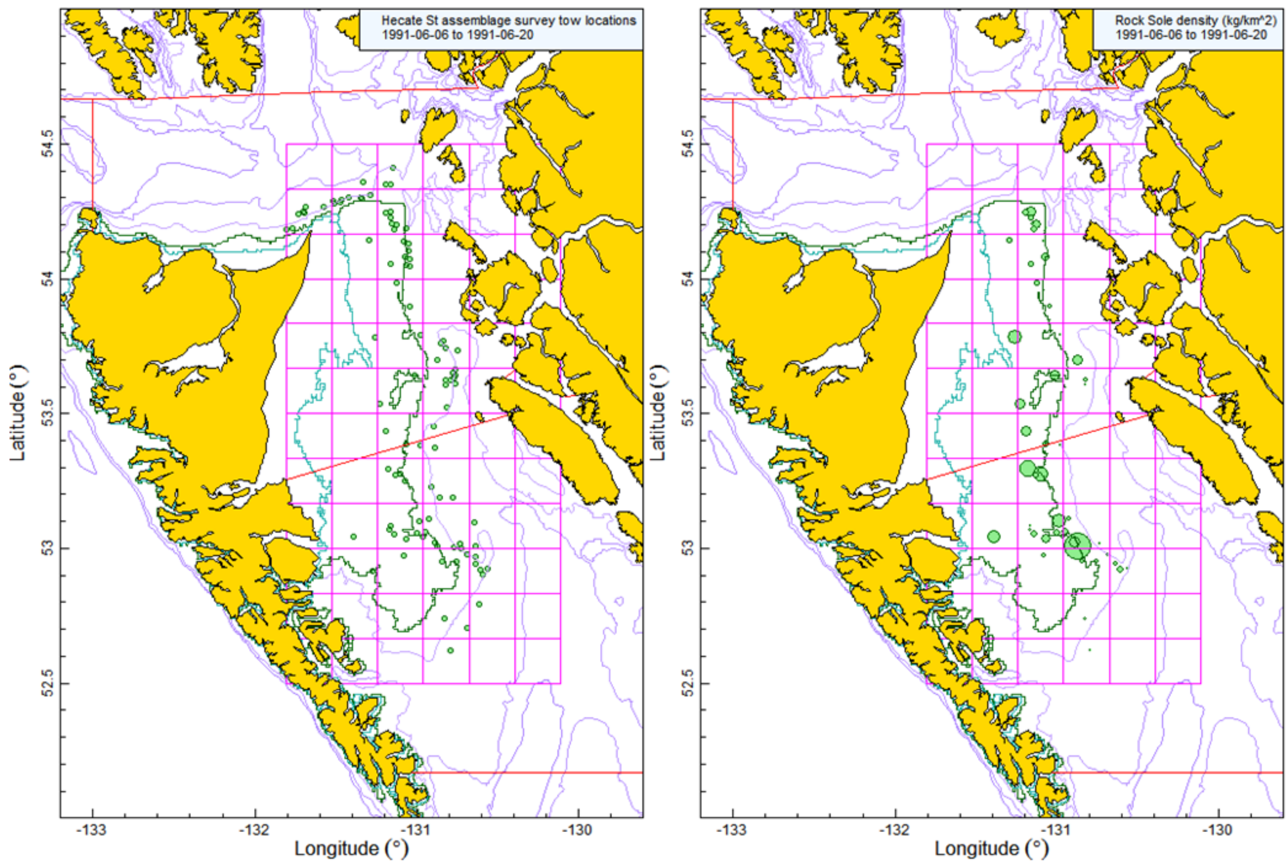


Figure C.4. Tow locations and density plots for the 1991 Hecate Strait assemblage survey (see Figure C.1 caption).

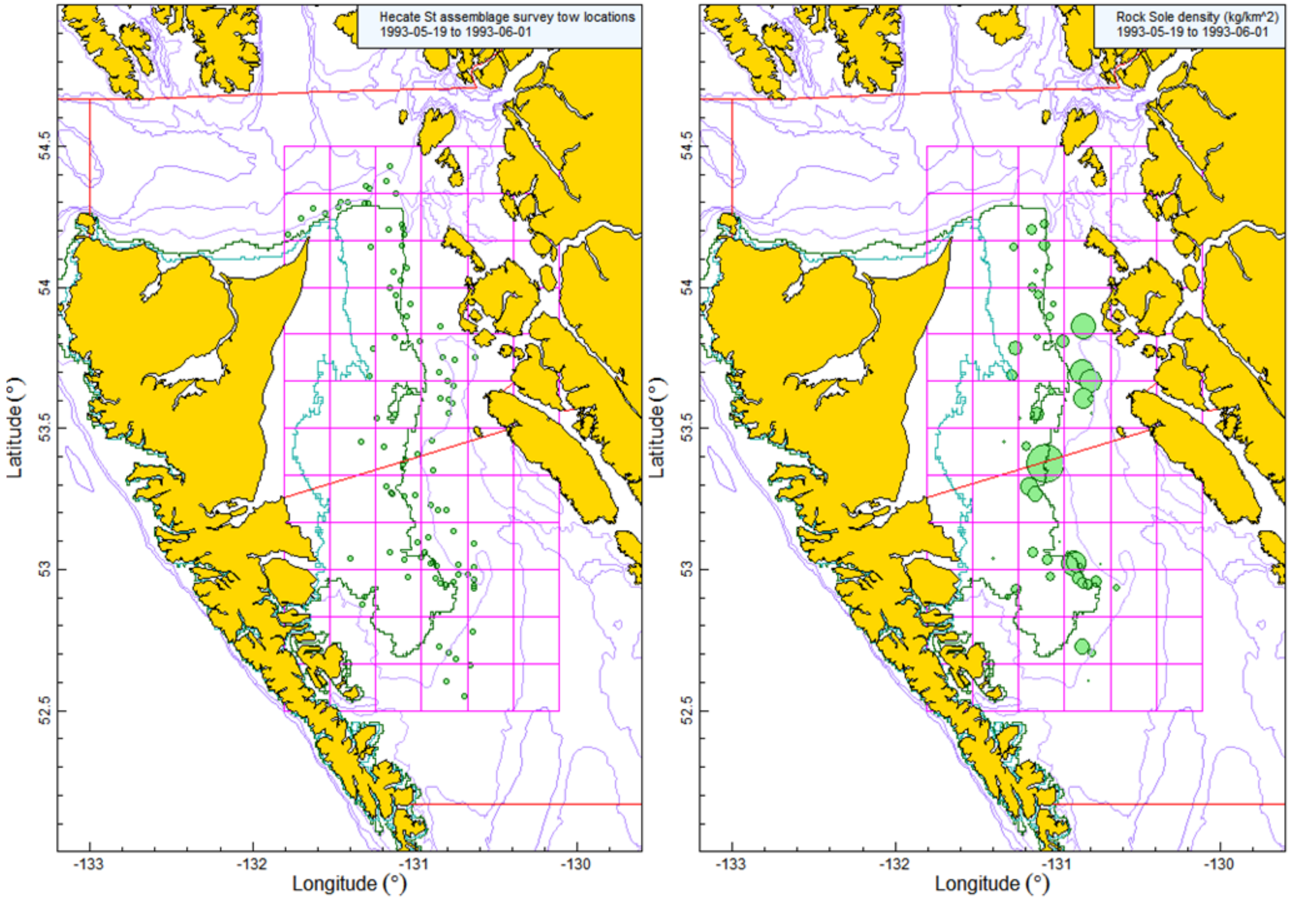


Figure C.5. Tow locations and density plots for the 1993 Hecate Strait assemblage survey (see Figure C.1 caption).

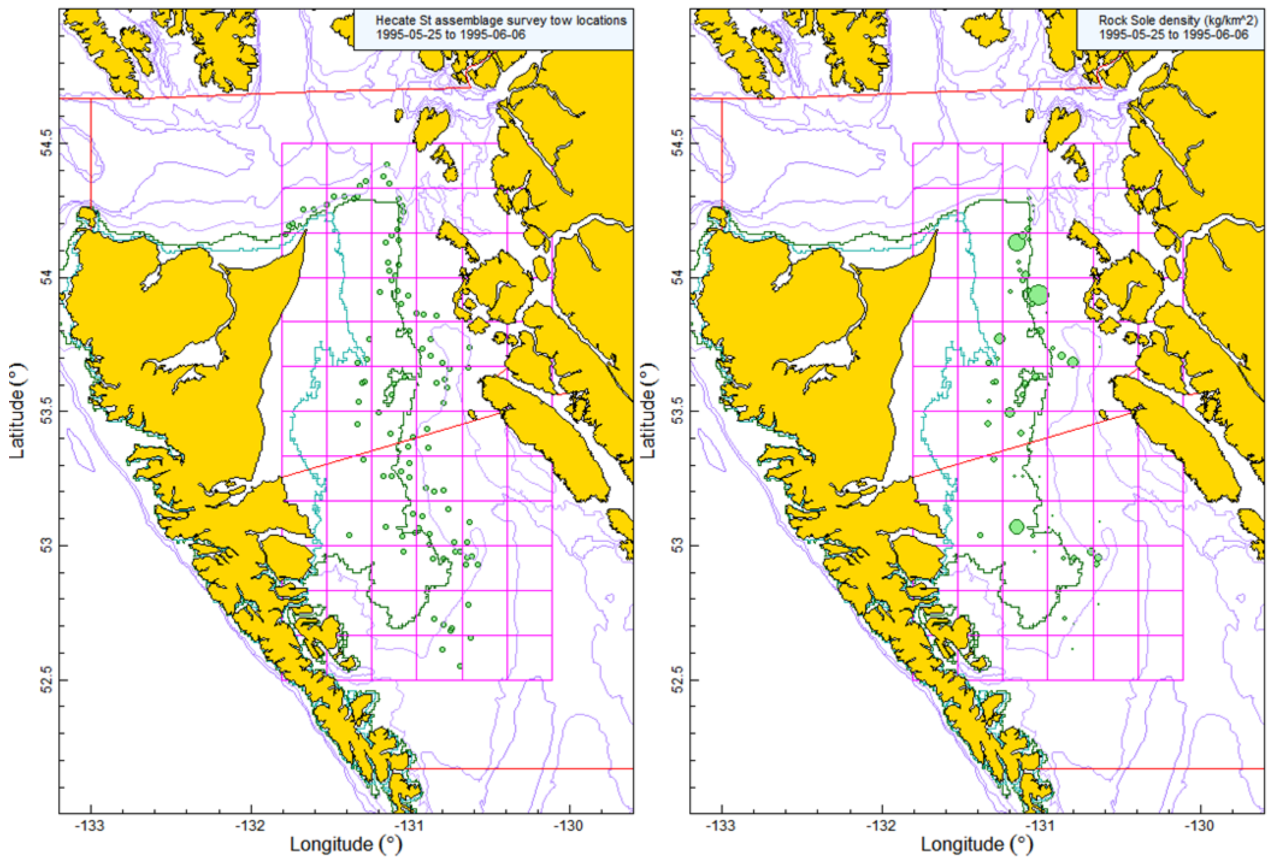


Figure C.6. Tow locations and density plots for the 1995 Hecate Strait assemblage survey (see Figure C.1 caption).

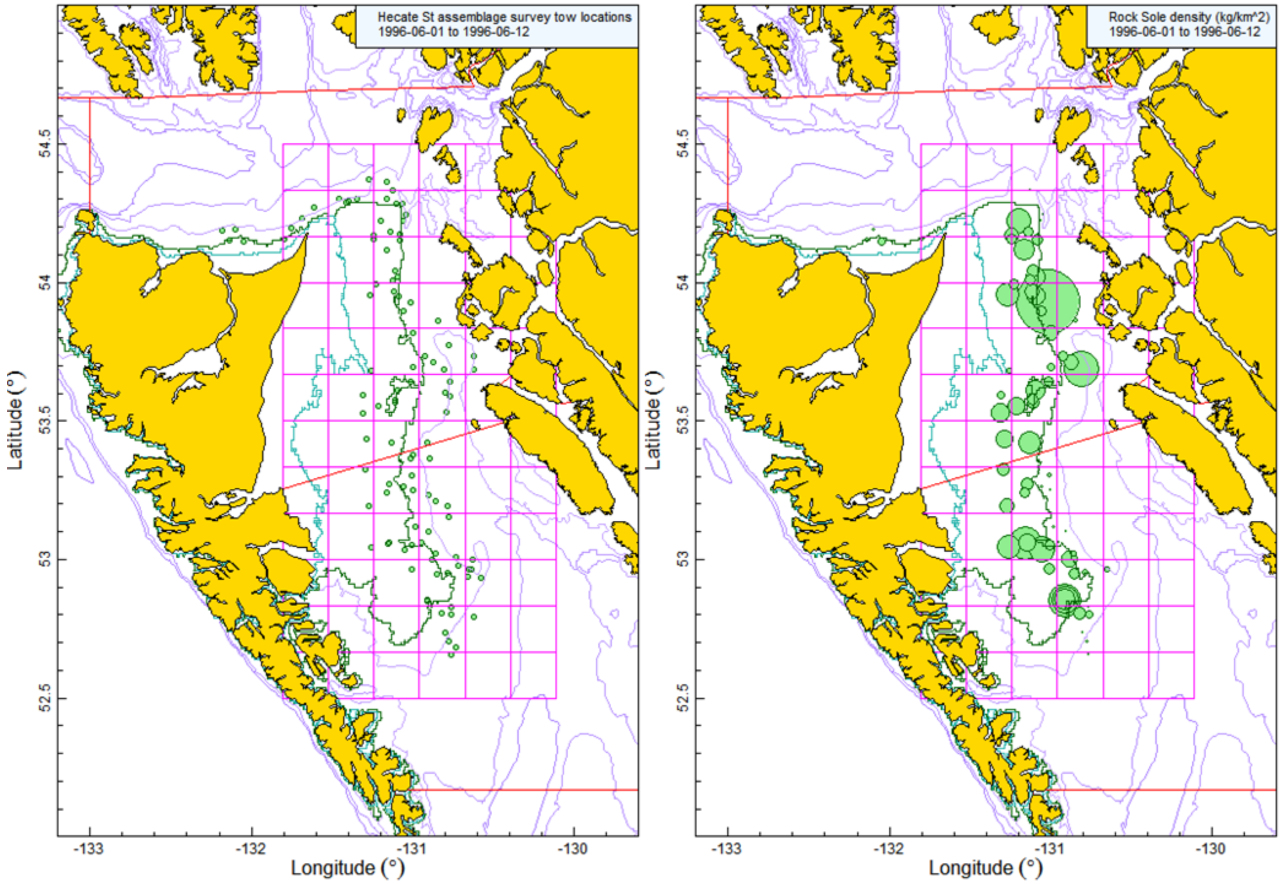


Figure C.7. Tow locations and density plots for the 1996 Hecate Strait assemblage survey (see Figure C.1 caption).

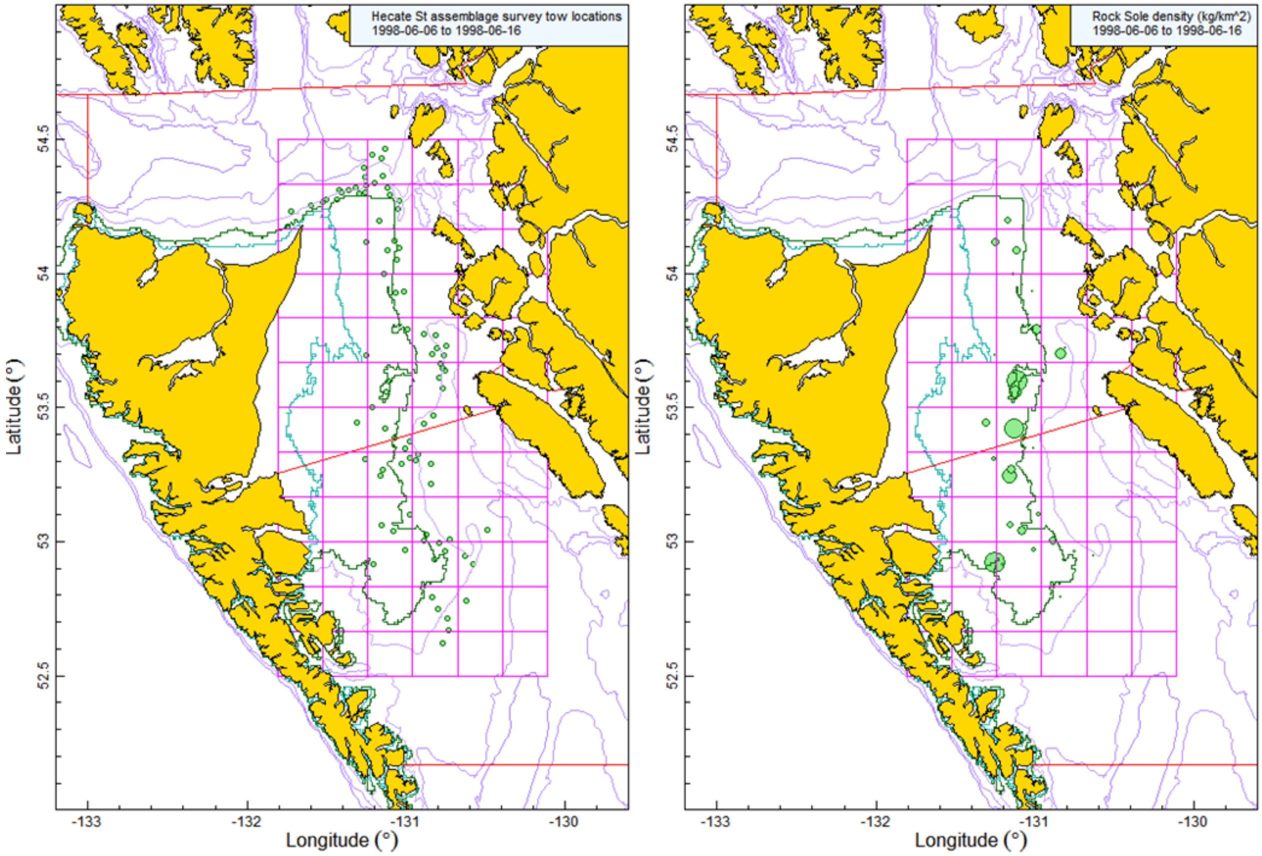


Figure C.8. Tow locations and density plots for the 1998 Hecate Strait assemblage survey (see Figure C.1 caption).

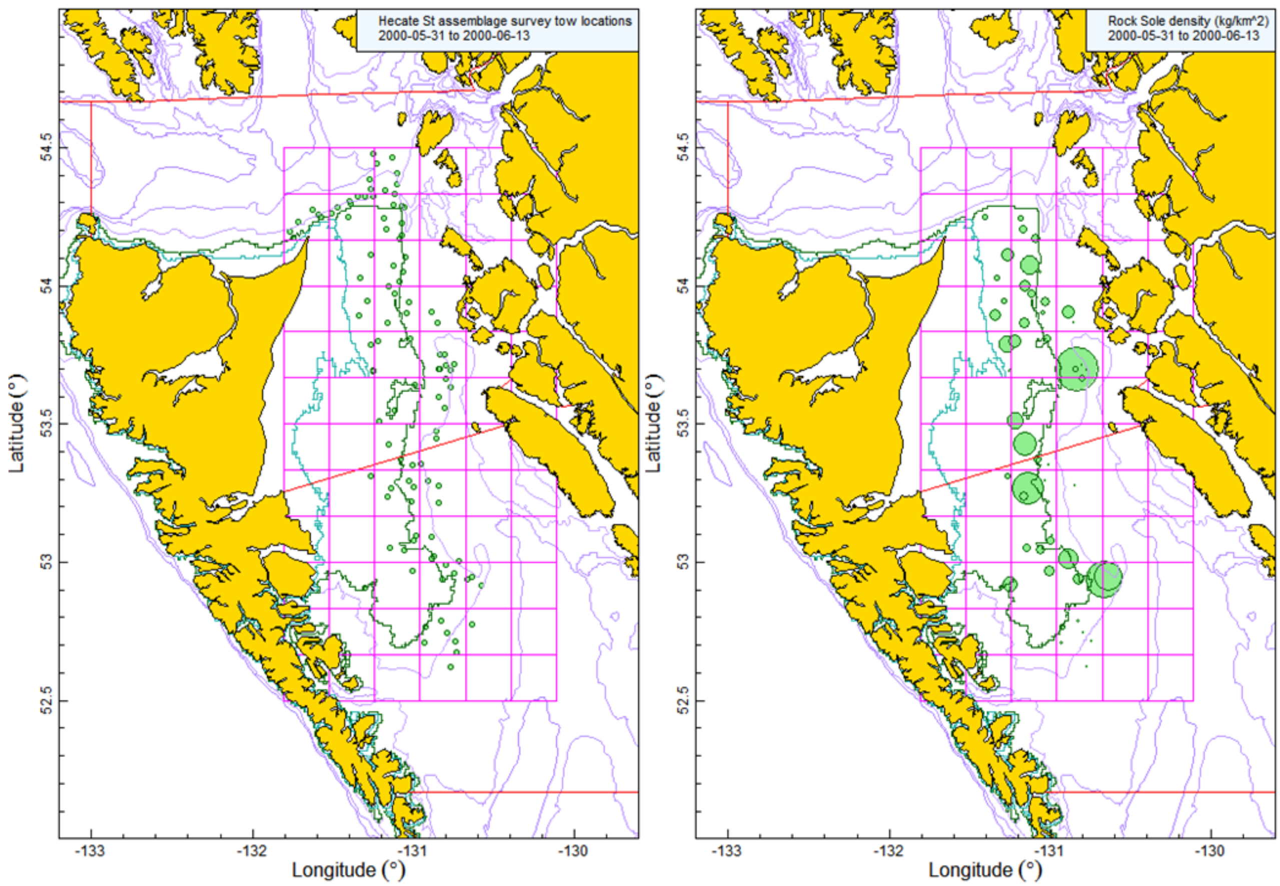
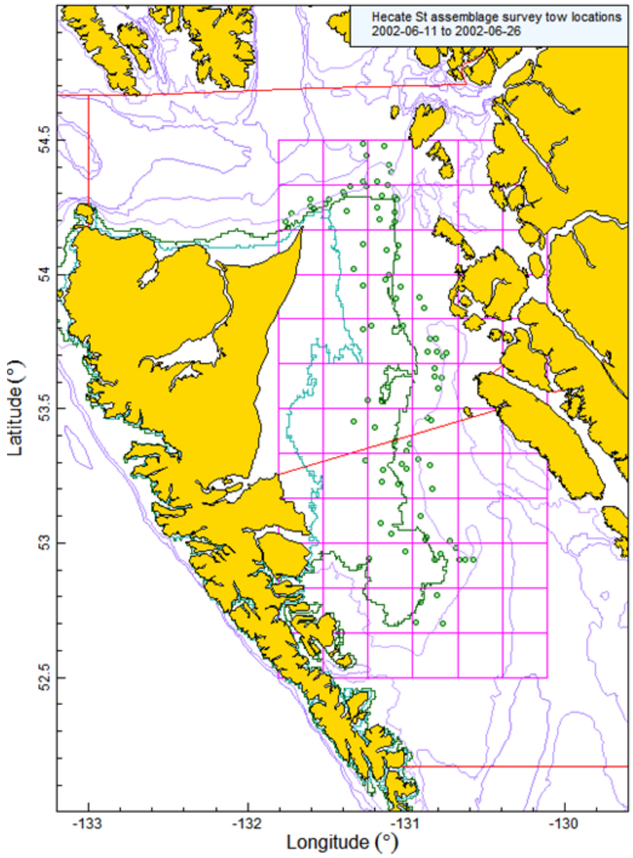


Figure C.9. Tow locations and density plots for the 2000 Hecate Strait assemblage survey (see Figure C.1 caption).



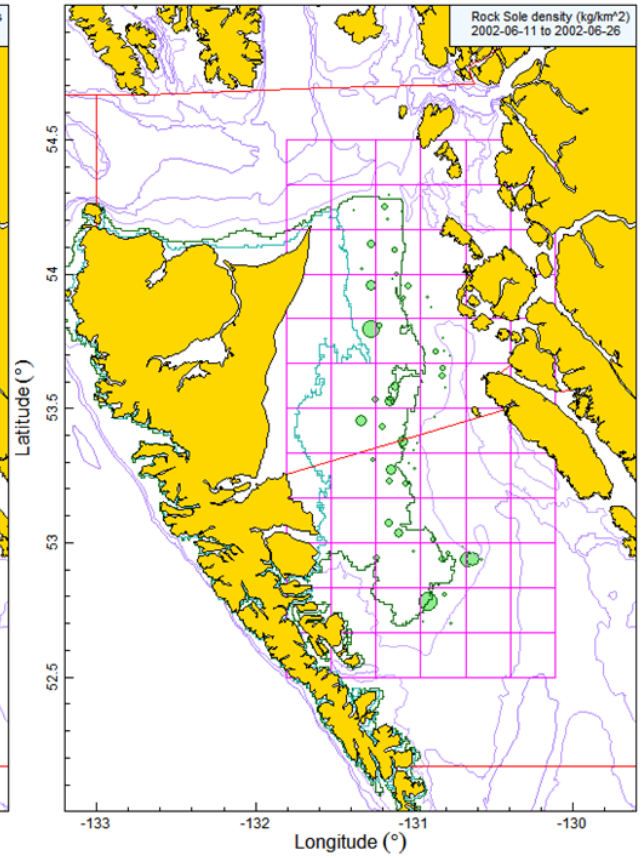


Figure C.10. Tow locations and density plots for the 2002 Hecate Strait assemblage survey (see Figure C.1 caption).

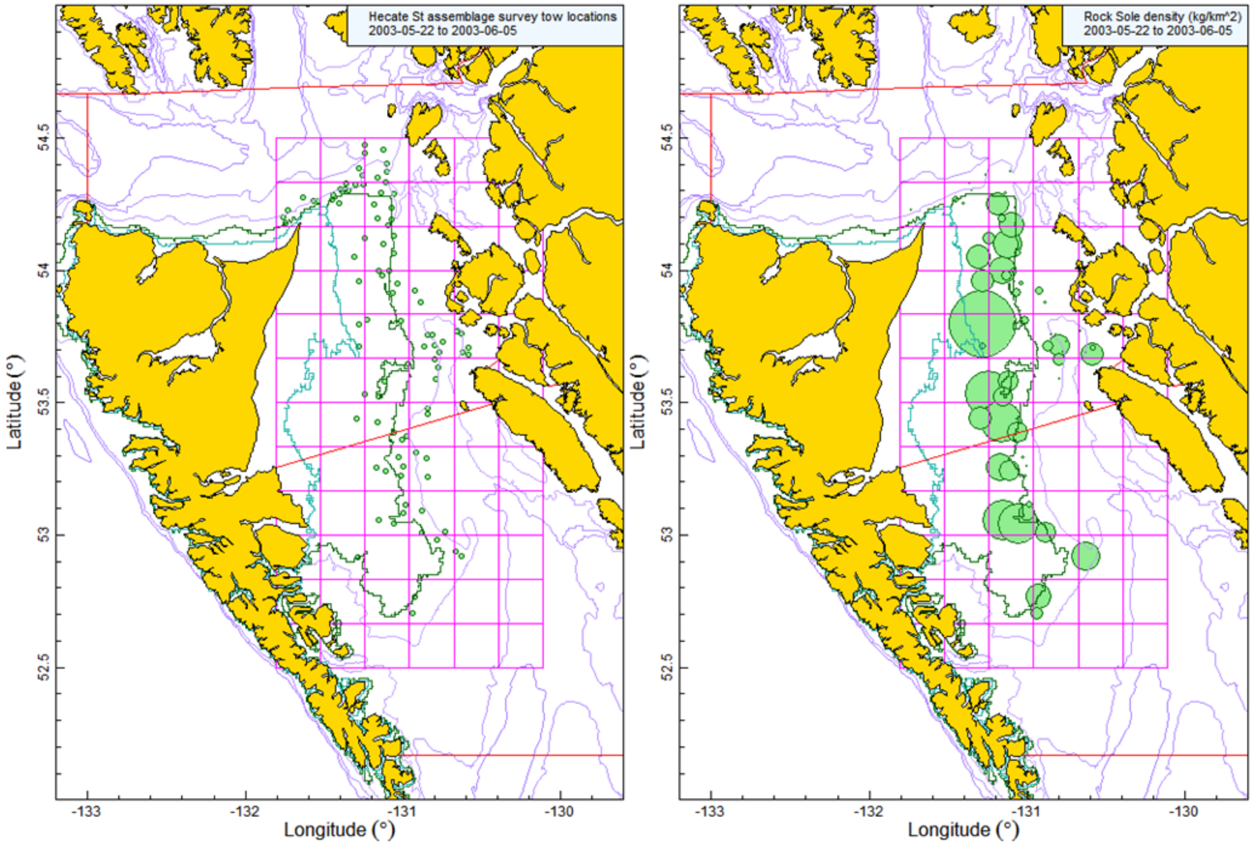


Figure C.11. Tow locations and density plots for the 2003 Hecate Strait assemblage survey (see Figure C.1 caption).

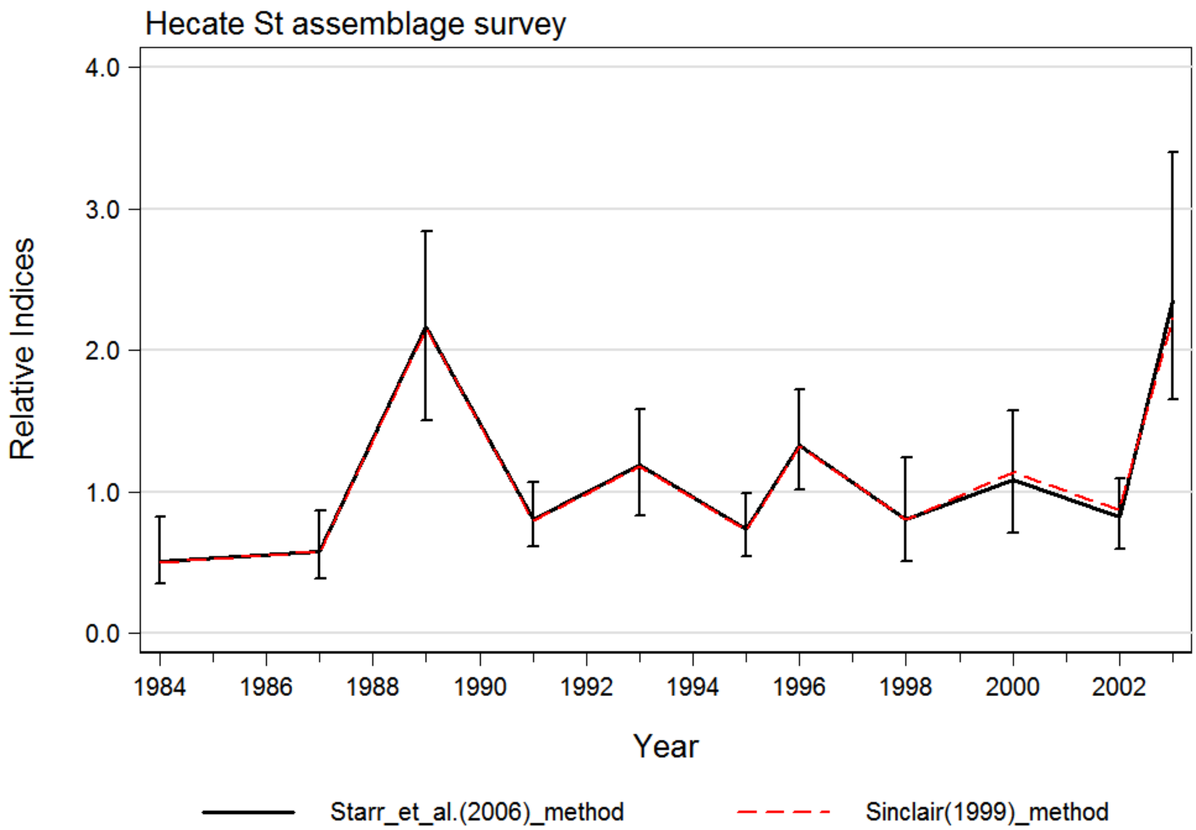


Figure C.12. Comparison of two methods used to estimate annual biomass indices from the Hecate Strait assemblage survey. See text for explanation of each method.

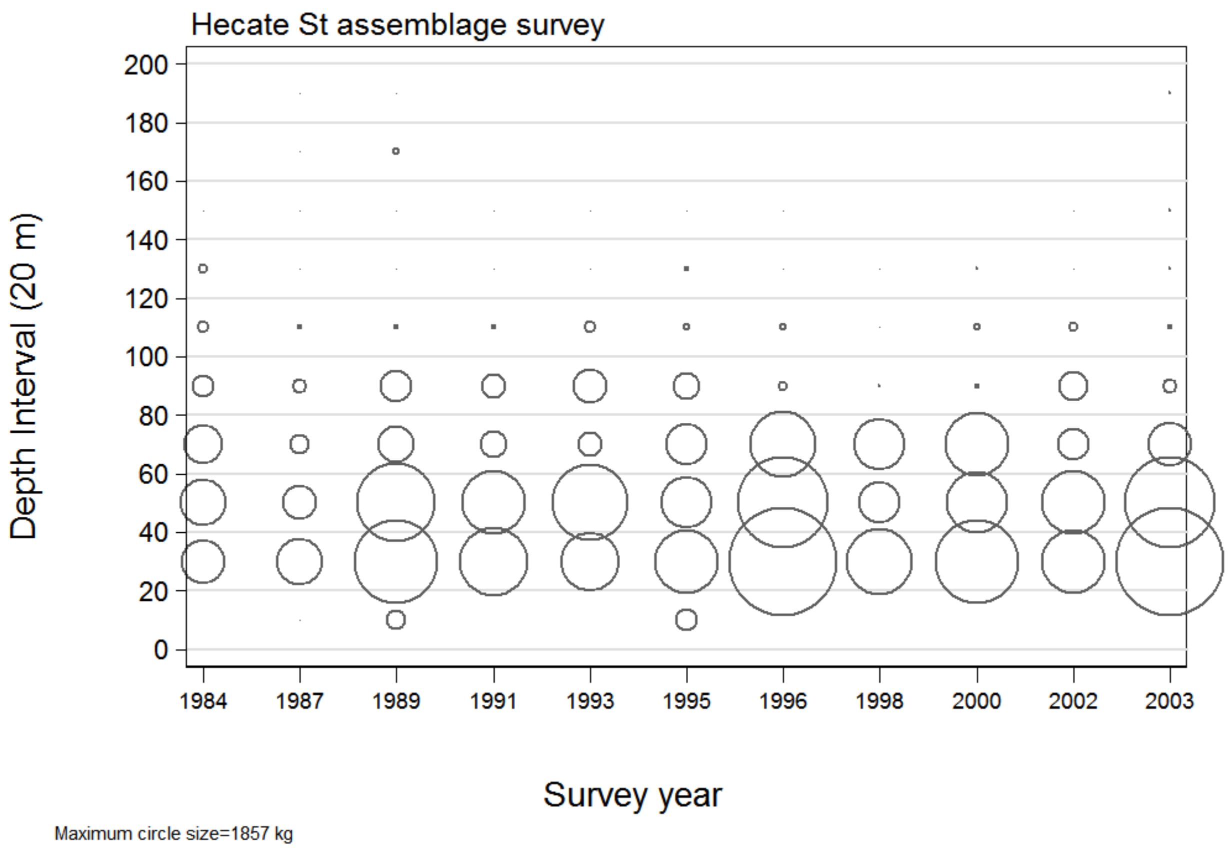


Figure C.13. Distribution of observed catch weights of Rock Sole for the Hecate Strait assemblage survey (Table C.2) by survey year and 20 m depth zone. Depth zones are indicated by the mid-point of the depth interval and circles in the panel are scaled to the maximum value (1,857 kg) in the 20–40 m interval in 2003. The 1% and 99% quantiles for the Rock Sole empirical start of tow depth distribution = 24 m and 123 m respectively.

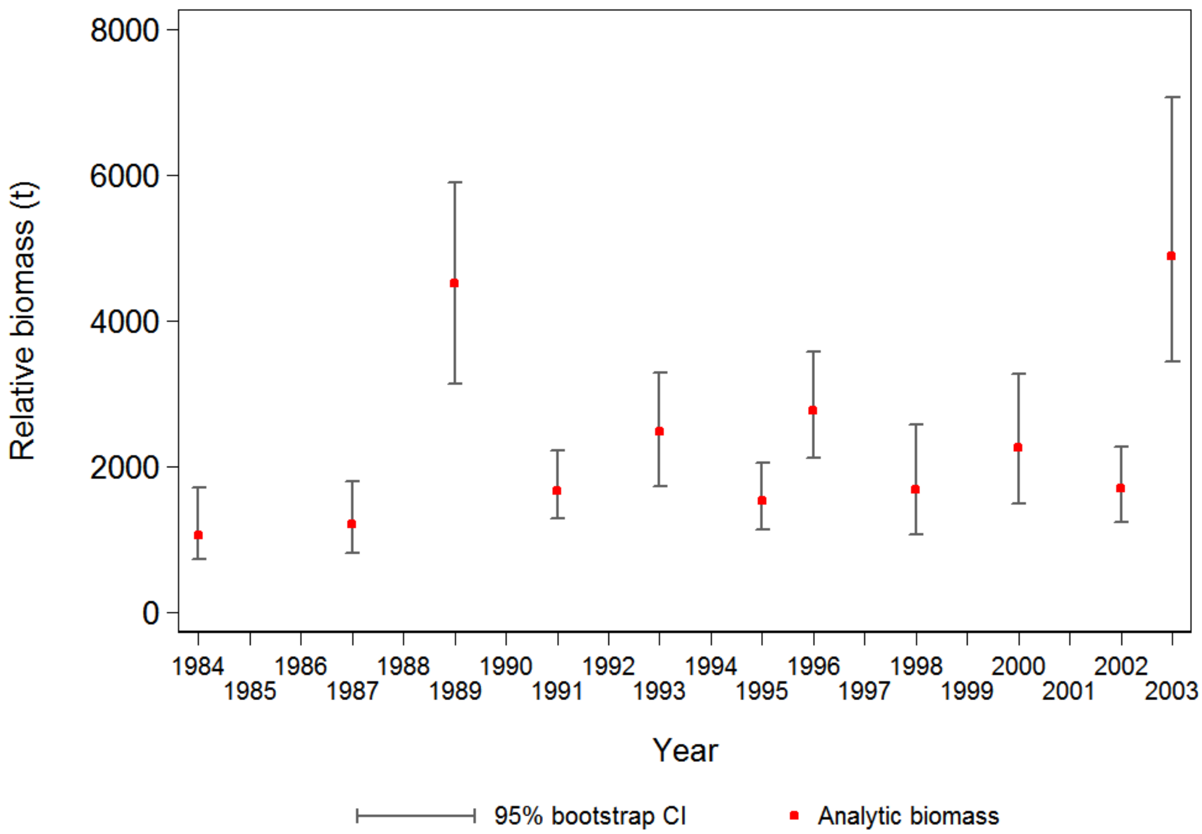


Figure C.14. Plot of biomass estimates for Rock Sole (values provided in Table C.3) from the Hecate Strait assemblage survey over the period 1984 to 2003. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

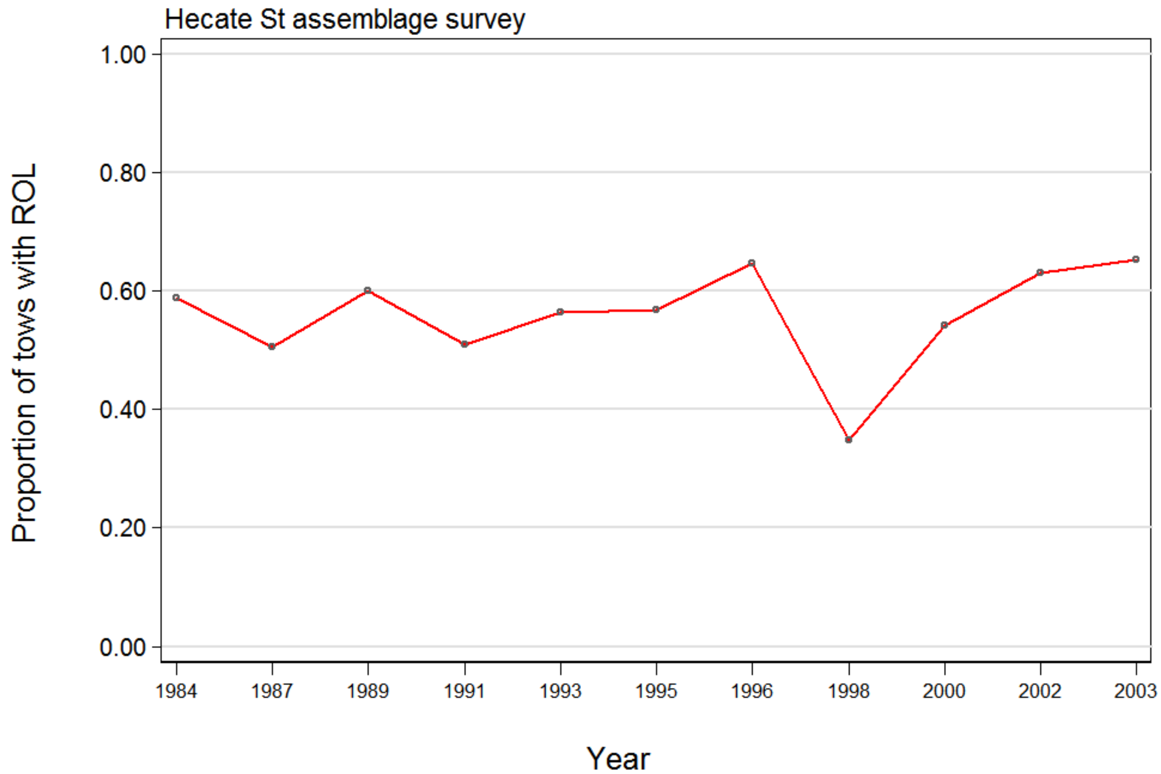


Figure C.15. Proportion of tows by year which contain Rock Sole (ROL) from the Hecate Strait assemblage survey over the period 1984 to 2003.

HECATE STRAIT SYNOPTIC SURVEY

Data selection

This survey has been conducted in five alternating years over the period 2005 to 2013 in Hecate Strait and in Dixon Entrance at the top of Graham Island (all valid tow starting positions by survey year are shown in Figure C.16 to Figure C.20). This survey treats the full spatial coverage as a single aerial stratum divided into four depth strata: 10–70 m; 70–130 m; 130–220 m; and 220–500 m (Table C.4).

A doorspread density value (Equation C.3) was generated for each tow based on the catch of Rock Sole from the mean doorspread for the tow and the distance travelled. [`distance travelled`] is a database field which is calculated directly from the tow track. This field is used preferentially for the variable D_{yij} in Equation C.3. A calculated value ([`vessel speed`] X [`tow duration`]) can be used for this variable if [`distance travelled`] is missing, but there were no instances of this occurring in the 5 trawl surveys. Missing values for the [`doorspread`] field were filled in with the mean doorspread for the survey year (217 values over all years: Table C.5).

Table C.4. Number of usable tows for biomass estimation by year and depth stratum for the Hecate Strait synoptic survey over the period 2005 to 2013. Also shown is the area of each depth stratum and the vessel conducting the survey by survey year.

		Depth stratum				Total
Year	**Vessel**	**10-70**	**70-130**	**130-220**	**220-500**	**tows**
2005	Frosti	80	88	26	9	203
2007	W.E. Ricker	48	43	36	7	134
2009	W.E. Ricker	53	43	48	12	156
2011	W.E. Ricker	71	51	50	14	186
2013	W.E. Ricker	74	42	43	16	175
Area (km^2)		5,958	3,011	2,432	1,858	13,259[1]

[1] total area for survey

Table C.5. Number of missing doorspread values by year for the Hecate Strait synoptic survey over the period 2005 to 2013. Also shown is the number of available doorspread observations and the mean doorspread value for the survey year.

Year	**Number tows with missing doorspreads**[1]	**Number tows with doorspread observations**[2]	**Mean doorspread (m) used for tows with missing values**[2]
2005	7	217	64.4
2007	98	37	59.0
2009	93	70	54.0
2011	13	186	54.8
2013	6	176	51.7
Total	217	686	57.2

[1] valid biomass estimation tows only

[2] includes tows not used for biomass estimation

Table C.6. Biomass estimates for Rock Sole from the Hecate Strait synoptic trawl survey for the survey years 2005 to 2013. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	**Biomass (t)**	**Mean bootstrap biomass (t)**	**Lower bound biomass (t)**	**Upper bound biomass (t)**	**Bootstrap CV**	**Analytic CV (Eq. C.6)**
2005	2,061	2,043	1,545	2,893	0.1523	0.1503
2007	1,963	1,979	1,389	2,552	0.1496	0.1565
2009	1,868	1,860	1,256	2,912	0.2246	0.2148
2011	2,317	2,329	1,670	3,317	0.1746	0.1745
2013	4,424	4,458	3,075	6,736	0.2052	0.2068

Results

Catch densities of Rock Sole from this survey were generally highest in the central part of Hecate Strait, extending to the top of Graham Island (Figure C.16 to Figure C.20). Very few (or none) Rock Sole were observed in Dixon Entrance. Rock Sole were mainly taken at depths from 23 to 112 m (5% and 95% quantiles of the empirical depth distribution), but there were sporadic observations at depths down to about 200 m and up to about 20 m (Figure C.21).

Estimated Rock Sole doorspread biomass from this trawl survey showed no overall trend from 2005 to 2011, but nearly doubled in 2013 relative to the 2011 observation (Table C.6; Figure C.22). The estimated relative errors were reasonable, ranging from 15 to 22% (Table C.7). On average, about half of the survey tows captured Rock Sole (ranging from 0.41 to 0.55) (Figure C.23). Overall, 425 of the 854 valid survey tows contained Rock Sole.

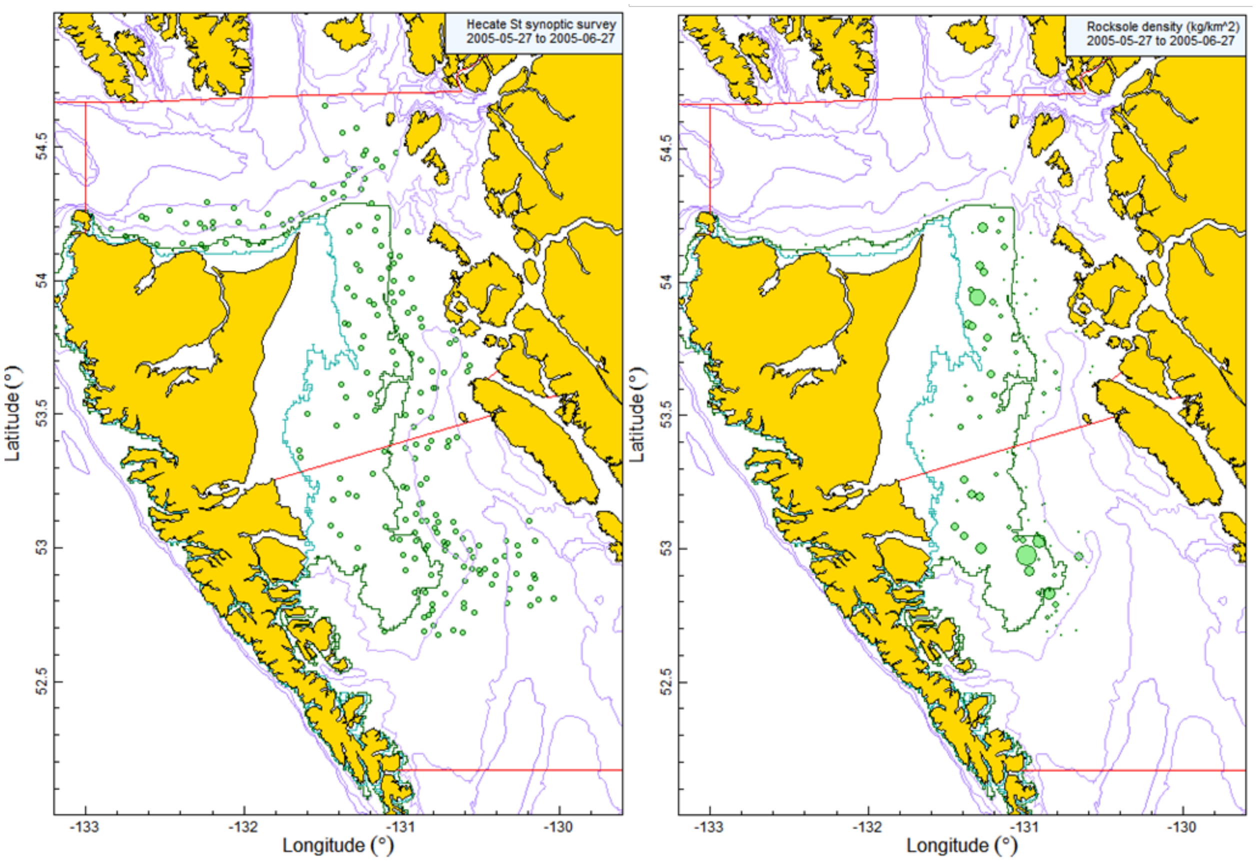


Figure C.16. Valid tow locations and density plots for the 2005 Hecate Strait synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2005, 2007, 2009, 2011, 2013), with the largest circle = 9,324 kg/km^2 in 2013. Red lines indicate boundaries for PMFC major statistical areas 5C and 5D.

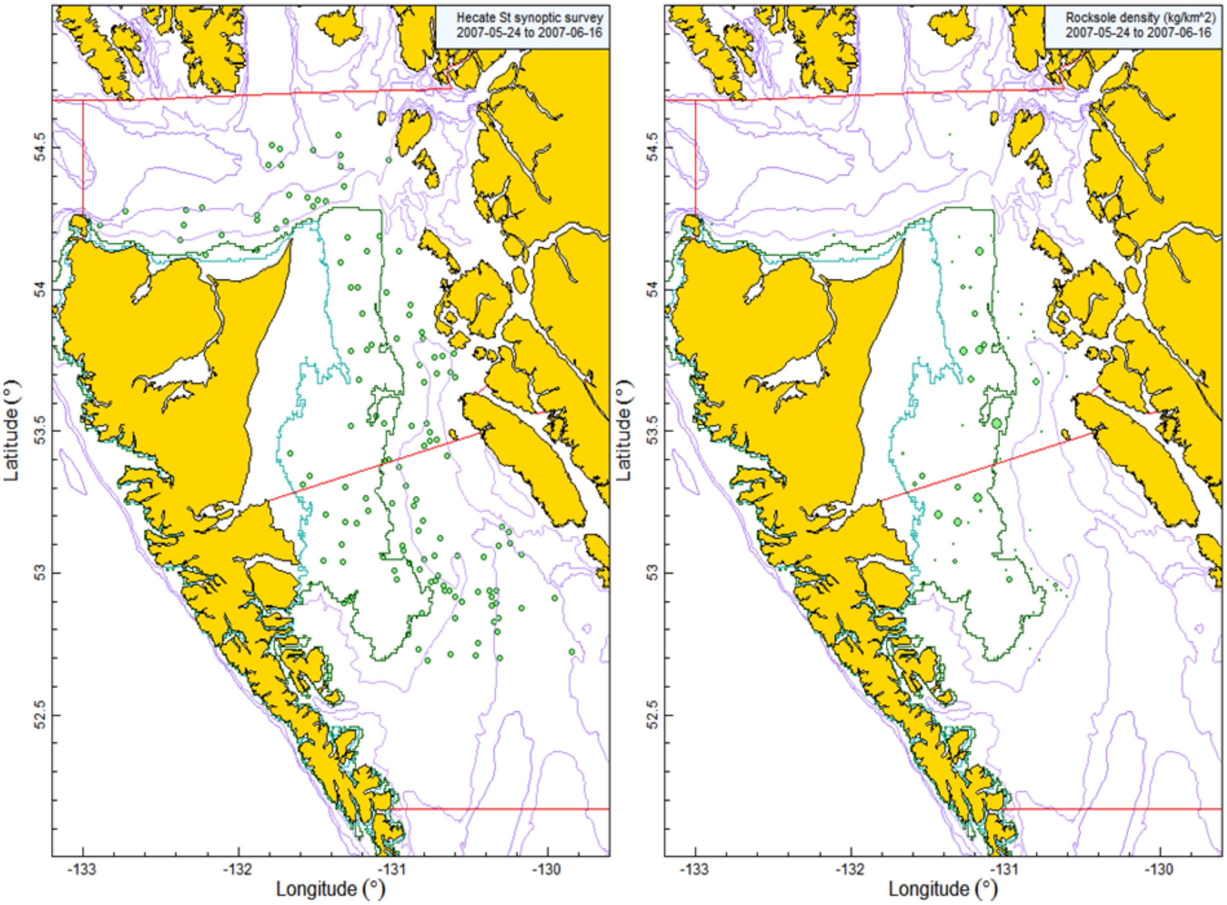


Figure C.17. Tow locations and density plots for the 2007 Hecate Strait synoptic survey (see Figure C.16 caption).

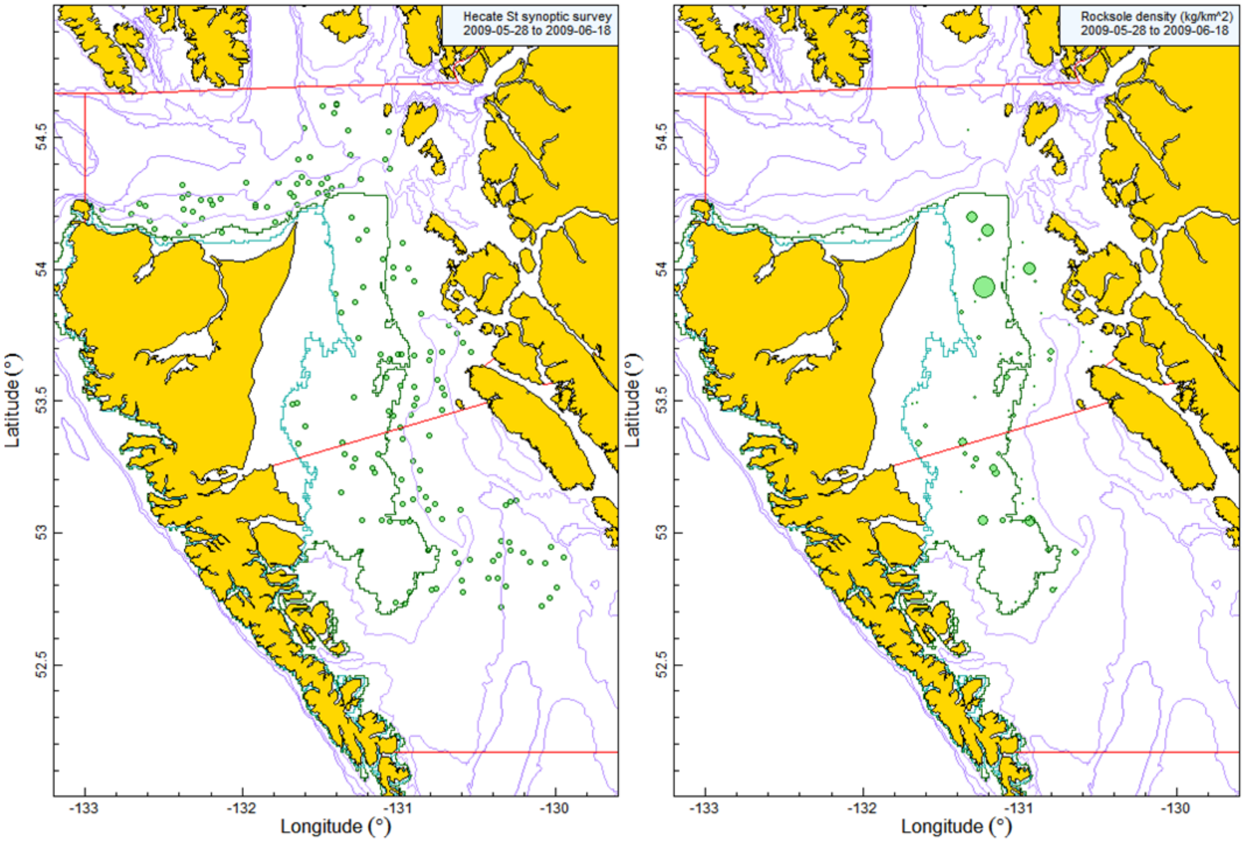


Figure C.18. Tow locations and density plots for the 2009 Hecate Strait synoptic survey (see Figure C.16 caption).

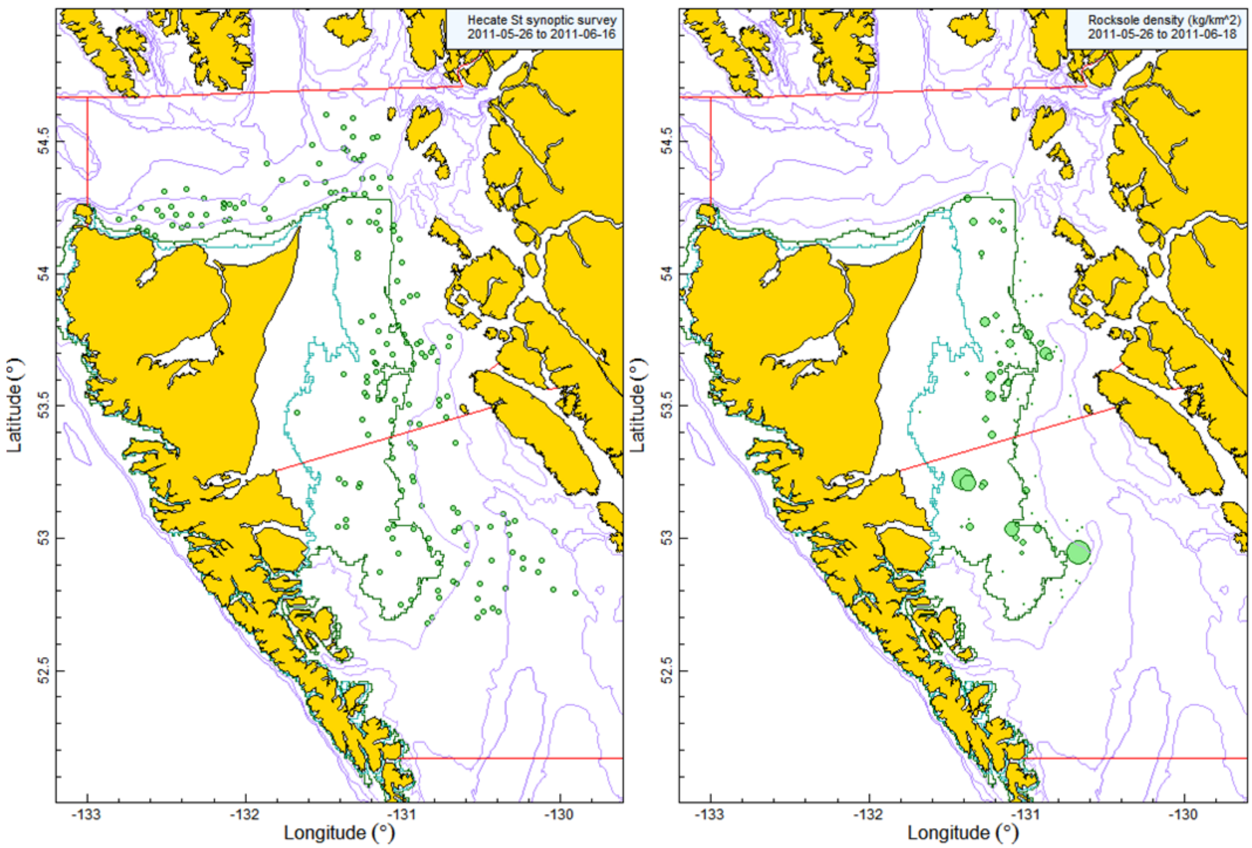


Figure C.19. Tow locations and density plots for the 2011 Hecate Strait synoptic survey (see Figure C.16 caption).

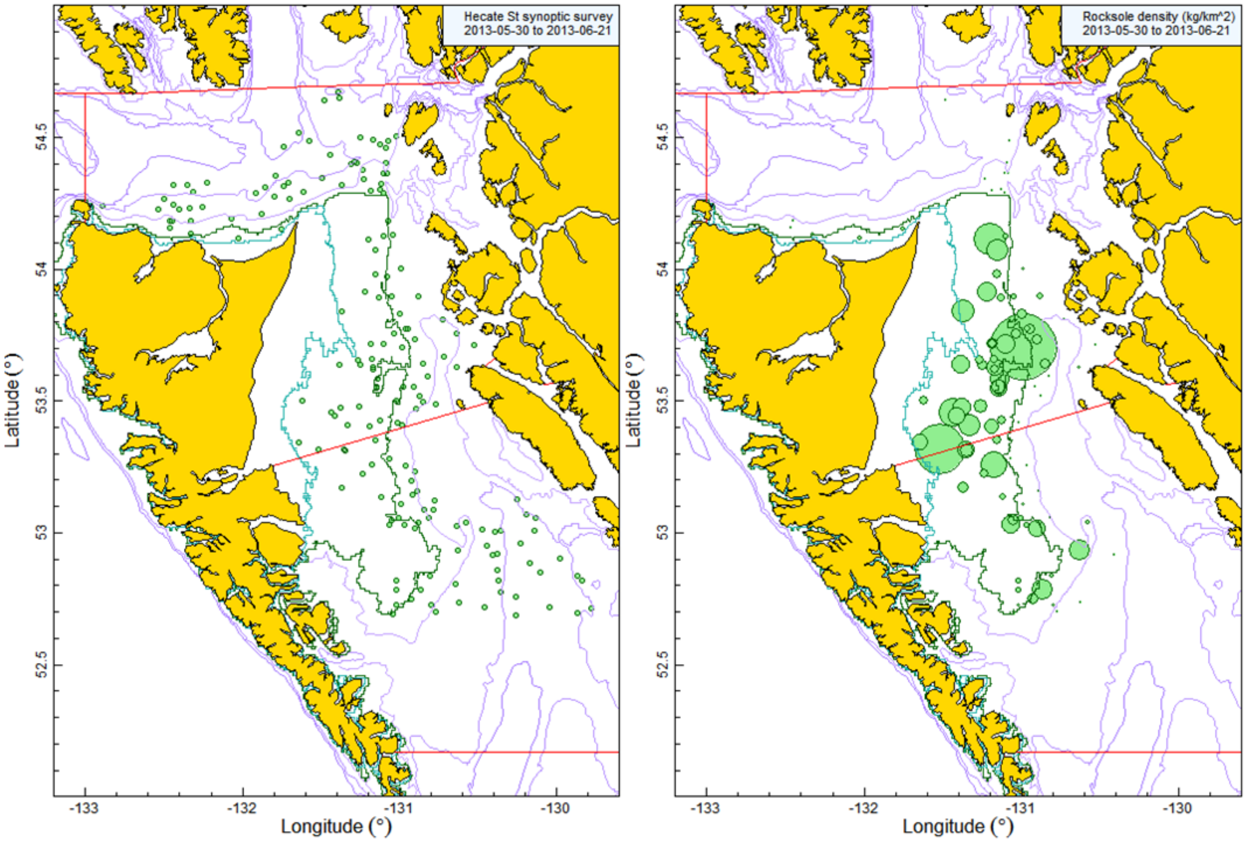


Figure C.20. Tow locations and density plots for the 2013 Hecate Strait synoptic survey (see Figure C.16 caption).

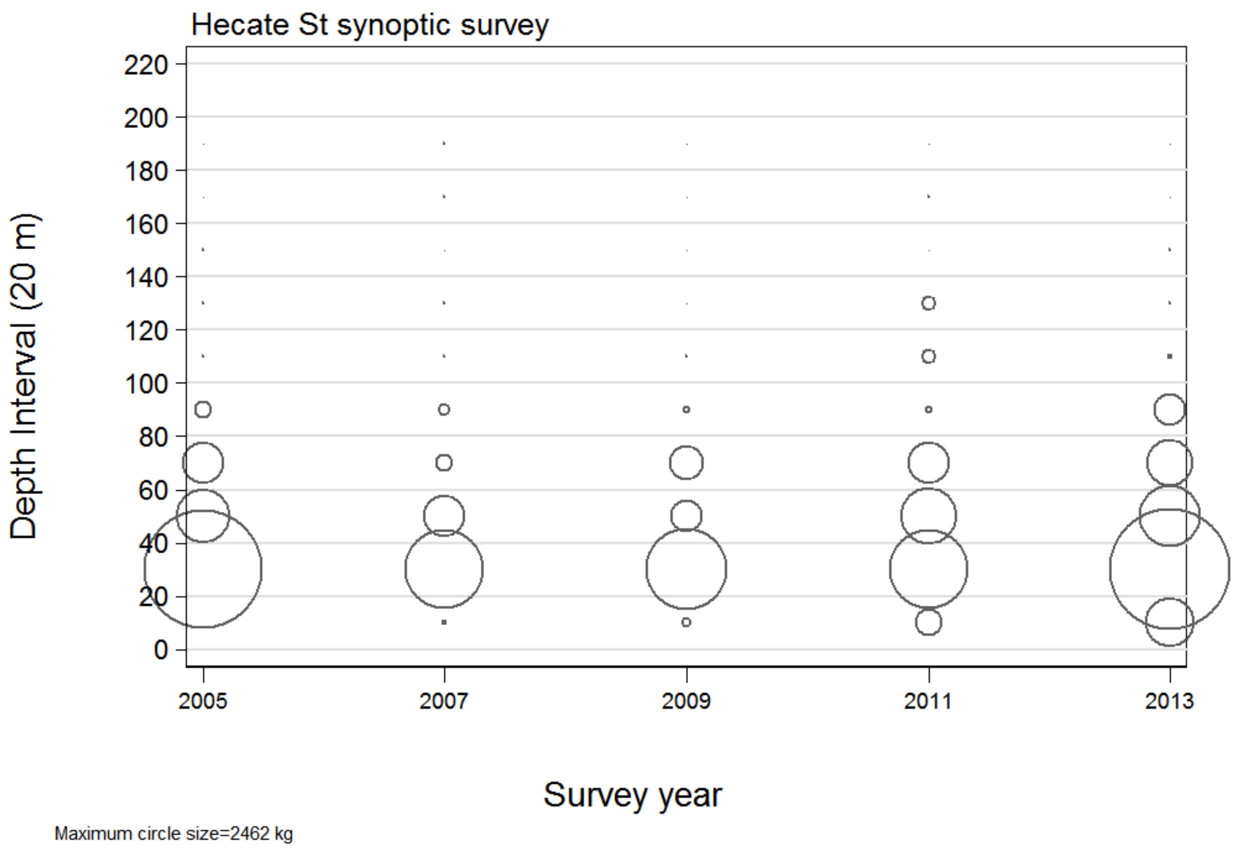


Figure C.21. Distribution of observed catch weights of Rock Sole for the Hecate Strait synoptic survey (Table C.4) by survey year and 20 m depth zone. Depth zones are indicated by the mid-point of the depth interval and circles in the panel are scaled to the maximum value (2,462 kg) in the 20–40 m interval in 2013. The 1% and 99% quantiles for the Rock Sole empirical start of tow depth distribution= 20 m and 162 m respectively.

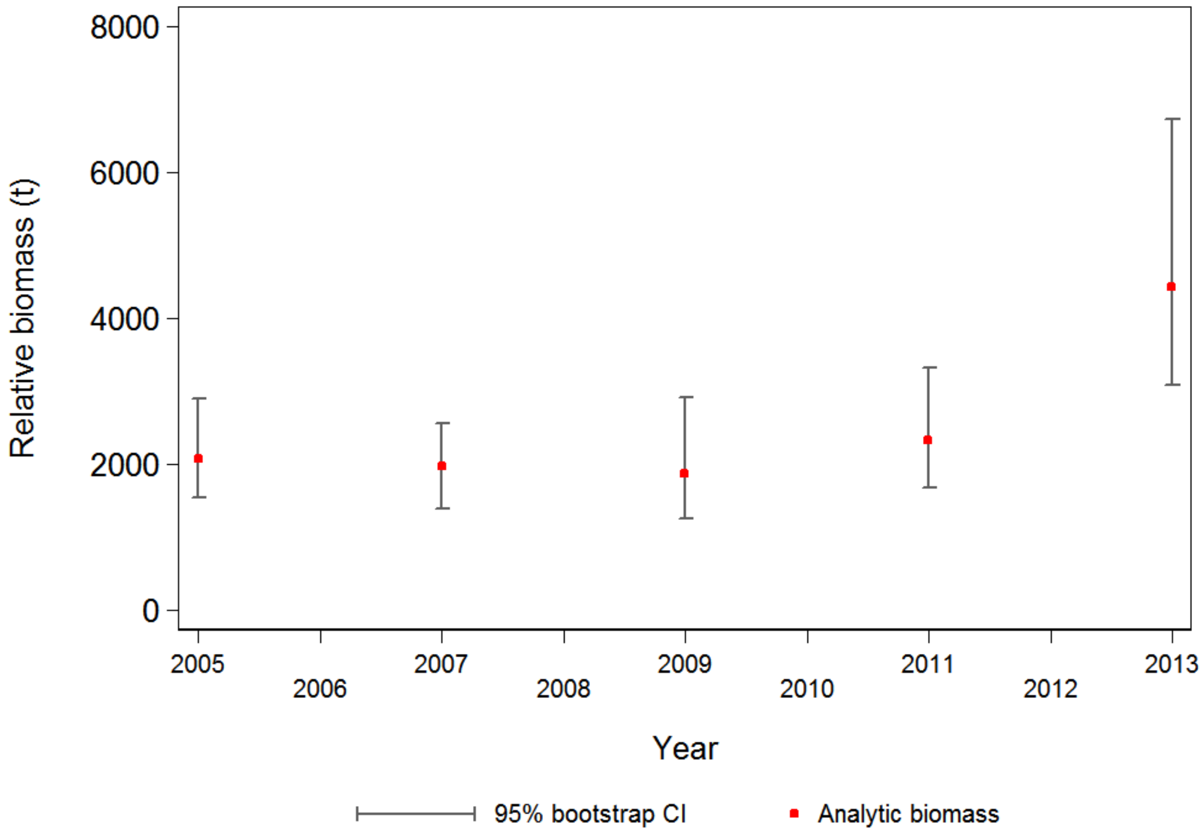


Figure C.22. Plot of biomass estimates for Rock Sole (values provided in Table C.6) from the Hecate Strait synoptic survey over the period 2005 to 2013. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

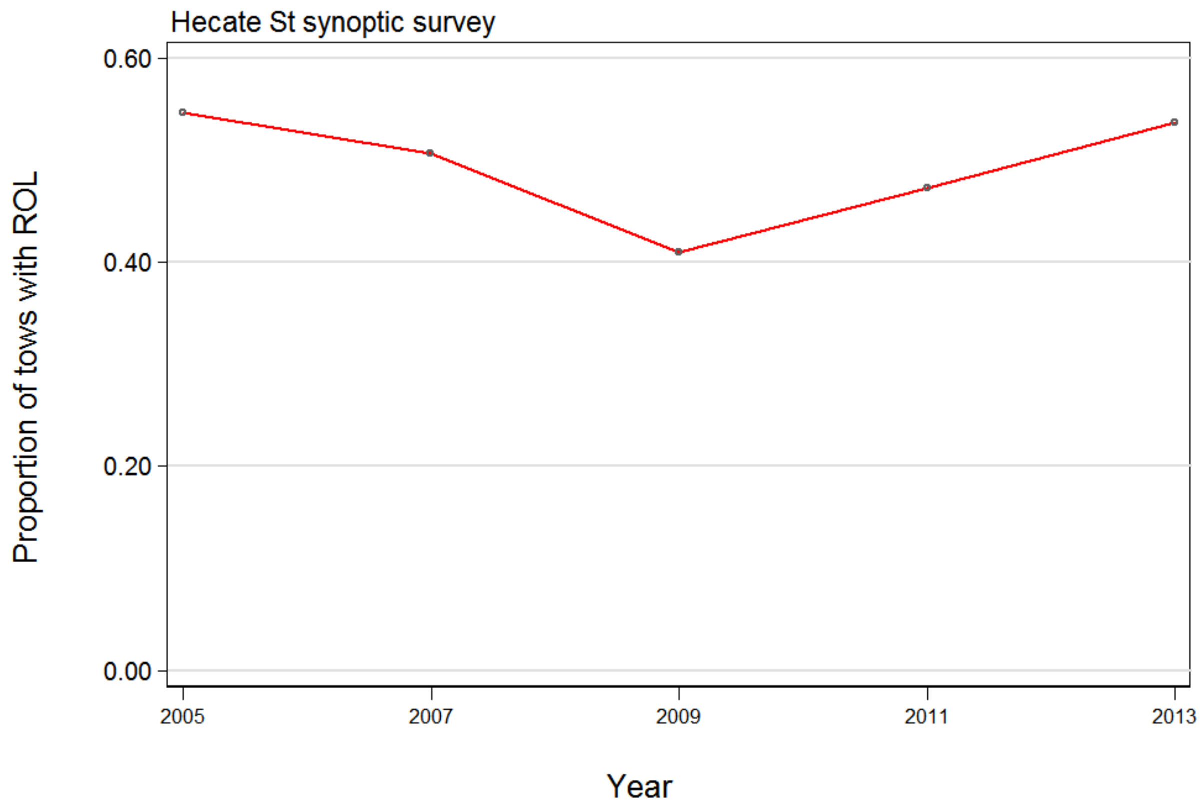


Figure C.23. Proportion of tows by year which contain Rock Sole from the Hecate Strait synoptic survey over the period 2005 to 2013.

QUEEN CHARLOTTE SOUND SYNOPTIC TRAWL SURVEY

Data selection

This survey has been conducted in seven years over the period 2003 to 2013 in Queen Charlotte Sound, which lies between the top of Vancouver Island and the southern portion of Moresby Island and extends into the lower part of Hecate Strait between Moresby Island and the mainland. The design divided the survey into two large aerial strata which roughly correspond to the PMFC regions 5A and 5B while also incorporating part of 5C (all valid tow starting positions are shown by survey year in Figure C.16 to Figure C.20). Each of these two areas was divided into four depth strata: 50–125 m; 125–200 m; 200–330 m; and 330–500 m (Table C.7).

A doorspread density value (Equation C.3) was generated for each tow based on the catch of Rock Sole from the mean doorspread for the tow and the distance travelled. [`distance travelled`] is a database field which is calculated directly from the tow track. This field is used preferentially for the variable D_{yij} in Equation C.3. A calculated value ([`vessel speed`] X [`tow duration`]) can be used for this variable if [`distance travelled`] is missing, but there were only two instances of this occurring in the 7 trawl surveys. Missing values for the [`doorspread`] field were filled in with the mean doorspread for the survey year (101 values over all years: Table C.8).

Table C.7. Number of usable tows for biomass estimation by year and depth stratum for the Queen Charlotte Sound synoptic survey over the period 2003 to 2013. Also shown is the area of each stratum and the vessel conducting the survey by survey year.

		South depth strata				North stratum				Total
Year	**Vessel**	**50-125**	**125-200**	**200-330**	**330-500**	**50-125**	**125-200**	**200-330**	**330-500**	**tows**
2003	Viking Storm	29	56	29	6	5	39	50	19	233
2004	Viking Storm	42	48	31	8	20	38	37	6	230
2005	Viking Storm	29	60	29	8	8	45	37	8	224
2007	Viking Storm	33	62	24	7	19	57	48	7	257
2009	Viking Storm	34	60	28	8	10	44	43	6	233
2011	Nordic Pearl	38	67	25	8	10	51	45	8	252
2013	Nordic Pearl	32	65	29	10	9	46	45	5	241
Area (km^2)		5,092	5,464	2,744	568	1,840	4,104	3,760	1,252	24,824

Table C.8. Number of missing doorspread values by year for the Queen Charlotte Sound synoptic survey over the period 2003 to 2013 as well as showing the number of available doorspread observations and the mean doorspread value for the survey year.

Year	Number tows with missing doorspreads [1]	Number tows with doorspread observations [2]	Mean doorspread (m) used for tows with missing values [2]
2003	13	236	72.1
2004	8	267	72.8
2005	1	258	74.5
2007	5	262	71.8
2009	2	248	71.3
2011	30	242	67.0
2013	42	226	69.5
Total	101	1,739	71.3

[1] valid biomass estimation tows only

[2] includes tows not used for biomass estimation

Table C.9. Biomass estimates for Rock Sole from the Queen Charlotte Sound synoptic trawl survey for the survey years 2003 to 2013. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. C.6)
2003	738	740	422	1,154	0.2489	0.2533
2004	1,518	1,483	603	2,916	0.3936	0.3988
2005	1,024	1,031	532	1,835	0.3140	0.3066
2007	651	652	274	1,409	0.4168	0.4134
2009	787	785	371	1,447	0.3366	0.3411
2011	949	961	548	1,518	0.2522	0.2585
2013	815	816	388	1,490	0.3343	0.3263

Results

Catch densities of Rock Sole from this survey were much higher in the South stratum, which includes the Goose Island Bank and Cape Scott Spit, and were nearly non-existent in the North stratum (Figure C.24 to Figure C.30). Rock Sole were mainly taken at depths from 51 to 148 m (5% and 95% quantiles of the empirical depth distribution), but there were sporadic observations at depths down to 330 m and up to about 45 m (Figure C.31).

Estimated Rock Sole biomass from this trawl survey showed no overall trend from 2003 to 2013. However, a strong increase appeared in 2004 which persisted into 2005 and then disappeared (Table C.9; Figure C.32). The estimated relative errors were high, lying between 25 and 41% (Table C.9). The proportion of tows that captured Rock Sole was always low (between 19 and 28% in the South stratum and generally under 10% in the North stratum) (Figure C.33). Overall, 276 of the 1670 valid survey tows contained Rock Sole, with 69 of the positive tows occurring in the North stratum.

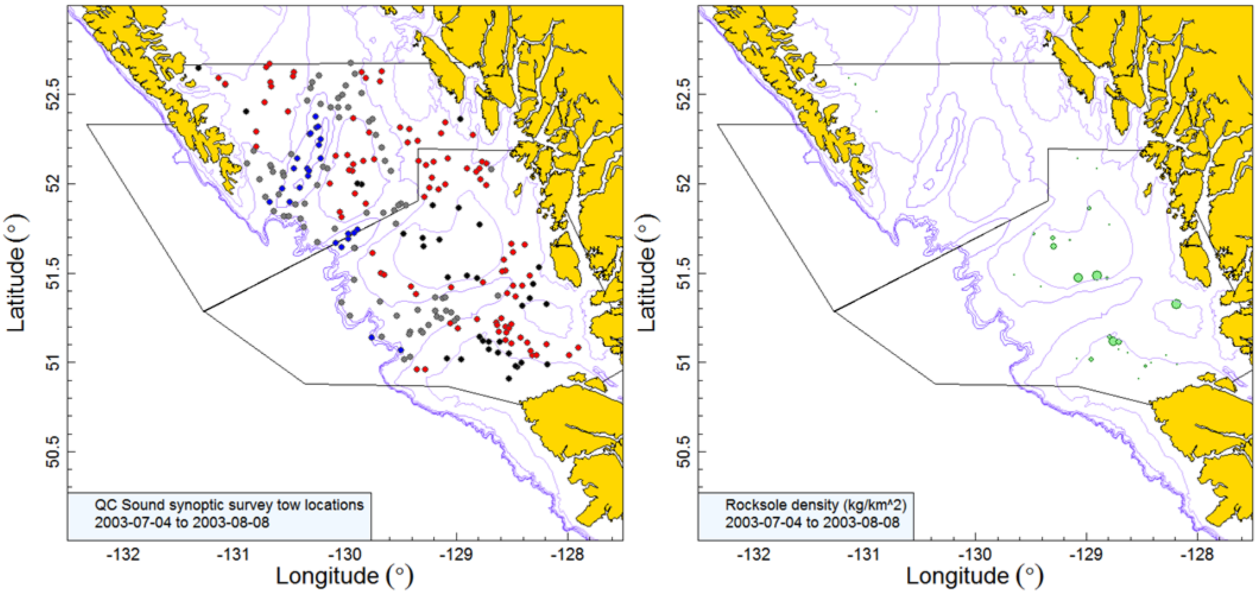


Figure C.24. Valid tow locations (50-125m stratum: black; 126-200m stratum: red; 201-330m stratum: grey; 331-500m stratum: blue) and density plots for the 2003 Queen Charlotte Sound synoptic survey. Circle sizes in the right-hand density plot are scaled across all years (2003–2005, 2007, 2009, 2011, 2013), with the largest circle = 4,106 kg/km^2 in 2004. Boundaries delineate the North and South aerial strata.

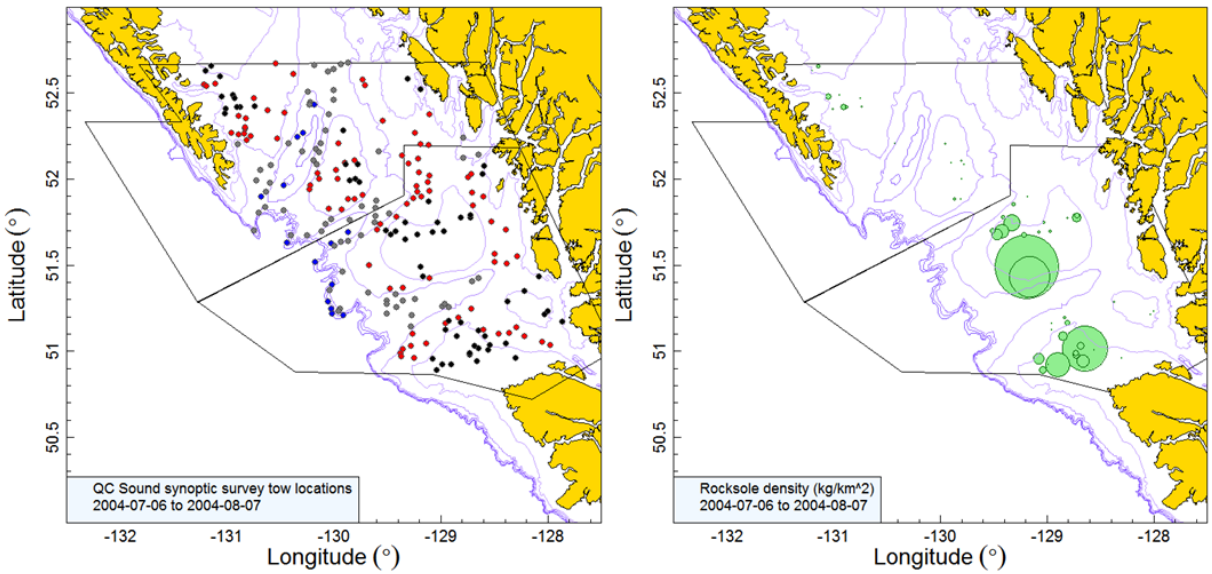


Figure C.25. Tow locations and density plots for the 2004 Queen Charlotte Sound synoptic survey (see Figure C.24 caption).

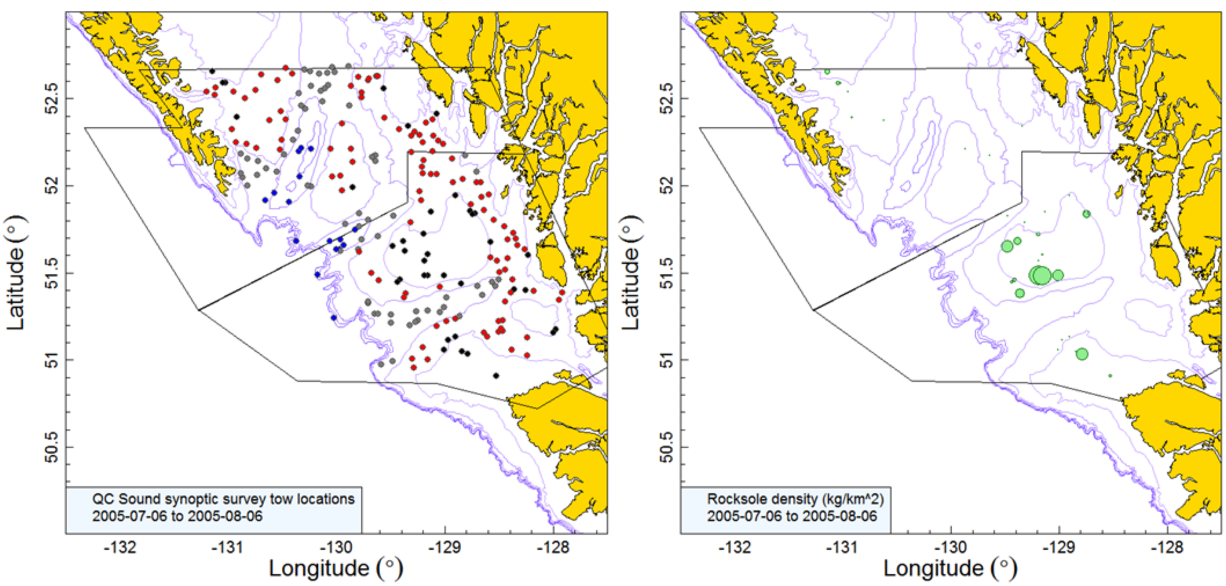


Figure C.26. Tow locations and density plots for the 2005 Queen Charlotte Sound synoptic survey (see Figure C.24 caption).

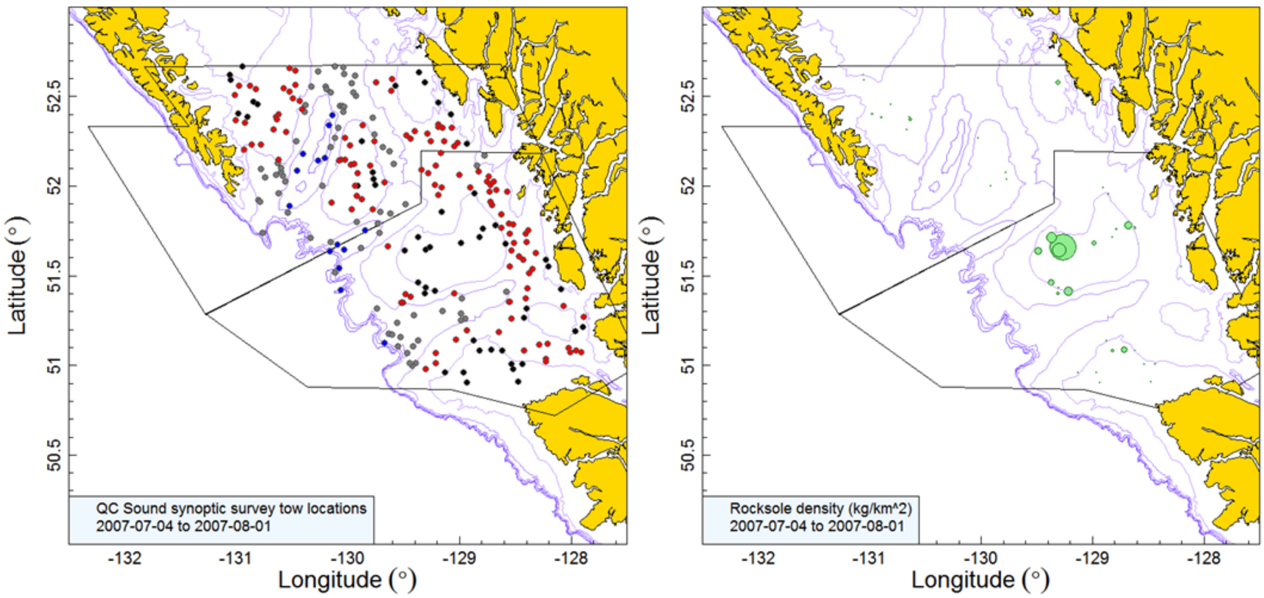


Figure C.27. Tow locations and density plots for the 2007 Queen Charlotte Sound synoptic survey (see Figure C.24 caption).

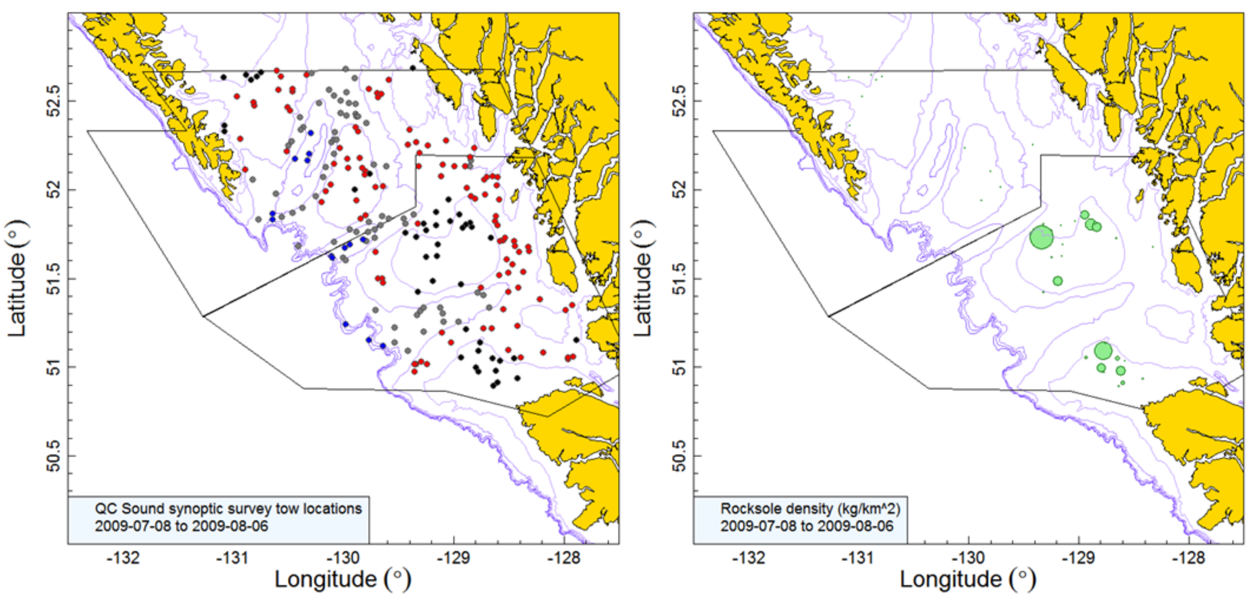


Figure C.28. Tow locations and density plots for the 2009 Queen Charlotte Sound synoptic survey (see Figure C.24 caption).

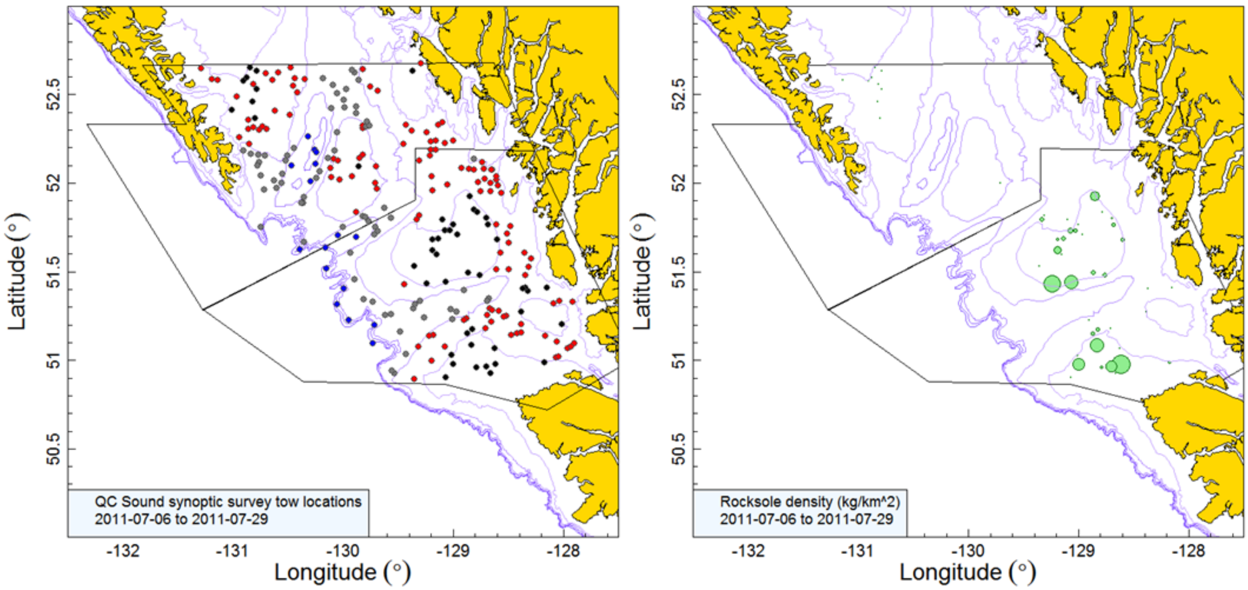


Figure C.29. Tow locations and density plots for the 2011 Queen Charlotte Sound synoptic survey (see Figure C.24 caption).

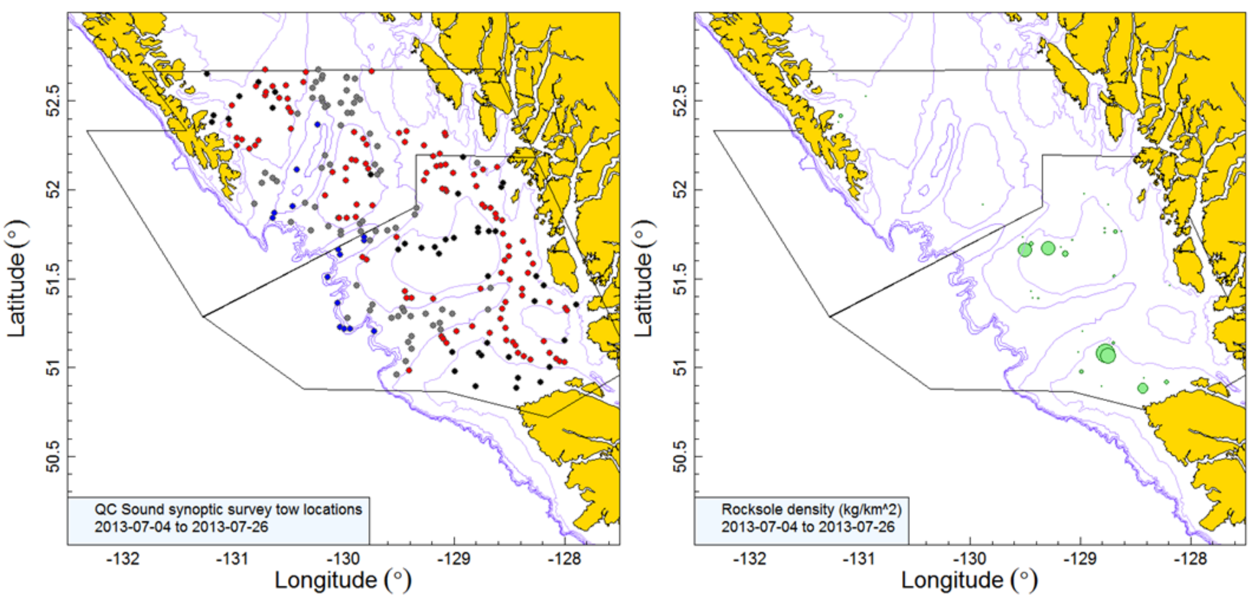


Figure C.30. Tow locations and density plots for the 2013 Queen Charlotte Sound synoptic survey (see Figure C.24 caption).

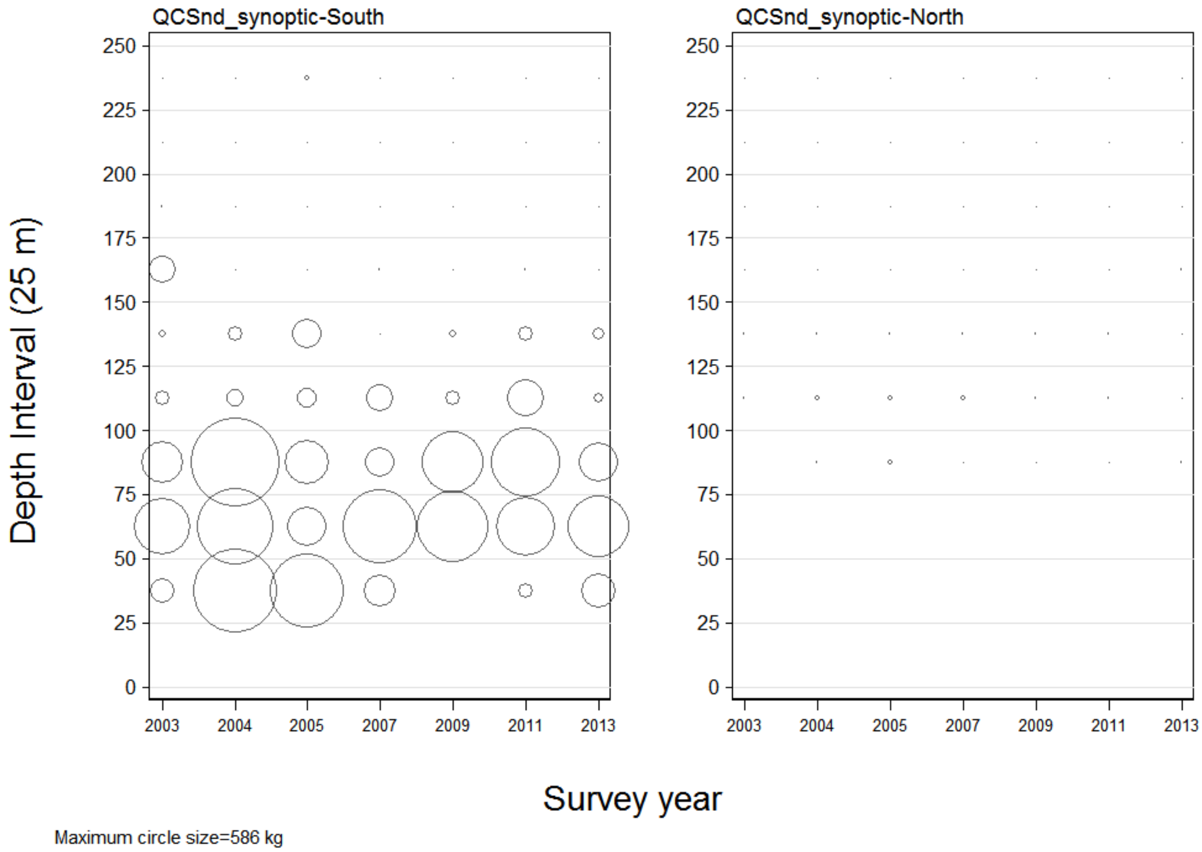


Figure C.31. Distribution of observed catch weights of Rock Sole for the two main Queen Charlotte Sound synoptic survey aerial strata (Table C.7) by survey year and 25 m depth zone. Depth zones are indicated by the mid-point of the depth interval and circles in the panel are scaled to the maximum value (586 kg) in the 75–100 m interval in 2004. The 1% and 99% quantiles for the Rock Sole empirical start of tow depth distribution= 45 m and 217 m respectively.

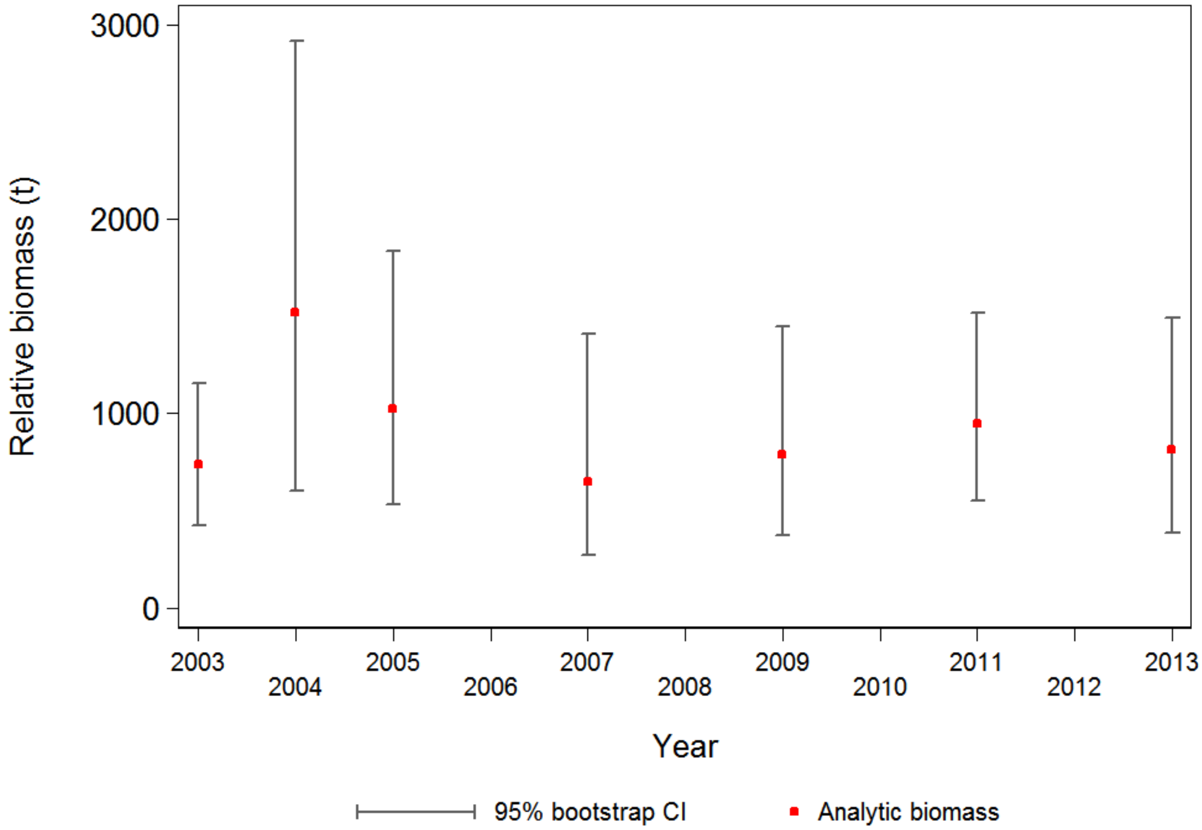


Figure C.32. Plot of biomass estimates for Rock Sole (values provided in Table C.9) from the Queen Charlotte Sound synoptic survey over the period 2003 to 2013. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

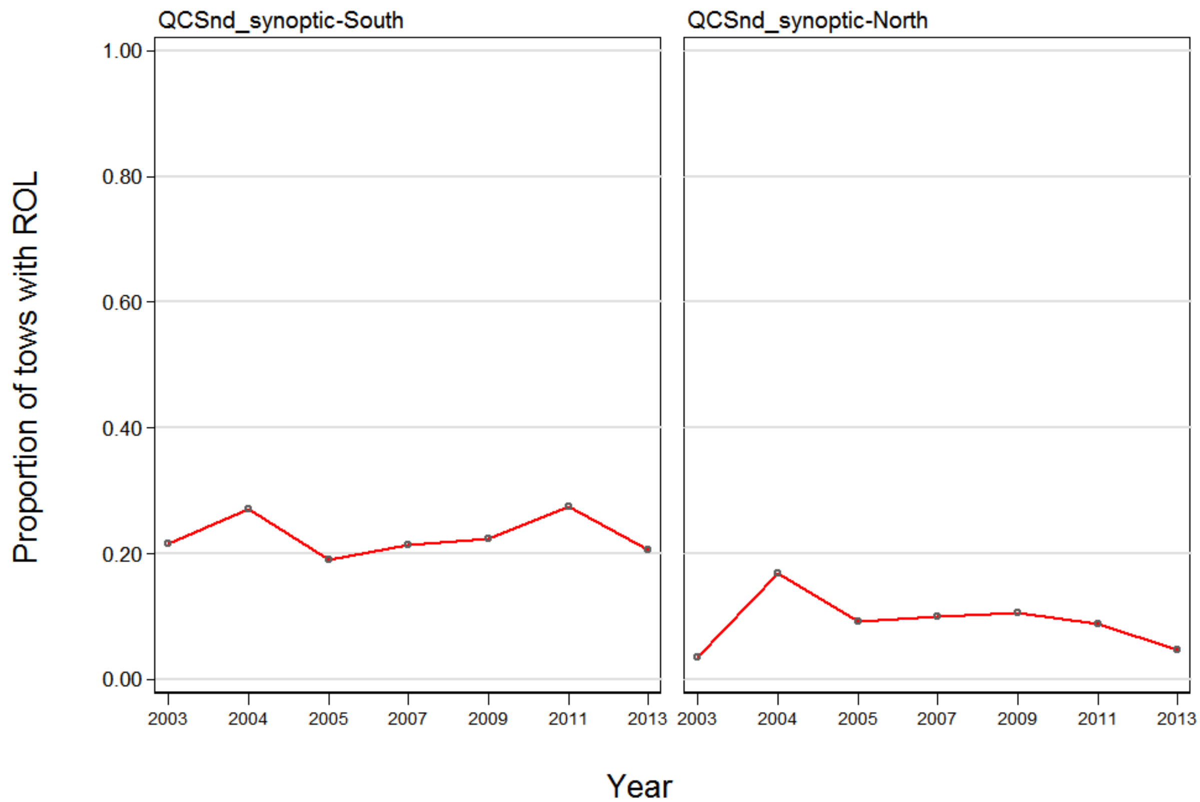


Figure C.33. Proportion of tows by stratum and year which contain Rock Sole from the Queen Charlotte Sound synoptic survey over the period 2003 to 2013.

WEST COAST VANCOUVER ISLAND SYNOPTIC SURVEY

The West Coast Vancouver Island Synoptic Survey has operated in Area 3CD on a biennial basis between 2004 and 2012. Bootstrap biomass estimates of 328 tonnes in 2004 declined to 69 tonnes in 2006 but increased to an average of 243 tonnes during 2008-2012 (Figure C.34).

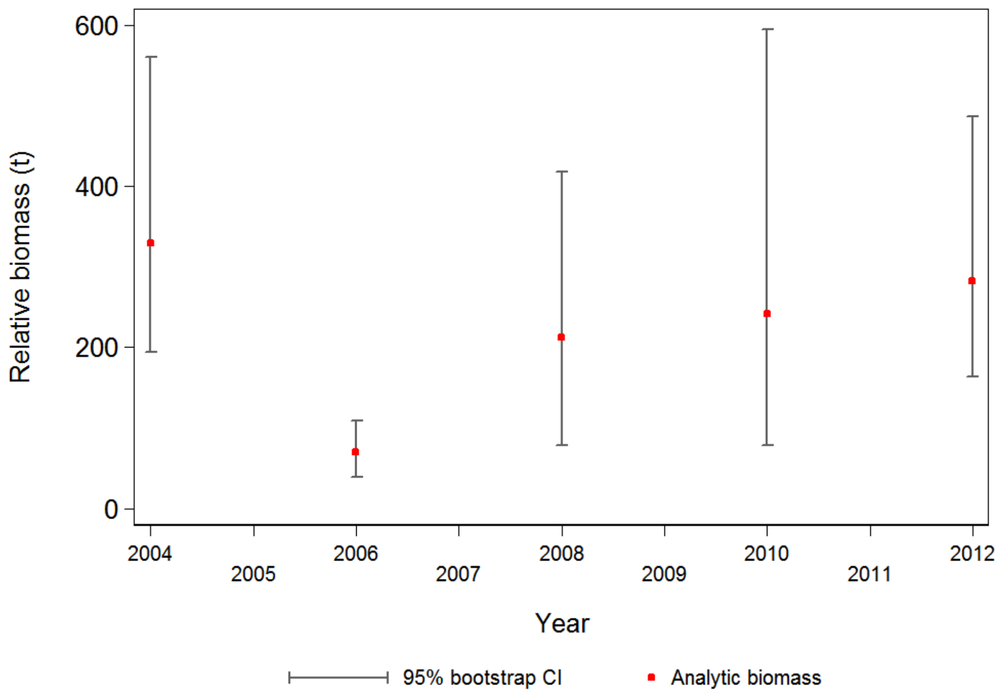


Figure C.34. Rock sole biomass estimates from West Coast Vancouver Island Synoptic survey in Area 3CD from 2004-2012. Error bars show the 95% confidence intervals from 1000 bootstrap replicates.

D.1 GROWTH AND MATURITY

D.1.1 Length-Weight

The parameterisation of the length-weight model used in the stock assessment is:

$$W_{rsi} = \alpha_{rs}(L_{rsi})^{\beta_{rs}} \tag{D.1}$$

where W_{rsi} = observed weight (kg) of individual i with sex s in area r,
L_{rsi} = observed length (cm) of individual i with sex s in area r,
α_{rs} = growth rate scalar for sex s in area r,
β_{rs} = growth rate exponent for sex s in area r.

The above model was fit as a linear regression to the logged length and weight pairs without regard to year or data origin. The resulting estimates for log(α_{rs}) were exponentiated to provide the α_{rs} parameters used in the stock assessments.

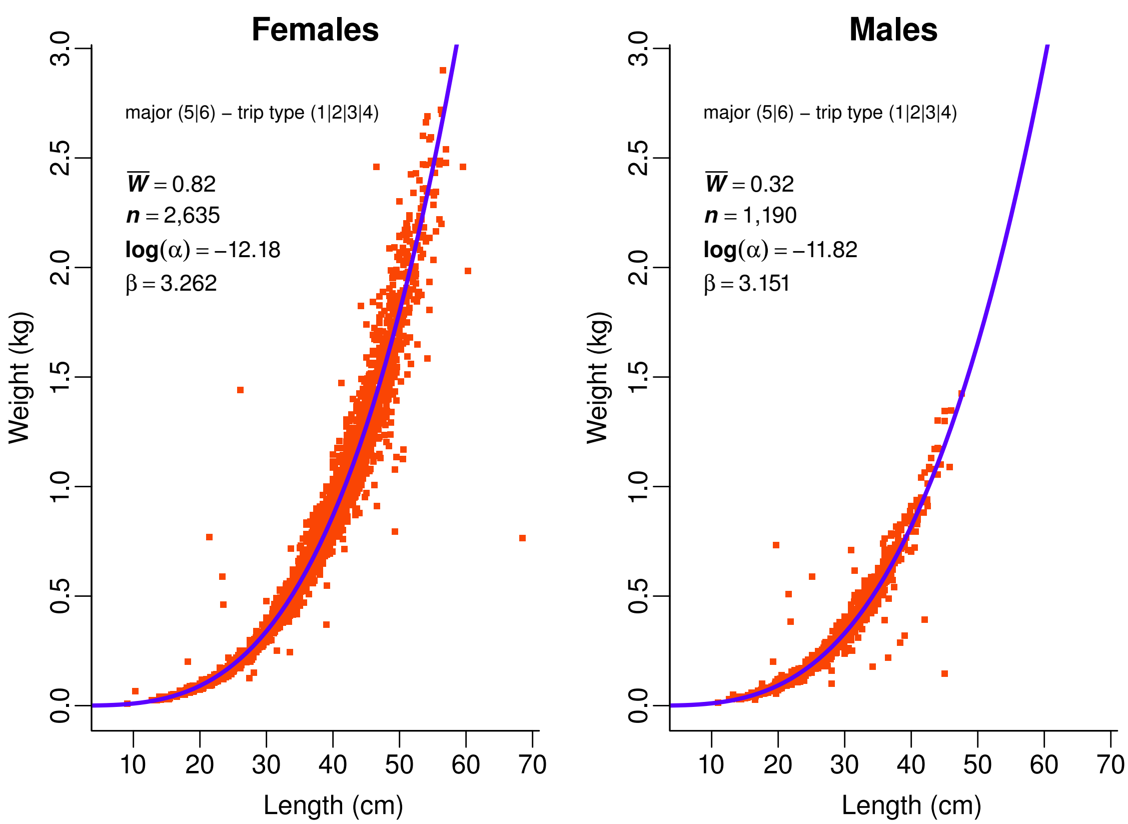


Figure D.1. Regression analyses showing the fitted model and length-weight pairs, for all specimens collected by commercial and research survey trips between 1999 and 2012, used to estimate α_s and β_s for Area 5AB. n = number of specimens, $\bar{W}$ = mean weight (kg).

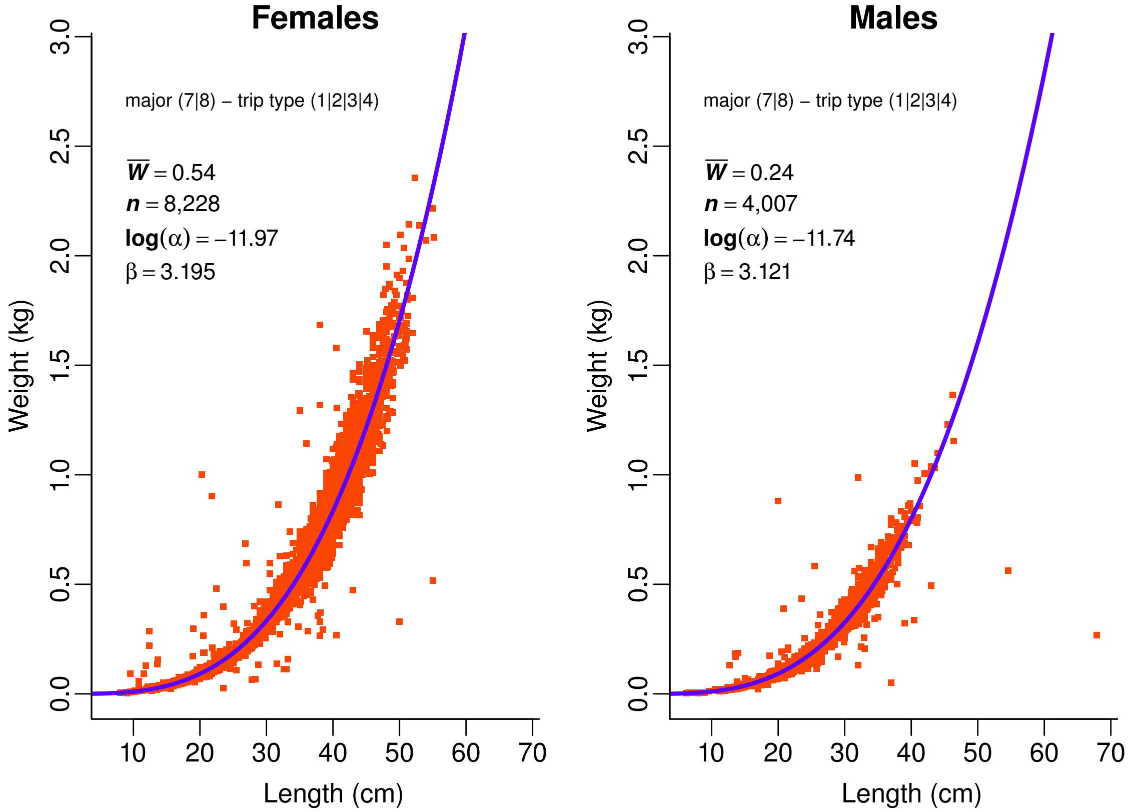


Figure D.2. Regression analyses showing the fitted model and length-weight pairs, for all specimens collected by commercial and research survey trips between 1994 and 2013, used to estimate α_s and β_s for Area 5CD. n = number of specimens, $\bar{W}$ = mean weight (kg).

Table D.1. Length-weight relationships for specimens collected by commercial and research survey trips between 1994 and 2013. Specimen sex s: F = female, M = male; n_s = number of specimens by sex; α_s = log(α_s).

	s	n_s	α_s	SE$_\alpha$	β_s	SE$_\beta$
5AB	F	2,635	-12.175	0.033052	3.2622	0.0092338
	M	1,190	-11.825	0.063286	3.1513	0.019127
5CD	F	8,228	-11.966	0.016650	3.1948	0.0048403
	M	4,007	-11.736	0.026910	3.1208	0.0083975

D.1.2 von Bertalanffy Growth

The parameterisation of the von Bertalanffy growth model is:

$$L_{ars} = L_{\infty,rs}\left(1 - \mathrm{e}^{-k_{rs}(a - t_{0,rs}}\right) \qquad \text{(D.2)}$$

where L_{ars} = average length (mm) of an individual with sex s in area r at age a,
$L_{\infty,rs}$ = average length (mm) of an individual with sex s in area r at maximum age,
k_{rs} = growth rate coefficient for sex s in area r,
$t_{0,rs}$ = age at which the average length is 0 for sex s in area r.

Non-linear von Bertalanffy models were fit to age-length pairs for research samples with data available up to July 21, 2011. The growth model fits for males reflect a lack of data at younger ages to anchor t_0; however, the assessment is a female-only model, so unreliable estimates for males will not affect results.

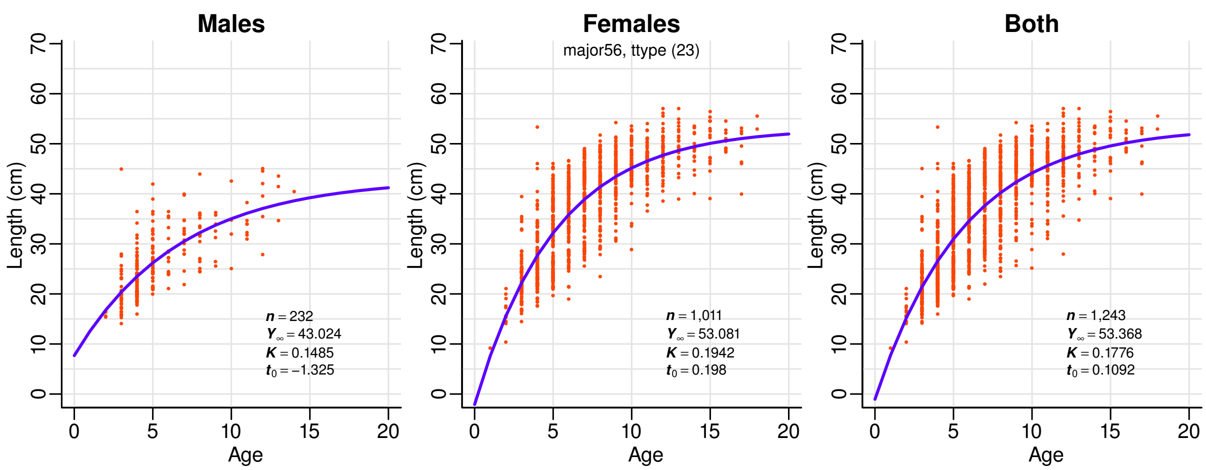


Figure D.3. Length-age relationships using the von Bertalanffy growth model (D2) for Rock sole specimens in Area 5AB collected on research survey trips between 1999 and July 2011. n = *number of specimens;* $Y = L_{\infty,s}$.

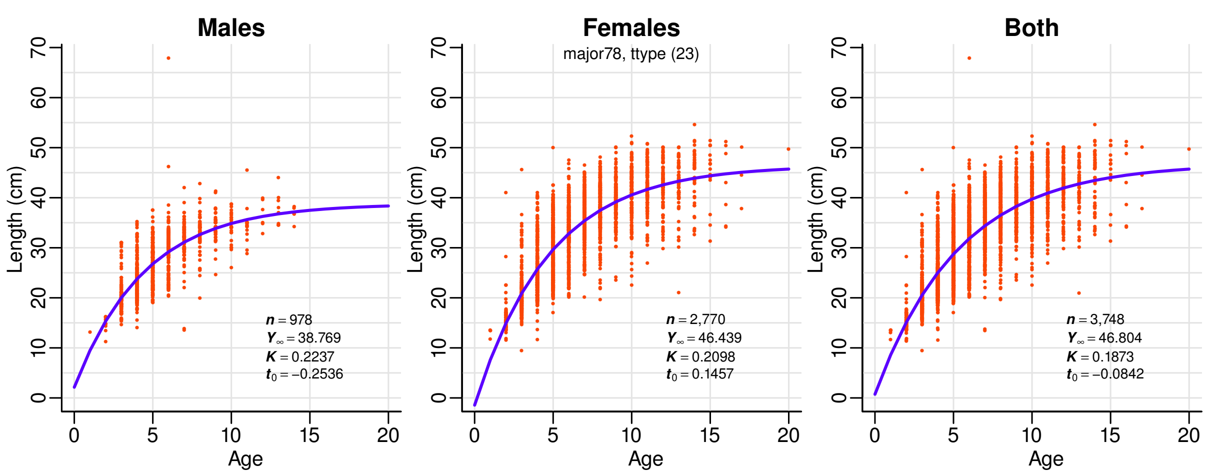


Figure D.4. Length-age relationships using the von Bertalanffy growth model (D2) for Rock sole specimens in Area 5CD collected on research survey trips between 1981 and 2011. n = *number of specimens;* $Y = L_{\infty,s}$.

Table D.2. Growth parameters for Rock Sole using the von Bertalanffy model.

	s	n_s	$L_{\infty,s}$	k_s	$t_{0,s}$
5AB	M	232	43.024	0.14854	-1.3251
	F	1,011	53.081	0.19417	0.19798
	Both	1,243	53.368	0.17756	0.10923
5CD	M	978	38.769	0.22366	-0.25360
	F	2,770	46.439	0.20976	0.14575
	Both	3,748	46.804	0.18731	-0.084199

D.1.3 Maturity

A frequency chart of all available maturity data (1965-2013) for Rock Sole (Figure D.5) suggests that females develop eggs between September and December, and that eggs are ripe for spawning release in January. To see changes in maturity, we normally use data from time periods that ensure a clear delineation between immature and mature fish. For Rock Sole females (Figure D.5), specimens coded 1 and 2 in September through December would likely not release eggs. They are therefore "immature" and all the rest (stage 3+) are "mature" during this period.

While September to December would therefore be the optimal sampling window to estimate maturity ogives, we depart from this practice in the current assessment by using maturity data only from the three relevant research surveys – Hecate Strait Synoptic, Hecate Strait Assemblage, and Queen Charlotte Sound Synoptic. This choice corresponds to the time period when most of the data are collected (May-Aug). Using stage 3 and up to denote mature fish, we construct a maturity ogive using a double-normal model (D.3). The maturity ogive for the population model uses empirical m_a for ages 1–5 and fitted m_a for ages 6–12 (Table D.3). The ages of 50% maturity (5.6 y for females and males) are interpolated from the curves (Figure D.6).

$$m_{as} = \begin{cases} e^{-(a-\nu_s)^2/\rho_{sL}}, & a \le \nu_s \\ 1, & a > \nu_s \end{cases} \tag{D.3}$$

where m_{as} = maturity at age a for sex s,
ν_s = age of full maturity for sex s,
ρ_s = variance for the left limb of the maturity curve for sex s.

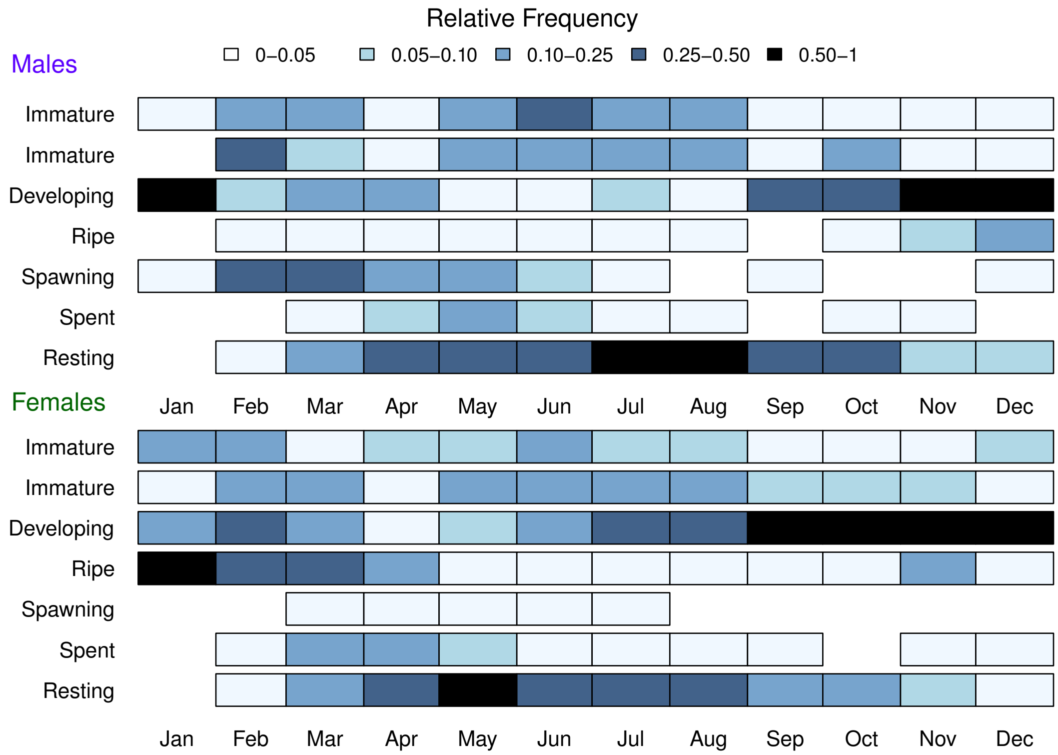


Figure D.5. Relative frequency of maturity codes by month (data stored in DFO's GFBioSQL *database) for Rock Sole. Frequencies are calculated within each maturity category for every month.*

Table D.3. Proportion of Rock Sole females mature by age used in the catch-age model. Maturity stages 1 and 2 were assumed to be immature fish and all other staged fish (stages 3 to 7) were assumed to be mature. Only fish samples from three surveys – Hecate Strait Synoptic, Hecate Strait Assemblage, and Queen Charlotte Sound Synoptic – were used in the calculation of observed proportion mature.

Age a	# Fish	Obs m_a	Fit m_a	Model m_a
1	5	0	0.01979	0
2	65	0.03077	0.04996	0.03077
3	281	0.06406	0.1114	0.06406
4	414	0.1667	0.2191	0.1667
5	392	0.3954	0.3808	0.3954
6	332	0.6958	0.5842	0.5842
7	303	0.7888	0.7914	0.7914
8	240	0.8208	0.9466	0.9466
9	179	0.8827	1	1
10	165	0.9152	1	1
11	115	0.9565	1	1
12	88	0.9205	1	1
13	52	0.9231	1	1
14	34	0.9706	1	1
15	16	1	1	1

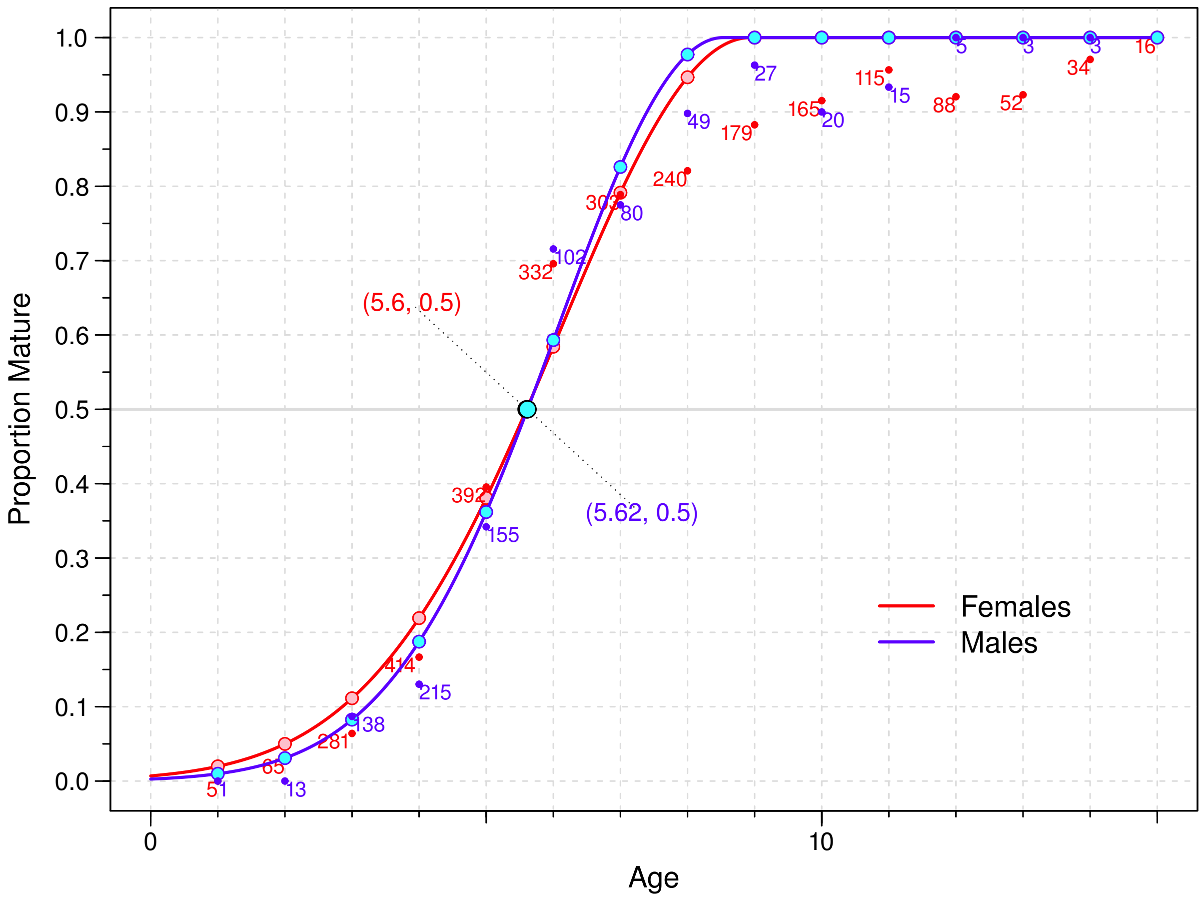


Figure D.6. Maturity ogives for BC Rock Sole females and males (data stored in DFO's GFBioSQL database; 1996 to 2011). Solid lines show the double-normal curve fits; open circles mark values at integer ages; solid circles denote input proportions-mature derived from the number of specimens indicated by each label. Age at 50% maturity is indicated along the median line.

D.2 WEIGHTED AGE PROPORTIONS

This appendix summarizes a method for representing commercial and survey age structures for a given species through weighting observed age frequencies x_a or proportions x'_a by catch‖density in defined strata. (Throughout this section, we use the symbol '‖' to delimit parallel values for commercial and survey analyses, respectively, as the mechanics of the weighting procedure are similar for both.) For commercial samples, these strata comprise quarterly periods within a year, while for survey samples, the strata are defined by longitude, latitude, and depth. Within each stratum, commercial ages are weighted by the catch weight (kg) of the species in tows that were sampled, and survey ages are weighted by the catch density (kg/km^2) of the species in sampled tows. A second weighting is then applied: quarterly commercial ages are weighted by the commercial catch weight of the species from all tows within each quarter; stratum survey ages are weighted by stratum areas (km^2) in the survey.

Ideally, sampling effort would be proportional to the amount of the species caught, but this is not usually the case. Personnel can control the sampling effort on surveys more than that aboard commercial vessels, but the relative catch among strata over the course of a year or survey cannot be known with certainty until the events have occurred. Therefore, the stratified weighting scheme presented below attempts to adjust for unequal sampling effort among strata.

For simplicity herein, we illustrate the weighting of age frequencies x_a, unless otherwise specified. The weighting occurs at two levels: h (quarters for commercial ages, strata for survey ages) and i (years if commercial, surveys in series if survey). Notation is summarised in Table D.4.

*Table D.4. Equations for weighting age frequencies or proportions for a given species. (**c**) = commercial, (**s**) = survey*

Symbol	Description
	Indices
a	age class (1 to A, where A is an accumulator age-class)
d	(**c**) trip IDs as sample units
	(**s**) sample IDs as sample units
h	(**c**) quarters (1 to 4), 91.5 days each
	(**s**) strata (area-depth combinations)
i	(**c**) calendar years (1977 to present)
	(**s**) survey IDs in survey series (e.g., QCS Synoptic)
	Data
x_{adhi}	observations-at-age a for sample unit d in quarter‖stratum h of year‖survey i
x'_{adhi}	proportion-at-age a for sample unit d in quarter‖stratum h of year‖survey i
C_{dhi}	(**c**) commercial catch (kg) of a given species for sample unit d in quarter h of year i
	(**s**) density (kg/km^2) of a given species for sample unit d in stratum h of survey i
C'_{dhi}	C_{dhi} as a proportion of total catch‖density $C_{hi} = \quad {}_d C_{dhi}$
y_{ahi}	weighted age frequencies at age a in quarter‖stratum h of year‖survey i
K_{hi}	(**c**) total commercial catch (kg) of species in quarter h of year i
	(**s**) stratum area (km^2) of stratum h in survey i
K'_{hi}	K_{hi} as a proportion of total catch‖area $K_i = \quad {}_h K_{hi}$
p_{ai}	weighted frequencies at age a in year‖survey i
p'_{ai}	weighted proportions at age a in year‖survey i

For each quarter‖stratum h we weight sample unit frequencies x_{ad} by sample unit catch‖density

For each quarter||stratum h we weight sample unit frequencies x_{ad} by sample unit catch||density of the assessment species. (For commercial ages, we use trip as the sample unit, though at times one trip may contain multiple samples. In these instances, multiple samples from a single trip will be merged into a single sample unit.) Within any quarter||stratum h and year||survey i there is a set of sample catches||densities C_{dhi} that can be transformed into a set of proportions:

$$C'_{dhi} = \frac{C_{dhi}}{\sum_d C_{dhi}} \ . \tag{D.4}$$

The proportion C'_{dhi} is used to weight the age frequencies x_{adhi} summed over d, which yields weighted age frequencies by quarter||stratum for each year||survey:

$$y_{ahi} = \sum_d \left(C'_{dhi} x_{adhi} \right) \ . \tag{D.5}$$

This transformation reduces the frequencies x from the originals, and so we rescale (multiply) y_{ahi} by the factor

$$\frac{\sum_a x_{ahi}}{\sum_a y_{ahi}} \tag{D.6}$$

to retain the original number of observations. (For proportions x' this is not needed.) Although we perform this step, it is strictly not necessary because at the end of the two-step weighting, we standardise the weighted frequencies to represent proportions-at-age.

At the second level of stratification by year||survey i, we calculate the the annual proportion of quarterly catch (t) for commercial ages or the survey proportion of stratum areas (km^2) for survey ages

$$K'_{hi} = \frac{K_{hi}}{\sum_h K_{hi}} \tag{D.7}$$

to weight y_{ahi} and derive weighted age frequencies by year||survey:

$$p_{ai} = \sum_h \left(K'_{hi} y_{ahi} \right) \ . \tag{D.8}$$

Again, if this transformation is applied to frequencies (as opposed to proportions), it reduces them from the original, and so we rescale (multiply) p_{ai} by the factor

$$\frac{\sum_a y_{ai}}{\sum_a p_{ai}} \ . \tag{D.9}$$

to retain the original number of observations.

Finally, we standardise the weighted frequencies to represent proportions-at-age:

$$p'_{ai} = \frac{p_{ai}}{\sum_a p_{ai}} \ . \tag{D.10}$$

If initially we had used proportions x'_{adhi} instead of frequencies x_{adhi} , the final standardisation would not be necessary; however, its application does not affect the outcome.

The choice of data input (frequencies x *vs*. proportions x') can sometimes matter: the numeric outcome can be very different, especially if the input samples comprise few observations. Theoretically, weighting frequencies emphasises our belief in individual observations at specific ages while weighting proportions emphasises our belief in sampled age distributions. Neither method yields inherently better results; however, if the original sampling methodology favoured sampling few fish from many tows rather than sampling many fish from few tows, then weighting frequencies probably makes more sense than weighting proportions. In this assessment, we weight age frequencies x.

The commercial age data for 5CD females (Figure D.7) show some cohort pattern. Stronger than usual recruitment appears to occur in transition years between regimes where the mean annual Pacific Decadal Oscillation (PDO) anomaly shifts from positive to negative. Ages below 4 are not well represented. For the model analysis, years with fewer than three sampled trips were excluded: 1982-1987, 1989, 2008, and 2011 (Table D.5).

The commercial age data for 5AB females (Figure D.8) show much less pattern than that for 5CD. Stronger than usual recruitment to the fishery occurred in the early 2000's, and again in 2010 and 2011, although sample sizes are small for the last two years. For the model analysis, years with fewer than three sampled trips were excluded: 1986, 1990, 1991, 1997, 2009, and 2011 (Table D.6).

The Hecate Strait Assemblage survey age data (Figure D.9) shows no real pattern other than a shift to younger ages by 2003. Table D.7 provides information on the samples. The Hecate Strait Synoptic survey (Figure D.10, Table D.8) provide four years of age data, again showing a shift to younger ages in the last two years (2009 and 2011). The Queen Charlotte Sound Synoptic survey (Figure D.11, Table D.9) appears to follow a 1999 or 2000 cohort that experienced good recruitment. A shift to younger ages in the 2011 survey compared to earlier survey years also suggests a strong cohort entering the population in recent years.

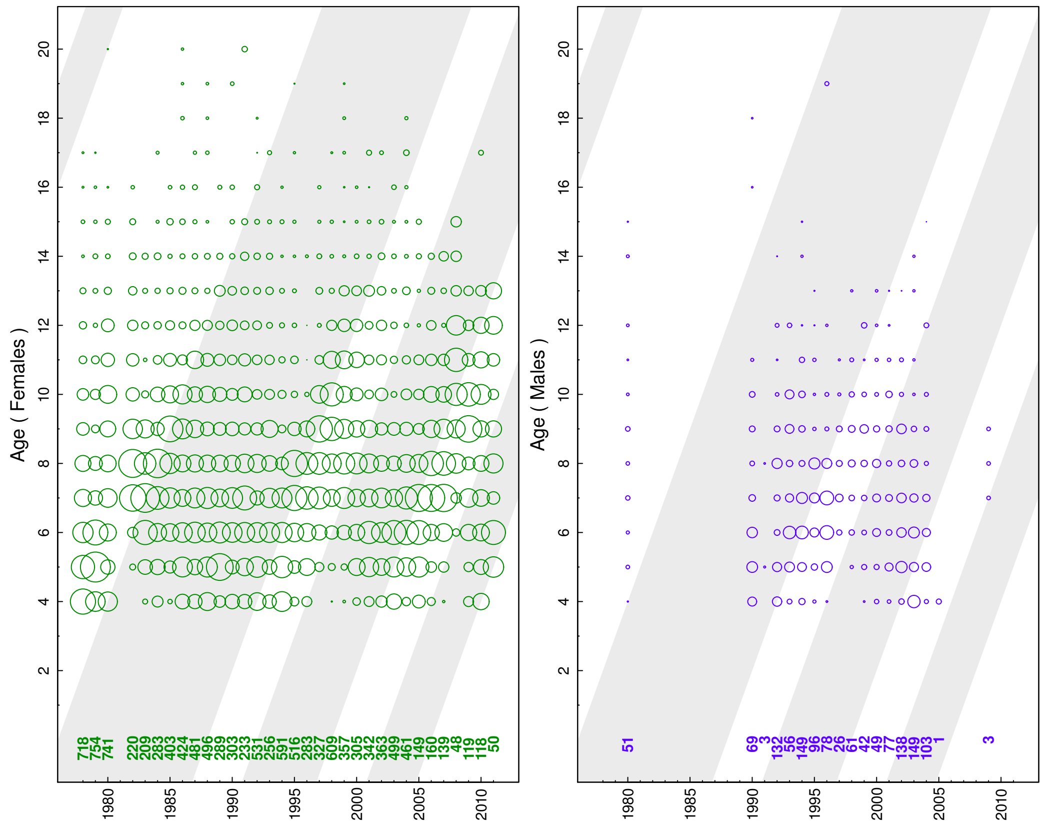


Figure D.7. Commercial Rock Sole proportions-at-age in 5CD based on age frequencies weighted by trip catch within quarters and commercial catch within years. Diagonal shaded bands indicate cohorts that were born when the mean annual Pacific Decadal Oscillation anomaly was positive. Number of specimens aged are displayed along the bottom axis.

Table D.5. Commercial 5CD trips: number of sampled trips, Rock Sole catch (t) by trip and per quarter.

Year	# Trips				Trip catch (t)				Commercial catch (t)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1978	0	4	0	0	0	35.8	0	0	60.4	457	324	73.8
1979	0	3	1	0	0	17.4	6.80	0	53.3	427	708	145
1980	0	2	1	0	0	52.2	11.3	0	113	467	400	19.7
1982	0	1	0	0	0	10.2	0	0	29.6	102	64.2	102
1983	0	1	0	0	0	12.3	0	0	36	134	37.8	42.5
1984	0	1	0	0	0	2.27	0	0	71.8	55.8	35.2	25.3
1985	0	0	2	0	0	0	29.2	0	24.3	18.3	54.5	15
1986	0	0	0	2	0	0	0	8.26	15.4	134	14.5	61.5
1987	0	1	1	0	0	2.27	9.98	0	43.1	193	142	171
1988	0	1	2	1	0	12.3	24.2	12.4	62.9	636	463	241
1989	1	1	0	0	7.94	12	0	0	135	797	183	380
1990	1	3	2	2	10.9	29.9	20.1	11.6	177	700	421	264
1991	2	5	7	0	5.44	43.1	79.7	0	141	1,343	724	442
1992	3	6	5	1	20.2	65.1	50.1	8.39	145	1,347	580	172
1993	0	4	2	0	0	21	11.5	0	278	1,081	406	318
1994	1	8	3	9	0.227	62.2	16.3	71.1	236	722	177	268

Continued on next page

Table D.5. Commercial 5CD trips: number of sampled trips, Rock Sole catch (t) by trip and per quarter.

Year	# Trips				Trip catch (t)				Commercial catch (t)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1995	3	6	1	0	19.1	47.4	8.17	0	178	591	549	0
1996	0	3	3	0	0	38.8	33.6	0	2.26	460	314	45.9
1997	5	0	1	1	23.2	0	4.99	7.26	155	329	224	91.8
1998	4	4	3	2	32.7	32.2	41.3	7.26	129	217	242	89.7
1999	0	6	1	1	0	32.7	7.85	9.72	103	339	339	48.8
2000	0	6	1	0	0	71.7	10.8	0	97	382	338	87.1
2001	0	5	3	0	0	17.6	41.1	0	17.6	342	233	102
2002	0	3	5	1	0	19.3	28.5	1.14	1.77	290	343	118
2003	0	11	4	1	0	43.9	25.9	1.56	2.01	263	419	119
2004	0	10	8	0	0	36	23.5	0	3.89	464	311	121
2005	0	6	5	0	0	29.6	16.3	0	7.25	264	269	105
2006	0	6	2	0	0	40.5	6.94	0	2.34	307	227	182
2007	0	4	3	0	0	12.9	9.44	0	2.83	284	271	53.9
2008	0	1	0	0	0	3.40	0	0	2.05	119	256	143
2009	0	5	2	0	0	27.4	13.6	0	5.47	457	281	160
2010	0	1	3	0	0	8.16	14.4	0	2.42	287	252	19.2
2011	0	1	0	0	0	3.18	0	0	0.302	165	377	117

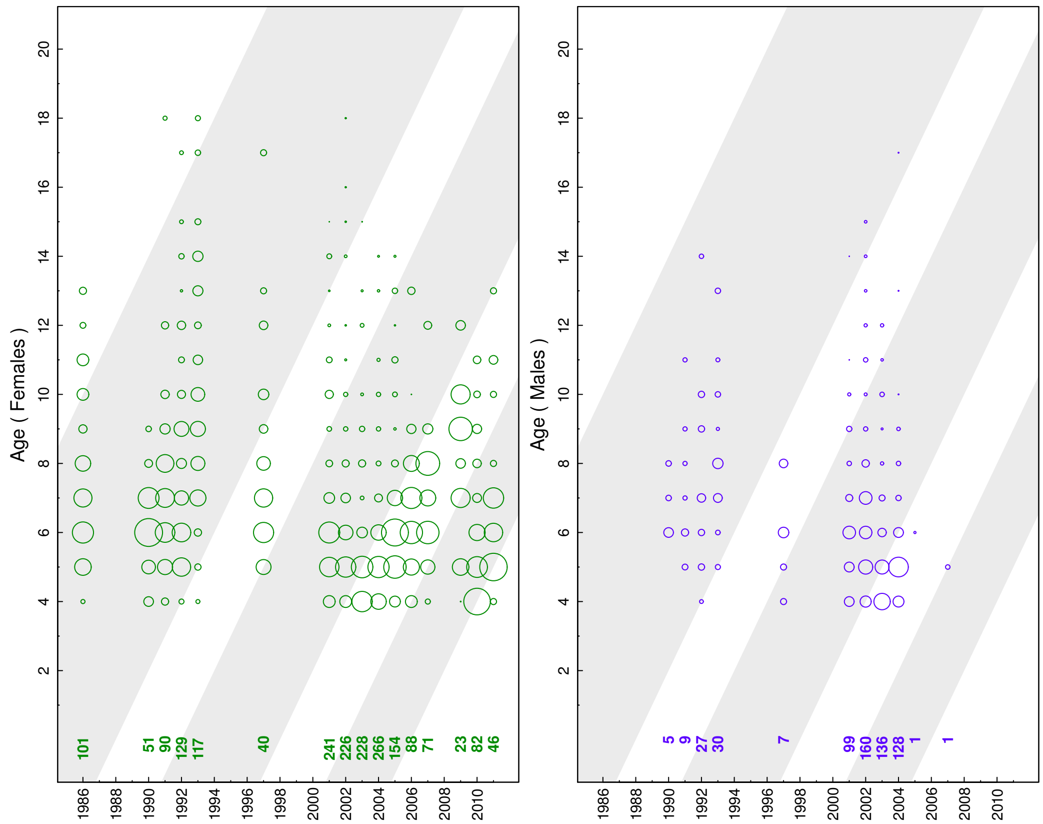


Figure D.8. Commercial Rock Sole proportions-at-age in 5AB based on age frequencies weighted by trip catch within quarters and commercial catch within years. See Figure D.7 for details on diagonal shaded bands and displayed numbers.

Table D.6. Commercial 5AB trips: number of sampled trips, Rock Sole catch (t) by trip and per quarter.

Year	# Trips				Trip catch (t)				Commercial catch (t)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1986	0	0	1	0	0	0	13.6	0	0.224	39.7	111	6.86
1990	0	1	0	0	0	9.75	0	0	4.11	178	368	30.2
1991	0	2	0	0	0	10.5	0	0	9.78	265	319	50.1
1992	0	3	0	0	0	30.5	0	0	37.6	267	358	56.1
1993	0	2	1	0	0	11.8	6.35	0	20.7	415	325	69.1
1997	0	0	1	0	0	0	11.4	0	6.29	74.1	149	33.7
2001	1	5	2	0	0.195	11	0.0467	0	10.5	230	271	16.7
2002	0	3	5	0	0	1.43	6.93	0	38.4	325	467	44.2
2003	0	8	6	0	0	4.93	3.50	0	29.5	377	482	35.3
2004	0	8	7	0	0	5.31	3.02	0	2.96	319	319	18.5
2005	0	7	4	0	0	9.74	3.75	0	4.81	215	306	3.22
2006	0	5	1	0	0	7.82	0.272	0	6.53	159	229	24.9
2007	0	1	2	0	0	1.51	2.60	0	0.888	96	152	3.04
2009	0	0	2	0	0	0	8.18	0	2.36	45.3	144	45.7
2010	0	2	3	0	0	2.74	7.42	0	3.40	257	303	21
2011	0	1	0	0	0	1.09	0	0	1.74	198	257	8.23

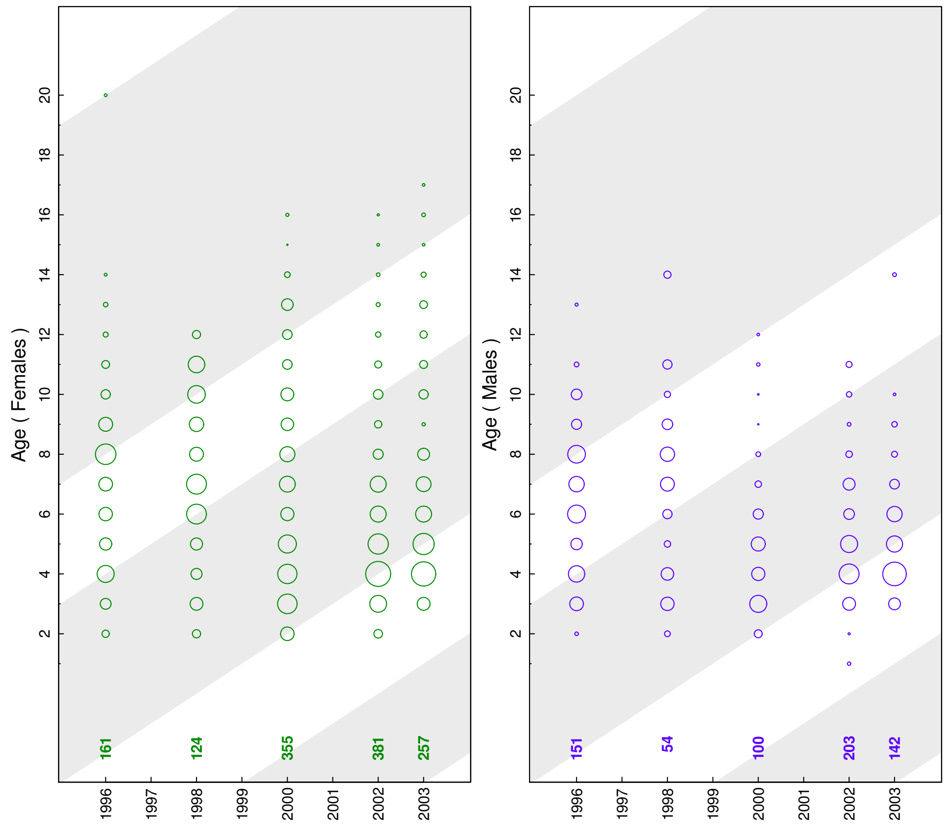


Figure D.9. Hecate Strait Assemblage survey Rock Sole proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure D.7 for details on diagonal shaded bands and displayed numbers.

Table D.7. Hecate Strait Assemblage survey: number of sampled tows and Rock Sole density per stratum (kg/km^2). Stratum areas: 077= 3064 km^2; 078= 1745 km^2; 079= 910 km^2; 080= 946 km^2; 081= 866 km^2

Year	# Samples					Mean density (kg/km^2)				
	077	078	079	080	081	077	078	079	080	081
1996	4	1	1	0	0	1,114	799	5,253	0	0
1998	1	0	3	0	0	479	0	612	0	0
2000	2	2	2	1	0	1,069	1,351	1,114	1,185	0
2002	8	1	2	1	1	246	213	596	50.5	188
2003	5	2	1	0	0	1,247	510	214	0	0

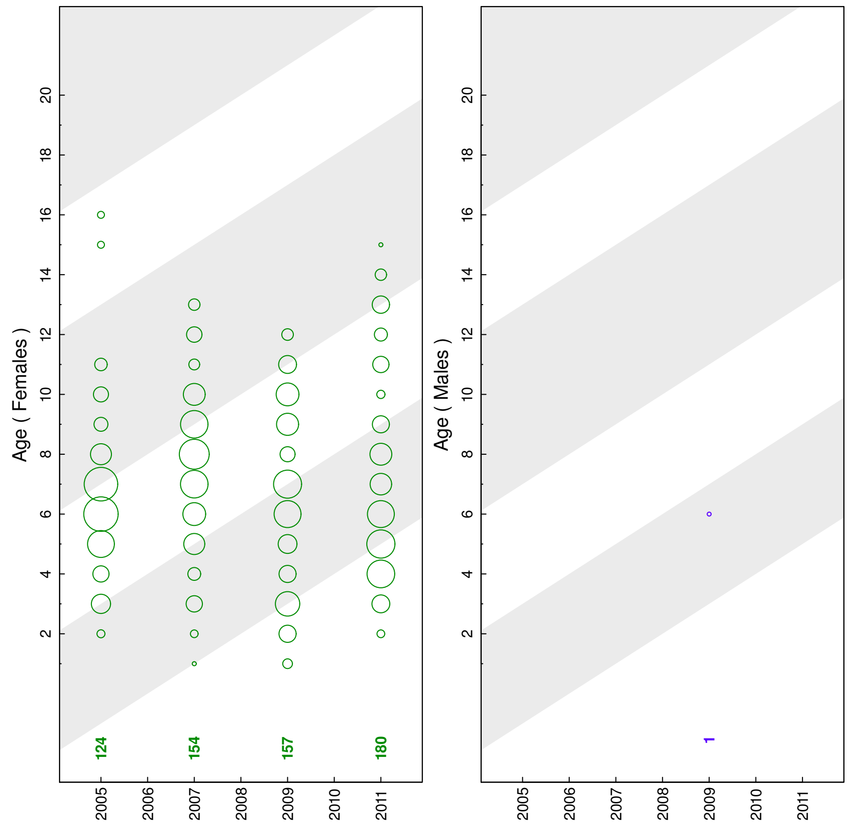


Figure D.10. Hecate Strait Synoptic survey Rock Sole proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure D.7 for details on diagonal shaded bands and displayed numbers.

Table D.8. Hecate Strait Synoptic survey: number of sampled tows and Rock Sole density per stratum (kg/km^2). Stratum areas: 072= 6072 km^2; 073= 3096 km^2

Year	# Samples		Mean density (kg/km^2)	
	072	073	072	073
2005	8	0	1,082	0
2007	13	0	600	0
2009	8	3	425	601
2011	24	0	876	0

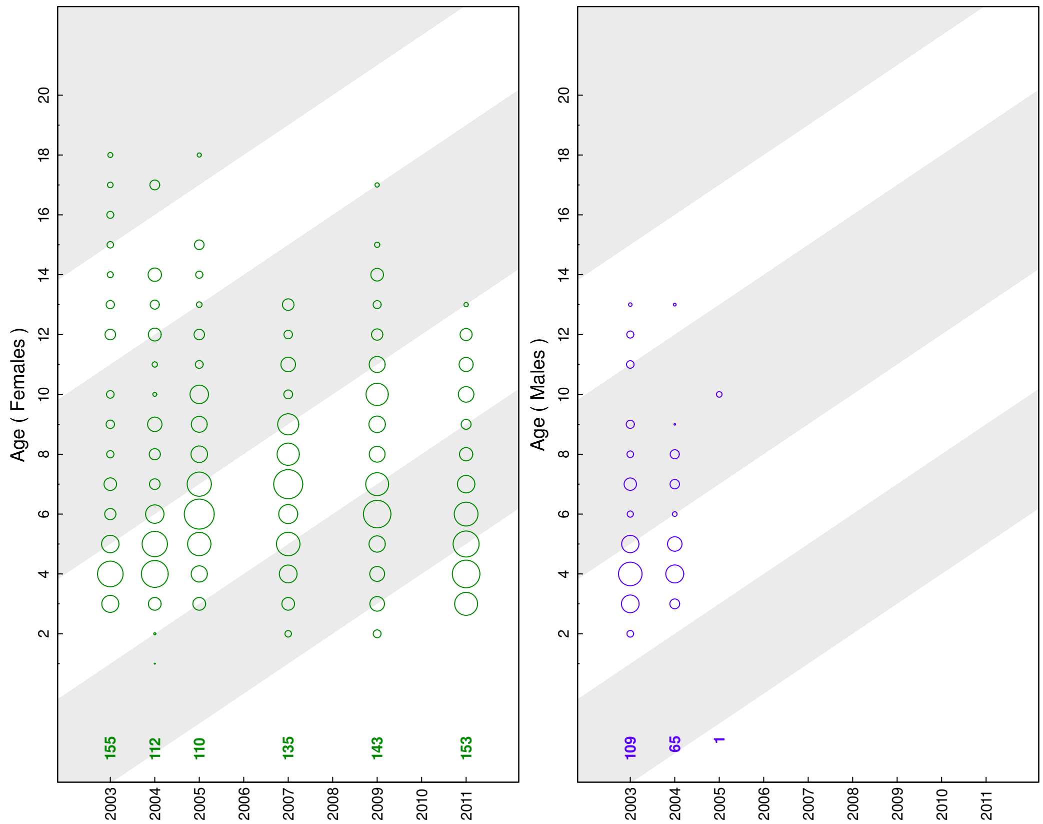


Figure D.11. Queen Charlotte Sound Synoptic survey Rock Sole proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure D.7 for details on diagonal shaded bands and displayed numbers.

Table D.9. Queen Charlotte Sound Synoptic survey: number of sampled tows and Rock Sole density per stratum (kg/km^2). Stratum areas: 018= 5092 km^2; 019= 5464 km^2; 023= 4104 km^2

Year	# Samples			Mean density (kg/km^2)		
	018	019	023	018	019	023
2003	11	0	1	318	0	26
2004	10	1	0	543	4.02	0
2005	7	0	0	654	0	0
2007	9	0	0	417	0	0
2009	11	0	0	433	0	0
2011	11	0	0	533	0	0

APPENDIX E. CATCH-AT-AGE MODEL

E.1 INTRODUCTION

We used a female-only age-structured model in a Bayesian estimation framework to assess stock status for Rock Sole in Areas 5AB and 5CD. For both Areas, the model was fit to catch data, two or more indices of abundance, and age composition data from commercial fisheries and research surveys. As only the female portion of the population was modelled, all catch data were scaled to represent female-only catch (including estimated discards) prior to input into the model (Appendix A).

Model implementation was done using a modified version of the Coleraine statistical catch-at-age software (Hilborn et al., 2003) called Awatea (A. Hicks, NOAA, pers. comm.). Awatea is a platform for implementing the AD (Automatic Differentiation) Model Builder software (Otter Research Ltd., 1999), which provides (a) maximum posterior density estimates using a function minimiser and automatic differentiation, and (b) an approximation of the posterior distribution of the parameters using the Markov Chain Monte Carlo (MCMC) method, specifically using the Hastings-Metropolis algorithm (Gelman et al., 2004).

The model structure is similar to that used previously in British Columbia for Yellowmouth Rockfish (Edwards et al., 2012a) and Pacific Ocean Perch (Edwards et al., 2012b, 2014a,b), except only one sex was modelled. We followed the weighting scheme suggestions by (Francis, 2011) to assign relative weights to multiple abundance indices, with a modification, as described below.

Running of Awatea was streamlined using code written in R (R Development Core Team, 2012), rather than the original Excel implementation. Figures and tables of output were automatically produced through R using code adapted from the R packages scape (Magnusson, 2009) and scape MCMC (Magnusson and Stewart, 2007). We used the R software Sweave (Leisch, 2002) to automatically collate, via LaTeX, the large amount of figures and tables into a single pdf file for each model run. The code for this procedure has been incorporated into a new R package PBSawatea (available from R. Haigh and A. Edwards, DFO).

Details of the age-structured model, the Bayesian procedure, the reweighting scheme and the methods for calculating reference points and performing projections are provided below. Note that the model is described in the general two-sex form, but that we constrained the sex to only be female for this assessment. This means that the index $s = 2$ (male) that appears in Tables E.1 to E.3, and the associated descriptions in the text of this appendix, did not exist.

E.2 MODEL ASSUMPTIONS

The assumptions of the model are:

1. Each assessment area, 5AB and 5CD, is treated as a single stock.

2. Catches are taken by a single fishery, are known without error, and occur in the middle of the year.

3. Recruitment is modelled using a time-invariant Beverton-Holt stock-recruitment relationship with log-normal error structure.

4. Selectivity differs between surveys and remains invariant over time. Selectivity parameters are

estimated when ageing data are available.

5. Natural mortality is held invariant over time, and estimated independently for females and males.

6. Growth parameters are fixed and assumed to be invariant over time.

7. Maturity-at-age parameters for females are fixed and assumed to be invariant over time.

8. Recruitment at age 1 comprises 100% females.

9. Fish ages determined using the surface ageing methods (before 1978) were considered too biased to use (Beamish, 1979). Ages determined using the otolith break-and-burn methodology (MacLellan, 1997) were assumed to have been aged without error.

10. Commercial samples of catch-at-age in a given year are representative of the fishery when $\geq$3 (5AB) and $\geq$4 samples (5CD) are available.

11. Relative abundance indices are proportional to the vulnerable biomass in the middle of the year, after half the catch and half the natural mortality are accounted for.

12. The age composition samples come from the middle of the year after half the catch and half the natural mortality are accounted for.

E.3 MODEL NOTATION AND EQUATIONS

The notation for the model is given in Table E.1, the model equations in Tables E.2 and E.3, and description of prior distributions for estimated parameters in Table E.4. The model description is divided into the deterministic components, stochastic components and Bayesian priors. Full details of notation and equations are given after the tables.

The deterministic components in Table E.2 can iteratively calculate numbers of fish in each age class through time. The only requirements are the commercial catch data, weight-at-age and maturity data, and known fixed values for all parameters.

We need to estimate many parameters within the assessment model because known fixed values are not available, as well as add stochasticity to recruitment. This is accomplished by the stochastic components given in Table E.3.

Incorporation of the prior distributions for estimated parameters gives a full Bayesian implementation, with the goal of minimising the objective function $f(\Theta)$ given by (E.23). This function is derived from the deterministic, stochastic and prior components of the model.

Table E.1 (continued overleaf). Notation for the catch-at-age model.

Symbol	Description and units
	Indices (all subscripts)
a	age class, where $a = 1, 2, 3, ...A$, and $A = 12$ is the accumulator age class
t	model year, where $t = 1, 2, 3, ...T$, and $t = 0$ represents unfished equilibrium conditions
g	index for certain data – see Table E.4
s	sex, $1 =$ females
	Index ranges
A	accumulator age-class, $A = 12$
T	number of model years, $T = 70$
$\mathbf{T}_g$	sets of model years for survey abundance indices from series g
$\mathbf{U}_g$	sets of model years with proportion-at-age data from series g
	Data and fixed parameters
p_{atgs}	observed weighted proportion of fish from series g in each year $t \in \mathbf{U}_g$ that are age-class a and sex s; so $\Sigma_{a=1}^{A} p_{atgs} = 1$ for each $t \in \mathbf{U}_g$
n_{tg}	assumed sample size that yields corresponding p_{atgs}
C_t	observed catch biomass in year $t = 1, 2, ..., T-1$, tonnes
w_{as}	average weight of individual of age-class a of sex s from fixed parameters, kg
m_a	proportion of age-class a females that are mature, fixed from data
I_{tg}	biomass estimates from survey g for year $t \in \mathbf{T}_g$, tonnes
κ_{tg}	standard deviation of I_{tg}
σ_R	standard deviation parameter for recruitment process error

Table E.1 (cont.). Notation for the catch-at-age model.

Symbol	Description, with fixed values and/or units where appropriate
	Estimated parameters
$\boldsymbol{\Theta}$	set of estimated parameters
R_0	virgin recruitment of age-1 fish (numbers of fish, 1000s)
M_s	natural mortality rate for sex s, $s = 1$
h	steepness parameter for Beverton-Holt recruitment
q_g	catchability for survey series g
μ_g	age of full selectivity for females for series g
v_{gL}	variance parameter for left limb of selectivity curve for series g
s_{ags}	selectivity for age-class a, series g and sex s, calculated from the parameters μ_g and v_{gL}
α, β	alternative formulation of recruitment: $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/(4hR_0)$
$\widehat{x}$	estimated value of observed data x
	Derived states
N_{ats}	number of age-class a fish of sex s at the start of year t, 1000s
u_{ats}	proportion of age-class a and sex s fish in year t that are caught
u_t	ratio of total catch to vulnerable biomass in the middle of the year (exploitation rate)
B_t	spawning biomass (mature females) at the start of year t, $t = 1, 2, 3, ..., T$; tonnes
B_0	virgin spawning biomass (mature females) at the start of year 0, tonnes
R_t	recruitment of age-1 fish (females) in year t, $t = 1, 2, ..., T-1$, numbers of fish, 1000s
V_t	vulnerable biomass (males and females) in the middle of year t, $t = 1, 2, 3, ..., T$; tonnes
	Deviations and likelihood components
ϵ_t	Recruitment deviations arising from process error
$\log L_1(\boldsymbol{\Theta} \| \{\epsilon_t\})$	log-likelihood component related to recruitment residuals
$\log L_2(\boldsymbol{\Theta} \| \{\widehat{p}_{atgs}\})$	log-likelihood component related to estimated proportions-at-age
$\log L_3(\boldsymbol{\Theta} \| \{\widehat{I}_{tg}\})$	log-likelihood component related to estimated survey biomass indices
$\log L(\boldsymbol{\Theta})$	total log-likelihood
	Prior distributions and objective function
$\pi_j(\boldsymbol{\Theta})$	Prior distribution for parameter j
$\pi(\boldsymbol{\Theta})$	Joint prior distribution for all estimated parameters
$f(\boldsymbol{\Theta})$	Objective function to be minimised

Table E.2. Deterministic components. Using the catch, weight-at-age and maturity data, with fixed values for all parameters, the initial conditions are calculated from (E.4)-(E.6), and then state dynamics are iteratively calculated through time using the main equations (E.1)-(E.3), selectivity functions (E.7) and (E.8), and the derived states (E.9)-(E.13). Estimated observations for survey biomass indices and proportions-at-age can then be calculated using (E.14) and (E.15). In Table E.3, the estimated observations of these are compared to data.

State dynamics ($2 \le t \le T,\ s=1$)

$$N_{1ts} = R_t \tag{E.1}$$

$$N_{ats} = e^{-M_s}(1-u_{a-1,t-1,s})N_{a-1,t-1,s}\,; \quad 2 \le a \le A-1 \tag{E.2}$$

$$N_{Ats} = e^{-M_s}(1-u_{A-1,t-1,s})N_{A-1,t-1,s} + e^{-M_s}(1-u_{A,t-1,s})N_{A,t-1,s} \tag{E.3}$$

Initial conditions ($t=1$)

$$N_{a1s} = R_0 e^{-M_s(a-1)}\,; \quad 1 \le a \le A-1,\ s=1 \tag{E.4}$$

$$N_{A1s} = R_0\,\frac{e^{-M_s(A-1)}}{1-e^{-M_s}}\,; \quad s=1 \tag{E.5}$$

$$B_0 = B_1 = \sum_{a=1}^{A} w_{a1} m_a N_{a11} \tag{E.6}$$

Selectivities

$$s_{ag1} = \begin{cases} e^{-(a-\mu_g)^2/v_{gL}}, & a \le \mu_g \\ 1, & a > \mu_g \end{cases} \tag{E.7}$$

$$s_{ag2} = \begin{cases} e^{-(a-\mu_g-\Delta_g)^2/v_{gL}}, & a \le \mu_g+\Delta_g \\ 1, & a > \mu_g+\Delta_g \end{cases} \tag{E.8}$$

Derived states ($1 \le t \le T-1$)

$$B_t = \sum_{a=1}^{A} w_{a1} m_a N_{at1} \tag{E.9}$$

$$R_t = \frac{4hR_0B_{t-1}}{(1-h)B_0+(5h-1)B_{t-1}} \quad \left(\equiv \frac{B_{t-1}}{\alpha+\beta B_{t-1}}\right) \tag{E.10}$$

$$V_t = \sum_{a=1}^{A} e^{-M_s/2}\, w_{as}\, s_{a4s}\, N_{ats} \tag{E.11}$$

$$u_t = \frac{C_t}{V_t} \tag{E.12}$$

$$u_{ats} = s_{a4s}\, u_t\,; \quad 1 \le a \le A,\ s=1 \tag{E.13}$$

Estimated observations

$$\widehat{I}_{tg} = q_g \sum_{a=1}^{A} e^{-M_s/2}(1-u_{ats}/2) w_{as} s_{ags} N_{ats}\,; \quad t \in \mathbf{T}_g,\ g=1,2,...,G-1 \tag{E.14}$$

$$\widehat{p}_{atgs} = \frac{e^{-M_s/2}(1-u_{ats}/2)s_{ags}N_{ats}}{\sum_{a=1}^{A} e^{-M_s/2}(1-u_{ats}/2)s_{ags}N_{ats}}; \quad 1 \le a \le A,\ t \in \mathbf{U}_g,\ s=1 \tag{E.15}$$

Table E.3. Calculation of likelihood function $L(\boldsymbol{\Theta})$ for stochastic components of the model in Table E.2, and resulting objective function $f(\boldsymbol{\Theta})$ to be minimised.

Estimated parameters

$$\boldsymbol{\Theta} = \{R_0, M_1, h;\ \ \text{5AB}: q_1, q_2, \mu_1, \mu_3, v_{1L}, v_{3L};\ \ \text{5CD}: q_1, q_2, q_3, q_4, \mu_1, \mu_2, \mu_5, v_{1L}, v_{2L}, v_{5L}\} \quad \text{(E.16)}$$

Recruitment deviations

$$\epsilon_t = \log R_t - \log B_{t-1} + \log(\alpha + \beta B_{t-1}) + \sigma_R^2/2\,;\ \ 1 \le t \le T-1 \quad \text{(E.17)}$$

Log-likelihood functions

$$\log L_1(\boldsymbol{\Theta}|\{\epsilon_t\}) = -\frac{T}{2}\log 2\pi - T\log\sigma_R - \frac{1}{2\sigma_R^2}\sum_{t=1}^{T-1}\epsilon_t^2 \quad \text{(E.18)}$$

$$\log L_2(\boldsymbol{\Theta}|\{\widehat{p}_{atgs}\}) = -\frac{1}{2}\sum_{g=1,4}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\log\left[p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right]$$
$$+ \sum_{g=1,4}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\log\left[\exp\left\{\frac{-(p_{atgs}-\widehat{p}_{atgs})^2\ n_{tg}}{2\left(p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right)}\right\} + \frac{1}{100}\right] \quad \text{(E.19)}$$

$$\log L_3(\boldsymbol{\Theta}|\{\widehat{I}_{tg}\}) = \sum_{g=1}^{3}\sum_{t\in\mathbf{T}_g}\left[-\frac{1}{2}\log 2\pi - \log\kappa_{tg} - \frac{(\log I_{tg} - \log\widehat{I}_{tg})^2}{2\kappa_{tg}^2}\right] \quad \text{(E.20)}$$

$$\log L(\boldsymbol{\Theta}) = \sum_{i=1}^{3}\log L_i(\boldsymbol{\Theta}|\cdot) \quad \text{(E.21)}$$

Joint prior distribution and objective function

$$\log(\pi(\boldsymbol{\Theta})) = \sum_j \log(\pi_j(\boldsymbol{\Theta})) \quad \text{(E.22)}$$

$$f(\boldsymbol{\Theta}) = -\log L(\boldsymbol{\Theta}) - \log(\pi(\boldsymbol{\Theta})) \quad \text{(E.23)}$$

Table E.4. Definition of datasets denoted by the index g in Tables E.1-E.3, as well as indicating (X) whether the dataset was used as an index of abundance and/or age composition data when fitting the catch-age model to data for base case scenarios. The c_p values show the amount of process error added to each abundance index to give a standard deviation of the normalized residuals to be near 1.0 when fitting assessment models to data (see Reweighting section for description).

Area	g	Dataset	Abundance index	c_p	Age Data
5AB	1	Queen Charlotte Sound synoptic survey	X	0.25	X
	2	Commercial trawl fishery CPUE index (1966-2012)	X	0.20	
	3	Commercial trawl fishery age data			X
5CD	1	Hecate Strait multi-species assemblage survey	X	0.35	X
	2	Hecate Strait synoptic survey	X	0.20	X
	3	Early commercial trawl fishery CPUE (1954-1995)	X	0.20	
	4	Recent commercial trawl fishery CPUE (1996-2012)	X	0.30	
	5	Commercial trawl fishery age data			X

E.4 DESCRIPTION OF DETERMINISTIC COMPONENTS

Notation (Table E.1) and set up of the deterministic components (Table E.2) are now described.

E.4.1 Age classes

Index (subscript) a represents age classes, going from 1 to the accumulator age class, A. Age class $a = 5$, for example, represents fish aged 4-5 years, and consequently age-class 1 fish were born the previous year. The variable N_{ats} is the number of age-class a fish of sex s at the *start* of year t.

E.4.2 Years

Index t represents model years, going from 1 to T, and $t = 0$ represents unfished equilibrium conditions. The model was run to the start of 2014 to incorporate the 2013 indices from the Queen Charlotte Sound synoptic survey (Area 5AB) and the Hecate Strait synoptic survey (Area 5CD). Catch data for all of 2013 were not available (since the assessment model was run in summer 2013), with the 2013 catch set equal to that observed for 2012.

E.4.3 Abundance Indices

Data from multiple abundance indices were used, as described in detail in Appendices B and C. The abundance series corresponding to each index g is described in Table E.4 for 5AB and 5CD.

E.4.4 Commercial data

The commercial catch has been reconstructed back to 1945 for Area 5CD and Area 5AB. This start year was selected so that all significant commercial catches could be included in each model and that it could be assumed that the population was at an unfished equilibrium at the beginning of the reconstruction, The time series for catches is denoted C_t. The proportions-at-age values are given by p_{atgs} with assumed sample size n_{tg}. These proportions are the weighted proportions calculated using the stratified weighting scheme described in Appendix D, that adjusts for unequal sampling effort across temporal and spatial strata.

E.4.5 Sex

For the current single-sex implementation for Rock Sole, s was set equal to 1 for all equations in Tables E.1 to E.3.

E.4.6 Weights-at-age

The weights-at-age are assumed fixed over time and are calculated from the growth rate parameters; see Appendix D for details.

E.4.7 Maturity of females

The proportion of age-class a females that are mature is m_a, and is assumed fixed over time; see Appendix D for details.

E.4.8 State dynamics

The set of dynamical equations (E.1)-(E.3) estimate the number N_{ats} of age-class a fish of sex s at the start of year t. Equation (E.1) states that all new recruits are females. Equation (E.2) calculates the numbers of fish in each age class that survive to the following year, where u_{ats} represents the proportion caught by the commercial fishery, and e^{-M_s} accounts for natural mortality. Equation (E.3) is for the accumulator age class A, allowing survivors in this class to remain in this class the following year.

Natural mortality M_s enters the equations in the form e^{-M_s} as the proportion of unfished individuals that survive the year.

E.4.9 Initial conditions

An unfished equilibrium situation is assumed at the beginning of the reconstruction. The initial conditions (E.4) and (E.5) are obtained by setting $R_t = R_0$ (virgin recruitment), $N_{ats} = N_{a1s}$ (equilibrium condition) and $u_{ats} = 0$ (no fishing) into (E.1)-(E.3). The virgin spawning biomass B_0 is then obtained from (E.9).

E.4.10 Selectivities

Separate selectivities were modelled for the commercial catch data and for each survey series. Selectivity for the commercial CPUE indices was considered to be the same as for the commercial catch data since both were using the same process. A half-Gaussian formulation was used, as given in (E.7) and (E.8), to give selectivities s_{ags} (note that the subscript $\cdot_s$ always represents the index for sex, while the variable $s_{...}$ always represents selectivity). This permits an increase in selectivity up to the age of full selection (μ_g for females). Given there was no evidence to suggest a dome-shaped function, it was assumed that fish older than μ_g remain fully selected.

The rate of ascent of the left limb is controlled by the parameter v_{gL} for females. Since selectivity for the commercial CPUE indices was the same as for the commercial catch, for 5AB $\mu_2 = \mu_3$ and $v_{2L} = v_{3L}$, and for 5CD $\mu_3 = \mu_4 = \mu_5$ and $v_{3L} = v_{4L} = v_{5L}$.

E.4.11 Derived states

The spawning biomass (biomass of mature females, in tonnes) B_t at the start of year t is calculated in (E.9) by multiplying the numbers of females N_{at1} by the proportion that are mature (m_a), and converting to biomass by multiplying by the weights-at-age w_{a1}.

Equation (E.13) calculates, for year t, the proportion u_{ats} of age-class a and sex s fish that are caught. This requires the commercial selectivities s_{a4s} and the ratio u_t, which equation (E.12) shows is the ratio of total catch to vulnerable biomass in the middle of the year, V_t, given by equation (E.11). So (E.12) calculates the proportion of the vulnerable biomass that is caught, and (E.13) partitions this out by sex and age.

E.4.12 Stock-recruitment function

A Beverton-Holt recruitment function is used, parameterised in terms of steepness, h, which is the proportion of the long-term unfished recruitment obtained when the stock abundance is reduced to 20% of the virgin level (Mace and Doonan, 1988; Michielsens and McAllister, 2004). The formulation shown in (E.10) comes from substituting $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/(4hR_0)$ into the Beverton-Holt equation $R_t = B_{t-1}/(\alpha + \beta B_{t-1})$, where α and β are from the standard formulation given in the Coleraine manual (Hilborn et al. 2003; see also Michielsens and McAllister 2004), R_0 is the virgin recruitment, R_t is the recruitment in year t, B_t is the spawning biomass at the start of year t and B_0 is the virgin spawning biomass.

E.4.13 Estimates of observed data

The model estimates of the biomass indices I_{tg} are denoted $\widehat{I}_{tg}$ and are calculated in (E.14). The estimated numbers N_{ats} are multiplied by the natural mortality term $e^{-M_s/2}$ (that accounts for half the annual natural mortality), the term $1 - u_{ats}/2$ (that accounts for half the commercial catch), weights-at-age w_{as} (to convert to biomass) and selectivity s_{ags}. The sum (over ages) is then multiplied by the catchability parameter q_g to give the model biomass estimate $\widehat{I}_{tg}$. The catchability parameter scales the selected biomass available to the index series (whether CPUE or a survey) relative to the index supplied. For survey indices, the index series is the estimate of fish biomass within the area swept by the trawl net so q_g is the ratio of the survey index (as biomass) relative to the total selected biomass estimated by the model. For CPUE indices, the index is supplied as a relative index with a geometric mean equal to 1.0 so the value of q_g is meaningless. Note that in equation E.14, a 0.001 coefficient in (E.14) is not needed to convert kg into tonnes, because N_{ats} is in 1000s of fish (true also for (E.6) and (E.9)).

The estimated proportions-at-age $\widehat{p}_{atgs}$ are calculated in (E.15). For a particular year and gear type, the product $e^{-M_s/2}(1 - u_{ats}/2)s_{ags}N_{ats}$ gives the relative expected numbers of fish caught for each combination of age and sex. Division by $\sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2)s_{ags}N_{ats}$ converts these to estimated proportions for each age-sex combination, such that $\sum_{a=1}^{A} \widehat{p}_{atgs} = 1$.

E.5 DESCRIPTION OF STOCHASTIC COMPONENTS

E.5.1 Parameters

The set $\mathbf{\Theta}$ gives the parameters that are estimated. The estimation procedure is described in the Bayesian Computations section below.

E.5.2 Recruitment deviations

For recruitment, a log-normal process error is assumed, such that the stochastic version of the deterministic stock-recruitment function (E.10) is

$$R_t = \frac{B_{t-1}}{\alpha + \beta B_{t-1}} e^{\epsilon_t - \sigma_R^2/2} \tag{E.24}$$

where $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$, and the bias-correction term $-\sigma_R^2/2$ term in (E.24) ensures that the mean of the recruitment deviations equals 0. This then gives the recruitment deviation equation (E.17) and log-likelihood function (E.18). The value of σ_R was fixed at 0.6, a commonly used default for finfish assessments (Beddington and Cooke, 1983). Early runs of the assessment models for Area 5CD and 5AB showed empirical σ_R values near 0.4.

E.5.3 Log-likelihood functions

The log-likelihood function (E.19) arises from comparing the estimated proportions-at-age with the data. It is the Coleraine (Hilborn et al., 2003) modification of the Fournier et al. (1990, 1998) robust likelihood equation. The Coleraine formulation replaces the expected proportions $\widehat{p}_{atgs}$ from the Fournier et al. (1990, 1998) formulation with the observed proportions p_{atgs}, except in the $(p_{atgs} - \widehat{p}_{atgs})^2$ term (Bull et al., 2005).

The $1/(10A)$ term in (E.19) reduces the weight of proportions that are close to or equal zero. The $1/100$ term reduces the weight of large residuals $(p_{atgs} - p\widehat{\ }_{atgs})$. The net effect (Stanley et al. 2009) is that residuals larger than three standard deviations from the fitted proportion are treated roughly as $3(p_{atgs}(1 - p_{atgs}))^{1/2}$.

Lognormal error is assumed for the survey indices, resulting in the log-likelihood equation (E.20). The total log-likelihood $\log L(\mathbf{\Theta})$ is then the sum of the likelihood components – see (E.21).

Parameter estimation compares the estimated (model-based) observations of survey biomass indices and proportions-at-age with the data, and minimises the recruitment deviations. This is done by minimising the objective function $f(\mathbf{\Theta})$, which equation (E.23) shows is the negative of the sum of the total log-likelihood function and the logarithm of the joint prior distribution, given by (E.22).

E.6 BAYESIAN COMPUTATIONS

The procedure for the Bayesian computations is as follows:

1. minimise the objective function $f(\mathbf{\Theta})$ to give estimates of the mode of the posterior density (MPD) for each parameter
    - this is done in phases

- a reweighting procedure is performed

2. generate samples from the joint posterior distributions of the parameters using Monte Carlo Markov Chain (MCMC) procedure, starting the chains from the MPD estimates.

The details for these steps are now given.

E.6.1 Reweighting

Given that sample sizes are not comparable between different types of data, a procedure that adjusts the relative weights between data sources is required. We based our adjustment of relative weights on the reweighting scheme proposed by Francis (2011).

For abundance data such as survey indices, Francis (2011) recommends reweighting observed coefficients of variation, c_0, by adding process error c_p to give a reweighted coefficient of variation

$$c_1 = \sqrt{c_0^2 + c_p^2}\,. \tag{E.25}$$

Francis recommends using a c_p of 0.2 for survey abundance indices, although he notes that there may be situations where differential weighting between surveys is justified. For this assessment we allowed c_p to vary among indices because the quality of the fit varied between the abundance indices, with some series clearly less variable and more able to track Rock Sole abundance than other series. The amount of process error added to each series was based on the standard deviation of the normalised residuals, with the intent to get the standard deviation close to 1.0 for all the abundance series. The amount of process error to add was selected using a criterion of achieving a standard deviation of normalized residuals between about 0.9 to 1.2 for each abundance series. The c_p values assigned to each abundance data set are shown in Table E.4. This procedure was followed so that the surveys and the CPUE series each received approximately equal weight in the minimisation process.

For each survey index, I_{tg}, the associated standard deviation is κ_{tg}. The associated coefficient of variation is therefore κ_{tg}/I_{tg}, which is used in (E.25) to determine the reweighted coefficient of variation associated with κ_{tg}. This reweighted coefficient of variation is then converted back to a standard deviation, which is used as the reweighted standard deviation κ_{tg} in the likelihood function (E.20).

Francis (2011) has shown that correlation effects are usually strong in age-composition data, which causes them to be overweighted when fitting catch-at-age models using standard statistical approaches. The Francis (2011) procedures take into account these correlations by reducing the weight assigned to composition data relative to the weights given to abundance data. Each age-composition data set has a sample size n_{tg}, which is typically in the range 3-20. Equation (T3.4) of Francis (2011; Method TA1.8 in Table A.1) is used to iteratively reweight the sample size as

$$n_{tg}^{(r)} = W_g^{(r)} n_{tg}^{(r-1)} \tag{E.26}$$

where $r = 1, 2, 3, ..., 6$ represents the reweighting iteration, $n_{tg}^{(r)}$ is the effective sample size for reweighting r, $W_g^{(r)}$ is the weight applied to obtain reweighting r, and $n_{tg}^{(0)} = n_{tg}$. So a single weight $W_g^{(r)}$ is calculated for each series $g = 1, 4$ for reweighting r.

The Francis (2011) weight $W_g^{(r)}$ given to each data set takes into account deviations from the mean age for each year, rather than the scheme used for the QCS POP assessment (Edwards et al., 2012b) that considered deviations from each proportion-at-age value. It is given by equation (TA1.8) of Francis (2011):

$$W_g^{(r)} = \left\{ \text{Var}_t \left[\frac{\bar{O}_{gt} - \bar{E}_{gt}}{\sqrt{\theta_{gt}/n_{tg}^{(r-1)}}} \right] \right\}^{-1} \tag{E.27}$$

where the observed mean age, the expected mean age and the variance of the expected age distribution are, respectively,

$$\bar{O}_{gt} = \sum_{a=1}^{A} a p_{atgs} \tag{E.28}$$

$$\bar{E}_{gt} = \sum_{a=1}^{A} a \widehat{p}_{atgs} \tag{E.29}$$

$$\theta_{gt} = \sum_{a=1}^{A} a^2 \widehat{p}_{atgs} - \bar{E}_{gt}^2 \tag{E.30}$$

and Var_t is the usual finite-sample variance function applied over the index t. We used three reweighting iterations, although the impact of the second and third iterations was small.

E.6.2 Prior distributions

Descriptions of the prior distributions for all estimated parameters are given in the main assessment document. The resulting probability density functions give the $\pi_j(\mathbf{\Theta})$, whose logarithms are then summed in (E.22) to give the joint prior distribution $\pi(\mathbf{\Theta})$. Since uniform priors are, by definition, constant across their bounded range (and zero outside), their contributions to the objective function can be ignored. Thus, in the calculation (E.22) of the joint prior distribution $\pi(\mathbf{\Theta})$, only those priors that are not uniform need to be considered in the summation.

E.6.3 MCMC properties

The MCMC searches started from the MPD values. For Area 5AB, 10,000,000 iterations were performed for the base case, sampling every 10,000th for 1,000 samples. For Area 5CD, 50,000,000 iterations were performed for the base case, sampling every 50,000th for 1,000 samples. In each case, the entire chain was used for the posterior, without requiring a burn-in period. This approach was adopted because the MCMC searches started from the MPD values, with sequences not expected to move substantially from initial values and the chains were very long and sparsely sampled.

E.7 REFERENCES POINTS, PROJECTIONS AND ADVICE TO MANAGERS

The model was projected forward across a range (0 to 0.801 in increments of 0.001) of constant harvest rates (u_t), for a maximum of 15,000 years or until equilibrium was reached (with a tolerance of 0.01 t) for estimating B_{MSY}. MSY is the largest of the equilibrium yields in this search, and the associated exploitation rate will be u_{MSY} and the associated spawning biomass is B_{MSY}. This calculation was done for each of the 1,000 MCMC samples, resulting in marginal posterior distributions for MSY, u_{MSY} and B_{MSY}.

The probability P$(B_{2014} > B_{\mathrm{ref}})$, where B_{ref} is any of the biomass-based reference points considered is then calculated as the proportion of the 1,000 MCMC samples for which $B_{2014} > B_{\mathrm{ref}}$ (and similarly for the other reference points).

Projections were made for 5 years (as agreed upon with N. Davis, DFO Groundfish Management Unit, pers. comm.), starting with the biomass and age structure calculated for the start of 2014. A range of constant catch strategies were used. For each strategy, projections were performed for each of the 1,000 MCMC samples (resulting in posterior distributions of future spawning biomass). Recruitments were calculated using (E.24) (i.e. based on lognormal recruitment deviations from the estimated stock-recruitment curve), using randomly generated values of $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. For each of the 1,000 MCMC samples a time series of $\{\epsilon_t\}$ was generated. For each MCMC sample, the same time series of $\{\epsilon_t\}$ was used for each catch strategy (so that, for a given MCMC sample, all catch strategies experience the same recruitment stochasticity).

APPENDIX F. MODEL RESULTS

F.1 INTRODUCTION

This Appendix describes the results from the mode of the posterior distribution (MPD) (to compare model estimates to observations), diagnostics of the Markov chain Monte Carlo (MCMC) results, and the MCMC results for the estimated parameters. The final advice and major outputs are obtained from the MCMC results. Estimates of major quantities and advice to management (such as decision tables) are also presented in the main text.

F.2 AREA 5AB

F.2.1 Mode of the posterior distribution (MPD) results

Awatea first determines the MPD for each estimated parameter. These are then used as the starting points for the MCMC simulations. The MPD fits are shown for the survey indices (Figure F.1), the CPUE indices (Figure F.2), the commercial catch-at-age data (as overlaid age structures in Figures F.3), and the Queen Charlotte Sound (QCS) synoptic survey series age data (Figure F.4). The results are sensible and are able to capture the main features of the data sets fairly well. There appears to be relative consistency between the available data sources.

Residuals to the MPD model fits are provided for the only survey index (Figures F.5), and the two sets of age data (Figures F.6 and F.7). These further suggest that the model fits are consistent with the data.

Figure F.8 shows the resulting stock-recruitment function and the MPD values of recruitment over time (though see Figure F.18 for the MCMC values of recruitment). Figure F.9 shows that the recruitment deviations display trend over time, and that the auto-correlation function of the deviations reflects this.

F.2.2 Bayesian MCMC Results

The MCMC procedure performed 50,000,000 iterations, sampling every 50,000$^{\mathrm{th}}$ to give 1,000 MCMC samples. The 1,000 samples were used with no burn-in period (because the MCMC searches started from the MPD values). The quantiles (0.05, 0.50, 0.95) for estimated parameters and derived quantities appear in Tables F.1 and F.2. In particular, the current year median estimate of B_{2014} is 2,776 t. The median depletion estimate B_{2014}/B_0 is 0.371.

MCMC traces show acceptable convergence properties (no trend with increasing sample number) for the estimated parameters (Figure F.10), as does a diagnostic analysis that splits the samples into three segments (Figure F.11). Many of the parameters (e.g., R_0) move from the initial MPD estimate to some other median value. Pairs plots of the estimated parameters (starting at Figure F.12) show no undesirable correlations between parameters. As this model fixes natural mortality M_1 to 0.2, there is no need to worry about a correlation with steepness h. A pairs plot of the reference points (Figure F.14) shows that h is correlated, in some cases strongly, with the MSY-based references but shows no correlation with the historical reference points.

Marginal posterior distributions and corresponding priors for the estimated parameters are shown in Figure F.15. For most parameters, with the exception of h, it appears that there is enough information in the data to move the posterior distribution away from the prior. There is very little updating of the h posterior from the prior. Corresponding summary statistics for the estimated parameters are given in Table F.1.

The marginal posterior distribution of vulnerable biomass and catch (Figure F.16) shows a decline in the population from 1950 to aprroximately 1970, a levelling off during the 1970s and 1980s, followed by a sharp decline in the 1990s (2014). The stock shows a generally increasing biomass trend from 1996 to present. The median spawning biomass relative to unfished equilibrium values (Figure F.17) reached a minimum of 0.154 in 1998 and currently sits at 0.371. The recruitment patterns for 5AB Rock Sole show occasional upticks in 1987, 2000, and 2007 (Figure F.18). Exploitation rates were elevated during various periods around 1969, 1980, 1995, and peaked in 2003 at a median value of 0.405 (Figure F.19). A phase plot showing the time-evolution of spawning biomass and exploitation rate relative to B_{MSY} and F_{MSY} (Figure F.20) shows a steady movement from well above B_{MSY} to around $0.6B_{\mathrm{MSY}}$ due to overexploitation ($u_t > u_{MSY}$), followed by a recovery into the healthy zone.

F.2.3 Projection results and decision tables

Projections were made to evaluate the future behaviour of the population under different levels of constant catch, given the model assumptions. The projections, starting with the biomass at the beginning of 2014, were made over a range of constant catch strategies (0-1,200 t) for each of the 1,000 MCMC samples in the posterior, generating future biomass trends by assuming random recruitment deviations. Future recruitments were generated through the stock-recruitment function using recruitment deviations drawn randomly from a lognormal distribution with zero mean and constant standard deviation (see Appendix E for full details). Projections were made for 5 years. This time frame was considered to be long enough to satisify the 'long-term' requirement of the Request for Science Information and Advice, yet short enough for the projected recruitments to be mainly based on individuals spawned before 2014 (and hence already estimated by the model).

Resulting projections of spawning biomass are shown for selected catch strategies (Figure F.21). These suggest that the recent increase in spawning biomass would most likely continue for a catch of 300 t, which is smaller than the recent average catch of 316 t.

Note that recruitment is drawn from the estimated stock-recruitment curve with lognormal error that has a standard deviation of 0.6 and a mean of zero. However, this approach of average recruitment does not accurately simulate the occasional large recruitment events that have occurred for this stock (Figure F.18).

Decision tables give the probabilities of the spawning biomass exceeding the reference points in specified years, calculated by counting the proportion of MCMC samples for which the biomass exceeded the given reference point.

Results for the three B_{MSY}-based reference points are presented in Tables F.3-F.5. For example, the estimated probability that the stock is in the provisional healthy zone in 2017 under a constant catch strategy of 1,000 t is P$(B_{2017} > 0.8B_{\mathrm{MSY}}) = 0.36$ (row '1000' and column '2017' in Table F.4).

Table F.6 provides probabilities that projected spawning biomass B_t will exceed the current-year biomass B_{2014} at the various catch levels. The first column populated by zero values simply means that the current-year biomass will never be greater than itself. Table F.7 shows the probabilities of projected exploitation rate u_t exceeding that at MSY (u_{MSY}).

For the maximum sustainable yield (MSY) calculations, projections were run for 801 values of constant exploitation rate u_t between 0 and 0.8, until an equilibrium yield was reached within a tolerance of 0.01 t (or until 15,000 years had been reached). This was done for each of the 1,000 samples. The lower bound of u_t was reached for none of the MCMC samples, and the upper bound was reached by none of the samples. Of the 801,000 projection calculations, all converged by 15,000 years.

The most recent Rock Sole assessment (Starr et al. 2006. Rock sole (*Lepidopsetta* spp) in British Columbia, Canada: Stock Assessment for 2005 and Advice to Managers for 2006/2007. PSARC Working Paper, Unpublished Manuscript, Available from K. Holt, Fisheries and Oceans Canada) used historical reference points – (i) a limit reference point based on the minimum biomass during a period when the biomass is experiencing depressed levels, and (ii) a target reference point based on the mean biomass during a period when biomass was considered stable and sustainable after fishing. For 5AB, the limit biomass is determined as the minimum estimated biomass from the years 1966-2005 and a target biomass is calculated as the mean over the years 1977-1985. Table F.8 and Table F.9 provide probabilities that projected biomass will exceed the historical limit and target reference points, respectively. Similarly, Table F.10 provides probabilities that the projected exploitation rate u_t exceeds a mean exploitation rate over the years 1966-2005.

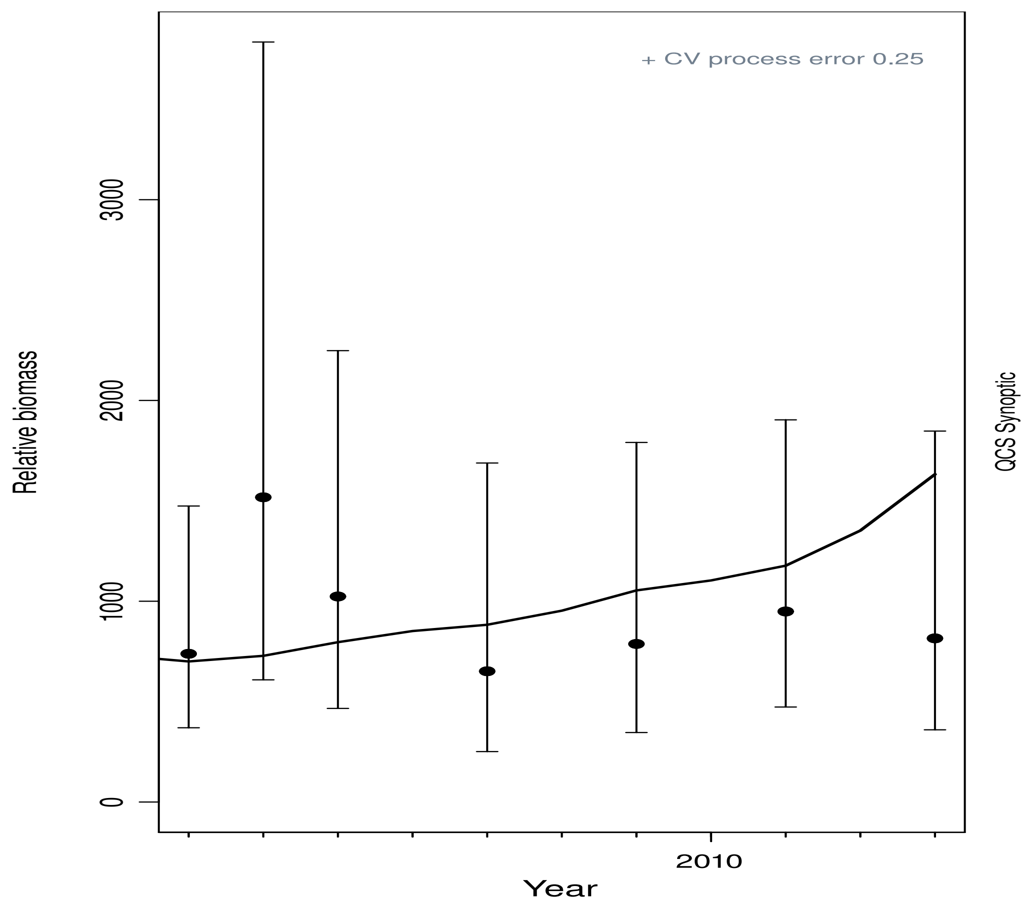


Figure F.1. Survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the Queen Charlotte Sound synoptic survey in Area 5AB.

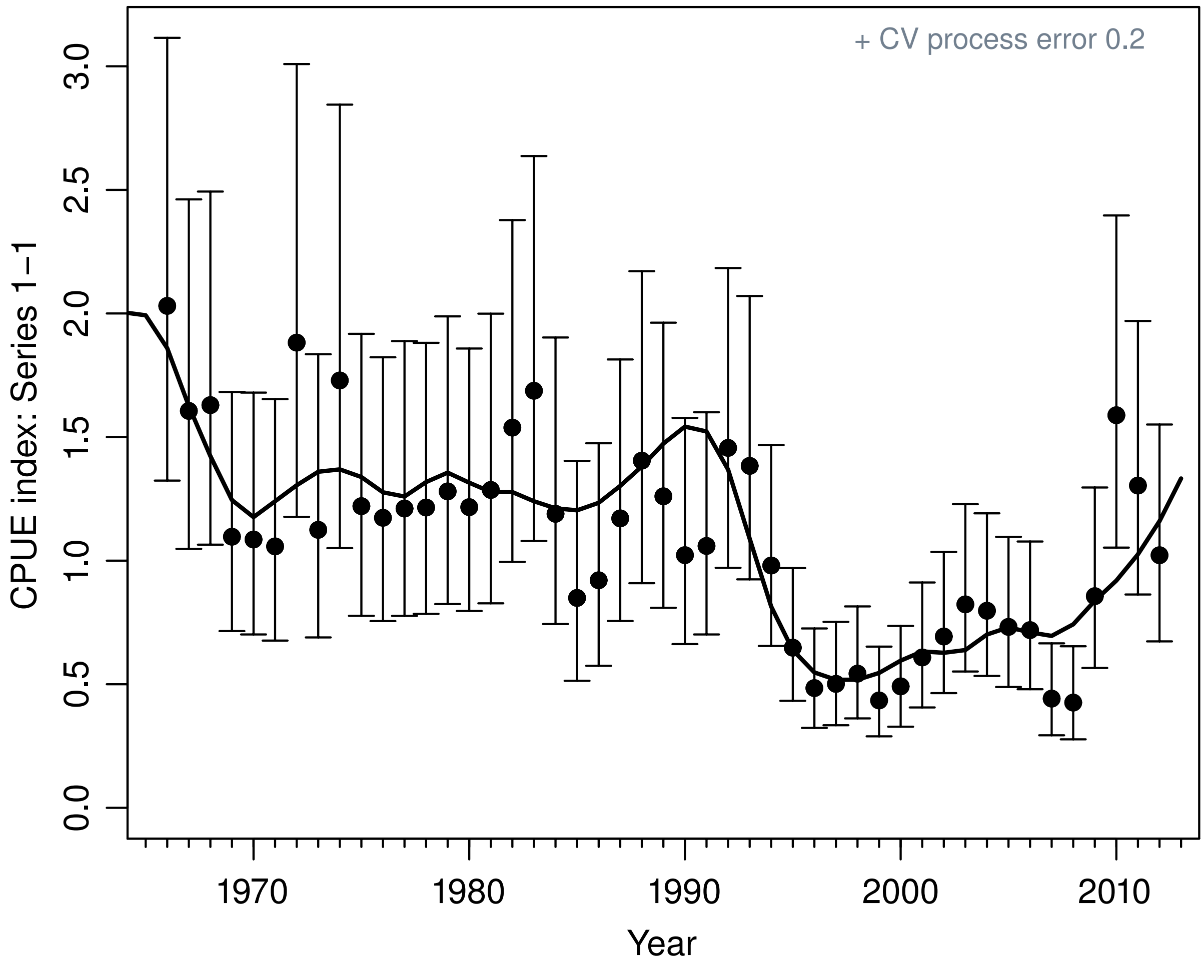


Figure F.2. CPUE index values for the long-term CPUE series used in the Area 5AB assessment (points with 95% confidence interval bars) and MPD model fits (solid line).

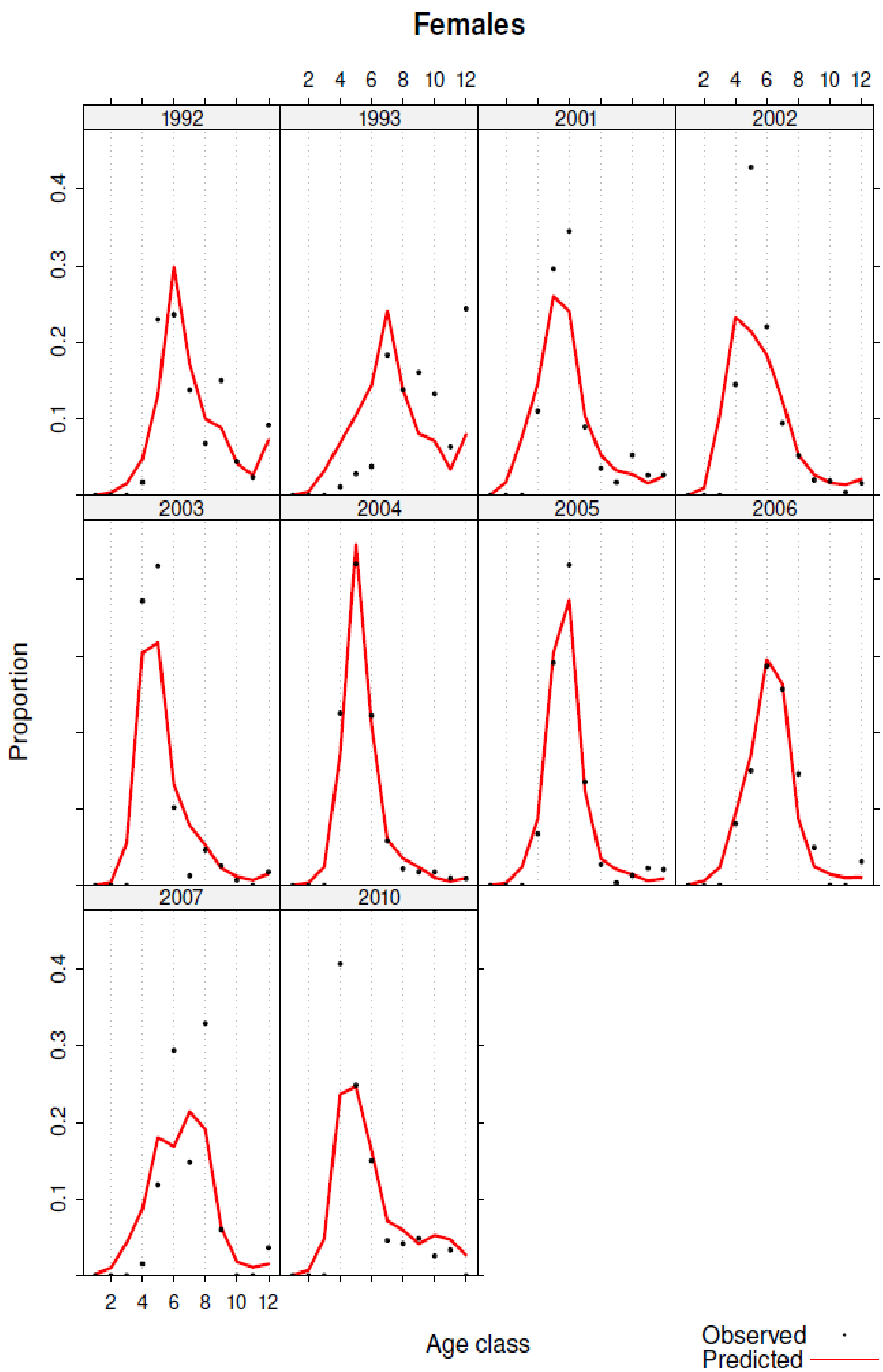


Figure F.3. Observed and predicted commercial proportions-at-age for females in Area 5AB. Note that years are not consecutive.

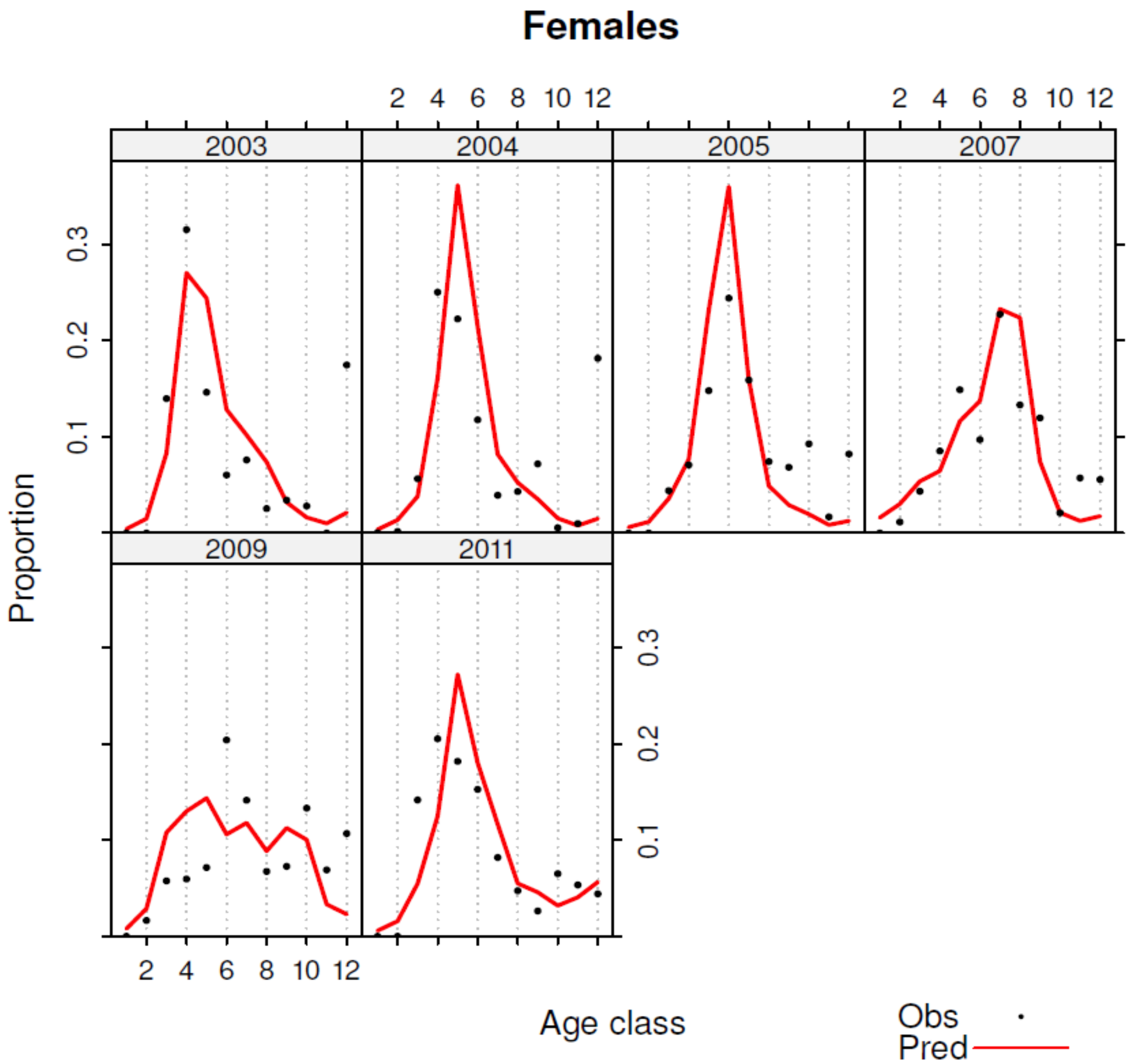


Figure F.4. Observed and predicted proportions-at-age for the Queen Charlotte Sound synoptic survey in the Area 5AB assessment.

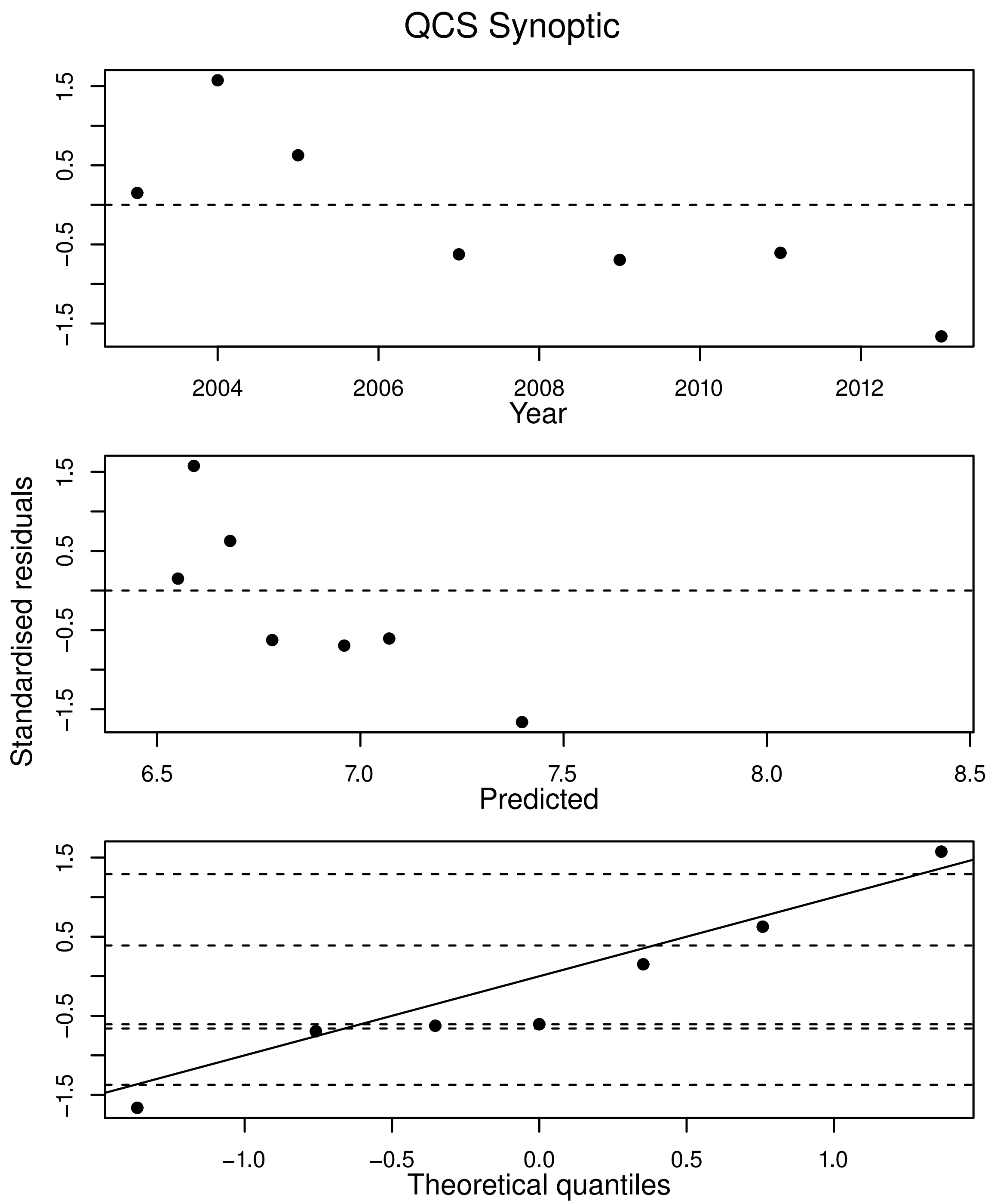


Figure F.5. Residuals of fits of model to the Queen Charlotte Sound synoptic survey in the Area 5AB assessment (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

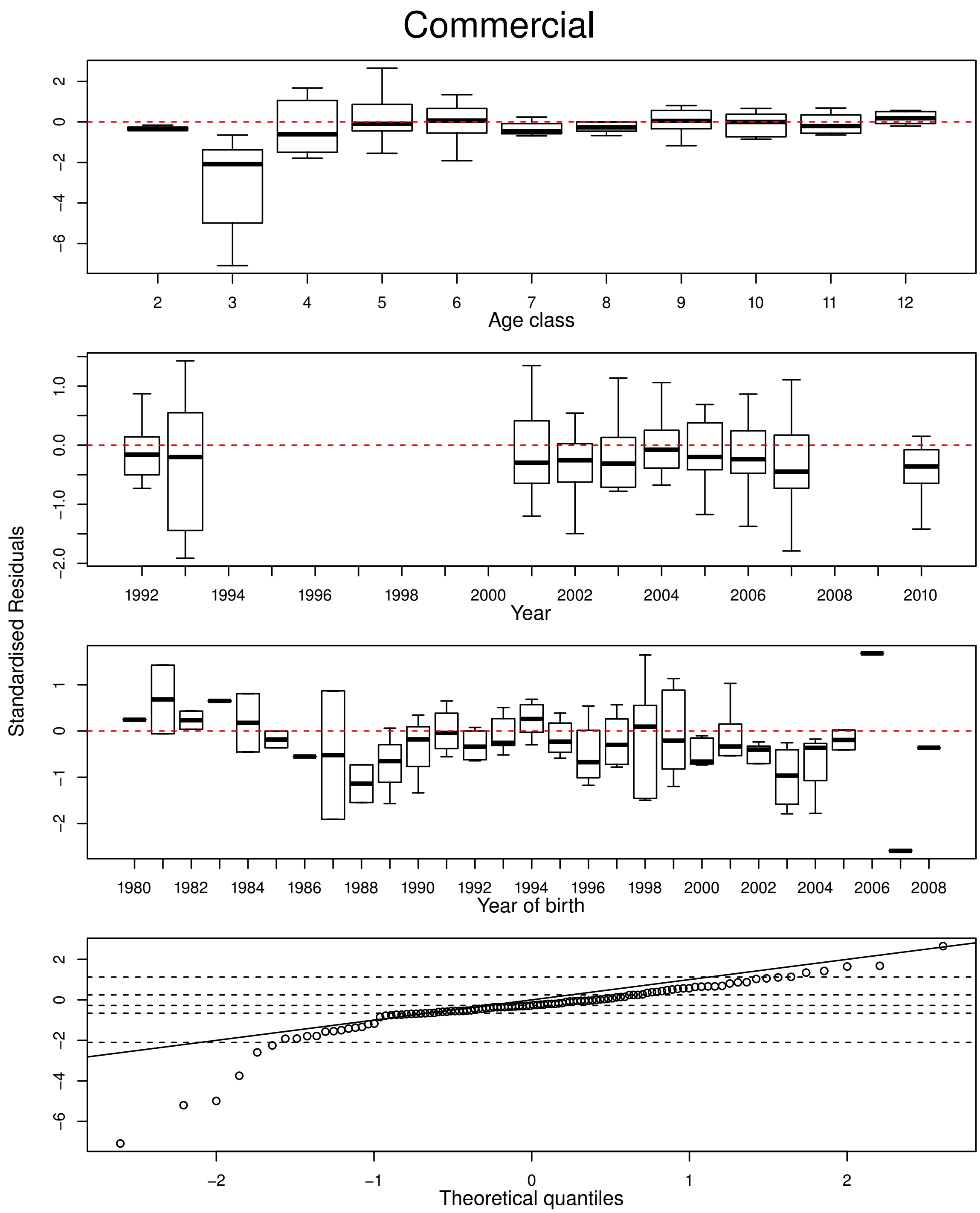


Figure F.6. Residual of fits of model to commercial proportions-at-age data (MPD values) for the Area 5AB assessment. Vertical axes are standardised residuals. Boxplots show, respectively, residuals by age class, by year of data, and by year of birth (following a cohort through time). Boxes give interquartile ranges, with bold lines representing medians and whiskers extending to the most extreme data point that is <1.5 times the interquartile range from the box. Bottom panel is the normal quantile-quantile plot for residuals, with the 1:1 line, though residuals are not expected to be normally distributed because of the likelihood function used; horizontal lines give the 5, 25, 50, 75, and 95 percentiles (for the total of 220 residuals).

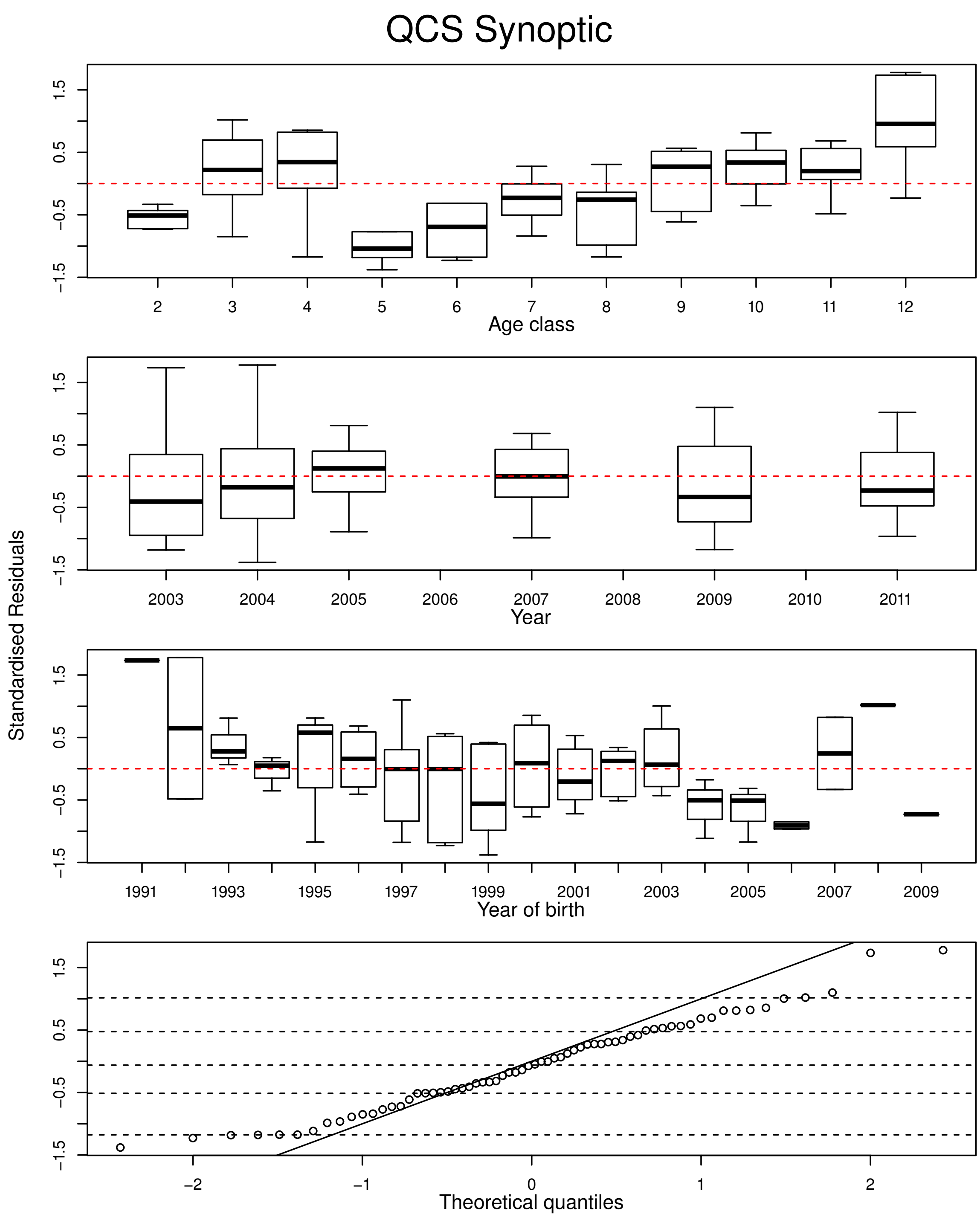


Figure F.7. Residuals of fits of model to proportions-at-age data (MPD values) from the Queen Charlotte Sound synoptic survey in the Area 5AB assessment. Details as for Figure F.6, for a total of 132 residuals.

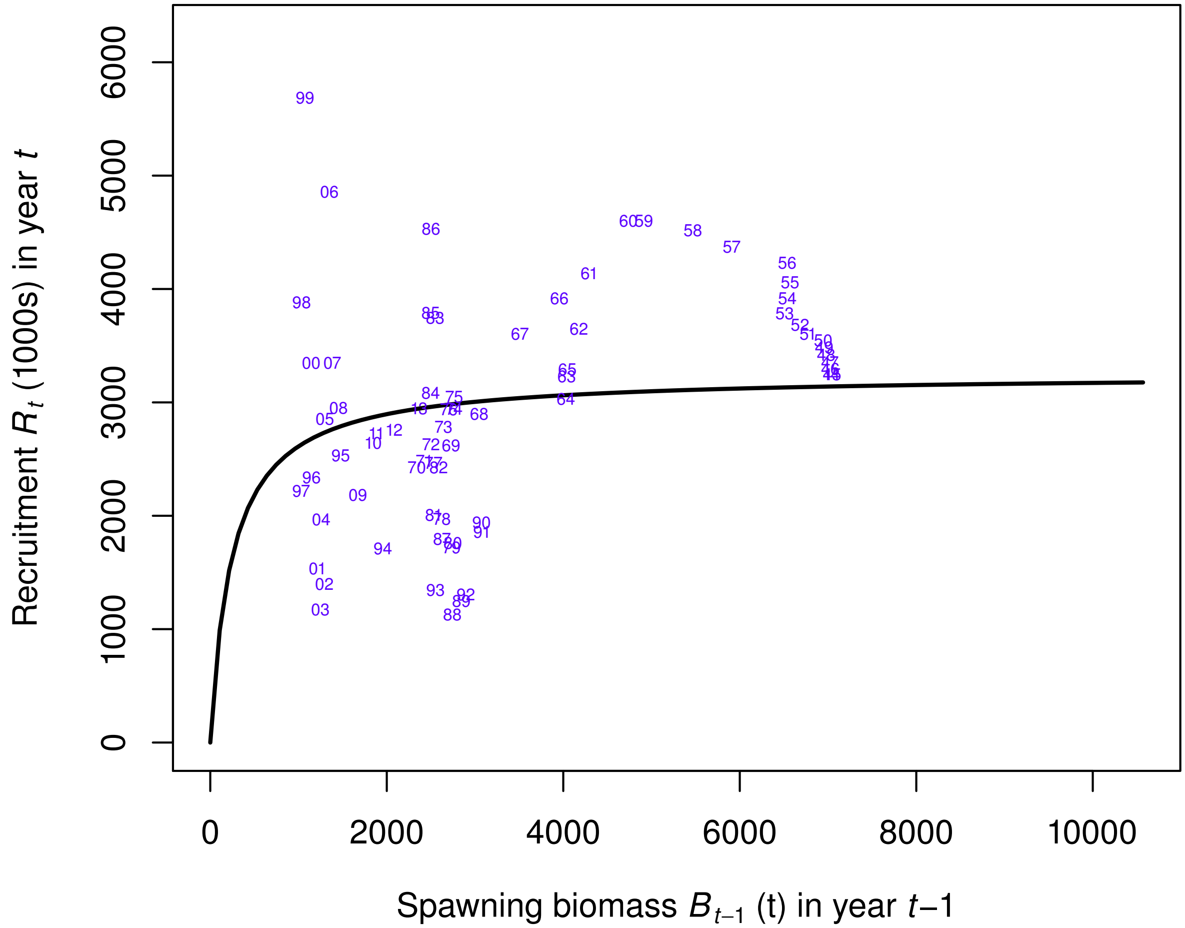
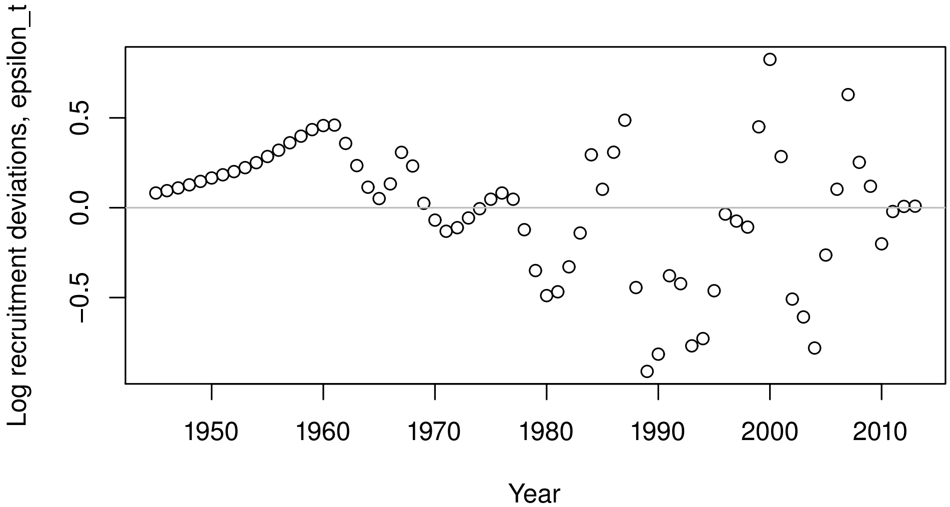


Figure F.8. Deterministic stock-recruit relationship from Area 5AB assessment model fit (black curve) and observed values (labelled by year of spawning) using MPD values. Both spawning biomass and recruitment only represent the female portion of the population.



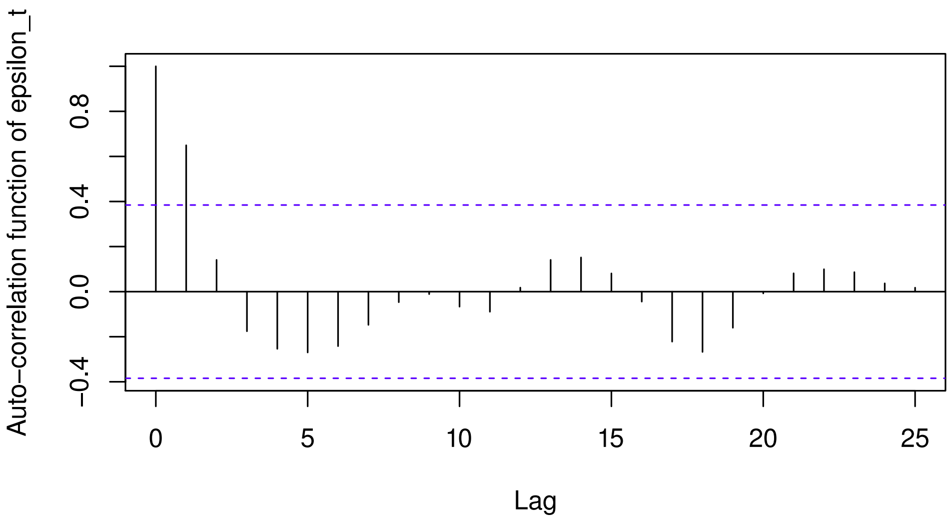


Figure F.9. Top: Log of the annual recruitment deviations predicted for Area 5AB, ϵ_t, where bias-corrected multiplicative deviation is e$^{\epsilon_t - \sigma_R^2/2}$ where $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. Bottom: Auto-correlation function of the logged recruitment deviations (ϵ_t), for years 1984-2009 (determined as the first year of commercial age data minus the accumulator age class plus the age for which commercial selectivity for females is 0.5, to the final year that recruitments are calculated minus the age for which commercial selectivity for females is 0.5).

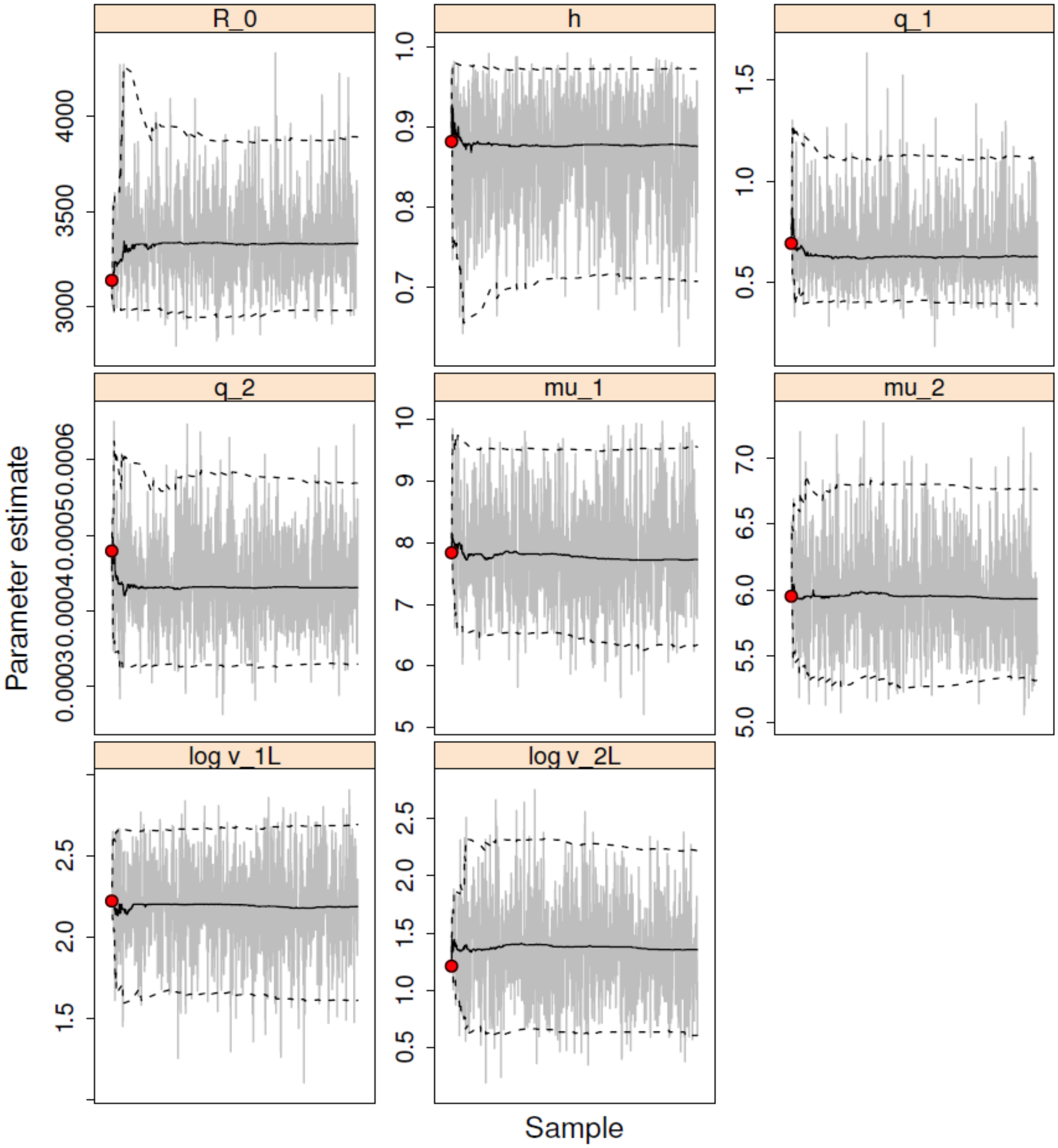


Figure F.10. MCMC traces for the estimated parameters in Area 5AB. Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates. For parameters other than M (if estimated), the subscript 1 corresponds to the Queen Charlotte Sound synoptic survey, and subscript 2 denotes the commercial fishery. Parameter notation is described in Appendix E.

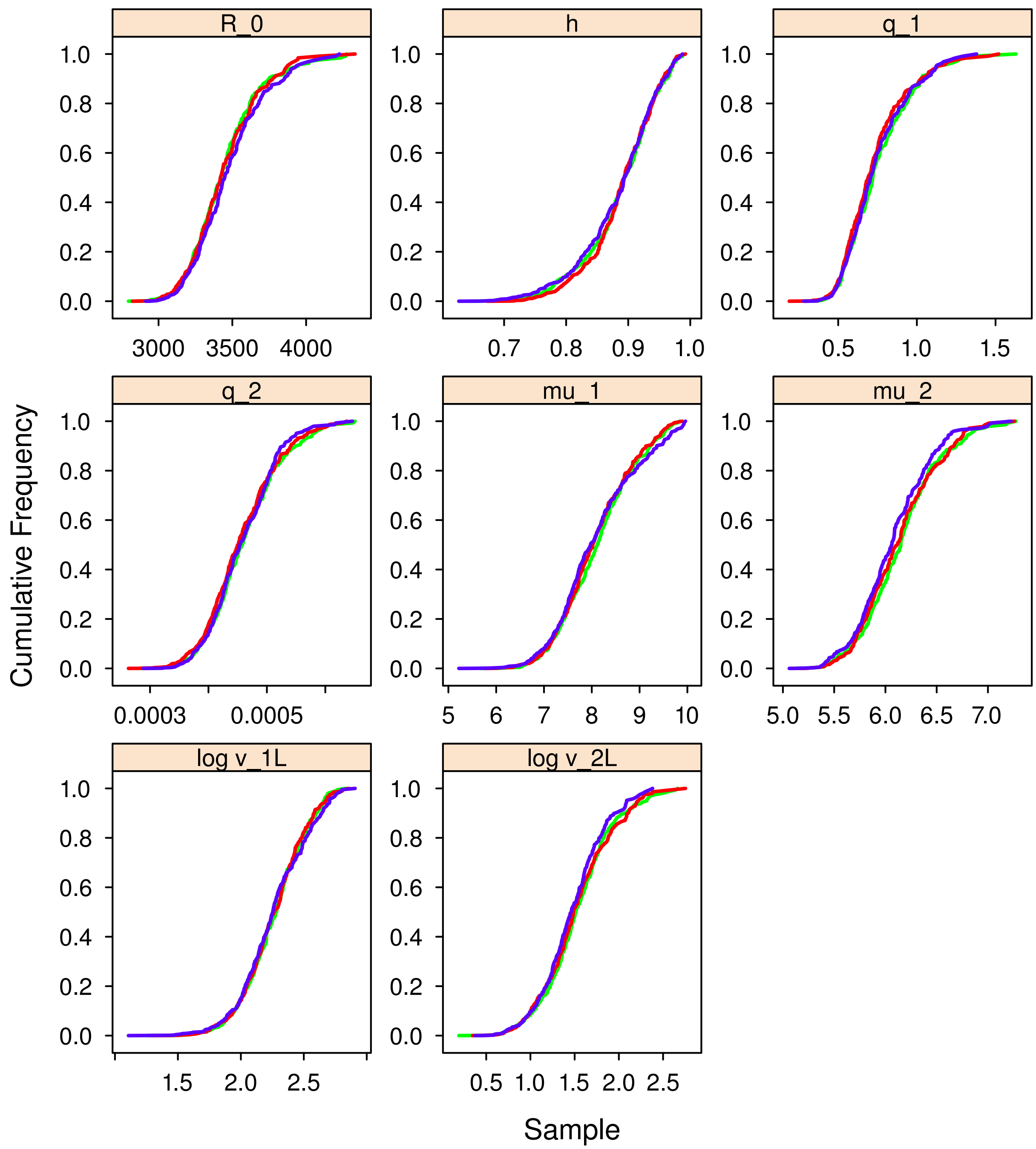


Figure F.11. Diagnostic plot from the Area 5AB assessment obtained by dividing the MCMC chain of 1,000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (green), second segment (red) and final segment (blue).

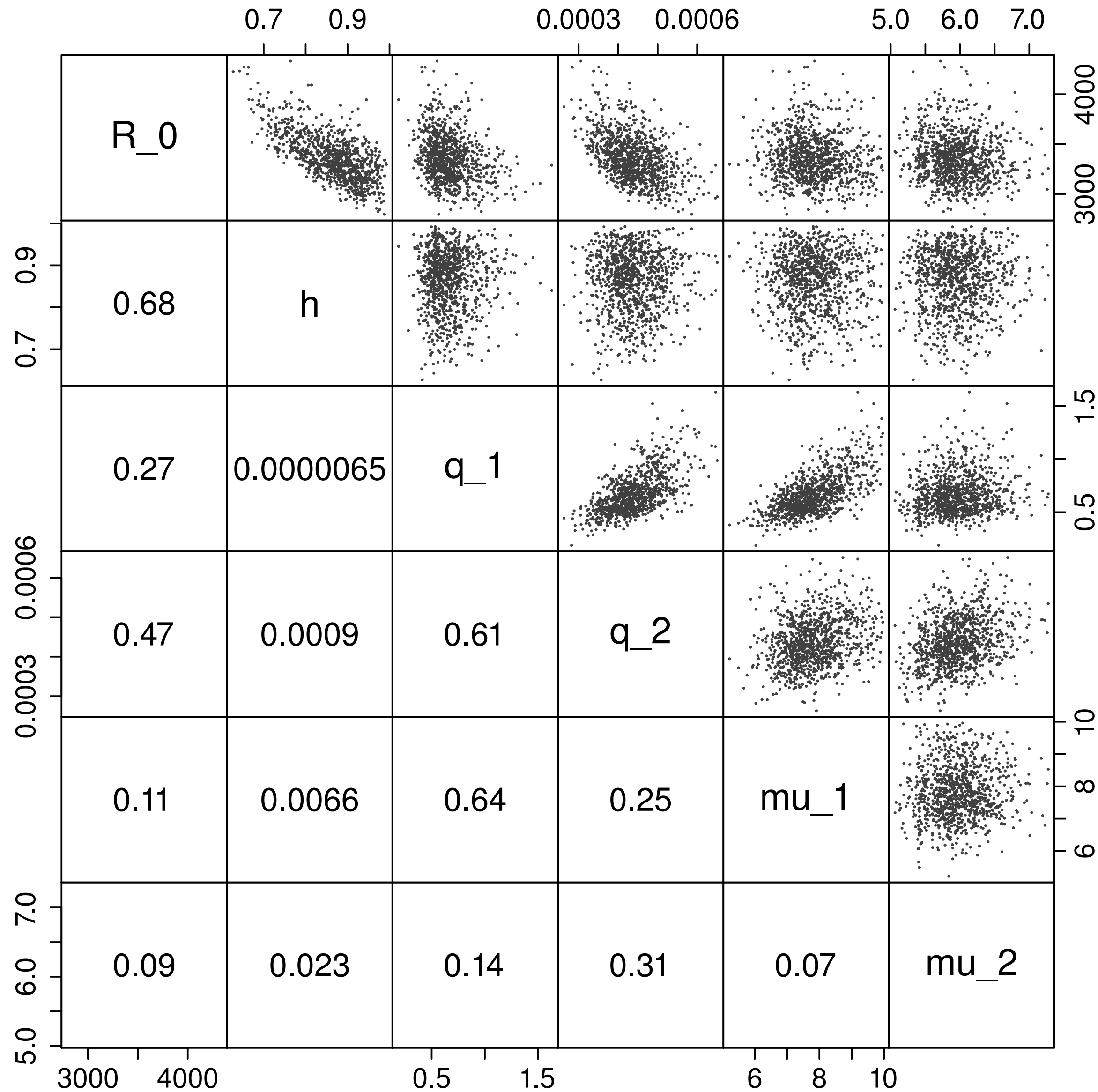


Figure F.12. Pairs plot from the Area 5AB assessment of 1,000 MCMC samples for first six parameters. Numbers are the absolute values of the correlation coefficients.

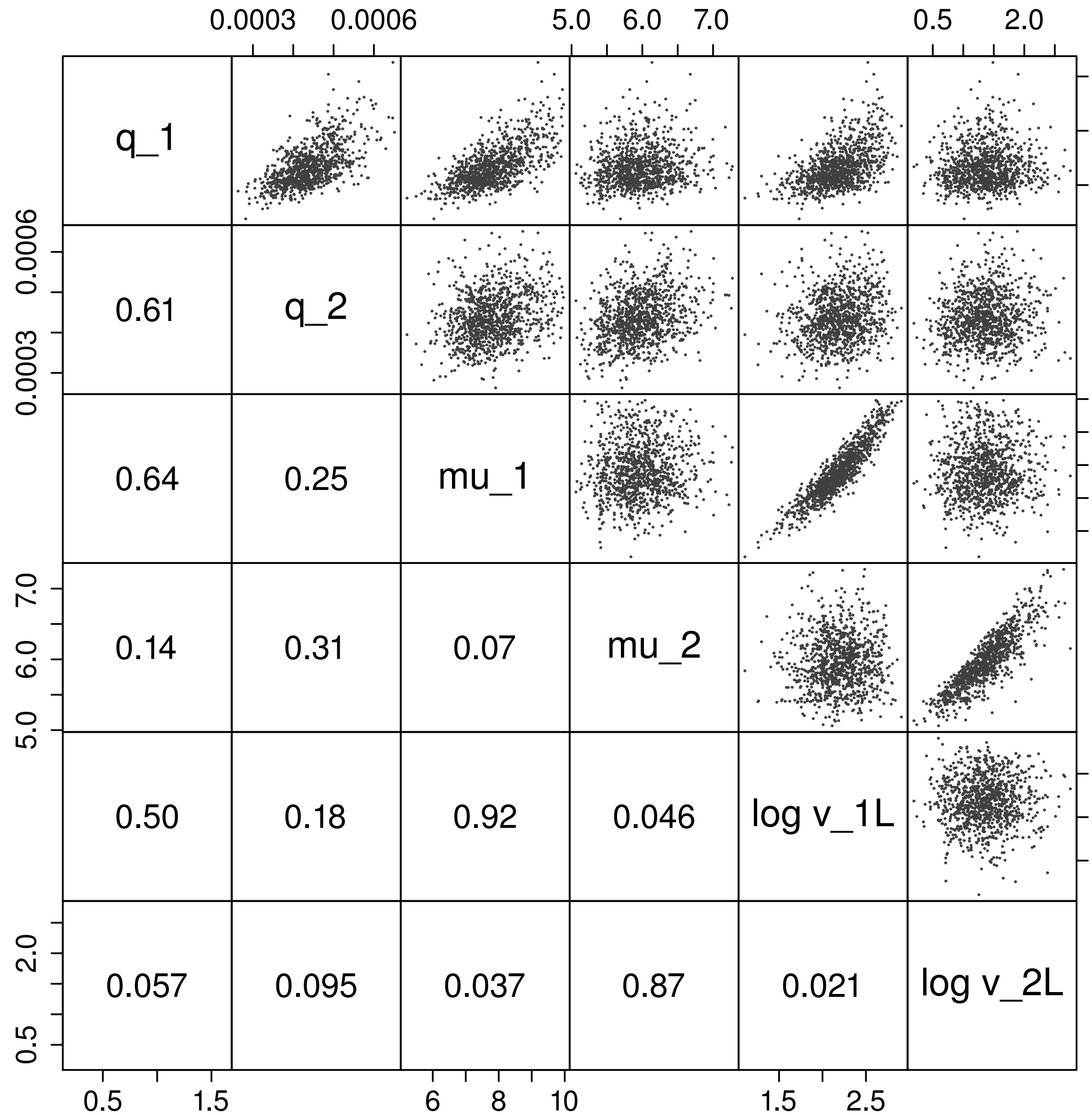


Figure F.13. Pairs plot from the Area 5AB assessment of 1,000 MCMC samples for second six parameters. Numbers are the absolute values of the correlation coefficients.

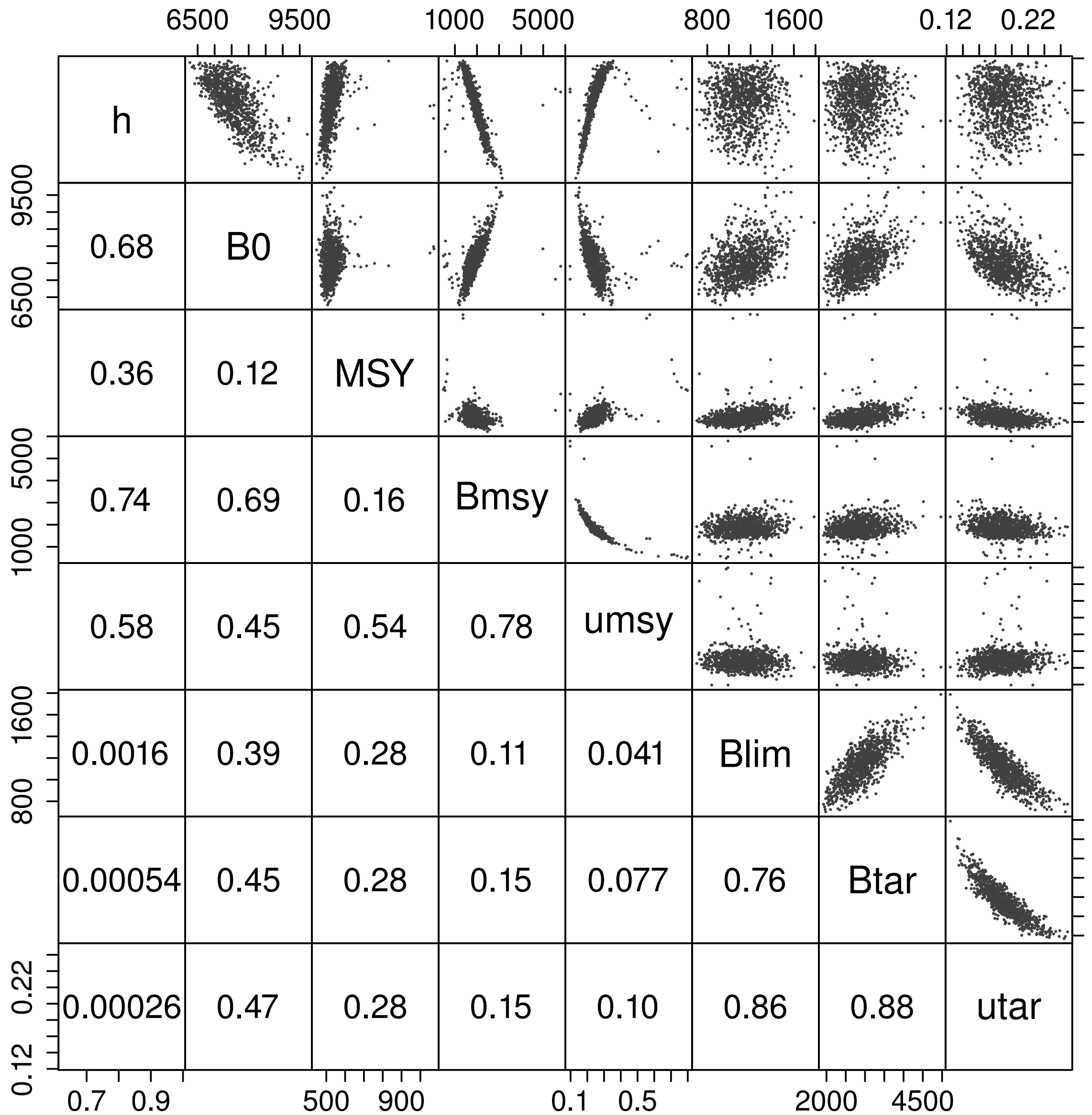


Figure F.14. Pairs plot comparing reference points from the Area 5AB assessment using 1,000 MCMC samples. Numbers are the absolute values of the correlation coefficients.

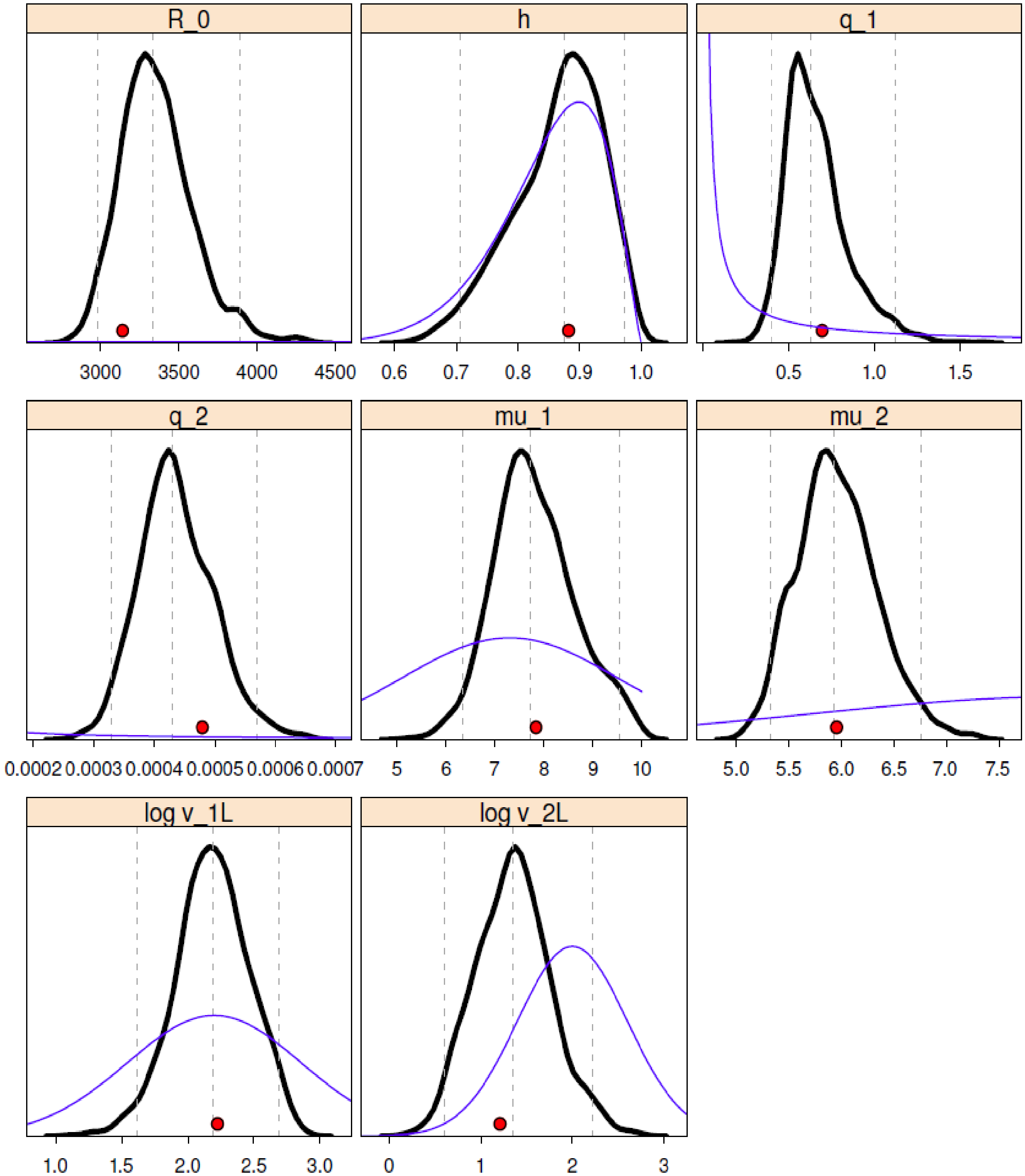


Figure F.15. Marginal posterior densities (thick black curves) and prior density functions (thin blue curves) for the estimated parameters from the Area 5AB assessment. Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates. For R_0 the prior is a uniform distribution on the range [100, 100000]. The priors for q_g are uniform on a log-scale, and so the probability density function is 1/(x(b − a)) on a linear scale (where a and b are the bounds on the log scale).

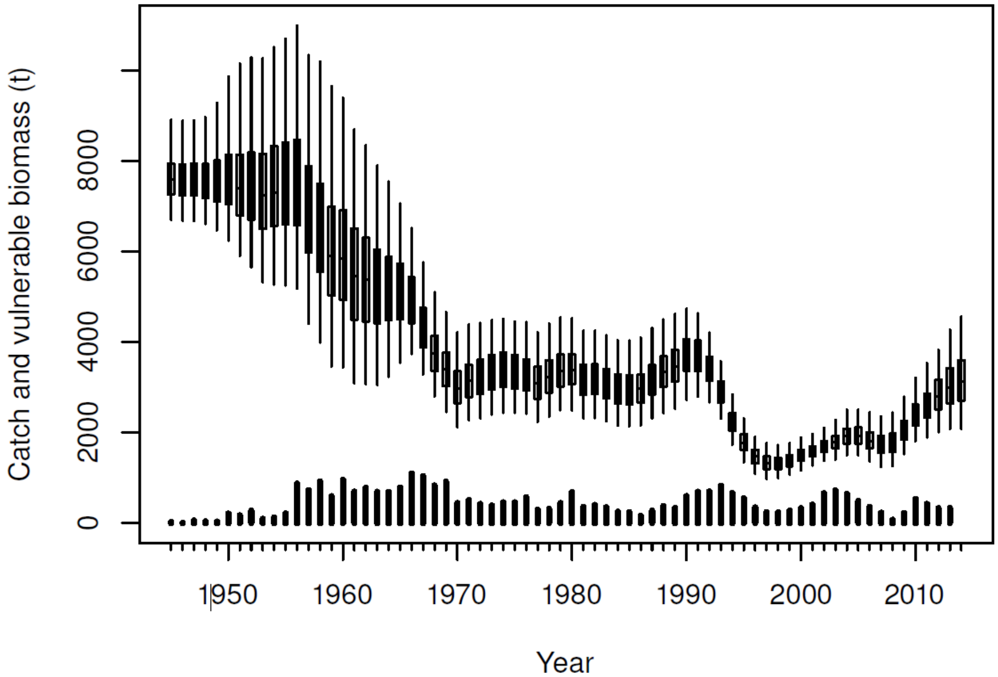


Figure F.16. Estimated female vulnerable biomass (boxplots) and commercial catch (vertical bars), in tonnes, over time for Area 5AB. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Female-only catch is shown to compare its magnitude to the estimated vulnerable biomass.

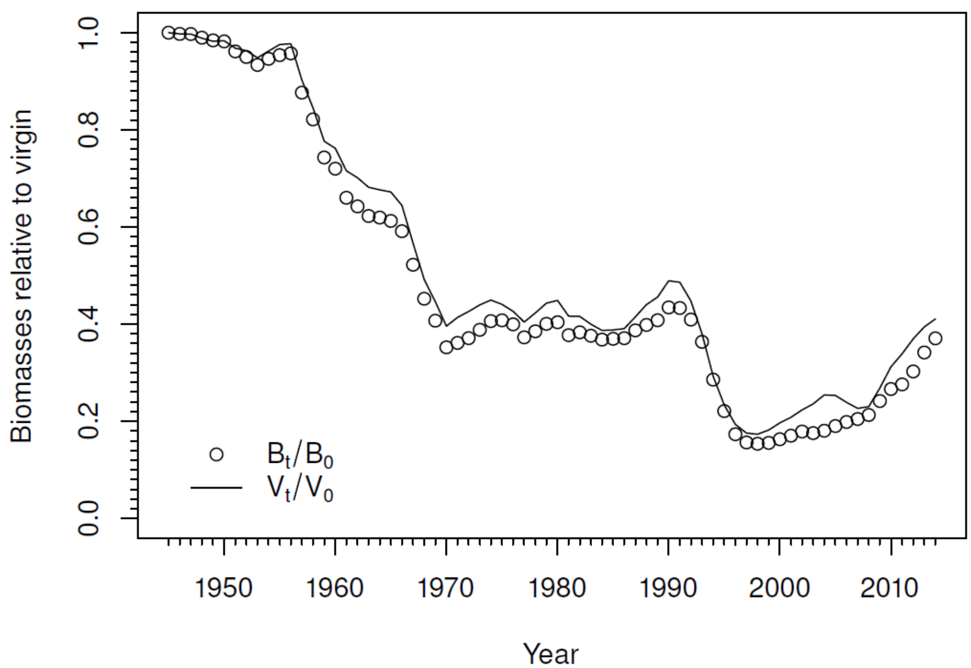


Figure F.17. Changes in B_t/B_0 and V_t/V_0 (female spawning and female vulnerable biomass relative to unfished equilibrium levels) over time for Area 5AB, shown as the medians of the MCMC posteriors

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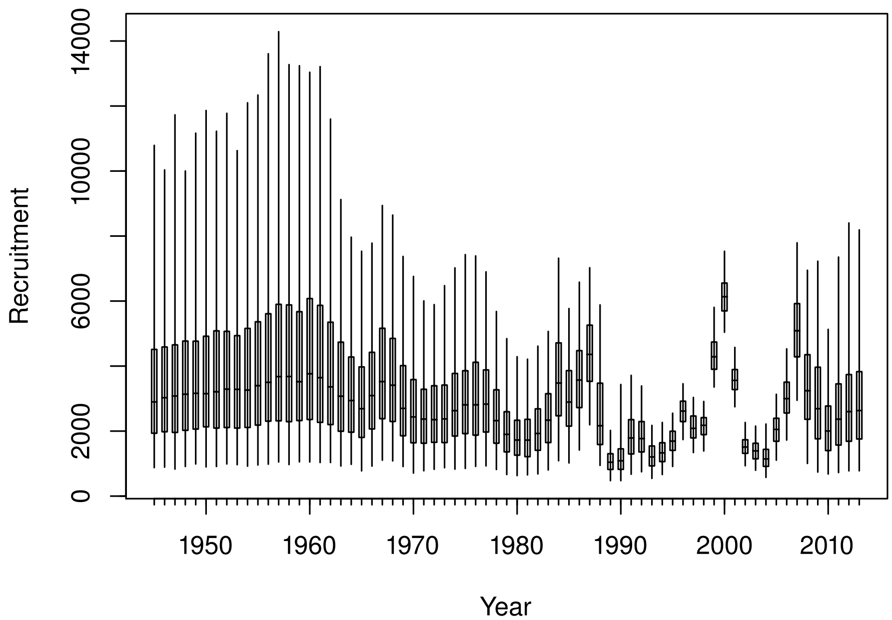


Figure F.18. Marginal posterior distribution of female recruitment in 1,000s of age-1 fish plotted over time for Area 5AB. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Note that the first year for which there are age data is 1992, and the plus-age class is 12, such that there are no direct data concerning age-1 fish before 1981. Also, the final few years have no direct age-data from which to estimate recruitment, because fish are not fully selected until age 5.9 by the commercial vessels or age 7.7 by surveys (mean of the MCMC median ages at full selectivity for commercial catch, μ_2, and survey μ_1, respectively).

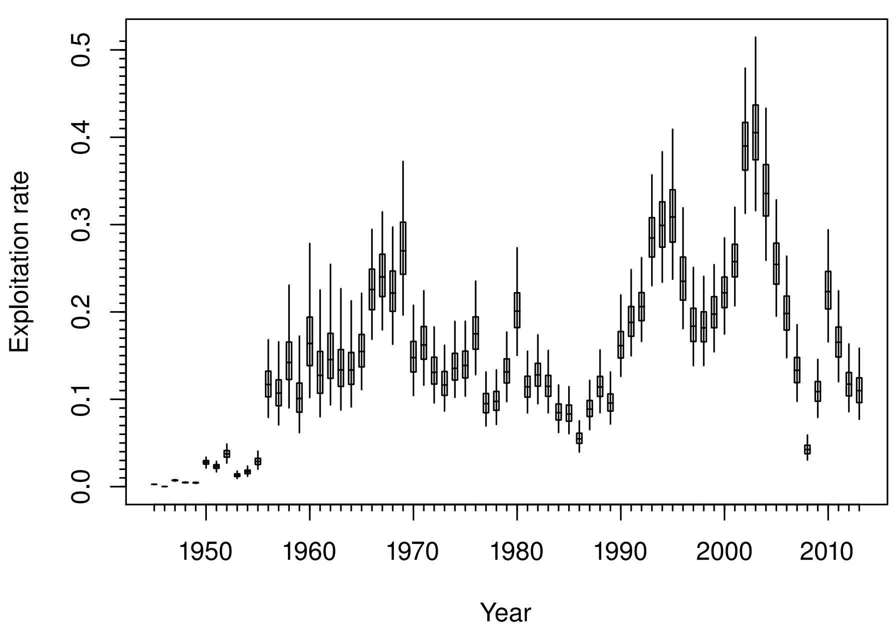


Figure F.19. Marginal posterior distribution of female exploitation rate in Area 5AB plotted over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

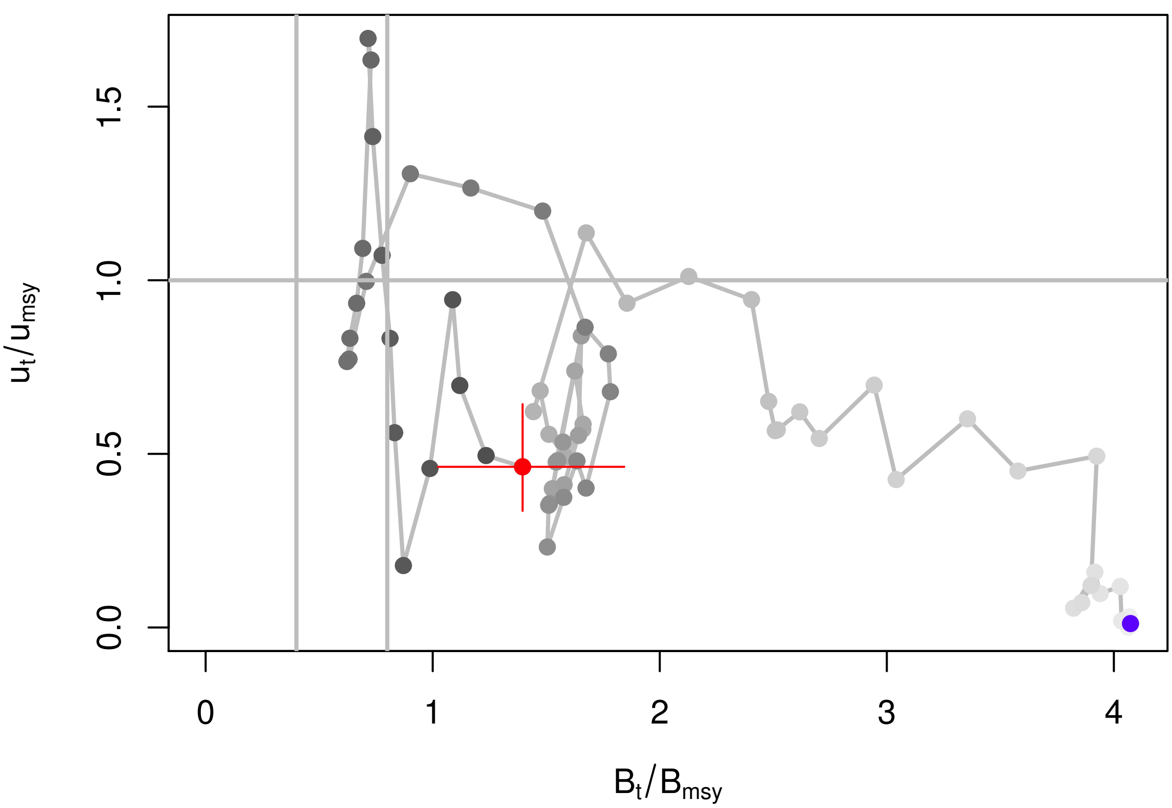


Figure F.20. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the female spawning biomass in year t relative to female-only B_{MSY}) and u_t/u_{MSY} (the female exploitation rate in year t relative to female-only u_{MSY}) for Area 5AB. Blue filled circle is the starting year (1945). Years then proceed from light grey through to dark grey with the final year (2013) as a filled red circle, and the red lines represent the 10% and 90% percentiles of the posterior distributions for the final year.

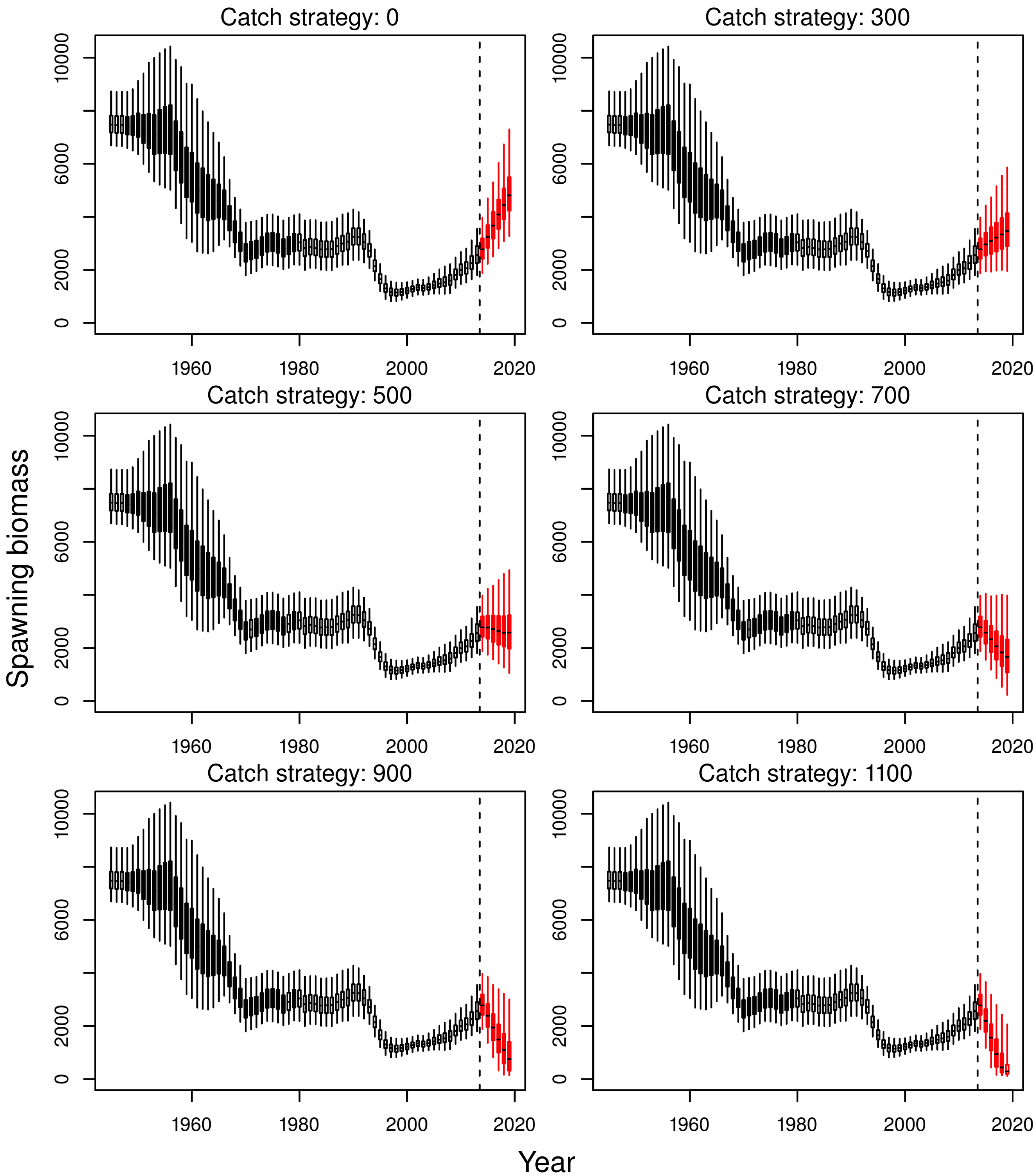


Figure F.21. Projected female spawning biomass (tonnes) under different constant catch strategies (tonnes, female-only catch) for Area 5AB; boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. For each of the 1,000 samples from the MCMC posterior, the model was run forward in time (red, with medians in black) with a constant catch, and recruitment was simulated from the stock-recruitment function with lognormal error (see Appendix E). For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t.

Table F.1. The 5$^{\mathrm{th}}$, 50$^{\mathrm{th}}$, and 95$^{\mathrm{th}}$ percentiles for model parameters derived via MCMC estimation (defined in Appendix E) for Area 5AB.

	5%	50%	95%
R_0	3,015	3,333	3,770
h	0.7298	0.8761	0.9663
q_1	0.4343	0.6280	1.020
q_2	0.0003443	0.0004309	0.0005413
μ_1	6.563	7.725	9.322
μ_2	5.403	5.933	6.614
$\log v_{1L}$	1.725	2.190	2.643
$\log v_{2L}$	0.7001	1.353	2.084

Table F.2. The 5$^{\mathrm{th}}$, 50$^{\mathrm{th}}$ and 95$^{\mathrm{th}}$ percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior from the Area 5AB assessment. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (females), B_{2014} – female spawning biomass at the start of 2014, V_{2014} – female vulnerable biomass in the middle of 2014, u_{2013} – exploitation rate (ratio of female catch to female vulnerable biomass) in the middle of 2013, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1945-2013), B_{MSY} – equilibrium female spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium female vulnerable biomass at MSY. The values B_{Lim} and B_{Tar} denote historical limit and target reference points min($B_{1966-2005}$) and mean($B_{1977-1985}$), respectively. The historical target exploitation rate is expressed as the mean($u_{1966-2005}$). All biomass values (and MSY) are in tonnes. For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t.

Value	Percentile		
	5%	50%	95%
	From model output		
B_0	6,765	7,479	8,457
V_0	6,799	7,592	8,680
B_{2014}	1,977	2,776	3,779
V_{2014}	2,185	3,122	4,344
B_{2014}/B_0	0.271	0.371	0.492
V_{2014}/V_0	0.298	0.411	0.549
u_{2013}	0.082	0.11	0.15
$u_{\max}$	0.333	0.407	0.492
	MSY-based quantities		
MSY	483	524	580
B_{MSY}	1,427	1,833	2,471
$0.4B_{\mathrm{MSY}}$	571	733	988
$0.8B_{\mathrm{MSY}}$	1,142	1,467	1,977
$B_{2014}/B_{\mathrm{MSY}}$	0.977	1.521	2.264
B_{MSY}/B_0	0.202	0.246	0.296
V_{MSY}	1,769	2,209	2,892
V_{MSY}/V_0	0.253	0.292	0.338
u_{MSY}	0.176	0.239	0.307
$u_{2013}/u_{\mathrm{MSY}}$	0.299	0.463	0.724
	History-based quantities		
B_{Lim}	863	1,133	1,422
B_{Tar}	2,216	2,879	3,663
$B_{2014}/B_{\mathrm{Lim}}$	1.862	2.452	3.26
$B_{2014}/B_{\mathrm{Tar}}$	0.738	0.959	1.271
u_{Tar}	0.154	0.188	0.229
$u_{2013}/u_{\mathrm{Tar}}$	0.464	0.59	0.75

Table F.3. Decision table for Area 5AB concerning the limit reference point $0.4B_{\mathrm{MSY}}$ for 1-5 year projections for a range of constant catch strategies (in tonnes, female-only catch). Values are P($B_t > 0.4B_{\mathrm{MSY}}$), i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the limit reference point. The probabilities are the proportion (to two decimal places) of the 1000 MCMC samples for which $B_t > 0.4B_{\mathrm{MSY}}$. For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.

	2014	2015	2016	2017	2018	2019
0	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
300	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00
600	1.00	1.00	1.00	1.00	0.99	0.96
700	1.00	1.00	1.00	0.98	0.94	0.88
800	1.00	1.00	0.99	0.94	0.84	0.71
900	1.00	1.00	0.98	0.86	0.68	0.49
1000	1.00	1.00	0.96	0.75	0.49	0.31
1100	1.00	1.00	0.90	0.61	0.34	0.19
1200	1.00	1.00	0.82	0.45	0.20	0.10

Table F.4. Decision table for Area 5AB concerning the upper reference point $0.8B_{\mathrm{MSY}}$ for 1-5 year projections, such that values are P($B_t > 0.8B_{\mathrm{MSY}}$). For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.

	2014	2015	2016	2017	2018	2019
0	0.99	1.00	1.00	1.00	1.00	1.00
100	0.99	1.00	1.00	1.00	1.00	1.00
200	0.99	1.00	1.00	1.00	1.00	1.00
300	0.99	0.99	1.00	0.99	0.99	1.00
400	0.99	0.99	0.99	0.99	0.98	0.97
500	0.99	0.99	0.97	0.95	0.93	0.91
600	0.99	0.98	0.94	0.88	0.84	0.77
700	0.99	0.97	0.88	0.78	0.68	0.56
800	0.99	0.95	0.81	0.66	0.48	0.38
900	0.99	0.93	0.74	0.50	0.33	0.22
1000	0.99	0.90	0.64	0.36	0.20	0.12
1100	0.99	0.86	0.55	0.25	0.13	0.06
1200	0.99	0.82	0.44	0.17	0.07	0.03

Table F.5. Decision table for Area 5AB concerning the reference point B_{MSY} for 1-5 year projections, such that values are P($B_t > B_{\mathrm{MSY}}$). For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.

	2014	2015	2016	2017	2018	2019
0	0.94	0.99	1.00	1.00	1.00	1.00
100	0.94	0.98	0.99	0.99	1.00	1.00
200	0.94	0.97	0.99	0.99	0.99	0.99
300	0.94	0.96	0.97	0.97	0.97	0.98
400	0.94	0.94	0.94	0.93	0.92	0.92
500	0.94	0.92	0.88	0.83	0.83	0.81
600	0.94	0.90	0.81	0.75	0.67	0.60
700	0.94	0.86	0.74	0.61	0.49	0.40
800	0.94	0.82	0.65	0.46	0.33	0.26
900	0.94	0.79	0.55	0.33	0.21	0.14
1000	0.94	0.74	0.44	0.23	0.12	0.07
1100	0.94	0.70	0.35	0.15	0.07	0.03
1200	0.94	0.65	0.26	0.10	0.04	0.01

Table F.6. Decision table for Area 5AB for comparing the projected biomass to the current biomass, given by probabilities P($B_t > B_{2014}$). For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.

	2014	2015	2016	2017	2018	2019
0	0.00	1.00	1.00	1.00	1.00	1.00
100	0.00	1.00	1.00	1.00	1.00	1.00
200	0.00	0.99	0.98	0.98	0.98	0.98
300	0.00	0.89	0.87	0.85	0.85	0.85
400	0.00	0.69	0.63	0.59	0.60	0.62
500	0.00	0.42	0.37	0.34	0.36	0.36
600	0.00	0.22	0.19	0.19	0.18	0.19
700	0.00	0.12	0.09	0.08	0.08	0.08
800	0.00	0.06	0.05	0.04	0.04	0.03
900	0.00	0.03	0.03	0.02	0.02	0.01
1000	0.00	0.02	0.01	0.01	0.01	0.01
1100	0.00	0.01	0.00	0.01	0.00	0.01
1200	0.00	0.00	0.00	0.00	0.00	0.00

Table F.7. Decision table for Area 5AB for comparing the projected exploitation rate to that at MSY, such that values are P($u_t > u_{\mathrm{MSY}}$), i.e. the probability of the exploitation rate in the middle of year t being greater than that at MSY. For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.

	2014	2015	2016	2017	2018	2019
0	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
400	0.02	0.01	0.02	0.02	0.03	0.03
500	0.08	0.12	0.16	0.17	0.18	0.20
600	0.24	0.30	0.39	0.46	0.51	0.53
700	0.41	0.55	0.66	0.72	0.76	0.79
800	0.61	0.75	0.83	0.86	0.90	0.92
900	0.78	0.88	0.92	0.94	0.96	0.97
1000	0.88	0.93	0.96	0.98	0.98	0.99
1100	0.93	0.96	0.98	0.99	0.99	0.99
1200	0.96	0.98	0.99	0.99	1.00	1.00

Table F.8. Decision table for Area 5AB concerning the historical limit reference point min($B_{1966-2005}$) for 1-5 year projections for a range of constant catch strategies (in tonnes). Values are P($B_t > min(B_{1966-2005})$), i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the historical limit reference point. The probabilities are the proportion (to two decimal places) of the 1000 MCMC samples for which $B_t > min(B_{1966-2005})$. For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.

	2014	2015	2016	2017	2018	2019
0	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
300	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	0.98	0.97
600	1.00	1.00	1.00	0.98	0.95	0.92
700	1.00	1.00	0.99	0.94	0.84	0.75
800	1.00	1.00	0.97	0.85	0.68	0.54
900	1.00	1.00	0.92	0.70	0.48	0.32
1000	1.00	0.99	0.85	0.54	0.31	0.18
1100	1.00	0.99	0.74	0.40	0.19	0.09
1200	1.00	0.98	0.64	0.27	0.11	0.05

Table F.9. *Decision table for Area 5AB concerning the historical target reference point mean($B_{1977-1985}$) for 1-5 year projections, such that values are P($B_t > mean(B_{1977-1985})$). For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.*

	2014	2015	2016	2017	2018	2019
0	0.41	0.74	0.90	0.97	0.99	0.99
100	0.41	0.68	0.83	0.92	0.96	0.98
200	0.41	0.61	0.73	0.82	0.87	0.90
300	0.41	0.54	0.62	0.67	0.72	0.76
400	0.41	0.47	0.50	0.52	0.54	0.55
500	0.41	0.42	0.38	0.36	0.35	0.36
600	0.41	0.36	0.28	0.24	0.21	0.20
700	0.41	0.30	0.20	0.15	0.12	0.11
800	0.41	0.25	0.14	0.09	0.07	0.05
900	0.41	0.20	0.10	0.06	0.04	0.03
1000	0.41	0.16	0.07	0.03	0.02	0.01
1100	0.41	0.13	0.04	0.02	0.01	0.01
1200	0.41	0.11	0.02	0.01	0.00	0.00

Table F.10. *Decision table for Area 5AB concerning the historical target reference point mean($u_{1966-2005}$) for 1-5 year projections, such that values are P($u_t > mean(u_{1966-2005})$). For reference, the average estimated female catch over the last 5 years (2008-2012) is 316 t. The maximum historical female catch estimate in Area 5AB was 1100 t in 1966.*

	2014	2015	2016	2017	2018	2019
0	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
400	0.02	0.02	0.04	0.04	0.05	0.07
500	0.17	0.26	0.33	0.36	0.38	0.40
600	0.57	0.66	0.71	0.76	0.77	0.77
700	0.86	0.90	0.91	0.92	0.93	0.94
800	0.97	0.98	0.98	0.98	0.98	0.98
900	0.99	1.00	1.00	1.00	0.99	0.99
1000	1.00	1.00	1.00	1.00	1.00	1.00
1100	1.00	1.00	1.00	1.00	1.00	1.00
1200	1.00	1.00	1.00	1.00	1.00	1.00

F.3 AREA 5CD

F.3.1 Mode of the posterior distribution (MPD) results

Awatea first determines the MPD for each estimated parameter. These are then used as the starting points for the MCMC simulations. The MPD fits are shown for the survey indices (Figure F.22), the commercial indices (Figure F.23), the commercial catch-at-age data (as overlaid age structures in Figures F.24), the Hecate Strait (HS) assemblage survey (Figure F.25), and the Hecate Strait (HS) synoptic survey series age data (Figure F.26). The results are sensible and are able to capture the main features of the data sets fairly well. There appears to be relative consistency between the available data sources.

Residuals to the MPD model fits are provided for the two survey indices (Figures F.27 and F.28), and the three sets of age data (Figures F.29, F.30, and F.31). These further suggest that the model fits are consistent with the data.

Figure F.32 shows the resulting stock-recruitment function and the MPD values of recruitment over time (though see Figure F.43 for the MCMC values of recruitment). Figure F.33 shows that the recruitment deviations display trend over time, and that the auto-correlation function of the deviations confirm this.

F.3.2 Bayesian MCMC Results

The MCMC procedure performed 50,000,000 iterations, sampling every 50,000$^{\mathrm{th}}$ to give 1,000 MCMC samples. The 1,000 samples were used with no burn-in period (because the MCMC searches started from the MPD values). The quantiles (0.05, 0.50, 0.95) for estimated parameters and derived quantities appear in Tables F.11 and F.12. In particular, the current year median estimate of B_{2014} is 15,385 t. The median depletion estimate B_{2014}/B_0 is 0.802.

MCMC traces show acceptable convergence properties (no trend with increasing sample number) for the estimated parameters (Figure F.34), as does a diagnostic analysis that splits the samples into three segments (Figure F.35). Most of the parameters (e.g., R_0) move from the initial MPD estimate to some other median value. Pairs plots of the estimated parameters (starting at Figure F.36) show no undesirable correlations between parameters. In particular, steepness, h, and the natural mortality parameter, M_1, show little correlation, suggesting there are sufficient data to estimate them simultaneously. Additionally, a pairs plot of the reference points (Figure F.39) shows that h is not correlated with unfished equilibrium biomass B_0 nor with the historical reference points. Thus, the MCMC computations seem satisfactory.

Marginal posterior distributions and corresponding priors for the estimated parameters are shown in Figure F.40. For most parameters, with the exception of h, it appears that there is enough information in the data to move the posterior distribution away from the prior. The estimate of natural mortality, M_1, shifted significantly higher from 0.20 to 0.25 while the h posterior basically mirrored the prior. Corresponding summary statistics for the estimated parameters are given in Table F.11.

The marginal posterior distribution of vulnerable biomass and catch (Figure F.41) shows a decline in the population from 1955 to approximately 1980, a levelling off during the 1980s and 1990s, followed by an increase from 2000 until the final year (2014). The median spawning biomass relative to unfished equilibrium values (Figure F.42) reached a minimum of 0.422 in 2001 and currently sits at 0.802. The recruitment patterns for 5CD Rock Sole show occasional upticks in 1989, 2000, and 2008 (Figure F.43). Exploitation rates were elevated during three periods 1966-71, 1975-80, and 1988-95, where the latter period saw rates on the order of 30% (Figure F.44). A phase plot showing the time-evolution of spawning biomass and exploitation rate relative to B_{MSY} and F_{MSY} (Figure F.45) show a meandering within a good zone (low exploitation, high biomass).

F.3.3 Projection results and decision tables

Projections were made to evaluate the future behaviour of the population under different levels of constant catch, given the model assumptions. The projections, starting with the biomass at the beginning of 2014, were made over a range of constant catch strategies (0-3,000 t) for each of the 1,000 MCMC samples in the posterior, generating future biomass trends by assuming random recruitment deviations. Future recruitments were generated through the stock-recruitment function using recruitment deviations drawn randomly from a lognormal distribution with zero mean and constant standard deviation (see Appendix E for full details). Projections were made for 5 years. This time frame was considered to be long enough to satisify the 'long-term' requirement of the Request for Science Information and Advice, yet short enough for the projected recruitments to be mainly based on individuals spawned before 2014 (and hence already estimated by the model).

Resulting projections of spawning biomass are shown for selected catch strategies (Figure F.46). These suggest that the recent increase in spawning biomass would most likely continue for a catch of 600 t, which is larger than the recent average catch of 577 t.

Note that recruitment is drawn from the estimated stock-recruitment curve with lognormal error that has a standard deviation of 0.6 and a mean of zero. However, this approach of average recruitment does not accurately simulate the occasional large recruitment events that have occurred for this stock (Figure F.43).

Decision tables give the probabilities of the spawning biomass exceeding the reference points in specified years, calculated by counting the proportion of MCMC samples for which the biomass exceeded the given reference point.

Results for the three B_{MSY}-based reference points are presented in Tables F.13-F.15. For example, the estimated probability that the stock is in the provisional healthy zone in 2017 under a constant catch strategy of 1,000 t is P$(B_{2017} > 0.8B_{\mathrm{MSY}}) = 1$ (row '1000' and column '2017' in Table F.14).

Table F.16 provides probabilities that projected spawning biomass B_t will exceed the current-year biomass B_{2014} at the various catch levels. The first column populated by zero values simply means that the current-year biomass will never be greater than itself. Table F.17 shows the probabilities of projected exploitation rate u_t exceeding that at MSY (u_{MSY}).

For the maximum sustainable yield (MSY) calculations, projections were run for 801 values of constant exploitation rate u_t between 0 and 0.8, until an equilibrium yield was reached within a tolerance of 0.01 t (or until 15,000 years had been reached). This was done for each of the 1,000 samples. The lower bound of u_t was reached for none of the MCMC samples, and the upper bound was reached by 63 of the samples. Of the 801,000 projection calculations, all converged by 15,000 years.

The most recent Rock Sole assessment (Starr et al. 2006. Rock sole (*Lepidopsetta* spp) in British Columbia, Canada: Stock Assessment for 2005 and Advice to Managers for 2006/2007. PSARC Working Paper, Unpublished Manuscript, Available from K. Holt, Fisheries and Oceans Canada) used historical reference points – (i) a limit reference point based on the minimum biomass during a period when the biomass is experiencing depressed levels, and (ii) a target reference point based on the mean biomass during a period when biomass was considered stable and sustainable after fishing. For 5CD, the 2006 assessment recommended that the limit biomass be determined from the years 1966-2005 and that the target biomass be calculated as the mean over the years 1971-1980. We have retained these histroical reference points for this assessment. Table F.18 and Table F.19 provide probabilities that projected biomass will exceed these historical limit and target reference points, respectively. Similarly, Table F.20 provides probabilities that the projected exploitation rate u_t exceeds a mean exploitation rate over the years 1966-2005.

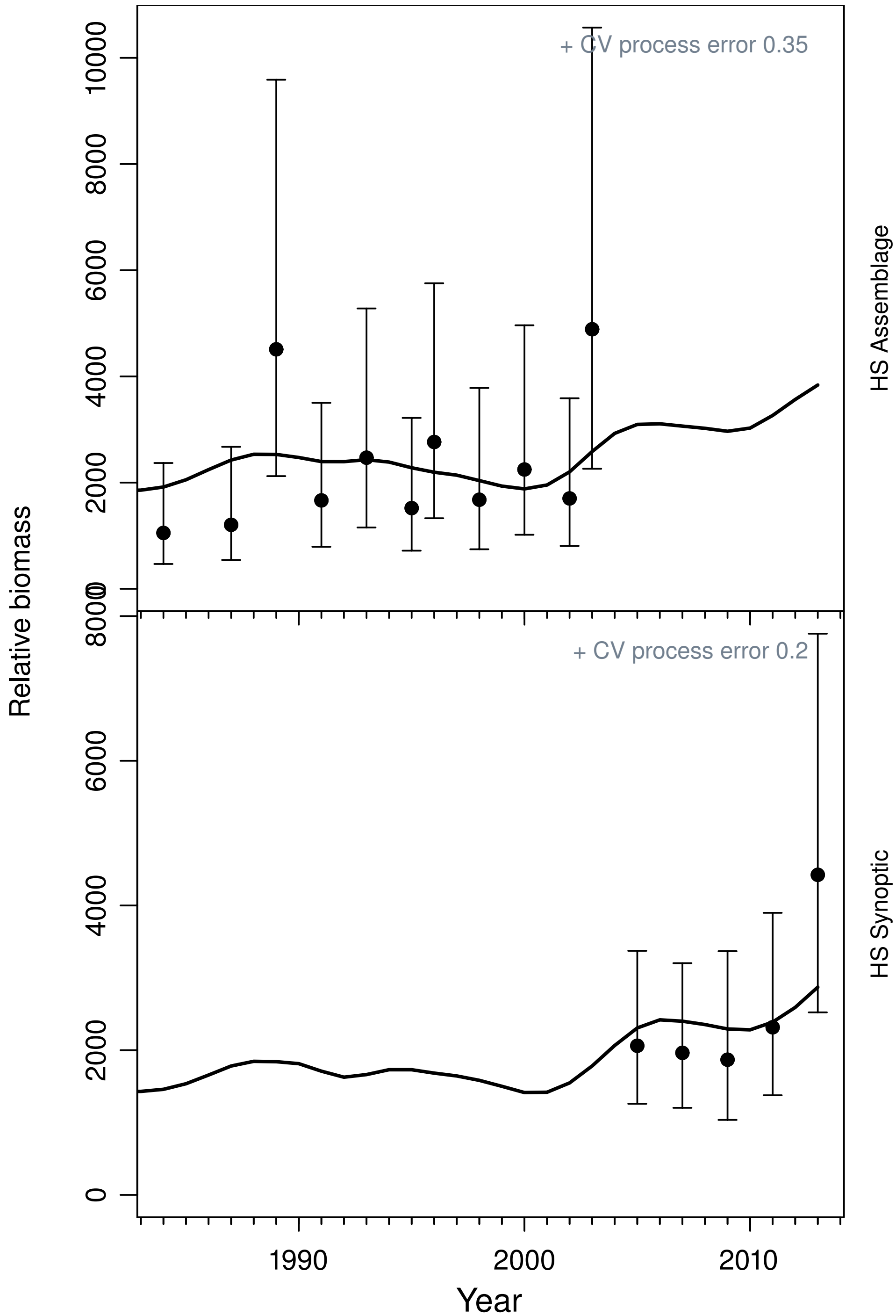


Figure F.22. Survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the fishery-independent survey series in Area 5CD (Hecate Strait Assemblage survey and Hecate Strait Synoptic survey).

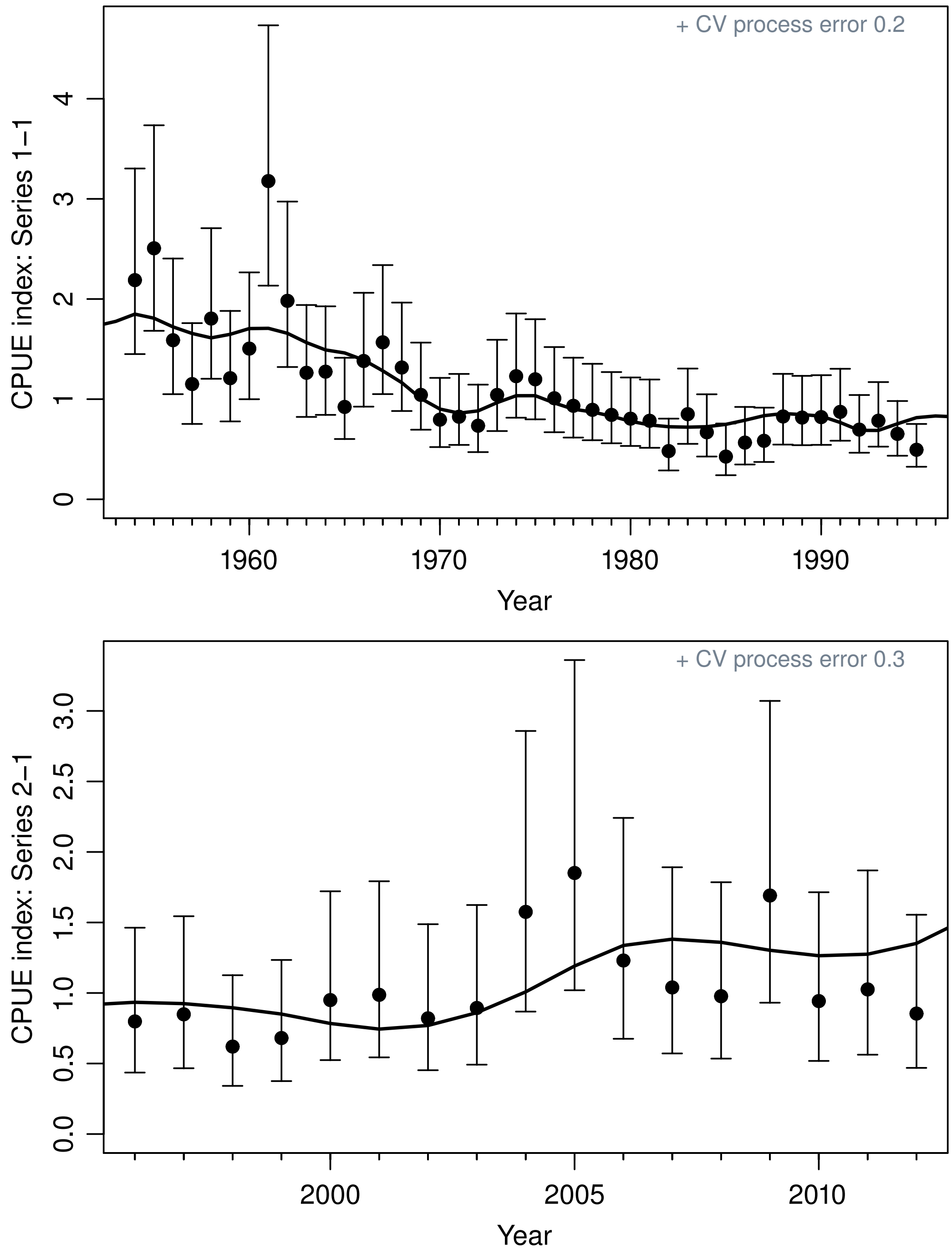


Figure F.23. CPUE index values for the two CPUE series used in the Area 5CD assessment (points with 95% confidence interval bars) and MPD model fits (solid line). The top panel shows the 1954–1995 CPUE series, while the bottom panel shows the 1996–2012 series.

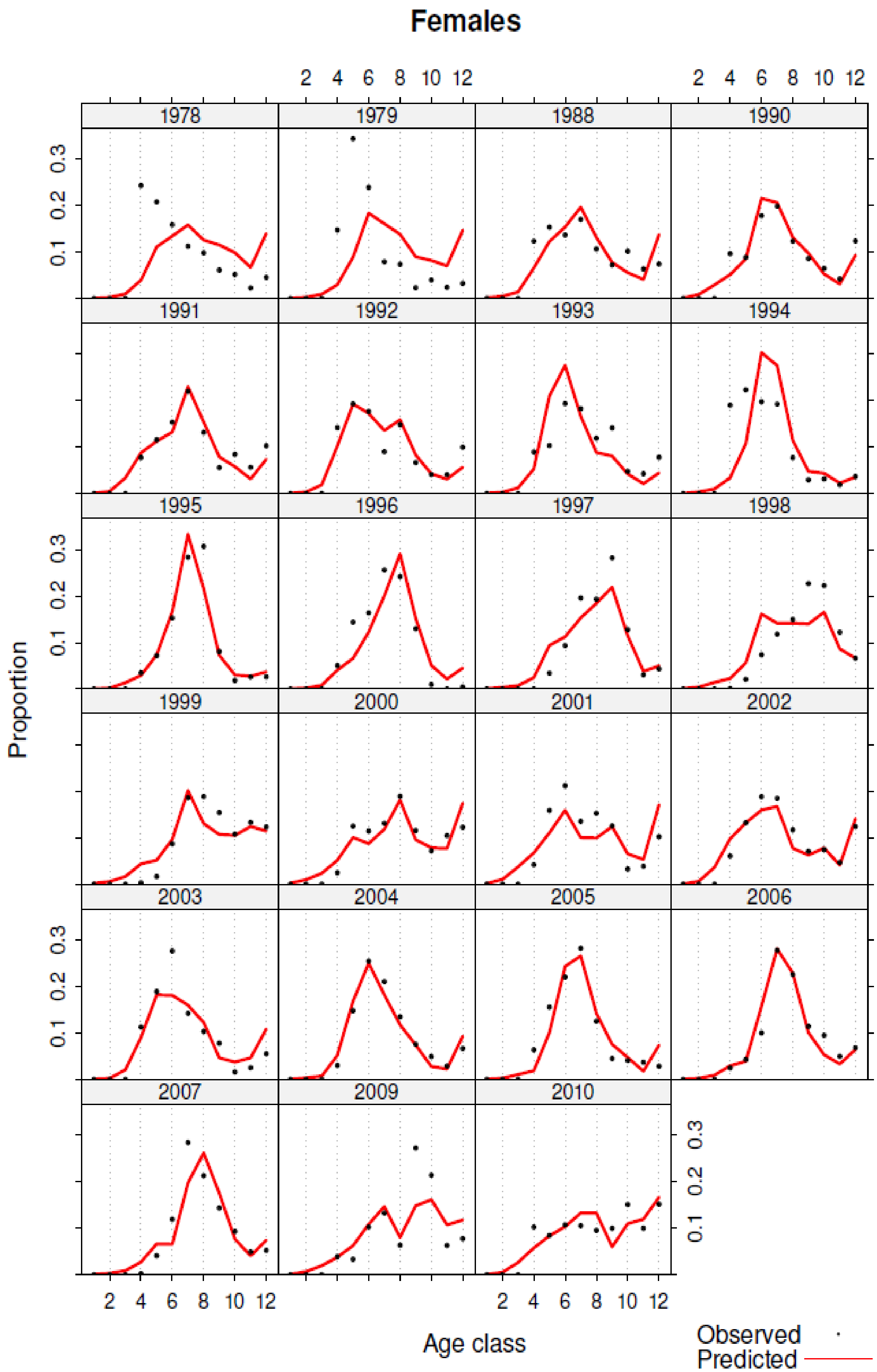


Figure F.24. Observed and predicted commercial proportions-at-age for females in Area 5CD. Note that years are not consecutive.

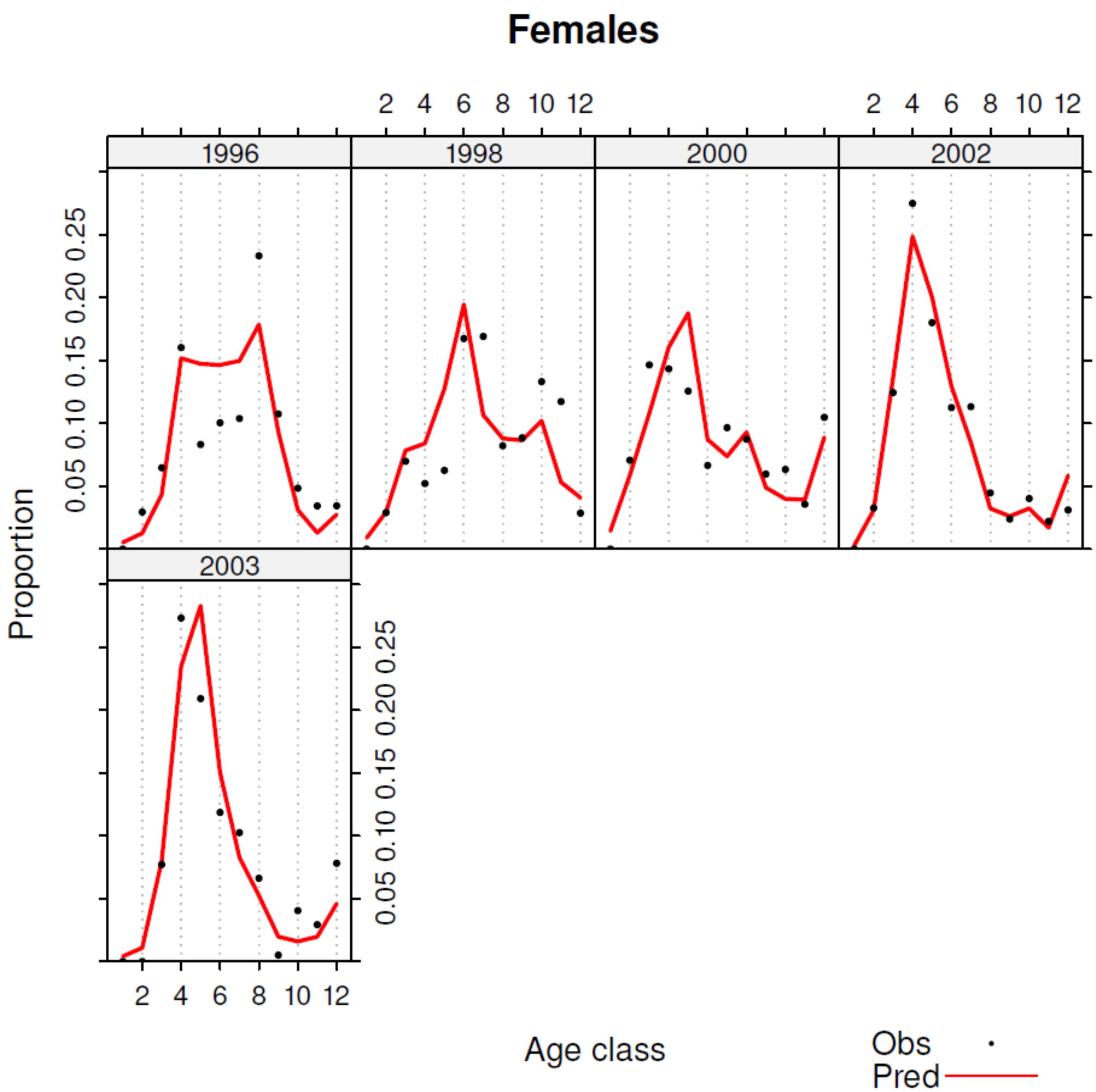


Figure F.25. Observed and predicted proportions-at-age for the Hecate Strait multispecies assemblage survey in Area 5CD.

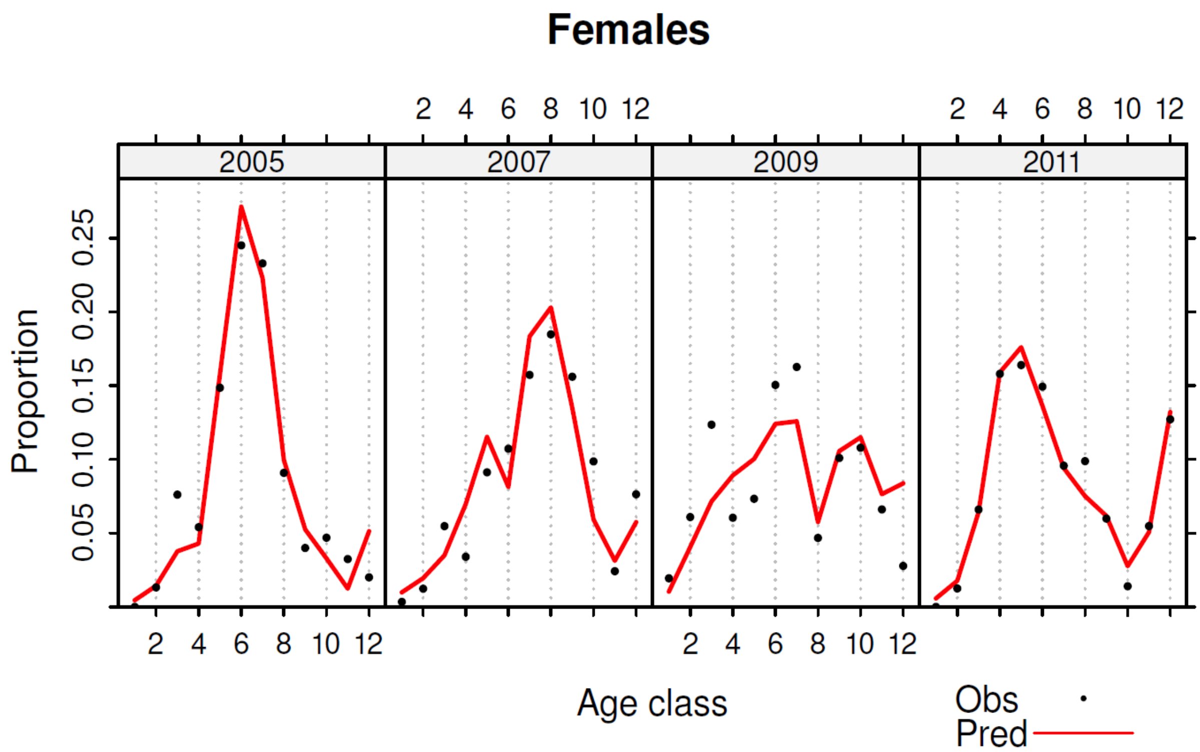


Figure F.26. Observed and predicted proportions-at-age for the Hecate Strait synoptic survey in Area 5CD.

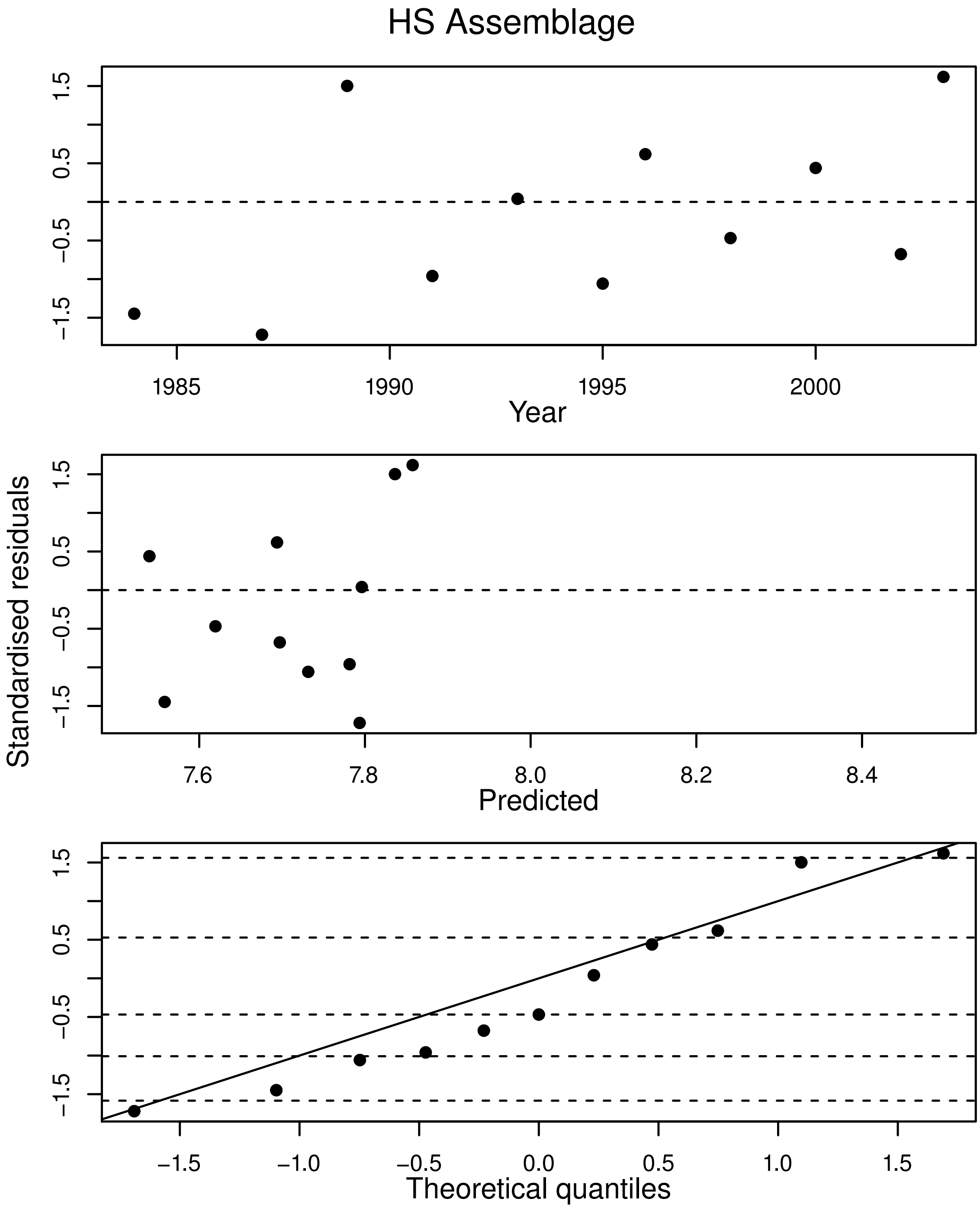


Figure F.27. Residuals of fits of model to the Hecate Strait assemblage survey in the Area 5CD assessment (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

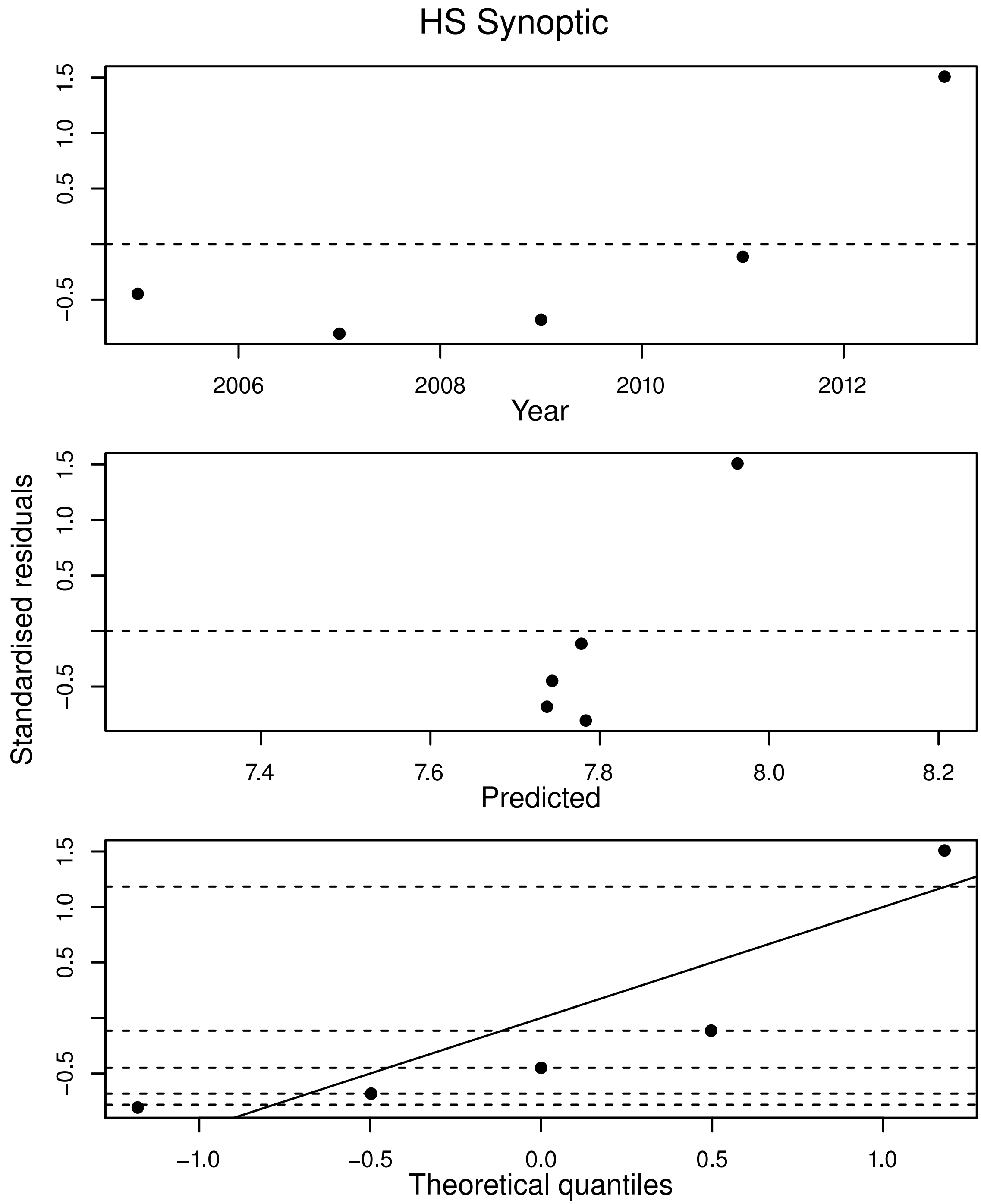


Figure F.28. Residuals of fits of model to the Hecate Strait synoptic survey in the Area 5CD assessment (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

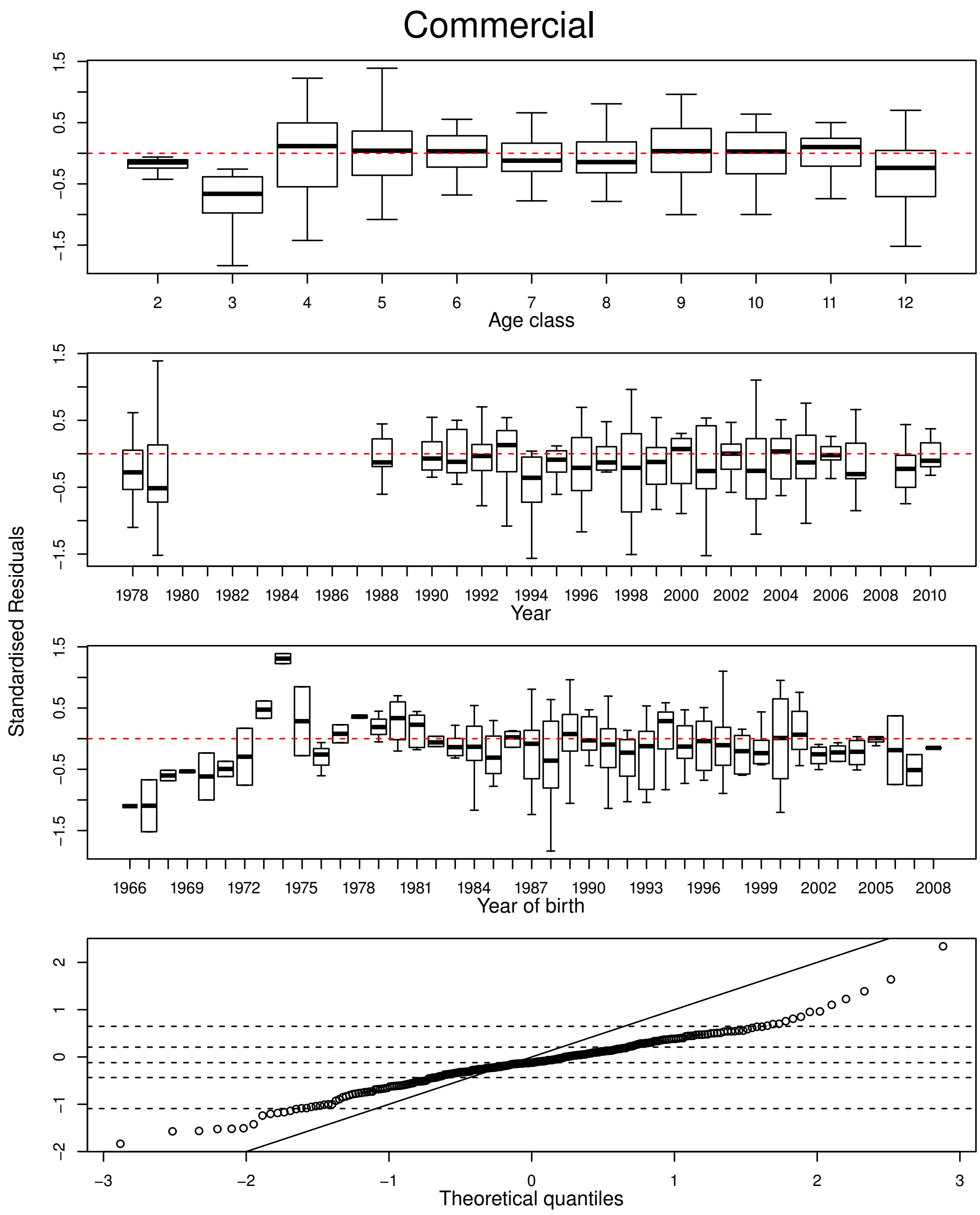


Figure F.29. Residual of fits of model to commercial proportions-at-age data (MPD values) for the Area 5CD assessment. Vertical axes are standardised residuals. Boxplots show, respectively, residuals by age class, by year of data, and by year of birth (following a cohort through time). Boxes give interquartile ranges, with bold lines representing medians and whiskers extending to the most extreme data point that is $<$1.5 times the interquartile range from the box. Bottom panel is the normal quantile-quantile plot for residuals, with the 1:1 line, though residuals are not expected to be normally distributed because of the likelihood function used; horizontal lines give the 5, 25, 50, 75, and 95 percentiles (for the total of 506 residuals).

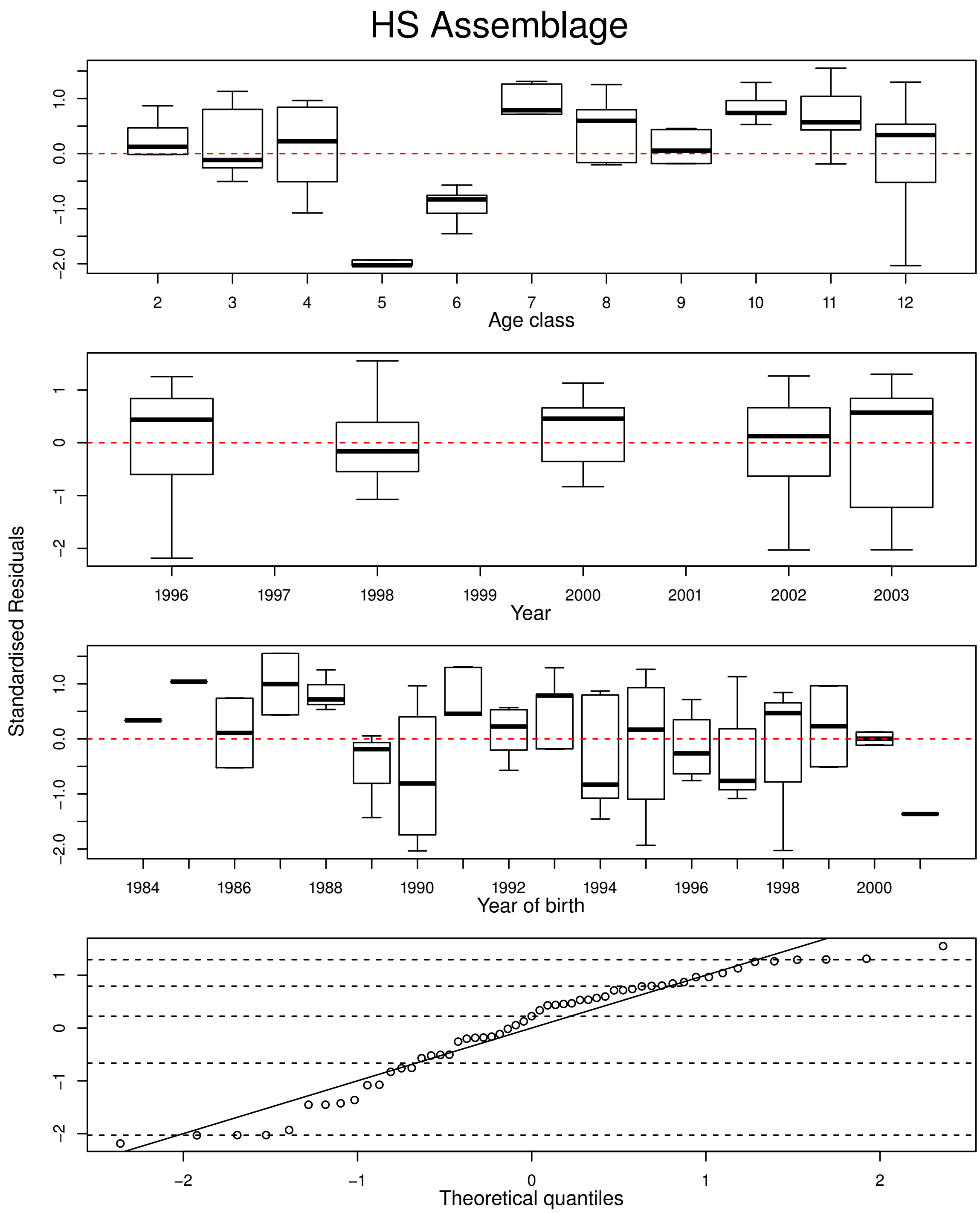


Figure F.30. Residuals of fits of model to proportions-at-age data (MPD values) from the Hecate Strait assemblage survey in the Area 5CD assessment. Details as for Figure F.29, for a total of 110 residuals.

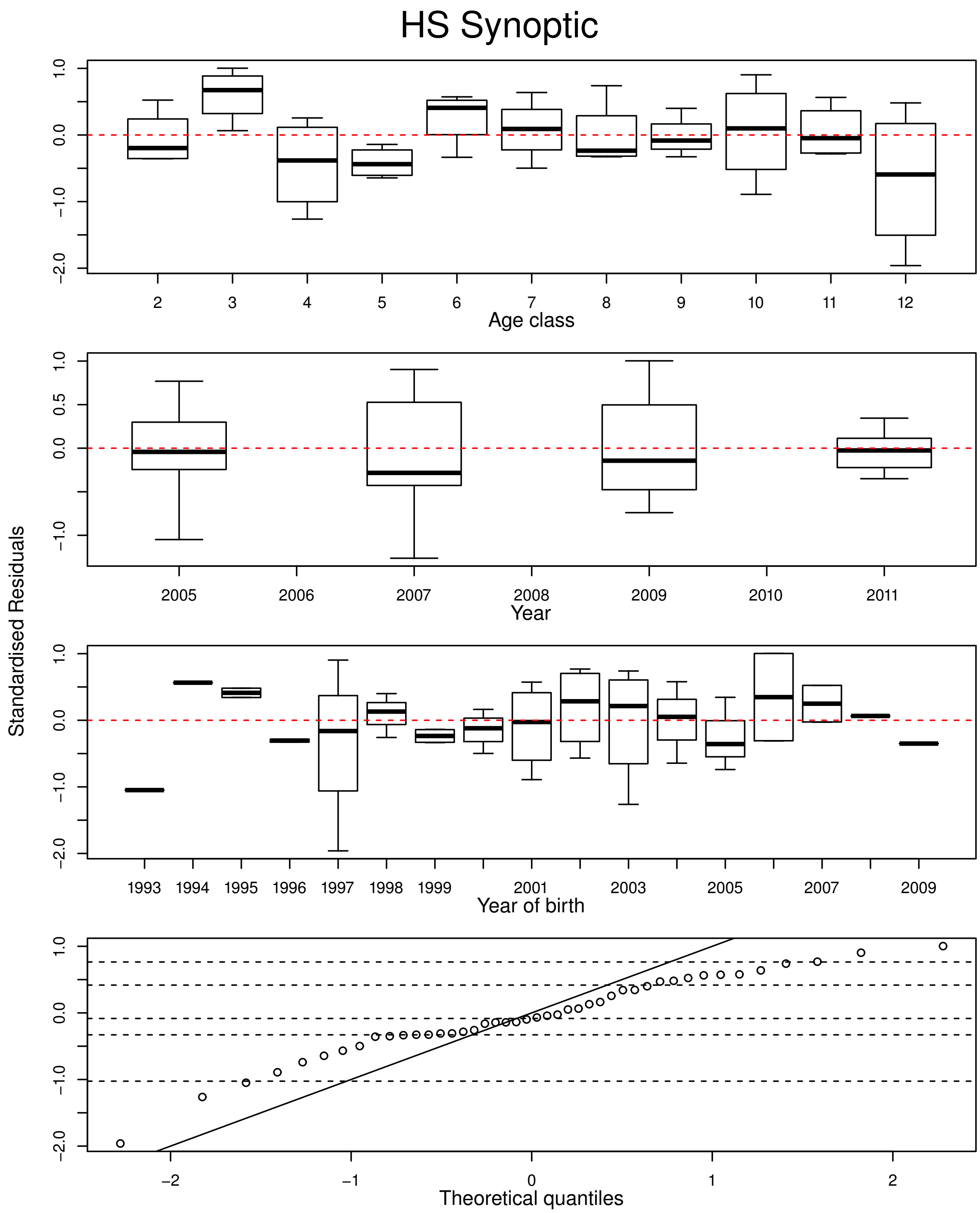


Figure F.31. Residuals of fits of model to proportions-at-age data (MPD values) from the Hecate Strait synoptic survey in the Area 5CD assessment. Details as for Figure F.29, for a total of 88 residuals.

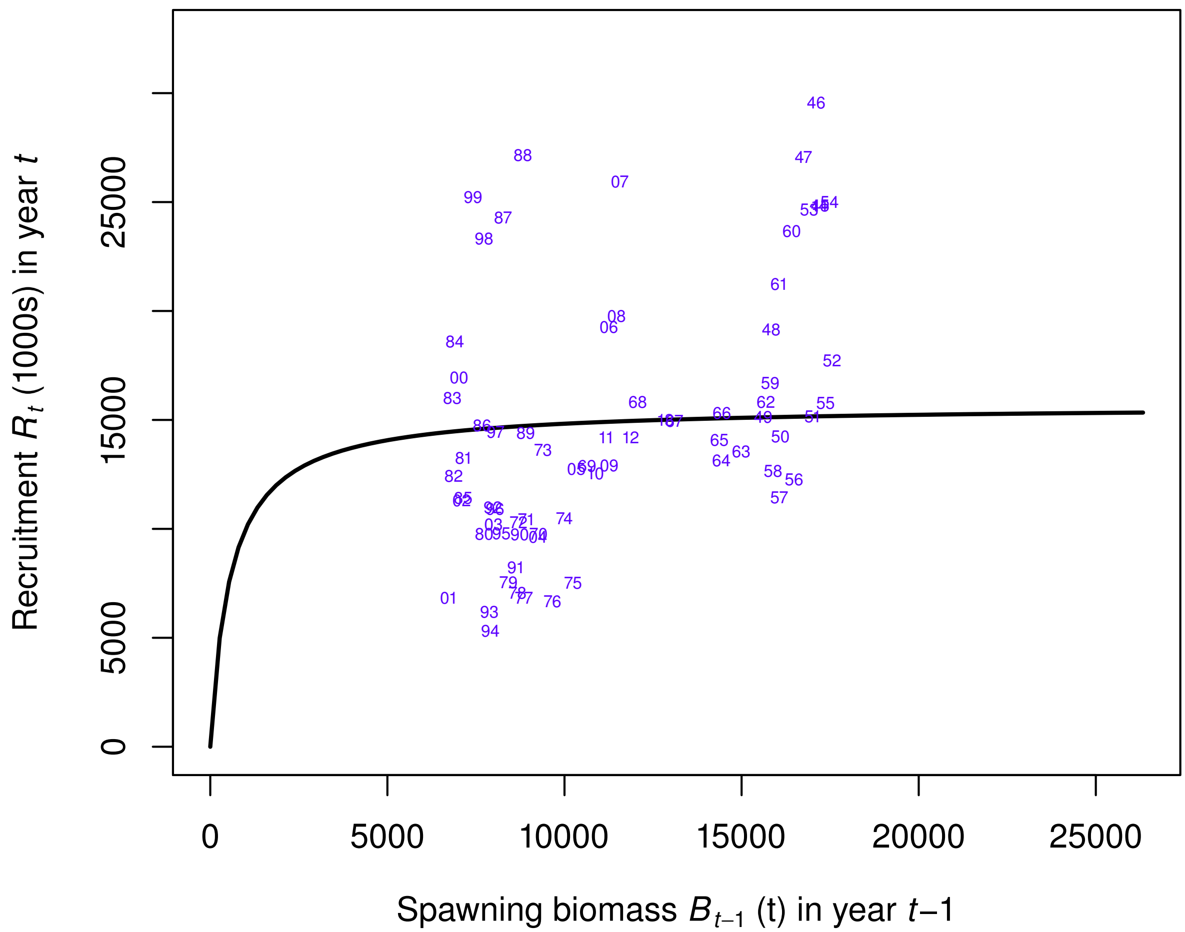
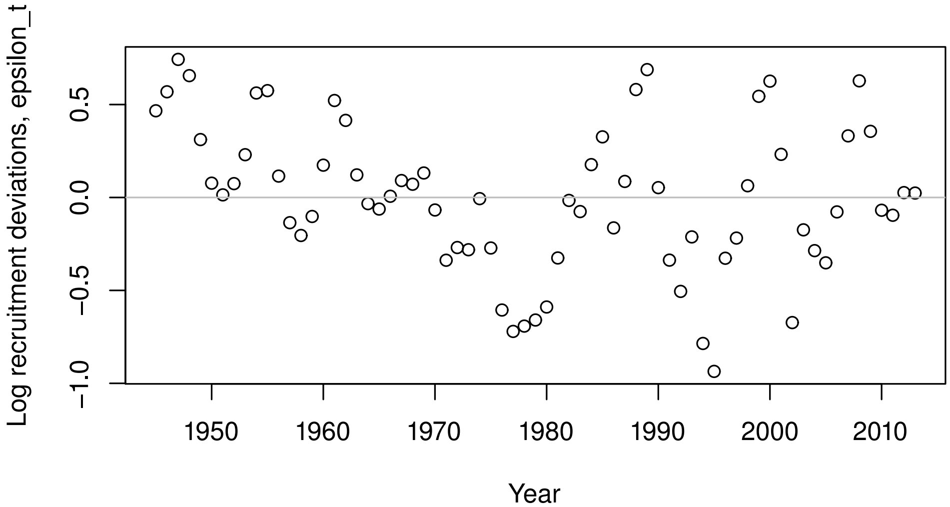


Figure F.32. Deterministic stock-recruit relationship from Area 5CD assessment model fit (black curve) and observed values (labelled by year of spawning) using MPD values. Both spawning biomass and recruitment only represent the female portion of the population.



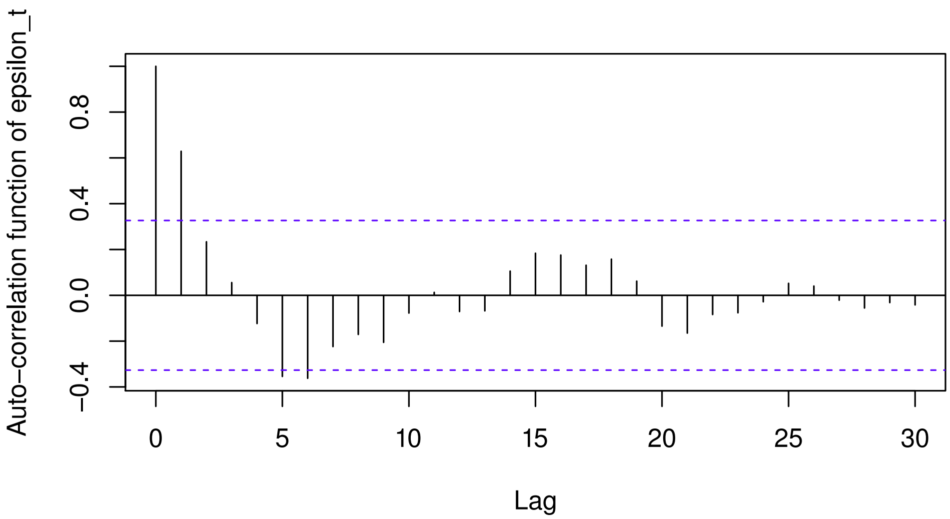


Figure F.33. Top: Log of the annual recruitment deviations predicted for Area 5CD, ϵ_t, where bias-corrected multiplicative deviation is e$^{\epsilon_t - \sigma_R^2/2}$ where $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. Bottom: Auto-correlation function of the logged recruitment deviations (ϵ_t), for years 1972-2007 (determined as the first year of commercial age data minus the accumulator age class plus the age for which commercial selectivity for females is 0.5, to the final year that recruitments are calculated minus the age for which commercial selectivity for females is 0.5).

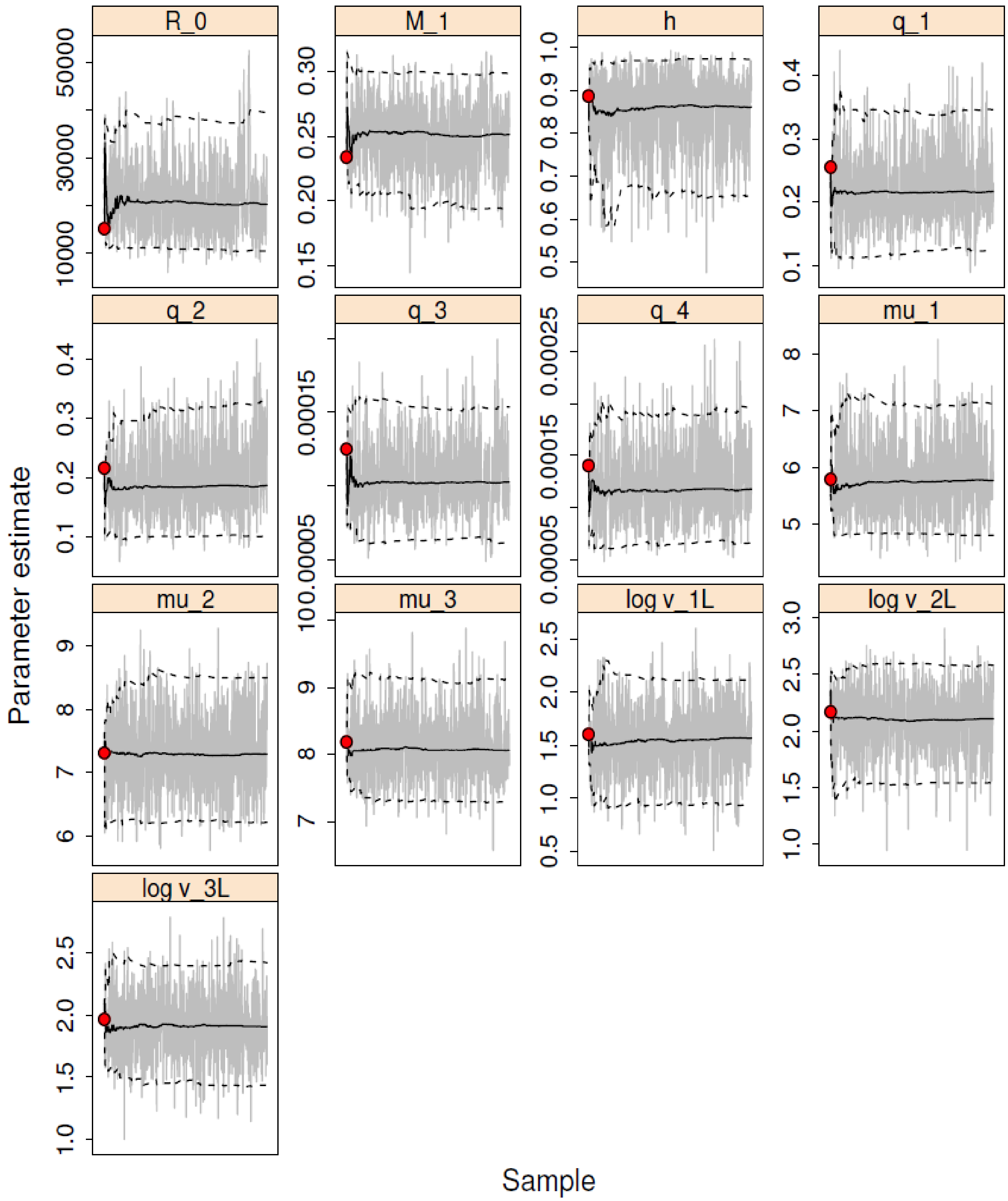


Figure F.34. MCMC traces for the estimated parameters in Area 5CD. Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates. For parameters other than M (if estimated), subscripts ≤ 2 correspond to fishery-independent surveys, and subscripts ≥ 3 denote the commercial fishery. Parameter notation is described in Appendix E.

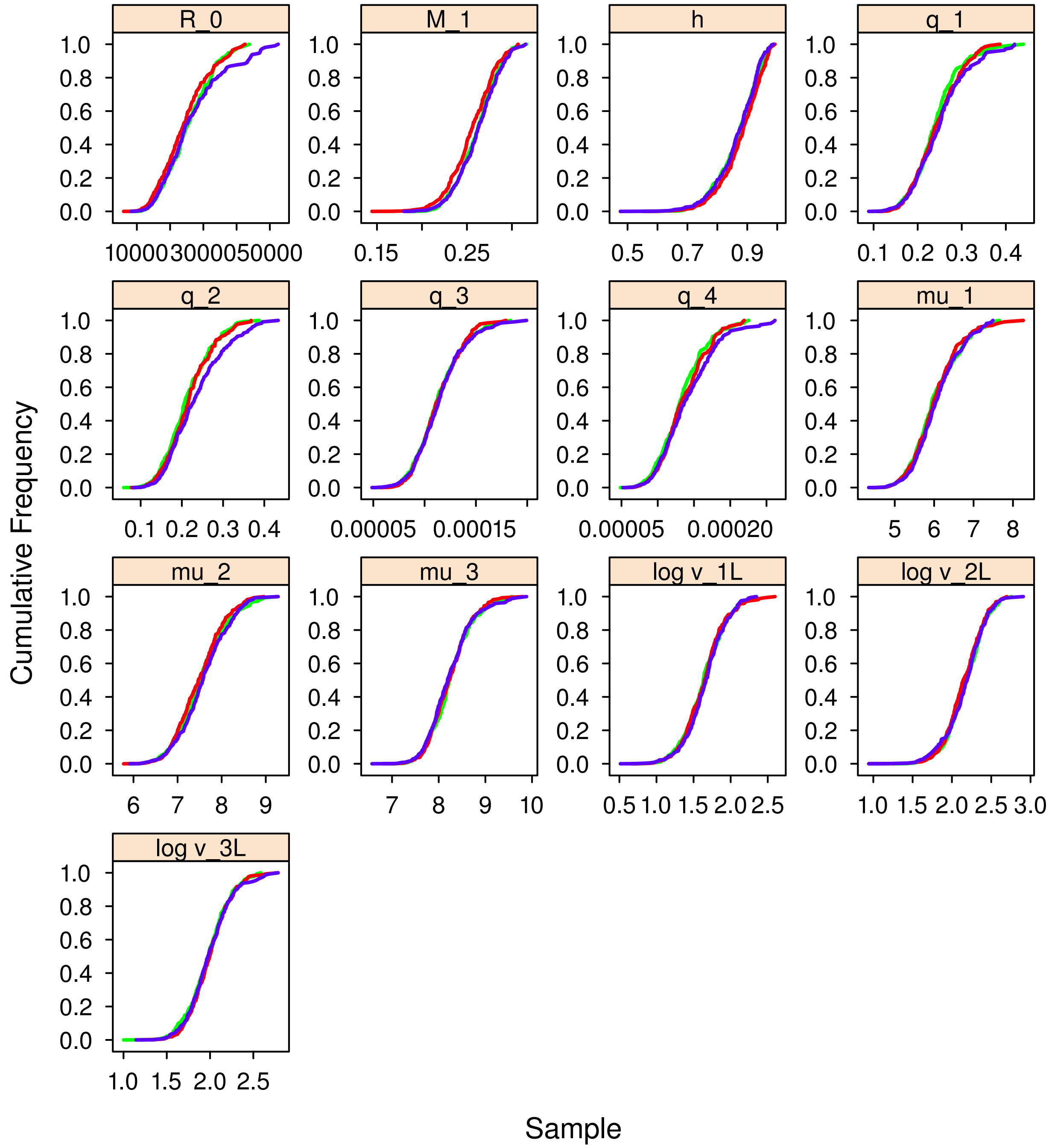


Figure F.35. Diagnostic plot from the Area 5CD assessment obtained by dividing the MCMC chain of 1,000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (green), second segment (red) and final segment (blue).

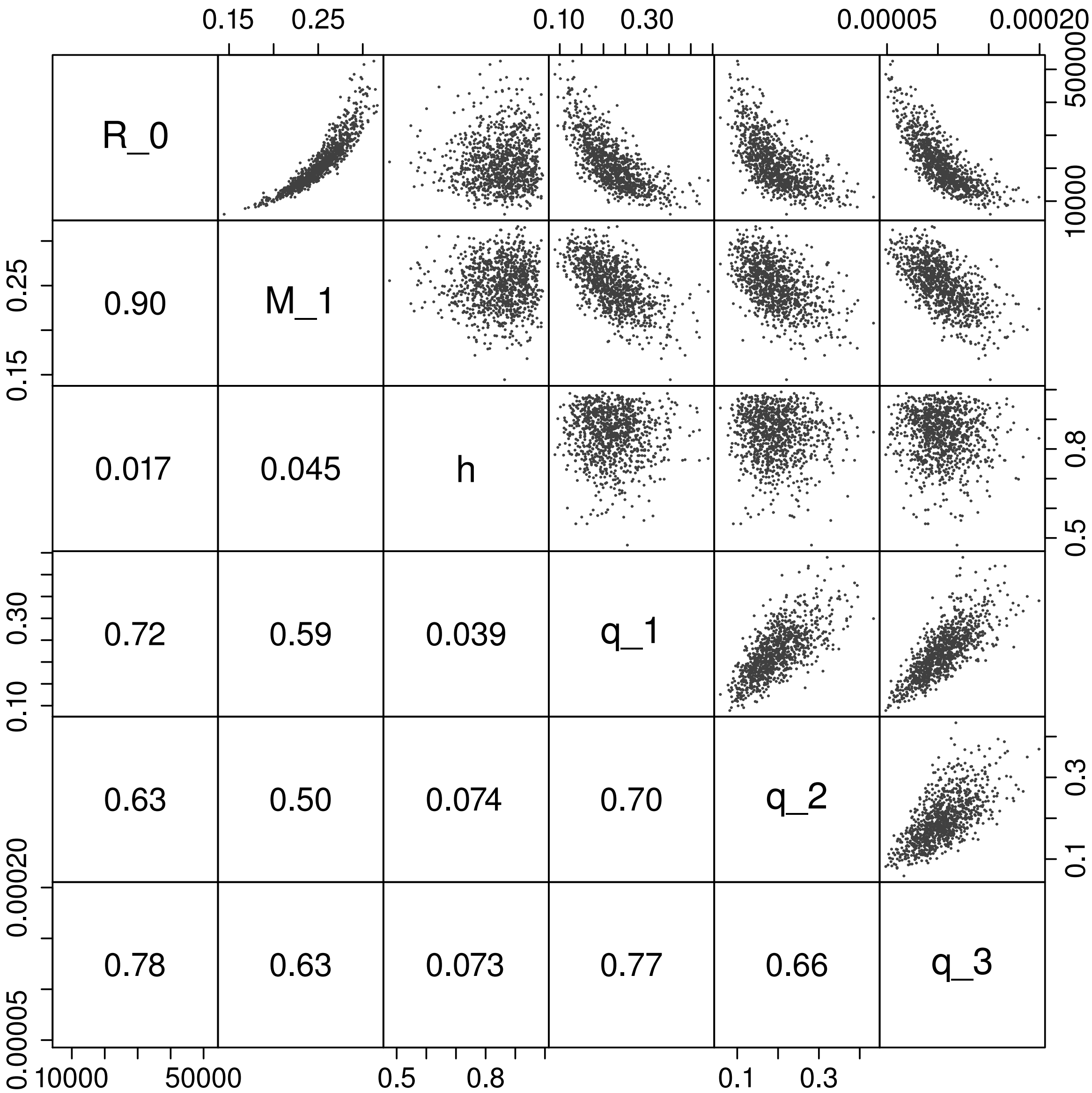


Figure F.36. Pairs plot from the Area 5CD assessment of 1,000 MCMC samples for first six parameters. Numbers are the absolute values of the correlation coefficients.

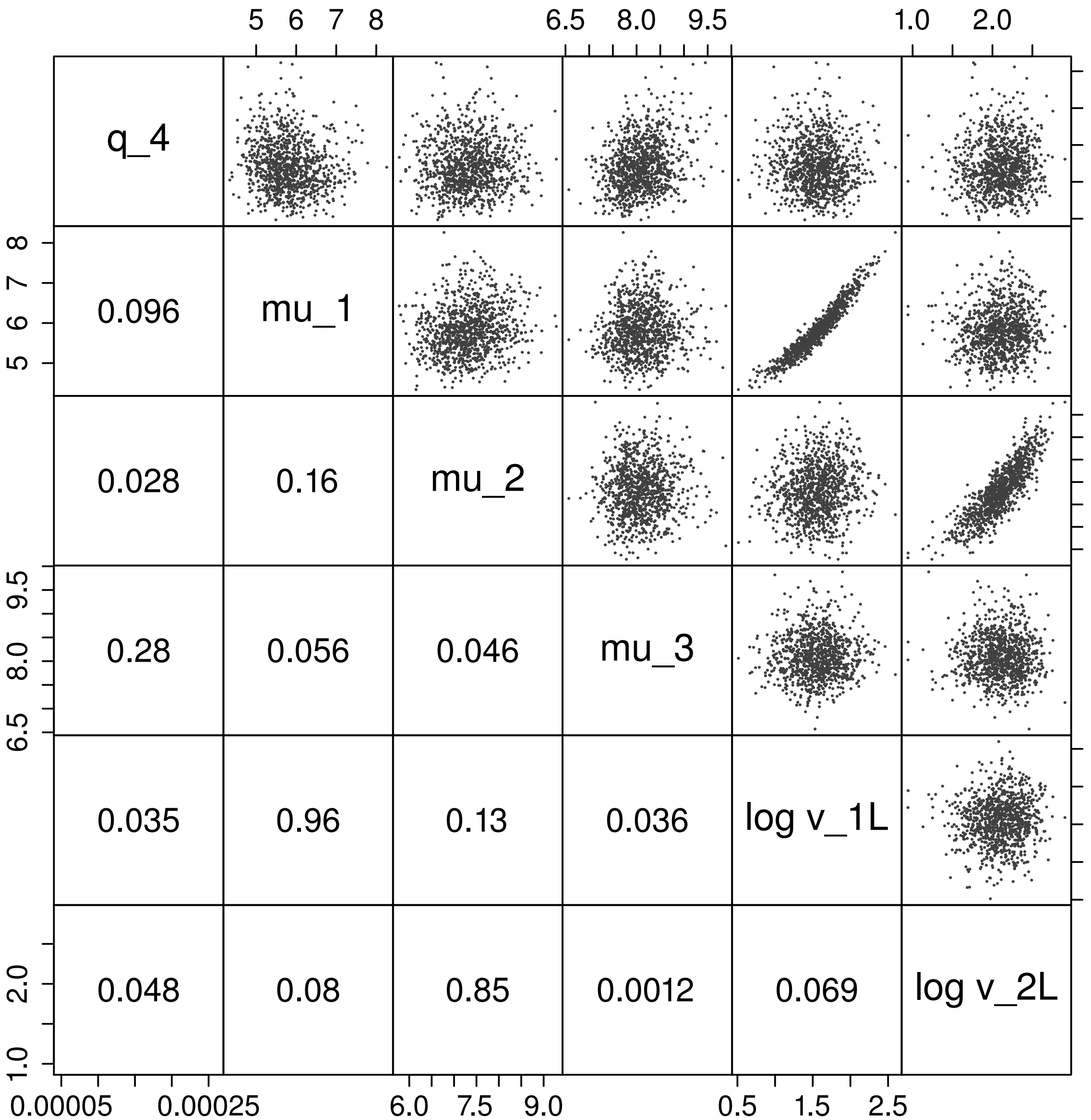


Figure F.37. Pairs plot from the Area 5CD assessment of 1,000 MCMC samples for second six parameters. Numbers are the absolute values of the correlation coefficients.

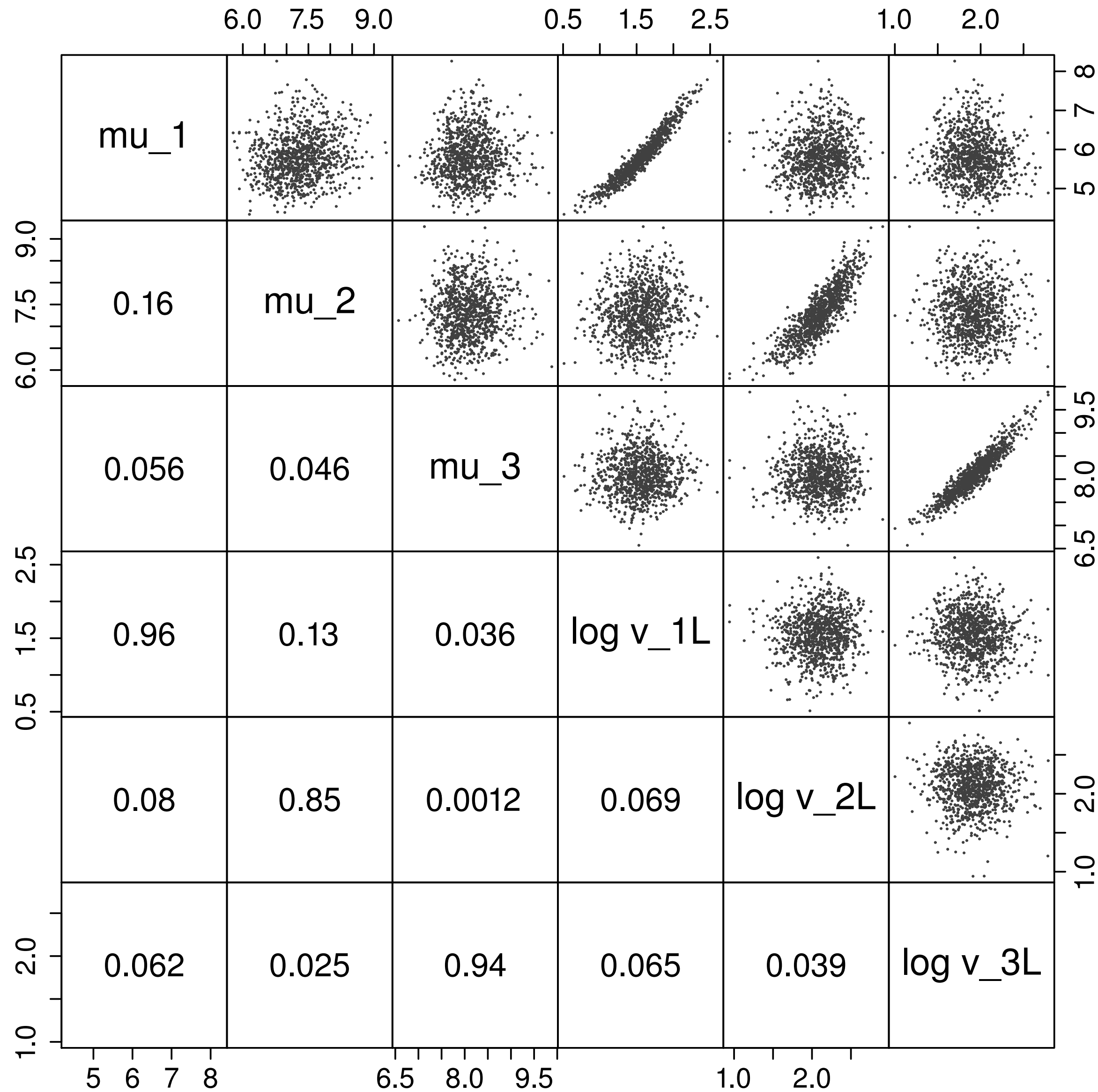


Figure F.38. Pairs plot from the Area 5CD assessment of 1,000 MCMC samples for third six parameters. Numbers are the absolute values of the correlation coefficients.

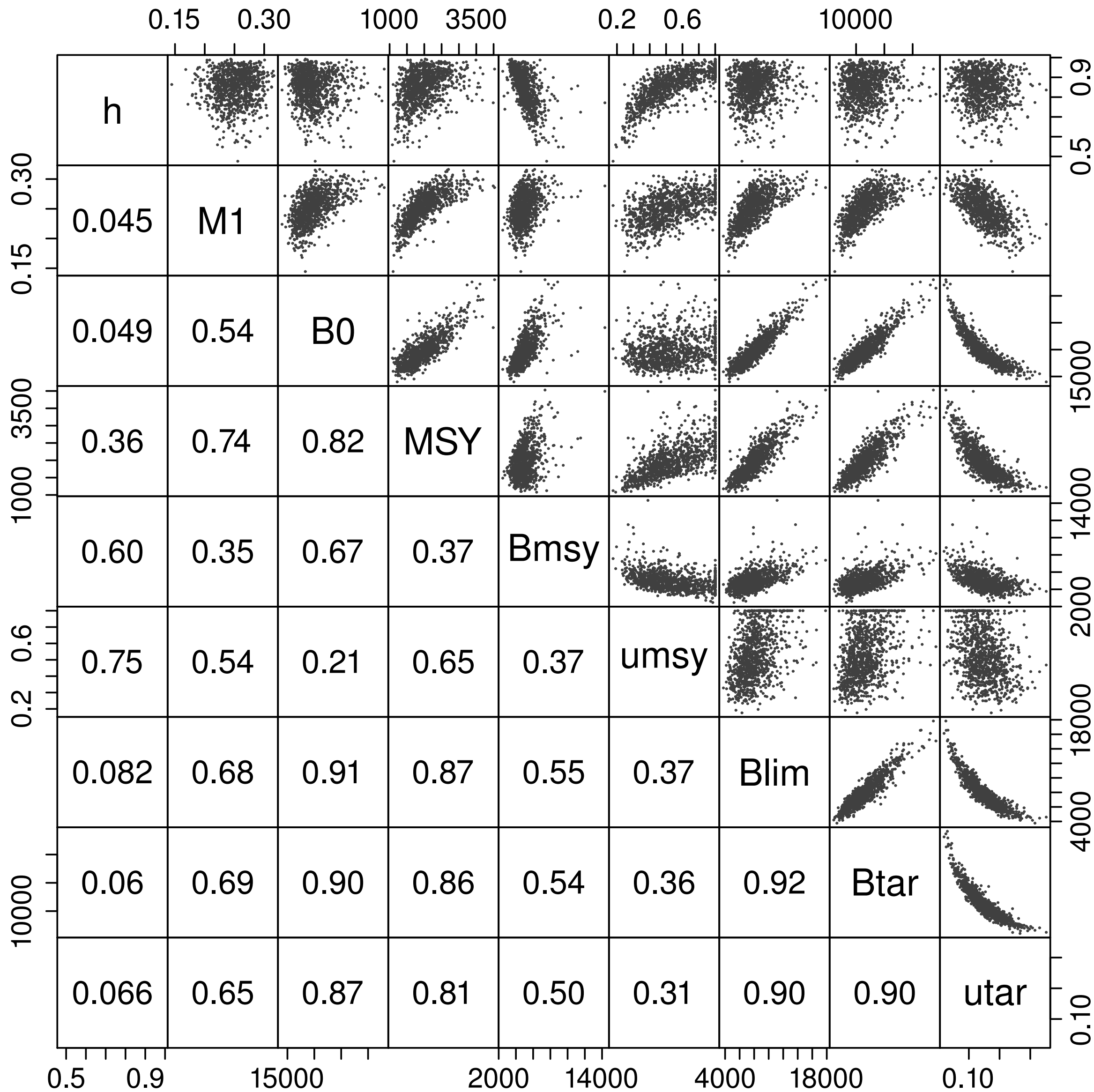


Figure F.39. Pairs plot comparing reference points from the Area 5CD assessment using 1,000 MCMC samples. Numbers are the absolute values of the correlation coefficients.

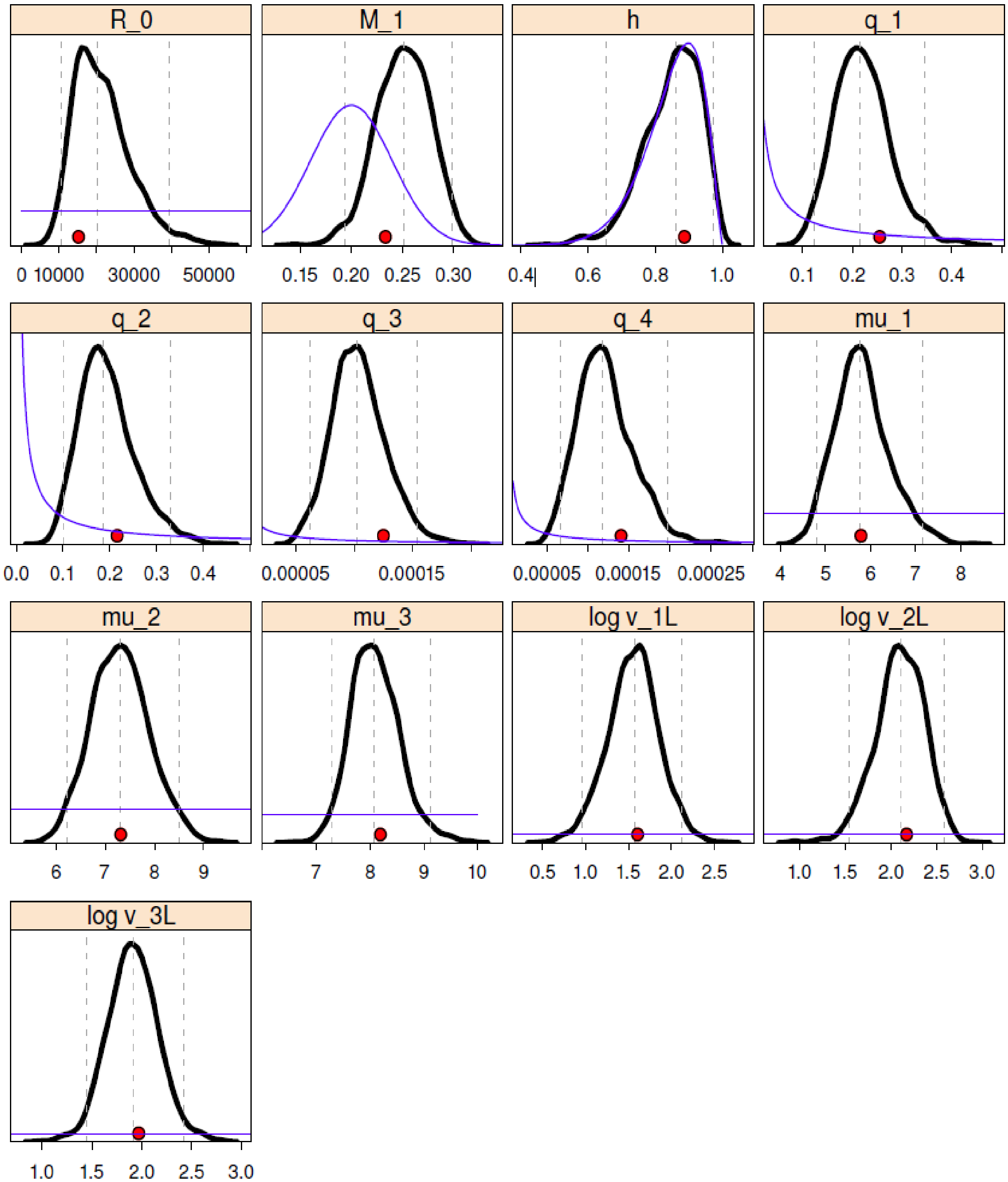


Figure F.40. Marginal posterior densities (thick black curves) and prior density functions (thin blue curves) for the estimated parameters from the Area 5CD assessment. Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates. For R_0 the prior is a uniform distribution on the range [100, 100000]. The priors for q_g are uniform on a log-scale, and so the probability density function is $1/(x(b-a))$ on a linear scale (where a and b are the bounds on the log scale).

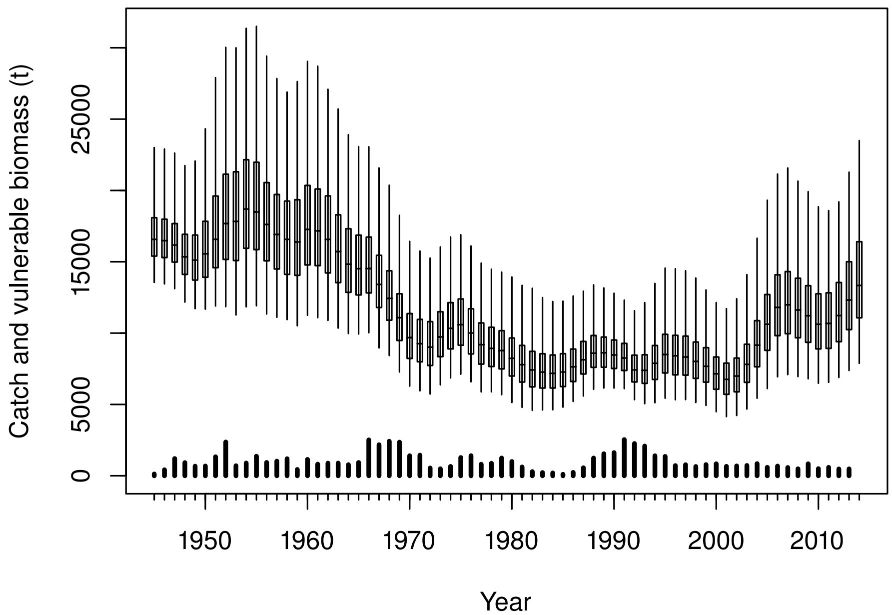


Figure F.41. Estimated female vulnerable biomass (boxplots) and commercial catch (vertical bars), in tonnes, over time for Area 5CD. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Female-only catch is shown to compare its magnitude to the estimated vulnerable biomass.

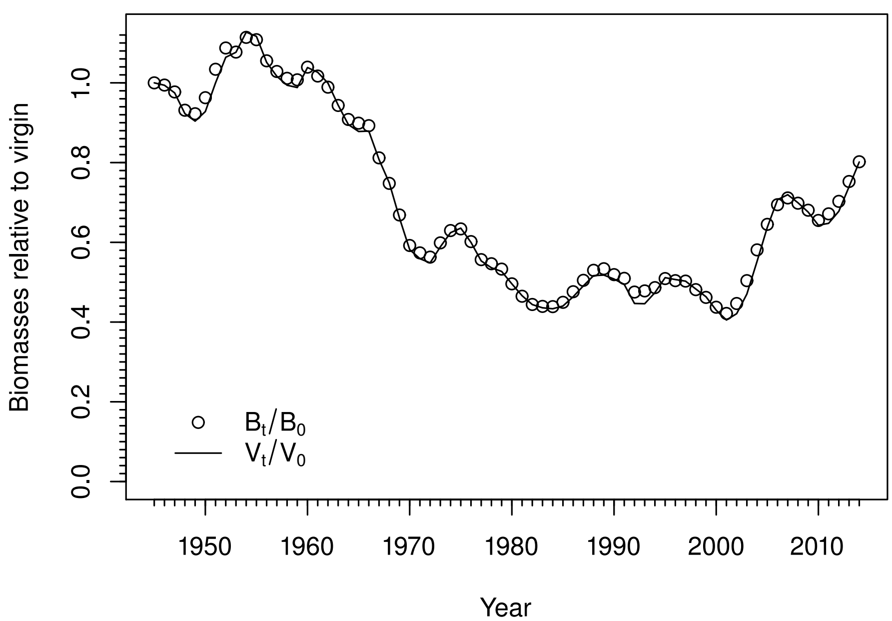


Figure F.42. Changes in B_t/B_0 and V_t/V_0 (female spawning and female vulnerable biomass relative to unfished equilibrium levels) over time for Area 5CD, shown as the medians of the MCMC posteriors.

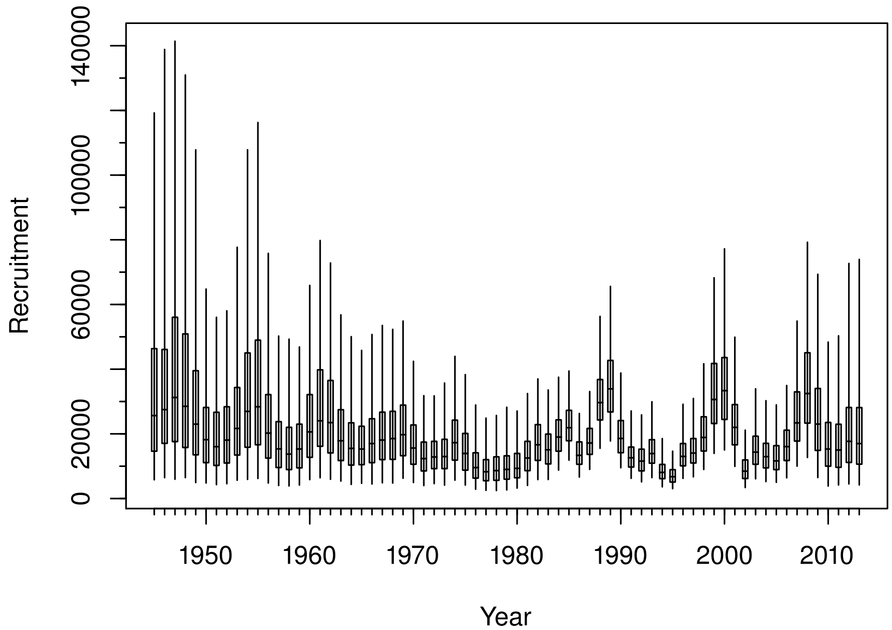


Figure F.43. Marginal posterior distribution of female recruitment in 1,000s of age-1 fish plotted over time for Area 5CD. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Note that the first year for which there are age data is 1978, and the plus-age class is 12, such that there are no direct data concerning age-1 fish before 1967. Also, the final few years have no direct age-data from which to estimate recruitment, because fish are not fully selected until age 8.1 by the commercial vessels or age 6.5 by surveys (mean of the MCMC median ages at full selectivity for commercial catch, μ_3*, and survey* $\mu_{1,2}$*, respectively).*

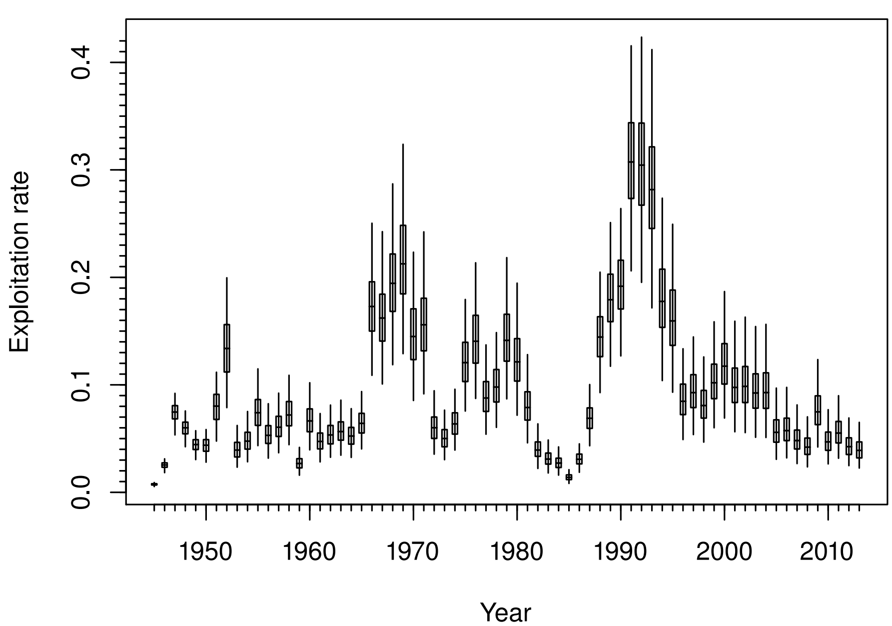


Figure F.44. Marginal posterior distribution of female exploitation rate in Area 5CD plotted over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

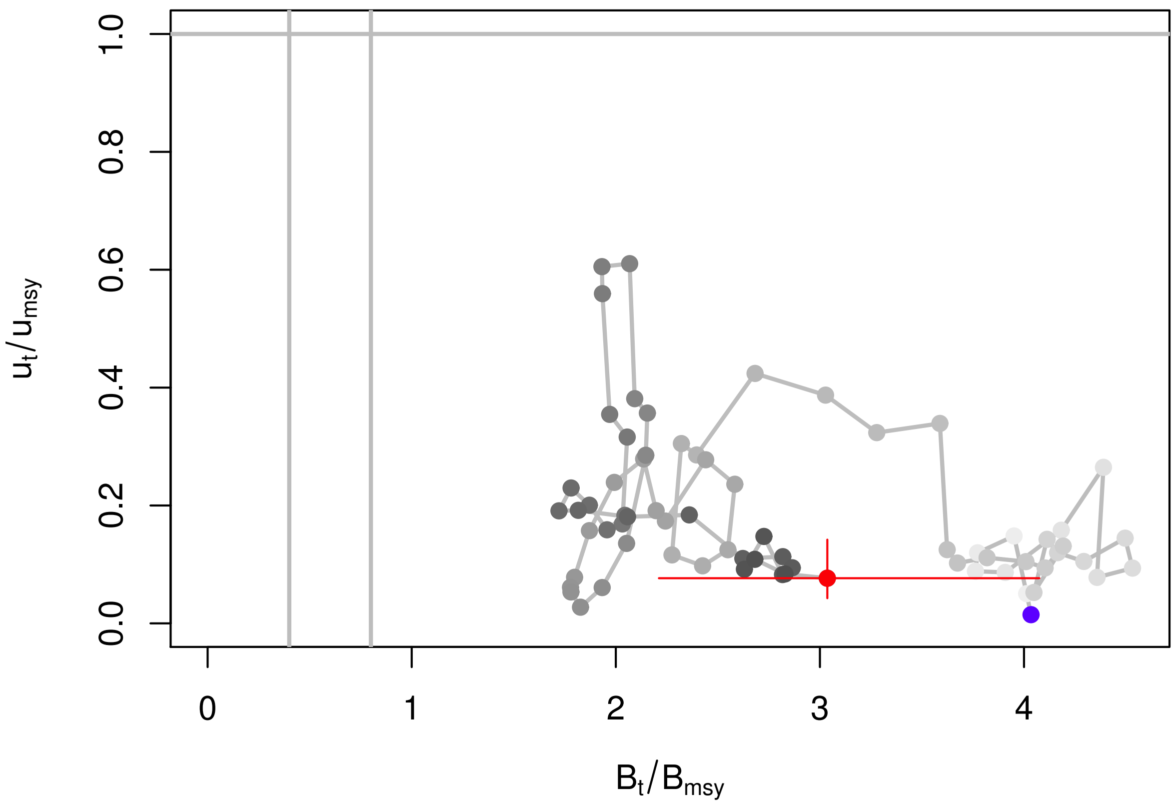


Figure F.45. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the female spawning biomass in year t relative to female-only B_{MSY}) and u_t/u_{MSY} (the female exploitation rate in year t relative to female-only u_{MSY}) for Area 5CD. Blue filled circle is the starting year (1945). Years then proceed from light grey through to dark grey with the final year (2013) as a filled red circle, and the red lines represent the 10% and 90% percentiles of the posterior distributions for the final year.

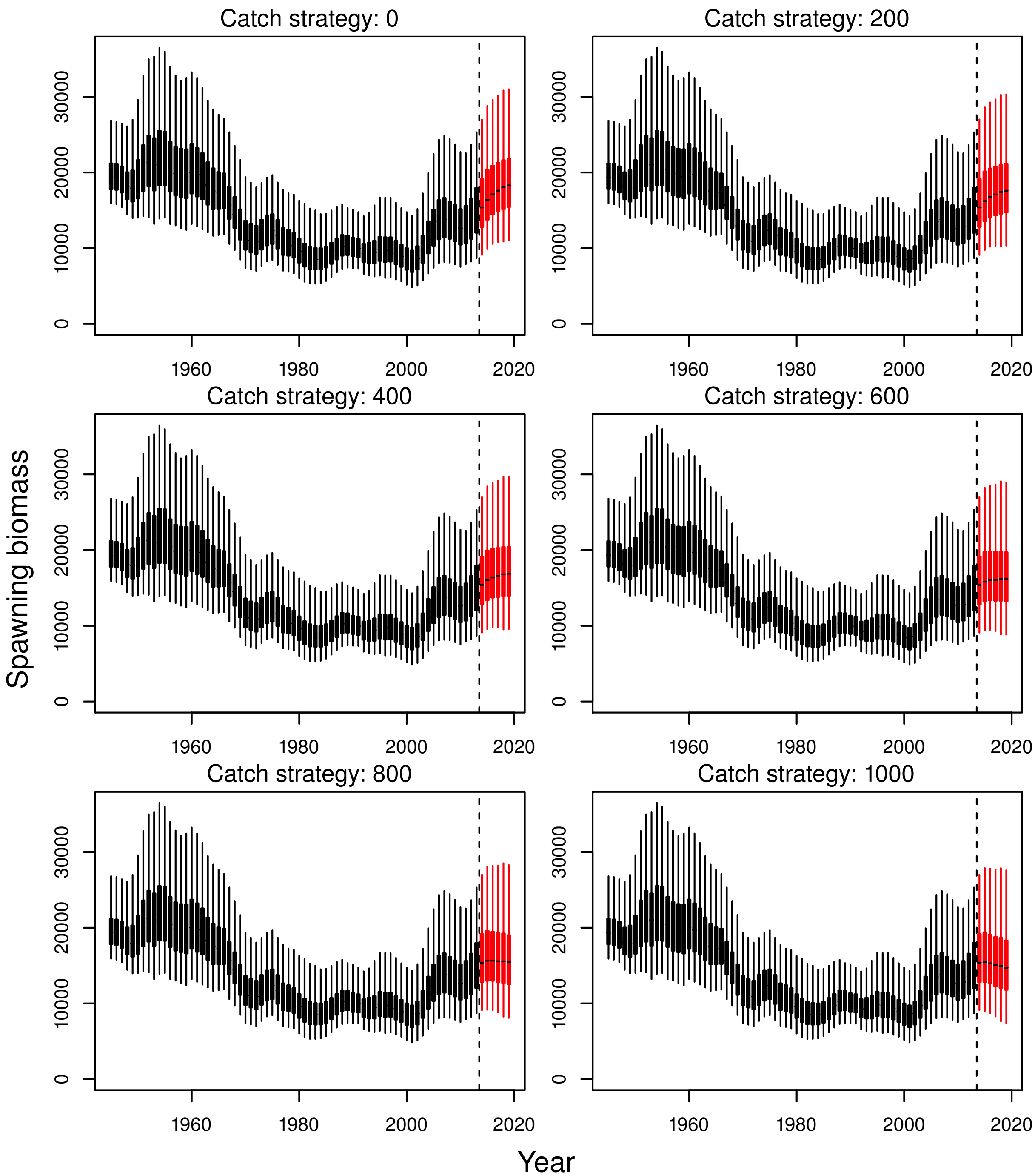


Figure F.46. Projected female spawning biomass (tonnes) under different constant catch strategies (tonnes, female-only catch) for Area 5CD; boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. For each of the 1,000 samples from the MCMC posterior, the model was run forward in time (red, with medians in black) with a constant catch, and recruitment was simulated from the stock-recruitment function with lognormal error (see Appendix E). For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t.

Table F.11. The 5$^{\mathrm{th}}$, 50$^{\mathrm{th}}$, and 95$^{\mathrm{th}}$ percentiles for model parameters derived via MCMC estimation (defined in Appendix E) for Area 5CD.

	5%	50%	95%
R_0	11,651	20,280	35,686
M_1	0.2077	0.2514	0.2923
h	0.6978	0.8616	0.9624
q_1	0.1365	0.2165	0.3191
q_2	0.1110	0.1869	0.3033
q_3	0.00006896	0.0001023	0.0001442
q_4	0.00007181	0.0001178	0.0001803
μ_1	4.891	5.770	6.897
μ_2	6.366	7.295	8.326
μ_3	7.411	8.063	8.890
$\log v_{1L}$	1.040	1.569	2.051
$\log v_{2L}$	1.638	2.109	2.507
$\log v_{3L}$	1.509	1.910	2.331

Table F.12. The 5$^{\mathrm{th}}$, 50$^{\mathrm{th}}$ and 95$^{\mathrm{th}}$ percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior from the Area 5CD assessment. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (females), B_{2014} – female spawning biomass at the start of 2014, V_{2014} – female vulnerable biomass in the middle of 2014, u_{2013} – exploitation rate (ratio of female catch to female vulnerable biomass) in the middle of 2013, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1945-2013), B_{MSY} – equilibrium female spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium female vulnerable biomass at MSY. The values B_{Lim} and B_{Tar} denote historical limit and target reference points min($B_{1966-2005}$) and mean($B_{1971-1980}$), respectively. The historical target exploitation rate is expressed as the mean($u_{1966-2005}$). All biomass values (and MSY) are in tonnes. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t.

Value	Percentile		
	5%	50%	95%
	From model output		
B_0	16,263	19,329	25,361
V_0	13,952	16,572	21,387
B_{2014}	9,949	15,385	24,724
V_{2014}	8,399	13,341	21,310
B_{2014}/B_0	0.581	0.802	1.068
V_{2014}/V_0	0.577	0.802	1.078
u_{2013}	0.025	0.039	0.061
$u_{\max}$	0.222	0.31	0.407
	MSY-based quantities		
MSY	1,326	1,895	2,810
B_{MSY}	3,613	4,853	6,799
$0.4B_{\mathrm{MSY}}$	1,445	1,941	2,720
$0.8B_{\mathrm{MSY}}$	2,890	3,883	5,439
$B_{2014}/B_{\mathrm{MSY}}$	2.1	3.223	4.638
B_{MSY}/B_0	0.201	0.248	0.308
V_{MSY}	2,736	3,793	5,501
V_{MSY}/V_0	0.178	0.227	0.296
u_{MSY}	0.295	0.507	0.8
$u_{2013}/u_{\mathrm{MSY}}$	0.037	0.077	0.163
	History-based quantities		
B_{Lim}	5,223	7,739	11,971
B_{Tar}	7,753	11,135	16,662
$B_{2014}/B_{\mathrm{Lim}}$	1.528	2.004	2.722
$B_{2014}/B_{\mathrm{Tar}}$	1	1.401	1.969
u_{Tar}	0.083	0.122	0.168
$u_{2013}/u_{\mathrm{Tar}}$	0.243	0.319	0.423

Table F.13. Decision table for Area 5CD concerning the limit reference point $0.4B_{\mathrm{MSY}}$ for 1-5 year projections for a range of constant catch strategies (in tonnes, female-only catch). Values are P$(B_t > 0.4B_{\mathrm{MSY}})$, i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the limit reference point. The probabilities are the proportion (to two decimal places) of the 1000 MCMC samples for which $B_t > 0.4B_{\mathrm{MSY}}$. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
300	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00
600	1.00	1.00	1.00	1.00	1.00	1.00
700	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00
1100	1.00	1.00	1.00	1.00	1.00	1.00
1200	1.00	1.00	1.00	1.00	1.00	1.00
1300	1.00	1.00	1.00	1.00	1.00	1.00
1400	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	1.00
1750	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.00	1.00	1.00	1.00	1.00	1.00
2250	1.00	1.00	1.00	1.00	1.00	1.00
2500	1.00	1.00	1.00	1.00	1.00	0.99
2750	1.00	1.00	1.00	1.00	0.99	0.97
3000	1.00	1.00	1.00	1.00	0.98	0.96

Table F.14. Decision table for Area 5CD concerning the upper reference point $0.8B_{\mathrm{MSY}}$ for 1-5 year projections, such that values are P$(B_t > 0.8B_{\mathrm{MSY}})$. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
300	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00
600	1.00	1.00	1.00	1.00	1.00	1.00
700	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00
1100	1.00	1.00	1.00	1.00	1.00	1.00
1200	1.00	1.00	1.00	1.00	1.00	1.00
1300	1.00	1.00	1.00	1.00	1.00	1.00
1400	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	1.00
1750	1.00	1.00	1.00	1.00	1.00	0.99
2000	1.00	1.00	1.00	1.00	0.99	0.98
2250	1.00	1.00	1.00	0.99	0.98	0.95
2500	1.00	1.00	1.00	0.99	0.96	0.91
2750	1.00	1.00	1.00	0.97	0.93	0.86
3000	1.00	1.00	0.99	0.96	0.90	0.81

Table F.15. Decision table for Area 5CD concerning the reference point B_{MSY} for 1-5 year projections, such that values are P$(B_t > B_{\mathrm{MSY}})$. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
300	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00
600	1.00	1.00	1.00	1.00	1.00	1.00
700	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00
1100	1.00	1.00	1.00	1.00	1.00	1.00
1200	1.00	1.00	1.00	1.00	1.00	1.00
1300	1.00	1.00	1.00	1.00	1.00	1.00
1400	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	0.99
1750	1.00	1.00	1.00	1.00	0.99	0.98
2000	1.00	1.00	1.00	0.99	0.97	0.95
2250	1.00	1.00	1.00	0.98	0.95	0.91
2500	1.00	1.00	0.99	0.96	0.93	0.87
2750	1.00	1.00	0.99	0.95	0.89	0.80
3000	1.00	1.00	0.98	0.93	0.84	0.72

Table F.16. Decision table for Area 5CD for comparing the projected biomass to the current biomass, given by probabilities P$(B_t > B_{2014})$. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	0.00	0.98	0.94	0.91	0.86	0.83
100	0.00	0.97	0.92	0.86	0.81	0.79
200	0.00	0.95	0.89	0.83	0.78	0.76
300	0.00	0.93	0.85	0.78	0.73	0.72
400	0.00	0.89	0.80	0.72	0.68	0.67
500	0.00	0.85	0.74	0.66	0.63	0.62
600	0.00	0.80	0.69	0.61	0.58	0.57
700	0.00	0.73	0.62	0.55	0.52	0.51
800	0.00	0.66	0.56	0.48	0.46	0.45
900	0.00	0.60	0.49	0.42	0.40	0.40
1000	0.00	0.54	0.41	0.36	0.34	0.35
1100	0.00	0.46	0.36	0.30	0.30	0.31
1200	0.00	0.41	0.30	0.27	0.26	0.28
1300	0.00	0.35	0.25	0.24	0.23	0.23
1400	0.00	0.29	0.22	0.20	0.20	0.19
1500	0.00	0.25	0.19	0.17	0.16	0.17
1750	0.00	0.15	0.12	0.11	0.10	0.11
2000	0.00	0.10	0.08	0.08	0.07	0.07
2250	0.00	0.07	0.05	0.04	0.05	0.04
2500	0.00	0.05	0.04	0.03	0.03	0.03
2750	0.00	0.03	0.02	0.02	0.02	0.02
3000	0.00	0.02	0.01	0.02	0.01	0.01

Table F.17. Decision table for Area 5CD for comparing the projected exploitation rate to that at MSY, such that values are P$(u_t > u_{\mathrm{MSY}})$, i.e. the probability of the exploitation rate in the middle of year t being greater than that at MSY. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00
500	0.00	0.00	0.00	0.00	0.00	0.00
600	0.00	0.00	0.00	0.00	0.00	0.00
700	0.00	0.00	0.00	0.00	0.00	0.00
800	0.00	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.00	0.00	0.00	0.00
1000	0.00	0.00	0.00	0.00	0.00	0.00
1100	0.00	0.00	0.00	0.00	0.00	0.00
1200	0.00	0.00	0.00	0.00	0.00	0.00
1300	0.00	0.00	0.00	0.00	0.00	0.00
1400	0.00	0.00	0.00	0.00	0.00	0.01
1500	0.00	0.00	0.00	0.00	0.01	0.01
1750	0.00	0.00	0.01	0.02	0.03	0.05
2000	0.00	0.01	0.03	0.04	0.07	0.10
2250	0.01	0.02	0.04	0.09	0.13	0.18
2500	0.02	0.04	0.08	0.15	0.22	0.28
2750	0.03	0.06	0.13	0.23	0.31	0.40
3000	0.04	0.10	0.20	0.31	0.42	0.50

Table F.18. Decision table for Area 5CD concerning the historical limit reference point min$(B_{1966-2005})$ for 1-5 year projections for a range of constant catch strategies (in tonnes, female-only catch). Values are P$(B_t > min(B_{1966-2005}))$, i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the historical limit reference point. The probabilities are the proportion (to two decimal places) of the 1000 MCMC samples for which $B_t > min(B_{1966-2005})$. For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
300	1.00	1.00	1.00	1.00	1.00	1.00
400	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00
600	1.00	1.00	1.00	1.00	1.00	1.00
700	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	0.99
1000	1.00	1.00	1.00	1.00	0.99	0.99
1100	1.00	1.00	1.00	1.00	0.99	0.99
1200	1.00	1.00	1.00	0.99	0.99	0.98
1300	1.00	1.00	1.00	0.99	0.98	0.97
1400	1.00	1.00	1.00	0.99	0.98	0.97
1500	1.00	1.00	0.99	0.99	0.97	0.95
1750	1.00	1.00	0.99	0.98	0.94	0.90
2000	1.00	1.00	0.98	0.95	0.89	0.83
2250	1.00	1.00	0.98	0.92	0.83	0.73
2500	1.00	1.00	0.97	0.88	0.75	0.64
2750	1.00	0.99	0.95	0.82	0.67	0.54
3000	1.00	0.99	0.92	0.76	0.58	0.46

Table F.19. Decision table for Area 5CD concerning the historical target reference point mean($B_{1971-1980}$) for 1-5 year projections, such that values are P($B_t > mean(B_{1971-1980})$). For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	0.95	0.97	0.98	0.98	0.99	0.99
100	0.95	0.97	0.98	0.98	0.98	0.98
200	0.95	0.97	0.98	0.98	0.98	0.98
300	0.95	0.97	0.98	0.97	0.97	0.97
400	0.95	0.97	0.97	0.97	0.97	0.97
500	0.95	0.96	0.97	0.96	0.96	0.96
600	0.95	0.96	0.96	0.95	0.95	0.93
700	0.95	0.95	0.95	0.94	0.93	0.91
800	0.95	0.95	0.94	0.93	0.92	0.90
900	0.95	0.95	0.93	0.92	0.90	0.88
1000	0.95	0.94	0.92	0.90	0.88	0.85
1100	0.95	0.94	0.91	0.89	0.85	0.83
1200	0.95	0.94	0.90	0.86	0.82	0.79
1300	0.95	0.93	0.89	0.84	0.80	0.76
1400	0.95	0.92	0.87	0.82	0.76	0.72
1500	0.95	0.92	0.86	0.79	0.73	0.68
1750	0.95	0.89	0.83	0.72	0.64	0.58
2000	0.95	0.87	0.77	0.66	0.56	0.49
2250	0.95	0.86	0.72	0.58	0.48	0.39
2500	0.95	0.85	0.68	0.52	0.39	0.30
2750	0.95	0.82	0.62	0.45	0.32	0.23
3000	0.95	0.80	0.57	0.38	0.26	0.18

Table F.20. Decision table for Area 5CD concerning the historical target reference point mean($u_{1966-2005}$) for 1-5 year projections, such that values are P($u_t > mean(u_{1966-2005})$). For reference, the average estimated female catch over the last 5 years (2009-2013) is 577 t. The maximum historical female catch estimate in Area 5CD was 2537 t in 1991.

	2014	2015	2016	2017	2018	2019
0	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00
500	0.00	0.00	0.00	0.00	0.00	0.00
600	0.00	0.00	0.00	0.00	0.00	0.00
700	0.00	0.00	0.00	0.00	0.00	0.00
800	0.00	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.00	0.01	0.01	0.02
1000	0.00	0.00	0.01	0.03	0.04	0.05
1100	0.01	0.02	0.05	0.07	0.10	0.14
1200	0.04	0.07	0.11	0.17	0.21	0.25
1300	0.11	0.14	0.23	0.30	0.36	0.39
1400	0.20	0.26	0.36	0.45	0.50	0.54
1500	0.32	0.39	0.50	0.58	0.63	0.67
1750	0.66	0.71	0.78	0.85	0.88	0.88
2000	0.87	0.89	0.93	0.95	0.95	0.96
2250	0.96	0.96	0.98	0.99	0.99	0.99
2500	0.99	0.99	1.00	1.00	1.00	1.00
2750	1.00	1.00	1.00	1.00	1.00	1.00
3000	1.00	1.00	1.00	1.00	1.00	1.00

APPENDIX G. SENSITIVITY ANALYSES

Sensitivity analyses were used to investigate how choices made during stock assessment model formulation affected results. These analyses focused on data selection with respect to CPUE series, the magnitude of process error added to the abundance indices, the prior distribution specified for the stock recruitment steepness parameter (*h*), and whether natural mortality (*M*) was estimated or assumed fixed at the prior mean. A summary of all sensitivity models runs completed is shown in Table G.*1*.

Maximum posterior density (MPD) fits and MCMC convergence of sensitivity runs were assessed though visual inspection of model outputs (results not shown), as described for the base runs in Appendix F. A brief summary of each model fit and MCMC convergence success is provided in Table G.*1*.

When discussing sensitivity analysis results below, MCMC results are only presented for runs with acceptable convergence. Otherwise, the MPD results are used.

AREA 5AB

Sensitivity analyses for the Area 5AB stock assessment explored the effect on stock assessment results of splitting the CPUE time series into two separate series (before 1996 and after 1996) and estimating natural mortality *M*.

Splitting the available CPUE indices into two independent abundance series (1966-1995 and 1996-2012) is justified due to known substantial changes in fishing behaviour when Individual Vessel Quota (IVQ) management and other regulatory changes were initiated in 1996 and 1997. This approach was originally deemed preferable to using a single CPUE series for this assessment (as was done in Area 5CD) because it seemed unlikely that these two time periods would share a single catchability coefficient, given the reduction in number of vessels fishing, the introduction of 100% observer coverage and the rationalisation of the fishery that came after 1996/97. However, model runs which uncoupled the CPUE series led to high estimates of Queen Charlotte Sound synoptic survey catchability (e.g., q = 0.82 for run 5AB_2CPUE). These high estimates lacked credibility given the much lower values seen for the Hecate Strait synoptic survey in the more data-rich Area 5CD (q = 0.18), which occurs in the exact same years as the Queen Charlotte Sound synoptic survey. As well, these runs estimated the second CPUE q to be more than double the first CPUE q, a result which was thought to be unlikely given the reduction of the number of participating vessels after 1996 and given that the 5CD q-estimates for the second series were very similar to the estimates for the first series. Consequently, we recommended that a single series that linked the two periods (1966-2012) by estimating a common q-parameter be used as a base case. We present the MPD and MCMC results for two runs with uncoupled CPUE series, one which fixed *M* (5AB_2CPUE) and another which estimated M (5AB_2CPUE_estM) as sensitivity analyses.

The treatment of discards differed between the 1 CPUE and 2 CPUE series (see Appendix B for a description of these series). The 1 CPUE series was based on landings only because the pre-1996 discard information was unreliable. In the 2 CPUE sensitivity cases, the post-1995 series included discards while the pre-1996 series was based on only landings. This treatment of discards in the 2 CPUE model could lead to slightly higher q-estimates for the second CPUE series over the first CPUE series if q were unchanged. Examination of the estimates of q for 5CD shows this is the case, with the q-estimates marginally higher for the second (later) CPUE series in the 5CD base case (see Table G.4 below). However, this difference in the treatment of discards is not enough to explain the large difference between the *q*-estimates in the 5AB assessment.

Allowing *M* to be estimated (with an informed prior distribution) is preferable to holding the parameter fixed because it allows the introduction of additional variability associated with this parameter. However, it was not possible to achieve MCMC convergence when this parameter was estimated in this assessment, thus requiring us to fix *M*=0.2 (which is the mean value used in the *M*-prior) for the base case. We present the MPD results for two 'estimate M' scenarios as sensitivity analyses. The prior distribution used to estimate *M* in both these cases was *Normal* (0.2, 0.04), which was also used for the 5CD assessment.

The effects of sensitivity scenarios on model results for the Area 5AB stock assessment are summarized in terms of MPD estimates of spawning biomass over time (Figure G.1), MPD estimates of stock assessment model parameters (Table G.2), selected percentiles of MCMC-derived management quantities (Table G.3), and estimated stock status relative to MSY-based reference points from MCMC results (Figure G.2).

Effect of splitting CPUE series

Splitting the CPUE series at 1996 into two independent time series had little effect on the trend in MPD biomass trajectories, regardless of whether *M* was estimated or held fixed (compare run 5AB with 5AB_2CPUE and run 5AB_estM with 5AB _2CPUE_ estM in Figure G.1). Splitting the CPUE series did affect estimates of current depletion, with B_{2014} / B_0 lower when two CPUE series were used than when only one series was used (Table G.2). Lower B_{2014} / B_0 estimates were due to the higher catchability estimates in the more recent portion of the time series and lower current biomass levels. Estimates of catchability for the Queen Charlotte Sound synoptic survey (which are only available from 2003 – 2012) were higher when CPUE series were split in two compared to when only one series was used. When two series were used, estimates of catchability for the recent CPUE series (CPUE2) were higher than estimates for the early CPUE series (CPUE1). We do not consider these estimates credible in the context of recent management changes and dissimilar results in the 5CD assessment.

Posterior distributions for both MSY-based and historical-based reference points (B_{MSY}, B_{Lim}, B_{Tar}, MSY, u_{MSY}) were relatively insensitive to splitting the CPUE series into two independent series; however, estimates of current biomass or harvest rate relative to these reference points were somewhat sensitive due to lower estimates of B_{2014} when two CPUE series were used (Table G.3).

Table G.1. Model runs conducted for sensitivity analyses. Run type describes whether a MCMC estimation procedure was used or whether the maximum posterior density (MPD) estimate was calculated. For MCMC runs, n indicates the number of MCMC posterior samples and k indicates the thinning interval used.

Area	Run ID	Description	Run type	Notes on Model Fit
5AB	5AB	Base case described in Appendix E.	MCMC n = 1x10^{7}; k = 1 x10^{4}	- Model fits consistent with data - Acceptable MCMC convergence
	5AB_2CPUE	Same as baseline case, but with CPUE modelled as two separate abundance indices. CPUE 1: 1966 – 1995 (landed catch), CPUE 2: 1996-2012 (landed + discarded catch). CVpro set at 0.15 for CPUE 1 and 0.40 for CPUE 2.	MCMC n = 5x10^{6}; k = 5x10^{3}	- Model fits consistent with data - Acceptable MCMC convergence
	5AB_estM	Same as base case, but with M estimated.	MCMC n = 5 x10^{7}; k = 5 x10^{4}	- Model fits consistent with data - No MCMC convergence
	5AB_2CPUE_estM	Same as run 5AB_2CPUE, but with M estimated.	MCMC n = 5 x10^{7}; k = 5 x10^{4}	- Model fits consistent with data - No MCMC convergence
5CD	5CD	Baseline case described in Appendix E.	MCMC n = 5 x10^{7}; k = 5 x10^{4}	- Model fits consistent with data - Acceptable MCMC convergence
	5CD_noCPUE	Same as baseline case, but with no CPUE data. Model fit to only survey data.	MCMC n = 5 x10^{7}; k = 5 x10^{4}	- Model fits consistent with data - No MCMC convergence
	5CD_noCPUE1	Same as baseline case, but with CPUE 1 series (1954 – 1995) dropped.	MPD	- Model fits consistent with data
	5CD_noCPUE2	Same as baseline case, but with CPUE 2 series (1996 – 2012) dropped.	MPD	- Model fits consistent with data

Area	Run ID	Description	Run type	Notes on Model Fit
	5CD_CVpro0.2	Same as baseline case, but with process error CV set to 0.2 for all abundance indices.	MCMC n = 5 x10^7; k = 5 x10^4	- Model fits consistent with data - Acceptable MCMC convergence
	5CD_fixM	Same as baseline case, but with M fixed at 0.2.	MCMC n = 5x10^6; k = 5x10^3	- Model fits consistent with data - Acceptable MCMC convergence
	5CD_priorh	Same as baseline case, but with prior on steepness set at *Beta*(12.7, 5.0), which has the following properties: mode = 0.74, mean = 0.72, CV = 15%.	MCMC n = 5x10^7; k = 5x10^4	- Model fits consistent with data - Acceptable MCMC convergence

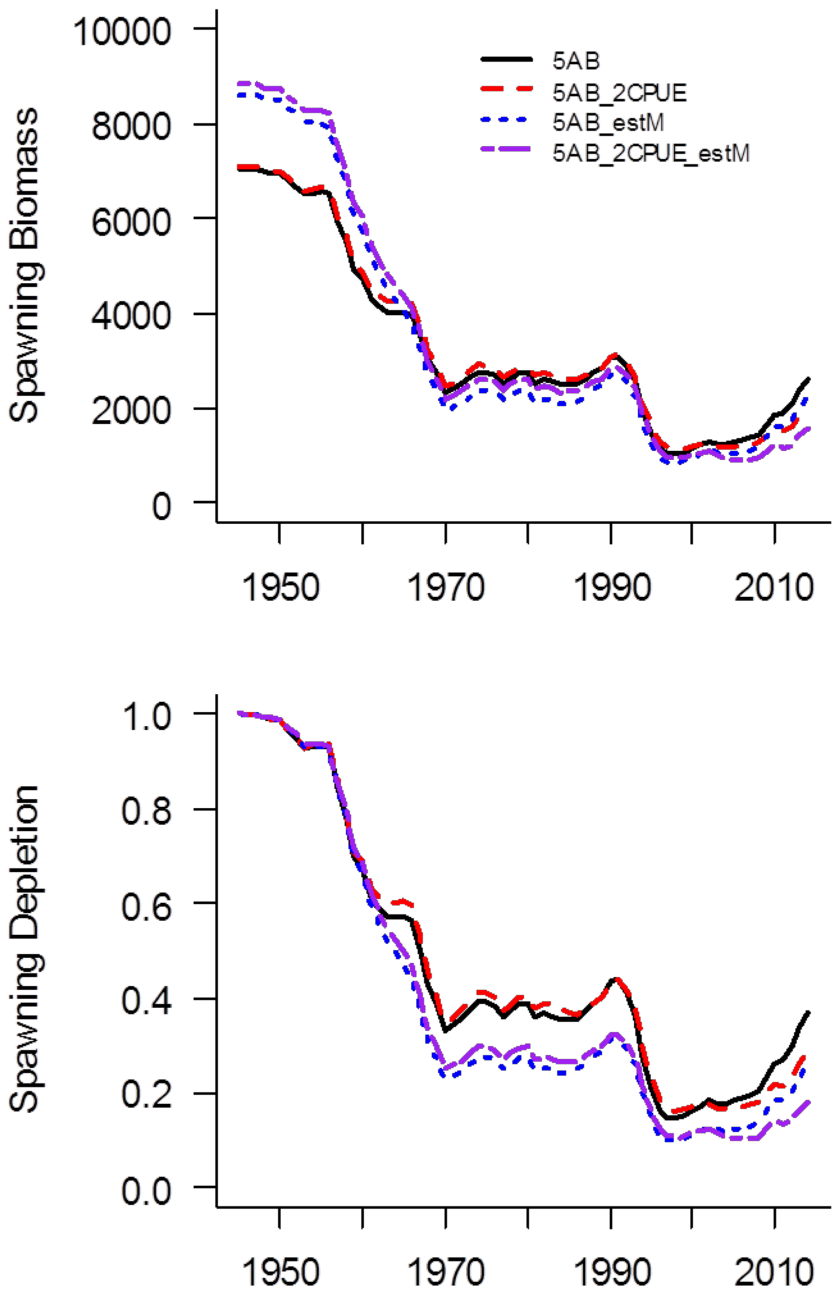


*Figure G.1. MPD estimates of spawning biomass and depletion (Bt/B_0) for Area 5AB sensitivity analysis model runs. Descriptions of each model run are given in Table G.*1*.*

Table G.2. MPD parameter estimates for Area 5AB sensitivity analysis model runs. Descriptions of each model run are given in Table G.1. Parameter definitions are given in Appendix E. Some subscripts have been modified from those used in Appendix E. Subscript definitions are as follows: CPUE = a single CPUE index series (1966-2012), CPUE1 = the early portion of the CPUE series (1966 – 1995), CPUE2 = the recent portion of the CPUE series (1996-2012), fishery = commercial bottom trawl fishery, and survey = Queen Charlotte Sound synoptic survey.

	Model Run			
Parameter	**5AB**	**_2CPUE**	**_estM**	**_2CPUE_estM**
B_{2014}	2,594	2,053	2,225	1,594
B_0	7,046	7,087	8,613	8,829
$B_{2014/}$ B_0	0.37	0.29	0.26	0.18
R_0	3,141	3,159	1,974	1,866
M	-	-	0.14	0.14
h	0.88	0.85	0.90	0.89
q_{CPUE}	0.000479	-	0.000555	-
q_{CPUE1}	-	0.000365	-	0.000404
q_{CPUE2}	-	0.000785	-	0.000974
q_{Survey}	0.694	0.815	0.794	1.029
$\mu_{fishery}$	5.95	5.93	5.85	6.03
μ_{Survey}	7.84	7.91	7.75	8.02
$v_{L\_fishery}$	1.21	1.17	1.16	1.31
v_{L_Survey}	2.22	2.24	2.25	2.32

Table G.3. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior for Area 5AB sensitivity runs for which MCMC sampling reached approximate convergence. B_{Lim} represents the historical limit biomass, defined for Rock Sole in Area 5AB as the minimum predicted biomass between 1966 and 2005. B_{Tar} represents the historical target biomass, defined as the mean predicted biomass level between 1977 and 1985. u_{Tar} represent the historical target exploitation rate, defined as the mean predicted harvest rate between 1966 and 2005.

	Model Run					
	5AB			**5AB_2CPUE**		
Parameter	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_{2014}	1,977	2,776	3,779	1,343	2,171	3,410
B_0	6, 765	7,479	8,457	6,723	7,426	8,427
B_{2014} / B_0	0.27	0.37	0.49	0.18	0.29	0.44
B_{MSY}	1,427	1,833	2,471	1,393	1,855	2,551
B_{2014} / B_{MSY}	0.98	1.52	2.26	0.64	1.19	1.97
MSY	482	524	580	470	516	584
u_{2013}	0.08	0.11	0.15	0.09	0.14	0.22
u_{MSY}	0.18	0.24	0.31	0.17	0.24	0.32
u_{2013} / u_{MSY}	0.30	0.46	0.72	0.34	0.58	1.05
B_{Lim}	863	1,133	1,422	943	1,182	1,463
B_{Tar}	2,216	2,879	3,663	2,267	3,044	3,888
B_{2014} / B_{Lim}	1.86	2.45	3.26	1.20	1.86	2.77
B_{2014} / B_{Tar}	0.74	0.96	1.27	0.44	0.73	1.14
u_{Tar}	0.15	0.19	0.23	0.15	0.18	0.23
u_{2013} / u_{Tar}	0.46	0.59	0.75	0.51	0.75	1.11

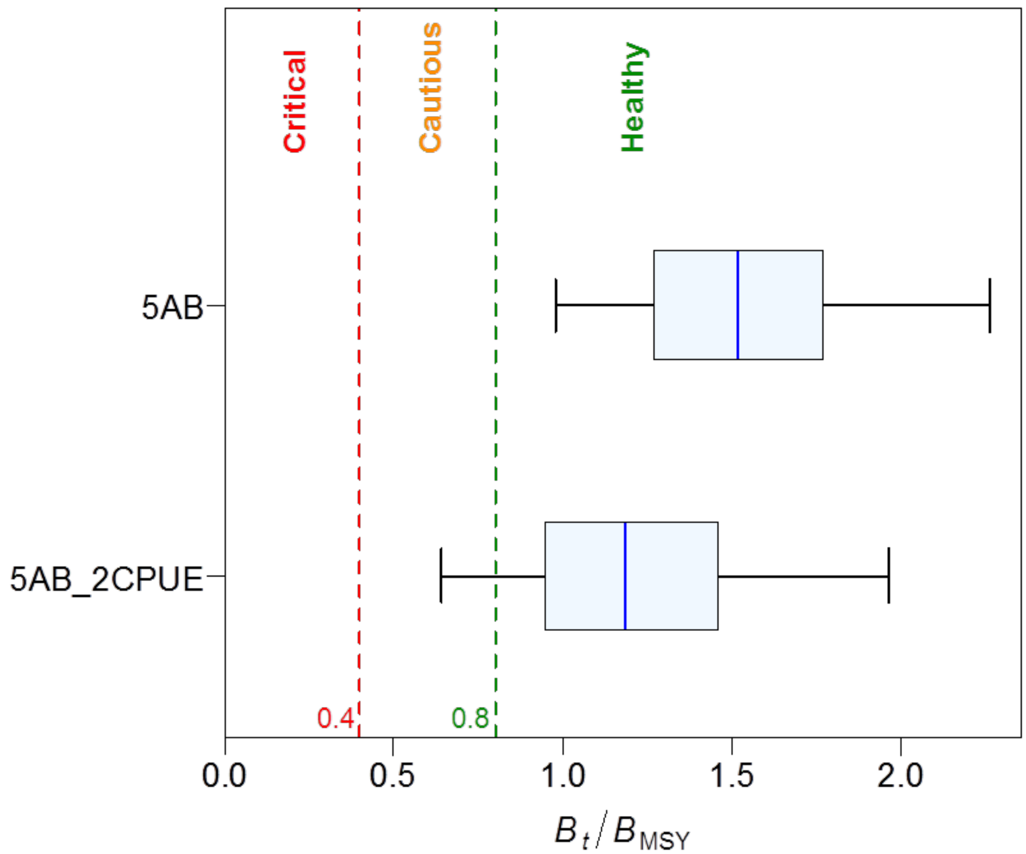


Figure G.2. Current stock status (represented as the ratio of B_{2014} to B_{MSY}) relative to the DFO Precautionary Approach provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ (vertical dashed lines) for Area 5AB sensitivity runs for which MCMC sampling reached approximate convergence Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

Effect of estimating natural mortality

Natural mortality (*M*) was estimated to be 0.14 for both "estimate *M*" sensitivity runs in Area 5AB (5AB_estM and 5AB_2CPUE_estM), which is smaller than the fixed value of M = 0.2 that was used in the 5AB base case and considerably lower than the equivalent values estimated for the 5CD assessment. These MPD estimates moved in the opposite direction from the prior mean value of 0.2 than estimates from Area 5CD (MPD estimate of M = 0.23 for 5CD base case). In Area 5AB, smaller values of *M* in the "estimate *M*" runs corresponded with larger estimates of both B_0 and *q*, which translated into lower estimates of B_{2014}/B_0 (Figure G.1; Table G.2). We think it is unlikely that *M* would differ so much for the same species in these two areas, and suggest that model misspecification is a more likely reason for the low *M* estimates in the 5AB assessment.

AREA 5CD

Sensitivity analyses for the Area 5CD stock assessment explored the effect on stock assessment results of excluding various combinations of CPUE indices when fitting the model to data, the magnitude of process error added to survey indices, and the prior distribution specified for the stock recruitment steepness parameter (*h*).

An analysis of the effect of excluding some or all CPUE indices from the assessment was based on concerns about the reliability of CPUE data for Rock Sole. Before 1996, effort and landings data are only available from logbooks maintained by fishermen, with total trip landings cross-validated with landing slips issued by the receiving processing plant. These data will be less reliable than post-1996 data that are collected by an independent at-sea observer, particularly for discard information and detailed information linking catch with effort. As well, it is believed that the introduction of an integrated fishery management system with transferable Individual Vessel Quotas in 1996 will have changed fishing behaviour, with economic and social considerations affecting Rock Sole catch rates as well as abundance. As a result, CPUE may be a poor predictor of Rock Sole biomass due to trends and high variability in the relationship between biomass and catch per effort.

We also chose to investigate the effect of the magnitude of process error used to assign relative weights to abundance indices on Area 5CD model results. We added different amounts of process error to each abundance series in the 5CD base case because we wished to balance the impact of these series in the model due to variation in the quality of fit among the series (see Appendix E). In the sensitivity run "5CD_CVpro0.2", the CV of the process error term was set at 0.2 for all abundance series instead of the base case values described in Appendix E. A process error CV of 0.2 was selected for this sensitivity analysis because it was the value recommended by Francis (2011).

Two additional sensitivity analyses were used to explore how the treatment of M and h in the base model affected stock assessment results in Area 5CD.

The effects of sensitivity scenarios on model results for the Area 5CD stock assessment are summarized in terms of MPD estimates of spawning biomass over time (Figure G.3), MPD estimates of stock assessment model parameters (Table G.4), selected percentiles of MCMC-derived management quantities (Table G.5), estimated stock status relative to MSY-based reference points from MCMC results (Figure G.4), and estimated female spawning biomass in 2014 relative to reference points from MCMC results (Figure G.4).

Effect of Eliminating CPUE Series

Elimination of CPUE data from the early part of the modelled time period had a large effect on the estimated scale of Rock Sole biomass in Area 5CD. B_0, R_0, and B_{2014} were about 15-20% smaller when CPUE was dropped entirely from the model (run "5CD_noCPUE") or when the early CPUE series (run "5CD_noCPUE1") was dropped (Table G.4). In both of these runs, the model also predicted a greater initial decline in biomass between 1945 and 1980 than that of the base case (Figure G.3). This difference is because, in the absence of early CPUE information, the biomass trajectory before the start of the Hecate Strait multispecies assemblage survey in 1984, is based solely on catch data. However, despite these differences, estimates of B_{2014} / B_0 are comparable between the base run and the two runs with no early CPUE information.

Eliminating only the recent CPUE series from the model fit (run "5CD_noCPUE2") had a smaller effect on the estimated MPD biomass trajectory than removing the earlier series. Estimates of B_{2014} / B_0 were greater when CPUE2 was dropped because the biomass estimate in 2014 was more heavily influenced by the high 2013 survey index from the Hecate Strait synoptic survey.

Estimates of current stock status relative to B_0 show low sensitivity to the inclusion or exclusion of the CPUE data (with the exception of the "5CD_noCPUE2" run, which showed moderate sensitivity). There is however some sensitivity to the inclusion of CPUE in our estimates of overall stock size and the amount of available yield.

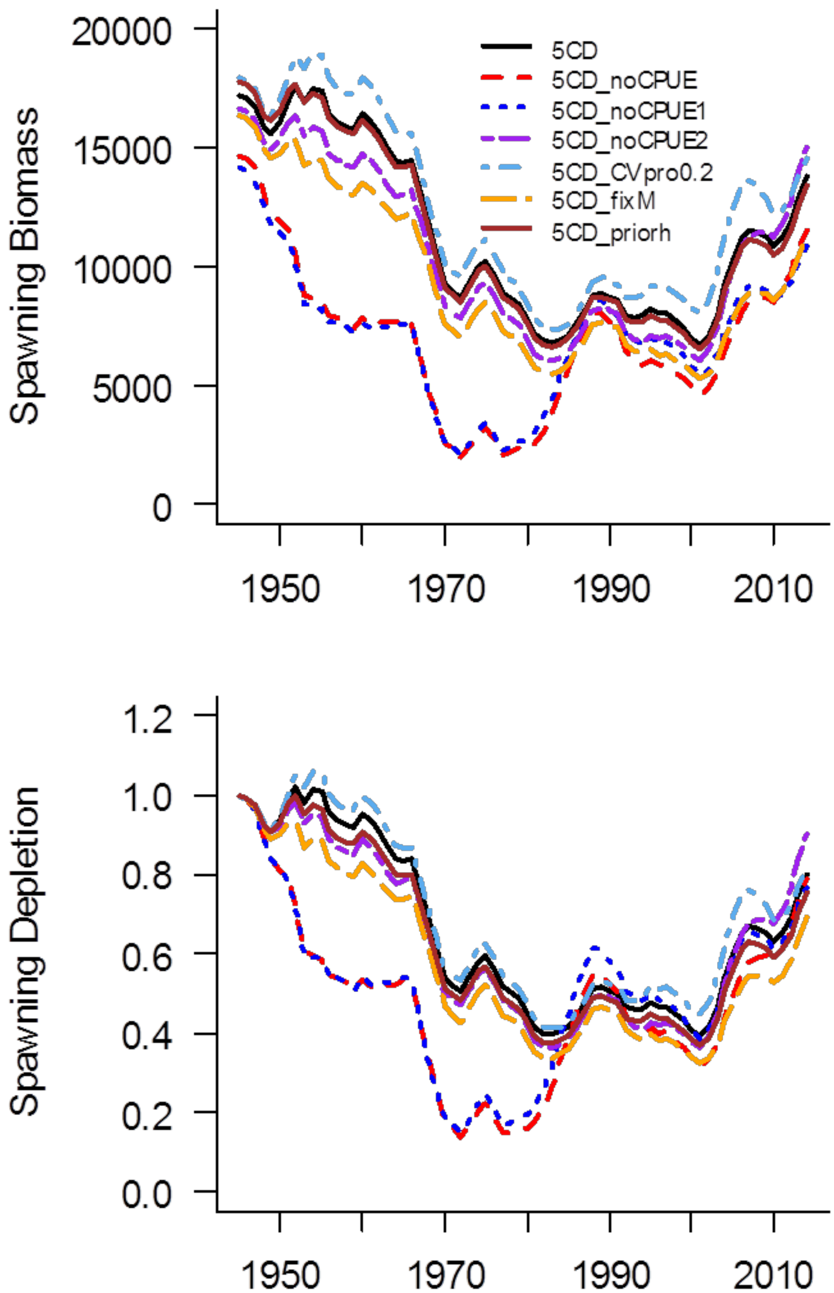


Figure G.3. MPD estimates of spawning biomass and spawning depletion (B_t/B_0) for Area 5CD sensitivity analysis model runs. Descriptions of each model run are given in Table G.1.

Table G.4. MPD parameter estimates for Area 5CD sensitivity analysis model runs. Descriptions of each model run are given in Table G.1. Parameter definitions are given in Appendix E. Some subscripts have been modified from those used in Appendix E. Subscript definitions are as follows: CPUE1 = the early portion of the CPUE series (1954 – 1995), CPUE2 = the recent portion of the CPUE series (1996-2012), fishery = commercial bottom trawl fishery, HSmulti = Hecate Strait multispecies assemblage survey, and Synoptic = Hecate Strait synoptic survey. The symbol '-' indicates that a values was not estimated or was fixed.

	Model Run						
Parameter	**5CD**	**_noCPUE**	**_noCPUE1**	**_noCPUE2**	**_CVpro0.2**	**_fixM**	**_priorh**
B_{2014}	13,758	11,569	10,855	14,997	14,583	11,302	13,412
B_0	17,218	14,635	14,131	16,650	17,915	16,386	17,742
$B_{2014/}$ B_0	0.80	0.79	0.77	0.90	0.81	0.69	0.76
R_0	15,168	8,863	10,074	14,647	18,062	10,252	15,385
M	0.23	0.20	0.21	0.23	0.25	-	0.23
h	0.89	0.89	0.90	0.89	0.89	0.88	0.73
q_{CPUE1}	0.000125	-	-	0.000142	0.000114	0.000149	0.000127
q_{CPUE2}	0.000140	-	0.000174	-	0.000117	0.000177	0.000145
$q_{HSmulti}$	0.255	0.327	0.291	0.282	0.220	0.308	0.262
$q_{Synoptic}$	0.216	0.280	0.268	0.218	0.188	0.271	0.224
$\mu_{fishery}$	8.19	8.45	8.32	8.29	8.07	8.22	8.18
$\mu_{HSmulti}$	5.79	5.51	5.56	5.82	5.86	5.47	5.78
$\mu_{Synoptic}$	7.32	7.41	7.24	7.57	7.18	7.21	7.33
$v_{L\_fishery}$	1.97	2.09	2.04	1.98	1.90	2.02	1.96
$v_{L\_HSmulti}$	1.60	1.49	1.52	1.61	1.64	1.49	1.61
$v_{L\_Synoptic}$	2.67	2.25	2.19	2.24	2.12	2.17	2.17

Effect of Magnitude of Process Error in Abundance Indices

Applying a constant process error CV of 0.2 to all abundance indices (run "5CD_CVpro0.2") rather than using different values for each index in the base run "5CD" (as described in Appendix E) increased the estimated scale of predicted stock biomass throughout the time series (Figure G.3). Estimates of B_0, R_0, and B_{2014} (Table G.4) were about 5% higher for the "5CD_CVpro0.2" run compared to the base run; however, estimates of B_{2014} / B_0 were nearly equal for both runs. Median posterior estimates of current stock status relative to reference points derived from the MCMC analysis were also very similar between the two runs, although posterior distributions tended to be narrower for the "5CD_CVpro0.2" scenario (as evidenced by the 5th and 95th percentile values in Table G.5). Overall conclusions about stock status were similar regardless of whether a constant process error term of 0.2 was added to abundance series or whether series-specific values used in the base case were added.

Table G.5. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior for Area 5AB sensitivity runs for which MCMC sampling reached approximate convergence. B_{Lim} represents the historical limit biomass, defined for Rock Sole in Area 5CD as the minimum predicted biomass between 1966 and 2005. B_{Tar} represents the historical target biomass, defined as the mean predicted biomass level between 1971 and 1980. u_{Tar} represents the historical target exploitation rate, defined as the mean predicted harvest rate between 1966 and 2005.

	5CD			**5CD_CVpro0.2**			**5CD_fixM**			**5CD_priorh**		
Quantity	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_{2014}	9,949	15,385	24,724	10,670	17,154	27,997	8,063	11,607	16,587	9,852	15,642	25,423
B_0	16,263	19,329	25,361	16,686	20,527	28,569	15,546	17,396	19,932	16,887	19,910	25,484
B_{2014} / B_0	0.58	0.80	1.07	0.62	0.83	1.06	0.49	0.67	0.89	0.54	0.78	1.05
B_{MSY}	3,613	4,853	6,799	3,749	5,112	7,591	3,231	4,469	6,036	4,397	5,910	8,035
B_{2014} / B_{MSY}	2.10	3.22	4.64	2.21	3.38	4.66	1.68	2.62	4.00	1.66	2.67	4.00
MSY	1,326	1,895	2,810	1,436	2,098	3,414	1,132	1,359	1,616	1,147	1,676	2,686
u_{2013}	0.03	0.04	0.06	0.02	0.04	0.06	0.04	0.05	0.07	0.02	0.04	0.06
u_{MSY}	0.30	0.51	0.80	0.32	0.54	0.80	0.23	0.36	0.56	0.20	0.36	0.64
u_{2013} / u_{MSY}	0.04	0.08	0.16	0.03	0.07	0.14	0.08	0.14	0.27	0.05	0.11	0.26
B_{Lim}	5,223	7,739	11,971	5,819	8,869	14,325	4,341	5,390	6,842	5,076	7,655	11,995
B_{Tar}	7,753	11,135	16,662	8,350	12,261	19,652	6,566	8,078	9,828	7,767	10,989	17,343
B_{2014} / B_{Lim}	1.53	2.00	2.72	1.46	1.91	2.53	1.61	2.14	2.85	1.53	2.02	2.73
B_{2014} / B_{Tar}	1.00	1.40	1.97	1.02	1.37	1.82	1.02	1.43	2.03	1.01	1.40	1.91
u_{Tar}	0.08	0.12	0.17	0.07	0.11	0.16	0.13	0.16	0.20	0.08	0.13	0.17
u_{2013} / u_{Tar}	0.24	0.32	0.42	0.26	0.33	0.41	0.23	0.32	0.43	0.24	0.32	0.42

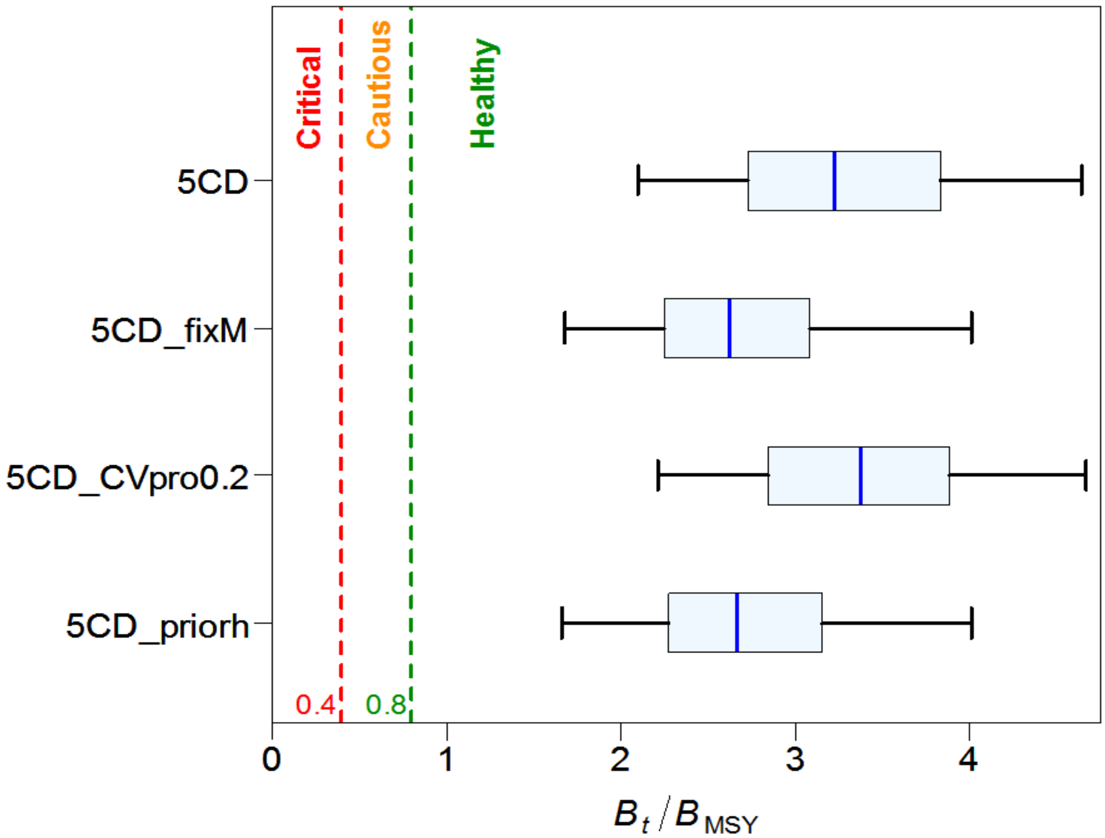


Figure G.4. Current stock status (represented as the ratio of B_{2014} to B_{MSY}) relative to the DFO Precautionary Approach provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ (vertical dashed lines) for Area 5AB sensitivity runs for which MCMC sampling reached approximate convergence. Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

Effect of Fixing M

Fixing the value of M at the prior mean 0.2 (run "5CD_fixM") resulted in a smaller predicted scale of the Rock Sole stock in Area 5CD compared to the base run, as evidenced by lower estimates of B_0, R_0, and annual biomass (Figure G.3; Table G.4). This result is unsurprising, given that M was estimated about 15% higher than 0.2 in the base case. The 5CD_fixM run also estimated higher catchability coefficients (q) for both survey time series, which translated into lower biomass estimates in recent years compared to B_0, including a lower estimate of B_{2014} / B_0.

Fixing the value of M also affected estimates of current stock status relative to reference points derived by MCMC analyses. As with the ratio of B_{2014} / B_0, the ratio of B_{2014} / B_{MSY} was lower when M was fixed (Table G.5; Figure G. 5). However, the ratios of B_{2014} to reference points based on historical biomass levels (i.e., B_{2014} / B_{Lim} and B_{2014} / B_{Tar}) were comparable or slightly higher than for the 5CD base run (Figure G. 5), demonstrating that the use of historical periods as reference levels provide greater stability for interpretation because they are less sensitive to shifts in model assumptions. We selected the run with estimated M as our base case because this run adds variability to estimated parameters compared to the fixed M run.

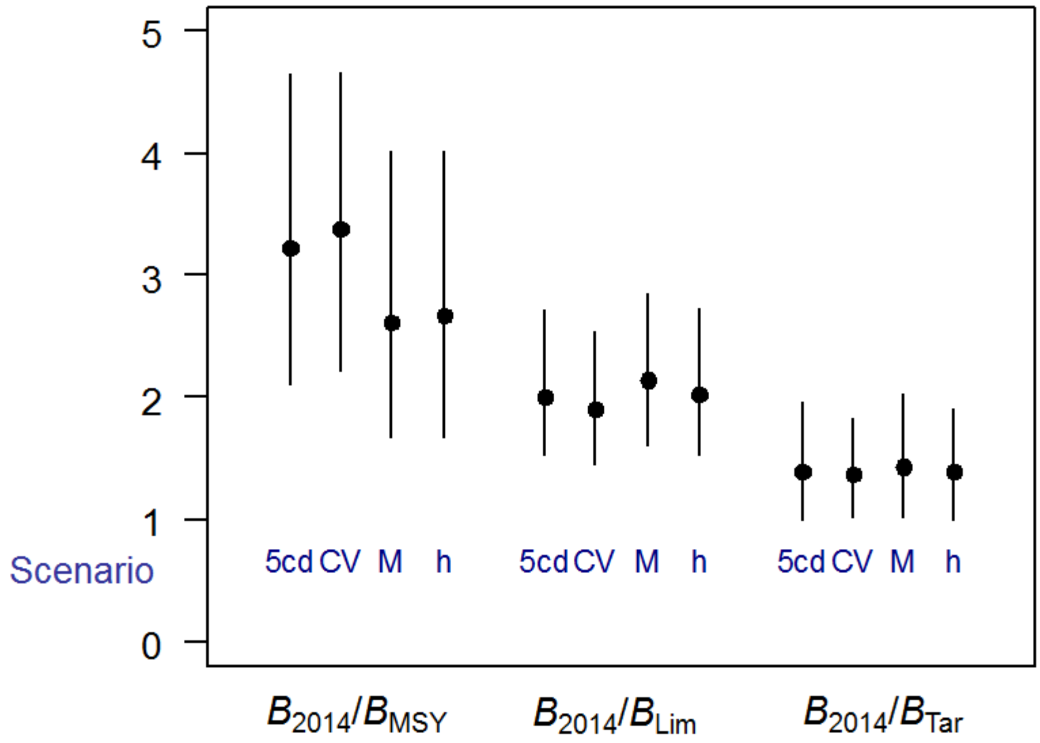


Figure G. 5. Estimated female spawning biomass in 2014 as a ratio of B_{MSY}, B_{LIM}, or B_{TAR} for Area 5CD sensitivity analysis model runs in which MCMC sampling reached approximate convergence ("5cd" = 5CD base case, "CV"= 5CD_CVpro0.2, "M" = 5CD_fixM," h" = 5CD_priorh). Black dots show the median of MCMC-derived posterior distributions while the error bars show the 5^th^ and 95^th^ percentiles.

Effect of Prior Distribution on Steepness

Our investigation of the effect of the prior distribution on stock recruitment steepness (*h*) showed that the data used to fit this stock assessment model contained very little information about this parameter. In both the 5CD base run and the 5CD_priorh run, the posterior distribution was not updated from the shape of the prior distribution (Figure G.6).

Using a prior distribution of *h* with a lower prior mean and a wider CV had little effect on the estimated biomass levels or on biomass relative to B_0. The predicted biomass trajectory and estimate of B_{2014} / B_0 for run 5CD_priorh were similar to those of the base run. The lower value of *h* in the 5CD_priorh run reduced estimated productivity of the stock, with lower estimates for productivity-based reference points such as MSY and u_{MSY} and a larger estimate of B_{MSY}. As a result, the posterior of B_{2014} / B_{MSY} was shifted lower for the 5CD_priorh scenario compared to the base scenario, while the posterior for u_{2013} / u_{MSY} was shifted upwards (Table G.5). As seen when investigating the effect of fixing *M*, current stock status relative to historical reference levels was relatively insensitive to assumptions about *h*, with ratios of B_{2014} / B_{Lim}, B_{2014} / B_{Tar}, and u_{2013} / u_{Tar} from the 5CD_priorh runs being comparable to those from the base run 5CD (Table G.5; Figure G. 5).

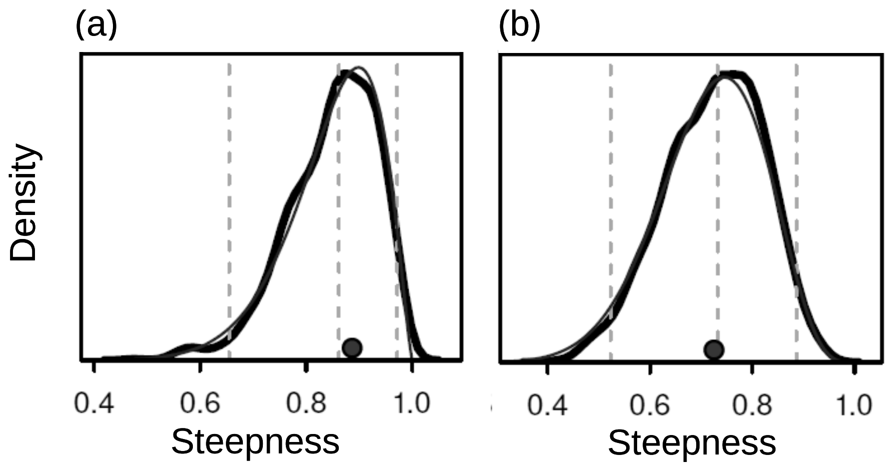


Figure G.6. Marginal posterior densities (thick curves) and prior density functions (thin curves) for the estimated steepness parameter for the base case 5CD run (run “5CD”; panel a) and the sensitivity analysis on the prior h distribution (run “5CD_priorh”; panel b). Vertical dashed lines represent the 2.5, 50, and 97.5 percentiles, and the solid circle shows the MPD estimate for each run.