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English sole (*Parophrys vetulus*) in British Columbia, Canada: Stock Assessment for 2006/07 and Advice to Managers for 2007/08

Carlottin anglais (*Parophrys vetulus*) en Colombie-Britannique, Canada: Évaluation des stocks pour 2006-2007 et avis aux gestionnaires pour 2007-2008

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ABSTRACT

Information pertaining to English sole (*Parophrys vetulus)* in British Columbia was reviewed and updated for inclusion in a delay-difference stock assessment model. This model was used to determine the status of two stocks of English sole: 5CD (Hecate Strait) and 3CD5AB (combined west coast Vancouver Island and Queen Charlotte Sound) and to provide quantitative advice on levels of catch and the associated risk relative to selected management performance indicators for each of these stocks.

A range of model uncertainties in both stock assessments were explored through sensitivity runs which varied model assumptions which could not be easily reconciled through inspection of the model fits to the data. Three pairs of alternative model assumptions were investigated:
a) estimating *M*, the rate of instantaneous natural mortality through the use of mean weight data sampled from the fishery or fixing *M* at the preferred value of 0.20 and dropping the mean weight data; b) varying the age of knife-edged recruitment between age 4 and age 5 (5CD only);
c) applying a single CPUE series for the entire model period, effectively assuming that the fishery catchability has been constant for 40 years or splitting the CPUE series between 1995 and 1996 in recognition of the severe management restrictions that were applied at that time.

The 5CD modelling results showed that within the range of the criteria investigated, the effects of fixing or estimating *M* and the age of knife-edge recruitment were relatively minor, with the management advice almost identical across these options. However, the effect of splitting the CPUE series was important, with the model estimating a drop in catchability in recent years and consequently being more optimistic about stock status. Both of the CPUE hypotheses indicate that 5 year projections of landings at the current 5CD TAC have a greater than 50% probability of remaining above B_{min} (99–100%) and B_{ref} (64–98%) reference points at the end of the projection period in 2012. The probability of staying above B_{min} and B_{ref} remains above 50% at catch levels higher than the current TAC, with the amount varying depending on the model hypothesis. However, all model runs predict that current stock abundance has a greater than 50% probability of declining by 2012 at landing levels greater than the current TAC.

The 3CD5AB modelling results are less optimistic, with stronger differences between the CPUE hypotheses. The split CPUE hypothesis indicates that the current TAC will remain above the selected B_{min} and B_{ref} reference points while the single CPUE hypothesis indicates that landings at this level are too high. There is also some sensitivity to the *M* estimation method, with the model runs which fix *M* predicting that the stock will decline at catch levels lower than the model runs which estimate *M*.

The credibility of both assessments requires the assumption that the fishery dependent CPUE series are tracking the abundance of these stocks. Neither assessment fits the available survey biomass indices very well and the 3CD5AB assessment is based on 5CD biological data because it lacks stock specific biological information.

RÉSUMÉ

L’information concernant le carlottin anglais en (Parophrys vetulus) Colombie-Britannique a été passée en revue et mise à jour afin d’être incluse dans un modèle d’évaluation des stocks à différence retardée. Ce modèle a été utilisé pour déterminer l’état de deux stocks de carlottin anglais dans les zones de gestion 5CD (détroit de Hécate) et 3CD5AB (côte ouest de l’île de Vancouver et détroit de la Reine-Charlotte) et pour formuler un avis quantitatif sur les niveaux de prises et les risques s’y rattachant relativement à des indicateurs de rendement choisis pour la gestion de chacun de ces stocks.

On a examiné un éventail d’incertitudes dans les deux évaluations de stocks à l’aide de séquences de sensibilité qui ont permis de varier les hypothèses modélisées que l’on ne pouvait faire concorder aisément aux données par le biais de l’inspection de l’étalonnage du modèle. Trois autres paires d’hypothèses de modèle ont été examinées : a) l’estimation de M, soit le taux de mortalité naturelle instantanée en fonction de l’utilisation des données sur le poids moyen échantillonné fourni par les pêches ou la détermination de M à la valeur préférée de 0,20 en laissant tomber les données sur le poids moyen; b) la variation de l’âge de recrutement bien tranché entre quatre et cinq ans (zone 5CD uniquement); c) l’application d’une seule série des prises par unité d’effort (CPUE) pour toute la période du modèle, en présumant avec justesse que la capturabilité des pêches a été constante pendant 40 ans ou en fractionnant les séries des CPUE entre 1995 et 1996 pour tenir compte des restrictions rigoureuses appliquées à cette période.

Les résultats de modélisation pour la zone 5CD ont indiqué que, dans la fourchette des critères étudiés, les effets de la détermination ou de l’estimation de M et l’âge de recrutement bien tranché étaient relativement mineurs, et donc les avis aux gestionnaires étaient pratiquement identiques pour ces options. Cependant, les séries fractionnées des PUE ont eu un effet important, le modèle estimant une chute de la capturabilité au cours des dernières années et, par conséquent, étant plus optimiste quant à l’état du stock. Les deux hypothèses liées aux CPUE ont indiqué que les projections de cinq ans sur les débarquements selon le total autorisé des captures (TAC) actuel dans la zone 5CD affichent une probabilité supérieure à 50 % de demeurer au-dessus des points de référence Bmin (99–100 %) et Bref (64–98 %) à la fin de la période de projection en 2012. La probabilité de demeurer au-dessus des points Bmin et Bref demeure supérieure à 50 % avec des niveaux de prises plus élevés que le TAC actuel, la quantité variant selon l’hypothèse modélisée. Toutefois, toutes les séquences de modèle prédisent que l’abondance du stock actuelle affiche une probabilité supérieure à 50 % de chuter d’ici 2012 avec des niveaux de débarquements supérieurs au TAC en vigueur.

Les résultats de modélisation pour la zone 3CD5AB sont moins optimistes, avec des différences plus grandes entre les hypothèses liées aux CPUE. L’hypothèse de la série fractionnée des CPUE indique que le TAC actuel demeurera au-dessus des points de références Bmin et Bref choisis, alors que l’hypothèse d’une seule série de CPUE indique que les débarquements à ce niveau sont trop élevés. On note également une certaine sensibilité liée à la méthode d’estimation de M, la séquence de modélisation avec un taux de M déterminé prédisant que le stock déclinera à des niveaux de prises inférieurs à ceux prédits par la séquence de modélisation avec un taux de M estimé.

La crédibilité des deux évaluations repose sur l’hypothèse que les séries des CPUE qui dépendent des pêches font le suivi de l’abondance de ces stocks. Les modèles d’évaluation appliqués aux deux stocks ne conviennent pas très bien aux indices de la biomasse des relevés dont on dispose; en raison de l’absence de données biologiques propres aux stocks, dans le cas de l’évaluation de la zone 3CD5AB, les données biologiques ont été dérivées des données biologiques de la zone 5CD.

INTRODUCTION

Landings and TAC for English sole

The groundfish resource in British Columbia (B.C.) increased in importance in the late 1970s with the implementation of Extended Jurisdiction in 1977 and subsequent expansion of the domestic fleet. Recommendations for quota management of groundfish species were not forthcoming until 1979 (Ketchen 1980). Since that time, detailed and interim assessments for various flatfish species have been conducted annually including recommendations for catch limitations. Assessments of English sole were conducted in 1998 (Fargo 1998), 1999 (Fargo 1999) and 2000 (Fargo et al. 2000).

English sole, along with rock sole (*Lepidopsetta spp*) and Pacific cod (*Gadus macrocephalus*), is an important component of the trawl fishery in Hecate Strait (DFO region 5CD). There was a period of relatively high landings for this species in Hecate Strait in the late 1950s, but these decreased to lower levels and have fluctuated around an apparent mean since then (Figure 1). There were other periods of strong historical landings (greater than 1200 t/year) in the late 1970s and early 1980s and a very strong peak in the early 1990s (Figure 1). The current TAC for English sole in 5CD is 544 t, which is 182 t below the long-term average landings (Average[1966–2005]=726 t). Recent landings in this fishery have been stable near the level of the current TAC, which was exceeded only in the most recent fishing year (Figure 1). High catches in this most recent fishing year were associated with the large Arrowtooth flounder fishery that operated in Hecate Strait, mainly in the Two Peaks/Butterworth areas, which are also known to be preferred areas for English sole.

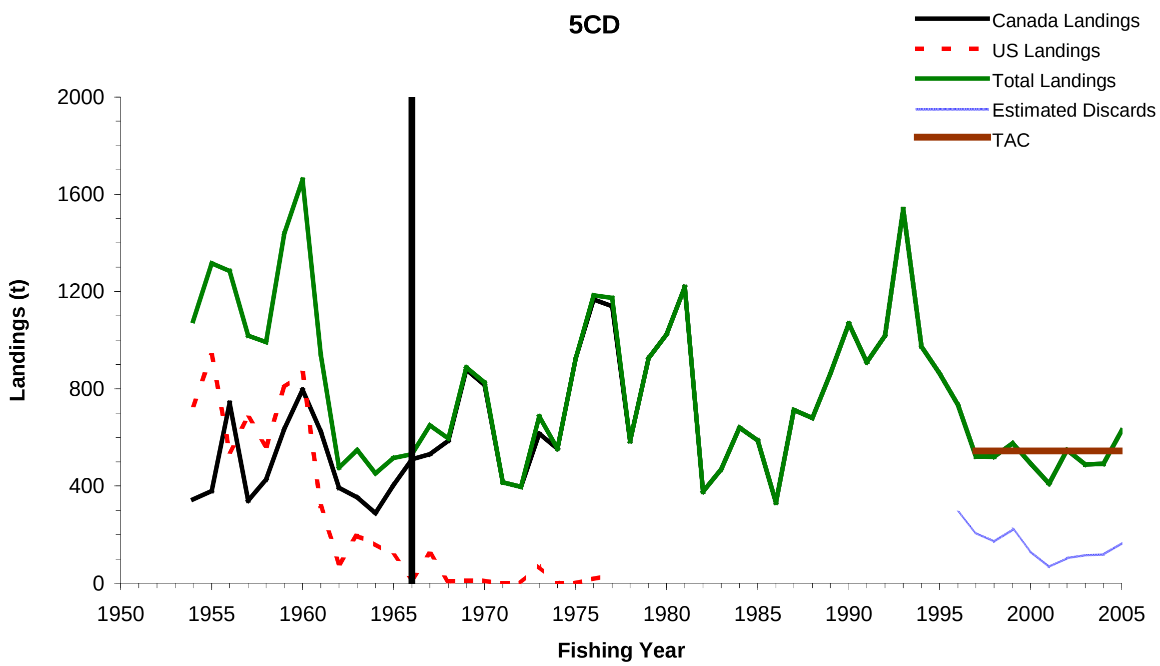

Figure 1. Historical landings of English sole in Hecate Strait (5CD): 1954–2005. Years represent the first half of the 1 April–31 March fishing year (e.g. 2005=2005/06). US catches from Fargo (1999); Canadian catches from the *GFCatch* and *PacHarvTrawl* databases. Vertical line at 1966 represents the beginning of the stock assessment for 5CD presented in this report.

DFO regions 3CD (west coast Vancouver Island) and 5AB (Queen Charlotte Sound) account for the other major fishery for English sole in British Columbia. Landings in the combined 3CD5AB have been relatively low over the entire history of landings, rarely going above 300 t/year (Figure 2). The current combined TAC for English sole in 3CD5AB is 186 t, which is slightly above the long-term average landings (Average[1966–2005]=152 t). Landings in 3CD5AB have increased steadily since 1996 and the TAC was fully taken in the most recent fishing year.

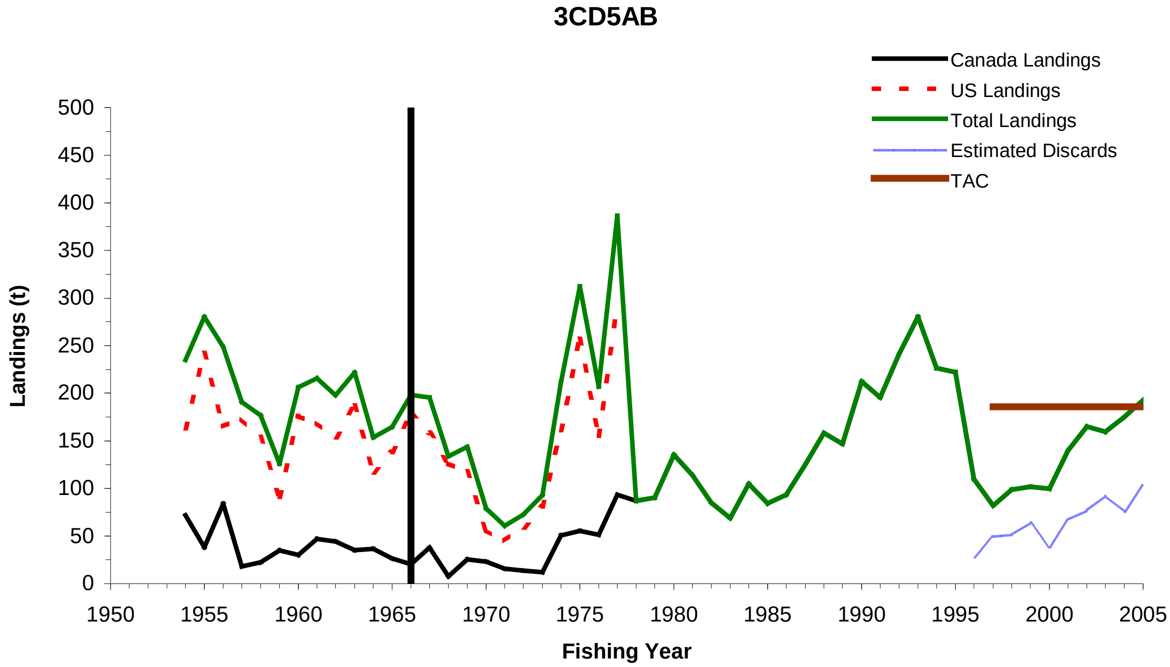

Figure 2. Historical landings of English sole in combined west coast Vancouver Island (3CD) and Queen Charlotte Sound (5AB): 1954–2005. Years represent the first half of the 1 April–31 March fishing year (e.g. 2005=2005/06). US catches from Fargo (1999); Canadian catches from the *GFCatch* and *PacHarvTrawl* databases. Vertical line at 1966 represents the beginning of the stock assessment for 3CD5AB presented in this report.

A general increase in catch and effort across groundfish species and areas beginning in about 1988 and peaking in the early 1990s was at least in part the result of competition for fishing history in anticipation of the application of individual quota management (IVQ). The IVQ qualification period ran from 1988 to 1992 and a formula based in part on aggregate landings in this period was used to allocate the total allowable catch by species. Consequently many species showed marked increases in landings and effort during this period which are unlikely to be related to changes in abundance. This may be a possible explanation for the large increase in English sole landings in both 5CD (Figure 1) and 3CD5AB (Figure 2), with landings peaking in both areas in the early to mid-1990s.

Biology of English sole

English sole are found at preferred depths from California to south east Alaska, but abundance appears to decline with increasing latitude and Hecate Strait is near the northern limit for this species (Fargo et al. 2000). The preferred depth range in Hecate Strait is from 5 m to 150 m, with mature fish found at deeper depths and the shallow depths being used mainly by pre-recruits (Fargo 1998).

English sole, like rock sole, exhibit sexual dimorphism, with females attaining much larger sizes than males. This has implications for the stock assessment, because smaller fish are not preferred by the fishery and tend to be discarded. Thus discards are predominantly male and the fishery is highly skewed towards females. Both sexes grow similarly for the first 3 years until they reach sexual maturity at around 300 mm (Fargo et al. 2000). After that age, males stop growing and devote most of their energy to reproduction. Females grow to a maximum length of around 500 mm, although larger specimens are occasionally found in the port samples. The oldest aged English sole in the DFO *GFBio* database is age 19, although a maximum age of 22 years has been reported (Chilton and Beamish 1982). Only 3% of the aged specimens are older than age 12 in the DFO *GFBio* database.

Previous assessments have used a fixed value of 0.20 for M, the instantaneous rate of natural mortality (Fargo 1998; Fargo 1999; Fargo et al. 2000), although these assessments do not provide much analysis to support this choice. The maximum age of 22 years implies M=0.21 using the method of Hoenig (1983). However, Hoenig's method uses the age which defines the final 1% of the age distribution of an unfished population, which implicitly implies that the current biomass of English sole is depleted if M=0.20, given the lack of older fish which dates back for more than 25 years (see Appendix A for the age distributions by year). This assessment has continued the practice of assuming that M=0.20, although M was estimated in over half of the model runs used in this assessment, constraining the estimates using an informed Bayesian prior centred on the value 0.20.

Spawning occurs from September to March, with peak spawning in October and November (Fargo et al. 2000). There is a pelagic larval phase that lasts 6 to 10 weeks, which would allow for some dispersal by currents.

Objectives of this assessment

The objectives of this working paper are taken from the "Request for a working paper" submitted by DFO Groundfish Management in September 2006:

> "*To provide assessments of the English sole populations in the waters off Vancouver Island and Queen Charlotte Sound (Areas 3C, 3D, 5A and 5B) and Hecate Strait (Areas 5C and 5D). These assessments will provide estimates of stock status relative to agreed target reference points as well as recommendations for levels of removals which will allow these populations to reach these targets. The assessments should include all available information, including surveys, biological sampling, catch records, logbooks, observer reports. These assessments will provide the basis for the management of the 2007/08 fisheries for English sole in the designated management areas.*"

The above objectives have been interpreted as follows:

1. Review the available stock assessment data for English sole for 5CD and 3CD5AB separately and evaluate their potential to support a quantitative stock assessment;

2. Summarise the biological information for English sole in the above two combined DFO regions;

3. Conduct quantitative stock assessments for 5CD and 3CD5AB separately to describe current stock status and summarise stock projections relative to selected performance measures.

This report consists of a main document with supporting Appendices A through F that contain detailed analyses supporting the conclusions presented in the main section of the document. A list of the documents and their contents can be found in the text table immediately following. Tables and figures referred to in the main text are sequentially numbered. Tables and figures in appendices are labelled with the letter code of the appendix and a sequential number, e.g., Table B.2 for the second table in Appendix B. Equations presented in the main text are numbered sequentially, as are equations within each appendix.

Description of document components

Document number	**Contents**
Main document	Introduction, summary of the assessment results and recommendations
Appendix A	Biological information used in the assessment
Appendix B	Results of GLM modelling used to generate fishery dependent abundance indices for use in the stock assessment model
Appendix C	Generation of fishery independent survey indices for use in the stock assessment model
Appendix D	Description and modelling results for the delay-difference stock assessment model
Appendix E	Comparison of current decision table results with the equivalent decision tables presented to PSARC (DFO [2007])
Appendix F	Request for Working Paper for updated English sole assessment

STOCK ASSESSMENT FOR 5CD AND 3CD5AB ENGLISH SOLE

Methods

The delay-difference model

The English sole stocks in region 5CD (Hecate Strait) and combined regions 3CD5AB (west coast Vancouver Island and Queen Charlotte Sound) were assessed using a female only delay-difference model fitted to biomass indices derived from fishery catch per unit effort (CPUE) data confined to the areas listed above (Appendix B), to mean fish weight data derived from samples of commercial landings in any area of B.C. (Appendix A), and to relevant survey indices, depending on the stock (Appendix C).

A delay-difference model approach (Appendix D) was adopted for this assessment because, although there are a reasonable number of age samples for 5CD English sole (Appendix A: Table A.6 and Figure A.14), it is not clear whether a statistical catch-at-age model is the best approach to use for assessing the 5CD stock. Previous assessments which used the catch-at-age data adopted the approach of fitting to the port sampled ages but using a growth model tuned to the research age data only, on the assumption that such a growth model is more representative of the entire population (e.g., Fargo et al. 2000). This was also the approach used by Starr et al. (2006) to assess rock sole, an allied species which exhibits a similar level of sexual dimorphism. However, this approach leads to problems which stem from the sorting procedure that operates between the time that the fish are brought up on deck and landed at the fish factory:

- The sampled age distribution reflects the fish that were landed, not the fish that were brought up on the deck. By using a growth model which does not correspond to the landed fish, the statistical catch-at-age model cannot reproduce the mean weights observed in the landed fish. This is demonstrated in Figure A.15, where it is shown that the research-based growth model underestimates the mean weight at landing.
- The statistical catch-at-age model can make up for this bias by increasing the number of fish in the model to match the catch weights. However, such a model is still tuned to the landed age distribution because there is no real information about the selection-at-sea process. Therefore, the selectivities estimated by the catch-at-model will be functionally the same as the knife-edge selectivity used in the delay-difference model, the main difference being that one will be gradual and the other will be more abrupt.
- The other reason to use a statistical catch-at-age model is to obtain information about recruitment based on the relative strengths of the observed year classes. However, this approach requires the assumption that the year classes will be selected by the fishery in the same manner in each year, so that the variation between year classes can be entirely assigned to variations in recruitment strength, rather than changes in the way that fish are selected for the market or other commercial considerations.

The delay-difference approach was used because it was hoped that it would be less affected by the operation of the fishery: effectively saying that a mean weight is possibly less likely to be biased than some of the proportional age compositions. For instance, young ages will contribute relatively little to the mean weight estimate but may be variably selected from year to year and thus increase the process error in the recruitment deviation estimates. Or there may be a trend in selection of smaller fish, which may bias the recruitment estimates.

The delay-difference model adopted for these assessments is explicitly a model of the landings, using a growth model based on port sample ages only and uses landed catches rather than attempting to adjust for discards. This last assumption effectively assumes that the discard rate is constant. However, this assumption must also be made for models which adjust for discards, because there are no useable discard estimates prior to 1996.

The delay-difference model is fundamentally a reduced age-structured model which requires some age information to establish the age for knife-edged recruitment. The delay-difference model assumes that all fish older than this age are vulnerable to the fishery while younger fish do not enter the fishery. This is a simplistic assumption and the often poor model residuals likely reflect the failure of this assumption in some situations. The approach adopted for these assessments has been to generate growth and length-weight parameter estimates outside of the model using the available growth and the length-weight information. This information was then used to establish the most likely age which would result in the observed mean weights in the fishery. This approach reduced the leverage resulting from potential model misspecification when fitting to the mean weight data, a problem that has been criticised by reviewers in previous assessments using this model (e.g., Starr et al. 2006).

The delay-difference approach is also mandatory for the 3CD5AB assessment as there are virtually no biological data available for the 3CD5AB assessment (Table A.6) so the 5CD biological data (growth, mean weights and proportion males) were used to characterise the 3CD5AB assessment.

The stock assessment model used here is similar to the model used by Sinclair and Starr (2005) to assess Pacific cod in Hecate Strait and by Starr et al. (2006) to assess rock sole in Queen Charlotte Sound, with a few exceptions:

- no environmental variable was available to tune the recruitment deviations;
- five year projections using randomly drawn recruitment deviations were used;
- the CPUE indices could be split into multiple series and fitted separately;
- An error was discovered in the code used in previous versions of this delay-difference model (Sinclair et al. 2001, Starr et al. 2002, Starr & Fargo 2004, Sinclair & Starr 2005, Starr et al. 2006) and it was present in the version of this assessment presented to the Groundfish Subcommittee of PSARC in January 2007 (DFO [2007]). This error concerned 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 in the first year of the assessment reconstruction. This error has been corrected in the current version (see Appendix D for a more detailed description of the nature of the error and how it was fixed. A comparison between the decision table results presented in DFO [2007] and Appendix D can be found in Appendix E).

Model inputs

Commercial catch rates were standardised using a generalised linear model (GLM) procedure, (Appendix B), with a separate series stretching from 1966 to 2005 generated for each of 5CD and 3CD5AB. Each assessment used two sets of fishery independent surveys (Appendix C) and each had a separate catch history.

A number of surveys exist which potentially index one of these English sole stocks. These are listed in the text table below, including whether they were used in the assessment, as well as reasons for not using the survey. While survey data were included in the model, they generally had less impact on the results than the CPUE series.

Survey	**Period covered**	**Status & stock**	**Comments**
WCVI Shrimp survey	1975–2006	Not used	Concerned only indexing English sole juveniles; very erratic indices requiring too much process error to be added
WCVI Triennial survey	1980–2001	3CD5AB	Transect survey; treated as if random stratified (discontinued)
QC Sound synoptic	2003–2005	3CD5AB	Good CVs; ongoing survey (Appendix C)
QC Sound shrimp	1999–2006	Not used	Concerned only indexing English sole juveniles; erratic indices
Hecate Strait Pacific cod monitoring survey	2002–2004	5CD	Short time series; designed for Pacific cod; unclear if it will be repeated
Hecate Strait assemblage	1983–2003	5CD	Treated as if a random stratified design (discontinued)

Previous assessments of Canadian groundfish stocks have treated the CPUE series as being consistently proportional to biomass throughout the time period. This assumption is very strong, linking historical catch rates from the 1960s and 1970s to the present by assuming that the catchabilities have not changed over the entire period. This assumption is particularly tenuous in the most recent 10 years, when most commercially important species have had TAC caps and there has been 100% observer coverage which forces every vessel to account for all catch and bycatch by species. This is in marked contrast with the earliest years (the 1960s and 1970s), when there were little effective management constraints. Later on, trip limits by species and other management tools were applied which would likely affect catch rates. In an attempt to acknowledge the existence of these changes, this model has the capacity to fit multiple CPUE series, estimating separate catchability parameters for each series. This capacity was investigated by splitting the CPUE series between 1995/96 and 1996/97. This is one year prior to the establishment of the current transferable quota system, but it is also is when a high level (100 %) of mandatory observer coverage was introduced. The split was moved as far back in time as was reasonable to make the second part of the series as long as possible. It was felt that this approach should work well in the context of the delay-difference model because this model treats the mean weight as absolute (i.e. total annual biomass divided by number of vulnerable fish), thus not allowing large changes in biomass at the period of the split.

Each stock assessment investigated the following factors which contribute to the overall uncertainty through a series of six alternative model runs for 5CD and four model runs for 3CD5AB (listed in Table 1), each of which incorporated various aspects of the hypotheses listed below:

1. the effect of using a single or split CPUE series to describe the relationship between the catch and abundance. A split series recognises that changes in the management of the fleet has affected the proportion of the biomass which is taken by the fleet;
2. the effect of estimating or fixing the *M* parameter. An informed Bayesian prior was applied to the *M* parameter when it was estimated and the weight data were not fitted when *M* was fixed at its preferred value of 0.2;
3. the age of knife-edge recruitment was tested by fitting models using growth models based on a knife-edge recruitment age (*r*) of r=4 or r=5 (this was only done in the 5CD assessment)

Stock assessment projections

A Bayesian approach, based on the Markov Chain Monte Carlo (MCMC) algorithm (Gelman et al. 1995), was used to estimate the joint posterior distributions of model parameters and to make projections for five years from 2007 to 2011 across a range of fixed catch options. None of the 10 investigated model runs (Table 1) exhibited poor MCMC convergence behaviour, given the search made of parameter space using 40×10^6 sample iterations (sampled once in every 20,000 iterations).

Five year projections were made from the posterior distribution of the terminal biomass with recruitments drawn randomly from a distribution in log-space of mean=0 and standard deviation=0.4 (which is the assumption for recruitment variation during the fitting phase). The projections are made starting from the 2007 beginning year biomass across a number of fixed catch options, ranging from 0 to 1000 t in 100 t steps for the 5CD assessment and from 0 to 400 t in 50 t steps for the 3CD5AB assessment. The resulting biomass levels for each year from 2008 to 2012 were evaluated against four performance indicators to generate a decision tables that can be used to provide management advice.

The performance indicators selected for this stock assessment are:

1. Exploitation rate in 2007–2011 relative to the average exploitation rate from 1966 to 2006 $\left(U_{ref} = \text{mean}\{U_t\}_{t=1966}^{2006}\right)$;

2. Beginning year biomass in 2008–2012 compared to the minimum biomass over the 1966-2006 period $\left(B_{ref} = \min\{B_t\}_{t=1966}^{2006}\right)$;

3. Beginning year biomass in 2008–2012 compared to the average biomass from one of two periods: $\left(B_{ref} = \text{mean}\{B_t\}_{t=startref}^{endref}\right)$, where *startref*=1978 for 5CD and *startref*=1974 for 3CD5AB; and *endref*=1988 for 5CD and *endref*=1986 for 3CD5AB. Each of these periods was selected as being of relative stability from which the stock has declined and recovered;

4. Beginning year 2008–2012 biomass compared to the beginning year biomass in 2007 $\left(B_{ref} = B_{2007}\right)$.

Two quantities were calculated for the three performance indicators that reference biomass levels (indicators 2, 3 and 4):

1. The cumulative probability that each draw from the MCMC posterior distribution would exceed one of the three biomass reference levels in year *y*: $\text{P}\left(\tilde{B}_y > B_{ref}\right)$;

2. The expected value from the MCMC posterior distribution of the ratio of the biomass in year *y* relative to one of the three biomass reference levels: $\text{E}\left(\tilde{B}_y / B_{ref}\right)$;

Only the cumulative probability in year 2011 that the exploitation rate would be below the reference exploitation was calculated for the first performance indicator $\text{P}\left(U_{2011} < U_{ref}\right)$.

These performance measures are based on management targets selected from the historical biomass trajectory. Such management targets are necessarily arbitrary but are preferred in this instance over model-based reference points that use model-based derived parameters such as B_0 or B_{MSY} because these latter parameters are usually poorly estimated, being very sensitive to model assumptions for parameters that are difficult to estimate, such as *M* or *h*. B_0 and B_{MSY} are also sensitive to the relative weighting among catch, average fish weight, or survey indices, and often change over time as more data are added to the analysis or as the stock assessment model evolves, while historical management targets tend to be more stable because they are defined as relative targets.

The B_{min} reference point does not work well for series where the biomass trend is continuously downward because the minimum does not reference anything of importance to the stock. The B_{min} reference point should be a level from which the stock subsequently recovers to a level above the B_{ref} reference point. This is the case for both the 5CD and the 3CD5AB assessments, even for the model runs that assume a single CPUE series. The main problem with the B_{min} reference point as applied to these two stocks is that the contrast between the high and low points of both stocks is low, especially for 3CD5AB. Therefore, it is likely that the minima reported in these assessments are conservative, in that very low relative stock sizes have not occurred for these stocks.

Another advantage of using reference points which are based on a historical period is that such reference levels are more comprehensible to stakeholders and there frequently exists institutional memory of these periods. In addition, there is always the option of changing the reference period if, once attained, it seems for some reason to be unsuitable.

Table 1. Mean exp(recruitment_deviations) for the entire series and the most recent 10 years from the MPD fits for each of the 10 runs presented in this assessment. Detailed descriptions of each of these model runs, including the hypotheses tested and assumptions can be found in Appendix D.

Run Number	Run description	$e^{\left(\frac{\sum_{t=1966}^{t=2006-r+1}(\phi_t)}{\left[(2006-r+1)-1966\right]}\right)}$	$e^{\left(\frac{\sum_{t=2006-r-9}^{t=2006-r+1}(\phi_t)}{\left[(2006-r+1)-(2006-r-9)\right]}\right)}$
5CD assessment			
Case 1	single CPUE series | $r = 4$ | est M	1.000	0.977
Case 2	single CPUE series | $r = 5$ | est M	1.000	0.946
Case 3	single CPUE series | $r = 5$ | fix M	1.000	0.947
Case 4	split CPUE series | $r = 4$ | est M	1.000	1.049
Case 5	split CPUE series | $r = 5$ | est M	1.000	0.996
Case 6	split CPUE series | $r = 5$ | fix M	1.000	0.960
3CD5AB assessment			
Case 7	single CPUE series | $r = 5$ | est M	1.000	0.981
Case 8	single CPUE series | $r = 5$ | fix M	1.000	0.991
Case 9	split CPUE series | $r = 5$ | est M	1.000	1.090
Case 10	split CPUE series | $r = 5$ | fix M	1.000	1.062

Results

5CD stock assessment

Appendix D provides decision tables showing the probabilities for each performance indicator and the expected values for the biomass performance indicators for the six 5CD model runs (Table D.6 to Table D.9) at catch levels that range from 0 to 1000 t per year in 100 t steps.

Two of the three sources of model uncertainty investigated in the 5CD assessment appear to be relatively unimportant while the third source is difficult to resolve on the basis of the available data. The two sources of uncertainty which are relatively unimportant within the context this stock assessment model are a) the choice of the age of knife-edge recruitment between age 4 and age 5; and b) whether M is fixed at a value of 0.20 (and the mean weight data are discarded) or estimated using an informed prior with mean 0.20 and standard deviation of 0.20 as well as including the mean weight data. Fixing M=0.20 is like specifying an extremely tight informed prior, with no variation allowed around this value. For this latter reason, the models which estimate M are likely preferable to the fixed M models because they allow additional uncertainty relative to the model runs which do not estimate this parameter. Examples of the lack of sensitivity to these two sources of uncertainty can be seen when comparing the cumulative probabilities of $\mathrm{P}\left(B_{2012} > \mathrm{mean}\left\{B_t\right\}_{t=1978}^{1988}\right)$ for model runs which only differ in how M is estimated while holding the other factors constant (Figure 3) or in the value used for r, again holding the other factors constant (Figure 4). The cumulative curves for different r values or M estimation methods nearly lie on top of each other, indicating that the management advice arising from these model runs would also be nearly identical. Comparisons between the same runs based on the other two biomass performance measures have similar outcomes, with the management advice being similar across the same runs { $\mathrm{P}\left(\tilde{B}_y > \min\left\{B_t\right\}_{t=1966}^{2006}\right)$: Figure 5 and Figure 6}; { $\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$: Figure 7 and Figure 8}.

The other source of model uncertainty has a much greater effect. This source stems from the decision to use a single CPUE series or split the series into two in recognition of the changes in management that were instituted in 1996 and 1997. Examples of the greater sensitivity to this source of uncertainty can be seen from the same graphs: the $\mathrm{P}\left(B_{2012} > \mathrm{mean}\left\{B_t\right\}_{t=1977}^{1984}\right)$ cumulative curve for the single CPUE series is shifted well to the left of the equivalent curves for the split CPUE series (Figure 3 and Figure 4). The effect is less marked for the $\mathrm{P}\left(\tilde{B}_y > \min\left\{B_t\right\}_{t=1966}^{2006}\right)$ cumulative curves because the probabilities of staying above the B_{min} reference point are much higher (Figure 5 and Figure 6). Nevertheless, the single CPUE curves are still to the left of the split CPUE curves. The situation changes with the $\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$ cumulative curves, with the split CPUE model runs lying to the left of the single CPUE runs (Figure 7 and Figure 8). Examination of the biomass trajectories for these runs shows the single CPUE runs tending upwards while the split CPUE runs have generally flat projections, thus accounting for the relative differences in probabilities (Figure D.37 to Figure D.42).

The cumulative probability curves for the single and split CPUE model runs are divergent, indicating that different management advice would be given, depending on which approach is preferred. However, the assumption of constant catchability over a forty-year period is very strong and it seems more likely that catchability has changed over time, given the changes that have occurred in the past 40 years. However, the problem is deciding in which direction has the change been made. Many of the changes in gear technology, including sounders, GPS and other electronic devices would make the fleet more efficient in terms of catchability. On the other hand the model estimates that catchability has dropped, presumably as a result of the severe management curtailments that have been instituted since 1996.

The probabilities that the stock will increase are less optimistic than the stock staying above the B_{min} and B_{ref} reference points, with predictions of stock decline at landed catch values about 100 t higher than the current TAC (Figure 7 and Figure 8). So while the 5CD stock is predicted, at catch levels that exceed the current TAC, to stay above the selected reference points with a greater than 50% probability, regardless of whether a single or a split CPUE series is assumed, some of the split CPUE runs predict that stock will decline in size over the next five years at landings equivalent to the current TAC.

The probabilities for the beginning year biomass in 2012 for each run and performance indicator are given for female landings equivalent to the current TAC of 500 t in Table 2. The equivalent expected values for the biomass indicators are also provided in this table. These runs are arranged in pairwise fashion where every paired comparison that can be made is shown side-by-side so that the specific differences can be seen. This table provides the exact probabilities for comparison at the current TAC and at the end of the 5 year projections for each performance indicator. All the conclusions presented above are confirmed: the method of dealing with M and the age at knife-edge recruitment have small effects compared to the differences generated by the number of CPUE series assumed in the model. There are a few model runs where the *M* estimation method makes a difference. For instance, $\mathrm{P}\left(B_{2012} > B_{2007}\right)$ for the "CPUEx2_*r*=5" is much greater for the run which fixes *M* than the run which estimates *M* (Table 2).

The 5CD assessment appears to be reasonably credible in that it is based on a large amount of biological information and there has been a long and consistent catch history for this stock. However, the biomass trend is primarily determined by the CPUE series, which may not be a reliable indicator of the abundance for this stock. The model fit to the Hecate Strait assemblage survey is poor, with the survey showing a stronger recovery than the CPUE series, which the model does not fit adequately (Figure D.1 to Figure D.4). This is caused by the large amount of process error which is added to fit the survey series consistently with the other data sets but which discounts its effect, probably due to the anomalous high index observed in 1993 (Figure C.11). These issues reduce the credibility of this 5CD assessment, but are a consequence of the lack of a long-term set of biomass indices based on fisheries independent research and the lack of consistency between the available data sets.

3CD5AB stock assessment

Appendix D provides decision tables showing the probabilities for each performance indicator and the expected values for the biomass performance indicators for the four 3CD5AB model runs (Table D.10 and Table D.11) at catch levels that range from 0 to 500 t per year in 50 t. A projection at catch level 175 t is also provided because this is equivalent to the female landings that could be taken under the current TAC.

The lack of sensitivity to the method of dealing with the *M* parameter is not as marked in this assessment, with some consistent differences between runs based on the *M* estimation methodology. For instance the two runs which fix *M* are shifted to the left of the runs which estimate *M* for the $\mathrm{P}\left(B_{2012} > \mathrm{mean}\left\{B_t\right\}_{t=1974}^{1986}\right)$ cumulative curve (Figure 9) and the $\mathrm{P}\left(\tilde{B}_y > \min\left\{B_t\right\}_{t=1966}^{2006}\right)$ cumulative curves (Figure 10). All the runs, no matter how *M* is estimated or whether it is a single or split CPUE series, predict a low probability for $\mathrm{P}\left(B_{2012} > B_{2007}\right)$ cumulative curve at levels of removal equivalent to the current TAC (Figure 11).

The predictions made by this stock assessment are always more pessimistic for the single CPUE model runs than for the equivalent split CPUE model runs (see Figure 9 and Figure 10), with the single CPUE cumulative curves for the $\mathrm{P}\left(B_{2012} > \mathrm{mean}\left\{B_t\right\}_{t=1974}^{1986}\right)$ and the $\mathrm{P}\left(\tilde{B}_y > \min\left\{B_t\right\}_{t=1966}^{2006}\right)$ reference points shifted well to the left of the equivalent split CPUE curves. This arises because there are clear differences between the split and single CPUE model runs. The split CPUE model runs indicate that the current TAC is about right, with a high probability of staying above the B_{min} reference point (P=0.88 and 0.85) and about a 50% probability (P=0.57 and 0.47) of staying above the B_{ref} reference point (Table 3). However, the equivalent single CPUE runs indicate that the current TAC is too high, with P=0.62 probability of staying above the B_{min} reference point and a very low (P=0.17) probability going above B_{ref} reference point (Table 3). Therefore, it is important to choose which of these alternative hypotheses is the more credible. As discussed for the 5CD stock assessment, it seems unlikely that catchability has remained constant. But there are logical reasons that catchability after the split could have increased or decreased relative to the catchability prior to the split. Both the 5CD and the 3CD5AB models are consistent in estimating that catchability has declined by 30-40% between the two series, indicating that, based on these model assumptions and using the assembled data, the result is a decrease in the overall catchability. This result is consistent with the hypothesis that recent management changes have intervened sufficiently to reduce the overall effectiveness of the fleet to capture fish. Simple TAC constraints may not necessarily achieve this result, but there has also been a substantial change in the total number of vessels operating, which could reduce the overall effect of the fleet

The probabilities that the stock will increase are very low for all the runs. The reason for this is that the mean landings from 1966 to 2005 are only 150 t (Figure 2), less than the current TAC, particularly after adjusting for the small component of male catch. The projections are made by drawing from a distribution centred at the average recruitment. This implies that the probability of stock increasing under catches which are higher than the long term average is low, unless there are strong recent recruitments. However, the biomass trajectories are nearly flat (Figure D.43 to Figure D.46), indicating that recruitment has been about average in recent years.

This assessment is less credible than the 5CD assessment because it is based on biological data taken from the 5CD stock. If Hecate Strait is near the northern limit of distribution for this species (Fargo et al. 2000), then it is possible that using the 5CD growth model will underestimate growth for this more southern stock. As well, the lack of contrast in the CPUE series means that the model derives very little information from the data and that what is being tracked in this assessment is noise rather than a real signal. Finally, the NFMS Triennial survey shows a strong upward trend which is ignored by this assessment, largely because it has been downweighted relative to the CPUE series which is treated as a more credible (and long term) information source.

Limitations of this stock assessment

There are insufficient survey data available to serve as fishery-independent abundance indices for population dynamics modelling, and the surveys which are available with longer time series (WCVI shrimp, WCVI triennial and Hecate Strait assemblage) are highly variable between years, indicating that there is a large amount of process error which reduces their capacity to contribute to the assessment model. The WCVI shrimp survey in particular had so much process error that it was dropped after attempting a number of initial fits. Therefore the CPUE series derived from trawl fishery catch rates is the primary source of stock abundance information in these runs. But there are serious problems with relying on fishery dependent information to assess stock status. For instance, we are generating abundance indices for a single species from commercial data which are likely confounded by the complex multi-species components of this fishery. Management restrictions imposed on other species, especially the necessity to “avoidance fish” because of reaching limits for any number of species, will affect the catch rates. This is in addition to market requirements which will affect targeting behaviour as well as the size of the bags being brought on board. It is now well accepted that restrictions on the catch of Pacific cod in Hecate Strait have affected the catch rates of allied species in the same area since the restrictions were imposed in 2001. In addition, the GLM analyses presented in this paper have not attempted to account for technological improvements over time in fishing gear or vessel electronics (e.g., colour plotters, GPS and other navigational aids) which may cause hyperstability of catch rates due to increased efficiency. But there is little alternative to the use of these catch rates if a stock assessment is to be prepared for any of these species.

The decision tables provided in this paper give guidance to the selection of short-term TAC recommendations and describe a range of possible future outcomes over the projection period at fixed levels of annual catch. The accuracy of the projections is predicated on the model being correct. Uncertainty in the parameters is explicitly addressed using the Bayesian approach but this only reflects the specified model, including the weights assigned to the various data components. Projection accuracy also depends on highly uncertain future recruitment values and the adoption of static harvest policies. For instance, it is likely that the data and the stock assessment will be updated during the time period covered by the projections which in turn would lead to different levels of catch through revised decision tables. A simple projection based on the assumption of a fixed catch policy provides an evaluation of alternative management decisions without any form of feedback. More complex feedback management evaluations are potentially possible but are beyond the scope of this analysis. However, there is value in continuing with this type of analysis in the short term because it can identify possible approaches that can be expanded into the more complex formal feedback evaluations. Analyses such as this one also can identify the strengths and weaknesses of the available data.

Data limitations and research priorities

The following issues should be considered when planning future stock assessments and management evaluations for English sole.

1. There should be a general ageing review for flatfish species: it appears that the current practise is to use port samples to provide ages to monitor the fishery. However, there is a major process of sorting which occurs at sea, with a large proportion of several flatfish species being discarded. This is especially true for species which exhibit sexual dimorphism, such as rock sole and English sole, because most males are discarded for being commercially too small. The entire system of flatfish data collection should be reviewed and possibly updated to reflect current management requirements.

2. Single species stock assessments are limited in value when considered in the context of multi-species nature of the fisheries which take these species. More thought should be given to how to progress the management of the species suites that are taken in the B.C. trawl fleet and what information needs to be collected to accomplish this management.

3. Continue the fishery-independent surveys for regions 3CD, 5AB, and 5CD to reduce the dependency on fishery CPUE data for English sole.

4. While the delay-difference stock assessment model has some advantages because it makes fewer demands for high quality data compared to statistical catch-at-age models, the properties of this model are not well understood. Further use of this model to assess fish stocks should be preceded by simulation modelling to demonstrate the capacity of this methodology to evaluate stock status.

Summary and Recommendations

1. Stock assessments have been prepared for English sole from 5CD (Hecate Strait) and from the combined west coast Vancouver Island/Queen Charlotte Sound (3CD5AB). Six model runs were made for 5CD and four for 3CD5AB which explored alternative methods for estimating *M*, different ages of knife-edge recruitment, and two hypotheses regarding CPUE: a single continuous series over the last forty years and a series that changes catchability coincident with the major changes in management which took place in 1996 and 1997.

2. The stock assessment modelling explored alternative procedures for dealing with the *M* parameter and the mean weight data, alternately fixing *M* to a value of 0.20 and dropping the mean weight data or estimating *M*, constrained by an informed Bayesian prior and including the mean weight data. Comparison of models fitted in each of these ways showed that there was little difference between these two alternatives in terms of the relative performance of the performance indicators across the range of the other investigated assumptions for the 5CD assessment and some minor differences between *M* estimation methods in the 3CD5AB assessment.

3. Very little difference in model predictions were found between the two ages for knife-edged recruitment investigated in the 5CD assessment (age 4 and age 5). These two ages were selected because a comparison of the mean weight data from the fishery with the theoretical mean weight of an unexploited population, given a fixed value for M=0.20, was more in line with knife-edge recruitment age r=4 or r=5. The low sensitivity of the assessment to these two ages of recruitment and to the method for *M* estimation demonstrates that these specifications for the model are probably reasonably correct.

4. The stock assessment also investigated using the CPUE series as either a single series driven by one catchability parameter, implying a constant relationship between the fishery and abundance over the 40 year period in the model, or splitting the CPUE series between 1995/96 and 1996/97 in recognition of the major changes in the management of the fishery that took place in the mid-1990s. The assessments using the single CPUE series were more pessimistic than the assessments based on the split series, resulting in a strong shift in the relative performance measures when these were compared. Model estimates of *q* for the second series were about two-thirds of the estimates for the first part of the series, implying that the current fishery is less effective at harvesting this species. The choice between a single or split CPUE series hypothesis is dependent on whether it is reasonable to conclude that the fishery is presently less effective than previous. It is suggested that the analysis of a single species taken within the context of a complex multi-species fishery with conflicting objectives may result in an apparent decline in catchability for that species.

5. Ten model runs for two separate stock assessments were made to investigate three alternative pairs of uncertainties. Of these, the effect of estimating *M* and the age of knife-edge recruitment is small compared to the overall uncertainty of the assessment. It is recommended that the decision tables using knife-edge recruitment age r=5 and the "estimate *M*" options be used to form management recommendations. The "split CPUE" runs explicitly address recent management changes in the context of the stock assessment model, and it is recommended that the runs using this option be used to form management recommendations, dependent on whether it is considered credible that catchability has declined in the most ten years.

6. The recommended assessment run for 5CD (`CPUEx2_r=5_estM`) predicts that the stock will stay well above the B_{min} and B_{ref} performance measures at the current TAC. Higher catch levels than the current TAC are also predicted to remain above these reference levels with a greater than 50% probability. However, this model run also predicts that the stock size will decline over the next five years at landings higher than the current TAC. The credibility of the 5CD stock assessment is dependent on the reliability of CPUE to index the abundance of this stock because this model does not fit the Hecate Strait survey biomass indices very well.

7. The recommended run for 3CD5AB (`CPUEx2_r=5_estM`) predicts that the stock will stay above the B_{min} and B_{ref} performance measures with a greater than 50 % probability at the current TAC but this probability drops below 50 % at landings only slightly greater than the current TAC. This model run also predicts that the stock size will decline over the next five years at the current TAC. It was also concluded that this assessment model is less credible than the 5CD assessment model because it relies on 5CD biological data (which may not be appropriate), does not fit the Triennial survey data very well and is based on a CPUE series which shows little contrast.

8. The reliance of these stock assessments on fishery dependent data is a serious weakness as it is likely that many considerations other than stock abundance will cause changes in the "abundance" index. The available survey data show large amounts of between-year variability, implying a large amount of process error which reduce the usefulness of these data in the model. Finally, the decision tables which are the centre of the management advice in this paper assume constant catch strategies without any form of feedback into the process. As such, these decision tables are only useful for comparing potential alternative management strategies at the present time and should not be taken as an actual prediction of the next five years.

9. Considerable uncertainty surrounds much of the available biological and fishery data for English sole and other flatfish species. In particular, the practise of taking the majority of the ageing structures from landed fish should be reviewed in the context of an overall strategy for sampling flatfish in B.C. It may be that ages need to be collected both at-sea and in ports to properly characterise these fisheries.

10. The delay-difference model should be simulation tested to better understand its behaviour before it is used again in a B.C. groundfish stock assessment.

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Table 2. Pairwise comparisons of probabilities associated with the four performance indices and expected values for three performance indices across related 5CD runs (Table 1) in projection year 2011 after applying the current TAC (500 t) for 5 years. Each block of runs compares the probabilities across a single pair of factors while holding the other two factors constant. A complete set of decision tables for all runs and levels of catch for the four performance indicators is provided in Appendix D.

5CD	**Probabilities**							
Factors held constant:	$P\left(U_{2011} < \text{mean}\{U_t\}_{t=1966}^{2006}\right)$		$P\left(B_{2012} > \min\{B_t\}_{t=1966}^{2006}\right)$		$P\left(B_{2012} > \text{mean}\{B_t\}_{t=1978}^{1988}\right)$		$P\left(B_{2012} > B_{2007}\right)$	
Estimate or fix *M*:	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***
CPUEx1_*r*=4	0.91	–	0.99	–	0.64	–	0.68	–
CPUEx1_*r*=5	0.88	0.86	0.99	0.99	0.69	0.68	0.70	0.73
CPUEx2_*r*=4	1.00	–	1.00	–	0.97	–	0.46	–
CPUEx2_*r*=5	0.99	0.98	1.00	1.00	0.96	0.94	0.50	0.63
Age of knife-edge recruitment:	***r*=4**	***r*=5**	***r*=4**	***r*=5**	***r*=4**	***r*=5**	***r*=4**	***r*=5**
CPUEx1_estM	0.91	0.88	0.99	0.99	0.64	0.69	0.68	0.70
CPUEx1_fixM	–	0.86	–	0.99	–	0.68	–	0.73
CPUEx2_estM	1.00	0.99	1.00	1.00	0.97	0.96	0.46	0.50
CPUEx2_fixM	–	0.98	–	1.00	–	0.94	–	0.63
Number of CPUE series	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**
r=4 _estM	0.91	1.00	0.99	1.00	0.64	0.97	0.68	0.46
r=5 _estM	0.88	0.99	0.99	1.00	0.69	0.96	0.70	0.50
r=5_ fixM	0.86	0.98	0.99	1.00	0.68	0.94	0.73	0.63

		Expected value					
Factors held constant:		$E\left(B_{2012}/\min\{B_t\}_{t=1966}^{2006}\right)$		$E\left(B_{2012}/\text{mean}\{B_t\}_{t=1978}^{1988}\right)$		$E\left(B_{2012}/B_{2007}\right)$	
Estimate or fix *M*:		**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***
CPUEx1_*r*=4		1.57	–	1.08	–	1.09	–
CPUEx1_*r*=5		1.79	1.79	1.15	1.14	1.13	1.16
CPUEx2_*r*=4		1.75	–	1.39	–	1.00	–
CPUEx2_*r*=5		1.83	1.94	1.43	1.51	1.03	1.09
Age of knife-edge recruitment:		***r*=4**	***r*=5**	***r*=4**	***r*=5**	***r*=4**	***r*=5**
CPUEx1_estM		1.57	1.79	1.08	1.15	1.09	1.13
CPUEx1_fixM		–	1.79	–	1.14	–	1.16
CPUEx2_estM		1.75	1.83	1.39	1.43	1.00	1.03
CPUEx2_fixM		–	1.94	–	1.51	–	1.09
Number of CPUE series		**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**
r=4 _estM		1.57	1.75	1.08	1.39	1.09	1.00
r=5 _fixM		1.79	1.83	1.15	1.43	1.13	1.03
r=6_wide_fixM		1.79	1.94	1.14	1.51	1.16	1.09

Table 3. Pairwise comparisons of probabilities associated with the four performance indices and expected values for three performance indices across related 3CD5AB runs (Table 1) in projection year 2011 after applying the current TAC (175 t) for 5 years. Each block of runs compares the probabilities across a single pair of factors while holding the other two factors constant. A complete set of decision tables for all runs and levels of catch for the four performance indicators is provided in Appendix D.

3CD5AB	**Probabilities**							
Factors held constant:	$P\left(U_{2011} < \text{mean}\{U_t\}_{t=1966}^{2006}\right)$		$P\left(B_{2012} > \min\{B_t\}_{t=1966}^{2006}\right)$		$P\left(B_{2012} > \text{mean}\{B_t\}_{t=1974}^{1986}\right)$		$P\left(B_{2012} > B_{2007}\right)$	
Estimate or fix *M*:	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***
CPUEx1_*r*=5	0.02	0.01	0.70	0.57	0.21	0.14	0.39	0.33
CPUEx2_*r*=5	0.07	0.07	0.94	0.85	0.62	0.45	0.29	0.26
Number of CPUE series	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**
r=5_estM	0.02	0.07	0.70	0.94	0.21	0.62	0.39	0.29
r=5_fixM	0.01	0.07	0.57	0.85	0.14	0.45	0.33	0.26

			Expected value			
Factors held constant:		$E\left(B_{2012}/\min\{B_t\}_{t=1966}^{2006}\right)$		$E\left(B_{2012}/\text{mean}\{B_t\}_{t=1974}^{1986}\right)$		$E\left(B_{2012}/B_{2007}\right)$
Estimate or fix *M*:		**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***
CPUEx1_*r*=5		1.14	1.07	0.86	0.78	0.97	0.93
CPUEx2_*r*=5		1.39	1.35	1.08	0.99	0.93	0.90
Number of CPUE series		**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**	**CPUEx1**	**CPUEx2**
r=5_estM		1.14	1.39	0.86	1.08	0.97	0.93
r=5_fixM		1.07	1.35	0.78	0.99	0.93	0.90

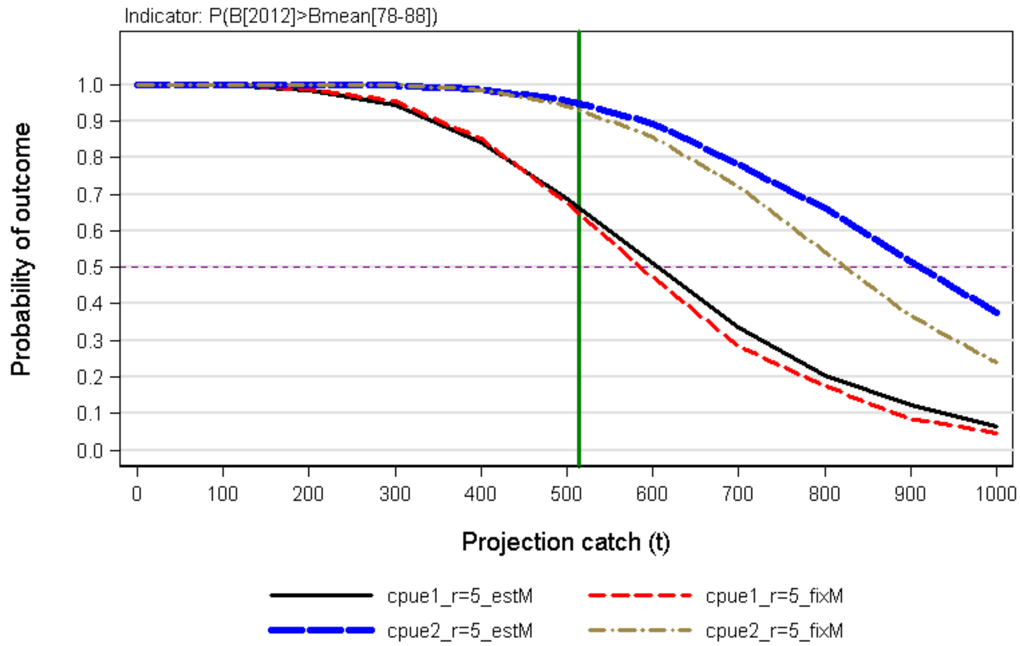


Figure 3. 5CD: Comparison of the probability of exceeding B_{ref} for four runs with knife-edge recruitment at age 5: single CPUE series: estimate *M* (`cpue1_r=5_estM`) and fix *M* (`cpue1_r=5_fixM`); split CPUE series: estimate *M* (`cpue2_r=5_estM`) and fix *M* (`cpue2_r=5_fixM`). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

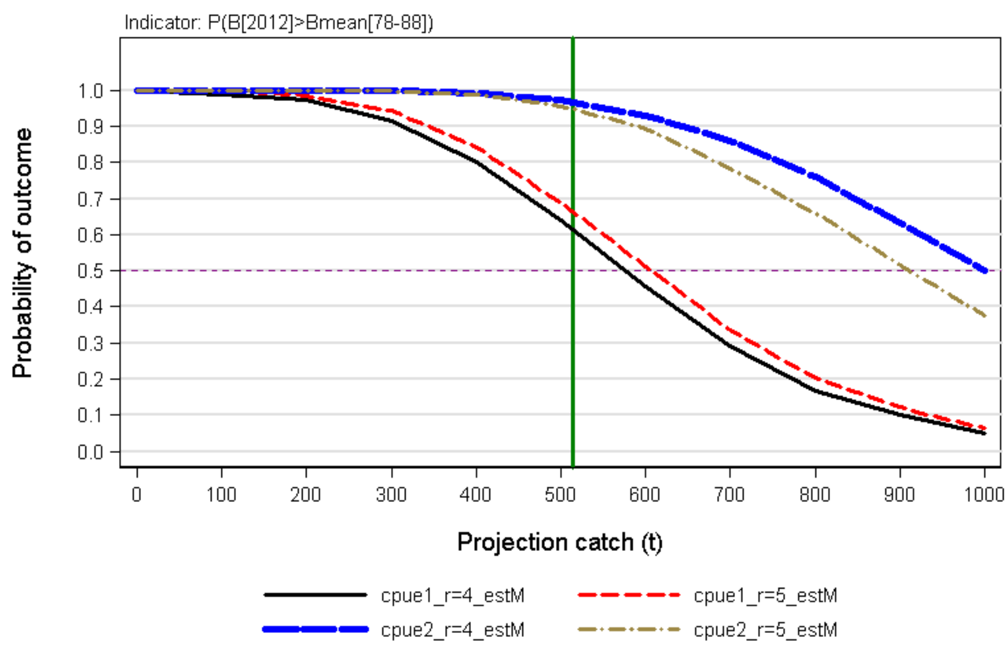


Figure 4. 5CD: Comparison of the probability of exceeding B_{ref} for four runs which estimate *M*: knife-edge recruitment at age 4: single CPUE series (`cpue1_r=4_estM`) and split CPUE series (`cpue2_r=4_estM`); knife-edge recruitment at age 5: single CPUE series (`cpue1_r=5_estM`) and split CPUE series (`cpue2_r=5_estM`). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

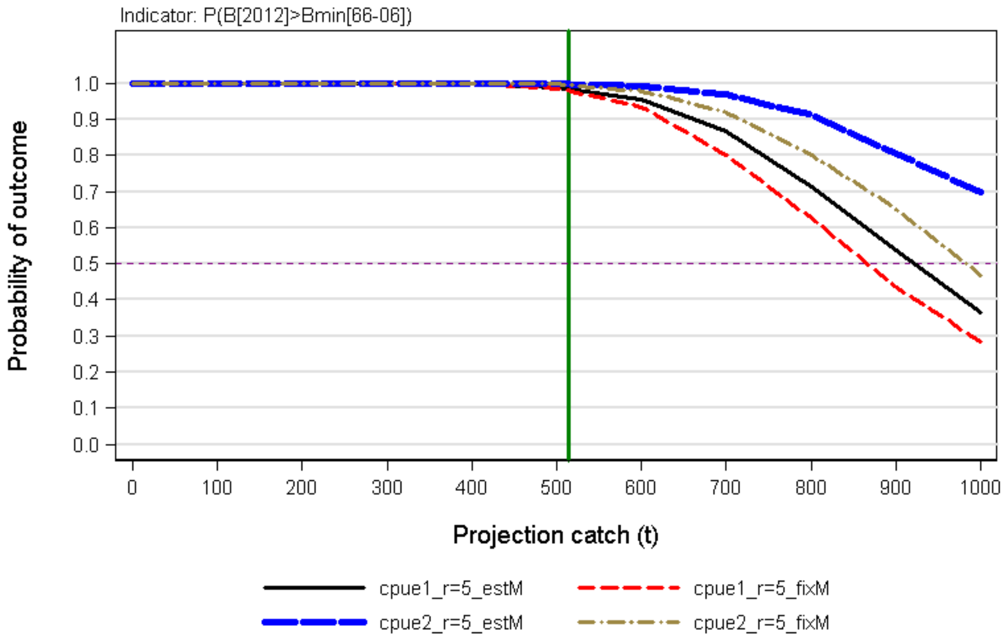


Figure 5. 5CD: Comparison of the probability of exceeding B_{min} for four runs with knife-edge recruitment at age 5: single CPUE series: estimate *M* (`cpue1_r=5_estM`) and fix *M* (`cpue1_r=5_fixM`); split CPUE series: estimate *M* (`cpue2_r=5_estM`) and fix *M* (`cpue2_r=5_fixM`). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

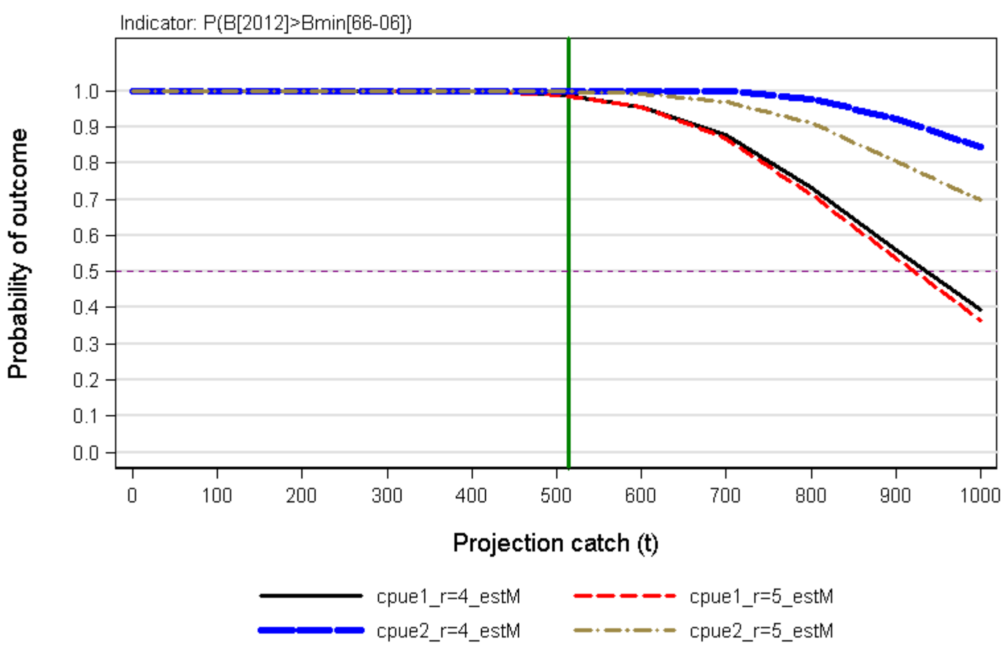


Figure 6. 5CD: Comparison of the probability of exceeding B_{min} for four runs which estimate *M*: knife-edge recruitment at age 4: single CPUE series (`cpue1_r=4_estM`) and split CPUE series (`cpue2_r=4_estM`); knife-edge recruitment at age 5: single CPUE series (`cpue1_r=5_estM`) and split CPUE series (`cpue2_r=5_estM`). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

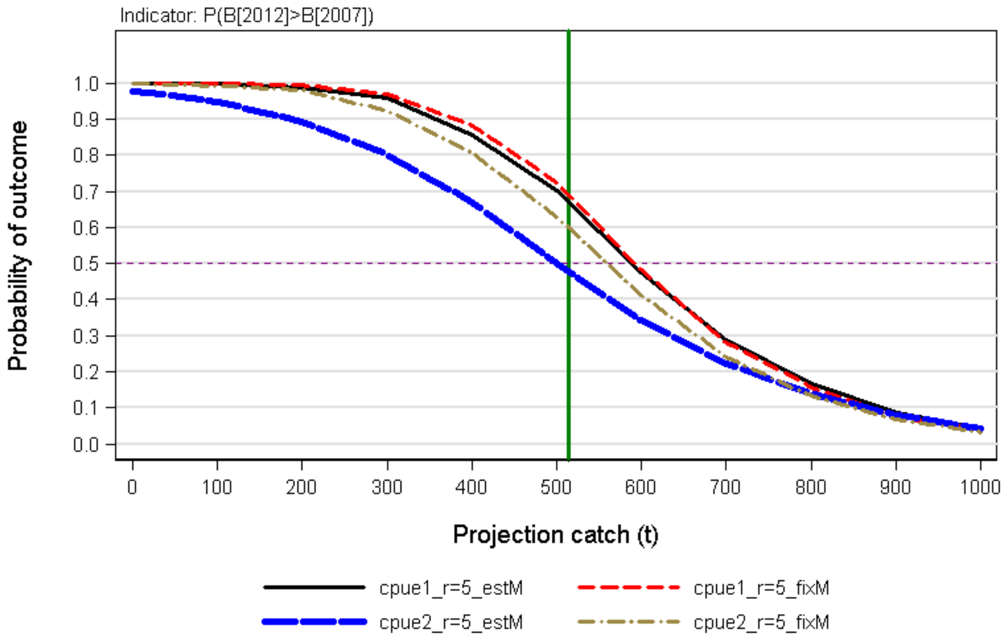


Figure 7. 5CD: Comparison of the probability of B_{2012} exceeding B_{2007} for four runs with knife-edge recruitment at age 5: single CPUE series: estimate *M* (`cpue1_r=5_estM`) and fix *M* (`cpue1_r=5_fixM`); split CPUE series: estimate *M* (`cpue2_r=5_estM`) and fix *M* (`cpue2_r=5_fixM`). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

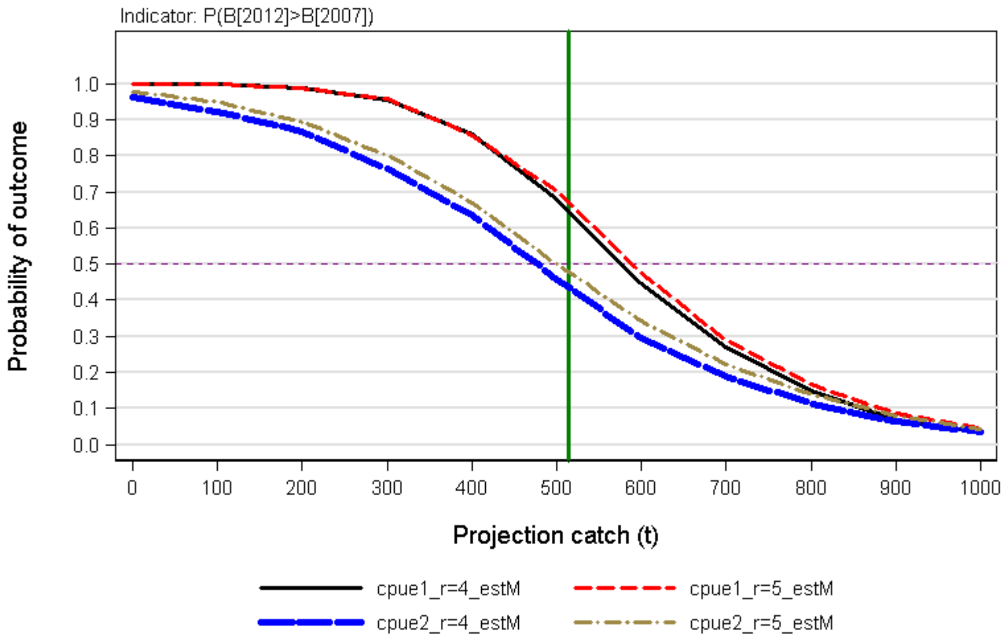


Figure 8. 5CD: Comparison of the probability of B_{2012} exceeding B_{2007} for four runs which estimate *M*: knife-edge recruitment at age 4: single CPUE series (`cpue1_r=4_estM`) and split CPUE series (`cpue2_r=4_estM`); knife-edge recruitment at age 5: single CPUE series (`cpue1_r=5_estM`) and split CPUE series (`cpue2_r=5_estM`). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

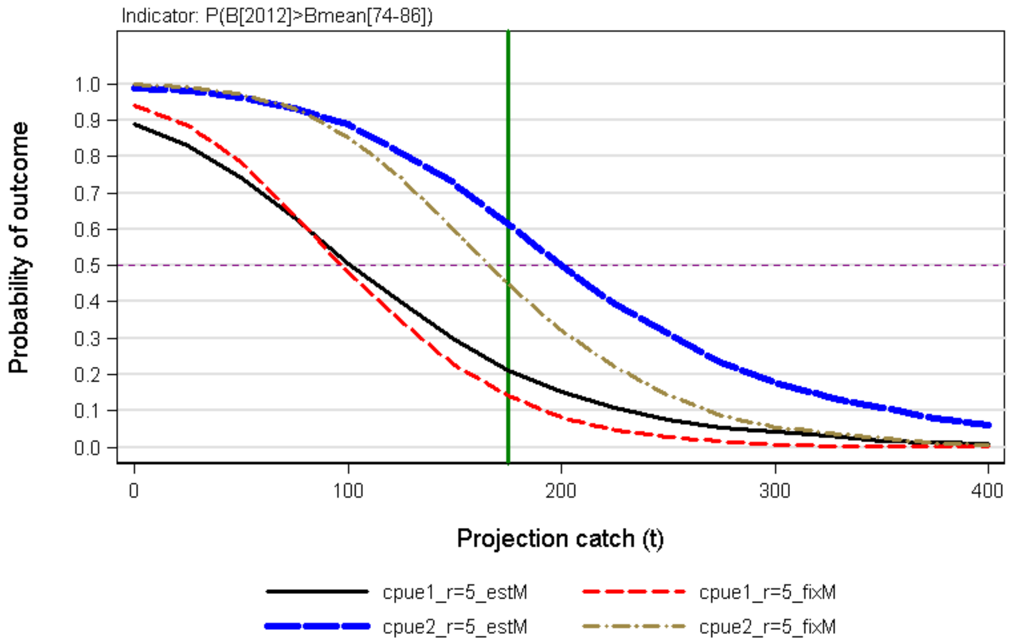


Figure 9. 3CD5AB: Comparison of the probability of exceeding B_{ref} for four runs with knife-edge recruitment at age 5: single CPUE series: estimate *M* (`cpue1_r=5_estM`) and fix *M* (`cpue1_r=5_fixM`); split CPUE series: estimate *M* (`cpue2_r=5_estM`) and fix *M* (`cpue2_r=5_fixM`). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

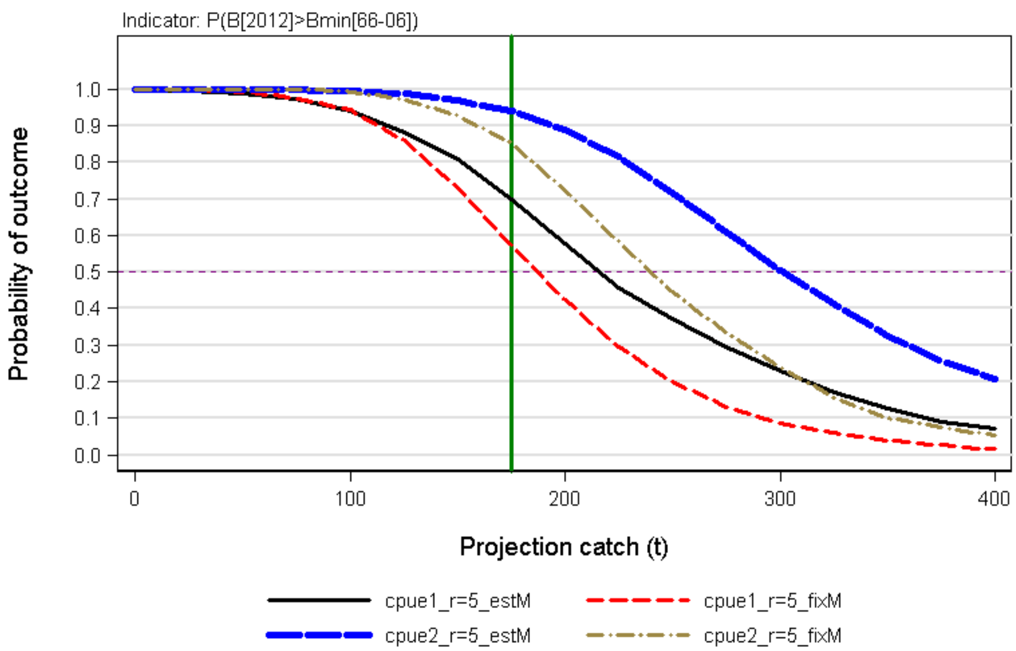


Figure 10. 3CD5AB: Comparison of the probability of exceeding B_{min} for four runs with knife-edge recruitment at age 5: single CPUE series: estimate *M* (`cpue1_r=5_estM`) and fix *M* (`cpue1_r=5_fixM`); split CPUE series: estimate *M* (`cpue2_r=5_estM`) and fix *M* (`cpue2_r=5_fixM`). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

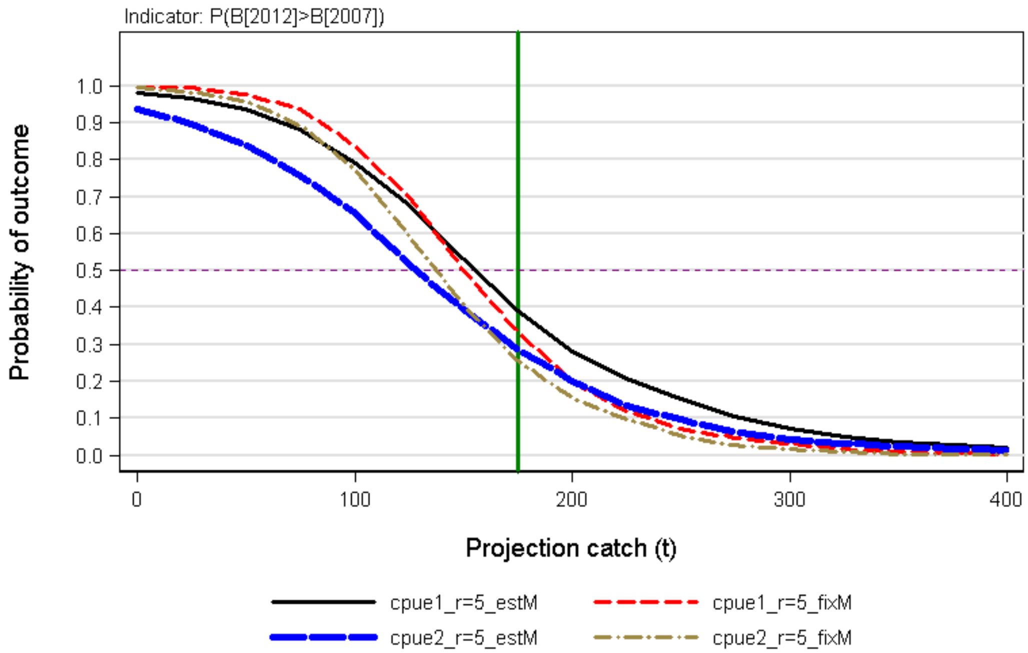


Figure 11. 3CD5AB: Comparison of the probability of B_{2012} exceeding B_{2007} for four runs with knife-edge recruitment at age 5: single CPUE series: estimate *M* (`cpue1_r=5_estM`) and fix *M* (`cpue1_r=5_fixM`); split CPUE series: estimate *M* (`cpue2_r=5_estM`) and fix *M* (`cpue2_r=5_fixM`). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

Appendix A. BIOLOGICAL ANALYSES FOR ENGLISH SOLE

Estimation of length-weight parameters

Every record with English sole data was extracted from the biological sample data available in GFBio (extract obtained 23 November 2006). This resulted in recovering 264,629 records distributed by year, sex and combined major area as reported in Table A.1. A further 171,446 records are missing either length, sex or sampling date information. The majority of these records (169,783) have no associated sex code.

Table A.1. Distribution of records by sex and combined major DFO reporting region for English sole as recorded in the GFBio database (current to 23 November 2006). These records all have a valid sex code, major DFO area code and a length observation. Records missing one of these fields are not included in this table.

	Males					Females				
Year	3CD	4B	5AB	5CD	Total	3CD	4B	5AB	5CD	Total
1953		2,764	306	1,913	4,983		4,503	527	4,908	9,938
1954		2,549	204	1,918	4,671		3,288	216	4,840	8,344
1955		1,232		1,888	3,120		2,341		6,321	8,662
1956		1,601	18	1,572	3,191		1,982	181	4,399	6,562
1957		658		1,289	1,947		1,007		3,169	4,176
1958		923	32	2,030	2,985		2,431	262	5,474	8,167
1959		930		1,448	2,378		1,436		4,726	6,162
1960		739		1,699	2,438		1,370		4,784	6,154
1961		941	15	2,386	3,342		2,267	78	5,696	8,041
1962		1,252	138	988	2,378		2,945	174	1,806	4,925
1963		779	68	1,074	1,921		2,547	208	2,449	5,204
1964		739	140	864	1,743		2,018	152	2,405	4,575
1965		789		582	1,371		2,633		2,727	5,360
1966	1	1,163	118	282	1,564	137	3,321	131	1,784	5,373
1967	7	630		342	979	171	2,307		1,898	4,376
1968		1,000		363	1,363		2,211		977	3,188
1969		998	13	753	1,764		2,074	168	1,785	4,027
1970		817	147	801	1,765		1,945	68	1,576	3,589
1971		605		559	1,164		1,069		620	1,689
1972		228		126	354		480		330	810
1973		291		297	588		614		720	1,334
1974		101		162	263		120		430	550
1975		52		360	412		159		784	943
1976		100		338	438		67		939	1,006
1977		143		1,407	1,550		302		2,194	2,496
1978		45		919	964		177		1,434	1,611
1979		136	56	1,871	2,063		170	186	2,419	2,775
1980		105		2,531	2,636		766		2,630	3,396
1981			242	2,389	2,631			209	3,255	3,464
1982			736	3,831	4,567			790	4,582	5,372
1983				1,941	1,941				3,057	3,057
1984				758	758				1,768	1,768
1985				858	858				1,672	1,672
1986				175	175				424	424
1987				1,842	1,842				2,239	2,239
1988				148	148				774	774
1989				283	283				1,197	1,197

Year	Males					Females				
	3CD	4B	5AB	5CD	Total	3CD	4B	5AB	5CD	Total
1990				106	106				747	747
1991				47	47				401	401
1992				96	96				605	605
1993				79	79				626	626
1994				144	144				826	826
1995	25			228	253	24			1,702	1,726
1996			99	125	224			126	967	1,093
1997				67	67			61	559	620
1998				240	240				660	660
1999			65	60	125			185	259	444
2000				244	244				402	402
2001				1,091	1,091				1,417	1,417
2002			35	3,448	3,483			25	5,068	5,093
2003	227	311	466	3,620	4,624	409	371	689	5,358	6,827
2004	628		563	314	1,505	1,710		683	1,042	3,435
2005	140		1,174	3,612	4,926	688	53	1,126	6,584	8,451
2006	457		448	11	916	1,673		270	205	2,148
Total	1,485	22,621	5,083	56,519	85,708	4,812	46,974	6,515	120,620	178,921

A linear regression model (Eq. A.1) was fitted to all available length-weight pairs categorised by sex and major combined DFO region (Table A.2) to see if there were major differences in the estimated parameters between the areas for each sex. The length data were trimmed to the 1 and 99 percentiles in each area to drop length outliers. Because there were a large number of large outliers (standardised residuals>4), the analysis was further constrained by removing those records where the standardised residuals were greater than 4 as determined through an initial fit to the data.

$$W = \alpha L^{\beta}$$
$$\ln\left(W_i\right) = \ln(\alpha) + \beta \ln\left(L_i\right) + \varepsilon_i \qquad \text{Eq. A.1}$$
$$\hat{\alpha} = \exp\left[\ln(\alpha)\right]$$

Table A.2. Distribution of available length-weight pairs for English sole by year, sex and combined major DFO areas.

Year	Male					Female				
	3CD	4B	5AB	5CD	Total	3CD	4B	5AB	5CD	Total
1979				59	59				65	65
1983				214	214				176	176
1996				84	84				63	63
1998				112	112				200	200
1999			61		61			139		139
2000				204	204				308	308
2001				464	464				686	686
2002				234	234				425	425
2003	41	27	245	425	738	61	58	292	885	1,296
2004	49		148	106	303	255		189	391	835
2005	13		199	515	727	76	53	197	964	1,290
2006	139		26	11	176	672		18	205	895
Total	242	27	679	2,428	3,376	1,064	111	835	4,368	6,378

Model fits and residual plots are provided for the combined DFO areas 3CD5AB (males: Figure A.1; females: Figure A.2) and combined DFO areas 5CD (males: Figure A.3; females: Figure A.4). Parameter estimates and some diagnostics from the fitted models for all area combinations are presented in Table A.3 and are plotted for comparison by sex and area in Figure A.5. Residuals for all models showed relatively poor fits to the data at the tails of each residual distribution. These are probably caused by data outliers which may be data errors. The parameter estimates for DFO areas 5CD do not differ greatly from the male estimates used by Fargo (1998) but diverge somewhat from his female parameter estimates (Table A.3). Examination of the parameter estimates by major DFO region shows relatively little difference between the sexes, although the females have consistently larger estimates for β and lower estimates for α than for males (Figure A.5).

Table A.3. Length-weight parameter estimates for English sole by sex and major combined area (3CD, 5AB, 3CD5AB and 5CD) and for all areas combined. All available length-weight pairs were used, regardless of sample origin. Each length distribution was truncated at the 1% and 99% of the empirical distribution to reduce the effect of outliers and large outliers (standardised residual>4 after a preliminary fit to the data) were also dropped. Also shown is the estimate used in the 1998 assessment for 5CD English sole (Fargo 1998).

Area	N	Parameter	Estimate	Transformed	SE	LB	UB
Males							
3CD	237	β	2.95	2.95	0.04	2.88	3.02
		α	-11.37	1.15E-05	0.20	-11.76	-10.99
5AB	667	β	3.02	3.02	0.02	2.98	3.07
		α	-11.80	7.51E-06	0.12	-12.04	-11.56
3CD5AB	905	β	3.01	3.01	0.02	2.97	3.04
		α	-11.71	8.23E-06	0.11	-11.92	-11.50
5CD	2,401	β	3.07	3.07	0.01	3.05	3.10
		α	-12.06	5.79E-06	0.06	-12.19	-11.93
Previous[1]		β	3.10	3.10			
5CD		α	-12.02	6.01E-06			
Females							
3CD	1,030	β	3.04	3.04	0.02	3.01	3.07
		α	-11.87	6.98E-06	0.10	-12.06	-11.68
5AB	816	β	3.11	3.11	0.02	3.08	3.14
		α	-12.29	4.58E-06	0.09	-12.47	-12.12
3CD5AB	1,856	β	3.07	3.07	0.01	3.05	3.09
		α	-12.03	5.94E-06	0.07	-12.16	-11.91
5CD	4,278	β	3.15	3.15	0.01	3.13	3.16
		α	-12.47	3.83E-06	0.04	-12.56	-12.39
Previous[1]		β	3.24	3.24			
5CD		α	-12.80	2.77E-06			

[1] Fargo (1998)

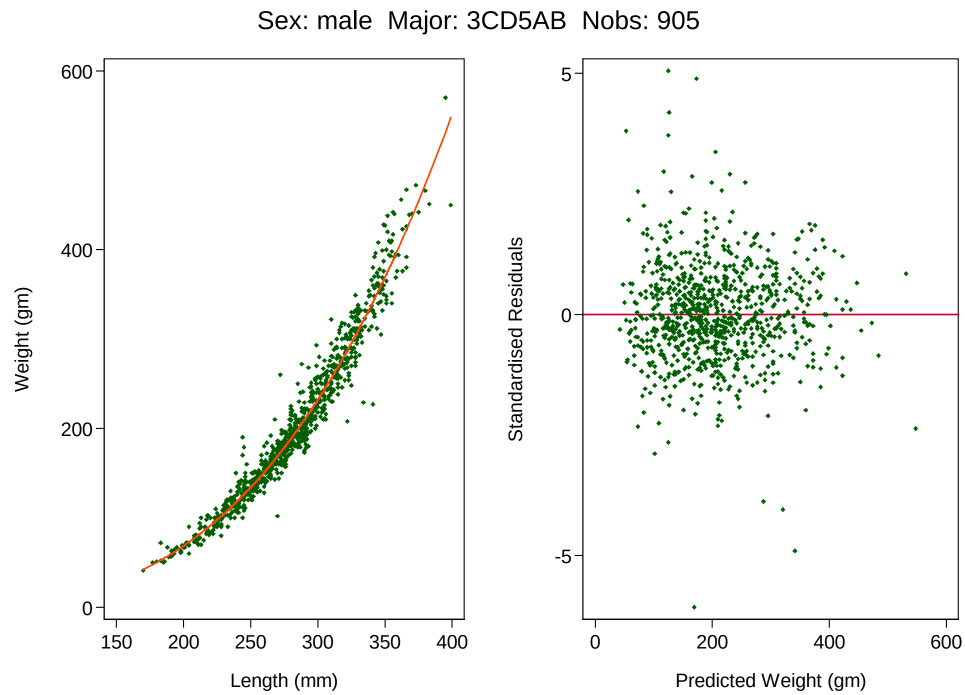


Figure A.1. Plot of the fit for length-weight data for males in combined area 3CD5AB. All available length-weight pairs for the area were used in the analysis, regardless of sample origin.

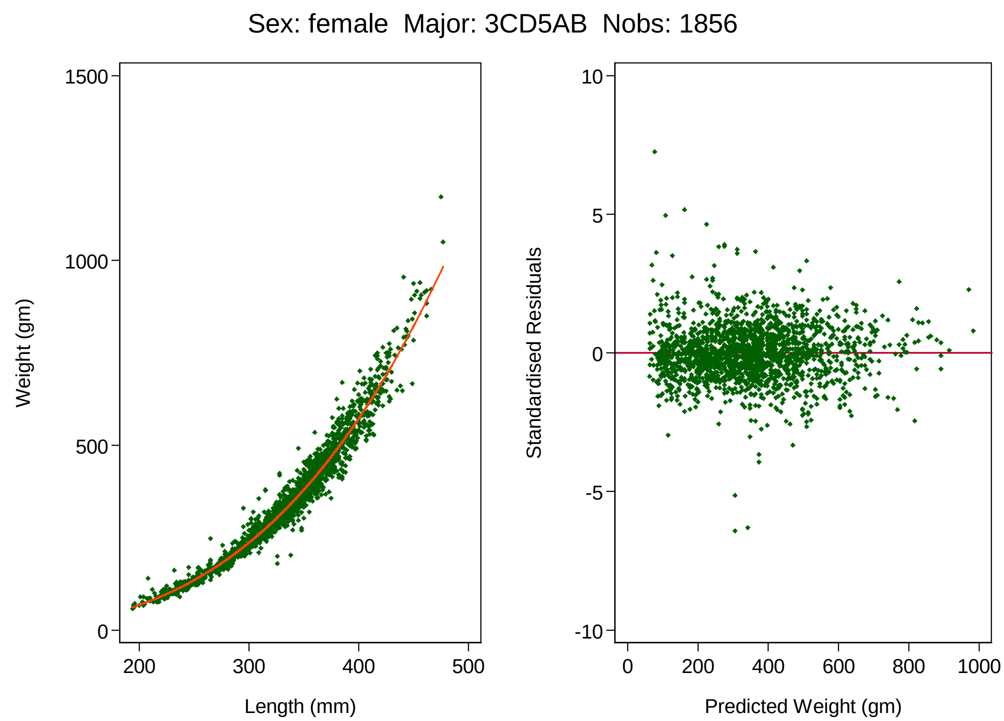


Figure A.2. Plot of the fit for length-weight data for females in combined area 3CD5AB. All available length-weight pairs for the area were used in the analysis, regardless of sample origin.

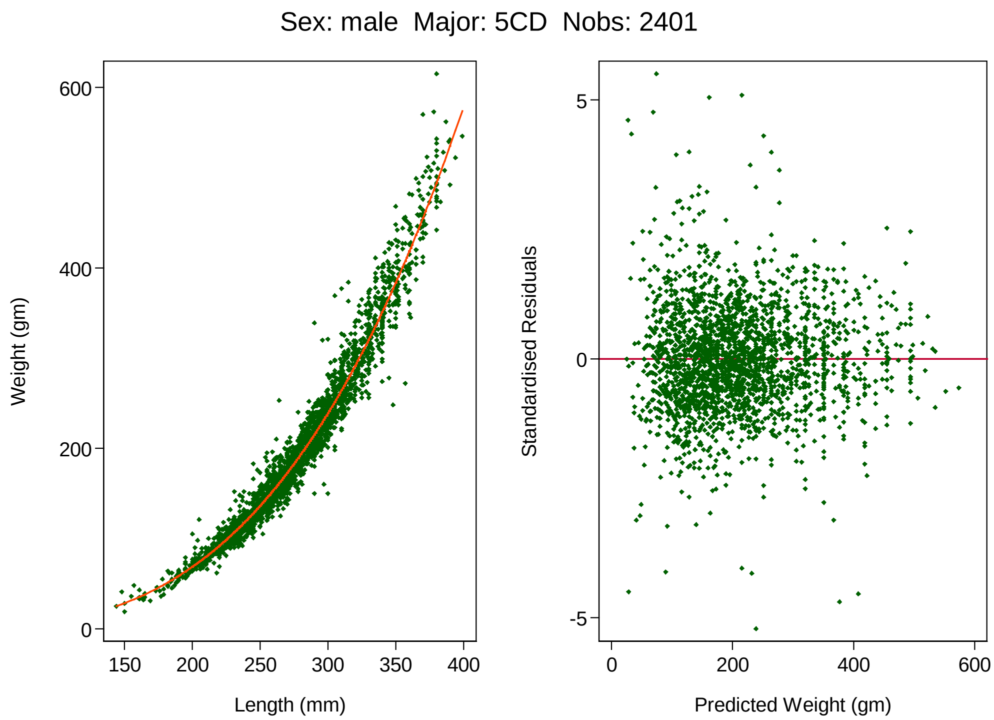


Figure A.3. Plot of the fit for length-weight data for males in 5CD. All available length-weight pairs for the area were used in the analysis, regardless of sample origin.

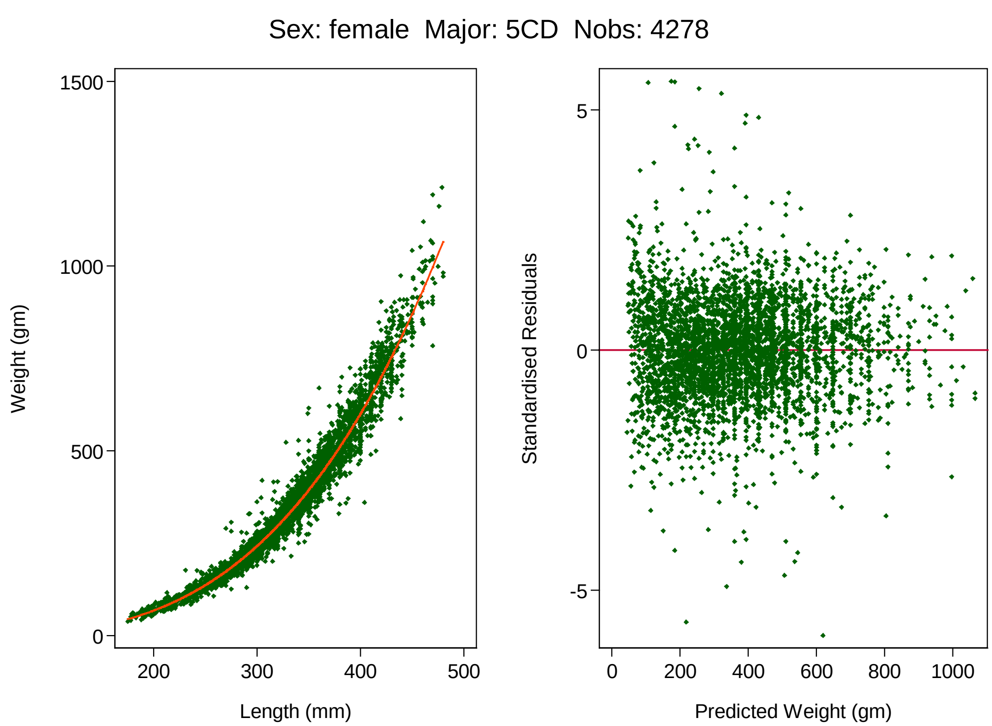


Figure A.4. Plot of the fit for length-weight data for females in 5CD. All available length-weight pairs for the area were used in the analysis, regardless of sample origin.

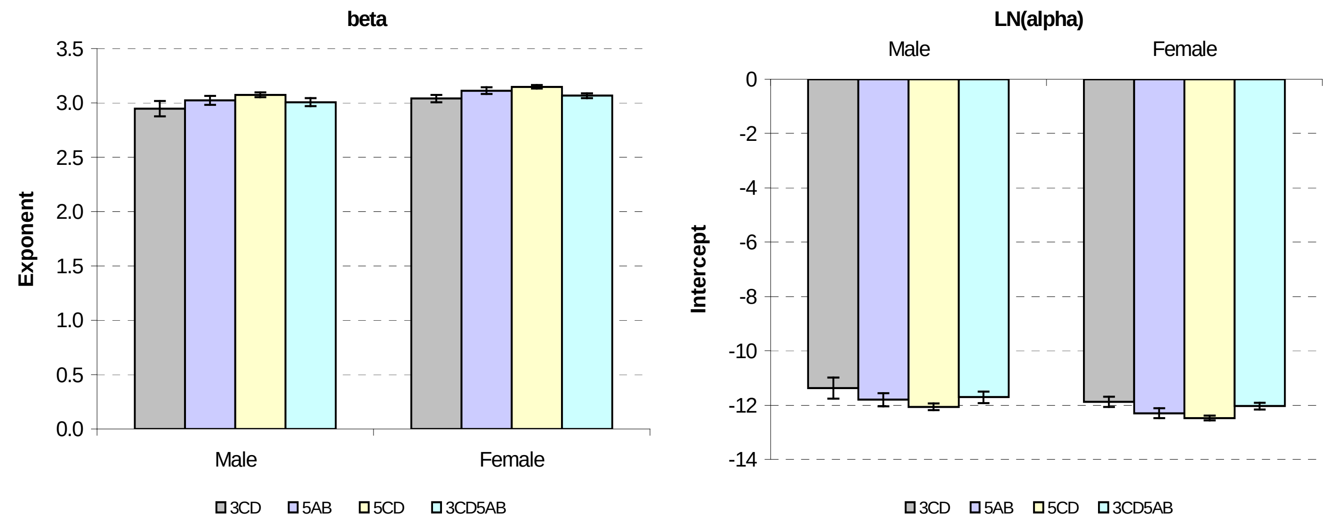


Figure A.5. Comparison of the estimates for each of the parameters in Table A.3 by combined major area, including 3CD5AB, by sex, showing the 95% confidence bounds.

The data for 5CD were examined for possible sampling effects between research and port sampling by re-estimating the length-weight parameters using only research data or port sampling data (Table A.4; parameter estimates in Table A.5). Model fits were similar to those presented in Figure A.1 to Figure A.4, so they are not repeated. A comparison plot of the separately estimated parameters (Figure A.6) shows that the error bars completely overlap for each sex between the two sampling types, indicating that these parameter estimates do not differ strongly and should be considered statistically equivalent. Therefore, the length-weight parameter estimates based on all available data by major DFO area (Table A.3) will be used in the 2006 English sole assessment

Table A.4. Number of length-weight pairs available by sample type and year for 5CD.

	Male		Female	
Year	**Port**	**Research**	**Port**	**Research**
1979		59		65
1983		214		176
1996		84		63
1998		112		200
2000		204		308
2001		464		686
2002	14	220	45	380
2003	66	320	400	420
2004	8	98	144	247
2005	7	508	141	823
2006	11		205	
Total	106	2283	935	3368

Table A.5. Length-weight parameter estimates for English sole by sex and sampling type (Port or Research) for DFO combined major area 5CD. Each length distribution was truncated at the 1% and 99% of the empirical distribution to reduce the effect of outliers and large outliers (standardised residual>4) were also dropped.

Area	N	Parameter	Estimate	Transformed	SE	LB	UB
Males							
Port	104	β	3.13	3.13	0.12	2.89	3.38
		α	-12.41	4.06E-06	0.72	-13.85	-10.98
Research	2255	β	3.08	3.08	0.01	3.05	3.10
		α	-12.08	5.70E-06	0.07	-12.21	-11.95
Females							
Port	913	β	3.11	3.11	0.03	3.05	3.17
		α	-12.26	4.75E-06	0.19	-12.63	-11.89
Research	3292	β	3.15	3.15	0.01	3.13	3.17
		α	-12.47	3.84E-06	0.05	-12.56	-12.38

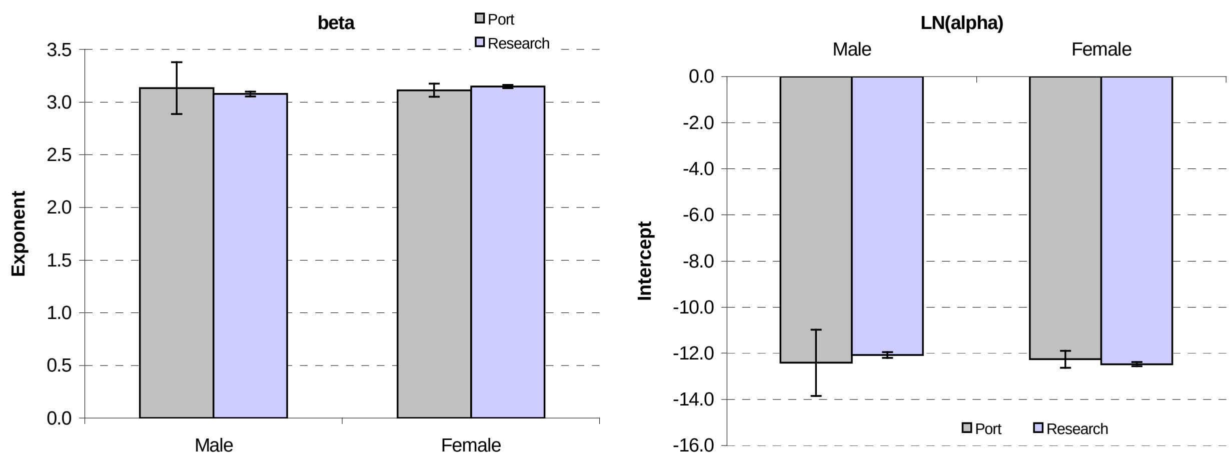


Figure A.6. Comparison of the estimates for the 5CD parameters in Table A.5 by sample type origin and by sex, showing the 95% confidence bounds.

Estimation of von-Bertalanffy growth parameters

Over eleven thousand age observations are available for English sole, primarily collected in DFO major area 5CD by port and research sampling (Table A.6). The port samples have been collected in nearly every year since 1980 while the research samples all date from the late 1990s to 2002. Only 200 age samples are available from DFO major area 5AB, collected in 1999 on a research cruise (Table A.6). For the purposes of this analysis, the small number of 5AB samples were lumped with the 5CD samples. Two lots of at-sea observer samples collected in 2001 and 2003 from 5CD were combined with the research samples as these originated from unsorted random samples. Ageing appears to have been performed using the preferred “break and burn” methodology from the beginning of the series (Table A.6). Although there are a significant number of ages for which the methodology is not recorded, most of the earliest age readings indicate that the “break and burn” methodology was used and the majority of the ages with “unknown ageing method” occur after 1982 when it is known that the “break and burn” methodology was standard (G. Workman, *pers. comm.*).

Table A.6. Number of age samples available for English sole by year, sample source and DFO major combined area. Also shown are the available data on the ageing methodology used in each year.

Year	5AB	5CD			Ageing method				Total
	Research	Port	Research	At-sea observer	Surface	Broken & burnt	Section & burnt	Unknown	
1980		579				299		280	579
1981		300	255		16	539			555
1982		548						548	548
1983		259						259	259
1984		354				151		203	354
1985		400						400	400
1986		201						201	201
1987		100						100	100
1988		100						100	100
1989		50						50	50
1990		100						100	100
1991		50						50	50
1992		689				332		357	689
1993		393						393	393
1994		300				4		296	300
1995		805	88			893			893
1996		333	209			542			542
1997		471				471			471
1998		293	312			605			605
1999	200	273			2	471			473
2000			425		4	421			425
2001		108	1,146	57	111	1,197	3		1,311
2002		323	198		3	518			521
2003		643		46	1	686	2		689
2004		207				207			207
2005		200				200			200
2006		170				170			170
Total	200	8249	2633	103	137	7,706	5	3,337	11,185

There is a substantial difference in the mean lengths at age between the research and port samples for English sole. This is shown in Figure A.7, where the distribution of female mean lengths at age is consistently lower for the research samples than for the port samples from the same age class. This result can be observed for other sample statistics, such as the median, minimum or a percentile of the distribution. Table A.6 indicates that there is also a difference in the years over which the data are collected, with much of the port sampling taking place earlier than the research sampling. To check if the difference between the research and port samples might be a function of the timing of the sample, the analysis plotted in Figure A.7 [left panel] was repeated using data from 1999 onwards, with little change in the apparent bias between sample origin ([right panel] Figure A.7). As a result of this difference in mean size at age between the sample origins, growth models were fitted separately to either the port or to the research data and no models which combined these data sources were attempted.

Von-Bertalanffy models (Eq. A.2) were systematically fitted to the data summarised in Table A.6 across a range of possible assumptions which might affect the results. The assumptions and ranges investigated are summarised in Table A.7. There are very few observations in the older age classes, particularly for males, so it was not necessary to investigate every age-sex combination across all sampling types (Table A.8). Partial year models based on spring/summer samples were only investigated for models which started at age=2. Only models which converged in less 100 iterations are reported.

$$L_i = L_\infty e^{\left(-k\left[a_i - t_0\right]\right)} \qquad \text{Eq. A.2}$$

Table A.7. Range of assumptions investigated for Von-Bertalanffy models fitted to English sole age-length data

Assumption	**Range investigated**
Sampling type	Port or Research
Weight type	Equal weight for each age or by number observations at age
Sex	Male or Female
Dates used	Entire year or April-September (start age=2 only)
Start age for model	Ages 1, 2, 3 or 4
End age for model	Ages 12 – 15

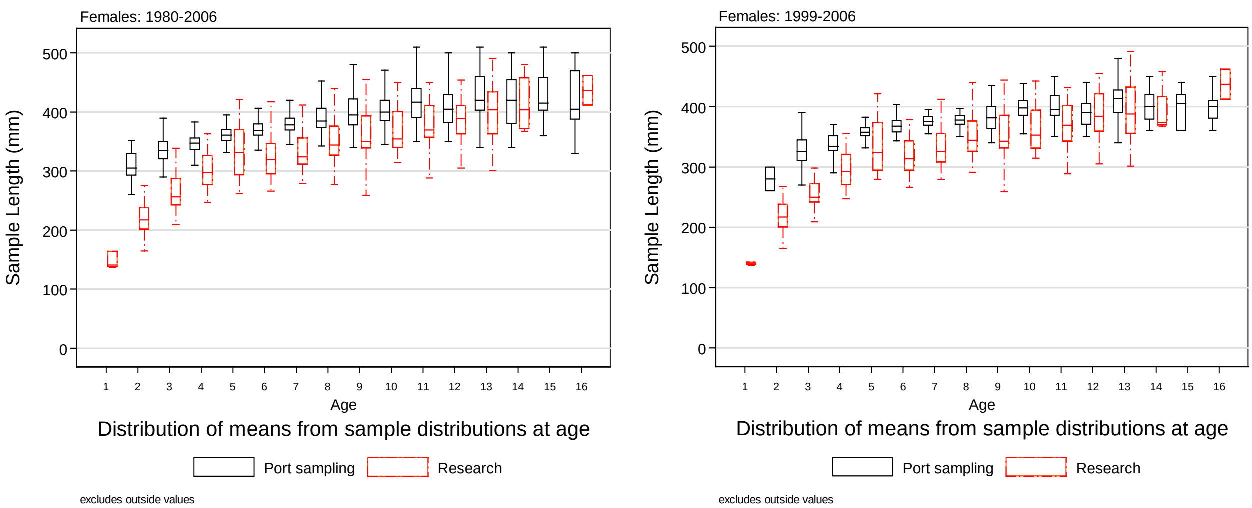


Figure A.7. Distribution of sample means for females at age from research and port samples [left panel] all age samples from 1980 to 2006; [right panel] only most recent (since 1999) age samples.

Results are reported for the L_∞ and k parameters. Results for the partial year fits are also not reported because they differ little from the fits based on data from the entire year. Many of the assumption combinations resulted in non-converged models or in estimates of the L_∞ parameter which appeared to be unreasonably large. This is because the mean lengths at age often form a straight line, making convergence a problem for a non-linear model. Parameter estimates for females seemed to be the most reasonable for models which were started at age 2 and extended to maximum age which still had sufficient data (Table A.9). Only a few of the male models based on the research data and starting at age 2 converged (Table A.9). Models which assumed equal weight in each age class were preferred over the models with natural weighting, given the predominance of younger aged fish and the apparent low level samples from older age classes, especially in the research data. Estimates of the L_∞ parameter were generally higher for the port sample data but this relationship was not consistent across all the reported models (Table A.9).

Table A.8. Number of observations and mean length for each age by sex and sample type origin.

	Number observations				Mean length (mm)			
	Port sampling		Research sampling		Port sampling		Research sampling	
Age	male	female	male	female	male	female	male	female
1			14	14			154	150
2	11	35	91	123	322	320	214	224
3	70	457	123	178	332	340	249	272
4	87	1,244	170	243	338	357	269	309
5	75	1,391	49	75	327	366	270	331
6	74	1,327	132	230	331	370	273	324
7	102	1,132	116	235	336	378	287	337
8	105	647	128	195	340	390	294	354
9	107	413	108	177	348	397	302	364
10	97	288	93	144	353	408	308	370
11	54	183	41	85	354	417	332	377
12	32	83	32	47	358	412	335	394
13	26	74	28	34	367	428	339	402
14	19	44	6	12	360	416	349	408
15	14	20	6	1	361	434	364	388
16	2	14	1	2	370	421	358	437
17	1	4	1		390	450	351	
18		5				470		
19		1	1			390	390	
Total	876	7,362	1,140	1,795	342	374	280	328

Models fitted under the assumption of equal weight for each age class are presented for females (Figure A.8) sampled from the commercial fishery. No fits to the male age-length data are presented as these models did not converge to sensible results. Fits to male (Figure A.9) and female (Figure A.10) data from research samples are also presented. Parameter estimates for the selected female models differ substantially between the port and research sampled fish (Figure A.11). However, the precision of the parameter estimates is low (particularly for the port sample data) and it is likely that the estimates are not statistically separable.

Parameters for the model selected for use in the English sole stock assessment are presented in Table A.10. Only female growth parameters based on the port sampling data are presented because the male growth models did not converge (Table A.9). This is not a large problem because the English sole stock assessment was performed on female only data, using the sampled proportions of males in the port sampling to estimate the catch of female English sole (Figure A.12). There is a declining trend in the proportion of males over the 40-year period which may lead to bias in the stock assessment if a constant proportion of males is assumed. Note that the proportion of males by weight was used to estimate the catch of females in the assessment model. The selected growth model fits the observed weight at age data well (Figure A.13).

Table A.9. Estimates of L_∞ and k for Eq. A.2 models fitted to the available port and research sampling age data under a range of starting and stopping assumptions for the non-linear regression and using two different data weighting options. Blank cells indicate non-converged models.

		Equal weight for each age class				Weighted by number ages in age class			
		Male		Female		Male		Female	
Start age for re-gression	**End age for re-gression**	**Port**	**Research**	**Port**	**Research**	**Port**	**Research**	**Port**	**Research**
L_∞ parameter									
2	12		418	459	393		357	651	386
	13		430	480	408		385	670	394
	14		452	452	419		395	543	398
	15			461	409			540	398
3	12			496	434			854	434
	13			539	468			834	453
	14			461	482			574	459
	15			475	430			567	457
4	12			581					
	13			722					
	14			467	3,918			1,461	
	15			486	465			1,014	4,285
k parameter									
2	12		0.079	0.115	0.256		0.131	0.031	0.267
	13		0.072	0.093	0.211		0.097	0.029	0.238
	14		0.063	0.127	0.184		0.089	0.051	0.226
	15			0.112	0.208			0.052	0.226
3	12			0.074	0.130			0.018	0.127
	13			0.055	0.096			0.018	0.107
	14			0.107	0.087			0.042	0.102
	15			0.091	0.139			0.044	0.103
4	12			0.041					
	13			0.024					
	14			0.097	0.003			0.007	
	15			0.079	0.086			0.012	0.003

Table A.10. Port sample based female growth parameter estimates selected for the English sole stock assessment. Equivalent parameter estimates using research sample ageing are also provided. Both sets of parameters are based on models fitted from ages 2 to 15 and apply equal weight for each age class.

Parameter	Based on port sample ageing	Based on research sample ageing	Previous assessment[1]
L_∞	461.48	409.38	494
k	0.11	0.21	0.28
t_0	-8.81	-2.10	-0.04

[1] Fargo (1999)

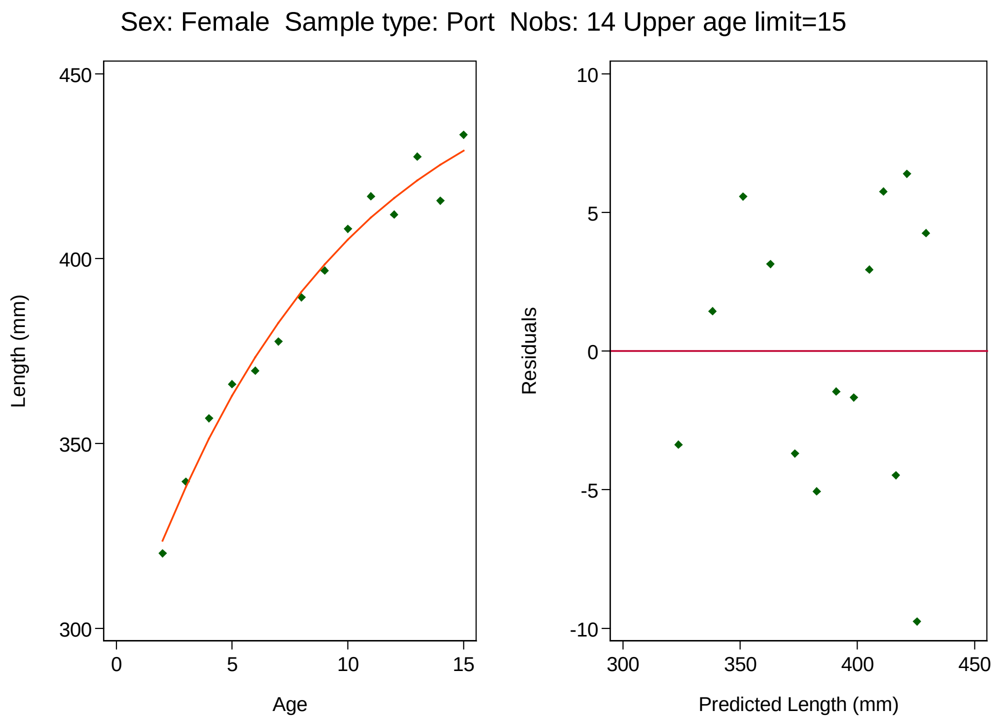


Figure A.8. Plot of the fit of a model starting at age 2 and ending at age 15 for the female age-length data obtained by port sampling, assuming equal weight for each age class.

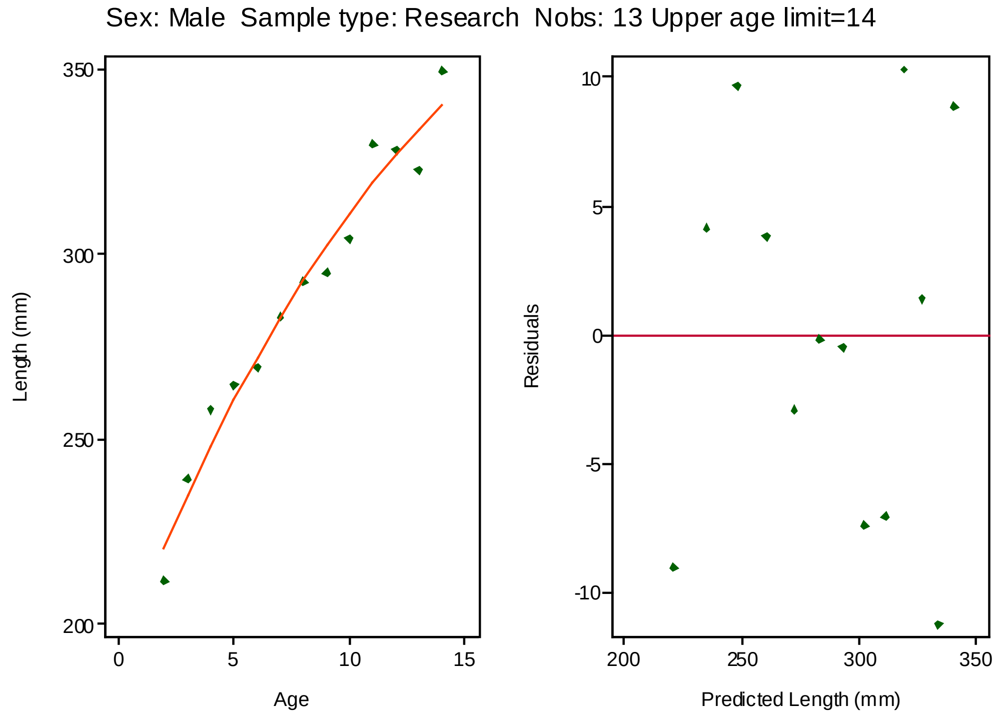


Figure A.9. Plot of the fit of a model starting at age 2 and ending at age 14 for the male age-length data obtained by research sampling, assuming equal weight for each age class.

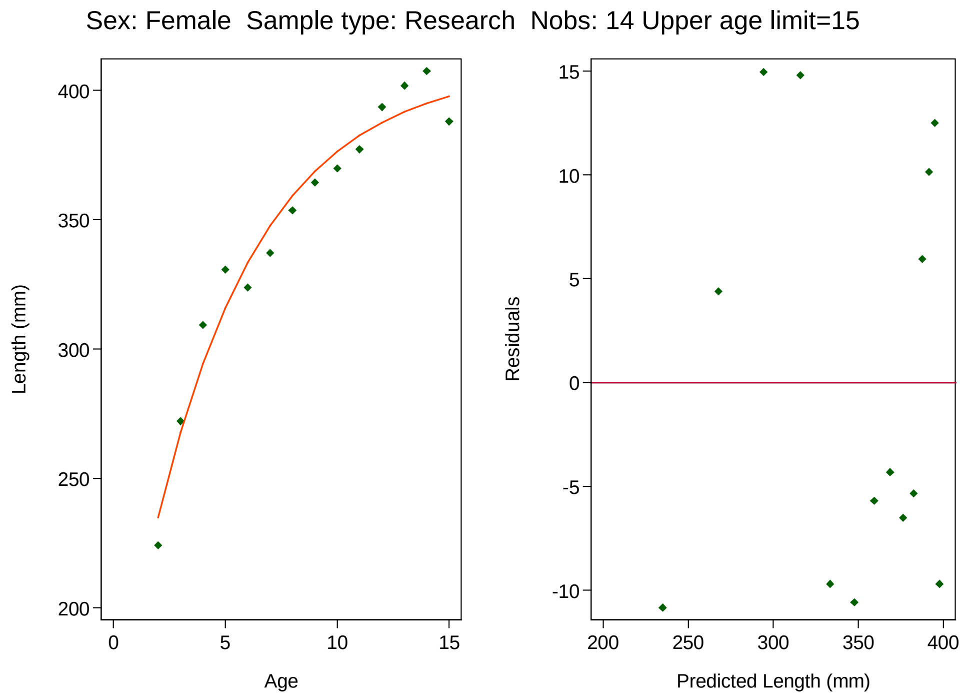


Figure A.10. Plot of the fit of a model starting at age 2 and ending at age 15 for the female age-length data obtained by research sampling, assuming equal weight for each age class.

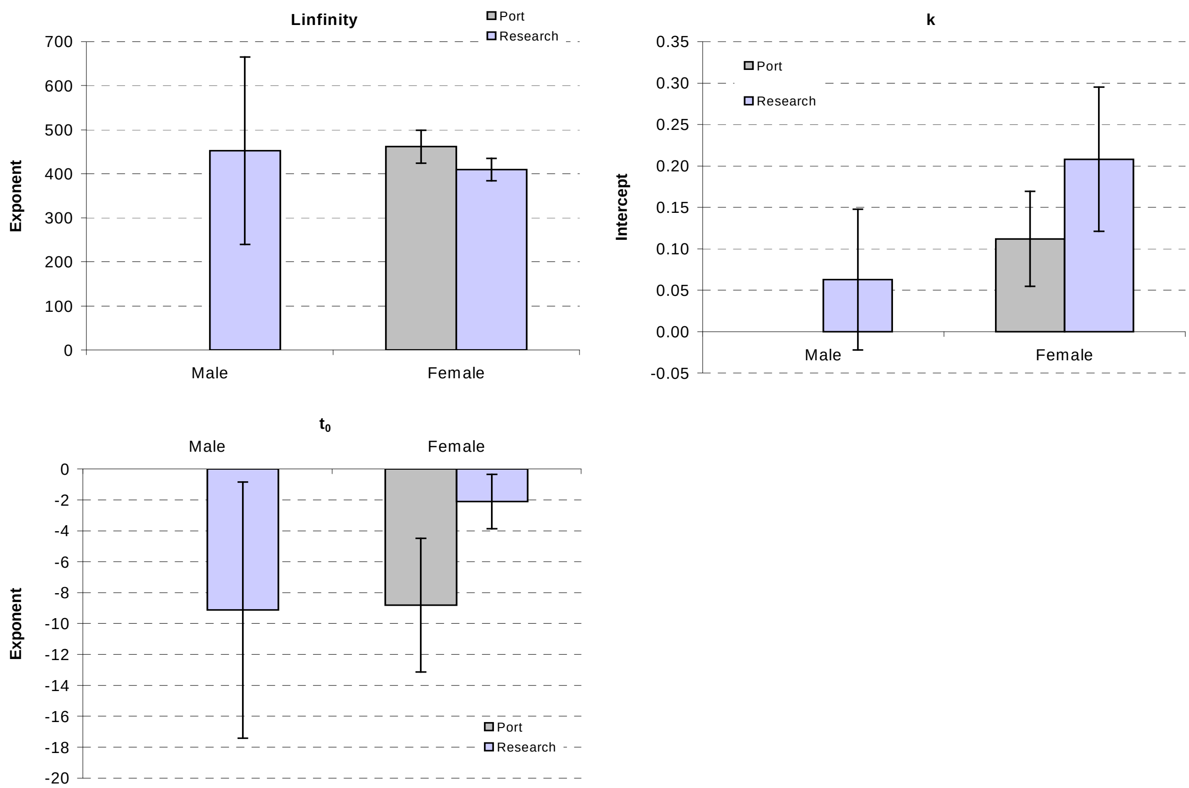


Figure A.11. Comparison of the estimates for the 5CD growth parameters (males: age 2 to 14; females: age2 to 15) by sample type origin and by sex, showing the 95% confidence bounds.

English sole biological information for 5CD stock assessment

The sample age distributions by year and sex for 5CD English sole port samples are presented in Figure A.14. There is substantial structure in these distributions, with relatively small proportions of older fish in the samples until the mid-1990s. There is then a gradual appearance of older aged fish, particularly for females, up to the end of the 1990s. There is also an apparent loss of age 4 fish beginning in the early 1990s which is likely associated with a change in mesh size regulations. It is possible that an age-structured stock assessment model would capture the structure in the age distributions shown in Figure A.14. However, the mean weight data used in the delay-difference model also contain some of this information as can be seen when the age structure information is converted into implied mean weight using the growth model based on the port sample ages (Table A.10) and the length-weight conversion parameters from Table A.5 (Figure A.15). Note that this figure shows that, while the mean weights based on the port sample ages match well with the mean weights calculated directly from the sampled lengths, the same conversion based on the growth model which uses the research ages seriously underestimates the mean weight observed in the port samples. This plot demonstrates that it would be an error to use the growth model based on the research ageing in the delay-difference stock assessment model because that model treats the observed and model estimates of mean weight as absolute which would result in model misspecification.

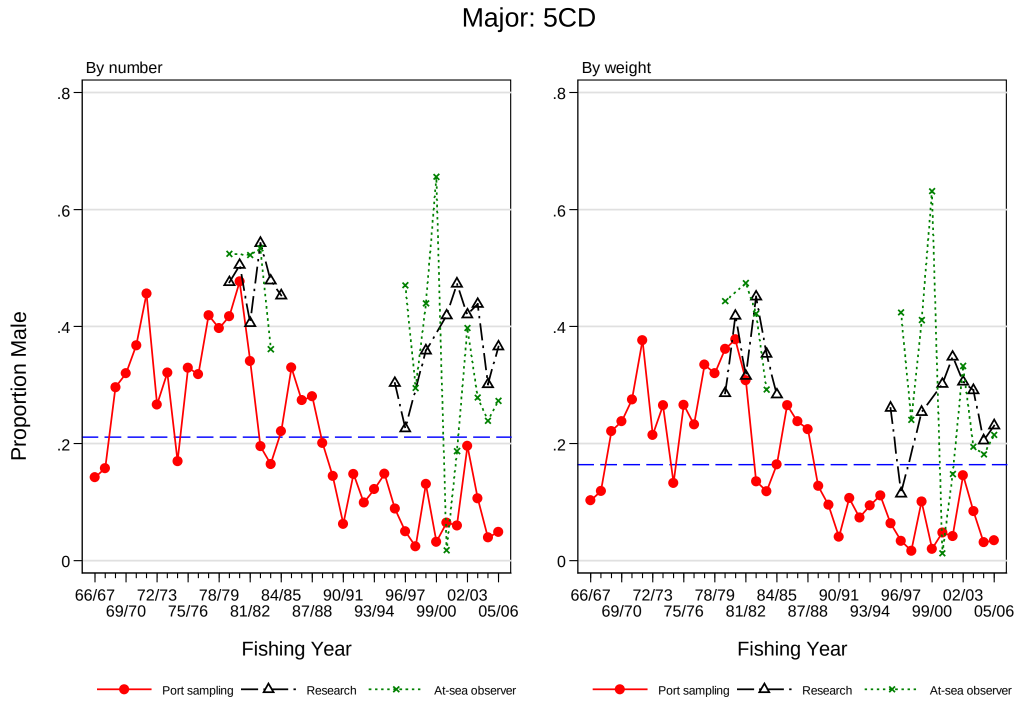


Figure A.12. Time series of the proportion of male English sole from the 5CD sampling data by sample origin, expressed in terms of sample numbers or sample weight. The long-term average proportion males from the port sampling data is 0.21 by number and 0.16 by weight (shown as horizontal dashed lines).

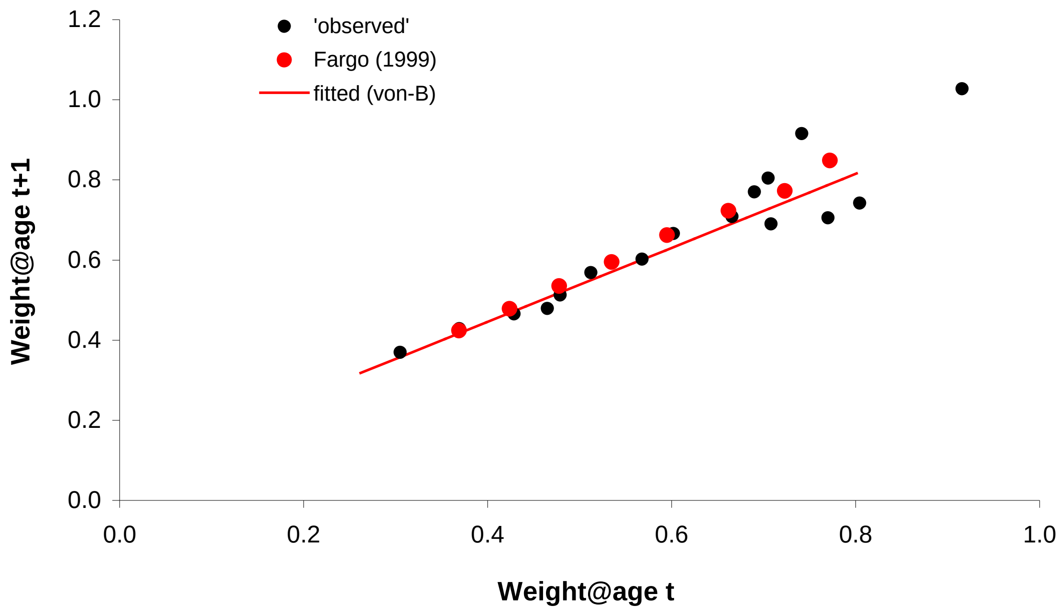


Figure A.13. Walford plot for 5CD female English sole using the growth parameters in Table A.10. Also plotted are the 'observed' W_a and W_{a+1} for port sampling derived by converting the mean length at age (Table A.8) to weight at age using length-weight parameters (Table A.3). The points labelled as Fargo (1999) are the female weight at age data presented in Appendix Table 4.2 from the 1999 English sole assessment.

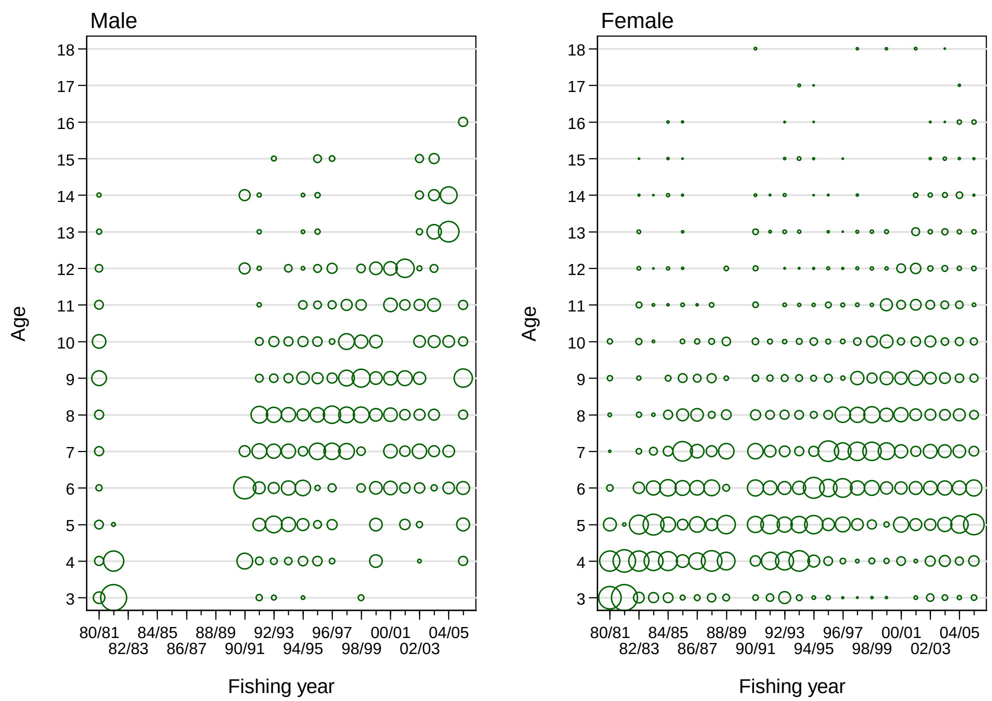


Figure A.14. Relative size of each age class of English sole port samples by sex and fishing year. Vertical columns sum to one from age 3 to age 18. Ages outside of this range have been dropped.

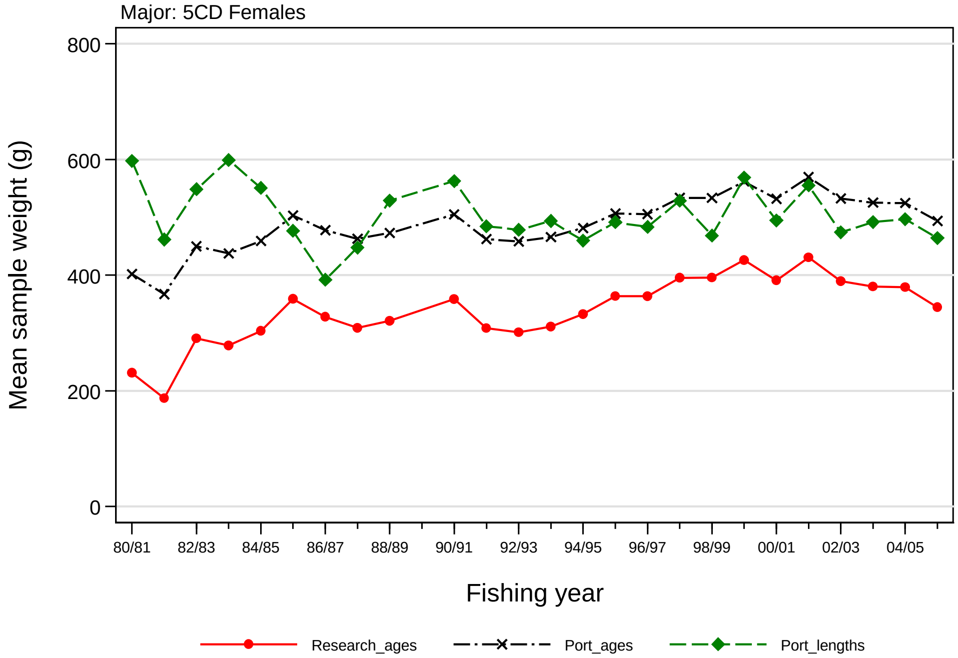


Figure A.15. Mean weight (g) for females from 5CD calculated under 3 alternative assumptions: a) converting the sample age distribution into the implied mean weight by using the predicted mean length at age based on the Von-Bertalanffy growth model from research age samples (Table A.10) and the length-weight parameters; b) same as for (a) but using the Von-Bertalanffy growth model based on port sample ages (Table A.10); c) converting all sampled lengths to weight using parameters from Table A.5

Distributions of sample statistics for 5CD female English sole derived from samples from different origins show that the port sample data were substantially larger for all statistics than research or at-sea samples (Figure A.16). This was true even when the research and at-sea samples were truncated by dropping sampled fish smaller than 300 mm. The 300 mm cut-off was selected because very few fish smaller than 300 mm are found in the port sample data (Figure A.16). When the distributions of 5CD female sample mean weights are compared with the model predicted mean weight for equilibrium recruited fish (derived parameter $\overline{w}$; Appendix D), the port sampled mean weights are above the unfished equilibrium mean weights for ages 3, slightly below for age 4 and below that for age 5 (Figure A.17). Age 5 was selected as the candidate age for knife-edge recruitment to be used in the delay-difference assessment model and this was tested by also fitting the model with the knife-edge recruitment set at age 4.

Annual mean weights were derived for input into the 5CD delay-difference stock assessment model by calculating the mean length within each three month quarter (beginning from April in each year) from all the samples obtained in that quarter. An annual mean length was then calculated from the quarterly mean lengths weighted by the commercial catch from 5CD in each quarter. The annual mean length was then converted to a mean weight using the length-weight parameters from Table A.5. Annual mean weights were included in the stock assessment model only when there were at least 5 samples available for a fishing year and at least three of the four annual quarters were represented. Twenty-four of a possible 40 mean weight estimates were used in the stock assessment model (Figure A.18).

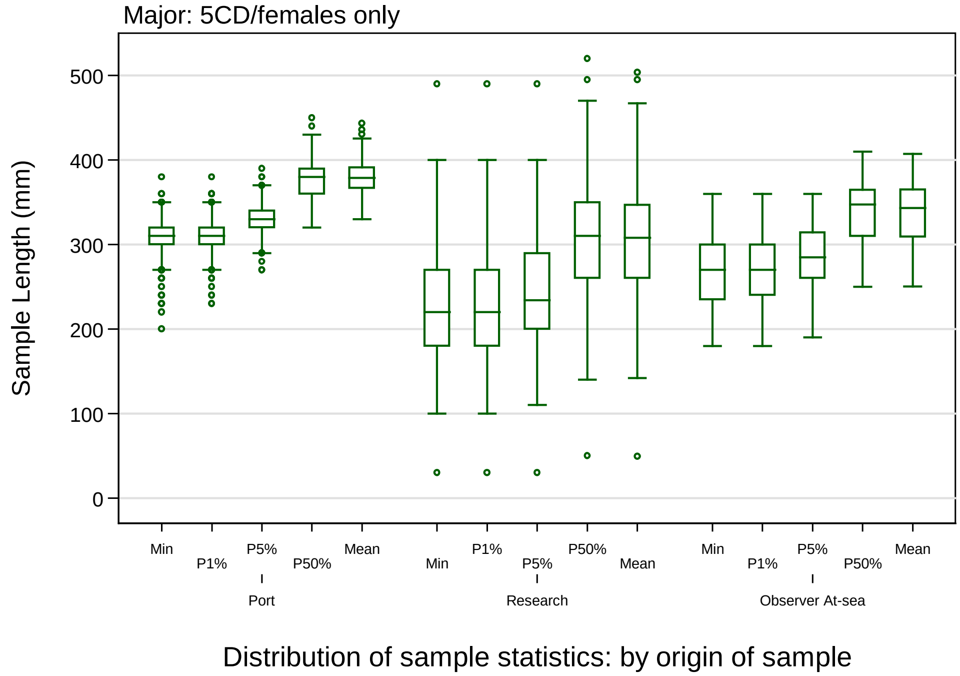


Figure A.16. Box plots of the distribution of statistics (minimum, P[1%], P[5%], median and mean lengths [mm]) derived from all samples within an origin type for female English sole in combined major areas 5CD.

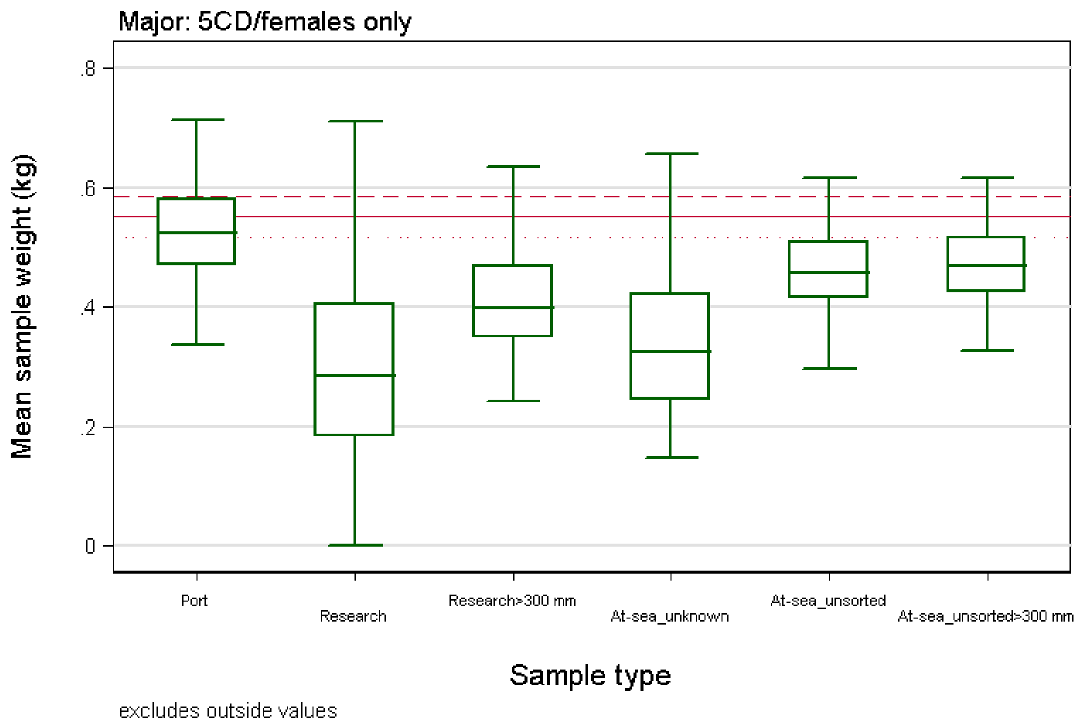


Figure A.17. Distribution of mean sample weight by sample type category for all samples of female English sole collected beginning in 1966/67 from DFO major areas 5CD. Horizontal lines show the predicted equilibrium mean weight for the model parameter $\bar{w}$ (mean weight when F=0) when the age of knife-edge recruitment is 3, 4 or 5. Mean weights are also provided for research and unsorted at-sea samples which have been truncated at 300 mm to simulate the fishery sorting process, where 300 mm is an approximate lower bound for sorting.

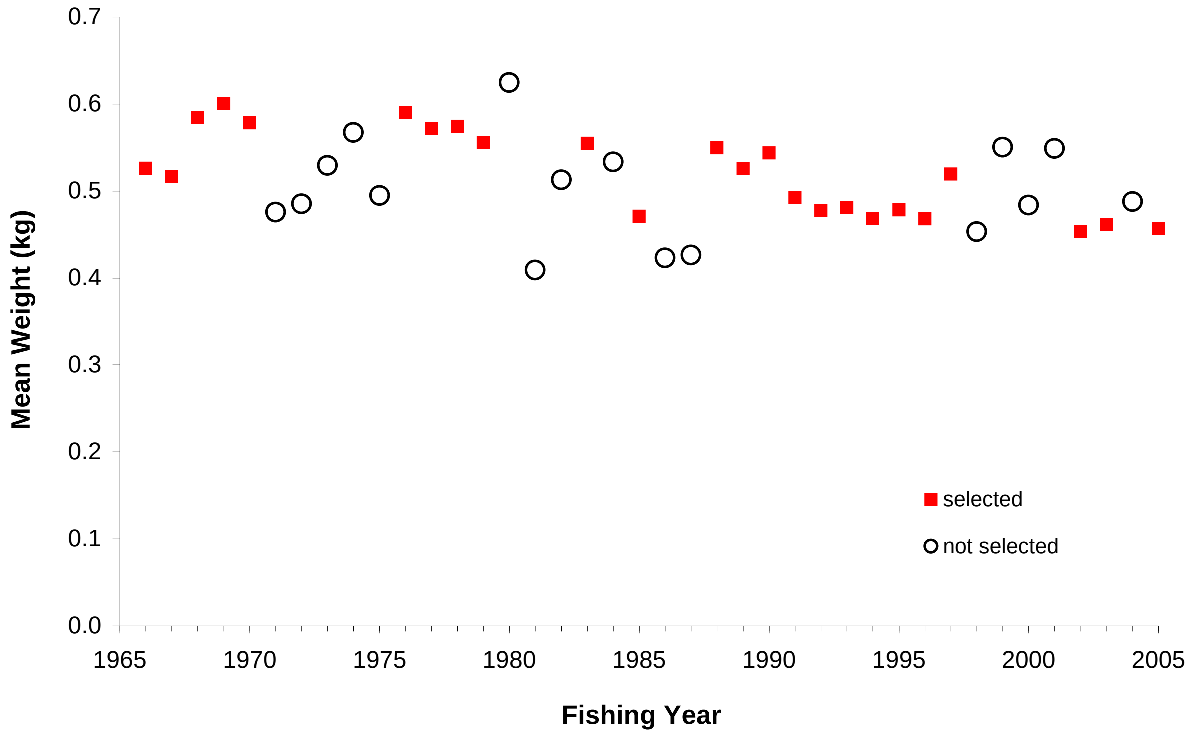


Figure A.18. Time series of port sampled mean weights used in the 5CD delay-difference stock assessment model. All annual mean weights are shown but the open circle estimates were not used in the model because they did not satisfy the 5 annual sample over at least 3 quarterly time periods in the year.

English sole biological information for 3CD5AB stock assessment

Mean weights calculated from port sampled females in DFO combined areas 3CD5AB show much higher values than those calculated from research or at-sea observer samples (Figure A.19). This observation is similar to the equivalent observations made for DFO combined areas 5CD (Figure A.17). The problem is that there are very few samples for 3CD5AB compared to those available from 5CD, particularly from the commercial fishery, where there are only five samples over the entire history of the fishery (Table A.11). It is worth noting that the distribution of mean weights by sample origin is similar for 3CD5AB compared to 5CD (Figure A.20).

The scarcity of data in 3CD5AB can be seen even more clearly when the proportions of male English sole are plotted by year for 3CD5AB (Figure A.21) and then compared to the equivalent plot for 5CD (Figure A.12). These comparison show that the available data for 3CD5AB are very variable when presented by year and seem too unreliable to use for an assessment. Because of the scarcity of biological data from the 3CD5AB areas, the assessment for this area used the 5CD time series for the proportion male (Figure A.12) to estimate the size of the female catch over the history of the fishery as well as the using the port sample female 5CD mean weights (Figure A.18) to represent the 3CD5AB female mean weights. This is in addition to using the 5CD growth model described in Table A.10 for 3CD5AB as almost all the available ageing is for 5CD (Table A.6).

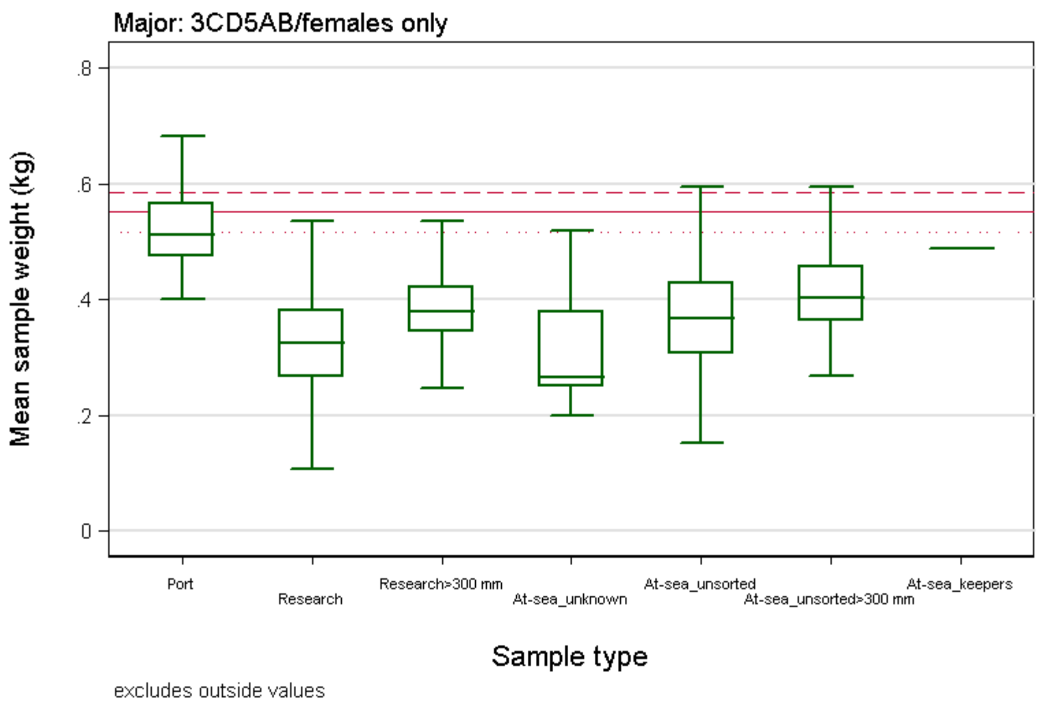


Figure A.19. Distribution of mean sample weight by sample type category for all samples of female English sole collected beginning in 1966/67 from DFO major areas 3CD5AB. Horizontal lines show the predicted equilibrium mean weight for the model parameter $\bar{w}$ (mean weight when F=0) when the age of knife-edge recruitment is 3, 4 or 5 (based on 5CD growth information). Mean weights are also provided for research and unsorted at-sea samples which have been truncated at 300 mm to simulate the fishery sorting process, where 300 mm is an approximate lower bound for sorting.

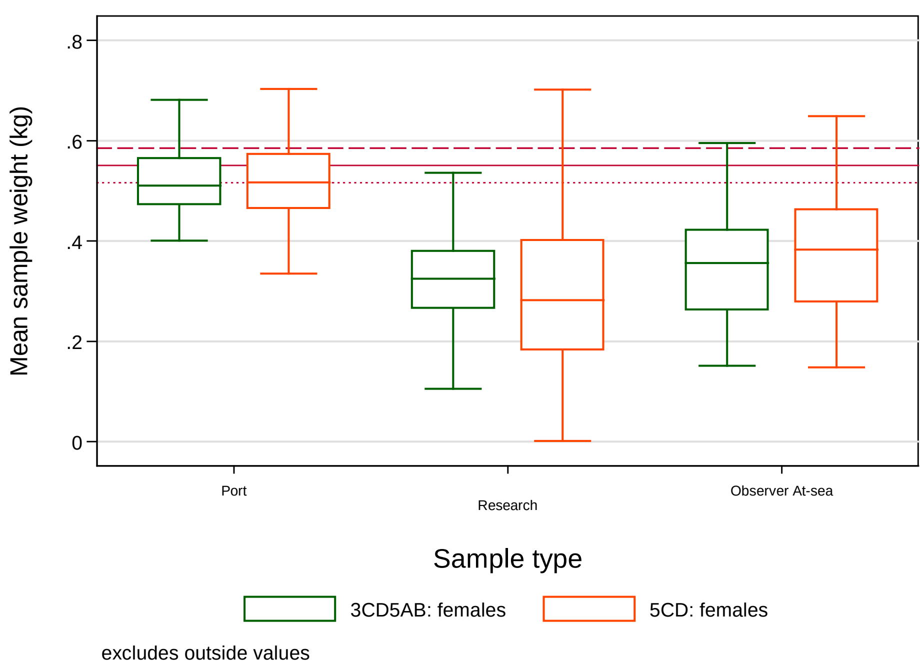


Figure A.20. Distribution of mean sample weight by sample type category for all samples of female English sole collected beginning in 1966/67 from DFO major areas 3CD5AB and 5CD. Horizontal lines show the predicted equilibrium values for the model parameter $\bar{W}$ when the age of knife-edge recruitment is 3, 4 or 5.

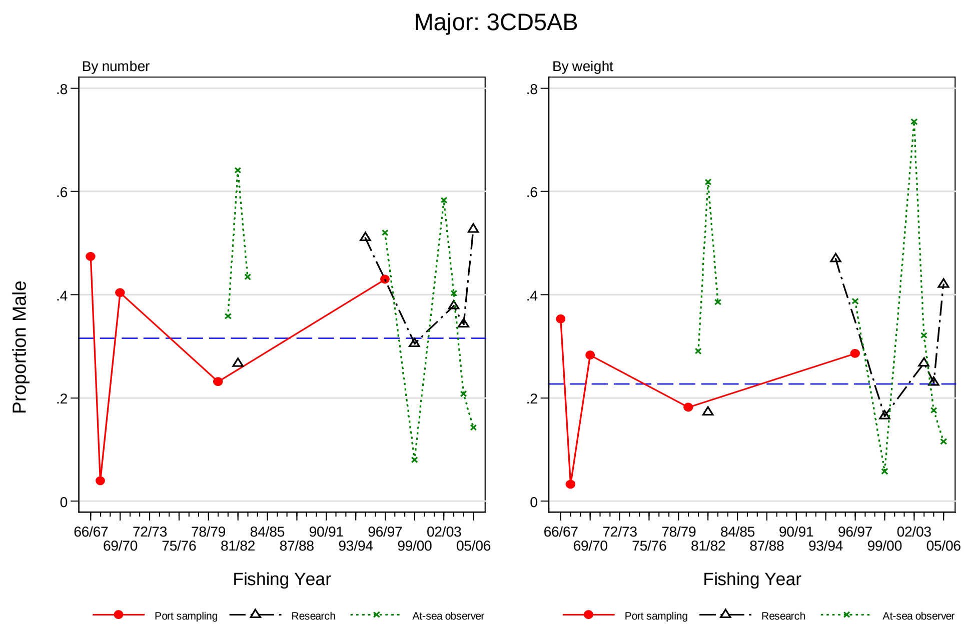


Figure A.21. Time series of the proportion of male English sole from the 3CD5AB sampling data by sample origin, expressed in terms of sample numbers or sample weight. The long-term average proportion males from the port sampling data is 0.32 by number and 0.22 by weight (shown as horizontal dashed lines).

Table A.11. Number of samples, number of female fish measured and mean weight of female fish from DFO major areas 3CD5AB and 5CD over the period 1966/67 to 2005/06, presented by sample origin.

	Combined 3CD5AB			Combined 5CD		
Sample origin	**Number samples**	**Number females**	**Mean weight (kg)**	**Number samples**	**Number females**	**Mean weight (kg)**
Port	5	935	0.533	196	34,948	0.524
Research	104	5,748	0.329	159	23,910	0.304
Observer At-sea	47	2,832	0.354	44	5,520	0.378
Total	156	9,515	0.341	399	64,378	0.390

Appendix B. ENGLISH SOLE GLM

Methods

A stepwise general linear model (GLM) regression procedure was used to estimate an annual series of the relative changes in English sole abundance over time. The regression was based on the relationship between CPUE for English sole and available predictive factors. The data were derived from the DFO *PacHarvestTrawl* and *GFCatch* commercial catch and effort databases. This approach is commonly used to analyse fisheries catch and effort data and has been described by various authors (e.g., Hilborn and Walters 1992, Quinn and Deriso 1999).

Quinn and Deriso (1999; page 19) described a general linear model based on the lognormal distribution:

$$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}} \qquad \text{Eq. B.1}$$

where U_{ijk} is an observed CPUE, U_0 is the reference CPUE, P_{ij} is a factor i at level j, and X_{ij} takes a value of 1 when the jth level of the factor P_{ij} is present and 0 when it is not. The random deviate ε_{ijk} for observation k is a normal random variable with 0 mean and standard deviation σ.

Taking the logarithm of Eq. B.1 yields an additive linear regression model:

$$\ln U_{ijk} = \ln U_0 + \sum_{i=1}^{p} \sum_{j=1}^{n_i - 1} X_{ij} \ln P_{ij} + \varepsilon_{ijk}$$

or Eq. B.2

$$Y_{ijk} = \beta_0 + \sum_{i=1}^{p} \sum_{j=1}^{n_i - 1} \beta_{ij} X_{ij} + \varepsilon_{ijk}$$

In the second form of the model, β_0 is the intercept of the model and β_{ij} is the logged coefficient of the factor j at level i under consideration.

The model described by Eq. B.1 and Eq. B.2 is overparameterised and constraints must be imposed to allow estimation of model parameters. A common solution is to create a reference level by setting a factor coefficient to zero, usually the first. The remaining n_i-1 coefficients of each factor i represent incremental effects relative to the reference level.

The estimated factor coefficients are not unique: coefficients obtained by fixing a factor level will differ with the choice of reference level. However, the relative differences among the estimated coefficients will not be affected by the choice of constraint. Following the suggestion of Francis (1999), coefficients for factor i were transformed to "canonical" coefficients over all levels j calculated relative to their geometric mean $\bar{\beta} = \sqrt[n]{\prod_1^n \beta_j}$ (including the level where β_j=0), so that

$$\beta_j^{'} = \beta_j / \overline{\beta}$$ Eq. B.3

As the analysis is done in log space, this is equivalent to:

$$b_j^{'} = e^{(\beta_j - \overline{\beta})}$$ Eq. B.4

The use of the canonical form allows the computation of standard errors for every coefficient, including the fixed coefficient (Francis 1999). Ordinarily, the use of a fixed reference coefficient sets the standard error for that coefficient to zero and spreads the error associated with that coefficient to the other coefficients in the variable.

A range of factors (P_{ij}) are available in the data which may be used to account for variability in the observed CPUE. These include factors such as the date of capture (usually year and month), the vessel, and the depth and location of capture. The year of capture is usually given special significance in these analyses as variations in the estimated year coefficients are interpreted as relative changes in the annual abundance. The resulting series of 'year' or 'fishing year' canonical coefficients is termed the "Standardised" annual CPUE index $\left[Y_j^{'}\right]$ in this report.

A selection procedure (Vignaux 1993, Vignaux 1994; Francis 2001) was applied to determine the relative importance of these factors in the model to the prediction of CPUE. The procedure involves a forward stepwise fitting algorithm which generates regression models iteratively, starting with the simplest model (one dependent and one independent variable) that progressively adds terms to the model subject to a stopping rule designed to include only the most important factors.

The following general procedure was used to fit the models, given a data set with candidate predictor variables:

1. Calculate a regression for each predictive factor (variable) against the natural log of CPUE (kg/h).
2. Generate the Akaike Information Criterion (AIC) (Akaike 1974) and select the predictor variable that has the lowest AIC. The AIC is used for model selection to account for variables which may have equivalent explanatory power in terms of residual deviance but require fewer degrees of freedom for the model (Francis 2001).
3. Repeat Steps 1 and 2, accumulating the number of selected predictor variables and increasing the model degrees of freedom, until the increase in residual deviance (as measured by R^2) for the final iteration is less than 0.01. The selection of 0.01 as the threshold is arbitrary but adding factors which explain small amounts of the total variance has little effect on the year coefficients and other coefficients of interest.

Other annual indices can be generated from the catch and effort data used for the linear modelling described above. The simplest estimate of mean annual CPUE is given by:

$$R_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}} \qquad \text{Eq. B.5}$$

where C_{jk} denotes that catch and E_{jk} denotes the effort for each record *k* in year *j*. The series of annual estimates is termed the "Arithmetic" CPUE index in this report.

Another annual index is specified by

$$U_j = \exp\left[\frac{\sum_{k=1}^{M_j} \ln\left(\frac{C_{jk}}{E_{jk}}\right)}{M_j}\right] \qquad \text{Eq. B.6}$$

where U_j is the annual geometric mean of the CPUE observations. The resulting annual index is termed the "Unstandardised" CPUE index in this report. Annual estimates obtained using Eq. B.6 are equivalent to the results obtained from a linear model where year is the only predictive factor.

Like the scaling described for the standardised index, the series specified by Eq. B.5 and Eq. B.6 can be scaled relative to their geometric means. This is done to provide comparability with the standardised index. Given *n* years in each series, the geometric means of the arithmetic and unstandardised series are given by $\bar{R} = \sqrt[n]{\prod_1^n R_j}$ and $\bar{U} = \sqrt[n]{\prod_1^n U_j}$, respectively. Thus, each series can be scaled to the corresponding geometric mean as:

$$R_j^{'} = R_j \big/ \bar{R} \qquad \text{Eq. B.7}$$

and

$$U_j^{'} = U_j \big/ \bar{U} \qquad \text{Eq. B.8}$$

The procedures described by Eq. B.1, Eq. B.2 and Eq. B.6 are necessarily confined to the positive catch observations in the data set as ln(0) is undefined. Observations with zero catch can be handled in a number of ways:

1. Zero catch records are frequently dropped from further consideration, usually because they are not accurately recorded. This is particularly true for catch records which are maintained by fishermen who frequently discount small amounts of catch as being inconsequential.
2. A small increment can be added to the zero catch records so that ln(0) can be calculated. This is not a satisfactory solution because model parameter estimates have been shown to be sensitive to the value selected for the increment.

3. A linear regression model based on a binomial distribution and using the presence/absence of the fish species as the dependent variable can be estimated using the same data set. Explanatory factors are estimated in the model in the manner described in Eq. B.1 and Eq. B.2. Such a model will provide another series of standardised coefficients of relative annual changes that may be analogous to the series estimated from the lognormal regression, depending on whether the probability of presence/absence can be considered an index of abundance. Such an approach should only be used for data sets where zero catch records are known to have good reliability, which is not the case for the long term series presented here.

4. A combined model which integrates the two series 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):

$$C_i = \frac{L_i}{\left(1 - P_0\left[1 - \frac{1}{B_i}\right]\right)} \qquad \text{Eq. B.9}$$

where C_i = combined index for year i
L_i = lognormal index for year i
B_i = binomial index for year i
P_0 = proportion zero for base year 0

It is relatively straightforward to calculate standard errors for the indices L_i and B_i. However, this is not the case for the combined index C_i because the standard errors of the two sets of indices are likely be correlated because they come from the same dataset. Francis (2001) suggests that a bootstrap procedure is the appropriate way to estimate the variability of the combined index.

Data sources

Trawl catch and effort data pertaining to English sole are available from two DFO databases: *GFCatch* which covers the period from 1954 to December 1995 (Rutherford 1995) and *PacHarvestTrawl* which covers the period from 1996 to the present. Data were obtained from *PacHarvestTrawl* in July 2006 that included data to the end of March 2006.

Catches

Total annual landings and discards for English sole are presented by major DFO region from 1979/80 to 2005/06 (Table B.1). Landings are generated from dockside monitoring programmes which have been in place since 1995. Prior to that year, landings are available from logbooks maintained by fishermen which have been cross-validated with landing slips issued by the receiving processing plant. Discard estimates are considered to be unreliable prior to 1996 because they were based on voluntary reporting and are known to be incomplete. Discards since

February 1996 are based on estimates made by an independent at-sea observer and are considered more reliable than those obtained from logbooks

Table B.1. Total landed and discarded catches for English sole in the combined GFCatch/PacHarvestTrawl databases, summarised by 1 April–31 March fishing year for the major DFO reporting areas, combined as indicated. Data from 1 April 1979 to 27 December 1995 are from the GFCatch database (Rutherford 1995). Data from 16 February 1996 to 31 March 2006 are from the PacHarvestTrawl database. The groundfish fishery was closed from 28 December 1995 to 15 February 1996. These catches have been summarised without data selection criteria.

	DFO Major Region						
Year	**Other[1]**	**3CD**	**4B**	**5AB**	**5CD**	**5E**	**Total**
Landed Catches (t)							
79/80		61.8	132.6	28.5	926.3	1.2	1,150.3
80/81		102.2	77.3	33.2	1,023.9	14.3	1,250.9
81/82		93.3	31.6	20.6	1,219.3	0.4	1,365.2
82/83		64.5	55.0	20.5	377.3	1.2	518.5
83/84	0.0	50.3	21.4	18.4	470.1	0.0	560.1
84/85		87.4	48.1	17.1	640.1	4.8	797.6
85/86		59.6	22.1	24.8	588.4	0.8	695.7
86/87		60.2	19.1	33.3	332.0	0.1	444.7
87/88		75.2	13.5	50.1	713.0	3.3	855.1
88/89		85.1	52.6	72.9	680.0	1.2	891.8
89/90		93.6	78.6	53.5	861.7	0.7	1,088.1
90/91		129.2	32.6	83.1	1,068.1	0.2	1,313.3
91/92		115.2	71.6	80.3	909.2	1.4	1,177.6
92/93		159.1	95.3	82.2	1,018.8	0.1	1,355.5
93/94		154.0	56.2	126.2	1,538.8	0.2	1,875.4
94/95		114.5	74.6	112.0	973.9	0.3	1,275.3
95/96	1.1	131.1	24.8	91.0	863.7	0.3	1,111.9
96/97	19.5	42.0	36.8	67.7	733.8	0.6	900.4
97/98	4.1	22.1	53.7	59.9	522.2	0.7	662.6
98/99	13.6	22.7	80.5	76.1	519.5	1.1	713.4
99/00	7.4	30.8	109.6	70.7	576.5	0.3	795.2
00/01	6.6	34.2	103.0	65.7	493.0	0.0	702.5
01/02	34.5	59.1	69.4	80.4	409.4	0.1	652.9
02/03	39.7	63.7	94.2	101.4	547.9	0.1	847.0
03/04	12.7	77.2	115.6	82.3	489.1	0.1	777.0
04/05	3.6	93.3	148.9	81.7	491.7	0.0	819.3
05/06	36.2	107.2	76.6	85.8	628.4	0.0	934.2
Total[2]	179.1	2,188.5	1,795.3	1,719.2	19,616.1	33.5	25,531.7
Discarded (t)							
96/97	0.0	10.5	1.1	17.3	292.0	0.0	320.9
97/98	0.0	7.8	0.0	41.7	207.3	0.0	256.7
98/99	0.0	10.9	0.0	40.2	170.9	0.0	221.9
99/00	0.0	20.1	0.0	43.8	222.9	0.2	287.0
00/01	0.0	13.0	0.0	25.5	132.6	0.1	171.3
01/02	0.0	25.8	1.7	41.3	66.8	0.0	135.6
02/03	0.0	29.7	7.4	46.9	102.6	0.0	186.7
03/04	0.0	42.4	12.3	50.2	115.4	0.1	220.4
04/05	0.0	36.3	12.7	39.3	118.0	0.0	206.2
05/06	0.0	66.3	5.9	36.6	164.6	0.0	273.4
Total[3]	0.0	262.6	41.2	382.7	1,593.1	0.5	2,280.3

Year	DFO Major Region Other[1]	3CD	4B	5AB	5CD	5E	Total
Sum(Landed + Discarded) (t)							
96/97	19.5	52.5	37.9	85.0	1,025.8	0.6	1,221.3
97/98	4.1	29.9	53.7	101.6	729.5	0.7	919.3
98/99	13.6	33.6	80.5	116.3	690.4	1.1	935.3
99/00	7.4	50.9	109.6	114.5	799.4	0.5	1,082.2
00/01	6.6	47.2	103.0	91.2	625.6	0.1	873.8
01/02	34.5	84.9	71.1	121.7	476.2	0.1	788.5
02/03	39.7	93.4	101.6	148.3	650.5	0.1	1,033.7
03/04	12.7	119.6	127.9	132.5	604.5	0.2	997.4
04/05	3.6	129.6	161.6	121.0	609.7	0.0	1,025.5
05/06	36.2	173.5	82.5	122.4	793.0	0.0	1,207.6
Total[3]	179.1	2,451.1	1,836.5	2,101.9	21,209.2	34.0	27,812.0

[1] includes catches in unknown areas and areas outside of Canadian waters
[2] 01 April 1979 to 31 March 2006
[4] 01 April 1996 to 31 March 2006

Long-term models: GFCatch and PacHarvestTrawl Data (1966/67–2005/06)

These analyses explored most of the period for which catch/effort data were available (from 1 April 1966 to 31 March 2006), using data from both the *GFCatch* and *PacHarvestTrawl* databases (Table B.2). Data earlier than 1 April 1966 were excluded because previous analyses had indicated that these data appear to be less reliable (Starr et al. 2006). The analyses were based on landed catch estimates because discard data prior to the establishment of the on-board observer programme are considered to be extremely unreliable. The fishing events archived in the database reflect the aggregated grouping individual sets prior to 1991 (Rutherford 1995). Also, a limited number of data fields have been collected consistently throughout the 1966 to 2006 period. These include the DFO "locality" (Rutherford 1995) for the aggregated fishing event, the mean depth of the aggregated sets, and the date associated with the aggregated fishing event or possibly the landing date for the trip. Data prior to 1991 are only available at this aggregated level of trip, DFO locality and mean depth. Data from 1991 onwards are available on a tow-by-tow basis. Therefore the post-1990 tow-by-tow data have been stratified to the pre-1991 level of stratification for comparability, which reduced the resolution of the spatial and temporal data.. As well, a small number possible "duplicate" observations, where the same trip fished in the same locality and depth, were dropped from the analysis (276 records across the two analyses from over 36,000 pre-1991 records, including records with no reported English sole landings).

Table B.2. Data criteria used to select records from the GFCatch and PacHarvestTrawl databases.

Tow start date from 1 April 1966 and 31 March 2006
Bottom trawl type
Fished in one of the following DFO Major regions: 3C, 3D, 5A, 5B, 5C, or 5D
Fishing success code <=1 (code 0= unknown; code 1= useable)
Catch of at least one fish or invertebrate species (no water hauls)
Valid depth field
Valid estimate of time towed that was greater than 0 hours

Five predictive factors were available for CPUE modelling using the step-wise selection procedure described above (Table B.3). The primary explanatory variables are year and month of catch, DFO locality and 30 m depth band. The DFO major area (3C to 5D, depending on the model) was also added in case there was additional explanatory power from this category. Vessel was not used as an explanatory variable because it seemed unlikely that vessels would behave consistently over such a long period. There is also uncertainty that vessel codes have been applied consistently over such a long period. The effort variable used in these analyses was the number of hours fished.

Table B.3. List of predictive factors available for long-term analyses from the *GFCatch* and *PacHarvestTrawl* databases.

Fishing year (1 April–31 March)
Month
DFO locality (Rutherford 1995)
Depth aggregated into depth bands which varied with the areas being analysed
DFO Major region (3C, 3D, 5A, 5B, 5C, or 5D)

Combined Areas 3C, 3D, 5A and 5B: Long-term standardised GLM (1966/67 to 2005/06):

Data from the *PacHarvestTrawl* database were used to define the preferred depth distribution for English sole in combined areas 3CD5AB, based on all bottom trawl records which recorded the capture of English sole. The depth distribution of this data set ranged from about 55 m to nearly 400 m, with sporadic observations at depths deeper than 500 m and more shallow than 40 m (Figure B.1). The GLM model for 3CD5AB used all valid tows occurring between 50 and 410 m aggregated into 40 m bins.

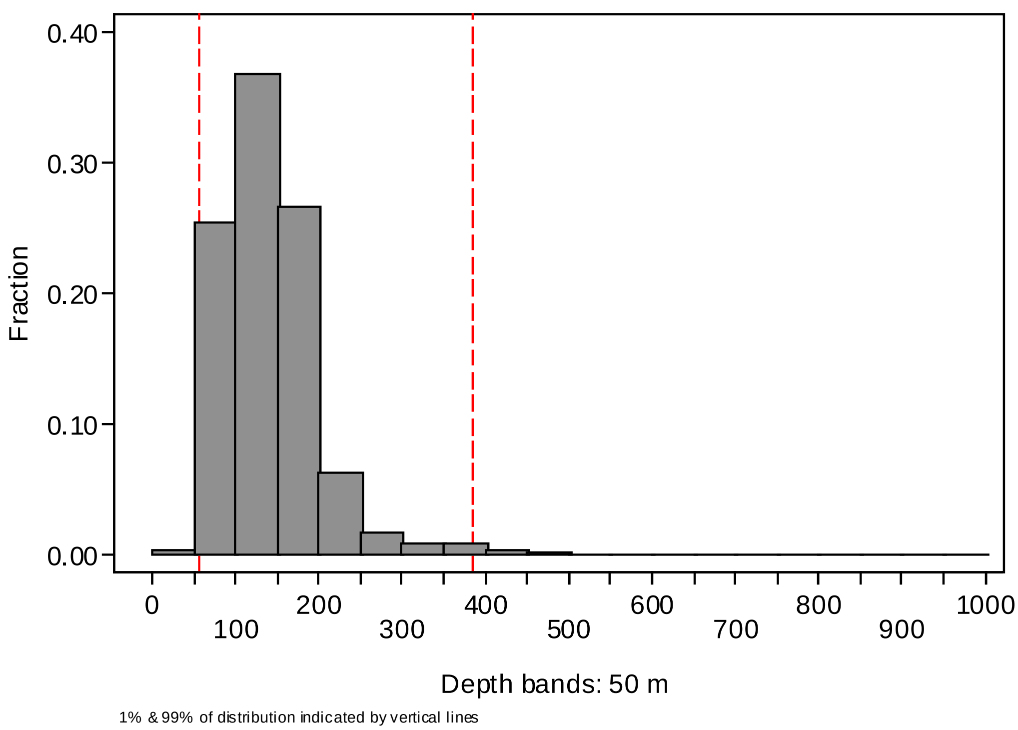


Figure B.1. Depth distribution of tows with reported English sole catch in the combined Areas 3C, 3D, 5A and 5B from 1996/97 to 2005/06 in 20 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=57 m; 99%=384 m.

The available explanatory variables used in the analysis are described in Table B.3. Depth entered the model as a factor with 9 levels determined by 40 m depth intervals and there were 37 DFO localities, including an accumulator group for localities with small numbers of observations. The final model accounted for 17% of the variation (Table B.4).

Table B.4: Order of acceptance of variables into the 1966/67–2005/06 combined areas 3C, 3D, 5A and 5B model of positive landed catches of English sole with the amount of explained deviance (R^2) for each additional model variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.

Variable	1	2	3	4
Year*	**0.046**			
DFO locality*	0.113	**0.143**		
Depth bands*	0.063	0.097	**0.169**	
Month	0.024	0.063	0.146	0.171
DFO major area	0.008	0.053	0.146	0.171
Improvement in deviance	0.000	0.097	0.026	0.003

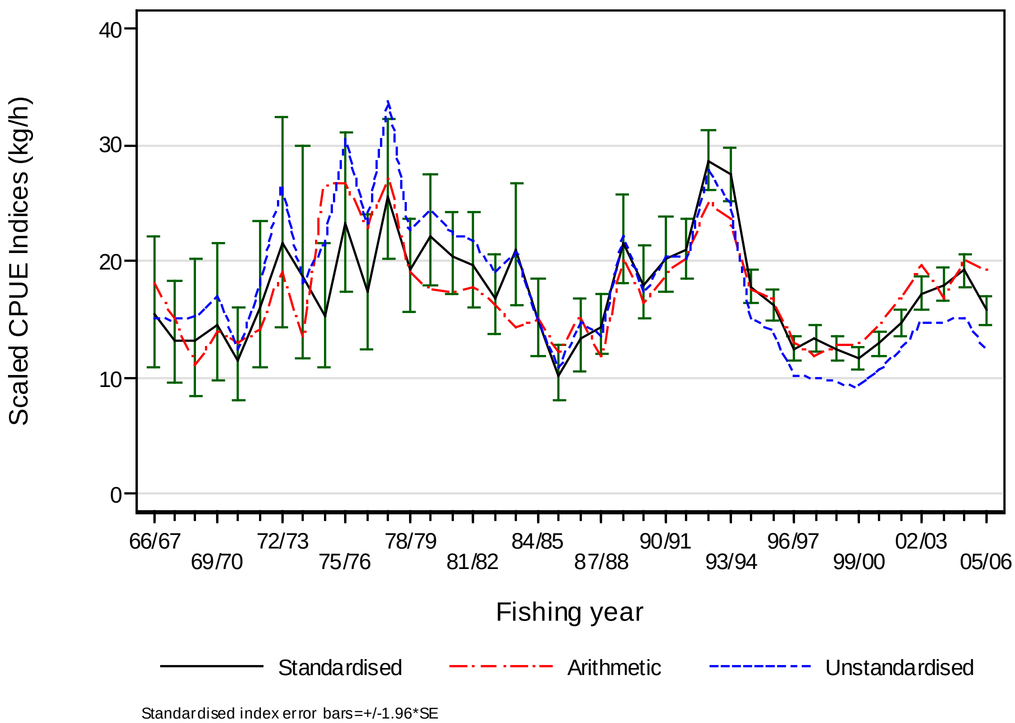


Figure B.2. Three annual series based on CPUE analyses (landed catch per hour) for combined areas 3C, 3D, 5A and 5B landed English sole catches from 1966/67 to 2005/06. The solid line is a standardised analysis correcting for year of catch, DFO locality, and 20 m depth band category (Eq. B.2). The other two series correspond to annual indices calculated using Eq. B.5 and Eq. B.6 respectively.

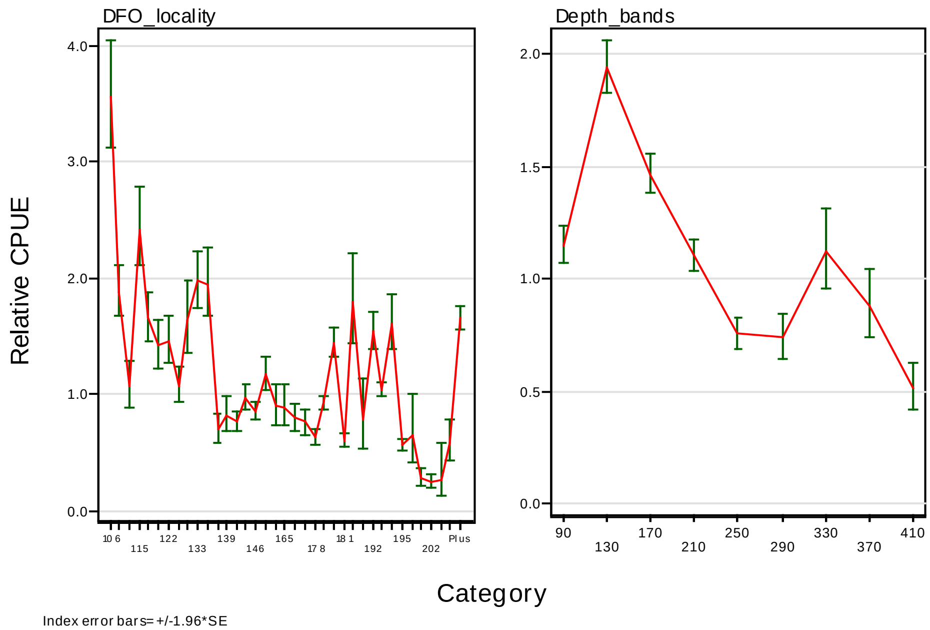


Figure B.3. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure B.2.

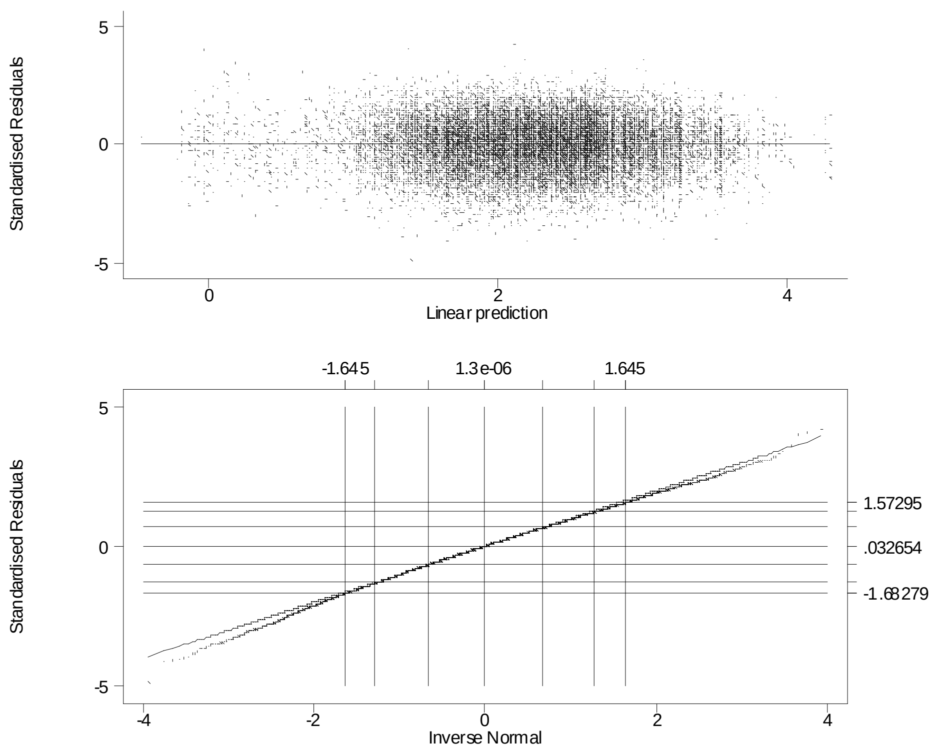


Figure B.4. Standardised (Pearson) residuals for the 5CD GLM analysis presented in Figure B.2. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

Table B.5. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised index for the combined areas 3C, 3D, 5A and 5B model of non-zero catches of English sole. The standardised series has been scaled to the geometric mean of the arithmetic series.

Year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
66/67	18.1	15.5	10.8	22.2	0.183
67/68	15.0	13.2	9.5	18.4	0.168
68/69	11.1	13.2	8.6	20.3	0.220
69/70	14.1	14.5	9.8	21.5	0.200
70/71	13.0	11.4	8.2	16.0	0.171
71/72	14.2	16.0	10.9	23.4	0.194
72/73	19.1	21.5	14.3	32.4	0.209
73/74	13.4	18.7	11.7	30.0	0.240
74/75	26.5	15.4	10.9	21.6	0.174
75/76	26.7	23.3	17.5	31.1	0.147
76/77	22.9	17.3	12.5	24.0	0.167
77/78	27.1	25.6	20.3	32.2	0.118
78/79	19.3	19.3	15.7	23.7	0.105
79/80	17.5	22.2	17.9	27.4	0.109
80/81	17.4	20.4	17.2	24.2	0.087
81/82	17.8	19.7	16.0	24.3	0.106
82/83	16.2	16.8	13.8	20.6	0.103
83/84	14.3	20.9	16.3	26.8	0.127
84/85	15.0	14.9	12.0	18.5	0.111
85/86	12.1	10.2	8.0	12.9	0.120
86/87	15.4	13.3	10.6	16.7	0.117
87/88	11.8	14.3	12.0	17.2	0.091
88/89	20.2	21.6	18.2	25.7	0.087
89/90	16.5	17.9	15.1	21.3	0.088
90/91	19.0	20.3	17.3	23.8	0.081
91/92	20.4	20.9	18.4	23.7	0.064
92/93	25.2	28.6	26.1	31.3	0.046
93/94	23.6	27.4	25.1	29.8	0.043
94/95	17.6	17.8	16.4	19.3	0.041
95/96	16.7	16.2	14.9	17.5	0.041
96/97	13.0	12.5	11.5	13.5	0.041
97/98	11.9	13.4	12.3	14.6	0.044
98/99	12.7	12.4	11.4	13.5	0.043
99/00	12.9	11.7	10.8	12.7	0.043
00/01	14.6	12.9	11.9	14.0	0.042
01/02	16.8	14.6	13.5	15.9	0.041
02/03	19.7	17.2	15.8	18.6	0.042
03/04	16.8	18.0	16.6	19.4	0.039
04/05	20.2	19.2	17.8	20.7	0.039
05/06	19.2	15.8	14.6	17.0	0.040

The standardised series shows a variable increasing trend to the late 1970s followed by a decline to the mid-1980s (Figure B.2; Table B.7). There is a subsequent increase in relative CPUE to a peak around 1993/94 followed by a steep drop towards 1996/97, the year that 100% observer coverage was introduced (Figure B.2). Relative CPUE bottomed out around 1999/2000 and has since increased up to 2004/05, followed by a drop in the most recent fishing year. The arithmetic CPUE series (Eq. B.5) and the unstandardised series (Eq. B.6) have trends which are very similar to that described for the standardised series. Plots of the explanatory coefficients are similar to the equivalent plots for the series based on data beginning in 1996/97, with the strongest relative CPUE associated with the Swiftsure DFO locality (coded 106; Figure B.3). Model residuals show small deviations from the lognormal assumption at the lower tail of the distribution (Figure B.4).

Combined areas 5C and 5D: Long-term standardised GLM (1966/67 to 2005/06):

Data from the *PacHarvestTrawl* database were used to define the preferred depth distribution for English sole in combined areas 5CD, based on all bottom trawl records which recorded the capture of English sole. The depth distribution of this data set ranged from 30 m to about 200 m, with only sporadic observations at depths more shallow than 30 m and deeper than 200 m (Figure B.5). The GLM models for Area 5CD used all valid tows occurring between 30 and 210 m aggregated into 20 m bins.

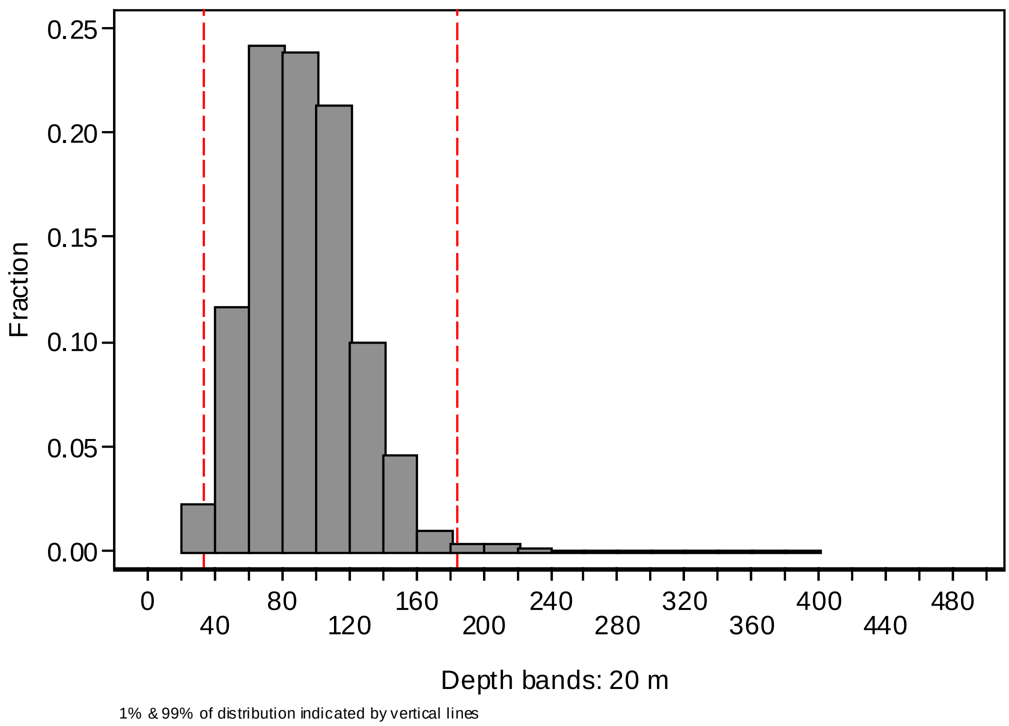


Figure B.5. Depth distribution of tows with reported English sole catch in the combined Areas 5C and 5D from 1996/97 to 2005/06 in 20 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=33 m; 99%=185 m.

Table B.6: Order of acceptance of variables into the 1966/67–2005/06 combined areas 5C and 5D model of positive landed catches of English sole with the amount of explained deviance (R^2) for each additional model variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.

Variable	1	2	3	4
Year*	**0.043**			
DFO locality*	0.299	**0.331**		
Depth bands*	0.137	0.169	**0.363**	
Month	0.006	0.049	0.335	0.367
DFO major area	0.059	0.099	0.331	0.363
Improvement in deviance	0.000	0.288	0.032	0.004

The available explanatory variables used in the analysis are described in the introductory section. Depth entered the model as a factor with 9 levels determined by 20 m depth intervals and there were 21 DFO localities. The final model accounted for 36% of the variation (Table B.6).

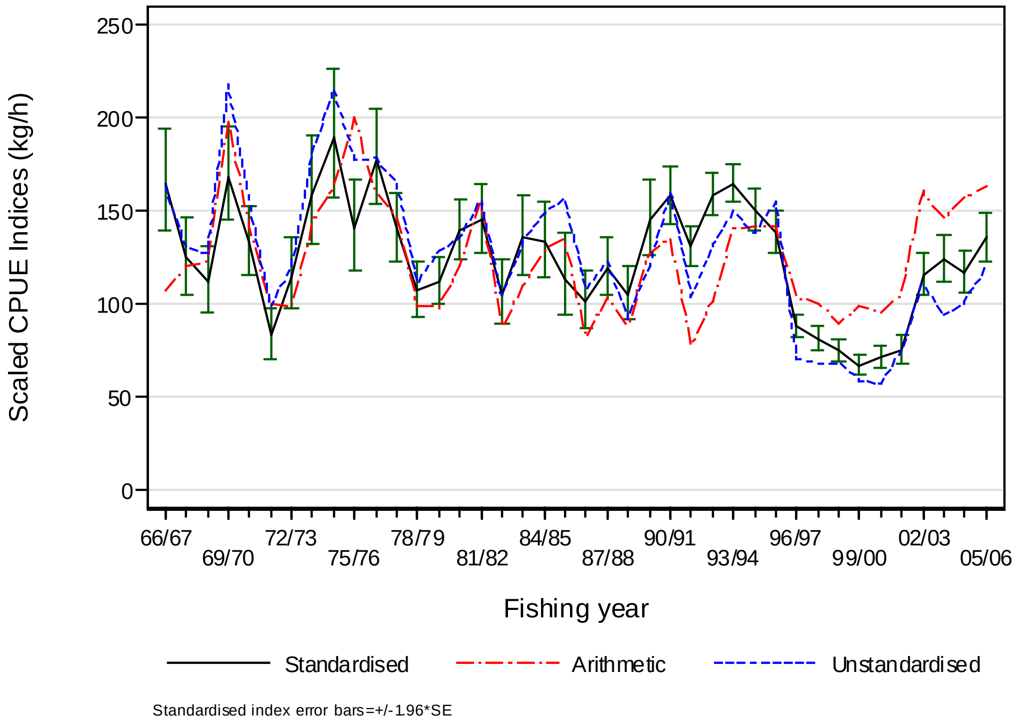


Figure B.6. Three annual series based on CPUE analyses (landed catch per hour) for combined areas 5C and 5D landed English sole catches from 1966/67 to 2005/06. The solid line is a standardised analysis correcting for year of catch, DFO locality, and 20 m depth band category (Eq. B.2). The other two series correspond to annual indices calculated using Eq. B.5 and Eq. B.6 respectively.

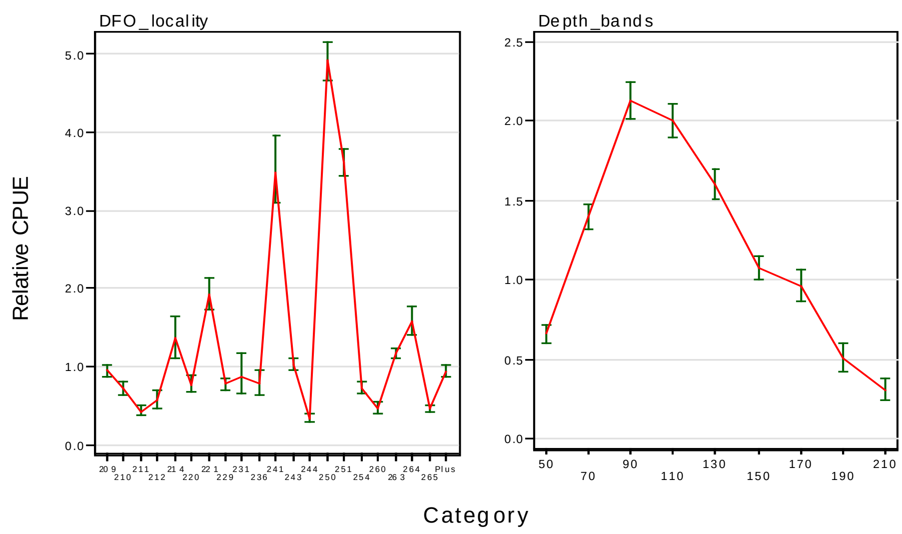


Figure B.7. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure B.6.

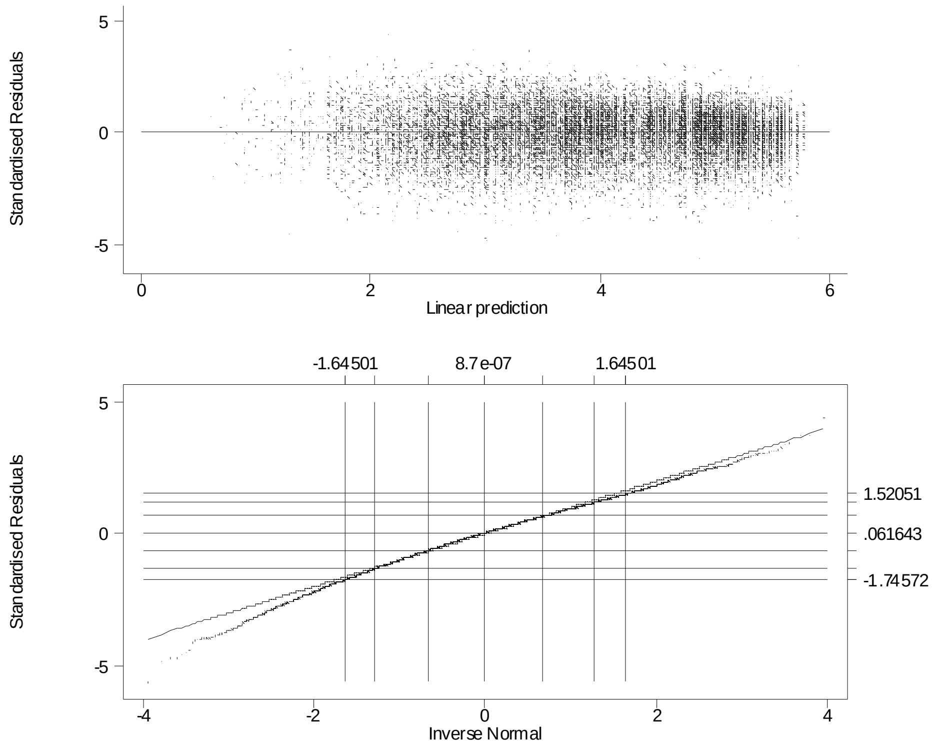


Figure B.8. Standardised (Pearson) residuals for the 5CD GLM analysis presented in Figure B.6. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

The standardised series shows some short-term fluctuations in the late 1960s and the 1970s (which may be an artefact of the data) followed by a period of little trend from the late 1970s to the mid-1990s (Figure B.6; Table B.7). There is a strong drop in relative CPUE in 1996/97, the year that 100% observer coverage was introduced, followed by several years at this lower level (Figure B.6). Relative CPUE has increased steadily since the early 2000s. The arithmetic CPUE series has been relatively steady throughout the series, except since 2001/02 when the series has increased more quickly than either the standardised or unstandardised series. A plot of the explanatory locality coefficients shows strong peaks associated with west Two Peaks (index=241), Butterworth (index=250), and Two Peaks (index=251; Figure B.7). These are all areas of known good English sole catch rates. The depth bin coefficients peak at the 70-90 m bin, with rapidly dropping catch rates at deeper depths. There is no strong seasonal pattern as the month variable did not enter the model above the 1% deviance threshold. Model residuals show some deviations at the lower tail of the distribution (Figure B.8).

Table B.7. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised index for combined areas 5C and 5D model of non-zero catches of English sole. The standardised series has been scaled to the geometric mean of the arithmetic series.

Year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
66/67	107	165	140	194	0.084
67/68	120	125	106	147	0.084
68/69	123	112	96	131	0.080
69/70	199	168	145	195	0.075
70/71	142	133	116	153	0.070
71/72	100	83	71	98	0.083
72/73	98	115	98	135	0.083
73/74	144	159	133	190	0.092
74/75	163	189	158	226	0.092
75/76	200	140	119	166	0.086
76/77	161	178	154	205	0.072
77/78	147	140	123	160	0.068
78/79	99	107	93	123	0.070
79/80	98	112	100	125	0.056
80/81	120	139	124	156	0.058
81/82	156	145	128	165	0.065
82/83	88	105	90	124	0.083
83/84	110	136	116	159	0.080
84/85	129	133	114	155	0.078
85/86	135	114	94	138	0.098
86/87	82	101	86	118	0.080
87/88	104	119	105	135	0.065
88/89	89	105	92	120	0.070
89/90	128	145	126	167	0.070
90/91	135	158	143	174	0.050
91/92	78	131	120	142	0.043
92/93	102	159	148	170	0.036
93/94	140	164	155	175	0.031
94/95	142	151	140	162	0.038
95/96	142	138	127	150	0.042
96/97	103	88	82	95	0.036
97/98	101	82	75	88	0.040
98/99	90	75	70	81	0.040
99/00	99	67	62	72	0.041
00/01	95	71	66	78	0.043
01/02	106	76	68	84	0.052
02/03	161	116	105	128	0.049
03/04	146	124	113	137	0.050
04/05	158	117	106	129	0.051
05/06	164	135	123	149	0.048

Investigations into the effect of interactions in the 5CD long-term CPUE analysis:

Interaction effects were investigated for the 5CD long-term model through two additional models. One model discarded the DFO locality information and relied on the month and depth explanatory variables along with an added monthXdepth interaction term to account for a known pattern in the Hecate Strait fishery where vessels move to deeper water in the winter to capture spawning or mature fish. This model had much less explanatory power than the base model, with only 19% of the variability explained compared to 36% for the base model (Table B.8).

However, the resulting year indices are virtually identical to the base model, indicating that most of the shift in the base model from the arithmetic series is probably due to the month and depth variables (Figure B.9). A second model built on the fit presented in Table B.6 by offering the base model two interaction terms (DFOLocalityXdepth and MonthXDepth) after the base model had been fit. This model explained an additional 4% of deviance, raising the overall deviance explained to 40% (Table B.9). However, the year indices estimated by this model differed very little from the year indices from the base model (Figure B.9).

Table B.8: Order of acceptance of variables into the 1966/67–2005/06 combined areas 5C and 5D model of positive landed catches of English sole with the amount of explained deviance (R^2) for each additional model variable. The model was restricted to the depth and month primary variables followed by offering the model a single depthXmonth interaction term after the two primary variables had been accepted. Year was forced as the first variable.

Variable	1	2	3	4
Year*	**0.0432**			
Depth bands*	0.1371	**0.169**		
Month	0.0057	0.049	**0.1742**	
MonthXDepth				**0.1887**
Improvement in deviance	0	0.1258	0.0052	0.0146

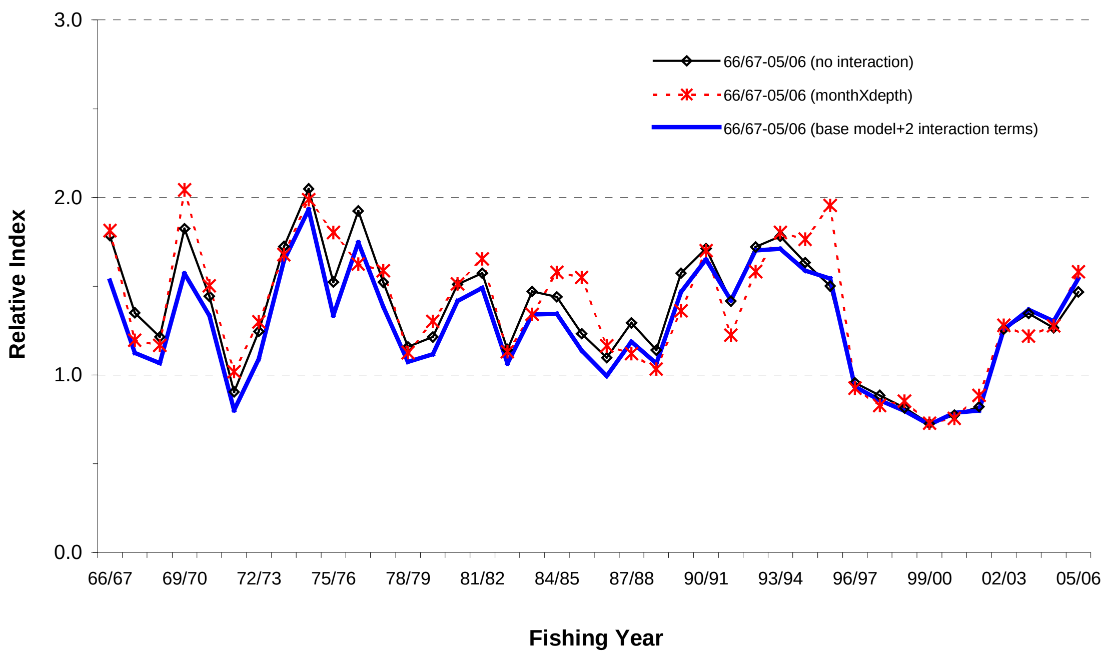


Figure B.9. Plots of year indices for three standardised models: a) base model with 4 explanatory variables (Table B.6); b) model with year, month, depth, and monthXdepth variables only (Table B.8); c) base model with additional interaction terms (Table B.9). Each series has been normalised relative to its mean.

Interactions with the year variable were not investigated because it is not clear how to interpret such effects. If there is such an interaction, then the interpretation is that each of the areas should be analysed independently. However, such an analysis is not always useful when using the assessment to provide management advice for wide areas of the coast. Accordingly it was assumed that, for the purposes of this assessment, that the year indices calculated from the based models provided useable estimates of abundance trends for English sole in 5CD and 3CD5AB from 1966/67 to 2005/06.

Table B.9: Order of acceptance of variables into the 1966/67–2005/06 combined areas 5C and 5D model of positive landed catches of English sole with the amount of explained deviance (R^2) for each additional model variable. The model was then offered two interaction terms after all the primary variables had been accepted. Year was forced as the first variable.

Variable	1	2	3	4	5
Year	**0.043**				
DFO locality	0.299	**0.331**			
Depth bands	0.137	0.169	**0.363**		
Month	0.006	0.049	0.335		
DepthXLocality				**0.390**	
MonthXDepth				0.375	**0.400**
Improvement in deviance	0.000	0.288	0.032	0.027	0.011

Suggestions from fishing industry representatives for improving the English sole CPUE analysis:

In December 2006, Ron Gorman and Brian Mose, both west coast trawl skippers of considerable experience and at the request of the Canadian Groundfish and Conservation Society (CGRCS), provided a set of rules that characterised the English sole fisheries on the B.C. coast in the Queen Charlotte Sound (Areas 5AB) and Hecate Strait (Areas 5CD; Table B.10). These rules were used to select data to be incorporated into an alternative long-term standardised CPUE analysis which could be compared to the original analysis based on a more complete data set.

Table B.10. List of characteristics that define the Petrale sole and English sole fisheries on the west coast of Canada for use in selecting data for standardised CPUE analyses performed on these species.

	CGRCS rules	**Original analysis**
Most representative areas	5AB 5CD	3CD5AB 5CD
Representative depth range	5AB: 100–190 m (60–100 fm)	5AB: 50–280 m
	5CD: 50-65 fm (expanded to 40–65 m because of insufficient data)	5CD: 30-210 m
Representative season	5AB: March–Nov. 5CD: May–Oct.	5AB: April–March 5CD: April–March

Analyses were performed on 5AB and 5CD English sole using the "CGRCS rules" which were then compared to analyses using a wider (in terms of fewer restrictions when filtering the data) and thus a more comprehensive data set, as summarised in Table B.10. Note that the details of the 5AB wider analysis is not presented in this document because the analysis was not used in the stock assessment. However, the revised analysis using the more restricted data set was nearly identical to the analysis based on the wider data set, both in terms of the trajectories (Figure B.10) and in terms of the absolute mean CPUE (expressed in kg/hour; Table B.11). The trajectories show the same pattern and will be interpreted similarly by the stock assessment model.

In the case of the 5CD analysis, there is a considerable difference between the wider analysis (presented beginning page 55) and the trajectory based on the restricted data set, whether viewed in terms of kg/hour ([left panel] Figure B.11) or as relative indices scaled to the same mean ([right panel] Figure B.11). This is borne out when the mean CPUE for each analysis is compared, with the CPUE based on the original (wider) analysis being about 30% higher than the

CPUE using the CGRCS rules described in Table B.10 (126 kg/h compared to 95 kg/h; Table B.11). Both series show a strong upturn at the end of the series, but the upturn occurs sooner and stronger for the indices based on the original analysis.

Table B.11. Number of records and mean CPUE from all records for each analysis based on the region analysed and the set of data selection rules that were applied.

			CGRCS rules	**Original analysis**
English sole	Number records (1966–2005)	5CD	8914	25472
		5AB	4852	12369
	Mean CPUE (kg/h)	5CD	95	126
		5AB	18	16

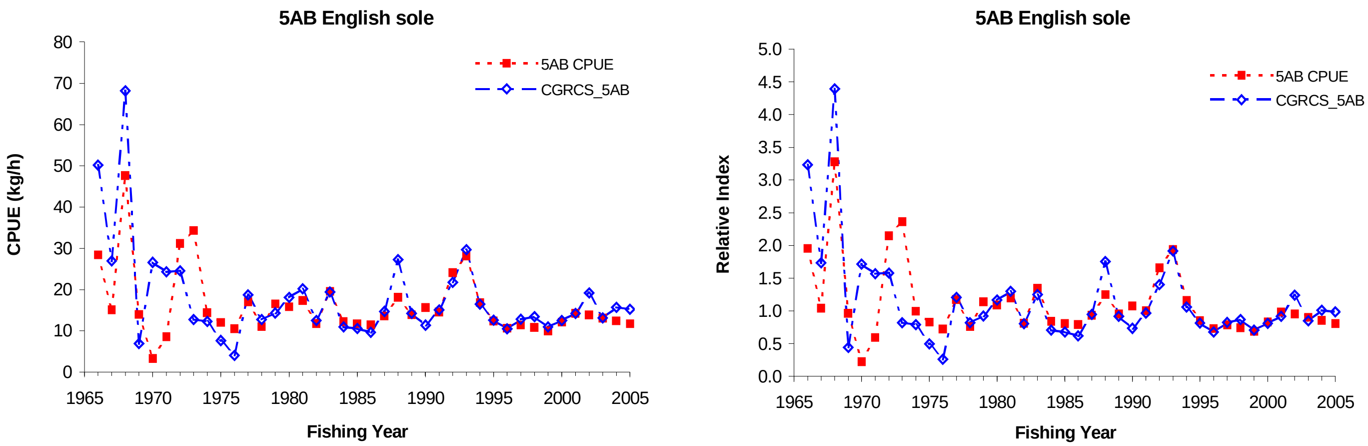


Figure B.10. 5AB English sole CPUE for the period 1966/67 to 2005/06 using the two sets of data selection “rules” described in Table B.10. [left panel]: CPUE plotted as kg/h; [right panel]: CPUE plotted as an index relative to the average 1966/67–2005/06 CPUE.

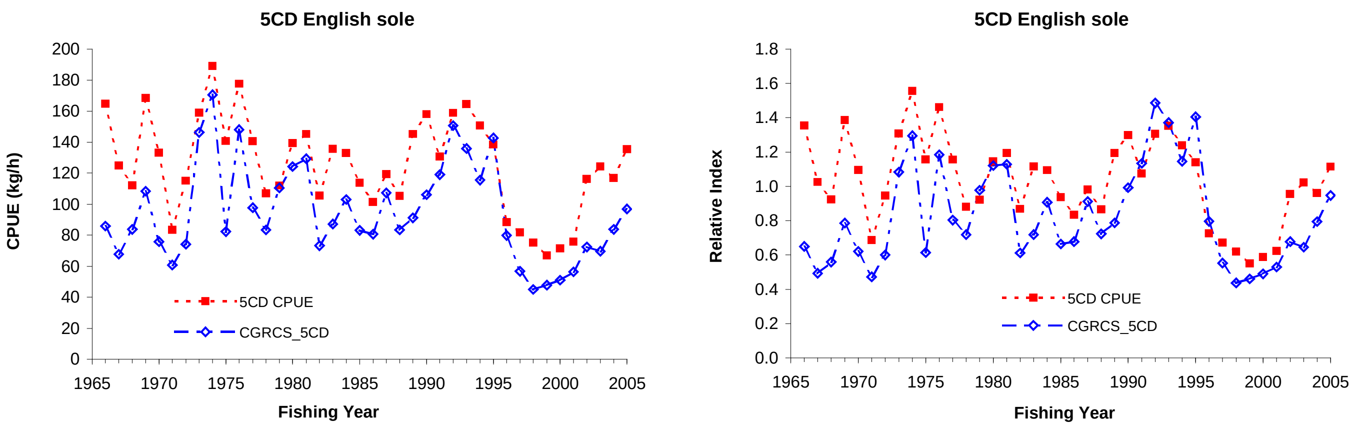


Figure B.11. 5CD English sole CPUE for the period 1966/67 to 2005/06 using the two sets of data selection “rules” described in Table B.10. [left panel]: CPUE plotted as kg/h; [right panel]: CPUE plotted as an index relative to the average 1966/67–2005/06 CPUE.

The “wide” analyses (labelled “original analysis” in Table B.10) were selected to be used in both the 5CD and the 3CD5AB assessments. This choice was based on better model performance (in terms of residual diagnostics) shown by the “wide” models, largely because they included a greater amount of data and thus representing a larger piece of the fishery.

Appendix C. ENGLISH SOLE FISHERY INDEPENDENT SURVEYS

Introduction

Four sets of trawl survey indices were used in the west coast B.C. English sole assessment. These were the west coast Vancouver Island (WCVI) Triennial survey, the Queen Charlotte (QC) Sound synoptic survey, the Hecate Strait (HS) Pacific cod monitoring survey and the Hecate Strait assemblage survey. The indices for English sole from these four surveys are documented in this Appendix. Two other surveys, the WCVI shrimp trawl survey and the QC shrimp trawl survey, potentially may provide information that would be useful in a quantitative stock assessment for English sole. However, close examination of these indices indicated that it was unlikely that they could provide useful indices of abundance for this species. The trajectory for the WCVI shrimp survey is characterised by a long period of over 20 years where there were low and somewhat erratic biomass levels (Figure C.1). The most recent ten years show higher biomass levels, but these fluctuate greatly from year to year, indicating a very high level of process error in these estimates. The QC Sound shrimp survey, a more recent addition, appears to be following a similar erratic process (Figure C.1). Early attempts at using these surveys in the assessment model indicated that it would not be possible to fit the large variations in abundance and it was decided to discard these two indices from the assessment.

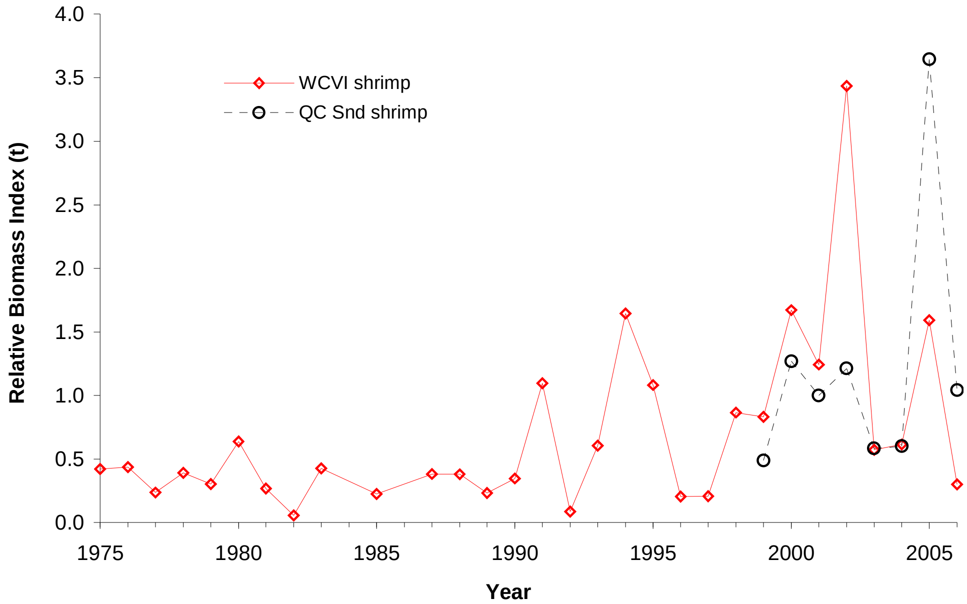


Figure C.1. English sole biomass indices from the WCVI and QC Sound shrimp surveys, plotted as indices relative to the 1999–2006 mean, which is the period covered by the QC Sound shrimp survey.

Theory

All survey data for English sole were analysed using the following equations which assume that tow locations were selected randomly within a stratum relative to the biomass of English sole. This is an assumption made by the following equations but may not have been part of the original survey design. Comments on this issue will be made when each survey is discussed.

The biomass in any year *y* was obtained by summing the product of the CPUE and the area surveyed across the surveyed strata *i*:

$$B_y = \sum_{i=1}^{k} C_{y_i} A_i = \sum_{i=1}^{k} B_{y_i} \qquad \text{Eq. C.1}$$

where C_{y_i} = mean CPUE density (kg/km^2) for species *s* in stratum *i*

A_i = area of stratum *i* (km^2), and

B_{y_i} = biomass of English sole in stratum *i* for year *y*.

k = number of strata

CPUE $\left(C_{y_i}\right)$ for English sole in stratum *i* for year *y* was calculated as a density in kg/km^2 by

$$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \big/ D_{y_i j} w_{y_i j} \right)}{n_{y_i}} \qquad \text{Eq. C.2}$$

where $W_{y_i j}$ = catch weight (kg) for English sole in stratum *i* for year *y* and tow *j*

$D_{y_i j}$ = distance travelled (km) by tow *j* in stratum *i* for year *y*

$w_{y_i j}$ = net opening (km) by tow *j* in stratum *i* for year *y*

n_{y_i} = number of tows in stratum *i*

The variance of the survey biomass estimate V_y for English sole in year *y* is calculated in kg^2 as follows:

$$V_y = \sum_{i=1}^{k} \sigma_{y_i}^2 A_i^2 \big/ n_{y_i} = \sum_{i=1}^{k} V_{y_i} \qquad \text{Eq. C.3}$$

where $\sigma_{y_i}^2$ = variance of CPUE (kg^2/km^4) for species *s* in stratum *i*

V_{y_i} = variance of English sole in stratum *i* for year *y*

The CV for English sole for each year *y* was calculated as follows:

$$CV_y = \frac{\sqrt{V_y}}{B_y} \qquad \text{Eq. C.4}$$

Five thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Effron 1982).

NFMS triennial trawl survey

Introduction and data

Tow-by-tow data from the triennial survey covering the Vancouver INPFC (International North Pacific Fisheries Commission) region were provided by Mark Wilkins (U.S. National Marine Fisheries Service; NFMS) for the seven years that surveyed Canadian waters (Figure C.2; Table C.1). These tows are assigned to strata by the NFMS, but the size and definition of these strata have changed over the life of the survey (Table C.2). The NFMS also provided information as to which country's waters the tow was located. This information was plotted and checked against the accepted US/Canada marine boundary: all tows appeared to be appropriately located with respect to country, based on the tow start position (Figure C.2). The NFMS designations were accepted for tows located near the marine border.

Table C.1. Number of tows by stratum and by survey year for the NFMS triennial survey. Strata which are coloured grey have been excluded from the analysis due to incomplete coverage across the seven survey years or to locations outside of the Vancouver INPFC area (Table C.2).

Stratum		**1980**		**1983**		**1989**		**1992**		**1995**		**1998**		**2001**
No.	Canad	**US**	Canad	**US**	**Canad**	**US**	**Canad**	**US**	**Canad**	**US**	**Canad**	**US**	**Canad**	**US**
10		17		7										
11	48			39										
12			38											
17N						8		9		8		8		8
17S						27		27		25		26		25
18N					1		1							
18S						32		23		12		20		14
19N					58		53		55		48		33	
19S						4		6		3		3		3
27N						2		1		2		2		2
27S						5		2		3		4		5
28N					1		1		2		1			
28S						6		9		7		6		7
29N					7		6		7		6		3	
29S						3		2		3		3		3
30		4		2										
31	7			11										
32			5											
37N										1		1		1
37S										2		1		1
38N									1					
38S										2				3
39									6		4		2	
50		5		1										
51	4			10										
52			4											
Total	**59**	**26**	**47**	**70**	**67**	**87**	**61**	**79**	**71**	**68**	**59**	**74**	**38**	**72**

All usable tows have an associated net width and distance travelled, allowing for the calculation of the area swept by the tow. Biomass indices and the associated analytical CVs for English sole were calculated for the total Vancouver INPFC region and for each of the Canadian and Vancouver sub-regions, using appropriate area estimates for each stratum and year (Table C.2). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table C.1; Table C.2), allowing the remaining data to provide a comparable set of data for each year from 1989 onwards (Table C.3). The stratum definitions used in the 1980 and 1983 surveys were considerably different than those used in subsequent surveys, particularly in

Canadian waters (Table C.3). Therefore, the 1980 and 1983 indices were scaled up by the ratio (1.24=9169 km^2/7399 km^2) of the total stratum areas relative to the 1989 and later surveys so that the coverage from the first two surveys would be comparable to the surveys conducted from 1989 onwards. The tow density was much higher in the US waters although the overall number of tows was approximately the same for each country (Table C.3). This is because the size of the total area fished was about twice as large in Canadian waters than in US waters (Table C.3).

Table C.2. Stratum definitions by year used in the NFMS triennial survey to separate out the survey results by country and by INPFC area. Stratum definitions in grey are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or to locations outside of the Vancouver INPFC area.

Year	Stratum No.	Area (km^2)	Start	End	Country	INPFC area	Depth range
1980	10	3537	47°30	US-Can Border	US	Vancouver	55-183 m
1980	11	6572	US-Can Border	49°15	Canad	Vancouver	55-183 m
1980	30	443	47°30	US-Can Border	US	Vancouver	184-219 m
1980	31	325	US-Can Border	49°15	Canad	Vancouver	184-219 m
1980	50	758	47°30	US-Can Border	US	Vancouver	220-366 m
1980	51	503	US-Can Border	49°15	Canad	Vancouver	220-366 m
1983	10	1307	47°30	47°55	US	Vancouver	55-183 m
1983	11	2230	47°55	US-Can Border	US	Vancouver	55-183 m
1983	12	6572	US-Can Border	49°15	Canad	Vancouver	55-183 m
1983	30	66	47°30	47°55	US	Vancouver	184-219 m
1983	31	377	47°55	US-Can Border	US	Vancouver	184-219 m
1983	32	325	US-Can Border	49°15	Canad	Vancouver	184-219 m
1983	50	127	47°30	47°55	US	Vancouver	220-366 m
1983	51	631	47°55	US-Can Border	US	Vancouver	220-366 m
1983	52	503	US-Can Border	49 °15	Canad	Vancouver	220-366 m
1989&after	17N	1033	47°30	47°50	US	Vancouver	55-183 m
1989&after	17S	3378	46°30	47°30	US	Columbia	55-183 m
1989&after	18N	159	47°50	48°20	Canad	Vancouver	55-183 m
1989&after	18S	2123	47°50	48°20	US	Vancouver	55-183 m
1989&after	19N	8224	48°20	49°40	Canad	Vancouver	55-183 m
1989&after	19S	363	48°20	49°40	US	Vancouver	55-183 m
1989&after	27N	125	47°30	47°50	US	Vancouver	184-366 m
1989&after	27S	412	46°30	47°30	US	Columbia	184-366 m
1989&after	28N	88	47°50	48°20	Canad	Vancouver	184-366 m
1989&after	28S	787	47°50	48°20	US	Vancouver	184-366 m
1989&after	29N	942	48°20	49°40	Canad	Vancouver	184-366 m
1989&after	29S	270	48°20	49°40	US	Vancouver	184-366 m
1995&after	37N	102	47°30	47°50	US	Vancouver	367-500 m
1995&after	37S	218	46°30	47°30	US	Columbia	367-500 m
1995&after	38N	66	47°50	48°20	Canad	Vancouver	367-500 m
1995&after	38S	175	47°50	48°20	US	Vancouver	367-500 m

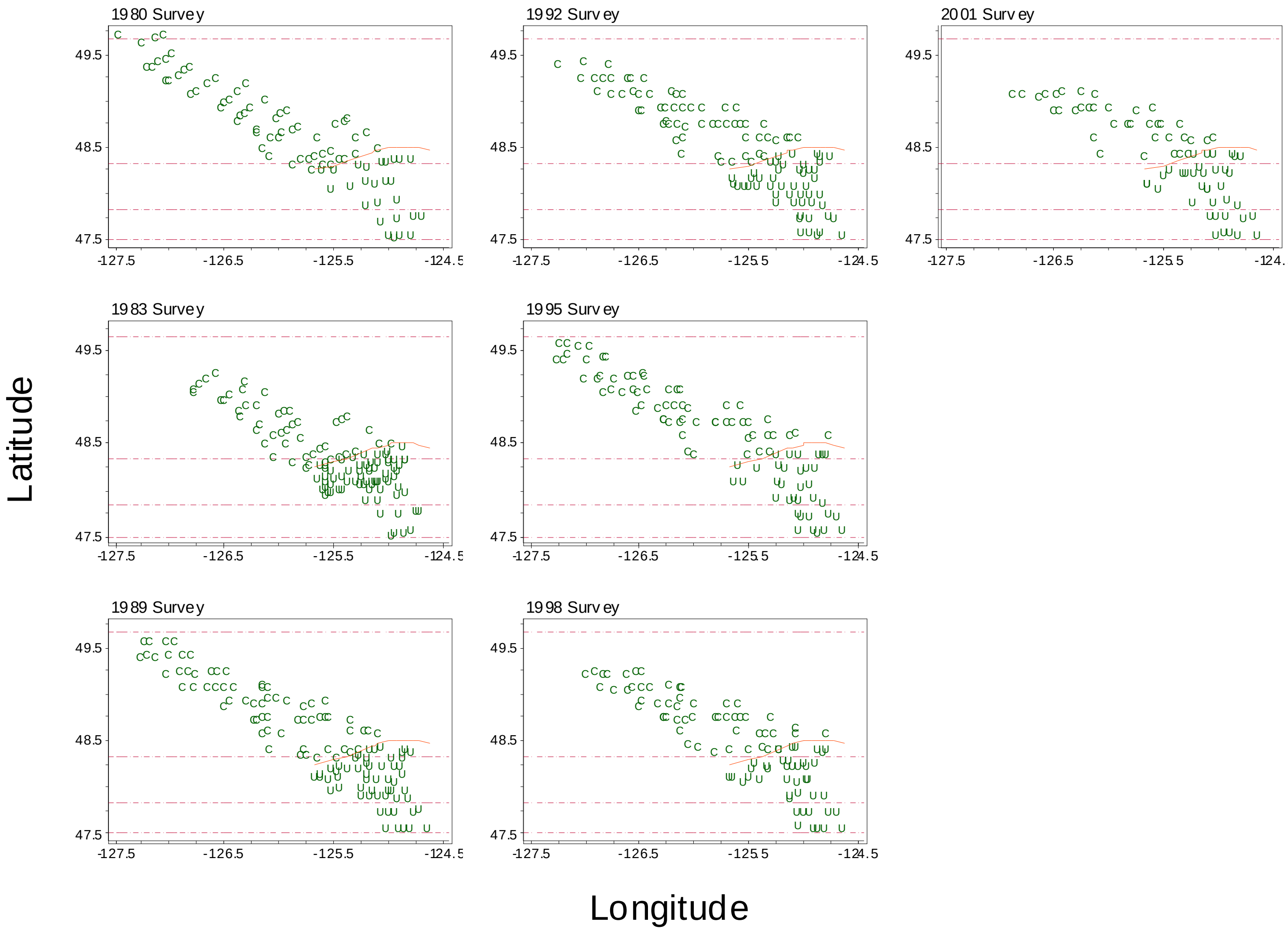


Figure C.2. Plot of tow locations in the Vancouver INPFC region for each of the seven triennial surveys that surveyed Canadian waters. The approximate position of the US/Canada marine boundary is shown and each tow is coded with a "C" or a "U", depending on to which nation the tow is assigned in the database. The horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°40'.

Table C.3. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States. Strata 18N, 28N, 37, 38 and 39 (Table C.2) were dropped from this analysis as they were not consistently conducted over the survey period. All strata occurring in the Columbia River INPFC region (17S and 27S; Table C.2) were also dropped.

	Number tows			Area surveyed (km^2)		
Survey year	**Canadian waters**	**US waters**	Total	**Canadian waters**	**US waters**	**Total**
1980	59	26	85	7,399	4,738	12,137
1983	47	70	117	7,399	4,738	12,137
1989	65	55	120	9,166	4,699	13,865
1992	59	50	109	9,166	4,699	13,865
1995	62	35	97	9,166	4,699	13,865
1998	54	42	96	9,166	4,699	13,865
2001	36	37	73	9,166	4,699	13,865
Total	382	315	697	–	–	–

Methods

The data were analysed using Eq. C.1 to Eq. C.4, along with some additional assumptions which were required to calculate separate biomass estimates for United States and Canadian waters. It was assumed that the variance and CPUE within any stratum was equal, even for strata that were split by the presence of the US/Canada border. The total biomass $\left(B_{y_i}\right)$ within a stratum which straddled the border was split between the two countries $\left(B_{y_{i_c}}\right)$ by the ratio of the relative area within each country:

$$B_{y_{i_c}} = B_{y_i} \frac{A_{y_{i_c}}}{A_{y_i}} \qquad \text{Eq. C.5}$$

where $A_{y_{i_c}}$ = area (km^2) within country c in year y and stratum i

The variance $V_{y_{i_c}}$ for that part of stratum i within country c was calculated as being in proportion to the ratio of the square of the area within each country c relative to the total area of stratum i. This assumption resulted in the CVs within each country stratum being the same as the CV in the entire stratum:

$$V_{y_{i_c}} = V_{y_i} \frac{A^2_{y_{i_c}}}{A^2_{y_i}} \qquad \text{Eq. C.6}$$

The partial variance $V_{y_{i_c}}$ for country c was used in Eq. C.3 instead of the total variance in the stratum V_{y_i} when calculating the variance for the total biomass in US or Canadian waters. The CV for each year y and country was calculated as in Eq. C.4 using the appropriate biomass and variance.

The biomass estimates (Eq. C.1) and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table C.3. This was required to adjust the Canadian biomass estimates for 1980 and 1983 to account for the smaller area surveyed in those years compared to the succeeding surveys. The biomass estimates from Canadian waters were consequently multiplied by the ratio 1.24 (=9166/7399) to make them equivalent to the coverage of the surveys from 1989 onwards.

Biomass estimates were bootstrapped for 5000 random draws with replacement to obtain bias corrected (Effron 1982) 95% confidence regions for each year and for three area categories (total Vancouver region, Canadian Vancouver only and US Vancouver only) based on the distribution of biomass estimates and using the above equations.

Results

English sole were caught frequently in all seven surveys, although this species appears to be less frequent in the first two surveys compared to subsequent surveys (Figure C.3). The northern extension of the survey has varied between years (Figure C.3). This difference has been compensated for by using a constant survey area for all years. Coverage by depth has been consistent for all seven years of the survey (Figure C.4).

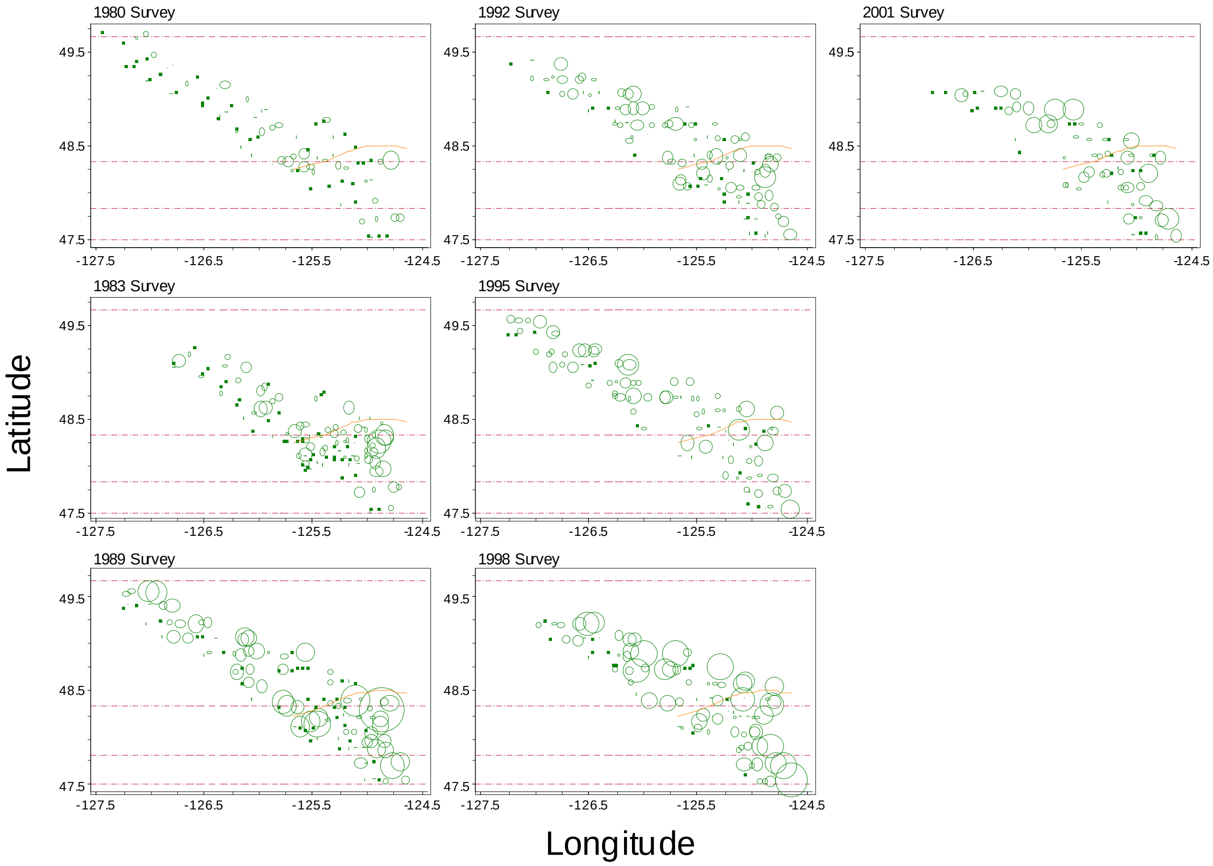


Figure C.3. Plot of valid tows, weighted by the catch of English sole, in the Vancouver INPFC region for the seven triennial surveys that surveyed Canadian waters. Catches in each year are scaled to the weight of the largest catch of English sole (172 kg in 1989). Tows with zero catch of English sole are coded with a "■". The approximate position of the US/Canada marine boundary is shown. The horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°40'.

The biomass estimates obtained show an increasing trend for both the Canadian Vancouver sub-region and for the US Vancouver section of the region over the first six surveys (Figure C.5). There is a drop between the last survey in 2001 compared to the previous index in 1998, although there is considerable overlap in the confidence bounds. The trend for the Total Vancouver INPFC region is similar to the series from either side of the border. The English sole biomass estimates have reasonably precise CVs, ranging from about 15% in 1992 to 36% in 1980 for the total Vancouver region (Table C.4). This indicates that the overall series trend is credible, although adjacent indices are likely not significantly different. Note that the bootstrap estimates of CV do not include any uncertainty with respect to the ratio expansion required to make the 1980 and 1983 survey estimates comparable to the 1989 and later surveys. Therefore, it is likely that the true uncertainty for this series is greater than estimated here.

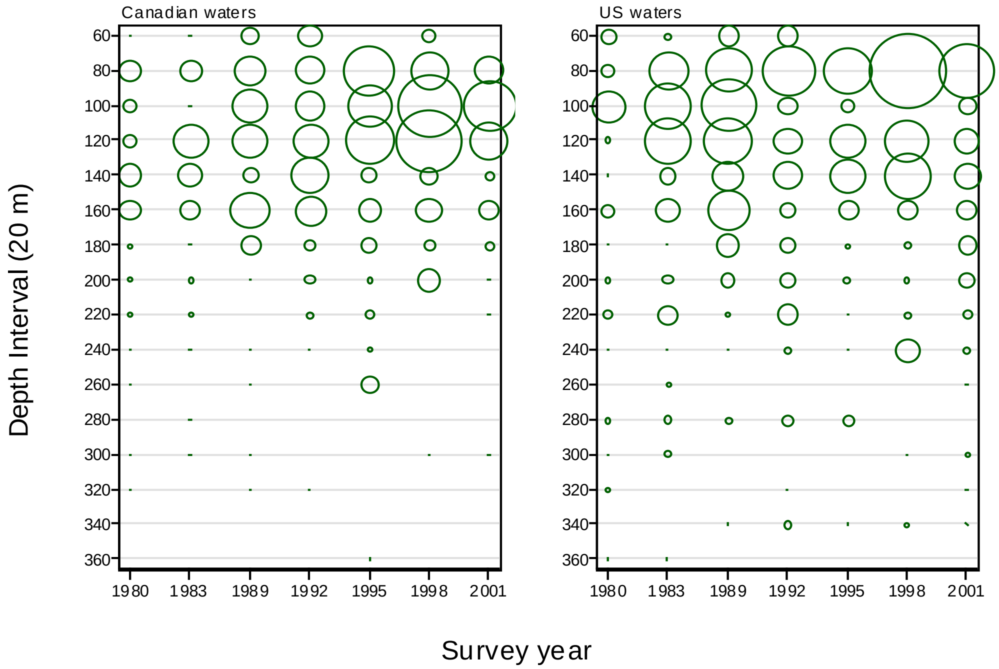


Figure C.4. Distribution of English sole catch weights for each survey year summarised into 20 m depth intervals for all valid tows (Table C.2) in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the deepest limit of the interval. Maximum circle size=341 kg (US waters).

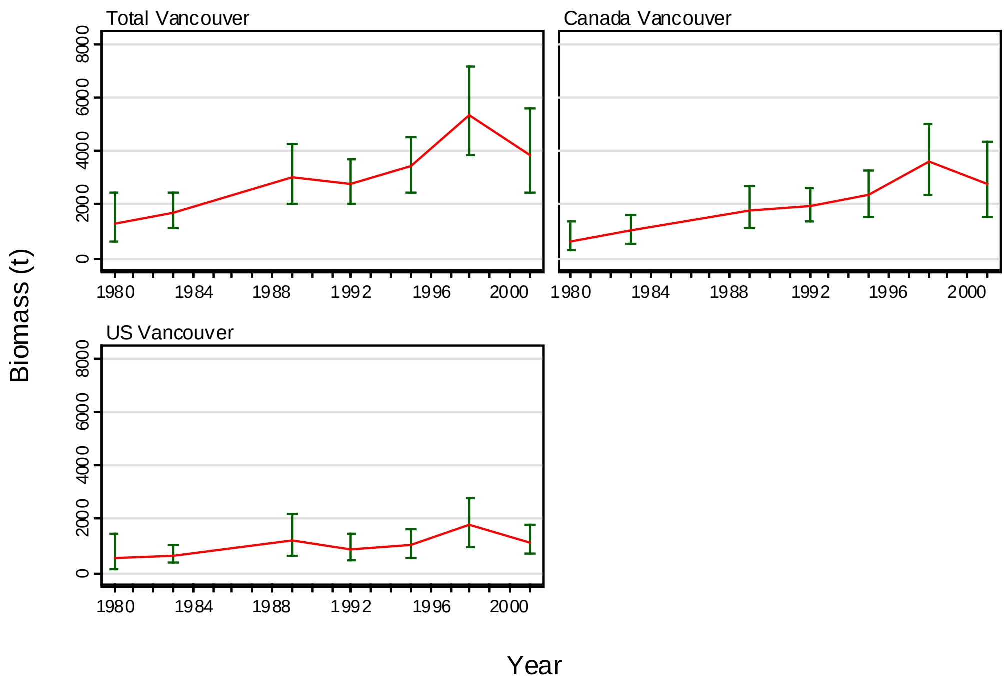


Figure C.5. Three biomass estimates for English sole in the INPFC Vancouver region (total region, Canadian waters only and US waters only) with 95% bias corrected error bars estimated from 5000 bootstraps.

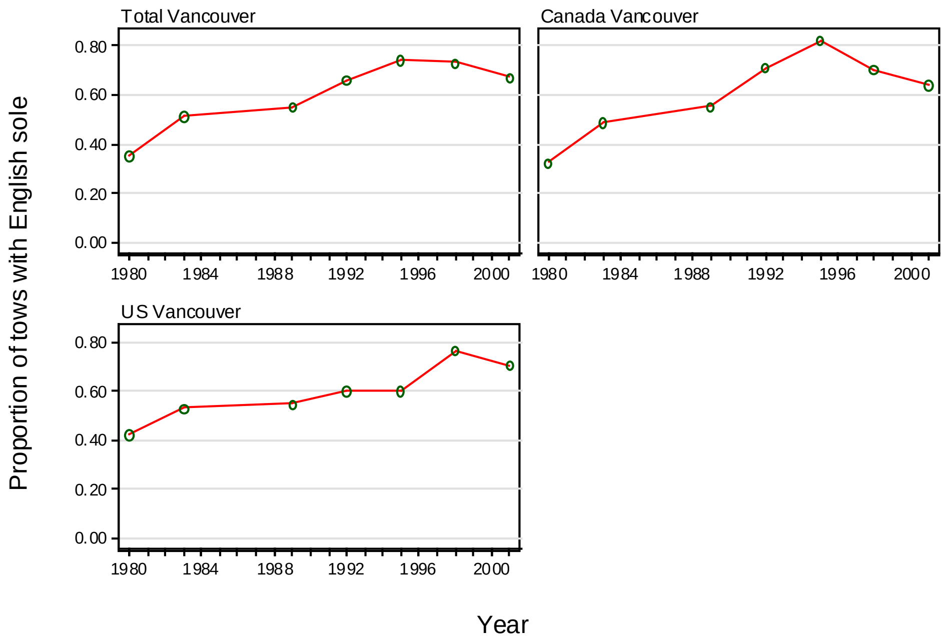


Figure C.6. Proportion of tows with English sole by year for the Vancouver INPFC region (total region, Canadian waters only and US waters only).

Table C.4. Biomass estimates for English sole in the Vancouver INPFC region (total region, Canadian waters only and US waters only) with 95% confidence regions based on the bootstrap distribution of biomass. Biomass estimates are calculated as in Eq. 1. The bootstrap estimates are based on 5000 random draws with replacement.

Estimate type	**Year**	**Biomass (Eq. 1)**	**Mean bootstrap biomass**	**Lower bound biomass**	**Upper bound biomass**	**CV bootstrap**	**CV Analytic (Eq. 4)**
Total Vancouver	1980	1,253	1,250	582	2,390	0.358	0.364
	1983	1,666	1,667	1,097	2,393	0.197	0.201
	1989	2,978	2,981	1,998	4,224	0.189	0.192
	1992	2,790	2,786	2,020	3,689	0.152	0.154
	1995	3,401	3,408	2,423	4,489	0.156	0.162
	1998	5,370	5,369	3,800	7,129	0.158	0.165
	2001	3,886	3,895	2,465	5,599	0.205	0.206
Canada Vancouver	1980	646	644	264	1,326	0.402	0.406
	1983	986	982	531	1,628	0.279	0.284
	1989	1,772	1,768	1,108	2,655	0.224	0.228
	1992	1,926	1,926	1,349	2,625	0.169	0.175
	1995	2,350	2,355	1,554	3,294	0.187	0.191
	1998	3,619	3,620	2,363	5,026	0.188	0.196
	2001	2,746	2,759	1,514	4,303	0.259	0.261
US Vancouver	1980	576	574	144	1,504	0.572	0.588
	1983	662	666	342	1,070	0.279	0.280
	1989	1,205	1,212	620	2,163	0.319	0.320
	1992	863	860	495	1,479	0.284	0.286
	1995	1,052	1,053	584	1,657	0.260	0.277
	1998	1,751	1,749	963	2,760	0.263	0.278
	2001	1,141	1,137	684	1,762	0.239	0.251

Five hundred twenty eight of the 878 tows in this data set caught English sole over the entire history of the survey. The proportion of tows which contain English sole has been relatively consistent around 60% of the tows, although that proportion dropped below 40% for the 1980 survey (Figure C.6).

Hecate Strait assemblage survey

Data from the Hecate Strait assemblage trawl survey for every year in each tow were made available (N. Olsen *pers. comm.*). The recommendations by Sinclair (1999) were used to analyse these data. These recommendations include:

a. distributing the tows into strata represented by 10 fathom depth intervals;

b. analysing the data in the range of 10 to 80 fathoms (to ensure comparability between surveys); and

c. applying a constant factor of 0.0486 km^2/h to convert the estimates of CPUE in kg/h to swept area estimates (see Eq. C.7 below).

Table C.5. Number of tows by depth zone and year of the Hecate Strait assemblage survey. Also shown are the estimated sizes of each stratum for the survey in square kilometres.

Year	**10-19 fm**	**20-29 fm**	**30-39 fm**	**40-49 fm**	**50-59 fm**	**60-69 fm**	**70-79 fm**	**Total**
1984	19	19	23	25	23	23	14	146
1987	15	12	12	11	16	10	9	85
1989	17	12	12	15	12	9	13	90
1991	18	12	15	10	21	15	7	98
1993	16	20	11	15	10	15	7	94
1995	17	19	15	16	14	14	7	102
1996	25	24	21	10	11	10	4	105
1998	14	11	17	13	13	14	4	86
2000	18	22	19	14	15	11	6	105
2002	17	17	15	16	11	10	6	92
2003	15	16	16	18	15	9	5	94
Area (km^2)	2,657	1,651	908	828	912	792	612	8,360

The distribution of tows by depth zone and survey year as presented by Sinclair (1999) could not be duplicated exactly, but the differences were small (compare Table C.10 below with Table 4 in Sinclair 1999). These differences may be due to different conversion assumptions as the depth data are provided in metres and the depth intervals are defined in fathoms. Alternatively, the original data may have been recorded in fathoms and there may be a loss in precision when converting from fathoms to metres and back to fathoms.

The data were analysed using Eq. C.1 to Eq. C.4 which assume that tow locations were selected randomly within a stratum relative to the biomass of English sole. This was not an assumption made by the original survey design and the depth zone stratum definitions presented in Table C.5 were not part of the original design when conducting the survey.

Sinclair (1999) suggested modifying the equation (Eq. C.7) for CPUE $\left(C_{y_i}\right)$ for English sole in stratum *i* for year *y* to obtain a density in kg/km^2 because there are insufficient data available to calculate density estimates in every year using Eq. C.2.

$$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \big/ E_{y_i j}\, 0.0486 \right)}{n_{y_i}} \qquad \text{Eq. C.7}$$

where $W_{y_i j}$ = catch weight (kg) for English sole in stratum *i* for year *y* and tow *j*

$E_{y_i j}$ = effort (h) by tow *j* in stratum *i* for year *y*

0.0486 = constant factor (km^2/h) applied to convert CPUE in kg/h to swept area (kg/km^2)

n_{y_i} = number of tows in stratum *I*

Results

The distribution of English sole catches from this survey tend to be along the edge of the shelf (Figure C.7). They are taken at all survey depths, but are most abundant from the 20-29 to 50-59 fathom depth strata (Figure C.8).

Table C.6. Biomass estimates for English sole from the Hecate Strait assemblage trawl survey for the survey years 1984 to 2003. Biomass estimates are based on a post-stratification of this survey into 10-fathom depth zones (Table C.5) and by assuming that the survey tows were randomly selected within these depth zones. Bootstrap bias corrected confidence intervals and CVs are based on 5000 random draws with replacement. The analytic CV (Eq. C.4) is based on the assumption of random tow selection within a stratum.

Survey year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. C.4)
1984	12,368	12,359	7,453	19,762	0.250	0.251
1987	9,541	9,536	5,315	16,541	0.295	0.289
1989	23,356	23,402	14,528	34,655	0.221	0.219
1991	20,025	20,040	14,942	26,832	0.149	0.148
1993	50,499	50,479	26,519	88,707	0.311	0.312
1995	11,933	11,879	7,023	19,989	0.272	0.271
1996	13,128	13,131	8,590	19,615	0.213	0.217
1998	15,287	15,233	8,416	26,024	0.290	0.285
2000	25,189	25,116	18,092	33,133	0.150	0.149
2002	24,912	24,817	16,905	35,855	0.192	0.194
2003	42,270	42,221	23,340	69,314	0.274	0.274

Estimated biomass levels for English sole from the Hecate Strait assemblage trawl survey were relatively flat over the first four surveys, but the biomass showed a very strong and significant increase in the 1993 survey to about 50,000 t (Figure C.9; Table C.6). The biomass then dropped to the previous levels in the next two surveys but has since recovered to near the maximum level. Confidence bounds are relatively good, with the estimated CVs for English sole ranging from about 0.15 to 0.31, depending on the year (Table C.6). The proportion of tows which held

English sole has been high throughout this survey, ranging from 65% to 90% per year, except for the 1987 survey where only 54% of the tows contained English sole (Figure C.10).

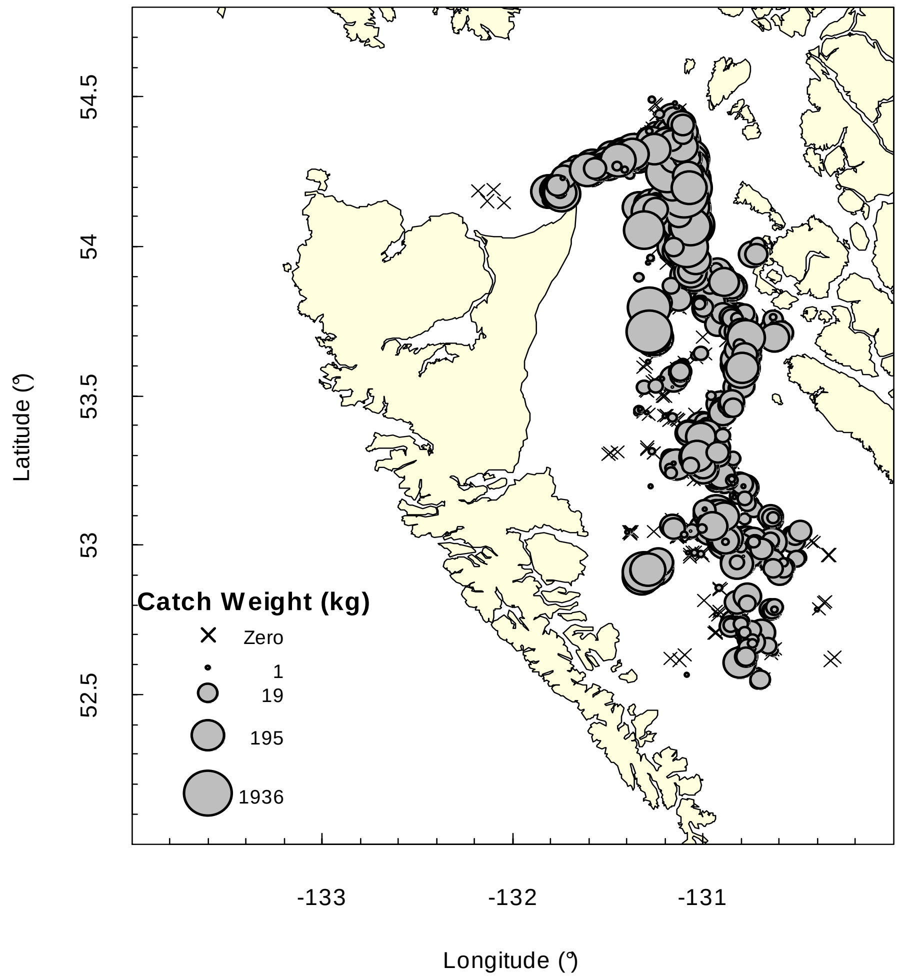


Figure C.7. Plot of starting tow locations for all survey tows in the Hecate Strait assemblage trawl survey: those that caught English sole are marked with circles proportional to the catch weight while those that caught no English sole are marked with an X.

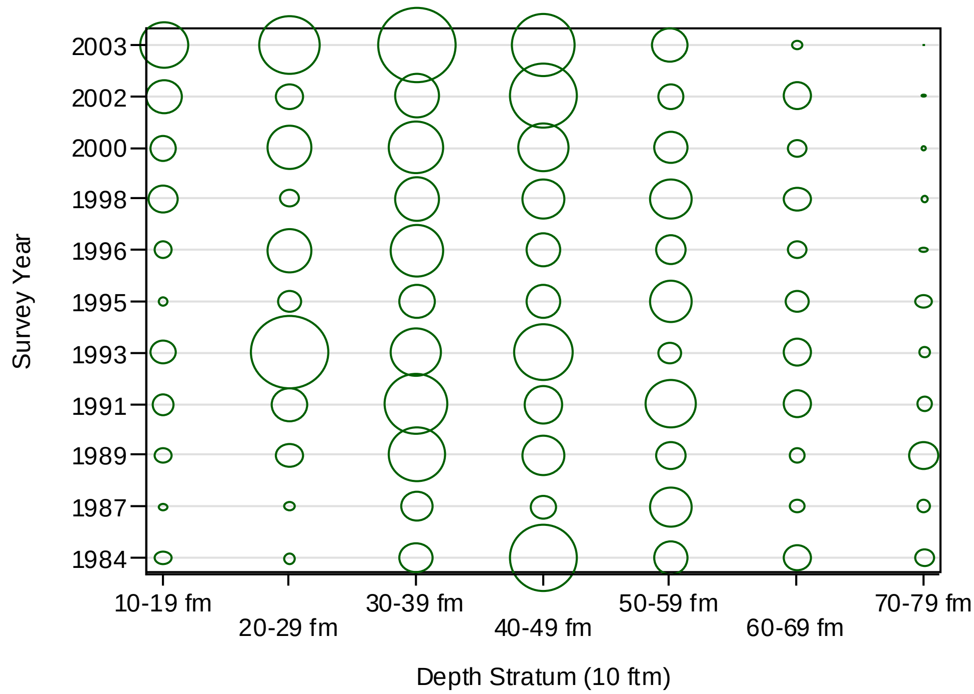


Figure C.8. Distribution of catch weight of English sole by depth stratum and survey year. Maximum circle size: 3780 kg.

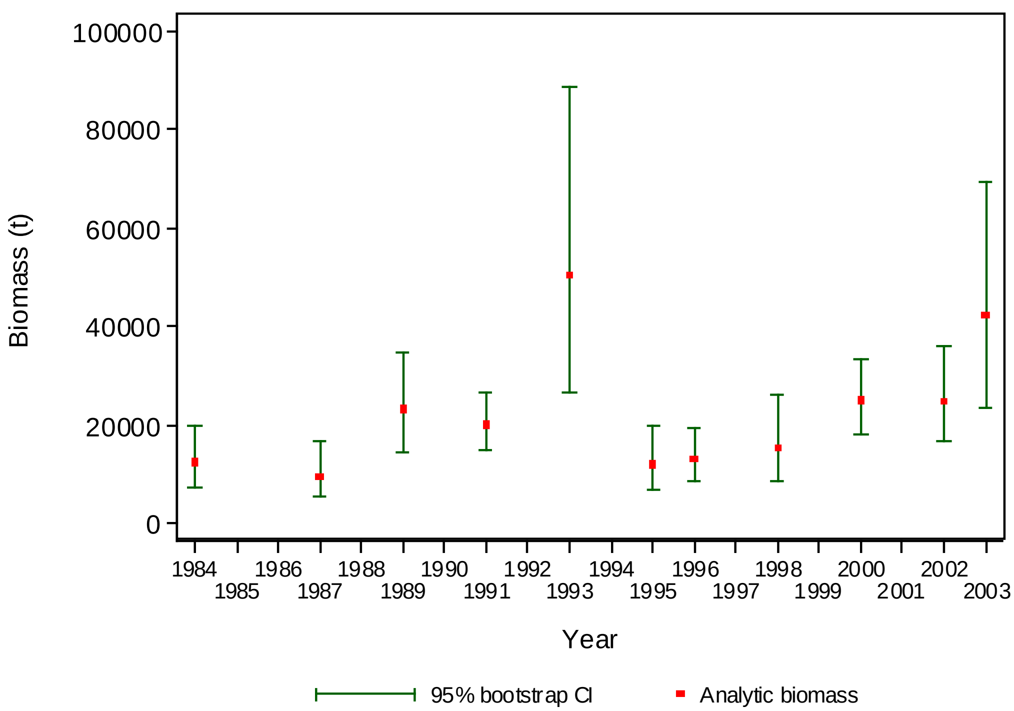


Figure C.9. Plot of biomass estimates for English sole from the Hecate Strait assemblage trawl survey for the period 1984 to 2003. Bias corrected 95% confidence intervals from 5000 bootstrap replicates are plotted.

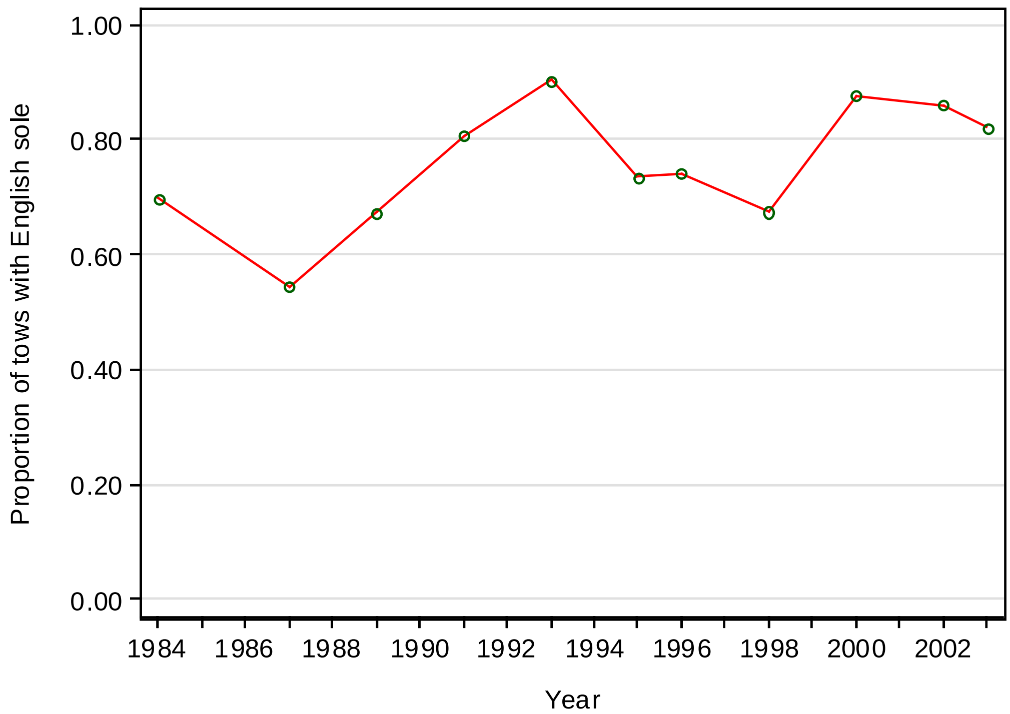


Figure C.10. Proportion of non-zero tows for English sole in the Hecate Strait assemblage survey

Hecate Strait assemblage survey: estimation of index for recruited English sole

The stock assessment of English sole using the delay-difference model only models that part of the population which is recruited to the fishery. Therefore, in principle, the biomass estimates from the surveys should index only the recruited population as well. Otherwise, there will be a mismatch between the biomass index from the survey and the predicted population in the model. This may be a problem with surveys, because survey nets tend to have smaller mesh sizes than used in commercial fisheries so that the survey can capture a wider range of sizes in the population. This means that some fraction of the biomass index will likely represent pre-recruits and these should not be included in the index.

For practical reasons, it is usually very difficult or impossible to estimate only recruited fish in every tow. This is because there usually are insufficient biological samples taken in multi-species surveys: it is not feasible to take a biological sample from every species in every tow. However, there are a large number of biological samples for English sole taken from the Hecate Strait assemblage survey, so it was decided to partition the survey index based on the available sample information.

Table C.7 summarises the available biological information for English sole from the Hecate Strait assemblage survey. Over 700 of over 1,100 tows had sampling information which represented over 90% of the total catch weight in the survey. There were only two years (1991 and 1996) where a significant amount of the survey catch of English sole had not been sampled. A prodigious number of English sole had been measured: over 100,000 length measurements over the 11 survey years (Table C.7). Unfortunately, most of these measurements had no associated sex information (Table C.7), so a combined sex length-weight model was used, based on the male/females parameters estimated using 5CD research sampling data only (Table A.5) and assuming a sex ratio of 0.43/0.57 (the male/female ratio for the sexed samples in Table C.7). This model estimated the parameters $\alpha = 4.473\text{E}-09$ and $\beta = 3.12$ (Eq. A.1) which were used to convert all the sampled lengths from length to weight on a tow-by-tow basis.

Table C.7. Biological sampling information from the Hecate Strait assemblage survey used to calculate a biomass index for recruited English sole.

Survey year	Sets without samples	Sets with samples	Total sets	Catch weight without samples	Catch weight with samples	Total catch weight	Number sampled males	Number sampled females	Number sampled unknown	Total number sampled
1984	32	114	146	26	5,243	5,269	0	0	14,760	14,760
1987	28	62	90	0	2,319	2,319	0	0	5,638	5,638
1989	21	74	95	0	4,752	4,752	0	0	12,435	12,435
1991	40	59	99	2,189	4,570	6,759	0	0	9,801	9,801
1993	5	89	94	1	8,646	8,647	0	0	13,943	13,943
1995	49	53	102	371	3,013	3,384	27	62	6,461	6,550
1996	47	58	105	1,106	3,761	4,867	84	63	11,274	11,421
1998	38	48	86	433	4,167	4,600	112	200	5,246	5,558
2000	31	74	105	612	5,433	6,045	204	308	12,054	12,566
2002	43	50	93	253	6,069	6,322	3,280	4,527	474	8,281
2003	44	51	95	339	10,701	11,040	3,287	4,208	0	7,495
Total	378	732	1,110	5,330	58,674	64,005	6,994	9,368	92,086	108,448

Table C.8. Results of the conversion of samples from length to weight and the calculation of the fraction above the assumed cut-off for recruited English sole of 300 mm.

Survey year	Total number sampled	Number sampled >300 mm	Sampled lengths converted to kg	Sampled lengths >300 mm converted to kg	$\dfrac{\sum_{i=1}^{>300\,\text{mm}\,N_y} \alpha L_y^\beta}{\sum_{i=1}^{\text{total}\,N_y} \alpha L_y^\beta}$
1984	14,760	6,085	3,493	2,489	0.628
1987	5,638	2,234	1,394	989	0.594
1989	12,435	2,921	2,153	1,076	0.419
1991	9,801	3,474	2,017	1,336	0.509
1993	13,943	4,045	2,681	1,476	0.504
1995	6,550	2,206	1,287	809	0.581
1996	11,421	3,459	2,138	1,204	0.513
1998	5,558	2,572	1,313	1,016	0.527
2000	12,566	3,159	2,165	1,280	0.526
2002	8,281	3,229	1,836	1,325	0.620
2003	7,495	2,635	1,597	1,086	0.596
Total	108,448	36,019	22,074	14,088	0.547

The length distributions of port-sampled females were examined to determine an appropriate cut-off to use as a proxy for recruited English sole. A plot of statistics from sample distributions of length taken by port samples (Figure A.16) showed that the distribution of the minimum lengths in the port samples had a median near 300 mm. This value was selected as an approximate measure of the lower end of the distribution of recruited English sole. Figure A.16 shows that

English sole larger than this value are frequently encountered in the port samples and it was felt that a much larger value for the minimum size in the distribution would drop too much of the survey data. Table C.8 shows how many English sole were excluded by using this measure of 300 mm and also gives the mean ratio by weight of fish greater than 300 mm compared to the total sample weight. This mean ratio was applied to all tows within a year which had no associated samples.

Table C.9. Biomass estimates for English sole from the Hecate Strait assemblage trawl survey for the survey years 1984 to 2003 based on the estimated fraction of the catch above 300 mm, which was assumed to be a proxy for recruited fish (Table C.8). Biomass estimates use the same assumptions as in Table C.6. The bootstrap confidence intervals and CVs are based on 5000 random draws with replacement but do not take into account any additional variation associated with the process of estimating the fraction of recruited fish.

Survey year	**Biomass (t)**	**Mean bootstrap biomass (t)**	**Lower bound biomass (t)**	**Upper bound biomass (t)**	**Bootstrap CV**	**Analytic CV (Eq. C.4)**
1984	8,235	8,201	5,234	13,026	0.236	0.233
1987	5,474	5,485	3,176	8,507	0.247	0.253
1989	10,773	10,779	6,215	17,332	0.255	0.254
1991	10,418	10,407	7,522	14,520	0.168	0.167
1993	19,406	19,383	11,721	31,170	0.252	0.253
1995	8,170	8,123	4,261	15,487	0.335	0.334
1996	7,954	7,975	4,745	12,263	0.242	0.240
1998	11,668	11,643	6,094	21,454	0.321	0.319
2000	13,343	13,340	9,532	17,967	0.162	0.164
2002	16,288	16,211	10,229	24,624	0.223	0.224
2003	21,897	22,019	12,256	35,634	0.271	0.272

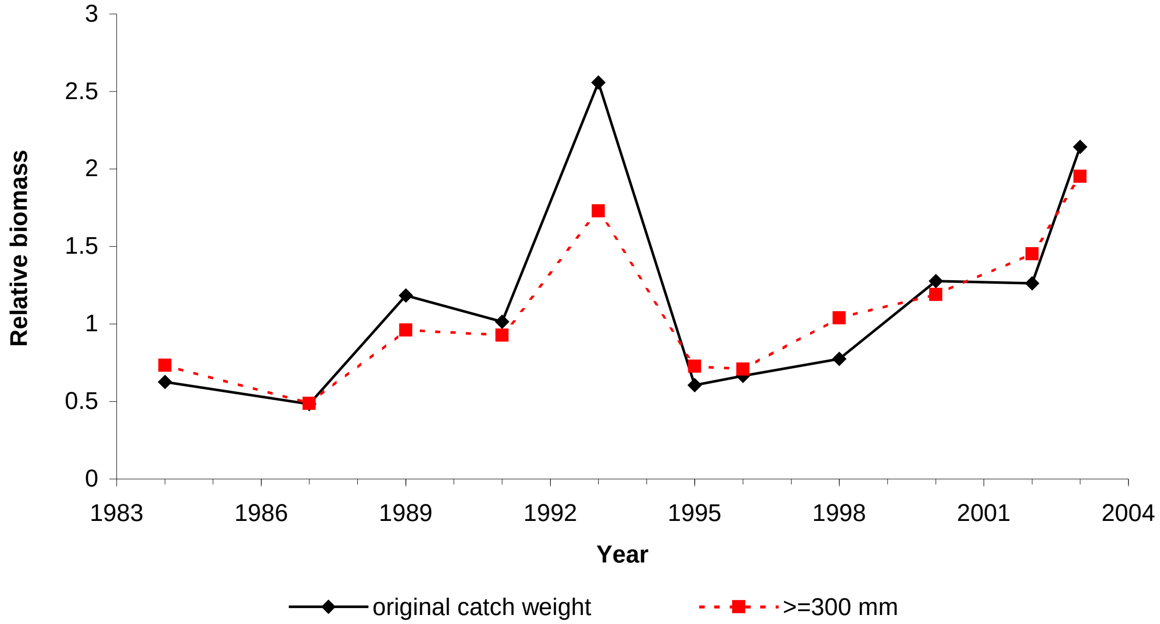


Figure C.11. Comparison of biomass estimates for English sole from the Hecate Strait assemblage trawl survey for the period 1984 to 2003 based on the total catch weight of English sole and the estimated fraction greater than 3000 which was used as proxy for the survey catch of recruited fish. The biomass indices have been standardised relative to the mean of each series.

As expected, the estimates of the relative survey indices do not differ greatly from the survey indices generated from the full data set (Table C.9; Figure C.11). The only substantive difference is the estimate for the 1993 survey, which is reduced by nearly 50% compared to the original estimate. However, the sample ratio of recruited to total fish for this survey year is not out of line with the rest of the survey years (about 0.5 compared to the survey mean of 0.54; Table C.8), so there is no reason to discount this result.

No attempt was made to estimate the additional variation associated with the survey estimates of the recruited fraction of English sole (Table C.9). The reasons for this were twofold: 1) the work involved in correctly constructing a bootstrap analysis to resample the entire estimation process would not be trivial and 2) the estimation process used in the stock assessment involves adding additional process error to obtain a satisfactory fit to the complete data set (see Appendix D for a description of this process). As the Hecate Strait assemblage survey tends to get a relatively large amount of process error added to it during the fitting process, it was felt that the additional effort to estimate appropriate survey CVs would be largely dissipated by the added process error. Also, it is not clear which method (bootstrap error or added process error) is the most reasonable for including an appropriate amount of error to these survey indices in the stock assessment.

Queen Charlotte Sound synoptic survey

All data from the Queen Charlotte Sound synoptic trawl survey, including the catches of English sole caught in each tow over the three years of this survey, were made available (N. Olsen *pers. comm.*). This survey operated three times in the Queen Charlotte Sound between Vancouver Island and Moresby Island between 2003 and 2005. This survey also operated in the lower part of Hecate Strait between Moresby Island the mainland. It is divided into two large aerial strata which roughly correspond to the DFO Regions 5A and 5B (Figure C.12). Each of these two areas is divided into four depth strata: 50–120 m; 120–250 m; 250–370 m; and 370–500 m (Table C.10; Figure C.12).

A doorspread density value (Eq. C.2) was generated for each tow based on the catch of English sole, the mean doorspread for the tow and the distance travelled. The distance travelled was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values for the doorspread field were filled in using the mean doorspread for the stratum in the survey year (27 values over all three years). Missing values in the vessel speed field were filled in using the mean value for the entire survey in that year (11 values in the first two years). Missing values in the bottom contact time field substituted the winch time (time from winch lockup to winch retrieval; 7 values over the three survey years).

The data were analysed using Eq. C.1 to Eq. C.4 which assume that tow locations were selected randomly within a stratum relative to the biomass of English sole. This assumption was an integral part of the design used during the execution of this survey.

Table C.10. Stratum designations, number of useable tows, number of tows that captured English sole (ENL) and total ENL catch weight (kg) for all three years of the Queen Charlotte Sound survey. Also shown is the area (in km^2) of each stratum

			2003			2004			2005			
Stratum number	Area designation	Depth zone	No. tows	No. ENL tows	Catch wt (kg)	No. tows	No. ENL tows	Catch wt (kg)	No. tows	No. ENL tows	Catch wt (kg)	Area (km^2)
18	5AB-South	50-125 m	30	15	42.2	46	18	150.7	31	10	125.2	5,334
19		125-200 m	56	19	60.9	49	24	200.5	61	24	93.9	5,873
20		200-330 m	30	1	3.0	31	3	2.2	29	5	16.6	3,134
21		330-500 m	6	0	0.0	8	0	0.0	8	0	0.0	625
22	5AB-North	50-125 m	5	4	26.8	20	9	48.3	8	4	28.7	2,279
23		125-200 m	39	23	133.1	39	19	77.9	45	22	164.8	4,926
24		200-330 m	54	5	10.5	40	3	2.6	38	1	1.0	4,688
25		330-500 m	19	0	0.0	7	0	0.0	8	0	0.0	1,343
Total			239	67	276.5	240	76	482.2	228	66	430.2	28,202

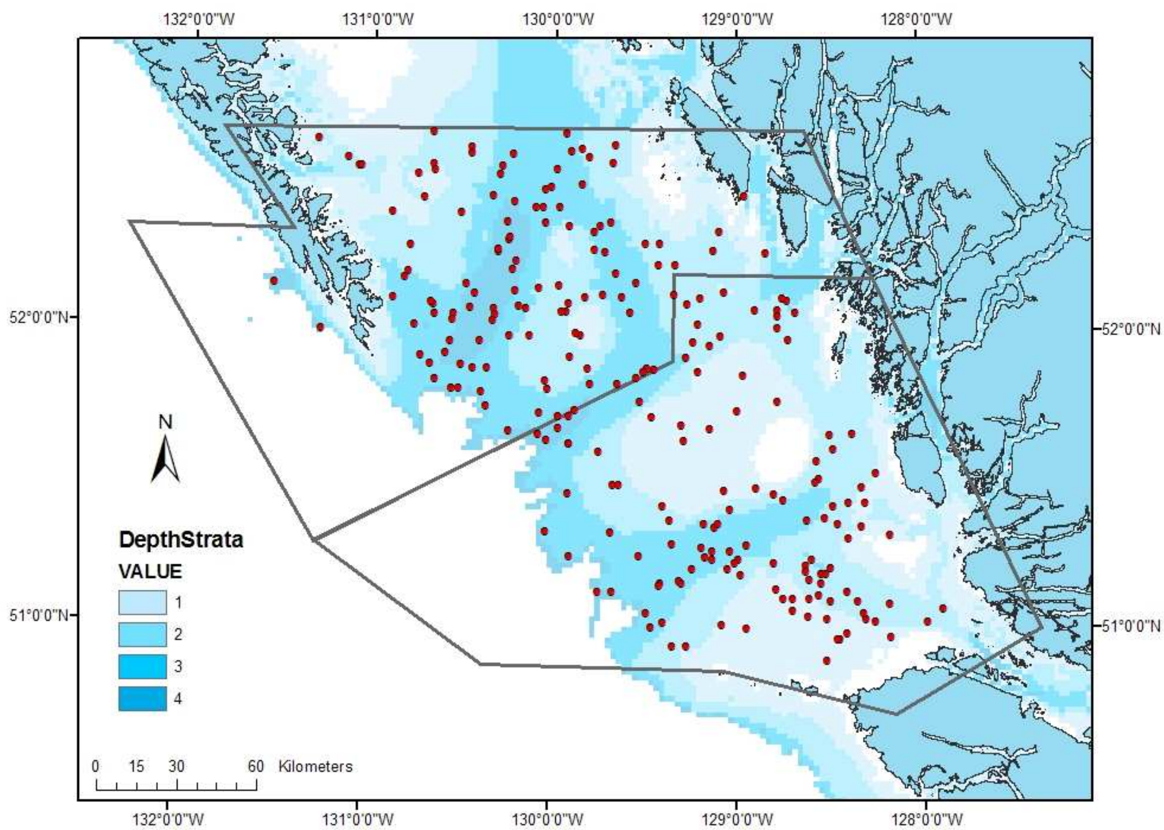


Figure C.12. Map showing the two aerial strata and the four depth zones used in the Queen Charlotte Sound survey. The red dots indicate the locations of the start positions for each useable tow from the 2003 survey. Depth zone codes: 1=50-125 m; 2=125-200 m; 3=200-330 m; 4=330-500 m.

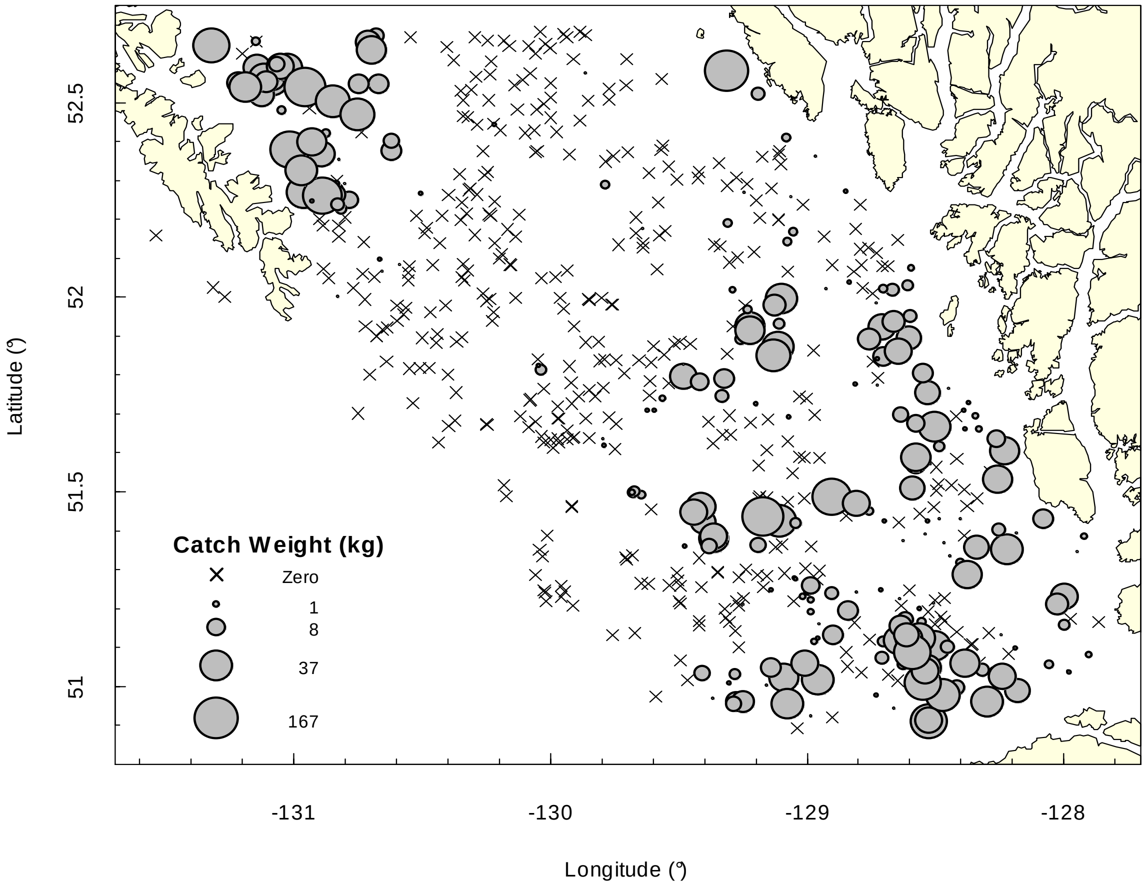


Figure C.13. Map of the locations of all trawls from the Queen Charlotte Sound synoptic trawl survey (2003–2005): those that caught English sole are marked with circles proportional to the catch weight while those that caught no English sole are marked with an X.

Results

Catches of English sole are widely distributed throughout the entire survey area (Figure C.13). English sole were mainly taken at depths from 70 to 220 m, but range from 37 to 379 m overall (Figure C.14).

Estimated biomass levels for English sole from the QC Sound synoptic trawl survey were nearly identical for the first two survey years, followed by a 30% non-significant drop in the final year (Figure C.15; Table C.11). The estimated CVs for English sole from this survey are good in all survey years, with 0.21 and 0.19 in the final two years (Table C.11).

The proportion of tows which took English sole was nearly constant over the three survey years, with values of 0.31, 0.34, and 0.35 for 2003, 2004, and 2005 respectively.

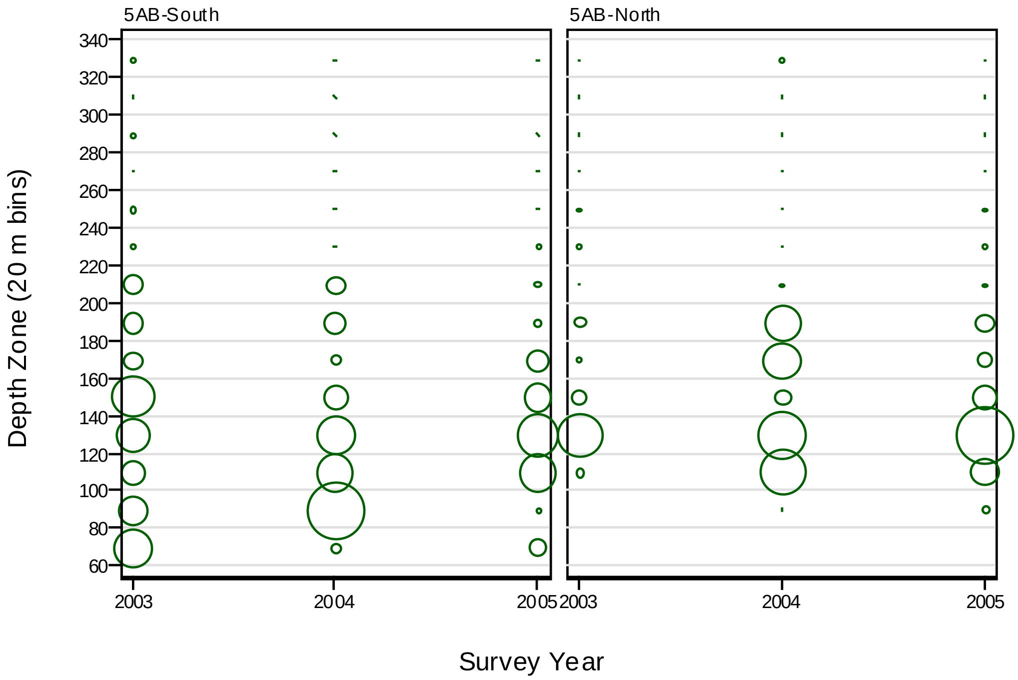


Figure C.14. Distribution of catch weight of English sole by large area stratum (Table C.10), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Maximum circle size: 5AB-South=383 kg (90 m bin); 5AB-North=268 kg (130 m bin). Minimum depth observed for ENL: 37 m; maximum depth observed for ENL: 379 m. Depth is the mean of the start and end depths for the tow.

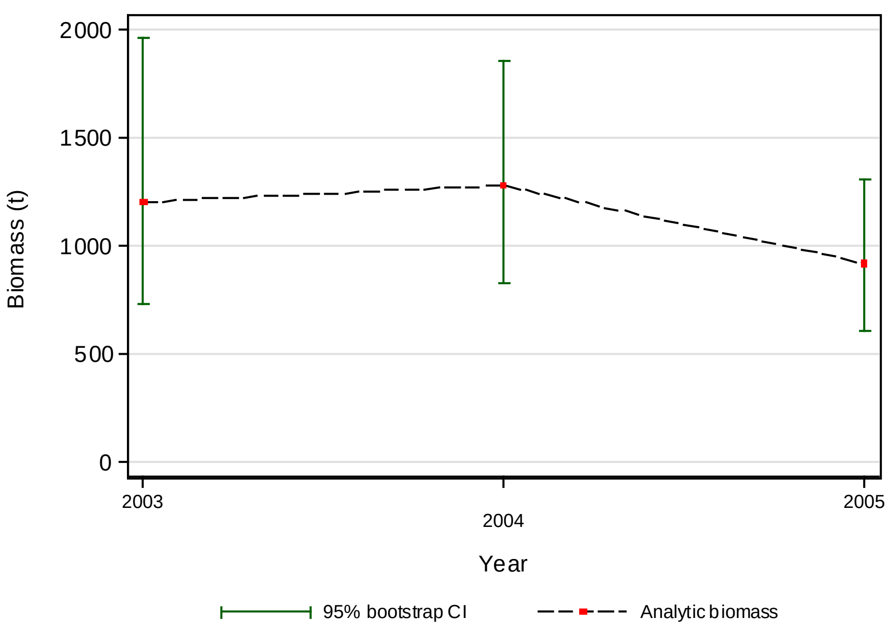


Figure C.15. Plot of biomass estimates for English sole from the QC Sound synoptic trawl survey for 2003 to 2005. Bias corrected 95% confidence intervals from 5000 bootstrap replicates are plotted.

Table C.11. Biomass estimates for English sole from the QC Sound synoptic trawl survey for the survey years 2003 to 2005. Bootstrap bias corrected confidence intervals and CVs are based on 5000 random draws with replacement. The analytic CV (Eq. C.4) is based on the assumption of random tow selection within a stratum.

Survey Year	**Biomass (t)**	**Mean bootstrap biomass (t)**	**Lower bound biomass (t)**	**Upper bound biomass (t)**	**Bootstrap CV**	**Analytic CV (Eq. C.4)**
2003	1,201	1,194	726	1,956	0.253	0.254
2004	1,278	1,274	829	1,855	0.206	0.205
2005	917	913	606	1,305	0.195	0.191

Hecate Strait Pacific cod monitoring survey

The design of the Hecate Strait Pacific cod survey was based on the selection of five fishing grounds (Two Peaks /Butterworth, White Rocks, Shell Grounds, Horseshoe and Reef Island; Figure C.16) that were known to be important for Pacific cod (Sinclair & Workman 2002). Other bottom trawl species were not considered at the design phase. Grids defined by 0.01° longitude and 0.01° latitude were identified within each of these five areas and those which had had at least one commercial tow were used in the survey. These grids formed a pool of 930 potential locations (Figure C.16) from which a random sample was drawn, the number of samples being approximately proportional to the number of grids in each of the five areas. The total number of survey tows were 180 per year, which were allocated among five monthly strata (March to July), effectively generating a mini-survey of 36 tows in each of five months. A further 4 tows per month were allocated to the skipper, who fished these tows outside of the survey design. This survey operated three times in Hecate Strait between 2002 and 2004. All data from the Pacific cod monitoring trawl survey, including the catches of English sole caught in each tow over the three years of this survey, were provided by N. Olsen (*pers. comm.*).

A wingspread density value (Eq. C.2) was generated for each tow based on the catch of English sole, a fixed wingspread for all tows and the distance travelled. The distance travelled was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from time the winch was blocked to the time the gear was retrieved. There were no missing values in the data. The four tows per month which were allocated to the skipper outside of the survey random design were inadvertently included in the analysis. The biomass estimates were stratified by month and area, for a total of 25 strata per year.

Table C.12. Stratum designations, number of useable tows, number of tows that captured English sole (ENL) and total ENL catch weight (kg) for all three years of the Hecate Strait Pacific cod monitoring survey. Also shown is the area (in km^2) of each stratum. This table includes the skipper selected (non-random) tows.

	2003			2004			2005			
Stratum Name	No. tows	No. ENL tows	Catch wt (kg)	No. tows	No. ENL tows	Catch wt (kg)	No. tows	No. ENL tows	Catch wt (kg)	Area (km^2)
Two Peaks/Butterworth	67	61	11,369	73	72	14,625	73	69	18,617	298
White Rocks	57	55	2,942	55	55	8,516	56	55	9,178	390
Shell Ground	29	20	1,265	25	18	1,494	25	15	354	161
Reef Island	10	10	945	10	10	3,194	10	10	1,106	24
Horseshoe	37	35	491	37	36	1,866	36	36	1,732	249
Total	200	181	17,012	200	191	29,694	200	185	30,987	1,122

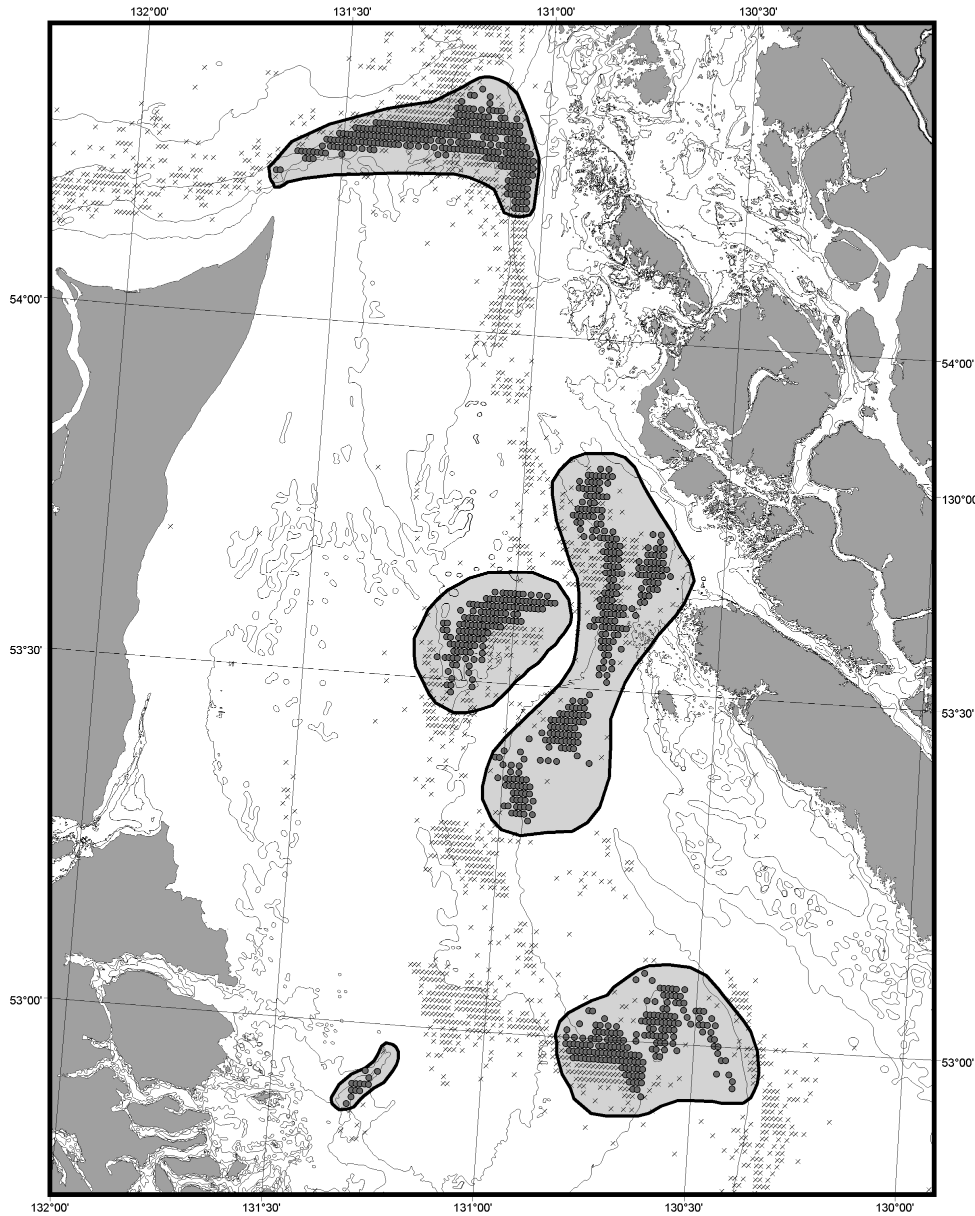


Figure C.16. Map showing the five areas (Two peaks /Butterworth, White Rocks, Shell Grounds, Horseshoe and Reef Island) selected for monitoring for the Hecate Strait Pacific cod monitoring survey. The heavy dots indicate the locations of the grids which were selected from the commercial data with at least one commercial tow from 1996 to 2002 (Sinclair & Workman 2002).

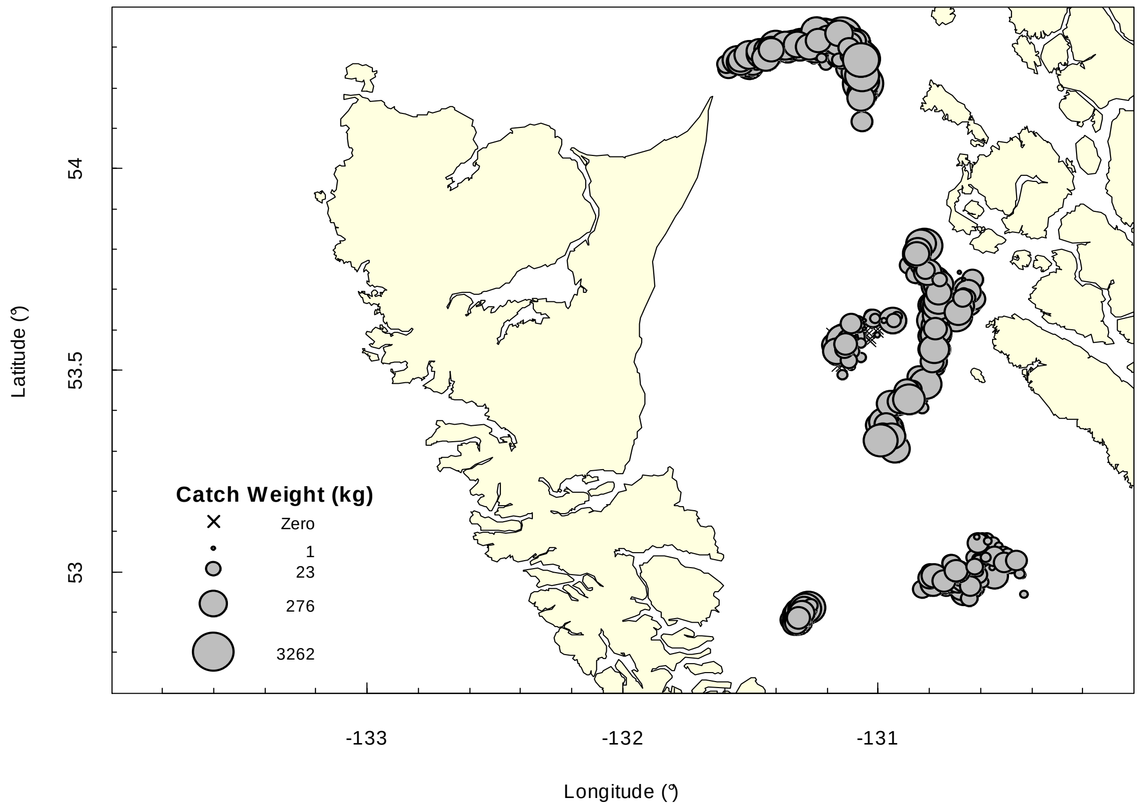


Figure C.17. Map of the locations of all trawls from the Hecate Strait Pacific cod monitoring survey (2002–2004): those that caught English sole are marked with circles proportional to the catch weight while those that caught no English sole are marked with an X.

Results

Catches of English sole were taken in all of the five aerial strata (Figure C.17). English sole were mainly taken at depths from 50 to 130 m, but ranged from about 30 m to 160 m overall (Figure C.18). Catches of this species were very large, with 17 t caught in the first year and 30 and 31 t in the second and third years respectively (Table C.12). Most of the catch of this species took place in the Two Peaks/Butterworth area stratum. This species was also very prevalent (i.e., the frequency of tows which contain this species), as it occurs in nearly every tow (Table C.12).

Estimated biomass levels for English sole from the Hecate St. Pacific cod monitoring survey were relatively low in the first survey year, followed by a strong but non-significant rise of about 75% in the second year which was maintained in the third year (Figure C.19; Table C.13). The estimated CVs for English sole from this survey are very good in all survey years, especially in the final two years where they are 0.13 and 0.09 respectively (Table C.13). The non-random skipper tows were inadvertently left in the original calculations for the survey estimates used in the 5CD stock assessment. However, removing these tows did not materially affect the biomass estimates (Figure C.19 [right panel]; Table C.13).

The proportion of tows which took English sole was nearly constant and at a very high level over the three survey years, with values of 0.91, 0.96, and 0.93 for 2003, 2004, and 2005 respectively.

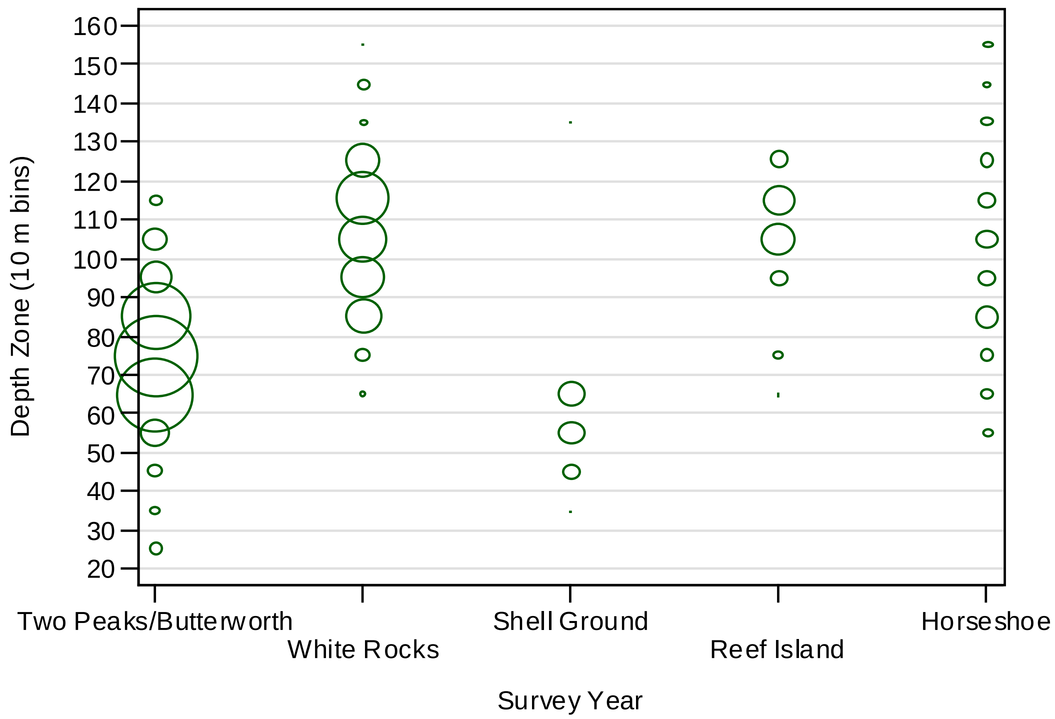


Figure C.18. Distribution of catch weight of English sole by area stratum (Table C.10) and 20 m depth zone, summarised over the three survey years. Depth zones are indicated by the centre of the depth interval. Maximum circle size: 15184 kg (70-80 m bin in Two Peaks/Butterworth). Minimum depth observed for ENL: 24 m; maximum depth observed for ENL: 154 m. Depth is the mean of the start and end depths for the tow.

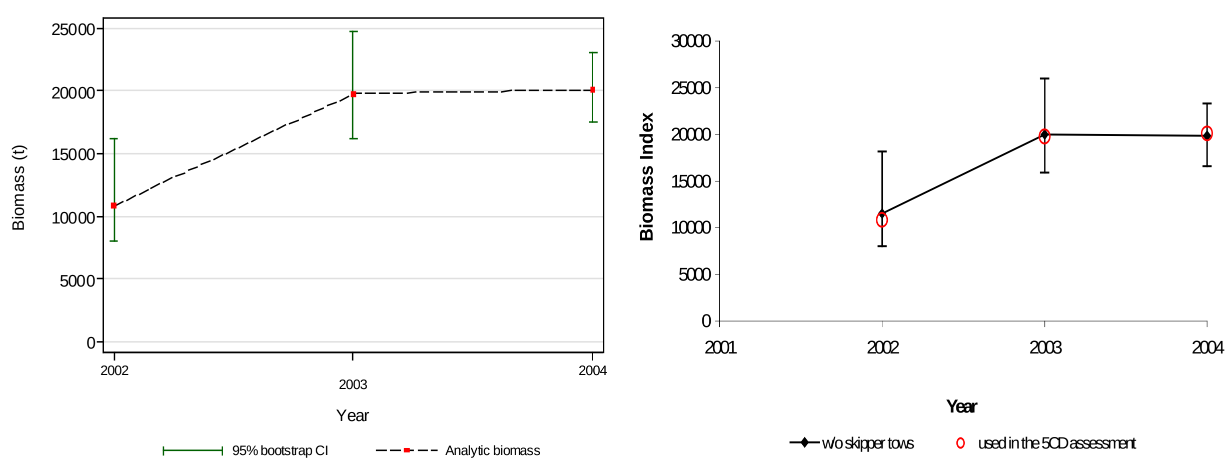


Figure C.19. [left panel]: Plot of the biomass estimates (based all survey tows) for English sole from the Hecate Strait Pacific cod monitoring survey for 2002 to 2004 used in the 5CD stock assessment. Bias corrected 95% confidence intervals from 5000 bootstrap replicates are plotted; [right panel]: Plot of biomass estimates calculated without the non-random skipper tows which were inadvertently included in the original biomass estimates, showing the revised biased corrected confidence bounds (based on 5000 bootstrap replicates) and the original survey estimates for comparison.

Table C.13. Biomass estimates for English sole from the Hecate Strait Pacific cod monitoring survey for the survey years 2002 to 2004. Bootstrap bias corrected confidence intervals and CVs are based on 5000 random draws with replacement. The analytic CV (Eq. C.4) is based on the assumption of random tow selection within a stratum. Two sets of biomass indices are presented: the ones used in the 5CD stock assessment which inadvertently had included the non-random skipper tows and a second set which omits these tows.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. C.4)
Estimates used in the 5CD stock assessment (includes non-random skipper tows)						
2003	10,847	10,751	8,031	16,277	0.189	0.187
2004	19,767	19,620	16,202	24,743	0.110	0.110
2005	20,110	20,022	17,494	23,091	0.072	0.071
Estimates calculated without the non-random skipper tows						
2002	11,516	11,434	8,040	18,170	0.220	0.217
2003	20,007	19,822	15,914	25,980	0.126	0.125
2004	19,847	19,794	16,606	23,315	0.085	0.085

Comparison of the available survey estimates with the standardised CPUE series

Figure C.20 presents a comparison of the indices generated by the two longer term fishery independent series with the relevant standardised fishery dependent series (WCVI Triennial with the 3CD5AB series and the HS Assemblage with the 5CD series; see Appendix B for a discussion of how these two series were generated). Neither series matches the fishery independent surveys particularly well, but this could be for a number of reasons: a) the surveys are not tracking the English sole abundance; b) the CPUE indices are not tracking abundance; c) the surveys are taking younger fish than the fishery and hence are showing recovery sooner than would be seen in the fishery. However, there still is a poor match with the indices for the Hecate Strait assemblage survey after adjusting the indices to remove the pre-recruits (Figure C.20 [right panel]). It is notable that the high 1993 index value for this survey is very much out of line with the CPUE trend and that the downward adjustment to account for the recruited fraction seems in the right direction.

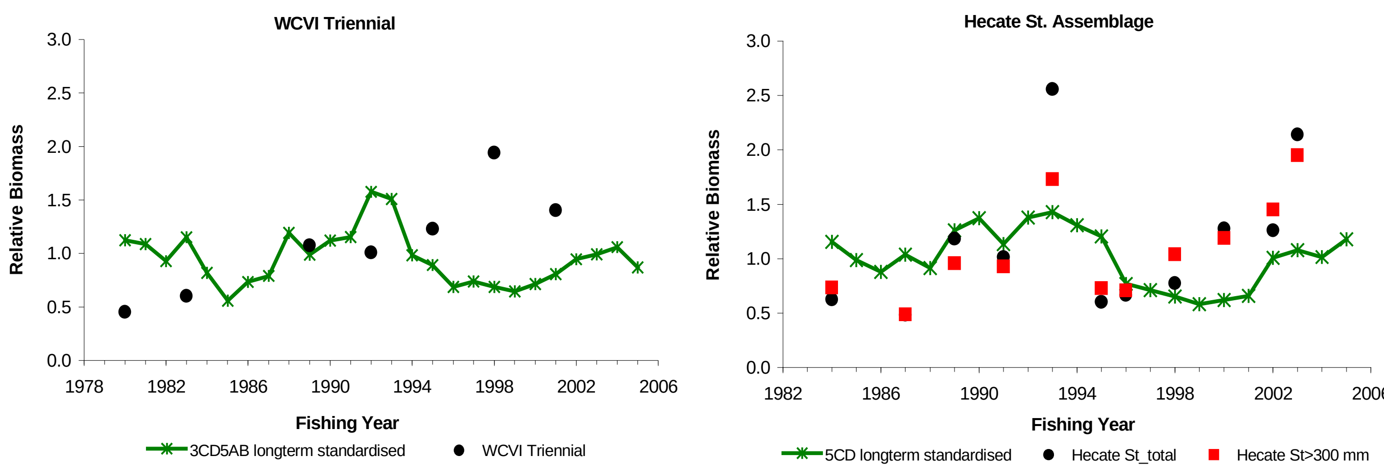


Figure C.20. Comparison of the 5CD and 3AB5CD fishery dependent standardised series with the appropriate long-term survey series used in the English sole stock assessment. Each series is standardised to the same years that the fishery independent series operated. [left panel]: WCVI Triennial survey; [right panel]: HS assemblage survey.

Appendix D. DELAY DIFFERENCE MODEL

Model description

A delay-difference stock production model (Quinn and Deriso 1999, Starr et al. 2002; Sinclair and Starr 2005) was used to estimate stock size, parameters and reference points relevant to management for English sole in two separate DFO combined areas 3CD5AB and 5CD. The model uses two age groups, recruits and spawners. A Beverton-Holt stock-recruitment function was used to link the two groups.

Delay-difference models assume knife-edge selectivity to the fishery at a specific age. Age 5 was adopted for English sole based on comparing the distribution of sample mean weights taken by port sampling with the equilibrium mean average weight predicted by the model under different ages of knife edge selectivity and a fixed value for M=0.2 (Figure A.17) for a presentation of this information). Comparison of predicted model trajectories for vulnerable biomass from a delay-difference model fitted to 5CD rock sole data with an age-structured model fitted to data from the same area showed that the best correspondence between the two model trajectories was obtained when the age of knife-edge recruitment corresponded approximately to the mid-point of the selectivity curve estimated by the age-structured model (Figure F-1; Starr et al. 2006).

The same comparisons between the 5CD rock sole delay-difference and age-structured models indicated that 1966 was a good point at which to begin the delay-difference model. Data extend further back into time but the correspondence between all years becomes more tenuous the further back in time the data are extended. The year 1966 was selected as a good starting point for the 5CD rock sole models (both delay-difference and age-structured) and this starting point was also used for modelling English sole. The delay-difference model estimates the ratio of the initial biomass to unfished biomass, which allows it to begin in a non-equilibrium state.

Growth was assumed to follow a von-Bertalanffy function and both growth and the weight-length relationship was assumed to be constant over time. Growth and length-weight parameters were estimated as presented in Appendix A (Table A.3 and Table A.10) and were assumed to be known without error. The model represents the stock vulnerable to fishing. Therefore, a growth model based on female growth using age samples taken by port sampling only was used because the growth model based on research data cannot represent the mean lengths observed in the port samples (Figure A.15). The model should be considered a model of female vulnerable biomass and estimates of discards were not included in catch data. The model was conditioned on fishing effort, estimated as the ratio of total female landings divided by the catch per unit effort. Models were fitted to a standardised fishery-dependent stock abundance index developed for 3CD5AB and 5CD as described in Appendix B as well as two surveys applicable to each region (described in Appendix C).

The objective function included terms for minimising the differences between the predicted and the observed catch, the predicted and observed mean fish weight, the predicted and observed biomass indices from the appropriate surveys, a term to minimise the recruitment deviations relative to the mean recruitment and terms penalising deviations from the informed priors placed on the M and recruitment deviation parameters.

This assessment chose to estimate the natural mortality parameter *M* instead of the stock-recruitment steepness parameter *h*. This choice was made for two reasons, the first being that it was felt that the fitted mean weight information would be more informative for *M* than for *h* and the second being that it was felt that the *h* parameter cannot be reliably estimated.

The model used in this assessment is very similar to the model used to assess Hecate Strait Pacific cod (*Gadus macrocephalus*), except that an environmental parameter was not fitted (Sinclair and Starr 2005). Several improvements have been made to this model over the one used by Sinclair & Starr (2005):

- The model now allows the estimation of multiple catch and effort series, in recognition that the relationship between CPUE and biomass may have changed over the history of the fishery. This feature was added in recognition that fishing has evolved considerably on the west coast of Canada since the 1960s and that the current management of the fishery provides very different incentives for catching fish that those existed prior to about 1996. Accordingly, a number of the model runs investigated in this assessment estimated separate catchability coefficients by splitting the series between 1995/96 and 1996/97.
- Predictions are made over five years instead of a single year and recruitment is selected randomly based on the recruitment standard deviation. Predictions are also constrained by a maximum exploitation rate which means that high catch levels are not achieved if the predicted exploitation rate exceeds the maximum exploitation rate.
- Provision is made for informed priors for all model parameters
- Added log-normal bias correction to recruitment deviation predictions
- An error was discovered in the code used in previous versions of this delay-difference model (Sinclair et al. 2001, Starr et al. 2002, Starr & Fargo 2004, Sinclair & Starr 2005, Starr et al. 2006) and was present in the version of this assessment presented to the Groundfish Subcommittee of PSARC in January 2007 (DFO [2007]).. This error concerned 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 in the first year of the assessment reconstruction. This is not a problem for assessments which assume that the reconstruction begins with an unfished equilibrium biomass. However, previous assessments performed using this model for west coast Canadian stocks assumed that the initial biomass was at equilibrium at some fraction of the unfished biomass (estimated as a free parameter) and therefore a lower mean weight would be expected. The model used in this assessment now calculates the mean weight for an equilibrium biomass using the fishing mortality in the initial year. As this fishing mortality is derived from an estimated model parameter and the input effort data, the associated mean weight can be calculated analytically, as well as the initial biomass (see equations below). Therefore, there is no longer any need to estimate, using an additional free parameter, the fraction of the unfished biomass in the initial year of the reconstruction.

The following tables describe the model parameters, data, dynamics and likelihoods.

Estimated Parameters

Parameter	Description
B_0	Unfished equilibrium population biomass
M	Instantaneous natural mortality rate
${}^{C}q_z$	Fishery catchability: one parameter for each series *z*
${}^{S}q_j$	Catchability for survey *j*: two survey series were fitted for the 5CD model (Hecate St. assemblage and Hecate St. Pacific cod monitoring survey) and two surveys were fitted for the 3CD5AB model (WCVI NFMS Triennial survey and Queen Charlotte Sound synoptic survey)
ϕ_t	Recruitment anomalies in year *t* (there are 37 of these parameters from 1966 to 2002 with recruitment knife-edged at age 5 and 38 parameters up to 2003 with recruitment knife-edged at age 4

Fixed parameters

Parameter	Value	Description
h	0.75	"Steepness" of the Beverton-Holt stock-recruitment curve, where fraction defines the proportion of the maximum recruitment which is available when the spawning stock size is 20% B_0 (Francis 1992)
L_∞	461.48	Asymptotic length in von-Bertalanffy growth equation (mm)
k	0.112	Growth rate parameter in von-Bertalanffy growth equation
t_0	-8.81	Time at L_0 in von-Bertalanffy growth equation
b_0	3.832E-09	Slope of weight-length relationship (mm to kg) [5.937E-09 for 3CD5AB females]
b_1	3.149	Exponent of length – weight relationship [3.069 for 3CD5AB females]
r	5	Age of knife edge recruitment to fishery and spawning population (age=4 investigated as a sensitivity)
ρ	0.9233[1]	Slope of the Ford-Walford plot, age *r*=5 to 18 ($\rho = 0.9261$ for $r = 4$)
α	0.0765[2]	Intercept of Ford-Walford plot, age *r*=5 to 18 ($\alpha = 0.0746$ for $r = 4$)
${}^{R}\sigma$	0.4	Standard deviation for recruitment
$U_{\max}$	0.9	Maximum exploitation on vulnerable biomass

[1] $\rho = 0.9222$ for 3CD5AB English sole because of the difference in the b_0 and b_1 fixed parameters

[2] $\alpha = 0.0729$ for 3CD5AB English sole because of the difference in the b_0 and b_1 fixed parameters

Annual input data

Data series	Description
$C_{z,t}$	Weight (t) of catch for series *z* in year *t*: models were fitted either as a single series or split between 1995/96 and 1996/97 in recognition of the major change in the management of the fishery
$E_{z,t}$	Fishing effort (h) for series *z* in year *t*: where $E_{z,t} = C_{z,t} / \text{CPUE}_{z,t}$, and $\text{CPUE}_{z,t}$ is the CPUE index for series *z* in year *t*
w_t	Mean weight (kg) of the recruited population in year *t*
$I_{j,t}$	Index for trawl survey *j* in year *t*
$X_{j,t}$	Standard error for trawl survey *j* in year *t*

Derived parameters

Equation	Description
$w_r = b_0 \left(L_\infty \left(1 - e^{-k(r-t_0)} \right) \right)^{b_1}$	Weight at the age of recruitment
$S = e^{-M}$	Natural survival rate

Equation	Description
$\bar{w} = \frac{S\alpha + w_r(1-S)}{(1-S\rho)}$	Average body weight in the unfished equilibrium population
$N_0 = \frac{B_0}{\bar{w}}$	Equilibrium population numbers at B_0
$R_0 = N_0(1-S)$	Equilibrium recruitment at B_0
$a = \frac{B_0}{R_0}\left(1 - \frac{(h-0.2)}{(0.8h)}\right)$	Beverton-Holt 'alpha' parameter expressed in terms of the steepness parameter (Francis 1992)
$b = \frac{5h-1}{4hR_0}$	Beverton-Holt 'beta' parameter expressed in terms of the steepness parameter (Francis 1992)

Model equations

Equation	Description
$F_{z,t} = {}^{C}q_z E_{z,t}$	Instantaneous fishing mortality for series *z* in year *t*
$N_t = N_{t-1}e^{(-M-F_{z,t-1})} + R_{t-r+1}$	Population numbers in year *t*
$B_t = (\alpha N_{t-1} + \rho B_{t-1})e^{(-M-F_{z,t-1})} + w_r R_{t-r+1}$	Population biomass at beginning of year *t*
$\hat{w}_t = B_t / N_t$	Predicted mean weight of individuals in the population in year *t*
$\hat{w}_1 = \frac{S_1^{'}\alpha + w_r(1-S_1^{'})}{(1-S_1^{'}\rho)}$	Predicted weight in year 1, assuming biomass is at equilibrium with the fishing mortality $(F_{z,1} = {}^{C}q_z E_{z,1})$ in year 1: $(S_1^{'} = e^{-M-F_{z,1}})$
$\hat{B}_1 = \frac{(\hat{w}_1/(1-S_1^{'}) - a)}{b}$	Predicted biomass in year 1 using a Beverton-Holt stock-recruitment function
$R_{t+r} = \frac{B_t}{(a + b B_t)} e^{\phi_t} e^{\delta v_t}$	Recruitment in year *t+r* using a Beverton-Holt stock-recruitment function
$\hat{C}_{z,t} = \frac{B_t\left(1-e^{(-M-F_{z,t})}\right)F_{z,t}}{M + F_{z,t}}$	Predicted catch in year *t*
$\hat{I}_{j,t} = {}^{S}q_j B_t$	Predicted trawl survey biomass index for survey *j* in year *t*
$C_{z,t} = \frac{B_t\left(1-e^{(-M-F_{z,t})}\right)F_{z,t}}{M + F_{z,t}}$	Find $F_{z,t} = {}^{C}q_z E_{z,t}$ that achieves Projection $C_{z,t}$ for *t*=2007 – 2011
$U_t = 1 - \exp^{(-{}^{C}q_z E_{z,t})}$	Exploitation rate for series *z* in year *t*

Objective function

The objective function consisted of likelihood components corresponding to the recruitment deviations and the contributions from the catch, fish weight, and the survey index data sources. There was one likelihood component for each weight, survey and catch series component. Let *O* represent the observations, *P* represent the fitted values, and σ represent the standard deviation of the observation in the likelihood functions. The following text table summarises the specific values for the various data sets:

Data:	O	P	σ
Catch	$C_{z,t}$	$\hat{C}_{z,t}$	${}^{C}\sigma_z$
Survey	$I_{j,t}$	$\hat{I}_{j,t}$	$\sqrt{X_{j,t}^2 + {}^{S}\sigma_j^2}$
Weight	w_t	$\hat{w}_t$	${}^{W}\sigma$

A lognormal distribution was assumed for each of the above data components, with the negative log-likelihood for observation *O*:

$$-\log(L) = \ln(\sigma) + 0.5\left(\frac{\ln(O/P) + 0.5\sigma}{\sigma}\right)^2,$$

and calculating the Pearson residuals as:

$$\left(\ln(O/P) + 0.5\sigma\right)/\sigma$$

The assumption of a log-normal distribution (mean zero and standard deviation ${}^{R}\sigma$) for the recruitment residuals results in the following contribution to the objective function for observations ϕ_t:

$$-\log(L) = \sum_{t=1966}^{t=2006-r+1}\left(\ln\left({}^{R}\sigma\right) + 0.5\left(\frac{\phi_t}{{}^{R}\sigma}\right)^2\right).$$

The standard deviation of the Pearson residuals were calculated for each data set and the value for σ adjusted so that this standard deviation was approximately 1.0, the theoretical value for a normal distribution. This was done to ensure that each data set received approximately the same relative weight in the model fit. For the survey indices, a single process error term was added to each index value to bring the standard deviation of the survey residuals to the re-weighting target (Francis et al. 2001). The *CVs* used for each model run are provided in table reporting the MPD results.

Table of priors used in all model runs. NA indicates not applicable.

Parameter	**Prior type**	**Lower bound**	**Upper bound**	**Mean**	**SD**
B_0	Uniform	500	1000000	NA	NA
${}^{C}q_z$	Uniform	5.00E-08	5.00E-03	NA	NA
${}^{S}q_j$	Uniform	5.00E-08	10	NA	NA
M	Normal	0.01	1	0.2	0.2
ϕ_t (log space)	Normal	-5	5	0	0.4

An assumed uniform distribution with wide bounds was used as Bayesian priors to prevent the estimation from being restricted by the choice of the bounds. The exception to this was the use of informed priors for the natural mortality and the recruitment deviation parameters. The recruitment deviations were assumed to be normally distributed in log space, with a mean of zero and a standard deviation of 0.4. Natural mortality was also assumed to be normally distributed, with a mean of 0.2 which is the assumed value used for this parameter in previous English sole assessments (Fargo 1998; Fargo 1999; Fargo *et al.* 2000). The value of 0.2 selected for the standard deviation of the prior was an arbitrary choice, meant to allow the model scope for estimating a different value for *M* if supported by the data.

The following penalties were added to the objective function as the prior contribution:

$$-\log(L) = 0.5\left(p-\mu \big/ \sigma\right)^2 \qquad \text{for normal prior}$$

$$-\log(L) = \log(p) + 0.5\left(\log(p/\mu) \big/ \sigma + 0.5\sigma\right)^2 \qquad \text{for log-normal prior}$$

where p is the prior mean, σ is the prior standard deviation and μ is the parameter estimate.

Bayesian estimation procedure

A Bayesian procedure was used to assess parameter uncertainty for current biomass and the biomass projections:

1. Model parameters were estimated by minimising the sum of the log likelihood and log priors. The resultant maximum posterior density (MPD) estimates represent the mode of the joint posterior distributions of the parameters;
2. Forty million samples from the joint posterior distribution of parameters were generated using the Markov chain–Monte Carlo (MCMC) procedure. The Hastings-Metropolis algorithm (Gelman et al. 1995) was used to generate the chain. Each chain was sampled once every 20,000 draws to produce an approximation of the posterior density based on 2000 points;
3. For each sample of the posterior for the beginning year 2007 biomass, a five-year projection was made up to the beginning year 2012 female biomass over a catch range of 0 to 1000 t, in 100 t increments (0 to 500 t in 50 t increments for the 3CD5AB assessment). Recruitment deviations were drawn randomly with mean 0 and ${}^{R}\sigma = 0.40$, beginning in year $t = 2006 - r + 2$;
4. The marginal posterior distribution for each parameter of interest was approximated by integrating the product of the likelihood and the priors over all model parameters; the posterior distribution was described by the mean, 5^{th}, 50^{th}, and 95^{th} percentiles.

Model Results

Runs investigated

Runs were made to investigate model predictions across a range of assumptions which could not be easily reconciled (Table D.1). Model runs were varied by applying a single CPUE series or a CPUE series split between 1995 and 1996 in recognition of the substantial changes in management of the fishery made in the mid-1990s. For 5CD English sole, both the split and single CPUE series were investigated using either a fixed or estimated *M* assumption (Table D.1). The fixed *M* assumption used the preferred value of *M*=0.2 and did not use the weight data. The estimated *M* assumption used an informed prior for this parameter and was fitted to the weight data. These four runs were based on an assumed age for the knife-edged recruitment of *r*=5. The sensitivity of the model predictions to the assumed age of recruitment was investigated by refitting each of the "estimate *M*" options with an assumed age of knife-edged recruitment of *r*=4 (instead of five) (Table D.1). A "fixed *M*" model run for 5CD using *r*=4 was not pursued as preliminary model fits did not give sensible runs for this combination of assumptions. Four model runs were investigated for 3CD5AB English sole: two with a single CPUE series (one each "estimate M" and "fix M") and two with split CPUE series (again one each "estimate M" and "fix M") (Table D.1). The same procedure was followed as was done for the 5CD English sole and the age of knife-edge recruitment for these runs was *r*=5.

Table D.1. Description of the 6 model runs used to assess 5CD English sole and the 4 model runs made for 3CD5AB English sole. See text for an explanation for the components of each cell of the table below. Years reference the first year of fishing year pairs.

	5CD assessment		**3CD5AB assessment**	
	Single CPUE series: 1966–2005	**Split CPUE series: 1966–1995 & 1996–2005**	**Single CPUE series: 1966–2005**	**Split CPUE series: 1966–1995 & 1996–2005**
Estimate *M*	$r=4$: Case 1	$r=4$: Case 4	$r=5$: Case 7	$r=5$: Case 9
	$r=5$: Case 2	$r=5$: Case 5		
Fix *M*=0.20	$r=5$: Case 3	$r=5$: Case 6	$r=5$: Case 8	$r=5$: Case 10

Preliminary maximum posterior density fits

5CD model runs MPD fits

Table D.2 provides maximum posterior density (MPD) results for the six 5CD runs described in Table D.1. The 5CD models which assume knife-edge recruitment at age 4 rather than at age 5estimate, as expected, a larger virgin vulnerable unfished biomass (the former in the order of 11,000 to 13,000 t while the latter estimate B_0 to be near 8,000 t). All of the models estimated the beginning population to be less than B_0 which is reasonable considering that this fishery has a long history of exploitation prior to the commencement of the model data. Note that for the models with split CPUE series, the ratio of the catchability for the second catch series is about two-thirds of the catchability for the first catch series for the models which estimated *M* while it is about 50% for the model which fixed *M*. This is a reasonable result, given that most of the management activity since 1996 has been directed at reducing the relative effectiveness of the fleet.

All the models which estimated *M* did not stray far from the mean of the prior of 0.2 (Table D.2). This result confirms that there is relatively little information to inform this parameter in the data used in these models, although it is interesting that the two models for which it was assumed that *r*=4, estimated an *M* which was below the prior mean while all the models with *r*=5 estimated M values about 10–20% above the prior mean. All the survey *q*'s appear to be very high, most being well above 1.0, even for the Hecate St. assemblage survey which has been adjusted to reflect the catch of English sole greater than 300 mm. This is not a surprising result, given that this model is for vulnerable fish only and it is likely that the surveys include fish below the age of recruitment in the indices. There is also a herding effect for some flatfish species and this may be affecting the estimate of *q*. The bounds for *q* were moved upwards in this model fit so that the estimates for the other parameters would be comparable to those made by the other 5CD model runs. There are insufficient data from the other surveys (other than the Hecate St. assemblage survey) to estimate an index which pertains to vulnerable fish only.

All of the models slightly underestimate the total catches over the forty year period, with the sum of the total observed catch exceeding the model estimated catch on the order of 2.2 to 3.0% (Table D.2). Average exploitation rates are reasonable for all model runs, with the possible exception of the two 5CD models with fixed *M* values, where there is a higher average exploitation rate and a greater level of depletion in the final model year.

Fits to the catch data are good and are similar between runs, indicating that the data are probably not sufficient to distinguish between the competing runs. The fits to the weight data are the poorest among the data sets and show trends, which is probably not surprising, given the low number of samples from which to generate these estimates and lack of freedom in the model to change mean weights quickly from year to year (compared to a statistical catch-at-age model). The fits to the survey data indicate that there is a lot of process error in the survey indices relative to the estimated biomass trajectory. Example data fits are provided for four of the six 5CD model runs in Table D.1: single CPUE, *r*=5, estimate *M* (Figure D.1); single CPUE, *r*=5, fix *M* (Figure D.2); split CPUE, *r*=5, estimate *M* (Figure D.3); and split CPUE, *r*=5, fix *M* (Figure D.4). The two 5CD *r*=4 runs which estimate *M* have been omitted because the data fits in these models are very similar to the equivalent *r*=5 models.

Population trajectory plots, the time series of harvest rate estimates and the estimated recruitments by year are presented for the same four runs listed above: single CPUE, *r*=5, estimate *M* (Figure D.5); single CPUE, *r*=5, fix *M* (Figure D.6); split CPUE, *r*=5, estimate *M* (Figure D.7); and split CPUE, *r*=5, fix *M* (Figure D.8). The 5CD model runs which are based on a single CPUE series estimate that recent biomass levels are near the mean biomass for the model period while the model runs which split the CPUE series estimate that the current biomass levels are at the highest observed in the past 40 years. This dichotomy is caused by the split CPUE models estimating separate catchabilities for the two series and that the estimates for the catchabilities in the second series are lower that in the first series. Whether this is a correct interpretation of the data depends on whether it is believed that the current management effectively causes fishing for this species to be relatively less effective that it was prior to the management changes instituted in the mid-1990s.

The period between 1978 and 1988 was selected as a reference biomass level for 5CD English sole because of the relative stability during this period and that the vulnerable biomass trajectory has been below this level and has recovered (Figure D.5 and Figure D.7 are examples). All the 5CD split CPUE series have current biomass estimates that are above the selected reference period, while the single CPUE series models tend to be very close to this level (Table D.2). All the 5CD model runs are above the minimum biomass observed in the time series, although the split CPUE series models tend to exceed this level by more than the single CPUE series (Table D.2).

Model residuals show poor performance in the fit to the weight data by year, including a strong trend across the years (Figure D.13), but show reasonable behaviour in the annual fits to the first catch series (Figure D.14) and the second catch series (Figure D.15). There are trends in the annual fit to the Hecate St. assemblage survey (Figure D.16). Similarly, there are poor patterns to the fit to the weight data for all models when the residuals are plotted against the predicted values (Figure D.17). However, the equivalent plots (predicted values against standardised residuals) are acceptable for the fits to the first catch series (Figure D.18), second catch series (Figure D.19) and the HS assemblage survey (Figure D.20). Model residuals fit the lognormal distribution assumptions slightly less well for the weight data (Figure D.21) than for the first catch series (Figure D.22), the second catch series (Figure D.23), and the HS assemblage survey (Figure D.24). As noted above, there is a strong similarity in the pattern of residuals across all model fits, indicating that there are probably processes in the data which are not being modelled.

3CD5AB model runs MPD fits

The 3CD5AB model estimated, as would be expected given the catch history, lower values for B_0 than for the equivalent 5CD models (Table D.2). The estimated survey *q*'s are not as large for these models compared to the high values estimated for the 5CD assessments. The ratio of the catchability for the second catch series is about 70% of the catchability for the first catch series for both 3CD5AB models with the split CPUE series.

Plots of the fits to the data for two of the four 3CD5AB runs are provided: single CPUE, *r*=5, estimate *M* (Figure D.9); and split CPUE, *r*=5, fix *M* (Figure D.10). The fits to the weight data show even more trend than did the 5CD fits, which is not surprising given that these mean weight data apply to 5CD and not to 3CD5AB. The fits to the catch data are good but there is a great deal of process error in the fit to the WCVI Triennial survey, which has a stronger upward trajectory than the predicted biomass.

Population trajectory plots, the time series of harvest rate estimates and the estimated recruitments by year are also presented for these example 3CD5AB runs: single CPUE, *r*=5, estimate *M* (Figure D.11); and split CPUE, *r*=5, fix *M* (Figure D.12). The two model runs with split CPUE series estimate that recent biomass levels are at the highest observed in the past 40 years, but that there has been a recent downturn from a peak which occurred around 2003–2004. However, as for the 5CD assessment runs, model runs based on a single CPUE series estimate current biomass levels are near to or slightly below the long-term average biomass. However, there is little contrast in biomass levels over the history of the series.

The period 1974 to 1986 was selected for the 3CD5AB runs as a reference period, using the same reasoning as was applied for the selection of the 5CD reference period. The current status of the 3CD5AB stock relative to the B_{ref} and B_{min} indicators is near 1.0 for both because of the small amount of contrast in the biomass series, resulting in values for these two reference points that are nearly the same to each other and to recent biomass levels (Figure D.11, Figure D.12).

As for the 5CD model runs, residuals for the 3CD5AB model runs show poor performance in the fit to the weight data by year, with a strong trend in the residuals across years (Figure D.13), but show reasonable behaviour in the annual fits to the first catch series (Figure D.14) There are trends in the annual fit to the WCVI Triennial survey (Figure D.16) but residuals for the second catch series aren't too bad (Figure D.15). There is reasonable scatter when the standardised residuals for the weight data are plotted against the predicted values (Figure D.17) as are the equivalent plots (predicted values against standardised residuals) for the fits to the first catch series (Figure D.18), second catch series (Figure D.19) and WCVI Triennial survey (Figure D.20). As for the 5CD model runs, the model residuals fit the lognormal distribution assumptions slightly less well for the weight data (Figure D.21) than they do for the first catch series (Figure D.22), the second catch series (Figure D.23), and Triennial survey (Figure D.24). Again, as noted for the 5CD assessment runs, there is a strong similarity in the pattern of residuals across all model fits, indicating that there are probably processes in the data which are not being modelled and that the model fits to the data do not provide a good basis to select between run hypotheses.

Bayesian MCMC results

Forty million MCMC iterations were completed for all 10 model runs listed in Table D.1, with samples drawn from the MCMC chain every 20,000 iterations, thus providing a total of 2,000 samples. A comparative plot of the traces for model parameter B_0 from these 10 model runs shows good convergence behaviour in all model runs (Figure D.25). For those model runs with split CPUE hypotheses, scatter plots of the parameter pairs ${}^{C}q_1$ and ${}^{C}q_2$ were examined for possible poor MCMC behaviour, such as moving into unrealistic parameter space, because these parameters had freedom to act independently due to the broad uniform priors that were adopted which were not linked. However, the behaviour of these parameters seemed reasonable for all runs, with ${}^{C}q_2 < {}^{C}q_1$ in all cases, strong linear relationships between the two CPUE parameters (Figure D.26) and well-formed symmetrical marginal posterior distributions for the ratio ${}^{C}q_2 / {}^{C}q_1$ (Figure D.27). Therefore, it was concluded that these parameters were not causing problems in the investigated model runs.

5CD model runs: MCMC traces and posterior distributions

Traces of these draws for the main parameters from four representative 5CD runs: [`single CPUE series/`*r*`=5/estimate` *M*: Figure D.28a; `single CPUE series/`*r*`=5/fix` *M*: Figure D.28b; `split CPUE series/`*r*`=5/estimate` *M*: Figure D.28c; `split CPUE series/`*r*`=5/fix` *M*: Figure D.28d] have been plotted to demonstrate that the MCMC procedure has reasonably sampled the available parameter space. The lack of trends or sudden shifts in all these traces is taken as evidence that the MCMC procedure has converged successfully. Note the large shift away from the MPD estimate for the two 5CD runs where *M* is fixed (Figure D.28b and Figure D.28d). Table D.2 shows that these two model fits were not consistent with the fits where *M* was estimated: these models estimated a very low initial population ratio, resulting in high harvest rates and high estimates for the survey *q*'s. However the Bayesian search procedure has resulted in model runs for the fixed *M* assumption which more closely resemble the estimated *M* runs. The omitted traces from the other 4 runs resemble the ones presented here.

Marginal posterior distributions for the main parameters from the same representative runs [`single CPUE series/`*r*`=5/estimate` *M*: Figure D.29a; `single CPUE series/`*r*`=5/fix` *M*: Figure D.29b; `split CPUE series/`*r*`=5/estimate` *M*: Figure D.29c; `split CPUE series/`*r*`=5/fix` *M*: Figure D.29d] show that the distributions for these model runs are well formed and are centred in most cases near the MPD estimate, particularly for the runs which estimated *M*. Note again that the two 5CD models with fixed *M* have distributions that are shifted well away from the MPD estimate for the two *q*'s (Figure D.29b and Figure D.29d). The marginal posterior distributions for *M* tend to be symmetrical for the two example runs where this parameter was estimated (Figure D.29c and Figure D.29c), indicating that the model data are either not very informative for this parameter or that the model data are consistent with the assumption of the prior.

3CD5AB model runs: MCMC traces and posterior distributions

Traces of the draws for the main parameters from two of the model runs have also been plotted: [`single CPUE series/`*r*`=5/estimate `*M*`:` Figure D.28e; `split CPUE series/`*r*`=5/fix `*M*`:` Figure D.28f]. The lack of trends or sudden shifts in all these traces is taken as evidence that the MCMC procedure has converged successfully. The fixed *M* model run from this assessment does not show as extreme a shift away from the MPD estimate as do the two fixed *M* 5CD runs (Figure D.28f).

Marginal posterior distributions for the main parameters from the same representative runs: [`single CPUE series/`*r*`=5/estimate `*M*`:` Figure D.29e; `split CPUE series/`*r*`=5/fix `*M*`:` Figure D.29f] show that the distributions are well formed and are centred in most cases near the MPD estimate. As for the 5CD model runs, the marginal posterior distribution for *M* is symmetrical for the example run where this parameter was estimated (Figure D.29e), again indicating that the model data are either not very informative for this parameter or that the model data are consistent with the assumption of the prior.

Projections: 5CD and 3CD5AB stock assessments

Projections were made for five years, starting with the beginning year biomass in 2007/08, which is the biomass remaining at the end of the current (2006/07) fishing year. It was assumed that the 2006/07 landings in both assessments would match the TAC, which is 544 t for 5CD and 186 t for 3CD5AB, but these values were reduced to 514 t and 176 t respectively to convert the TAC to female landings based on the average 5CD proportion of females from 1996–2005 (0.94). Catch strategies ranging from 0 to 1,000 t in 100 t steps were applied to each of the 2,000 MCMC trajectories available for the six model runs for 5CD (Table D.1). The 3CD5AB assessment used catch strategies ranging from 0 to 500 t in 50 t steps.

Recruitments were randomly drawn in each year from a log-normal distribution with mean=0 and standard deviation=0.40, which was the recruitment standard deviation used in the model fitting phase. Random recruitments were started in the first year after the cessation of the estimation of recruitment deviates (2002 for *r*=5 and 2003 for *r*=4). The distribution of the beginning year biomass in each year from 2008 to 2012 resulting from each of these catch projections was then tested against four performance indicators to judge the effect of the removals. The four performance indicators considered are:

1. Exploitation rate in 2007–2011 relative to the average exploitation rate from 1966 to 2006 $\left(U_{ref} = \text{mean}\left\{U_t\right\}_{t=1966}^{2006}\right)$;
2. Beginning year biomass in 2008–2012 compared to the minimum biomass over the 1966-2006 period $\left(B_{ref} = \min\left\{B_t\right\}_{t=1966}^{2006}\right)$;
3. Beginning year biomass in 2008–2012 compared to the average biomass from one of two periods: $\left(B_{ref} = \text{mean}\left\{B_t\right\}_{t=startref}^{endref}\right)$, where *startref*=1978 for 5CD and *startref*=1974 for 3CD5AB; and *endref*=1988 for 5CD and *endref*=1986 for 3CD5AB. Each of these periods was selected as being of relative stability from which the stock has declined and recovered;

4. Beginning year 2008–2012 biomass compared to the beginning year biomass in 2007 $\left(B_{ref} = B_{2007}\right)$.

Two quantities were calculated for the three performance indicators that reference biomass levels (indicators 2, 3 and 4):

1. The cumulative probability that each draw from the MCMC posterior distribution would exceed one of the three biomass reference levels in year *y*: $\mathrm{P}\left(\tilde{B}_y > B_{ref}\right)$;

2. The expected value from the MCMC posterior distribution of the ratio of the biomass in year *y* relative to one of the three biomass reference levels: $\mathrm{E}\left(\tilde{B}_y / B_{ref}\right)$;

Only the cumulative probability in year 2011 that the exploitation rate would be below the reference exploitation was calculated for the first performance indicator $\mathrm{P}\left(U_{2011} < U_{ref}\right)$.

These performance indicators were selected over model-based reference points that use derived parameters such as B_0 or B_{MSY} because these latter parameters are usually poorly estimated, being very sensitive to assumptions made for parameters that are difficult to estimate, such as *M* or *h*. B_0 and B_{MSY} are also sensitive to the relative weighting among catch, average fish weight, or survey indices, and often change over time as more data are added to the analysis or as the stock assessment model evolves, while historical management targets are more stable because they are defined as relative targets.

The B_{min} reference point should be a level from which the stock subsequently recovers to a level above the B_{ref} reference point. This is the case for both the 5CD and the 3CD5AB assessments, even for the model runs that assume a single CPUE series. For instance, the most pessimistic of the 10 model runs presented, 3CD5AB using a single CPUE series and estimating *M*, shows a well developed minimum in the late 1960s from which the stock recovered to above the long-term average (Figure D.11). All the other runs appear to have risen above the B_{ref} reference point after experiencing a minimum. The main problem with the B_{min} reference point as applied to these two stocks is that the contrast between the high and low points of the stock is low , especially for 3CD5AB. Therefore, it is likely that the minima reported in these assessments are conservative, in that very low relative stock sizes have not occurred for these stocks.

Another advantage of using reference points which are based on a historical period is that such reference levels are more comprehensible to stakeholders and there frequently exists institutional memory of these periods. In addition, there is always the option of changing the reference period if, once attained, it seems for some reason to be unsuitable. The text table below provides the figure and table references by run number and run description for all the MCMC output.

References to tables and figures for all MCMC output by run (Table D.1)

Run Number	Assessment Region	Run description	Bayesian tabular output reference	Decision table reference	Biomass trajectory figure reference	Cumulative probability graph reference
Case 1	5CD	single CPUE series | $r = 4$ | est *M*	Table D.3	Table. D.6	Figure D.30	Figure D.40
Case 2	5CD	single CPUE series | $r = 5$ | est *M*		Table. D.7	Figure D.31	Figure D.41
Case 3	5CD	single CPUE series | $r = 5$ | fix *M*			Figure D.32	Figure D.42
Case 4	5CD	split CPUE series | $r = 4$ | est *M*	Table D.4	Table. D.8	Figure D.33	Figure D.43

Run Number	Assessment Region	Run description	Bayesian tabular output reference	Decision table reference	Biomass trajectory figure reference	Cumulative probability graph reference
Case 5	5CD	split CPUE series | $r = 5$ | est *M*		Table. D.9	Figure D.34	Figure D.44
Case 6	5CD	split CPUE series | $r = 5$ | fix *M*			Figure D.35	Figure D.45
Case 7	3CD5AB	single CPUE series | $r = 5$ | est *M*	Table D.5	Table. D.10	Figure D.36	Figure D.46
Case 8	3CD5AB	single CPUE series | $r = 5$ | fix *M*			Figure D.37	Figure D.47
Case 9	3CD5AB	split CPUE series | $r = 5$ | est *M*		Table. D.11	Figure D.38	Figure D.48
Case 10	3CD5AB	split CPUE series | $r = 5$ | fix *M*			Figure D.39	Figure D.49

5CD model runs: MCMC results

Box plots of the biomass trends for the six 5CD model runs include a five year projection at 500 t, which is close to the estimated female landings that would be taken by the TAC. All six of these 5CD model runs project that the biomass will either increase or stay close to current levels under the existing TAC. The two model runs with a split CPUE and which estimate M show a flat trend since about 2000, but both of these model runs indicate that a large shift occurred in the overall biomass at about that time. The single CPUE runs appear to be somewhat less optimistic than the split CPUE runs, but the difference does not seem to be as marked as was seen when the MPD estimates of the runs were compared (Table D.2).

There appears to be little sensitivity to whether *M* is estimated or not. This is likely because of the use of the informed prior on *M* which kept the estimate near to the fixed value used as the "best estimate" for this parameter. Also, the age of knife-edge recruitment was selected to ensure that the model estimates of absolute mean weight would be in the neighbourhood of the mean weight observed in the fishery. Therefore, in these instances, the mean weight data and the estimation of *M* tend to have little leverage over fixing *M* at the preferred value of 0.20. Model results also do not appear to be very sensitive to the choice of the two ages of knife-edge recruitment that were tested in this assessment.

All of the 5CD models indicate that the stock should stay above the four reference levels at the current TAC. The model runs which assume separate catchabilities with a split CPUE series are very optimistic although they predict a declining stock size over the next five years. These runs predict that catch would have to be above 800 t per year before the probability of going below the 1978–1988 reference point drops below 50% (even higher for the minimum biomass reference point). The runs which use a single CPUE series for 5CD are less optimistic, predicting that the 50% probability level for dropping below the 1978–1988 reference is associated with catch levels of around 600 t/year. All model runs predict that the stock size will decrease at landings greater than the current TAC.

3CD5AB model runs: MCMC results

Box plots of the biomass trends for the four 3CD5AB model runs include a five year projection at 175 t, which is very close to the estimated female landings that would be taken by the TAC. The four 3CD5AB model runs project that the biomass will on average decrease under the existing TAC. The two single CPUE runs are less optimistic than the split CPUE runs, with current stock levels near the lowest in the series, while the two split CPUE model runs reverse this observation, with levels in the early 2000s at the highest point in the series. However, it can be generally said that the four assessment runs made for the 3CD5AB stock are characterised by a large amount of uncertainty and little in the way of trend, regardless of which CPUE series was used. This lack of trend reflects the underlying CPUE series which also has no strong trend (Figure B.2).

The 3CD5AB models runs are generally pessimistic even at the current levels of landings, which is probably due to the fact that the catch history for this stock only averages around 150 t per year, which is lower than the current TAC. However, the results from this assessment are probably much less reliable than for the 5CD model, given the fact that the assessment is entirely based on 5CD biological information and that the data are not informing the model particularly well, given the wide uncertainty distributions which stay broad over the full reconstruction of the stock history. Part of this behaviour is probably due to the lack of contrast in the CPUE trajectory. Usually it is the contrast that informs these models because only a limited number of scenarios can fit the change in biomass. However, the number of feasible trajectories increases substantially when there is relatively little contrast, as is the case for both of these assessments.

Table D.2. Maximum posterior density (MPD) results for the 5CD and 3CD5AB English sole delay-difference stock assessment model runs described in Table 1. Fishing years are coded by first year in pair. The CPUE series have been split between the 1995/96 and 1996/97 fishing years. All biomass levels are for the beginning year. Parameters fixed at indicated values are shown in greyed cells. N/A or –: not applicable. SD: standard deviation of Pearson residuals for the indicated data set. Median: median of the absolute value of Pearson residuals for the indicated data set. *start ref year*=1978 for 5CD and =1974 for 3CD5AB; *end ref year*=1988 for 5CD and =1986 for 3CD5AB.

Assessment region	**5CD**						**3CD5AB**			
Number of CPUE series	**Single CPUE series**			**Split CPUE series**			**Single CPUE series**		**Split CPUE series**	
Knife-edge recruit age	$r=4$	$r=5$	$r=5$	$r=4$	$r=5$	$r=5$	$r=5$	$r=5$	$r=5$	$r=5$
Estimate or fix *M*:	**Estimate *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***
Parameters										
B_0	11,774	8,062	7,671	12,865	8,377	7,823	2,773	2,202	3,102	2,253
M	0.16	0.22	0.20	0.19	0.24	0.20	0.224	0.200	0.228	0.200
${}^{C}q_1$	2.65E-05	4.58E-05	7.42E-05	2.14E-05	4.10E-05	9.15E-05	1.13E-05	1.84E-05	1.09E-05	2.07E-05
${}^{C}q_2$	–	–	–	1.48E-05	2.87E-05	6.58E-05	–	–	7.91E-06	1.52E-05
${}^{S}q_1$	2.31	3.66	5.59	1.61	2.87	5.92	1.62	2.56	1.45	2.67
${}^{S}q_2$	3.51	5.49	8.49	1.86	3.43	7.50	0.64	1.03	0.44	0.83
Sigmas										
Weight	0.07	0.07	N/A	0.07	0.07	N/A	0.09	N/A	0.09	N/A
Catch(1)	0.17	0.13	0.13	0.16	0.14	0.15	0.18	0.18	0.20	0.19
Catch(2)	–	–	–	0.04	0.03	0.02	–	–	0.06	0.06
q_Survey(1)[1]	0.39	0.39	0.39	0.26	0.25	0.26	0.50	0.51	0.42	0.43
q_Survey(2)[2]	0.23	0.21	0.21	0.26	0.27	0.27	0.00	0.00	0.00	0.00
Rdevs	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Negative log likelihoods										
Weight	-30.0	-27.9	N/A	-29.7	-27.8	N/A	-22.3	N/A	-23.2	N/A
Catch(1)	-12.8	-23.7	-24.5	-11.8	-16.2	-13.7	-12.3	-13.5	-6.6	-7.4
Catch(2)	–	–	–	-20.2	-26.7	-28.8	–	–	-16.3	-16.5
q_Survey(1)	6.7	6.6	6.6	4.0	3.9	4.2	5.2	5.3	4.2	4.4
q_Survey(2)	-0.3	-0.4	-0.4	0.1	0.2	0.2	-1.2	-1.2	-1.3	-1.4
Recruitment deviations	3.4	5.9	6.1	9.2	8.2	7.1	3.1	3.6	4.4	4.8
Priors	3.7	5.9	6.0	9.1	8.7	7.0	3.2	3.5	4.5	4.7
Total likelihood	-29.3	-33.6	-6.2	-39.3	-49.7	-23.8	-24.4	-2.2	-34.3	-11.4
$\text{Catch}_{\text{observed}}/\text{Catch}_{\text{predicted}}$	1.029	1.023	1.022	1.030	1.025	1.024	1.023	1.028	1.015	1.021

Assessment region	5CD						3CD5AB			
Number of CPUE series	Single CPUE series			Split CPUE series			Single CPUE series		Split CPUE series	
Knife-edge recruit age	$r = 4$	$r = 5$	$r = 5$	$r = 4$	$r = 5$	$r = 5$	$r = 5$	$r = 5$	$r = 5$	$r = 5$
Estimate or fix *M*:	**Estimate *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***	**Estimate *M***	**Fix *M***
Derived reference parameters										
B_{MSY}/B_0	0.25	0.24	0.24	0.24	0.23	0.24	0.23	0.24	0.23	0.24
$\text{mean}\{U_t\}_{t=1966}^{2006}$	0.11	0.18	0.28	0.08	0.15	0.31	0.07	0.12	0.06	0.12
$\text{mean}\{B_t\}_{t=\text{start ref year}}^{\text{end ref year}}$	5,310	3,255	2,099	6,678	3,664	1,764	1,825	1,150	1,921	1,044
$\min\{B_t\}_{t=1966}^{2006}$	3,798	2,177	1,417	5,598	2,985	1,454	1,473	867	1,555	782
Year of $\min\{B_t\}_{t=1966}^{2006}$	2000	2000	2000	1999	1999	1999	1968	1968	1970	1968
$B_{2007}/\text{mean}\{B_t\}_{t=\text{start ref year}}^{\text{end ref year}}$	0.99	1.00	0.96	1.42	1.39	1.34	0.89	0.83	1.15	1.09
$B_{2007}/\min\{B_t\}_{t=1966}^{2006}$	1.39	1.50	1.42	4.75	2.56	1.18	1.10	1.10	1.12	0.58
Standardised normal (Pearson) residuals										
SD_weight	0.99	0.99	N/A	0.98	0.99	N/A	1.01	N/A	1.00	N/A
SD_catch(1)	1.01	1.01	1.00	1.02	1.02	1.05	0.99	0.99	1.01	1.00
SD_catch(2)	–	–	–	0.75	0.34	0.21	–	–	0.66	0.62
SD_survey(1)	1.00	1.00	1.00	1.02	1.03	1.04	1.00	1.01	1.01	1.03
SD_survey(2)	1.01	1.00	1.00	1.02	1.05	1.06	0.81	0.77	0.70	0.68
Median_weight	0.91	0.92	0.00	0.92	0.99	0.00	0.93	0.00	0.86	0.00
Median_catch(1)	0.89	0.79	0.72	0.87	0.77	0.76	0.57	0.51	0.68	0.46
Median_catch(2)	–	–	–	0.57	0.26	0.19	–	–	0.43	0.41
Median_survey(1)	0.86	0.74	0.77	0.76	0.81	0.81	0.74	0.74	0.48	0.51
Median_survey(2)	0.55	0.51	0.50	0.58	0.65	0.66	0.66	0.63	0.59	0.56

[1] Survey(1): Hecate Strait assemblage for 5CD and WCVI Triennial for 3CD5AB

[2] Survey(2): Hecate Strait Pacific cod monitoring for 5CD and Queen Charlotte Sound synoptic for 3CD5AB

Table D.3. Model parameter and derived parameter estimates (mean and Bayesian 90% confidence bounds) for the 5CD English sole delay-difference stock assessment model for three runs using a single CPUE series from 1966 to 2005. Performance probabilities for a projection to beginning year 2012, assuming landed mortalities of 500 t (equivalent to the current TAC as female only catch), are presented relative to the management reference points.

Assessment region									5CD
Number CPUE series									**Single CPUE series (1966–2005)**
Knife-edge recruitment age			$r = 4$			$r = 5$			$r = 5$
Estimate or fix M			**Estimate *M***			**Estimate *M***			**Fix *M***
	5%	**Mean**	**95%**	**5%**	**Mean**	**95%**	**5%**	**Mean**	**95%**
Parameters									
B_0	10,489	11,956	13,772	7,264	8,507	9,927	7,301	8,035	9,148
${}^{C}q_1$	2.10E-5	2.90E-5	3.80E-5	3.30E-5	4.60E-5	5.90E-5	3.30E-5	5.50E-5	8.20E-5
${}^{S}q_{\text{HS\_assemblage}}$	1.67	2.61	3.69	2.60	3.82	5.35	2.70	4.46	6.71
${}^{S}q_{\text{HS Pcod monitoring}}$	2.55	4.06	5.93	3.79	5.76	8.15	4.00	6.75	10.18
M	0.11	0.15	0.18	0.16	0.20	0.25	0.20	0.20	0.20
Derived reference parameters									
$\text{mean}\{U_t\}_{t=1966}^{2006}$	0.09	0.12	0.16	0.13	0.18	0.23	0.14	0.21	0.30
U_{2011}	0.06	0.10	0.15	0.09	0.14	0.22	0.09	0.17	0.28
$U_{2011} / \text{mean}\{U_t\}_{t=1966}^{2006}$	0.59	0.81	1.06	0.53	0.79	1.11	0.53	0.80	1.15
$B_{2007} / \min\{B_t\}_{t=1966}^{2006}$	1.20	1.45	1.74	1.26	1.59	1.98	1.21	1.55	1.95
$B_{2007} / \text{mean}\{B_t\}_{t=1978}^{1988}$	0.83	0.99	1.18	0.82	1.02	1.25	0.79	0.99	1.22
$B_{2012} / \min\{B_t\}_{t=1966}^{2006}$	1.14	1.57	2.12	1.19	1.79	2.55	1.19	1.79	2.60
$B_{2012} / \text{mean}\{B_t\}_{t=1978}^{1988}$	0.79	1.08	1.43	0.77	1.15	1.62	0.74	1.14	1.63
B_{2012} / B_{2007}	0.84	1.09	1.39	0.79	1.13	1.56	0.79	1.16	1.66
Year of $\min\{B_t\}_{t=1966}^{2006}$ [1]	1998	2000	2001	1998	2000	2001	1998	2000	2001
Probability of exceeding a reference value									
		Probability			**Probability**			**Probability**	
$P\left(B_{2007} > \min\{B_t\}_{t=1966}^{2006}\right)$		1.00			1.00			1.00	
$P\left(B_{2007} > \text{mean}\{B_t\}_{t=1978}^{1988}\right)$		0.46			0.51			0.44	
$P\left(B_{2012} > \min\{B_t\}_{t=1966}^{2006}\right)$		0.99			0.99			0.99	
$P\left(B_{2012} > \text{mean}\{B_t\}_{t=1978}^{1988}\right)$		0.64			0.69			0.68	
$P\left(B_{2012} > B_{2007}\right)$		0.68			0.70			0.73	

[1] median instead of mean for this row

Table D.4. Model parameter and derived parameter estimates (mean and Bayesian 90% confidence bounds) for the 5CD English sole delay-difference stock assessment model for three runs using two split CPUE series: one from 1966 to 1995 and the second from 1996 to 2005. Performance probabilities for a projection to beginning year 2012, assuming landed mortalities of 500 t (equivalent to the current TAC as female only catch), are presented relative to the management reference points.

Assessment region	5CD								
Number CPUE series	Split CPUE series (1966–1995 & 1996–2005)								
Knife-edge recruitment age	$r = 4$			$r = 5$			$r = 5$		
Estimate or fix *M*	**Estimate *M***			**Estimate *M***			**Fix *M***		
	5%	**Mean**	**95%**	**5%**	**Mean**	**95%**	**5%**	**Mean**	**95%**
Parameters									
B_0	10,779	12,356	14,607	7,652	8,806	10,130	7,501	8,262	9,375
${}^{C}q_1$	1.70E-5	2.70E-5	3.70E-5	2.90E-5	4.20E-5	5.60E-5	3.80E-5	6.20E-5	9.50E-5
${}^{C}q_2$	1.10E-5	2.00E-5	2.90E-5	1.90E-5	3.00E-5	4.30E-5	2.60E-5	4.50E-5	7.00E-5
${}^{S}q_{\text{HS\_assemblage}}$	1.25	2.11	3.09	1.97	3.05	4.28	2.65	4.31	6.36
${}^{S}q_{\text{HS Pcod monitoring}}$	1.40	2.63	4.15	2.27	3.81	5.92	3.08	5.55	8.76
M	0.13	0.17	0.21	0.17	0.22	0.27	0.20	0.20	0.20
Derived reference parameters									
$\text{mean}\{U_t\}_{t=1966}^{2006}$	0.07	0.10	0.14	0.11	0.15	0.20	0.14	0.22	0.31
U_{2011}	0.04	0.07	0.10	0.06	0.10	0.15	0.08	0.14	0.23
$U_{2011}/\text{mean}\{U_t\}_{t=1966}^{2006}$	0.51	0.66	0.83	0.47	0.66	0.88	0.43	0.65	0.92
$B_{2007}/\min\{B_t\}_{t=1966}^{2006}$	1.55	1.75	1.98	1.52	1.78	2.10	1.48	1.78	2.15
$B_{2007}/\text{mean}\{B_t\}_{t=1978}^{1988}$	1.15	1.39	1.65	1.13	1.40	1.71	1.07	1.38	1.75
$B_{2012}/\min\{B_t\}_{t=1966}^{2006}$	1.35	1.75	2.25	1.30	1.83	2.50	1.30	1.94	2.74
$B_{2012}/\text{mean}\{B_t\}_{t=1978}^{1988}$	1.04	1.39	1.80	1.01	1.43	1.96	0.98	1.51	2.18
B_{2012}/B_{2007}	0.80	1.00	1.26	0.76	1.03	1.38	0.78	1.09	1.51
Year of $\min\{B_t\}_{t=1966}^{2006}$ [1]	1982	1999	2000	1971	1999	2000	1971	1999	2000
Probability of exceeding a reference value									
		Probability			**Probability**			**Probability**	
$P\left(B_{2007} > \min\{B_t\}_{t=1966}^{2006}\right)$		1.00			1.00			1.00	
$P\left(B_{2007} > \text{mean}\{B_t\}_{t=1978}^{1988}\right)$		1.00			0.99			0.98	
$P\left(B_{2012} > \min\{B_t\}_{t=1966}^{2006}\right)$		1.00			1.00			1.00	
$P\left(B_{2012} > \text{mean}\{B_t\}_{t=1978}^{1988}\right)$		0.97			0.96			0.94	
$P\left(B_{2012} > B_{2007}\right)$		0.46			0.50			0.63	

[1] median instead of mean for this row

Table D.5. Model parameter and derived parameter estimates (mean and Bayesian 90% confidence bounds) for the 3CD5AB English sole delay-difference stock assessment model for four indicated runs. All runs assume knife-edge recruitment at age 5. Performance probabilities for a projection to beginning year 2012, assuming landed mortalities of 175 t (equivalent to the current TAC as female only catch), are presented relative to the management reference points.

Assessment region	3CD5AB											
Knife-edge recruitment age	***r*=5**											
Number of CPUE series:	**Single CPUE series (1966–2005)**						**Split CPUE series (1966–1995 & 1996–2005)**					
Estimate or fix M:	**Estimate M**			**Fix M**			**Estimate M**			**Fix M**		
	5%	**Mean**	**95%**	**5%**	**Mean**	**95%**	**5%**	**Mean**	**95%**	**5%**	**Mean**	**95%**
Parameters												
B_0	2,086	2,803	4,077	1,740	2,318	3,308	2,242	2,992	4,235	1,772	2,240	2,939
${}^{C}q_1$	6.3E-06	1.2E-05	1.9E-05	8.4E-06	1.8E-05	3.1E-05	7.0E-06	1.3E-05	2.0E-05	1.2E-05	2.2E-05	3.8E-05
${}^{C}q_2$	–	–	–	–	–	–	4.9E-06	9.6E-06	1.5E-05	8.6E-06	1.6E-05	2.8E-05
${}^{S}q_{\text{WCVI\_Triennial}}$	0.91	1.89	3.12	1.25	2.72	4.88	0.89	1.81	2.95	1.51	2.97	5.05
${}^{S}q_{\text{QC Snd\_synoptic}}$	0.34	0.72	1.17	0.48	1.04	1.75	0.27	0.54	0.87	0.48	0.91	1.49
M	0.17	0.21	0.26	0.20	0.20	0.20	0.16	0.21	0.26	0.20	0.20	0.20
Derived Reference Parameters												
$\text{mean}\{U_t\}_{t=1966}^{2006}$	0.04	0.08	0.12	0.05	0.11	0.19	0.04	0.08	0.12	0.07	0.13	0.21
U_{2011}	0.06	0.13	0.23	0.08	0.21	0.45	0.05	0.10	0.17	0.09	0.19	0.36
$U_{2011}/\text{mean}\{U_t\}_{t=1966}^{2006}$	1.11	1.59	2.24	1.16	1.77	2.74	0.96	1.33	1.78	0.97	1.47	2.17
$B_{2007}/\min\{B_t\}_{t=1966}^{2006}$	0.97	1.18	1.44	0.92	1.15	1.43	1.20	1.50	1.90	1.16	1.51	1.96
$B_{2007}/\text{mean}\{B_t\}_{t=1974}^{1986}$	0.72	0.89	1.08	0.66	0.84	1.04	0.94	1.16	1.42	0.84	1.10	1.40
$B_{2012}/\min\{B_t\}_{t=1966}^{2006}$	0.77	1.14	1.61	0.64	1.07	1.56	0.98	1.39	1.93	0.82	1.35	1.99
$B_{2012}/\text{mean}\{B_t\}_{t=1974}^{1986}$	0.57	0.86	1.20	0.45	0.78	1.14	0.76	1.08	1.47	0.58	0.99	1.44
B_{2012}/B_{2007}	0.69	0.97	1.32	0.60	0.93	1.31	0.70	0.93	1.22	0.59	0.90	1.25
Year of $\min\{B_t\}_{t=1966}^{2006}$ [1]	1968	1970	2003.5	1968	1968	2006	1968	1970	1996	1968	1968	1996
Probability of exceeding a reference value												
		Probability			**Probability**			**Probability**			**Probability**	
$P\left(B_{2007} > \min\{B_t\}_{t=1966}^{2006}\right)$		0.91			0.85			1.00			1.00	
$P\left(B_{2007} > \text{mean}\{B_t\}_{t=1974}^{1986}\right)$		0.15			0.10			0.86			0.71	
$P\left(B_{2012} > \min\{B_t\}_{t=1966}^{2006}\right)$		0.70			0.57			0.94			0.85	
$P\left(B_{2012} > \text{mean}\{B_t\}_{t=1974}^{1986}\right)$		0.21			0.14			0.62			0.45	
$P\left(B_{2012} > B_{2007}\right)$		0.39			0.33			0.29			0.26	

[1] median instead of mean for this row

Table. D.6. Tables of the probability and the expected value of the beginning year biomass in the projection year exceeding the minimum observed biomass for one to five year projections starting from the beginning year biomass in 2007 for the Case 1 5CD English sole runs (Table D.1). Total projection catch has been rounded up to next highest 1 t based on the mean proportion of males in the 5CD sampled commercial catch from 1996–2005: 0.0555. The approximate level of the current TAC is indicated with grey shading.

Projection Catch		5CD: single CPUE series | $r = 4$									
		Estimate *M*					**Estimate *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
		$\mathrm{P}\left(\tilde{B}_y > \min\{B_t\}_{t=1966}^{2006}\right)$					$\mathrm{E}\left(\tilde{B}_y / \min\{B_t\}_{t=1966}^{2006}\right)$				
0	0	1.00	1.00	1.00	1.00	1.00	1.61	1.78	1.94	2.08	2.20
106	100	1.00	1.00	1.00	1.00	1.00	1.58	1.73	1.86	1.98	2.08
212	200	1.00	1.00	1.00	1.00	1.00	1.55	1.67	1.78	1.87	1.95
318	300	1.00	1.00	1.00	1.00	1.00	1.52	1.61	1.70	1.76	1.83
424	400	1.00	1.00	1.00	1.00	1.00	1.49	1.56	1.61	1.66	1.70
530	500	1.00	1.00	0.99	0.99	0.99	1.46	1.50	1.53	1.55	1.57
636	600	0.99	0.98	0.98	0.97	0.95	1.43	1.44	1.45	1.45	1.45
742	700	0.99	0.97	0.94	0.90	0.88	1.40	1.38	1.36	1.34	1.32
848	800	0.98	0.93	0.86	0.80	0.73	1.37	1.32	1.28	1.23	1.19
953	900	0.97	0.88	0.76	0.66	0.56	1.34	1.27	1.20	1.13	1.06
1059	1000	0.95	0.81	0.65	0.50	0.40	1.31	1.21	1.11	1.02	0.93
		$\mathrm{P}\left(\tilde{B}_y > \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$					$\mathrm{E}\left(\tilde{B}_y / \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$				
0	0	0.77	0.93	0.98	0.99	1.00	1.11	1.23	1.34	1.43	1.51
106	100	0.73	0.89	0.96	0.98	0.99	1.09	1.19	1.28	1.36	1.43
212	200	0.66	0.83	0.91	0.95	0.97	1.07	1.15	1.22	1.29	1.34
318	300	0.60	0.74	0.82	0.88	0.91	1.05	1.11	1.17	1.21	1.26
424	400	0.54	0.65	0.71	0.76	0.80	1.03	1.07	1.11	1.14	1.17
530	500	0.48	0.54	0.59	0.62	0.64	1.01	1.03	1.05	1.07	1.08
636	600	0.42	0.44	0.44	0.45	0.46	0.98	0.99	1.00	0.99	0.99
742	700	0.36	0.35	0.33	0.31	0.29	0.96	0.95	0.94	0.92	0.91
848	800	0.30	0.27	0.24	0.20	0.17	0.94	0.91	0.88	0.85	0.82
953	900	0.26	0.20	0.16	0.13	0.10	0.92	0.87	0.82	0.78	0.73
1059	1000	0.22	0.15	0.10	0.07	0.05	0.90	0.83	0.77	0.70	0.64
		$\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$					$\mathrm{E}\left(\tilde{B}_y / B_{2007}\right)$				
0	0	0.99	1.00	1.00	1.00	1.00	1.11	1.23	1.35	1.44	1.53
106	100	0.98	0.99	1.00	1.00	1.00	1.09	1.20	1.29	1.37	1.44
212	200	0.94	0.96	0.98	0.99	0.99	1.07	1.16	1.23	1.30	1.35
318	300	0.85	0.88	0.92	0.94	0.95	1.05	1.11	1.17	1.22	1.27
424	400	0.68	0.75	0.79	0.83	0.86	1.03	1.07	1.12	1.15	1.18
530	500	0.51	0.58	0.62	0.65	0.68	1.01	1.03	1.06	1.07	1.09
636	600	0.36	0.43	0.44	0.44	0.45	0.99	0.99	1.00	1.00	1.00
742	700	0.26	0.28	0.29	0.28	0.27	0.97	0.95	0.94	0.92	0.91
848	800	0.16	0.18	0.19	0.16	0.15	0.95	0.91	0.88	0.85	0.82
953	900	0.11	0.12	0.12	0.10	0.07	0.92	0.87	0.83	0.78	0.73
1059	1000	0.07	0.08	0.07	0.05	0.04	0.90	0.83	0.77	0.70	0.64

Table. D.7. Tables of the probability and the expected value of the beginning year biomass in the projection year exceeding the minimum observed biomass for one to five year projections starting from the beginning year biomass in 2007 for the Case 2 and Case 3 5CD English sole runs (Table D.1). Total projection catch has been rounded up to next highest 1 t based on the mean proportion of males in the 5CD sampled commercial catch from 1996–2005: 0.0555. The approximate level of the current TAC is indicated with grey shading.

Projection Catch		5CD: single CPUE series | $r = 5$									
						Estimate *M*					**Fix *M***
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$P\left(\tilde{B}_y > \min\{B_t\}_{t=1966}^{2006}\right)$											
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
106	100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
212	200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
318	300	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
424	400	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00
530	500	1.00	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.99
636	600	0.99	0.98	0.97	0.95	0.96	0.98	0.95	0.94	0.94	0.93
742	700	0.98	0.94	0.92	0.89	0.87	0.95	0.90	0.85	0.83	0.80
848	800	0.97	0.89	0.82	0.77	0.71	0.92	0.82	0.74	0.69	0.63
953	900	0.94	0.82	0.70	0.62	0.54	0.87	0.72	0.61	0.51	0.44
1059	1000	0.92	0.73	0.57	0.45	0.36	0.83	0.61	0.47	0.37	0.28
$E\left(\tilde{B}_y / \min\{B_t\}_{t=1966}^{2006}\right)$											
0	0	1.83	2.10	2.33	2.52	2.69	1.84	2.16	2.43	2.66	2.85
106	100	1.79	2.02	2.21	2.38	2.51	1.78	2.06	2.29	2.49	2.65
212	200	1.74	1.93	2.09	2.22	2.33	1.73	1.95	2.15	2.31	2.44
318	300	1.70	1.84	1.97	2.07	2.15	1.67	1.85	2.00	2.12	2.22
424	400	1.65	1.75	1.84	1.91	1.97	1.62	1.74	1.85	1.94	2.01
530	500	1.60	1.67	1.72	1.76	1.79	1.56	1.64	1.71	1.76	1.79
636	600	1.56	1.58	1.60	1.61	1.61	1.51	1.54	1.56	1.57	1.58
742	700	1.51	1.49	1.47	1.45	1.43	1.45	1.43	1.42	1.39	1.37
848	800	1.46	1.41	1.35	1.30	1.25	1.40	1.33	1.27	1.22	1.17
953	900	1.42	1.32	1.23	1.14	1.07	1.34	1.23	1.14	1.06	0.99
1059	1000	1.37	1.23	1.11	1.00	0.91	1.29	1.14	1.01	0.92	0.84
$P\left(\tilde{B}_y > \text{mean}\{B_t\}_{t=1978}^{1988}\right)$											
0	0	0.84	0.96	0.99	1.00	1.00	0.81	0.97	1.00	1.00	1.00
106	100	0.78	0.92	0.98	0.99	1.00	0.75	0.93	0.98	0.99	1.00
212	200	0.71	0.86	0.94	0.97	0.98	0.67	0.86	0.94	0.97	0.99
318	300	0.65	0.78	0.88	0.92	0.94	0.60	0.77	0.86	0.92	0.95
424	400	0.58	0.68	0.76	0.82	0.84	0.52	0.67	0.74	0.81	0.85
530	500	0.51	0.57	0.62	0.66	0.69	0.45	0.54	0.60	0.65	0.68
636	600	0.44	0.47	0.48	0.50	0.51	0.38	0.42	0.47	0.46	0.47
742	700	0.39	0.38	0.37	0.35	0.34	0.32	0.32	0.32	0.31	0.28
848	800	0.33	0.29	0.27	0.23	0.20	0.27	0.24	0.22	0.20	0.18
953	900	0.28	0.23	0.18	0.15	0.12	0.22	0.17	0.14	0.11	0.09
1059	1000	0.24	0.17	0.13	0.09	0.06	0.18	0.12	0.09	0.05	0.05

Projection Catch		5CD: single CPUE series | $r = 5$									
		Estimate *M*					**Fix *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$\mathrm{E}\left(\tilde{B}_y \big/ \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$											
0	0	1.17	1.35	1.49	1.61	1.72	1.17	1.38	1.55	1.70	1.82
106	100	1.14	1.29	1.42	1.52	1.61	1.14	1.31	1.46	1.59	1.69
212	200	1.12	1.23	1.34	1.42	1.49	1.10	1.25	1.37	1.47	1.55
318	300	1.09	1.18	1.26	1.32	1.38	1.07	1.18	1.28	1.35	1.42
424	400	1.06	1.12	1.18	1.23	1.26	1.03	1.11	1.18	1.24	1.28
530	500	1.03	1.07	1.10	1.13	1.15	1.00	1.05	1.09	1.12	1.14
636	600	1.00	1.01	1.02	1.03	1.03	0.96	0.98	1.00	1.00	1.01
742	700	0.97	0.96	0.94	0.93	0.91	0.93	0.92	0.90	0.89	0.87
848	800	0.94	0.90	0.86	0.83	0.80	0.89	0.85	0.81	0.78	0.74
953	900	0.91	0.84	0.79	0.73	0.69	0.86	0.79	0.73	0.68	0.63
1059	1000	0.88	0.79	0.71	0.64	0.59	0.82	0.73	0.65	0.59	0.54
$\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$											
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
106	100	0.98	0.98	0.99	1.00	1.00	0.99	1.00	1.00	1.00	1.00
212	200	0.94	0.95	0.98	0.98	0.99	0.95	0.98	0.99	0.99	0.99
318	300	0.83	0.87	0.91	0.94	0.96	0.85	0.90	0.93	0.96	0.97
424	400	0.67	0.73	0.79	0.84	0.86	0.69	0.75	0.82	0.87	0.88
530	500	0.50	0.58	0.63	0.66	0.70	0.48	0.57	0.64	0.69	0.72
636	600	0.35	0.42	0.45	0.47	0.47	0.33	0.41	0.44	0.47	0.48
742	700	0.23	0.29	0.30	0.31	0.29	0.20	0.28	0.29	0.30	0.28
848	800	0.14	0.20	0.19	0.18	0.17	0.12	0.18	0.19	0.16	0.16
953	900	0.08	0.14	0.13	0.10	0.09	0.07	0.12	0.11	0.09	0.07
1059	1000	0.05	0.09	0.08	0.05	0.04	0.04	0.07	0.06	0.05	0.04
$\mathrm{E}\left(\tilde{B}_y \big/ B_{2007}\right)$											
0	0	1.15	1.33	1.48	1.60	1.71	1.18	1.40	1.58	1.73	1.86
106	100	1.12	1.27	1.40	1.51	1.60	1.15	1.33	1.49	1.62	1.73
212	200	1.09	1.22	1.32	1.41	1.48	1.11	1.26	1.39	1.50	1.58
318	300	1.06	1.16	1.24	1.31	1.36	1.07	1.19	1.29	1.38	1.44
424	400	1.03	1.10	1.16	1.21	1.25	1.04	1.12	1.20	1.26	1.30
530	500	1.00	1.05	1.08	1.11	1.13	1.00	1.06	1.10	1.14	1.16
636	600	0.98	0.99	1.01	1.01	1.02	0.97	0.99	1.01	1.02	1.02
742	700	0.95	0.94	0.93	0.91	0.90	0.93	0.92	0.91	0.90	0.88
848	800	0.92	0.88	0.85	0.81	0.78	0.89	0.85	0.82	0.78	0.75
953	900	0.89	0.82	0.77	0.72	0.67	0.86	0.79	0.73	0.68	0.63
1059	1000	0.86	0.77	0.69	0.63	0.57	0.82	0.73	0.65	0.59	0.54

Table. D.8. Tables of the probability and the expected value of the beginning year biomass in the projection year exceeding the minimum observed biomass for one to five year projections starting from the beginning year biomass in 2007 for the Case 4 5CD English sole runs (Table D.1). Total projection catch has been rounded up to next highest 1 t based on the mean proportion of males in the 5CD sampled commercial catch from 1996–2005: 0.0555. The approximate level of the current TAC is indicated with grey shading.

Projection Catch		5CD: split CPUE series | $r = 4$									
		Estimate *M*					**Estimate *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
		$P\left(\tilde{B}_y > \min\{B_t\}_{t=1966}^{2006}\right)$					$E\left(\tilde{B}_y / \min\{B_t\}_{t=1966}^{2006}\right)$				
0	0	1.00	1.00	1.00	1.00	1.00	1.85	1.97	2.07	2.16	2.23
106	100	1.00	1.00	1.00	1.00	1.00	1.83	1.92	2.01	2.08	2.14
212	200	1.00	1.00	1.00	1.00	1.00	1.80	1.88	1.95	2.00	2.04
318	300	1.00	1.00	1.00	1.00	1.00	1.78	1.83	1.88	1.92	1.95
424	400	1.00	1.00	1.00	1.00	1.00	1.75	1.79	1.82	1.83	1.85
530	500	1.00	1.00	1.00	1.00	1.00	1.73	1.74	1.75	1.75	1.75
636	600	1.00	1.00	1.00	1.00	1.00	1.71	1.70	1.69	1.67	1.66
742	700	1.00	1.00	1.00	1.00	1.00	1.68	1.65	1.62	1.59	1.56
848	800	1.00	1.00	1.00	0.99	0.98	1.66	1.61	1.56	1.51	1.46
953	900	1.00	1.00	1.00	0.98	0.92	1.64	1.56	1.49	1.43	1.36
1059	1000	1.00	1.00	0.98	0.93	0.84	1.61	1.52	1.43	1.34	1.27
		$P\left(\tilde{B}_y > \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$					$E\left(\tilde{B}_y / \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$				
0	0	1.00	1.00	1.00	1.00	1.00	1.47	1.56	1.64	1.71	1.77
106	100	1.00	1.00	1.00	1.00	1.00	1.45	1.52	1.59	1.65	1.69
212	200	1.00	1.00	1.00	1.00	1.00	1.43	1.49	1.54	1.58	1.62
318	300	1.00	1.00	1.00	1.00	1.00	1.41	1.45	1.49	1.52	1.54
424	400	1.00	0.99	1.00	0.99	0.99	1.39	1.42	1.44	1.45	1.47
530	500	0.99	0.99	0.98	0.98	0.97	1.38	1.38	1.39	1.39	1.39
636	600	0.98	0.98	0.96	0.95	0.93	1.36	1.35	1.34	1.33	1.31
742	700	0.98	0.96	0.92	0.89	0.86	1.34	1.31	1.29	1.26	1.24
848	800	0.97	0.93	0.88	0.81	0.76	1.32	1.28	1.24	1.20	1.16
953	900	0.96	0.90	0.81	0.72	0.63	1.30	1.24	1.19	1.13	1.09
1059	1000	0.95	0.86	0.73	0.60	0.50	1.28	1.21	1.14	1.07	1.01
		$P\left(\tilde{B}_y > B_{2007}\right)$					$E\left(\tilde{B}_y / B_{2007}\right)$				
0	0	0.89	0.92	0.94	0.96	0.96	1.06	1.12	1.18	1.23	1.28
106	100	0.82	0.86	0.90	0.91	0.92	1.04	1.10	1.15	1.19	1.22
212	200	0.71	0.78	0.82	0.84	0.87	1.03	1.07	1.11	1.14	1.17
318	300	0.60	0.66	0.71	0.74	0.76	1.02	1.05	1.08	1.10	1.11
424	400	0.48	0.54	0.58	0.60	0.64	1.00	1.02	1.04	1.05	1.06
530	500	0.36	0.41	0.44	0.46	0.46	0.99	1.00	1.00	1.00	1.00
636	600	0.25	0.31	0.32	0.32	0.29	0.97	0.97	0.96	0.96	0.95
742	700	0.17	0.22	0.22	0.20	0.19	0.96	0.94	0.93	0.91	0.89
848	800	0.12	0.15	0.15	0.13	0.11	0.95	0.92	0.89	0.86	0.84
953	900	0.08	0.10	0.11	0.08	0.06	0.93	0.89	0.85	0.81	0.78
1059	1000	0.05	0.07	0.07	0.05	0.04	0.92	0.87	0.82	0.77	0.72

Table. D.9. Tables of the probability and the expected value of the beginning year biomass in the projection year exceeding the minimum observed biomass for one to five year projections starting from the beginning year biomass in 2007 for the Case 5 and Case 6 5CD English sole runs (Table D.1). Total projection catch has been rounded up to next highest 1 t based on the mean proportion of males in the 5CD sampled commercial catch from 1996–2005: 0.0555. The approximate level of the current TAC is indicated with grey shading.

Projection Catch		5CD: split CPUE series | $r = 5$									
		Estimate *M*					**Fix *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$\mathrm{P}\left(\tilde{B}_y > \min\{B_t\}_{t=1966}^{2006}\right)$											
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
106	100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
212	200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
318	300	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
424	400	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
530	500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
636	600	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.98	0.98
742	700	1.00	1.00	0.99	0.98	0.97	1.00	0.99	0.96	0.94	0.92
848	800	1.00	0.99	0.97	0.95	0.91	0.99	0.96	0.90	0.86	0.80
953	900	1.00	0.98	0.93	0.87	0.80	0.99	0.92	0.82	0.73	0.65
1059	1000	1.00	0.96	0.87	0.76	0.70	0.97	0.86	0.70	0.58	0.47
$\mathrm{E}\left(\tilde{B}_y / \min\{B_t\}_{t=1966}^{2006}\right)$											
0	0	1.93	2.11	2.25	2.37	2.46	2.02	2.30	2.53	2.73	2.90
106	100	1.90	2.04	2.16	2.26	2.34	1.98	2.21	2.40	2.57	2.71
212	200	1.86	1.98	2.07	2.15	2.21	1.93	2.12	2.27	2.41	2.52
318	300	1.83	1.92	1.98	2.04	2.08	1.88	2.02	2.14	2.24	2.33
424	400	1.79	1.85	1.89	1.93	1.95	1.83	1.93	2.01	2.08	2.13
530	500	1.76	1.79	1.80	1.82	1.83	1.78	1.84	1.88	1.91	1.94
636	600	1.72	1.72	1.71	1.71	1.70	1.73	1.74	1.74	1.75	1.75
742	700	1.69	1.66	1.62	1.59	1.57	1.68	1.65	1.61	1.59	1.56
848	800	1.66	1.60	1.54	1.48	1.44	1.63	1.56	1.48	1.42	1.37
953	900	1.62	1.53	1.45	1.37	1.31	1.58	1.46	1.35	1.26	1.18
1059	1000	1.59	1.47	1.36	1.26	1.18	1.53	1.37	1.22	1.11	1.02
$\mathrm{P}\left(\tilde{B}_y > \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$											
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
106	100	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00
212	200	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00
318	300	0.99	0.99	0.99	1.00	1.00	0.98	0.99	0.99	1.00	1.00
424	400	0.98	0.98	0.98	0.99	0.99	0.97	0.98	0.98	0.98	0.99
530	500	0.97	0.97	0.96	0.96	0.96	0.95	0.94	0.94	0.94	0.94
636	600	0.96	0.95	0.92	0.91	0.89	0.93	0.90	0.87	0.86	0.86
742	700	0.95	0.91	0.87	0.82	0.78	0.90	0.83	0.78	0.75	0.72
848	800	0.93	0.86	0.78	0.70	0.66	0.86	0.76	0.67	0.61	0.54
953	900	0.91	0.80	0.67	0.58	0.52	0.81	0.66	0.53	0.44	0.37
1059	1000	0.88	0.71	0.56	0.47	0.38	0.76	0.56	0.42	0.31	0.24

Projection Catch		5CD: split CPUE series | $r = 5$									
		Estimate *M*					**Fix *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$\mathrm{E}\left(\tilde{B}_y / \mathrm{mean}\{B_t\}_{t=1978}^{1988}\right)$											
0	0	1.52	1.66	1.77	1.86	1.93	1.57	1.79	1.96	2.12	2.24
106	100	1.49	1.61	1.70	1.78	1.84	1.53	1.72	1.86	2.00	2.10
212	200	1.47	1.56	1.63	1.69	1.74	1.49	1.64	1.76	1.87	1.95
318	300	1.44	1.51	1.56	1.60	1.64	1.46	1.57	1.66	1.74	1.80
424	400	1.41	1.46	1.49	1.52	1.54	1.42	1.50	1.56	1.61	1.66
530	500	1.39	1.41	1.42	1.43	1.43	1.38	1.43	1.46	1.49	1.51
636	600	1.36	1.36	1.35	1.34	1.33	1.34	1.35	1.35	1.36	1.36
742	700	1.33	1.31	1.28	1.26	1.23	1.30	1.28	1.25	1.23	1.21
848	800	1.31	1.26	1.21	1.17	1.13	1.26	1.21	1.15	1.10	1.06
953	900	1.28	1.21	1.14	1.08	1.03	1.22	1.14	1.05	0.98	0.92
1059	1000	1.25	1.16	1.07	1.00	0.93	1.19	1.07	0.95	0.87	0.79
$\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$											
0	0	0.94	0.94	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00
106	100	0.87	0.89	0.92	0.94	0.95	0.96	0.97	0.99	0.99	0.99
212	200	0.77	0.81	0.85	0.88	0.89	0.90	0.92	0.95	0.97	0.98
318	300	0.65	0.69	0.75	0.79	0.80	0.77	0.81	0.87	0.91	0.92
424	400	0.49	0.58	0.60	0.65	0.67	0.61	0.68	0.73	0.78	0.81
530	500	0.36	0.45	0.47	0.49	0.50	0.43	0.52	0.55	0.59	0.63
636	600	0.25	0.32	0.35	0.35	0.34	0.28	0.35	0.39	0.41	0.41
742	700	0.17	0.24	0.25	0.23	0.22	0.17	0.25	0.26	0.26	0.24
848	800	0.11	0.17	0.17	0.16	0.14	0.10	0.17	0.17	0.15	0.13
953	900	0.07	0.12	0.12	0.09	0.08	0.06	0.11	0.10	0.08	0.07
1059	1000	0.05	0.09	0.08	0.06	0.04	0.03	0.07	0.06	0.04	0.03
$\mathrm{E}\left(\tilde{B}_y / B_{2007}\right)$											
0	0	1.08	1.18	1.27	1.33	1.39	1.13	1.30	1.43	1.54	1.64
106	100	1.06	1.15	1.22	1.27	1.32	1.11	1.24	1.35	1.45	1.53
212	200	1.04	1.11	1.17	1.21	1.25	1.08	1.19	1.28	1.36	1.42
318	300	1.02	1.08	1.11	1.15	1.17	1.05	1.14	1.20	1.26	1.31
424	400	1.00	1.04	1.06	1.08	1.10	1.02	1.08	1.13	1.17	1.20
530	500	0.98	1.00	1.01	1.02	1.03	0.99	1.03	1.05	1.08	1.09
636	600	0.97	0.97	0.96	0.96	0.95	0.96	0.98	0.98	0.98	0.98
742	700	0.95	0.93	0.91	0.90	0.88	0.94	0.92	0.90	0.89	0.87
848	800	0.93	0.89	0.86	0.83	0.81	0.91	0.87	0.83	0.80	0.76
953	900	0.91	0.86	0.81	0.77	0.73	0.88	0.82	0.75	0.71	0.66
1059	1000	0.89	0.82	0.76	0.71	0.66	0.85	0.76	0.68	0.62	0.57

Table. D.10. Tables of the probability and the expected value of the beginning year biomass in the projection year exceeding the minimum observed biomass for one to five year projections starting from the beginning year biomass in 2007 for the Case 7 and Case 8 3CD5AB English sole runs (Table D.1). Total projection catch has been rounded up to next highest 1 t based on the mean proportion of males in the 5CD sampled commercial catch from 1996–2005: 0.0555. The approximate level of the current TAC is indicated with grey shading.

Projection Catch		3CD5AB: single CPUE series | $r = 5$									
		Estimate *M*					**Fix *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
		$P\left(\tilde{B}_y > \min\{B_t\}_{t=1966}^{2006}\right)$									
0	0	0.96	0.98	0.99	1.00	1.00	0.96	0.99	1.00	1.00	1.00
53	50	0.93	0.96	0.98	0.98	0.99	0.91	0.96	0.98	0.99	0.99
106	100	0.89	0.90	0.93	0.94	0.94	0.84	0.89	0.91	0.93	0.94
159	150	0.83	0.81	0.80	0.80	0.81	0.74	0.74	0.74	0.73	0.73
186	175	0.80	0.75	0.73	0.71	0.70	0.70	0.65	0.63	0.61	0.57
212	200	0.76	0.69	0.64	0.61	0.58	0.65	0.57	0.52	0.48	0.42
265	250	0.68	0.55	0.49	0.42	0.37	0.54	0.41	0.32	0.25	0.20
318	300	0.59	0.43	0.33	0.26	0.23	0.43	0.27	0.18	0.12	0.09
371	350	0.51	0.32	0.23	0.17	0.13	0.33	0.17	0.10	0.05	0.04
424	400	0.43	0.24	0.15	0.10	0.07	0.26	0.10	0.05	0.02	0.02
477	450	0.37	0.18	0.10	0.06	0.04	0.20	0.06	0.03	0.01	0.01
530	500	0.31	0.13	0.06	0.04	0.03	0.15	0.04	0.01	0.01	0.01
		$E\left(\tilde{B}_y / \min\{B_t\}_{t=1966}^{2006}\right)$									
0	0	1.29	1.41	1.50	1.58	1.64	1.32	1.49	1.63	1.74	1.83
53	50	1.25	1.34	1.40	1.46	1.50	1.26	1.38	1.48	1.55	1.61
106	100	1.22	1.27	1.31	1.33	1.35	1.21	1.27	1.33	1.37	1.39
159	150	1.18	1.19	1.21	1.21	1.21	1.15	1.17	1.18	1.18	1.18
186	175	1.16	1.16	1.16	1.15	1.14	1.12	1.11	1.10	1.08	1.07
212	200	1.14	1.12	1.11	1.09	1.07	1.09	1.06	1.03	0.99	0.96
265	250	1.10	1.05	1.01	0.96	0.92	1.03	0.95	0.88	0.82	0.76
318	300	1.06	0.98	0.91	0.84	0.79	0.98	0.85	0.75	0.67	0.61
371	350	1.03	0.91	0.81	0.73	0.66	0.92	0.76	0.64	0.56	0.50
424	400	0.99	0.84	0.72	0.63	0.56	0.87	0.68	0.56	0.48	0.43
477	450	0.95	0.77	0.64	0.55	0.49	0.82	0.61	0.49	0.43	0.39
530	500	0.91	0.71	0.57	0.48	0.43	0.77	0.55	0.45	0.39	0.37
		$P\left(\tilde{B}_y > \text{mean}\{B_t\}_{t=1974}^{1986}\right)$									
0	0	0.39	0.61	0.75	0.83	0.89	0.35	0.62	0.81	0.89	0.94
53	50	0.32	0.47	0.60	0.68	0.74	0.27	0.46	0.61	0.71	0.78
106	100	0.26	0.36	0.43	0.47	0.51	0.20	0.31	0.39	0.44	0.48
159	150	0.21	0.26	0.28	0.30	0.29	0.15	0.20	0.22	0.22	0.23
186	175	0.19	0.22	0.23	0.23	0.21	0.13	0.15	0.16	0.15	0.14
212	200	0.17	0.18	0.17	0.17	0.15	0.11	0.11	0.11	0.10	0.08
265	250	0.13	0.13	0.10	0.09	0.07	0.08	0.06	0.05	0.03	0.03
318	300	0.10	0.08	0.06	0.05	0.04	0.06	0.03	0.02	0.01	0.01
371	350	0.08	0.05	0.04	0.03	0.02	0.04	0.02	0.01	0.00	0.00
424	400	0.06	0.04	0.02	0.02	0.01	0.03	0.01	0.00	0.00	0.00
477	450	0.04	0.02	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.00
530	500	0.03	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00

Projection Catch		3CD5AB: single CPUE series | $r = 5$									
		Estimate *M*					**Fix *M***				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$\mathrm{E}\left(\tilde{B}_y / \mathrm{mean}\{B_t\}_{t=1974}^{1986}\right)$											
0	0	0.98	1.06	1.13	1.19	1.24	0.96	1.08	1.18	1.26	1.33
53	50	0.95	1.01	1.06	1.10	1.13	0.92	1.01	1.08	1.13	1.17
106	100	0.92	0.96	0.99	1.01	1.02	0.88	0.93	0.97	0.99	1.02
159	150	0.89	0.90	0.91	0.92	0.92	0.84	0.85	0.86	0.86	0.86
186	175	0.88	0.88	0.88	0.87	0.86	0.82	0.81	0.81	0.79	0.78
212	200	0.86	0.85	0.84	0.82	0.81	0.80	0.77	0.75	0.73	0.70
265	250	0.83	0.80	0.76	0.73	0.70	0.76	0.70	0.65	0.60	0.56
318	300	0.81	0.74	0.69	0.64	0.60	0.72	0.63	0.55	0.49	0.45
371	350	0.78	0.69	0.62	0.55	0.50	0.68	0.56	0.47	0.41	0.37
424	400	0.75	0.64	0.55	0.48	0.43	0.64	0.50	0.41	0.35	0.32
477	450	0.72	0.59	0.49	0.42	0.37	0.60	0.45	0.36	0.31	0.29
530	500	0.69	0.54	0.43	0.37	0.33	0.56	0.41	0.33	0.29	0.27
$\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$											
0	0	0.94	0.95	0.97	0.98	0.98	0.98	0.99	0.99	1.00	1.00
53	50	0.86	0.87	0.90	0.93	0.94	0.92	0.93	0.95	0.97	0.98
106	100	0.68	0.69	0.74	0.77	0.79	0.71	0.74	0.79	0.83	0.84
159	150	0.46	0.47	0.51	0.51	0.53	0.42	0.46	0.49	0.49	0.50
186	175	0.37	0.38	0.39	0.40	0.39	0.31	0.35	0.36	0.35	0.33
212	200	0.29	0.30	0.31	0.30	0.28	0.22	0.25	0.26	0.23	0.20
265	250	0.16	0.19	0.19	0.17	0.15	0.10	0.13	0.12	0.09	0.07
318	300	0.09	0.12	0.11	0.09	0.07	0.06	0.06	0.05	0.03	0.03
371	350	0.05	0.08	0.07	0.05	0.04	0.03	0.03	0.02	0.01	0.01
424	400	0.03	0.05	0.04	0.03	0.02	0.01	0.02	0.01	0.01	0.00
477	450	0.01	0.03	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.00
530	500	0.01	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
$\mathrm{E}\left(\tilde{B}_y / B_{2007}\right)$											
0	0	1.10	1.20	1.28	1.35	1.40	1.14	1.29	1.42	1.52	1.60
53	50	1.06	1.14	1.20	1.24	1.28	1.09	1.20	1.29	1.36	1.41
106	100	1.03	1.08	1.11	1.14	1.16	1.04	1.10	1.15	1.19	1.22
159	150	1.00	1.01	1.03	1.03	1.03	0.99	1.01	1.02	1.02	1.02
186	175	0.98	0.98	0.98	0.98	0.97	0.97	0.96	0.96	0.94	0.93
212	200	0.97	0.95	0.94	0.92	0.91	0.94	0.92	0.89	0.86	0.83
265	250	0.93	0.89	0.86	0.82	0.79	0.89	0.82	0.76	0.71	0.66
318	300	0.90	0.83	0.77	0.72	0.67	0.84	0.74	0.65	0.58	0.53
371	350	0.87	0.77	0.69	0.62	0.56	0.79	0.66	0.56	0.48	0.43
424	400	0.84	0.71	0.61	0.53	0.48	0.75	0.58	0.48	0.42	0.38
477	450	0.80	0.65	0.54	0.46	0.41	0.70	0.52	0.43	0.37	0.34
530	500	0.77	0.60	0.48	0.41	0.37	0.66	0.48	0.39	0.34	0.32

Table. D.11. Tables of the probability and the expected value of the beginning year biomass in the projection year exceeding the minimum observed biomass for one to five year projections starting from the beginning year biomass in 2007 for the Case 9 and Case 10 3CD5AB English sole runs (Table D.1). Total projection catch has been rounded up to next highest 1 t based on the mean proportion of males in the 5CD sampled commercial catch from 1996–2005: 0.0555. The approximate level of the current TAC is indicated with grey shading.

Projection Catch		3CD5AB: split CPUE series | $r = 5$									
		Estimate *M*					Fix *M*				
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$P\left(\tilde{B}_y > \min\{B_t\}_{t=1966}^{2006}\right)$											
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
53	50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
106	100	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99
159	150	0.99	0.99	0.98	0.98	0.97	0.98	0.97	0.95	0.94	0.93
186	175	0.99	0.98	0.97	0.95	0.94	0.97	0.94	0.90	0.88	0.85
212	200	0.99	0.96	0.94	0.92	0.89	0.96	0.89	0.83	0.77	0.72
265	250	0.98	0.93	0.86	0.79	0.72	0.91	0.78	0.65	0.54	0.45
318	300	0.96	0.86	0.73	0.61	0.50	0.85	0.64	0.46	0.33	0.24
371	350	0.94	0.78	0.59	0.43	0.33	0.78	0.49	0.30	0.18	0.10
424	400	0.91	0.68	0.45	0.29	0.21	0.69	0.36	0.18	0.09	0.05
477	450	0.87	0.55	0.33	0.20	0.13	0.61	0.25	0.11	0.05	0.03
530	500	0.82	0.45	0.24	0.13	0.09	0.52	0.17	0.06	0.03	0.02
$E\left(\tilde{B}_y / \min\{B_t\}_{t=1966}^{2006}\right)$											
0	0	1.60	1.70	1.78	1.85	1.90	1.69	1.88	2.04	2.16	2.26
53	50	1.56	1.63	1.68	1.72	1.76	1.62	1.75	1.86	1.94	2.00
106	100	1.52	1.56	1.58	1.60	1.61	1.56	1.62	1.68	1.71	1.74
159	150	1.48	1.48	1.48	1.47	1.46	1.49	1.50	1.50	1.49	1.48
186	175	1.46	1.45	1.43	1.41	1.39	1.46	1.43	1.41	1.38	1.35
212	200	1.44	1.41	1.38	1.35	1.32	1.42	1.37	1.32	1.27	1.22
265	250	1.41	1.34	1.28	1.22	1.17	1.35	1.24	1.15	1.06	0.98
318	300	1.37	1.27	1.18	1.10	1.03	1.29	1.12	0.98	0.86	0.77
371	350	1.33	1.20	1.08	0.97	0.89	1.22	1.00	0.84	0.71	0.62
424	400	1.29	1.12	0.98	0.86	0.76	1.15	0.89	0.72	0.60	0.53
477	450	1.25	1.05	0.89	0.75	0.64	1.09	0.80	0.63	0.52	0.47
530	500	1.21	0.98	0.80	0.65	0.56	1.03	0.71	0.56	0.48	0.40
$P\left(\tilde{B}_y > \text{mean}\{B_t\}_{t=1974}^{1986}\right)$											
0	0	0.92	0.96	0.98	0.99	0.99	0.88	0.96	0.99	1.00	1.00
53	50	0.88	0.92	0.94	0.96	0.96	0.81	0.89	0.94	0.95	0.97
106	100	0.84	0.86	0.87	0.88	0.89	0.73	0.78	0.81	0.84	0.85
159	150	0.79	0.78	0.76	0.72	0.72	0.64	0.63	0.63	0.61	0.60
186	175	0.76	0.73	0.68	0.65	0.62	0.59	0.56	0.52	0.48	0.45
212	200	0.74	0.67	0.60	0.56	0.50	0.55	0.48	0.42	0.38	0.32
265	250	0.68	0.56	0.46	0.38	0.31	0.46	0.34	0.26	0.19	0.14
318	300	0.61	0.44	0.33	0.24	0.18	0.37	0.22	0.15	0.09	0.06
371	350	0.53	0.34	0.22	0.15	0.11	0.29	0.15	0.08	0.04	0.03
424	400	0.47	0.24	0.15	0.09	0.06	0.23	0.09	0.04	0.02	0.01
477	450	0.40	0.18	0.10	0.06	0.04	0.18	0.05	0.01	0.01	0.00
530	500	0.34	0.14	0.07	0.03	0.02	0.14	0.03	0.01	0.00	0.00

Projection Catch		3CD5AB: split CPUE series | $r = 5$									
						Estimate *M*					**Fix *M***
Total	**Female**	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2009**	**2010**	**2011**	**2012**
$\mathrm{E}\left(\tilde{B}_y / \mathrm{mean}\{B_t\}_{t=1974}^{1986}\right)$											
0	0	1.23	1.31	1.38	1.42	1.46	1.23	1.37	1.48	1.56	1.64
53	50	1.21	1.26	1.30	1.33	1.35	1.18	1.27	1.35	1.41	1.45
106	100	1.18	1.20	1.22	1.23	1.24	1.14	1.18	1.22	1.25	1.27
159	150	1.15	1.15	1.15	1.14	1.13	1.09	1.09	1.09	1.09	1.08
186	175	1.13	1.12	1.11	1.09	1.08	1.06	1.05	1.03	1.01	0.99
212	200	1.12	1.09	1.07	1.04	1.02	1.04	1.00	0.97	0.93	0.89
265	250	1.09	1.04	0.99	0.95	0.91	0.99	0.91	0.84	0.77	0.72
318	300	1.06	0.98	0.92	0.85	0.80	0.94	0.82	0.72	0.64	0.57
371	350	1.03	0.93	0.84	0.76	0.69	0.89	0.74	0.62	0.52	0.46
424	400	1.00	0.87	0.76	0.67	0.59	0.85	0.66	0.53	0.44	0.39
477	450	0.97	0.82	0.69	0.58	0.50	0.80	0.59	0.46	0.39	0.34
530	500	0.94	0.76	0.62	0.51	0.43	0.75	0.53	0.41	0.35	0.32
$\mathrm{P}\left(\tilde{B}_y > B_{2007}\right)$											
0	0	0.88	0.89	0.92	0.93	0.94	0.98	0.99	0.99	0.99	0.99
53	50	0.74	0.76	0.81	0.83	0.84	0.88	0.90	0.92	0.95	0.96
106	100	0.54	0.58	0.61	0.63	0.66	0.65	0.67	0.72	0.75	0.77
159	150	0.35	0.39	0.41	0.40	0.40	0.37	0.41	0.42	0.42	0.41
186	175	0.28	0.31	0.32	0.30	0.29	0.26	0.29	0.30	0.28	0.26
212	200	0.22	0.25	0.25	0.22	0.20	0.17	0.21	0.20	0.18	0.16
265	250	0.12	0.15	0.15	0.12	0.10	0.08	0.10	0.09	0.07	0.05
318	300	0.07	0.10	0.09	0.07	0.04	0.03	0.05	0.04	0.02	0.02
371	350	0.04	0.06	0.05	0.04	0.02	0.01	0.02	0.02	0.01	0.00
424	400	0.02	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00
477	450	0.02	0.03	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.00
530	500	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00
$\mathrm{E}\left(\tilde{B}_y / B_{2007}\right)$											
0	0	1.06	1.13	1.19	1.23	1.27	1.12	1.25	1.35	1.43	1.50
53	50	1.04	1.09	1.12	1.15	1.17	1.07	1.16	1.23	1.29	1.33
106	100	1.01	1.04	1.06	1.07	1.08	1.03	1.08	1.11	1.14	1.16
159	150	0.99	0.99	0.99	0.98	0.98	0.98	0.99	0.99	0.99	0.98
186	175	0.97	0.96	0.96	0.94	0.93	0.96	0.95	0.93	0.91	0.90
212	200	0.96	0.94	0.92	0.90	0.88	0.94	0.91	0.88	0.84	0.81
265	250	0.93	0.89	0.85	0.82	0.78	0.89	0.82	0.76	0.70	0.65
318	300	0.91	0.84	0.79	0.73	0.69	0.85	0.74	0.65	0.57	0.51
371	350	0.88	0.80	0.72	0.65	0.59	0.80	0.66	0.55	0.47	0.41
424	400	0.86	0.75	0.65	0.57	0.50	0.76	0.59	0.47	0.40	0.35
477	450	0.83	0.70	0.59	0.50	0.43	0.72	0.52	0.42	0.35	0.31
530	500	0.80	0.65	0.53	0.44	0.37	0.67	0.47	0.37	0.32	0.29

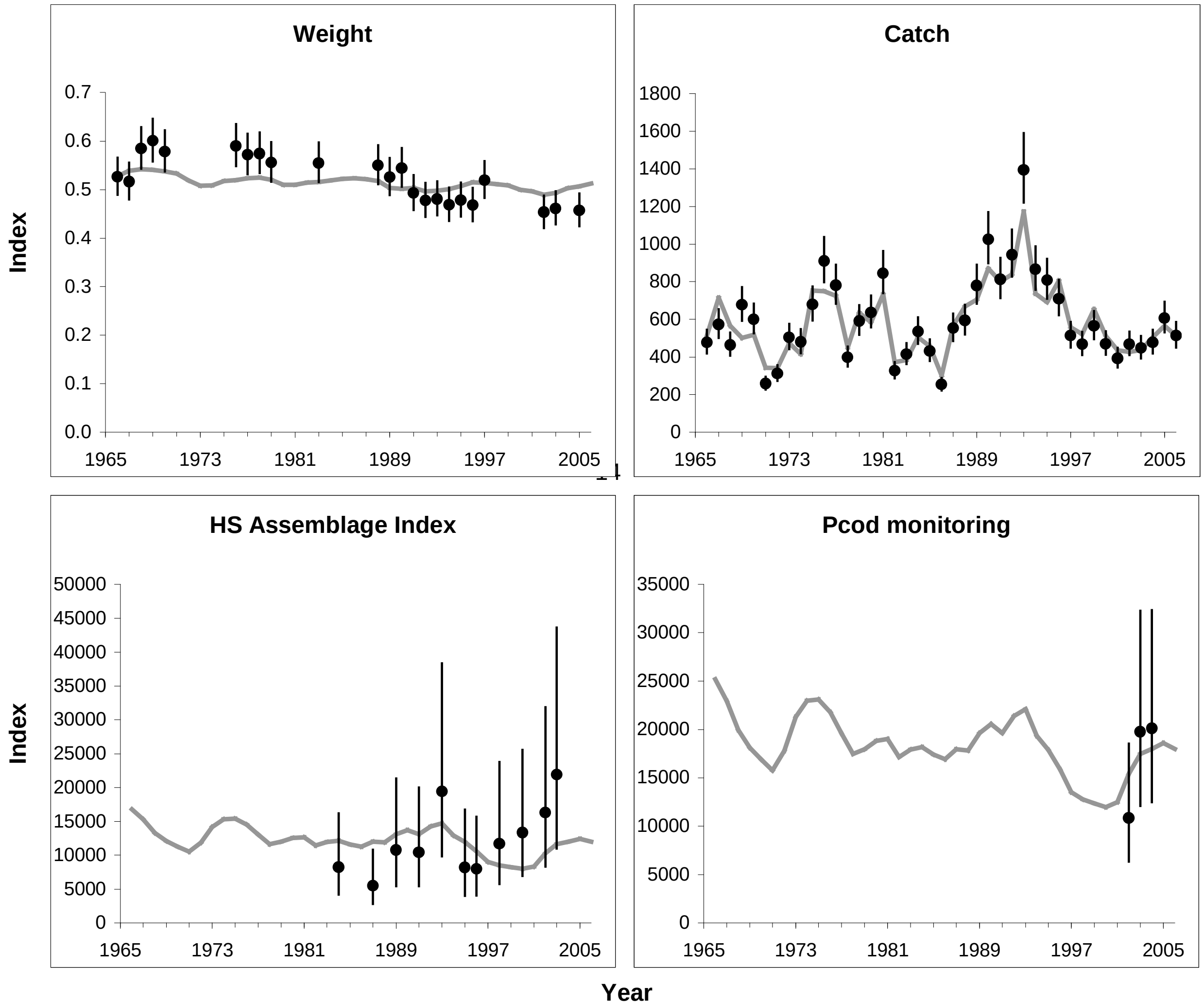


Figure D.1. Model fits to the observed data for the 5CD single CPUE series | $r = 5$ | est M model run (Table D.1).

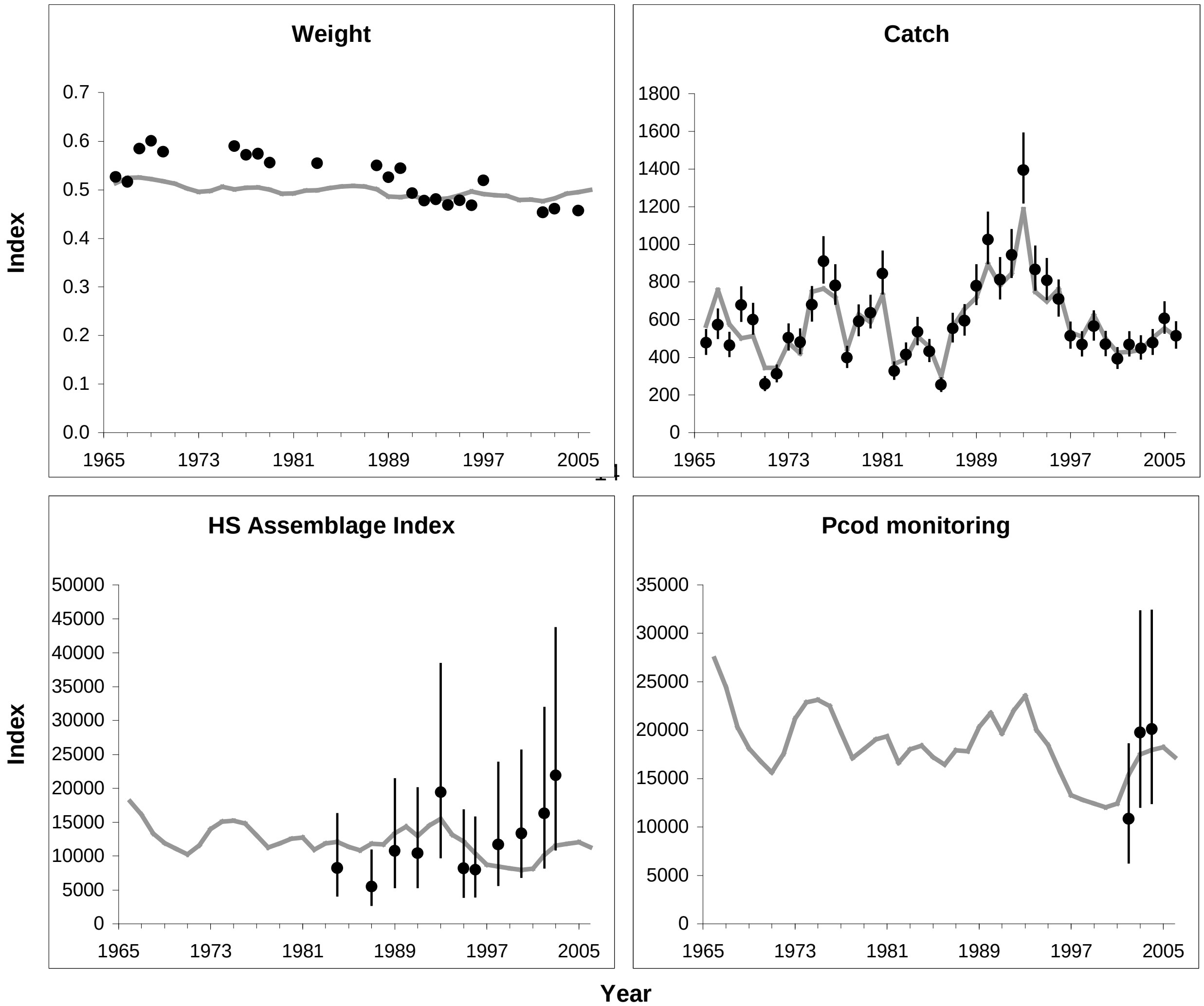


Figure D.2. Model fits to the observed data for the 5CD single CPUE series | $r = 5$ | fix M model run (Table D.1).

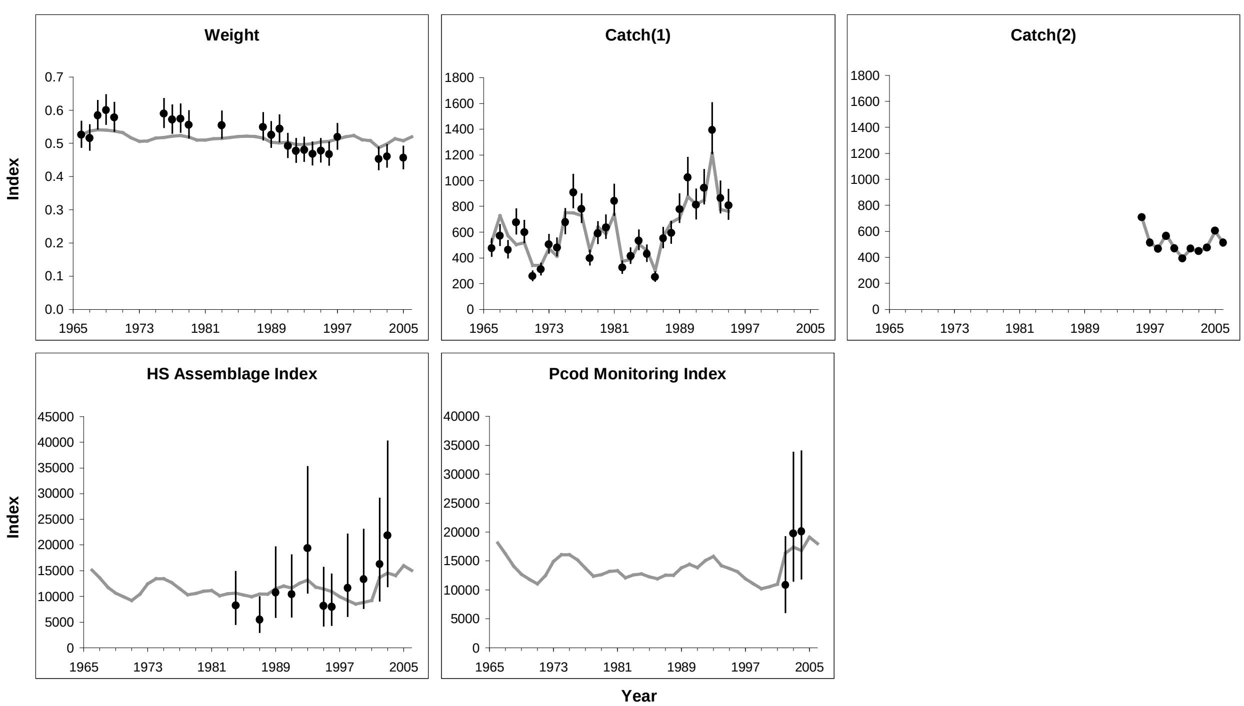


Figure D.3. Model fits to the observed data for the 5CD split CPUE series | $r = 5$ | est M model run (Table D.1).

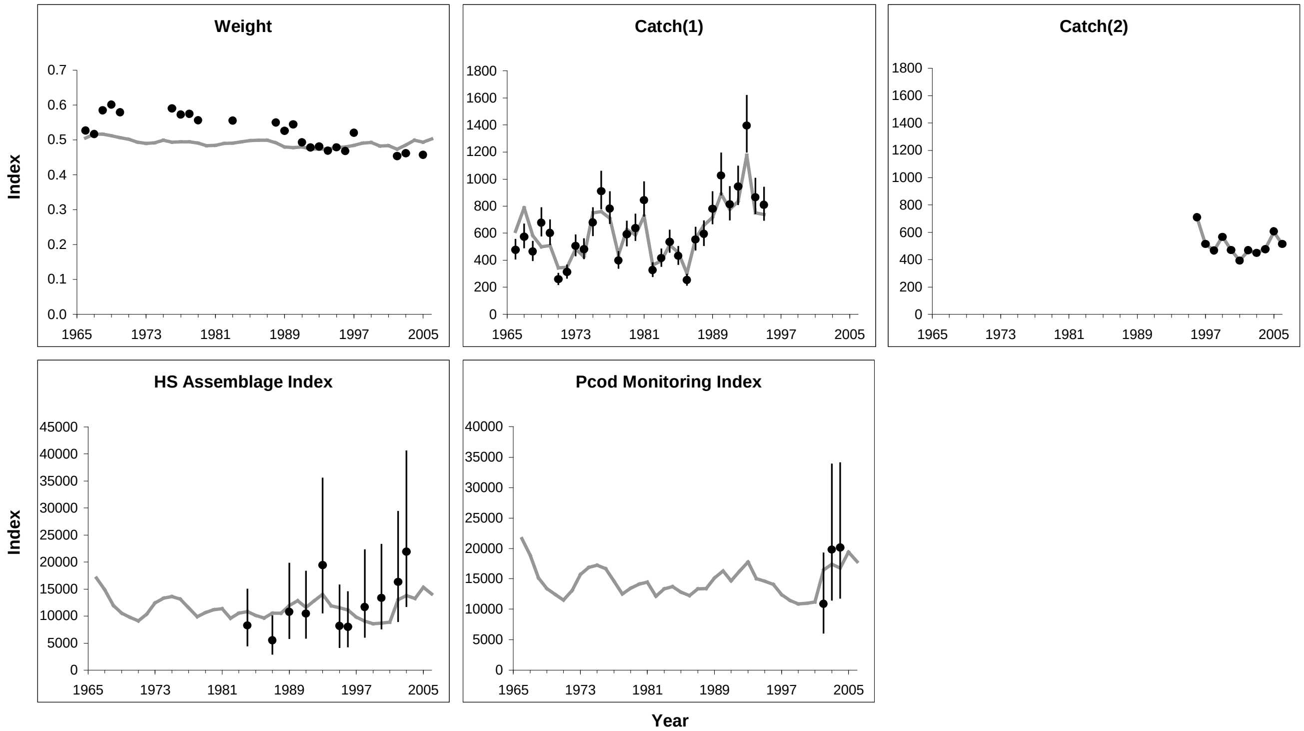


Figure D.4. Model fits to the observed data for the 5CD split CPUE series | $r = 5$ | fix M model run (Table D.1).

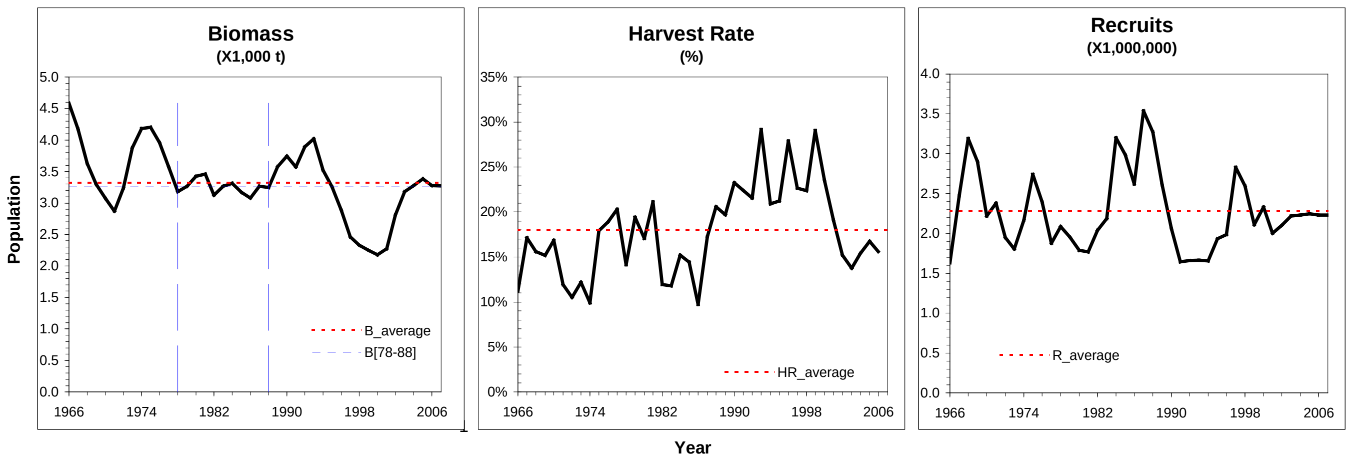


Figure D.5. MPD population trajectories for the 5CD single CPUE series | $r = 5$ | est M model run (Table D.1).). Vertical lines in the Biomass subgraph bracket the 1978 to 1988 reference period.

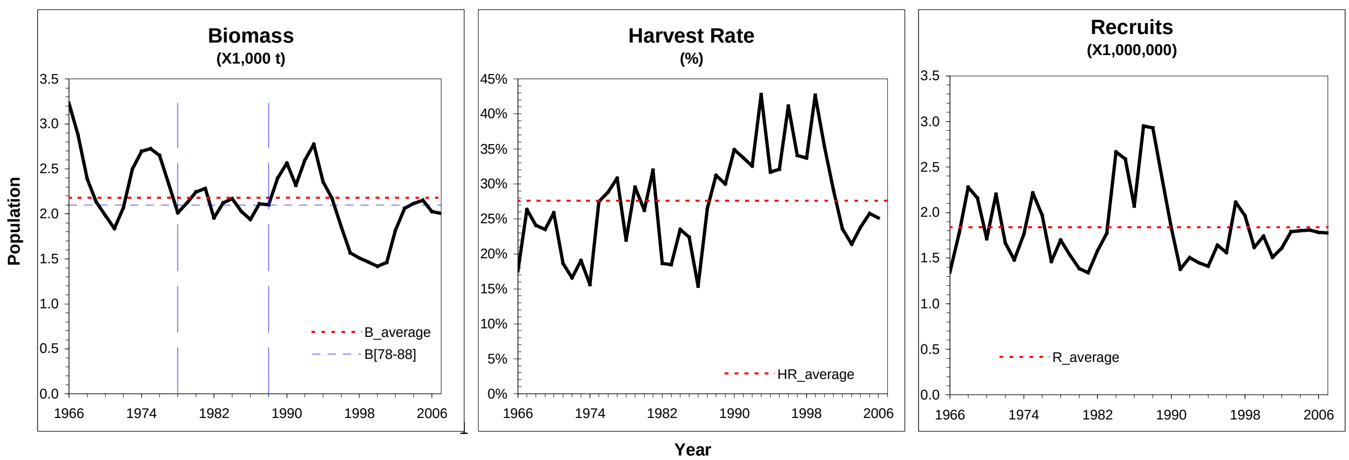


Figure D.6. MPD population trajectories for the 5CD single CPUE series | $r = 5$ | fix M model run (Table D.1). Vertical lines in the Biomass subgraph bracket the 1978 to 1988 reference period.

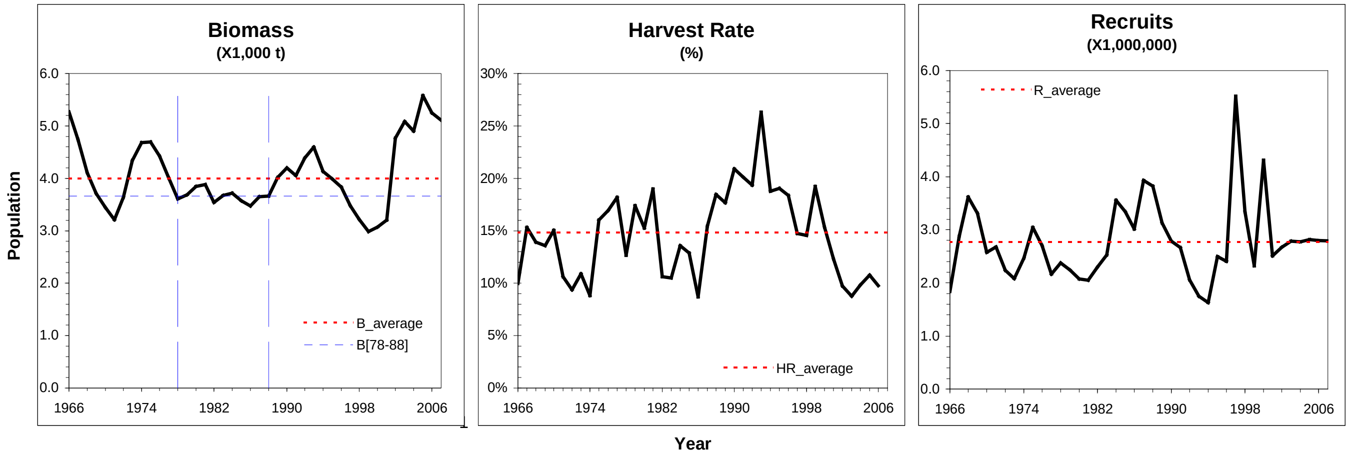


Figure D.7. MPD population trajectories for the 5CD split CPUE series | $r = 5$ | est M model run (Table D.1). Vertical lines in the Biomass subgraph bracket the 1978 to 1988 reference period.

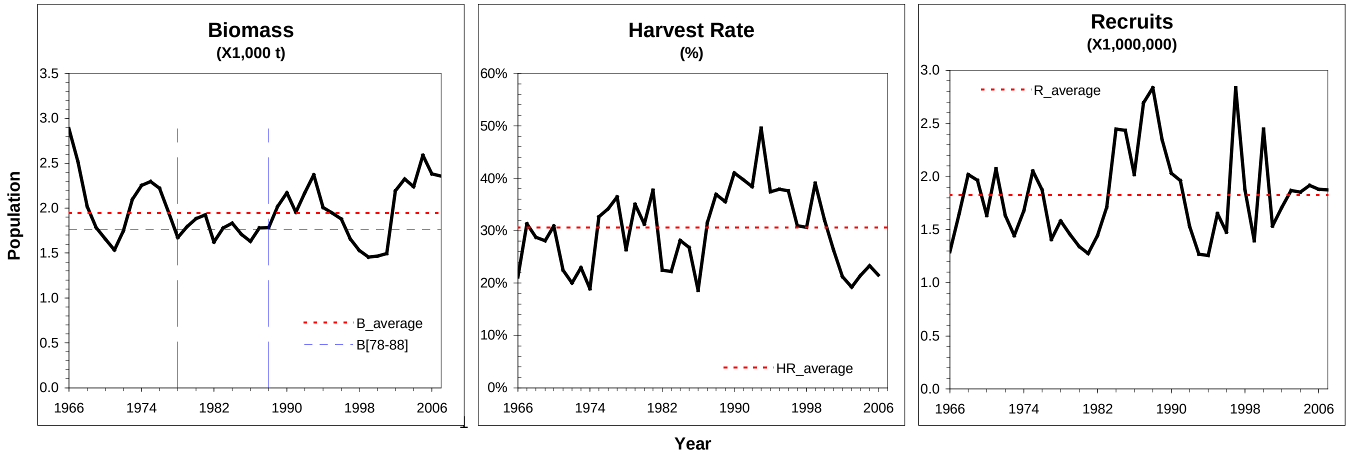


Figure D.8. MPD population trajectories for the 5CD split CPUE series | $r = 5$ | fix M model run (Table D.1). Vertical lines in the Biomass subgraph bracket the 1978 to 1988 reference period.

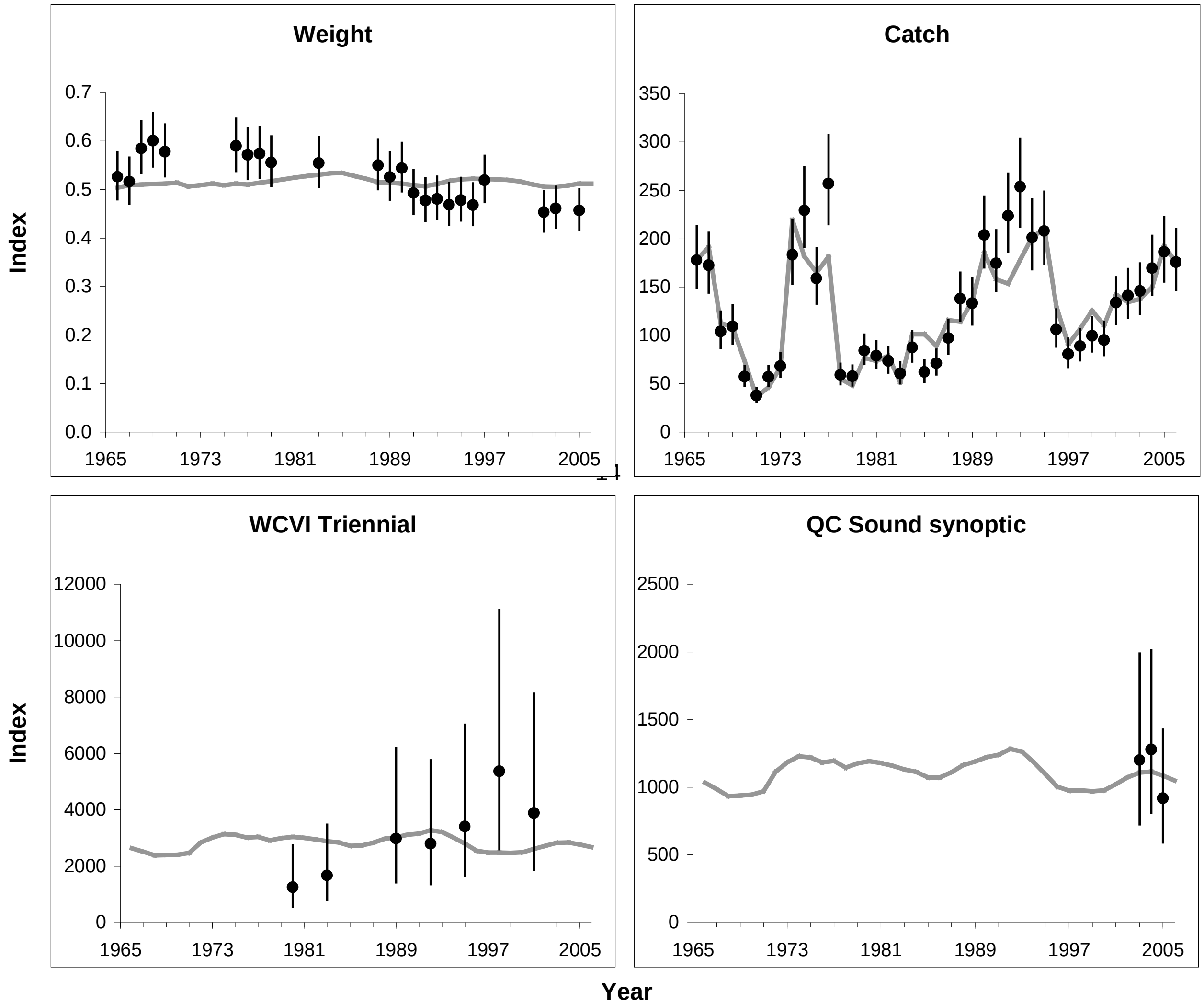


Figure D.9. Model fits to the observed data for the 3CD5AB single CPUE series | $r = 5$ | est M model run (Table D.1).

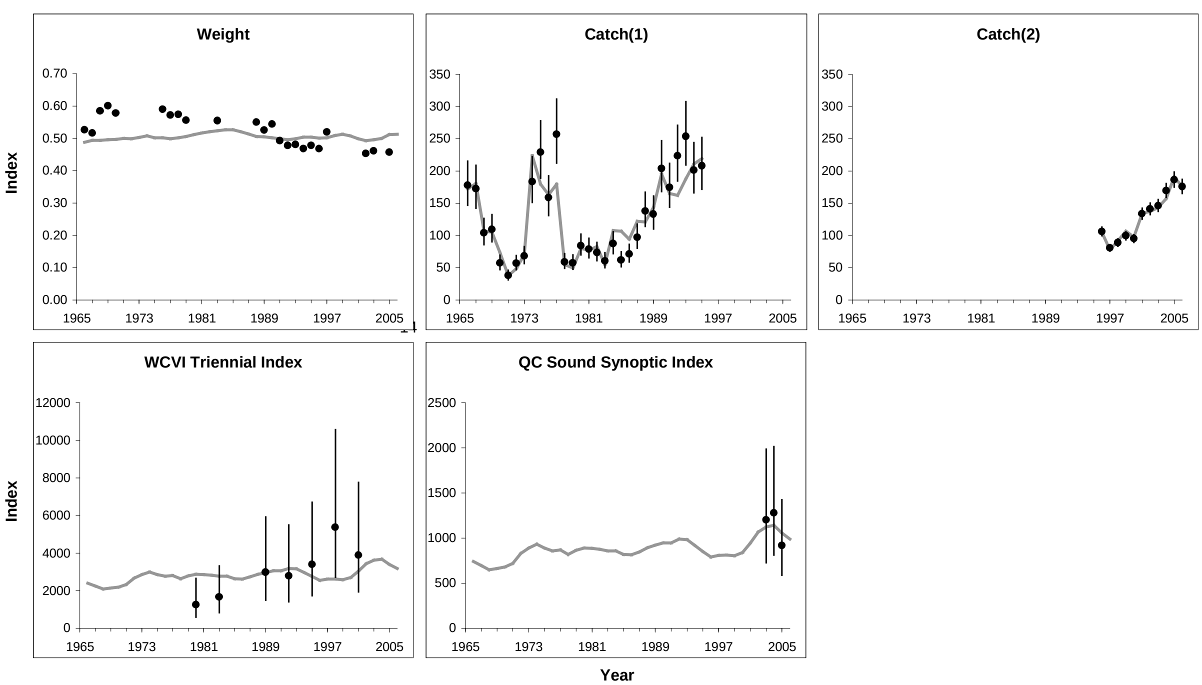


Figure D.10. Model fits to the observed data for the 3CD5AB split CPUE series | $r = 5$ | fix M model run (Table D.1).

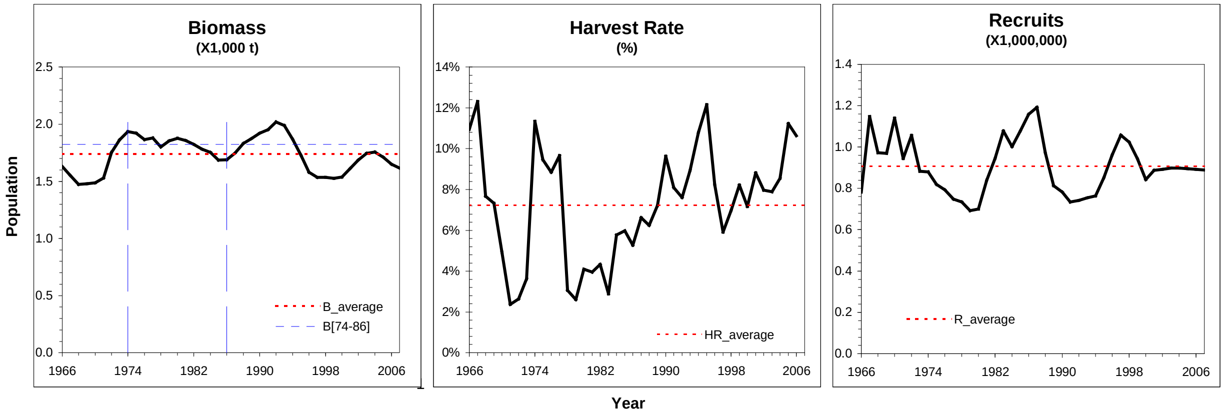


Figure D.11. MPD population trajectories for the 3CD5AB single CPUE series | $r = 5$ | est M model run (Table D.1). Vertical lines in the Biomass subgraph bracket the 1974 to 1986 reference period.

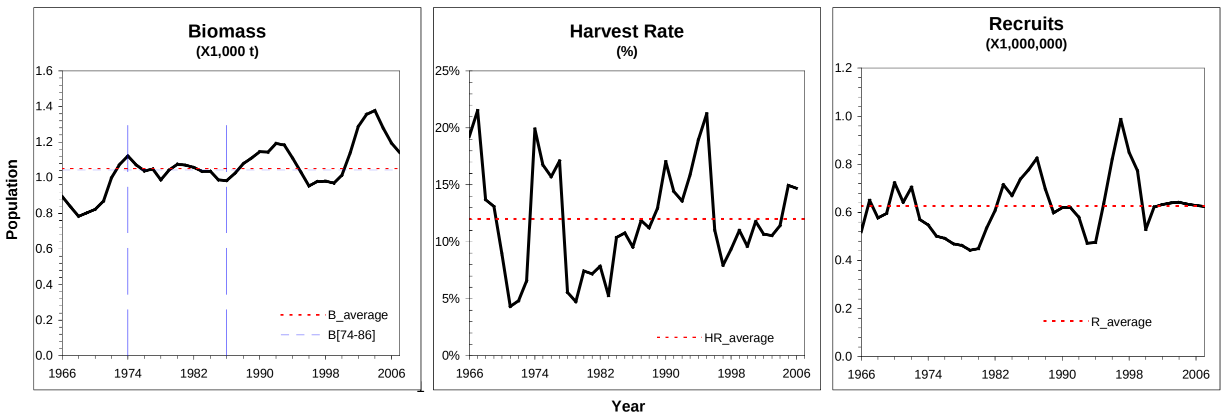


Figure D.12. MPD population trajectories for the 3CD5AB split CPUE series | $r = 5$ | fix M model run (Table D.1). Vertical lines in the Biomass subgraph bracket the 1974 to 1986 reference period.

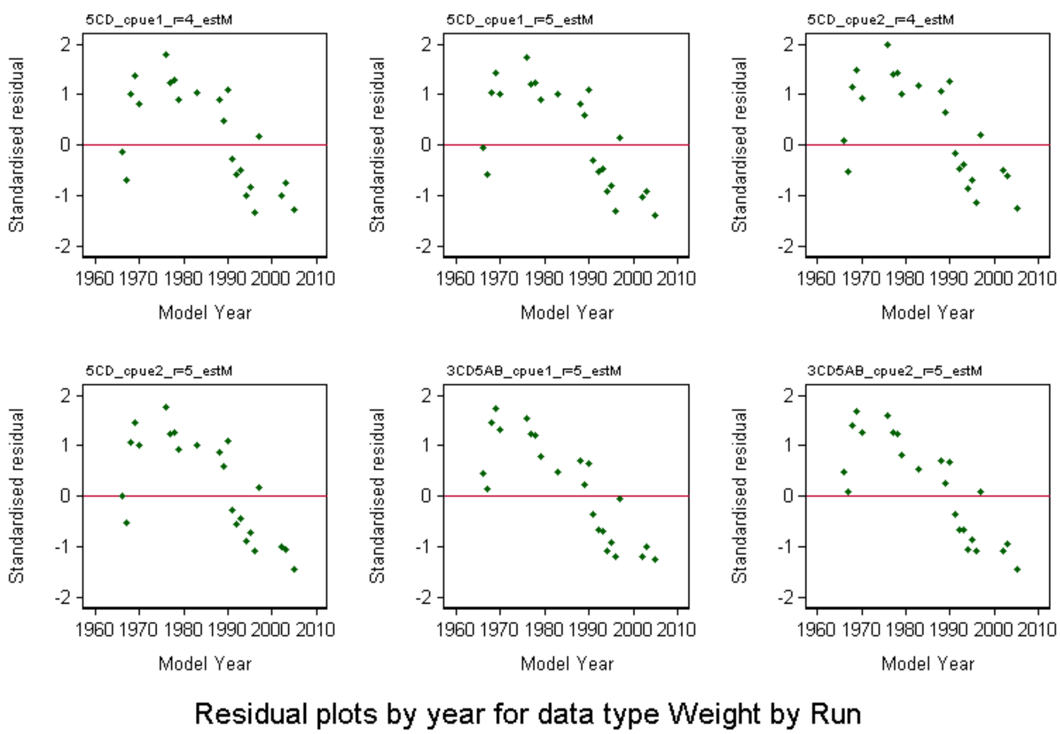


Figure D.13. Standardised (Pearson) residuals for the fit to the weight data plotted by year for the runs which used the weight data (Table D.1).

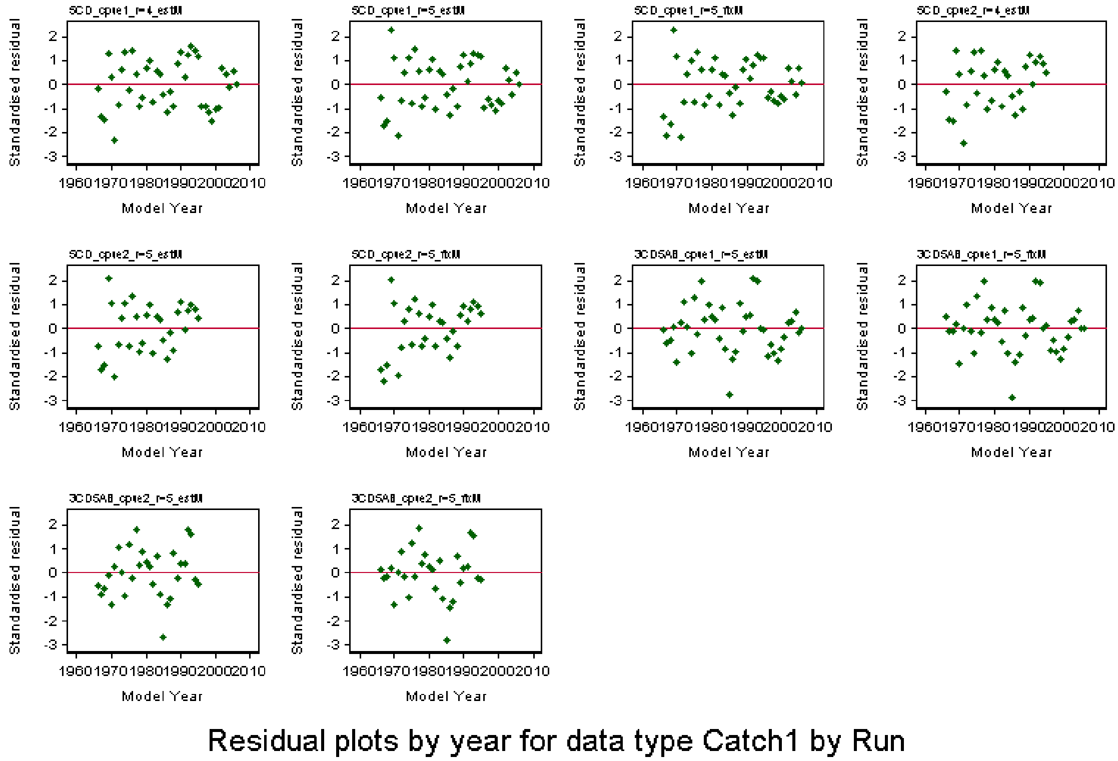


Figure D.14. Standardised (Pearson) residuals for the fit to the first series of catch data plotted by year (Table D.1).

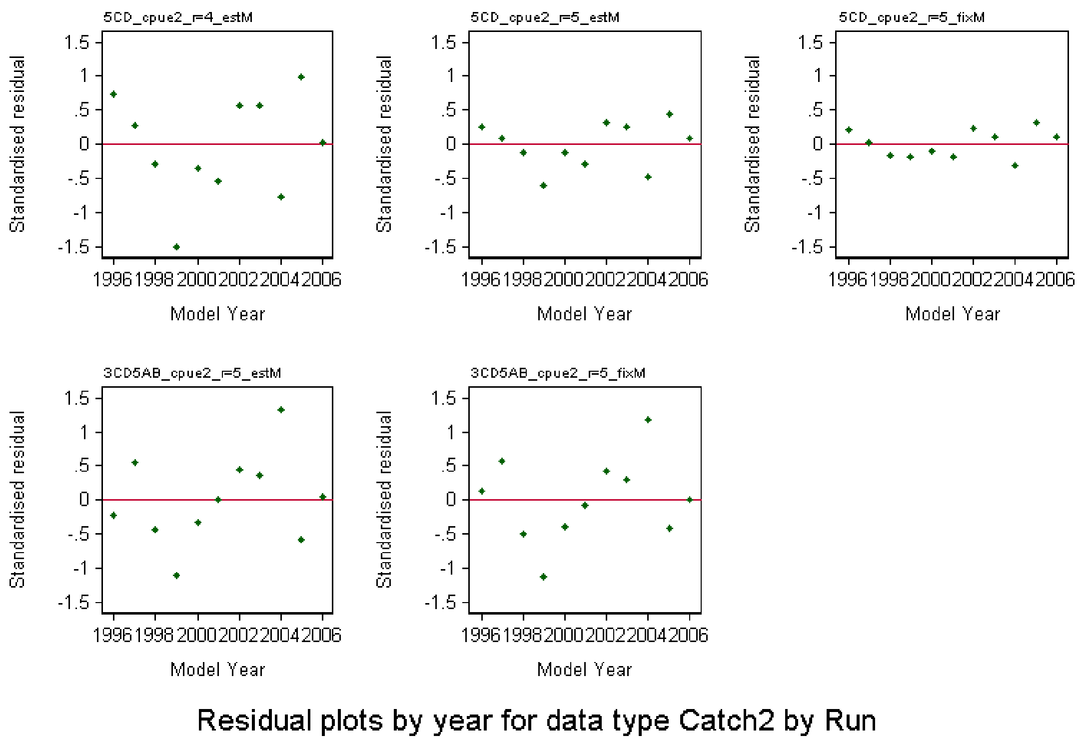
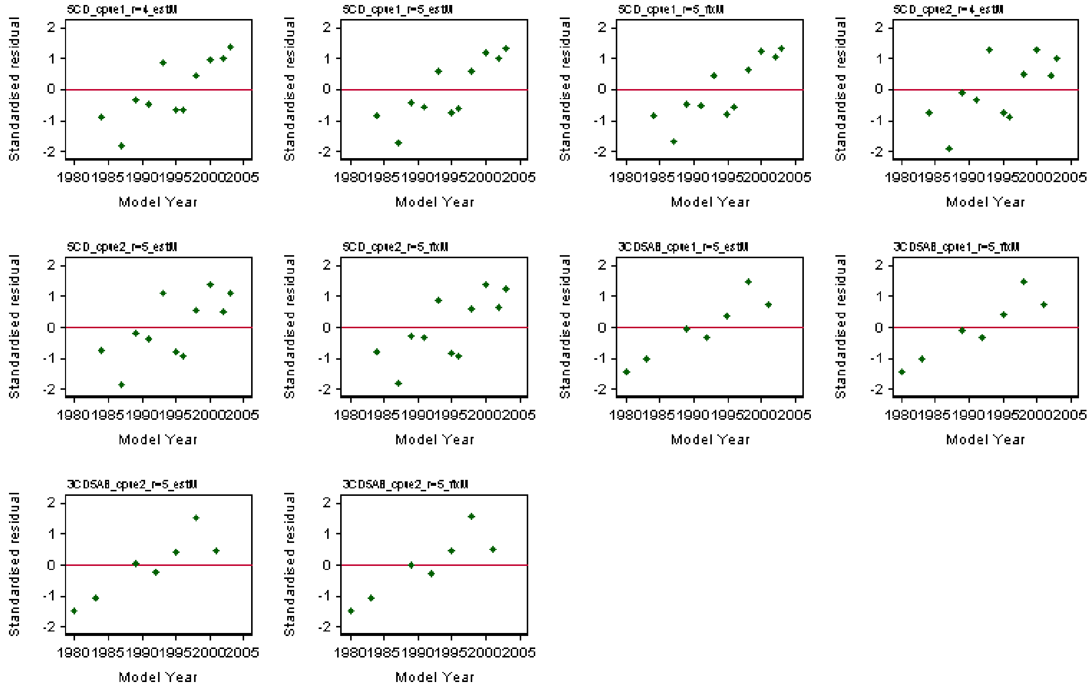
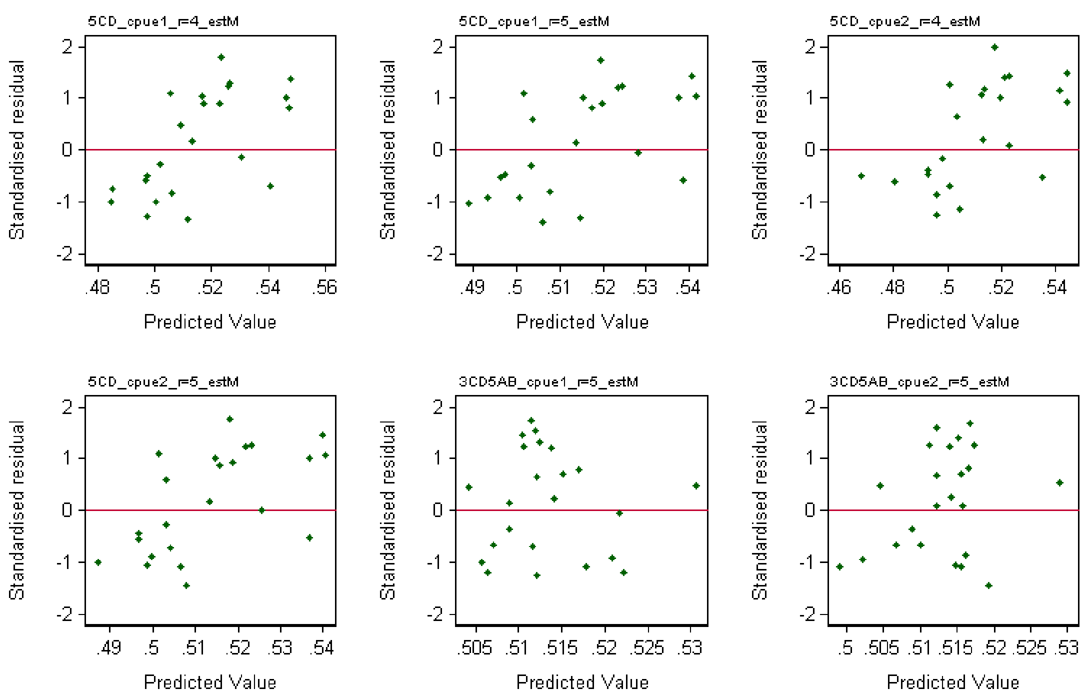


Figure D.15. Standardised (Pearson) residuals for the fit to the second series of catch data for the split CPUE runs plotted by year (Table D.1).



Residual plots by year for data type Survey1 by Run

Figure D.16. Standardised (Pearson) residuals for the fit to the "Survey1" data plotted by year (Table D.1). "Survey1" is the Hecate St. assemblage survey for the 5CD runs and the WCVI Triennial survey for the 3CD5AB runs.



Predicted-residual plots for data type Weight by Run

Figure D.17. Standardised (Pearson) residuals for the fit to the weight data plotted against the predicted value for the runs which used the weight data (Table D.1).

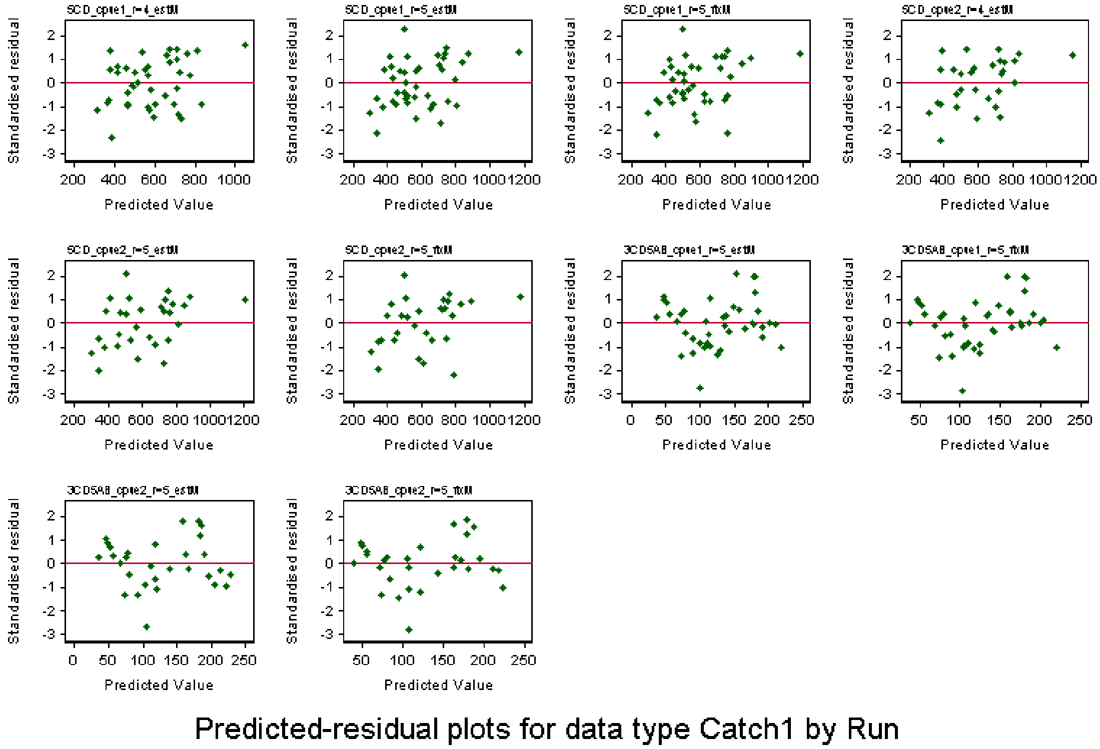


Figure D.18. Standardised (Pearson) residuals for the fit to the first series of catch data plotted against the predicted value (Table D.1).

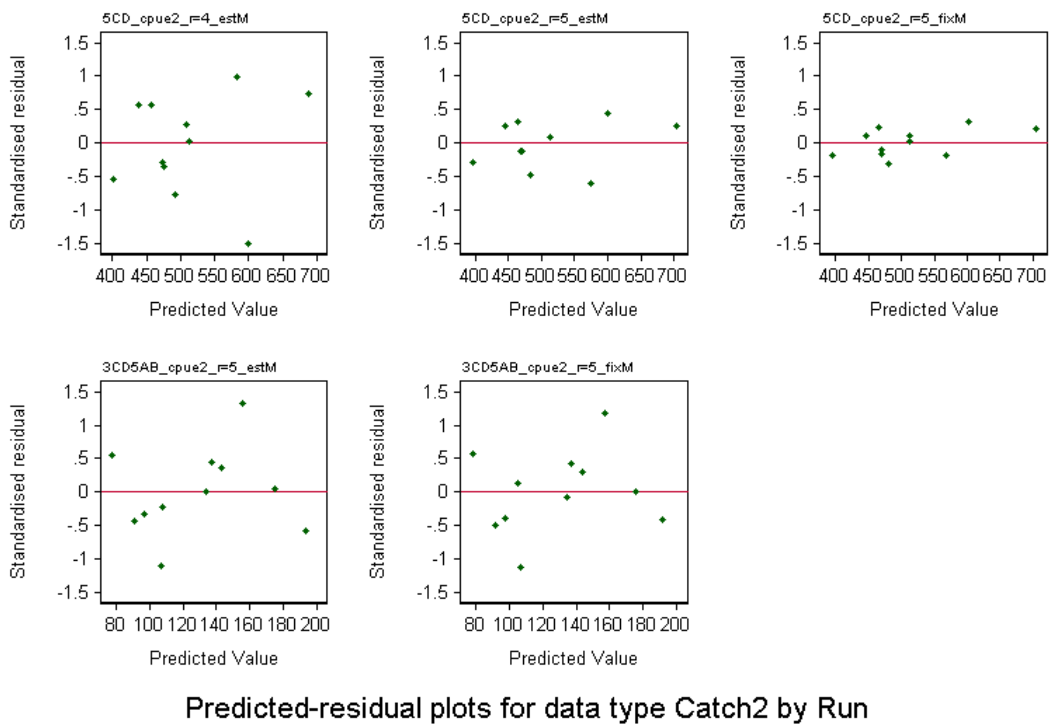


Figure D.19. Standardised (Pearson) residuals for the fit to the second series of catch data for the split CPUE runs plotted against the predicted value (Table D.1).

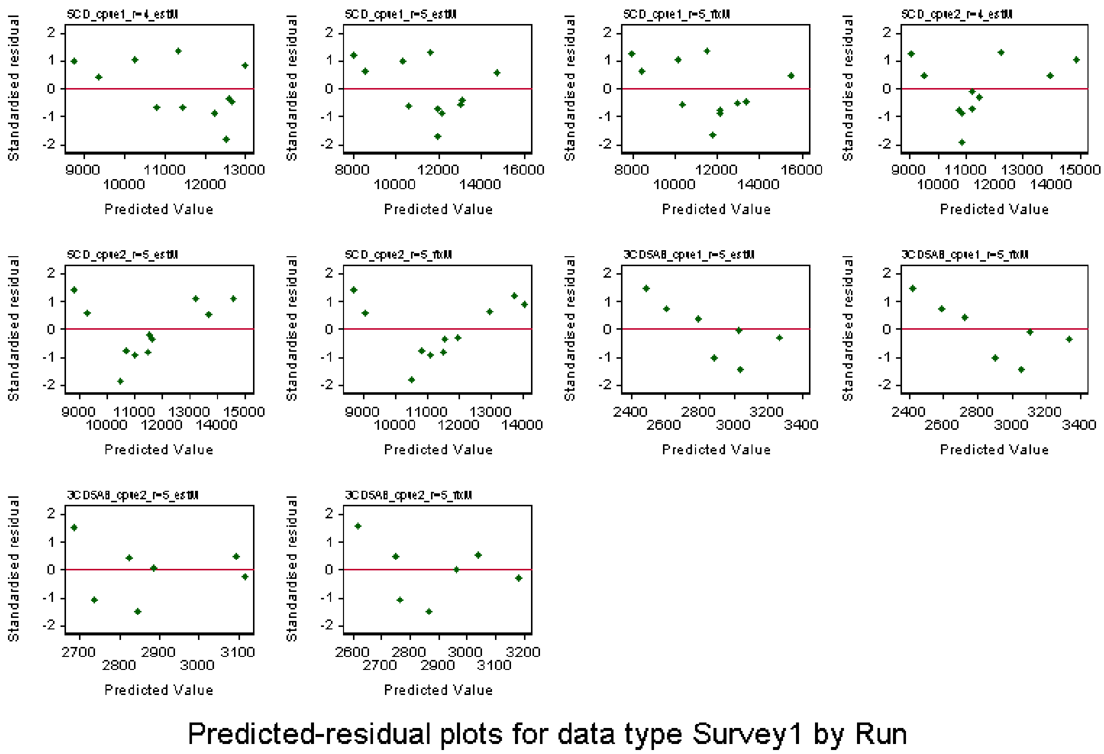


Figure D.20. Standardised (Pearson) residuals for the fit to the “Survey1” data plotted against the predicted value (Table D.1). “Survey1” is the Hecate St. assemblage survey for the 5CD runs and the WCVI Triennial survey for the 3CD5AB runs.

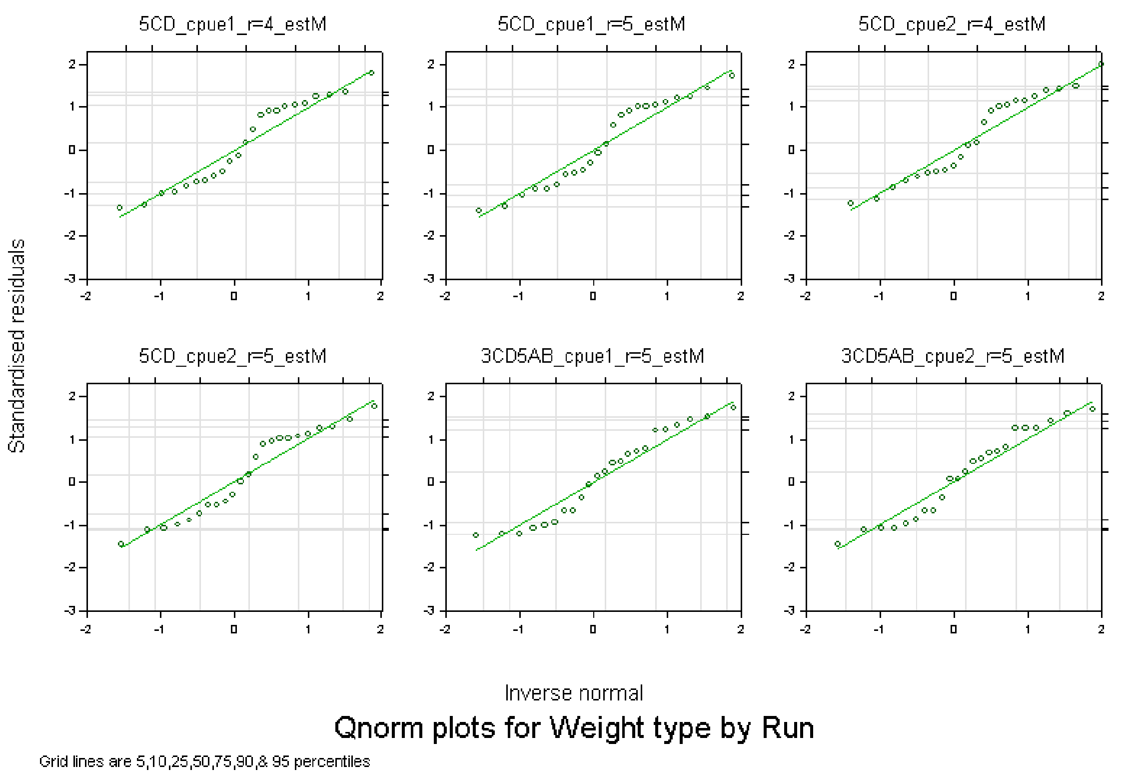


Figure D.21. Q-Q plots of the standardised (Pearson) residuals for the fit to the weight data for the runs which used the weight data (Table D.1).

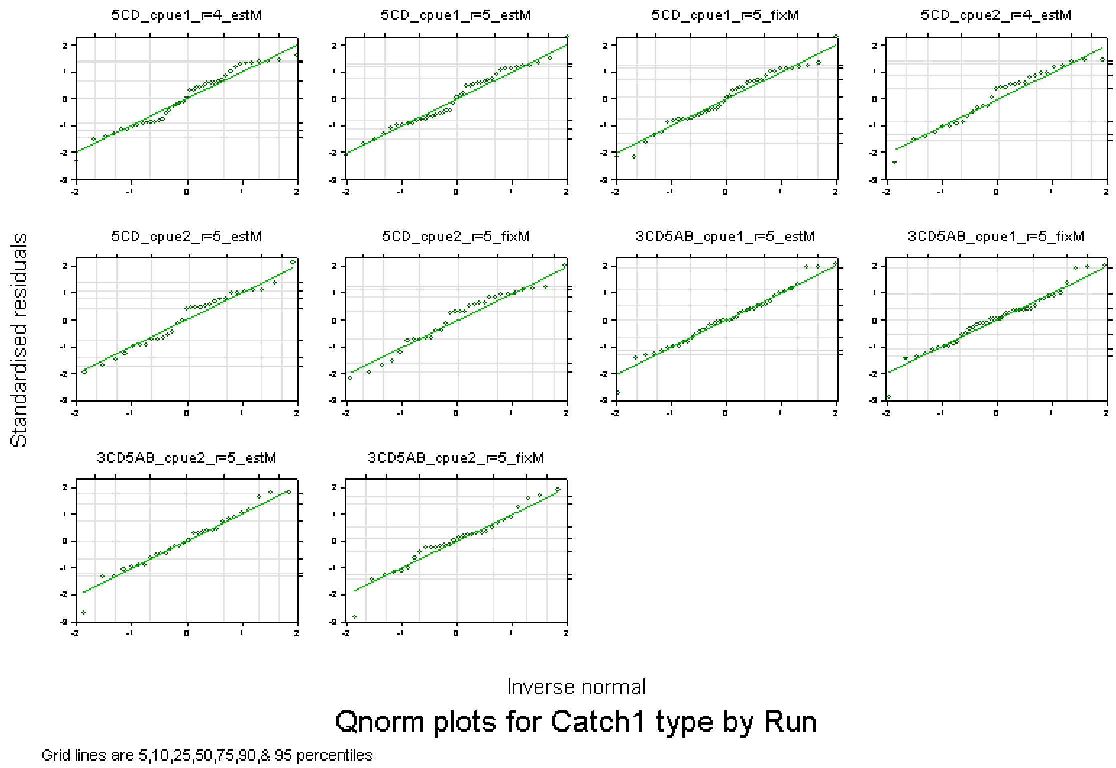


Figure D.22. Q-Q plots of the standardised (Pearson) residuals for the fit to the first series of catch data (Table D.1).

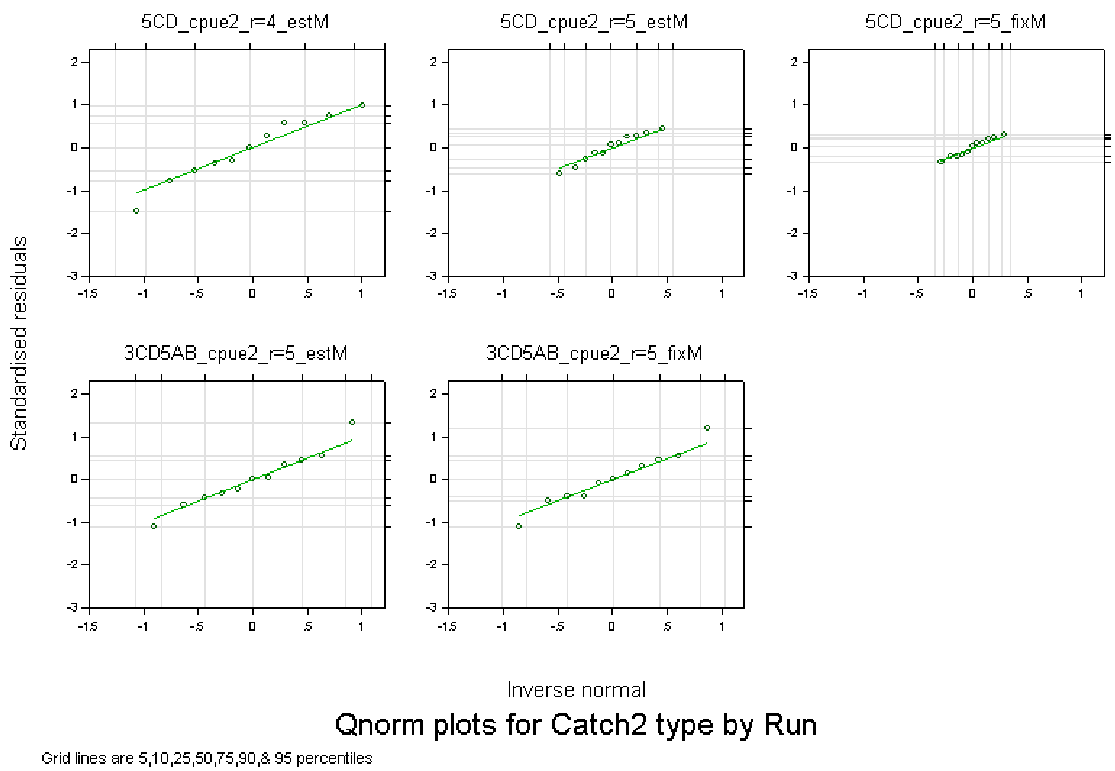


Figure D.23. Q-Q plots of the standardised (Pearson) for the fit to the second series of catch data for the split CPUE runs (Table D.1).

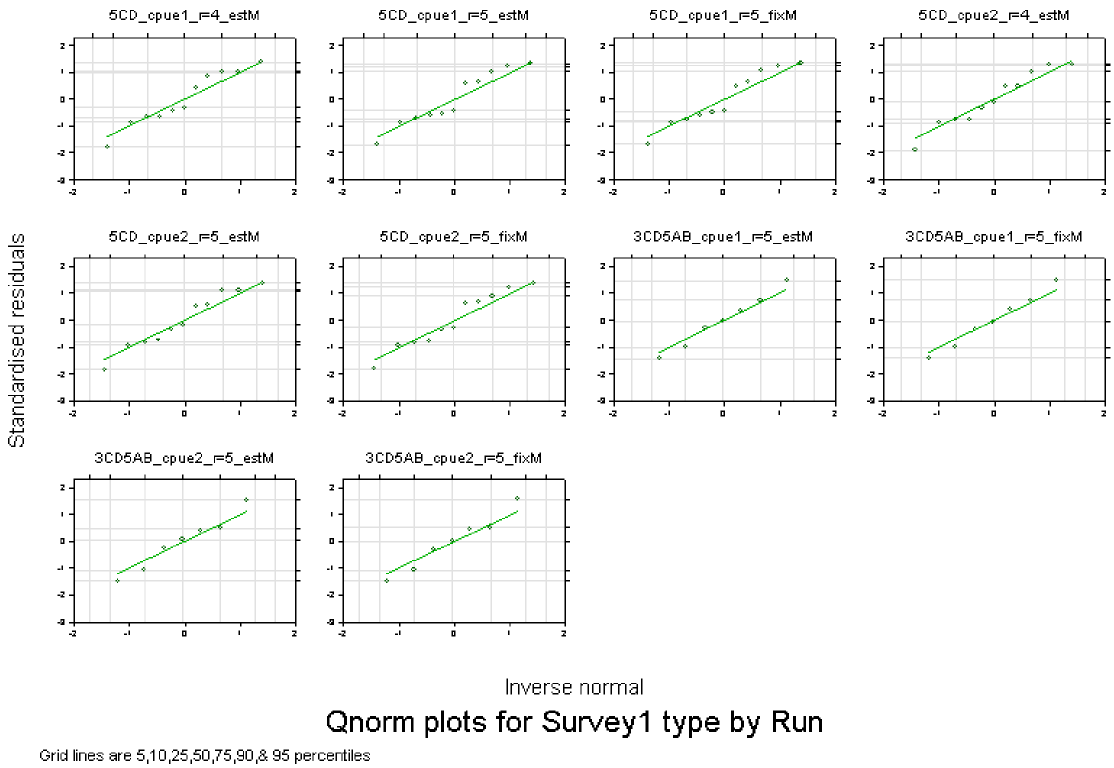


Figure D.24. Q-Q plots of the standardised (Pearson) for the fit to the "Survey1" data (Table D.1). "Survey1" is the Hecate St. assemblage survey for the 5CD runs and the WCVI Triennial survey for the 3CD5AB runs.

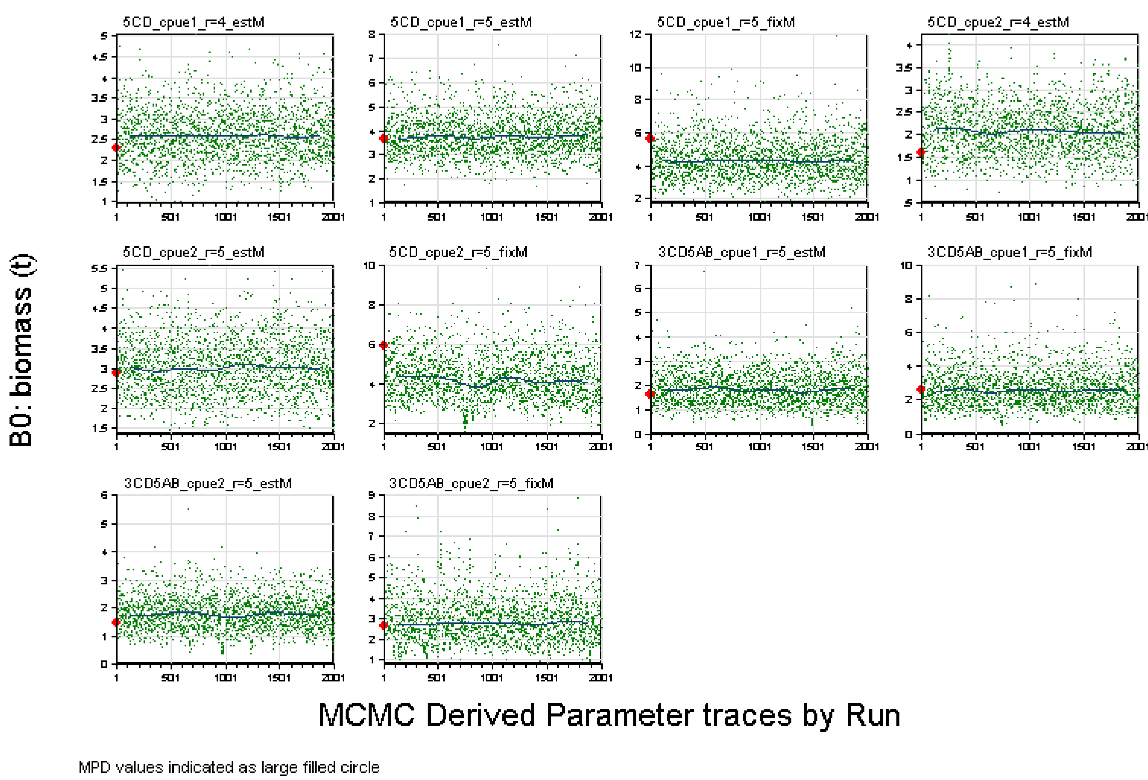


Figure D.25. MCMC traces of the B_0 parameter for the six 5CD and the four 3CD5AB model runs listed in Table D.1, based on 2,000 samples from each of the chains

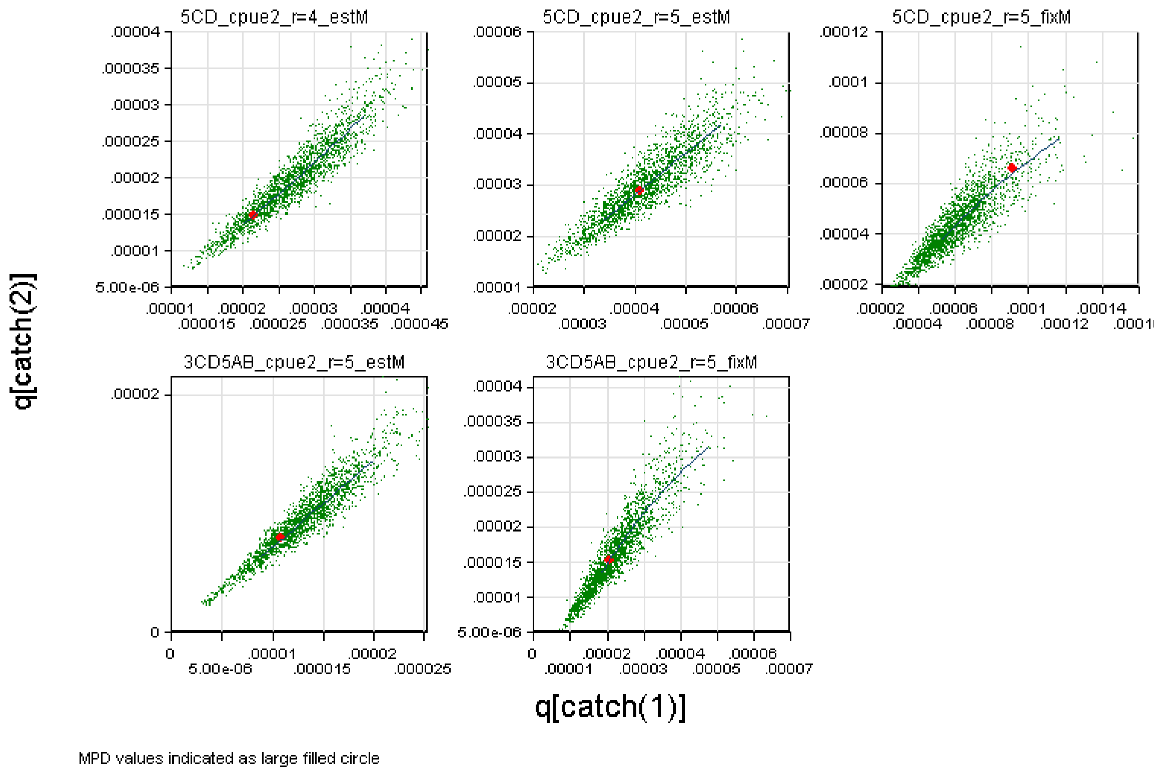


Figure D.26. Scatter plot of the paired MCMC samples of ${}^{C}q_1$ and ${}^{C}q_2$ for the three 5CD and the two 3CD5AB model runs listed in with split CPUE series (Table D.1). A cubic spline has been fitted to the data to aid the eye

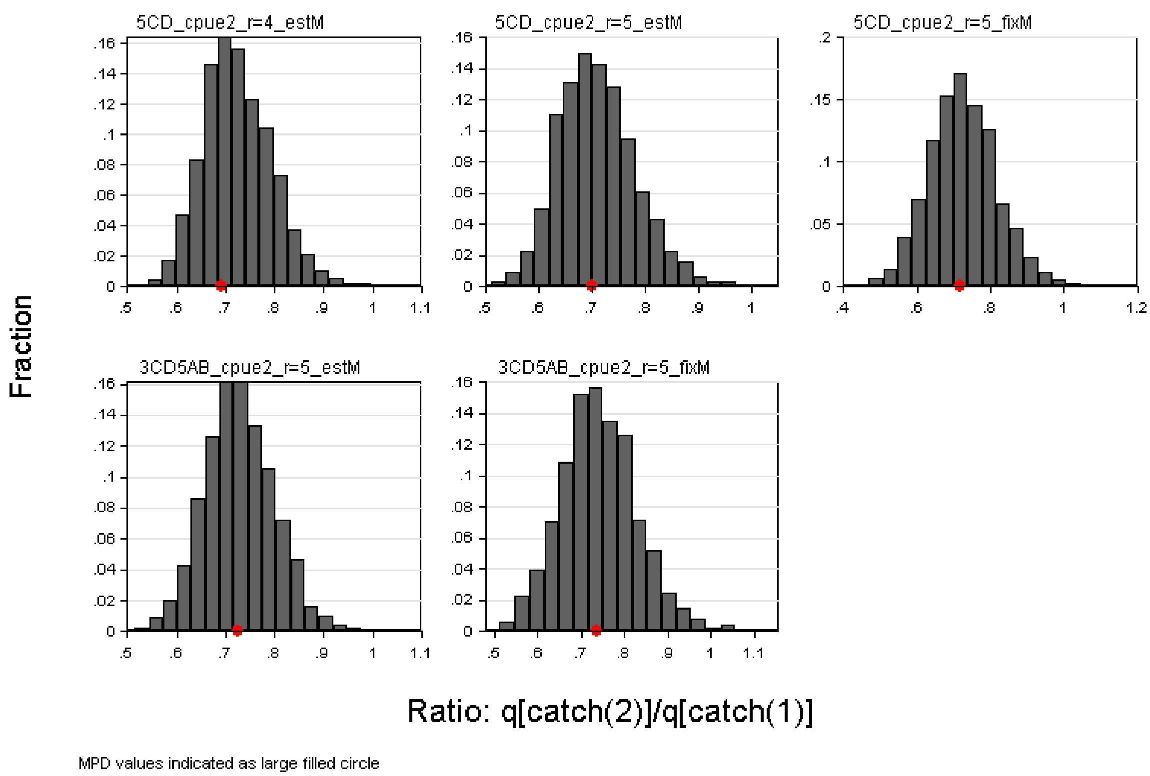
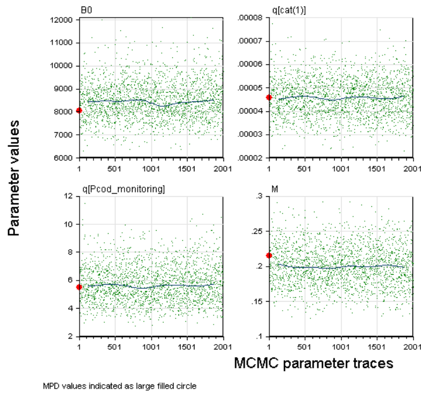
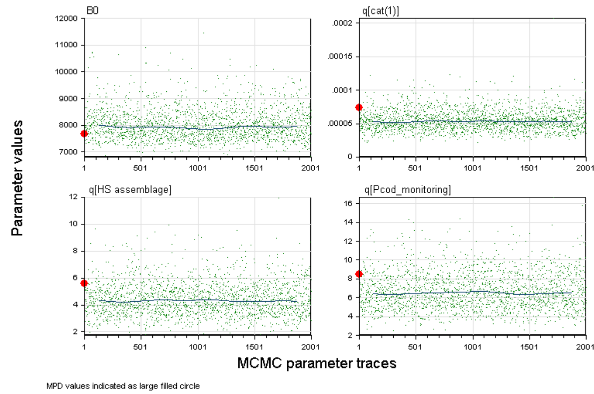


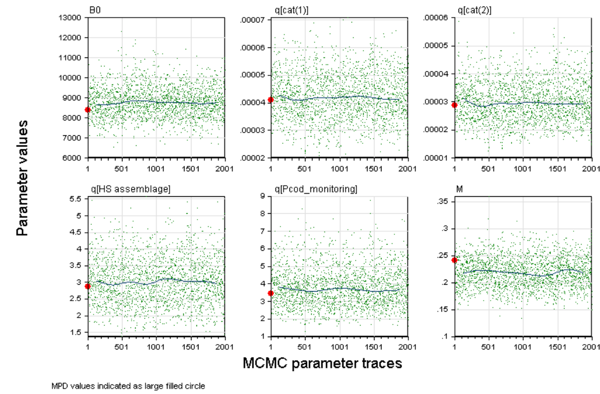
Figure D.27. Frequency distributions of the ratio ${}^{C}q_2/{}^{C}q_1$ for the three 5CD and the two 3CD5AB model runs listed in with split CPUE series (Table D.1) derived from the MCMC chains of 2,000 samples



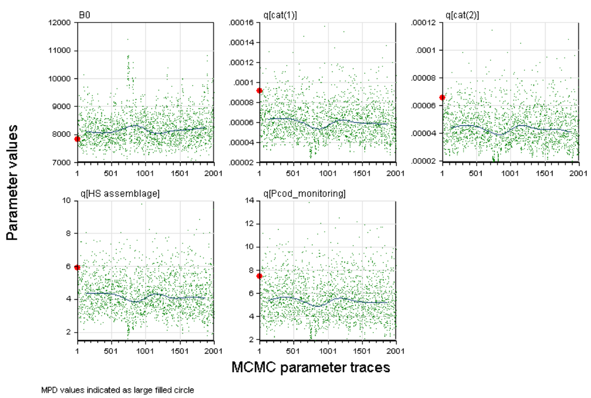
a) 5CD single CPUE series | $r = 5$ | est M



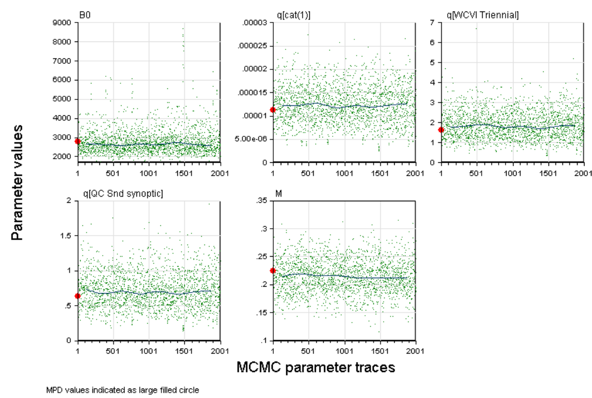
b) 5CD single CPUE series | $r = 5$ | fix M



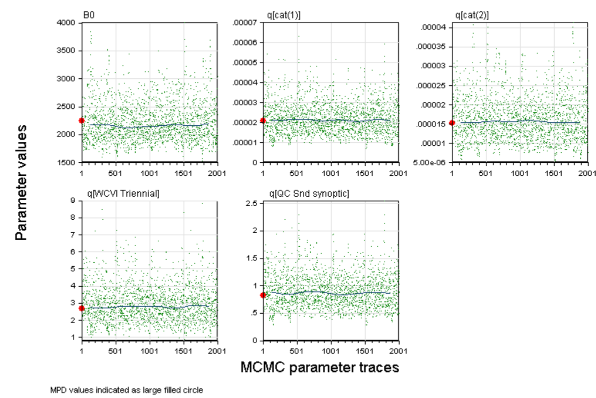
c) 5CD split CPUE series | $r = 5$ | est M



a) 5CD split CPUE series | $r = 5$ | fix M

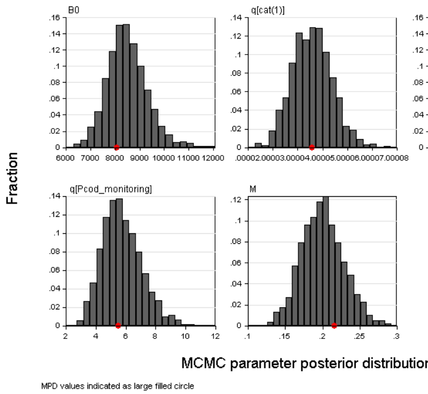


b) 3CD5AB single CPUE series | $r = 5$ | est M

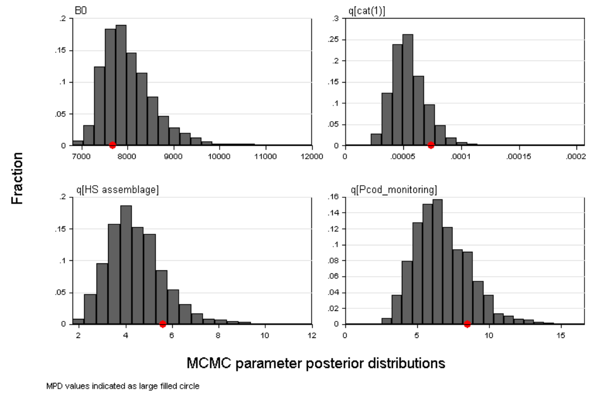


c) 3CD5AB split CPUE series | $r = 5$ | fix M

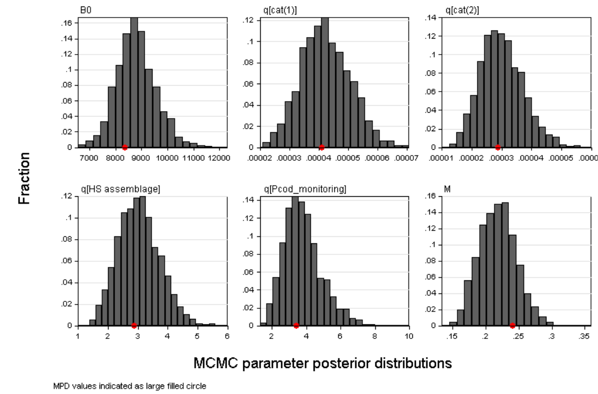
Figure D.28. MCMC traces of the main model parameters for six example model runs (Table D.1) based on a sample of 2,000 points from the chain.



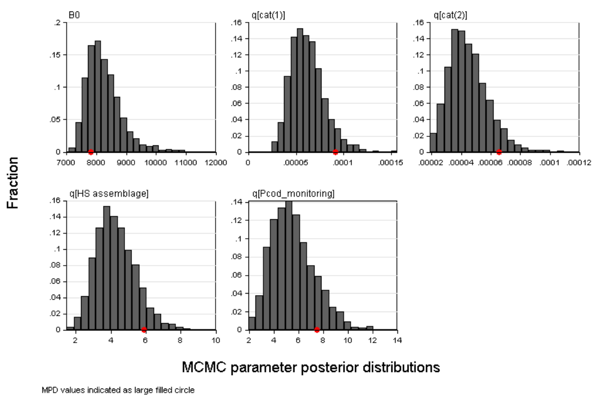
a) 5CD single CPUE series | $r = 5$ | est M



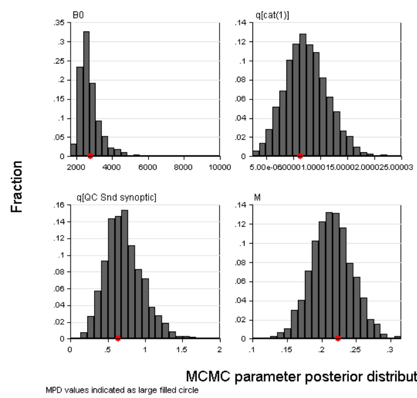
b) 5CD single CPUE series | $r = 5$ | fix M



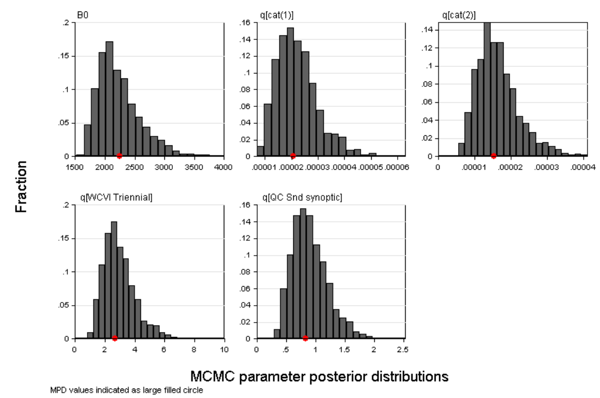
c) 5CD split CPUE series | $r = 5$ | est M



a) 5CD split CPUE series | $r = 5$ | fix M



b) 3CD5AB single CPUE series | $r = 5$ | est M



c) 3CD5AB split CPUE series | $r = 5$ | fix M

Figure D.29. Marginal posterior distributions of the main model parameters for six example model runs (Table D.1) based on a sample of 2,000 points from the chain.

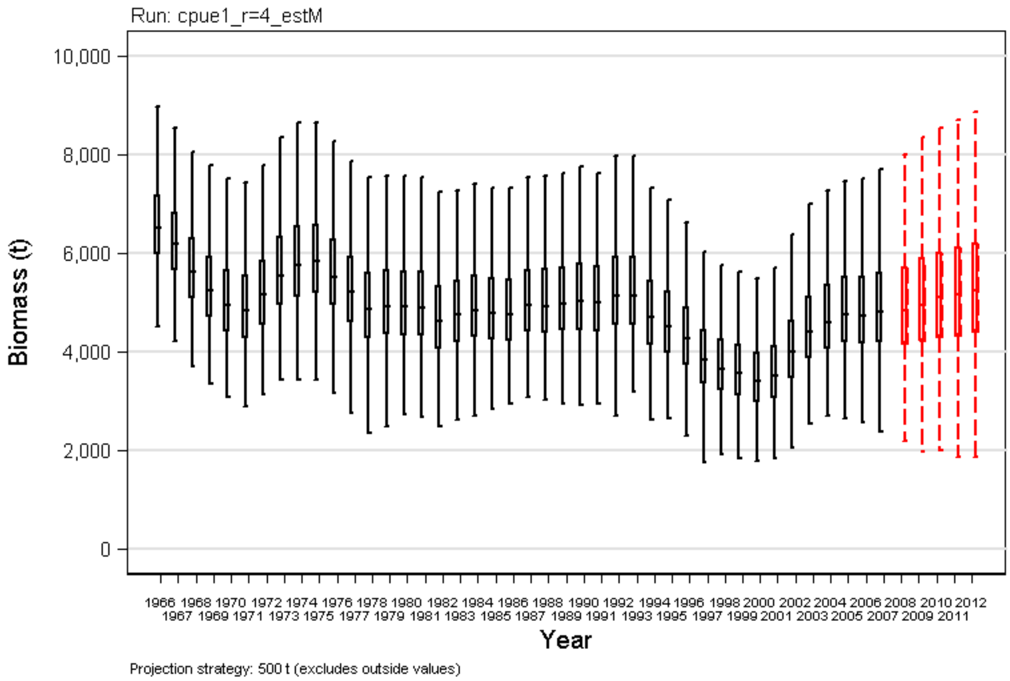


Figure D.30. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 5CD single CPUE series | $r = 4$ | est M model. Biomass for 2008–2012 projected assuming female landings of 500 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

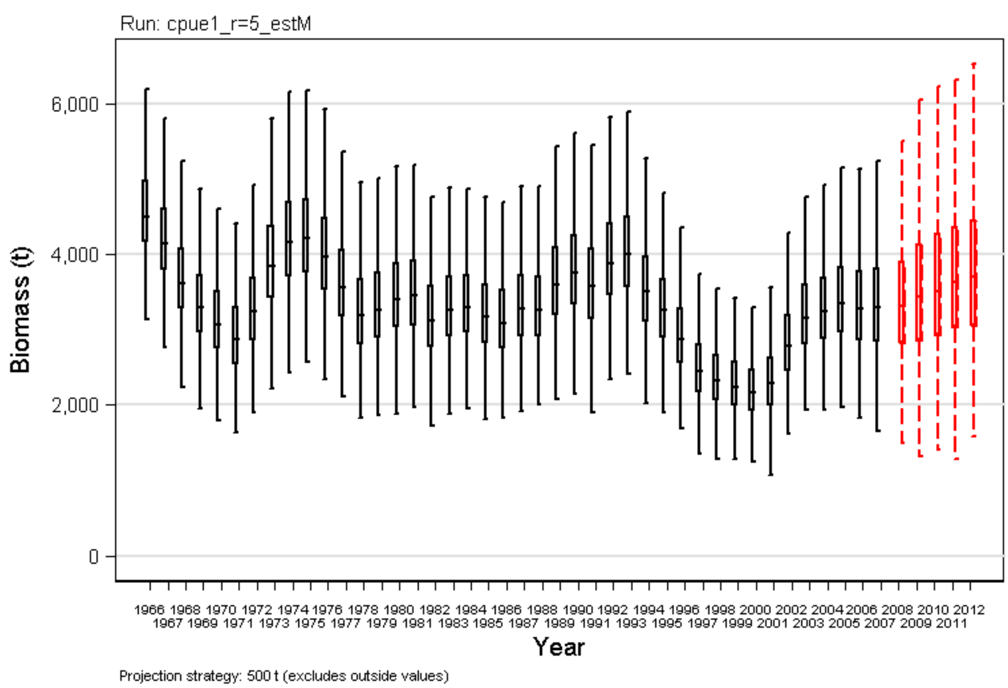


Figure D.31. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 5CD single CPUE series | $r = 5$ | est M model. Biomass for 2008–2012 projected assuming female landings of 500 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

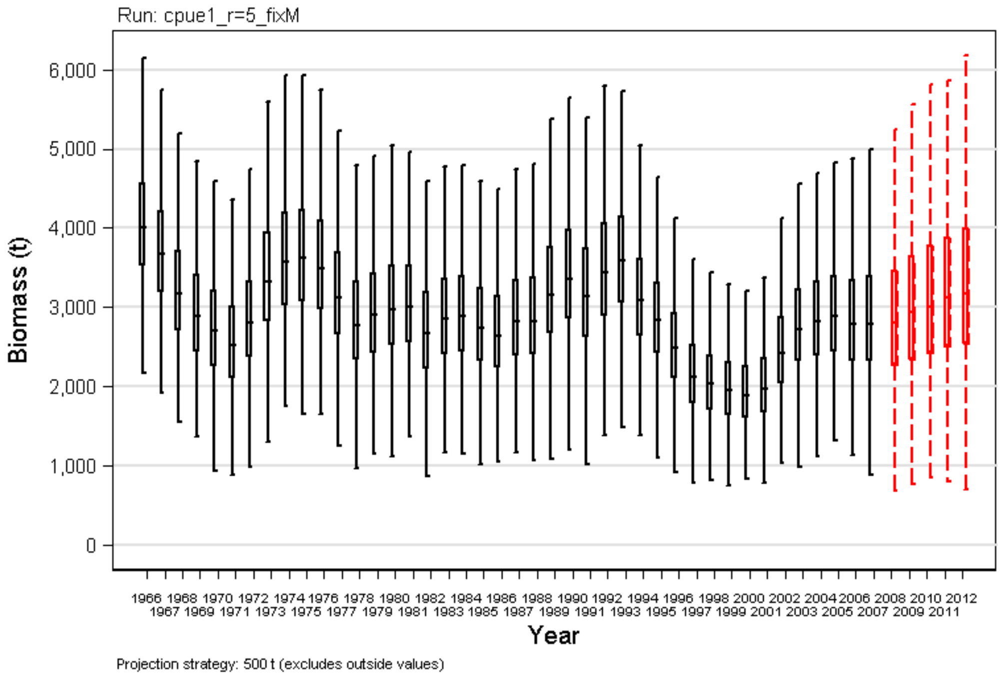


Figure D.32. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 5CD single CPUE series | $r = 5$ | fix M model. Biomass for 2008–2012 projected assuming female landings of 500 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

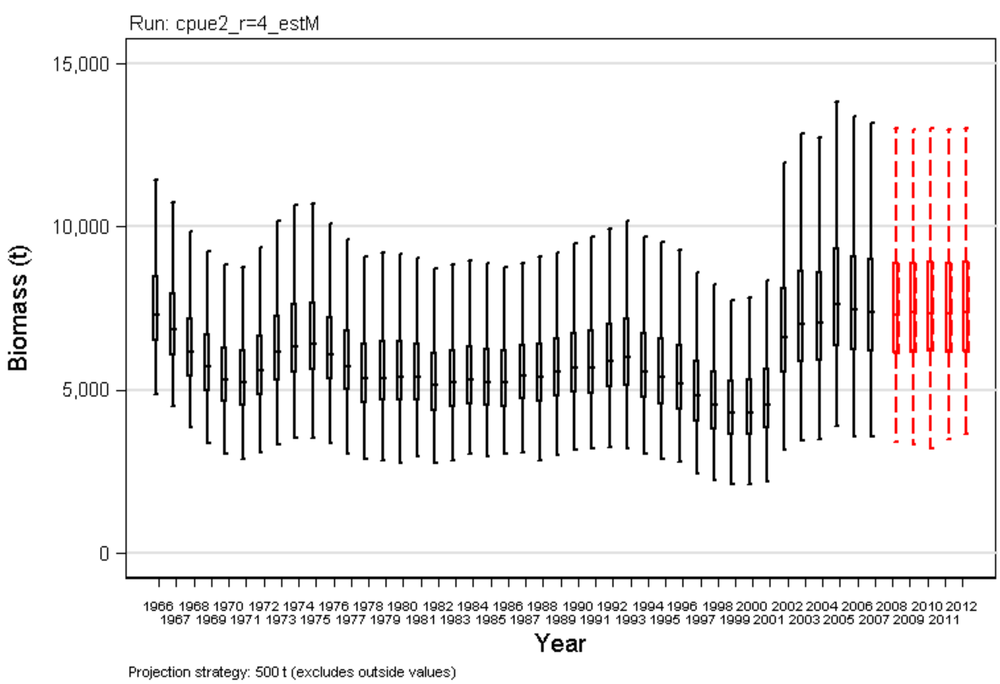


Figure D.33. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 5CD split CPUE series | $r = 4$ | est M model. Biomass for 2008–2012 projected assuming female landings of 500 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

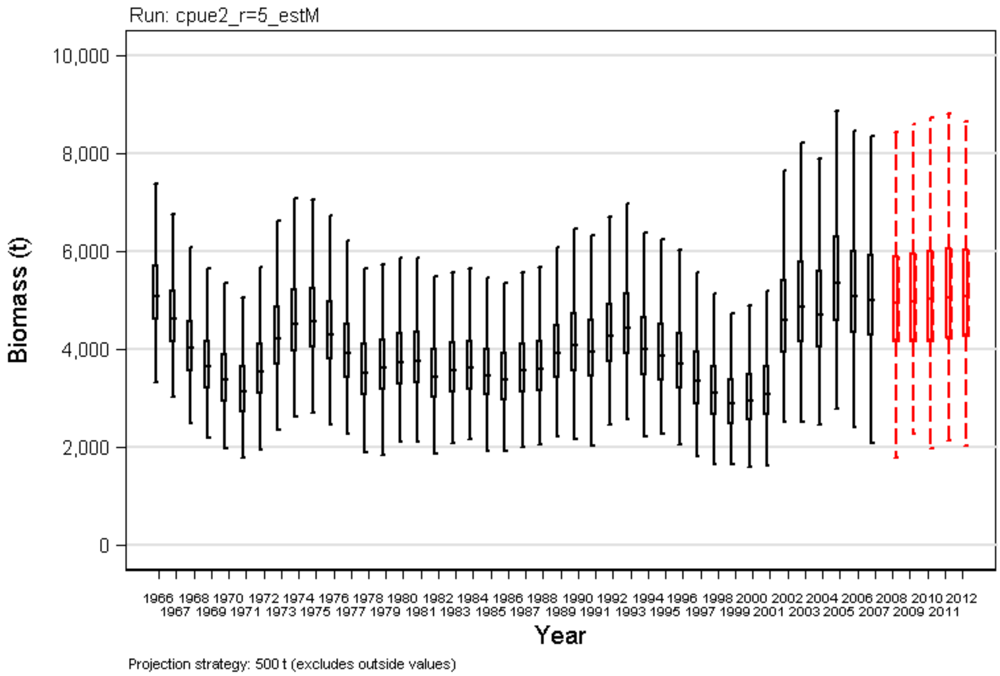


Figure D.34. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 5CD split CPUE series | $r = 5$ | est M model. Biomass for 2008–2012 projected assuming female landings of 500 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

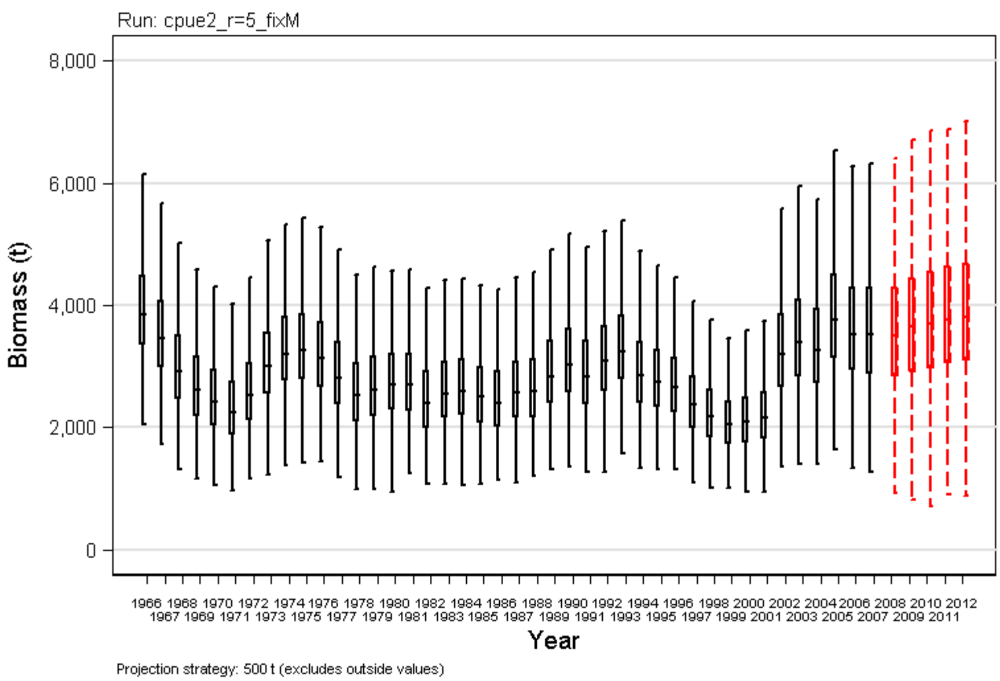


Figure D.35. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 5CD split CPUE series | $r = 5$ | fix M model. Biomass for 2008–2012 projected assuming female landings of 500 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

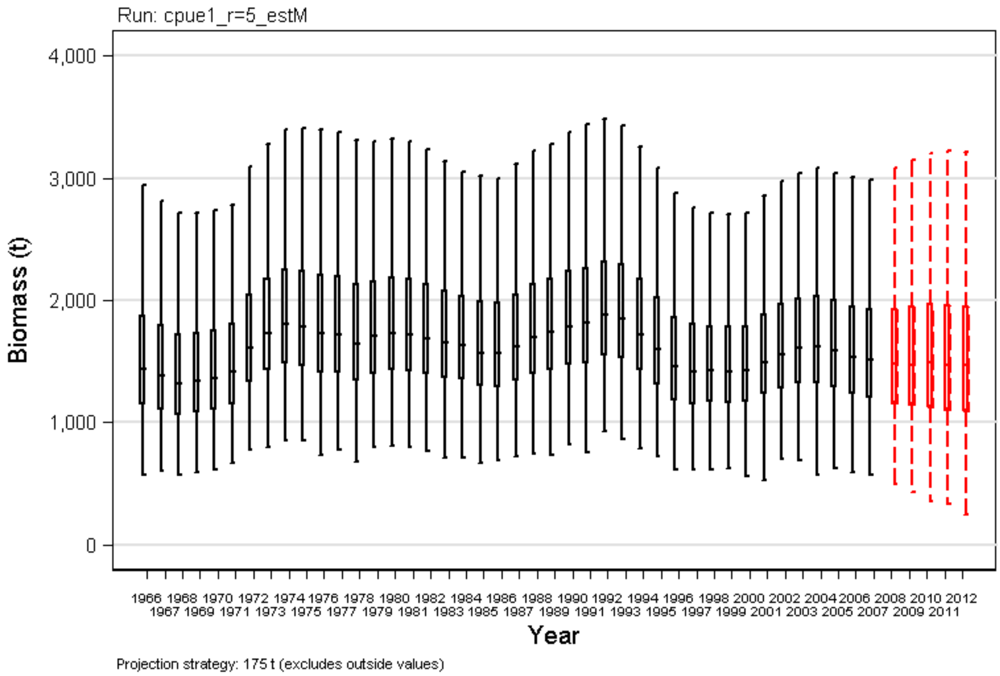


Figure D.36. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 3CD5AB single CPUE series | $r = 5$ | est M model. Biomass for 2008–2012 projected assuming female landings of 175 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

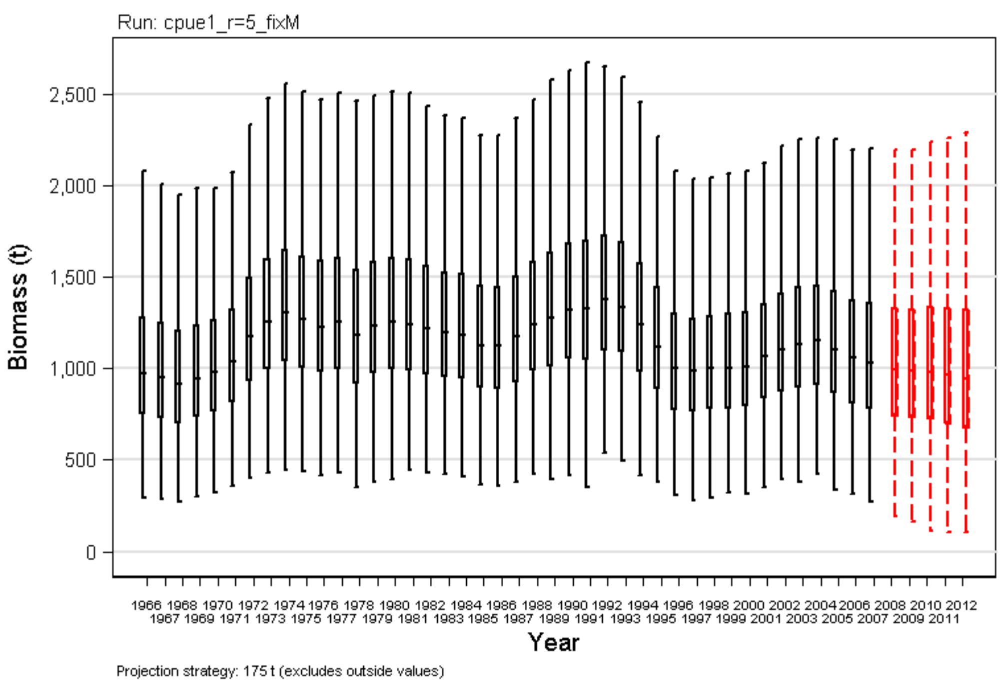


Figure D.37. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 3CD5AB single CPUE series | $r = 5$ | fix M model. Biomass for 2008–2012 projected assuming female landings of 175 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

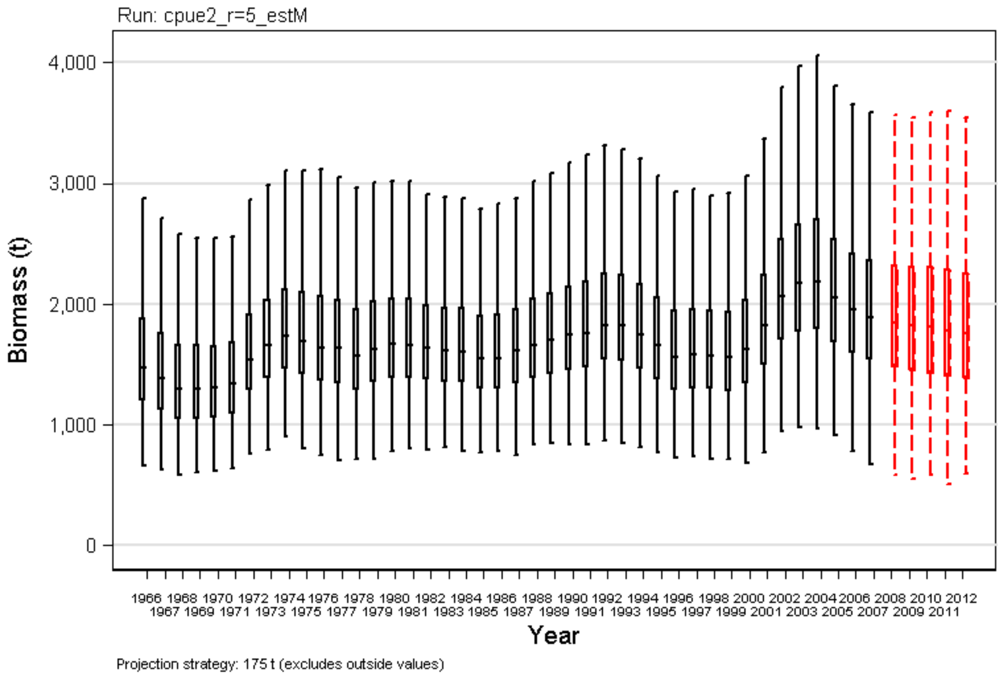


Figure D.38. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 3CD5AB split CPUE series | $r = 5$ | est M model. Biomass for 2008–2012 projected assuming female landings of 175 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

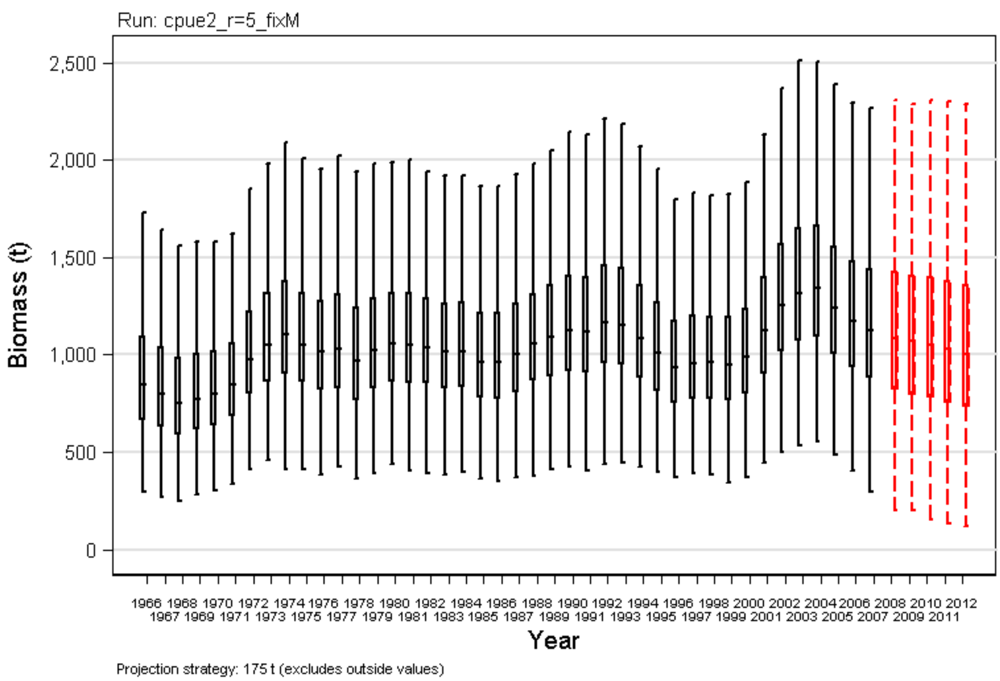


Figure D.39. Box plots of beginning year female biomass distributions based on a sample of 2,000 points from the chain for the 3CD5AB split CPUE series | $r = 5$ | fix M model. Biomass for 2008–2012 projected assuming female landings of 175 t per year. Boxes describe the 25th and 75th percentiles and the whiskers extend ±1.5*(75th-25th percentiles)

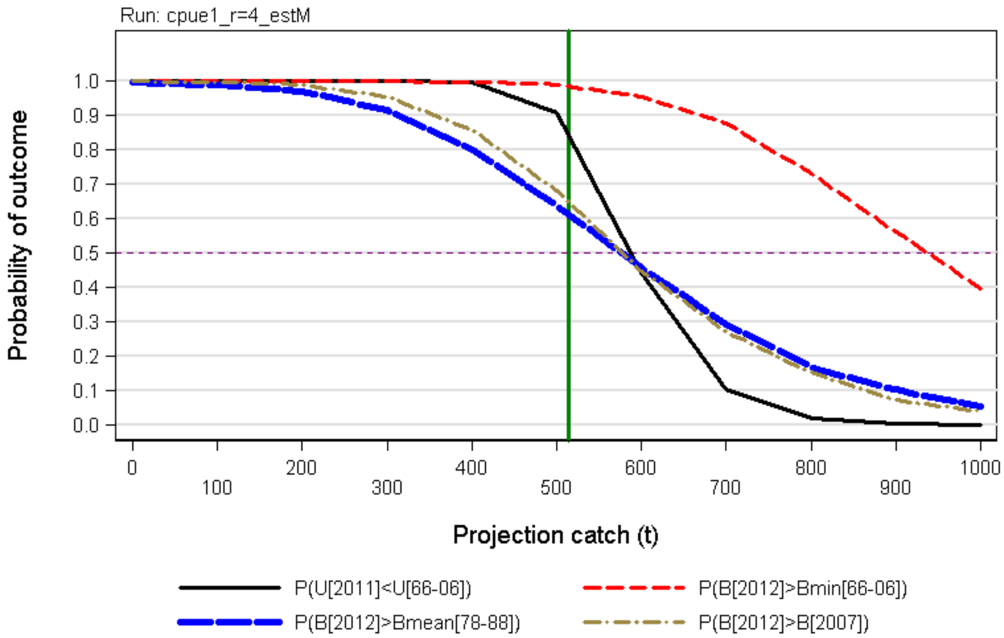


Figure D.40. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 5CD single CPUE series | $r = 4$ | est M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

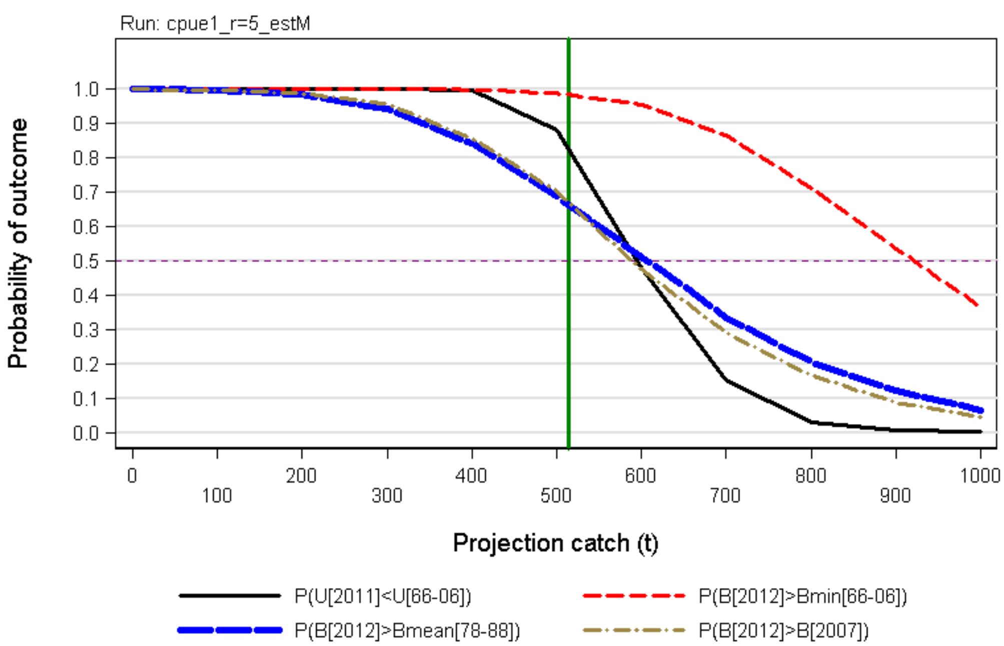


Figure D.41. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 5CD single CPUE series | $r = 5$ | est M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

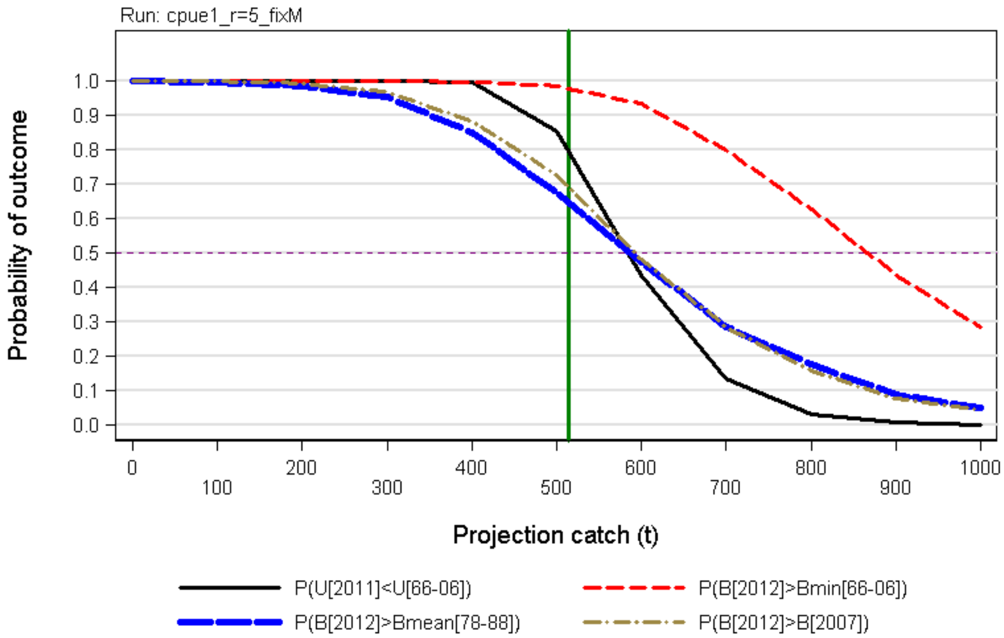


Figure D.42. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 5CD single CPUE series | $r = 5$ | fix M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

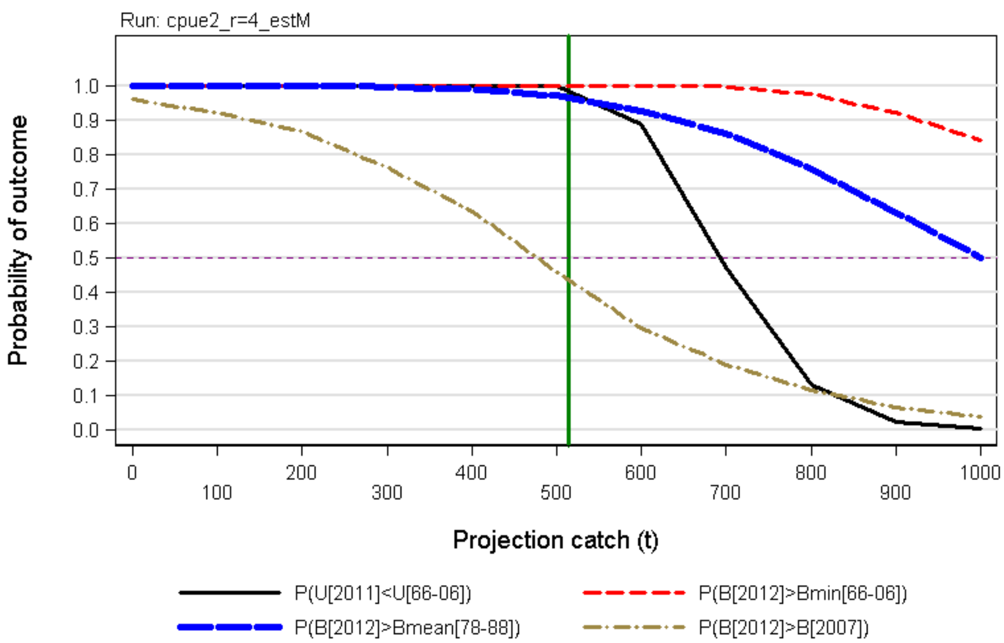


Figure D.43. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 5CD split CPUE series | $r = 4$ | est M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

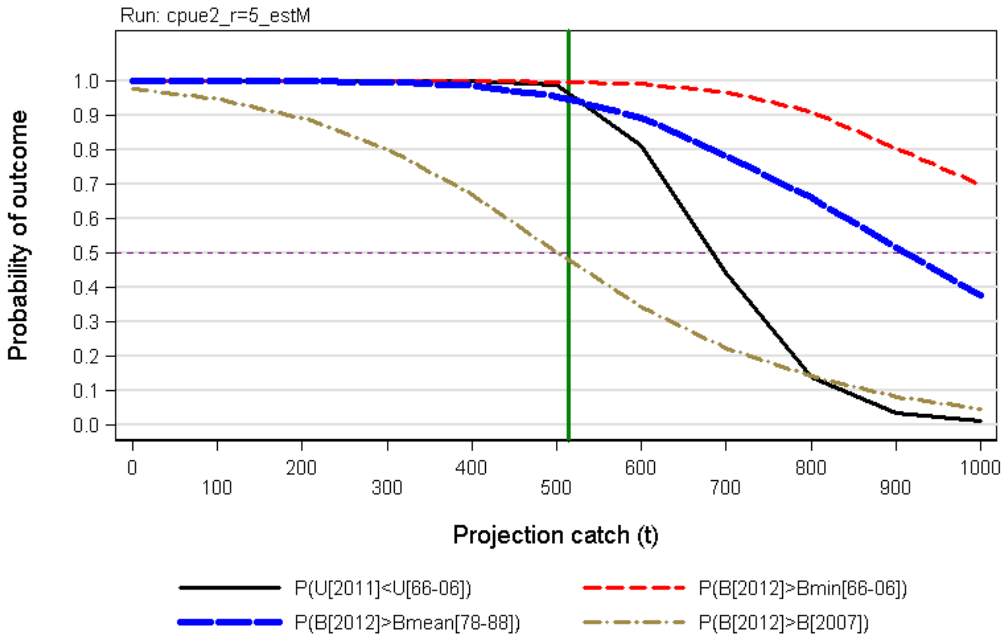


Figure D.44. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 5CD split CPUE series | $r = 5$ | est M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

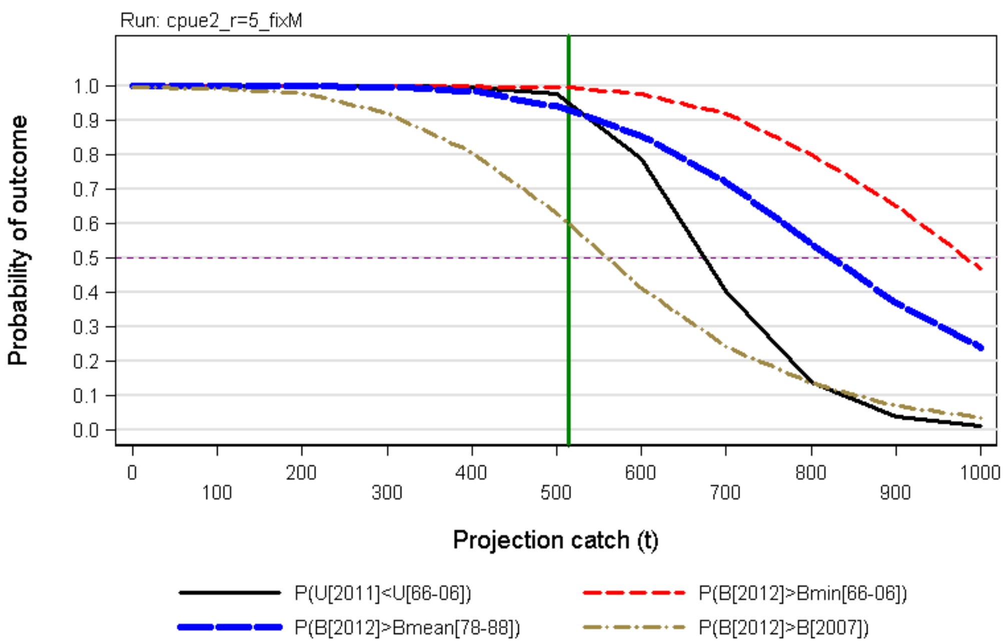


Figure D.45. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 5CD split CPUE series | $r = 5$ | fix M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

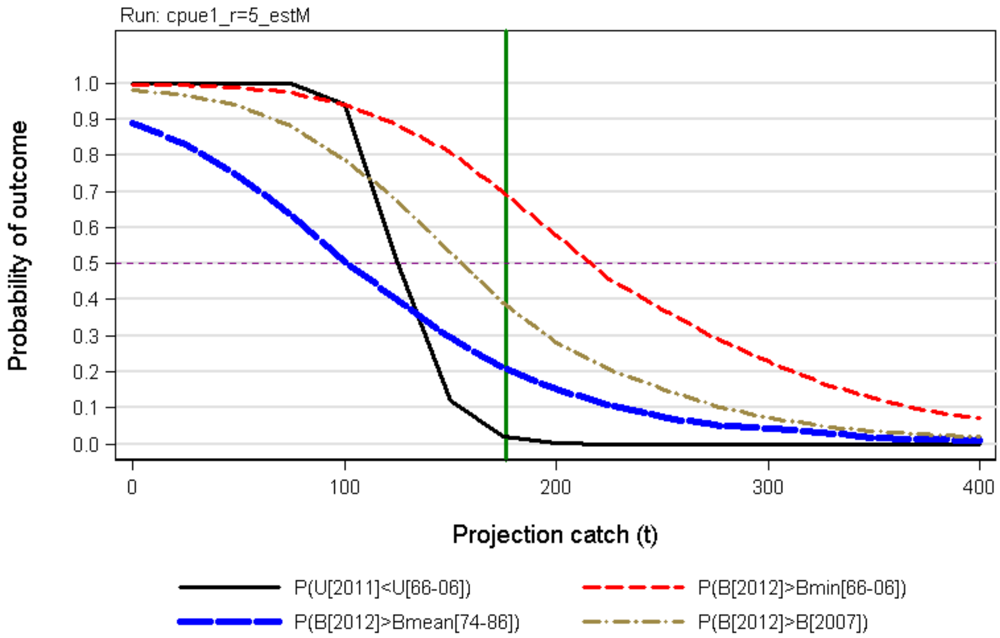


Figure D.46. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 3CD5AB single CPUE series | $r = 5$ | est M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

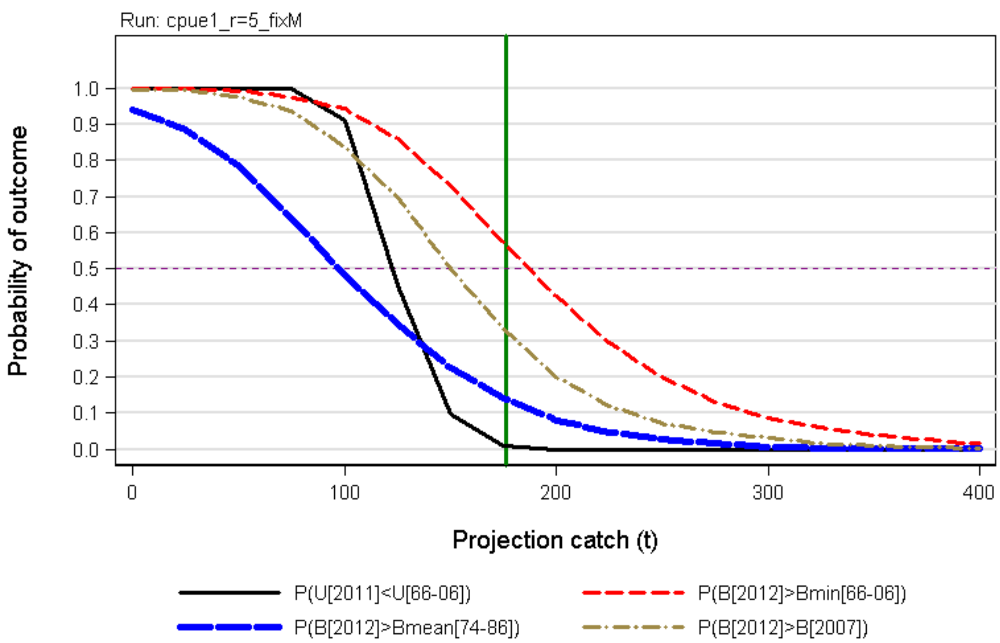


Figure D.47. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 3CD5AB single CPUE series | $r = 5$ | fix M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

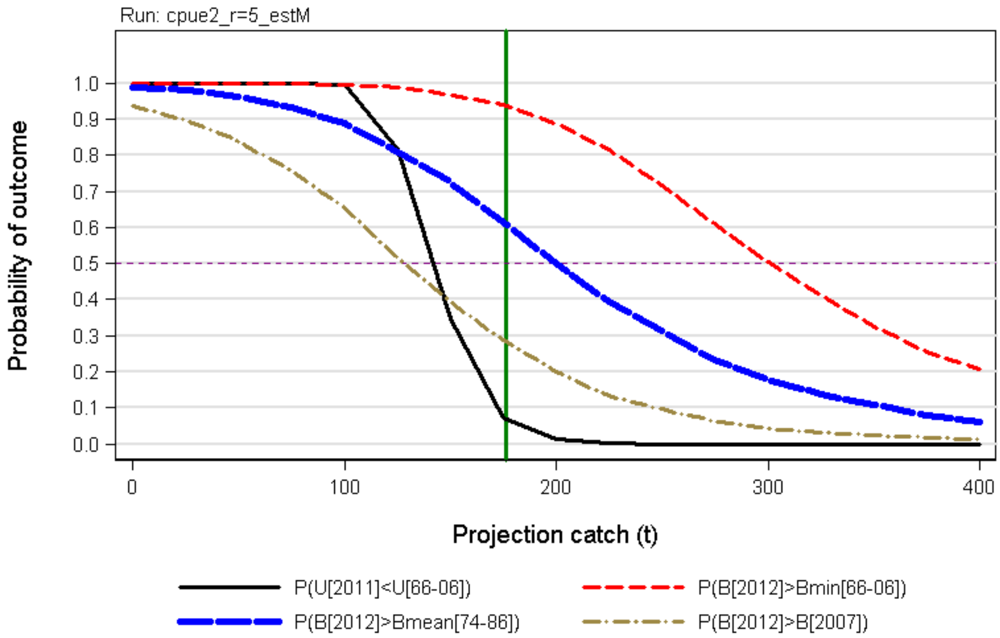


Figure D.48. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 3CD5AB split CPUE series | $r = 5$ | est M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t).

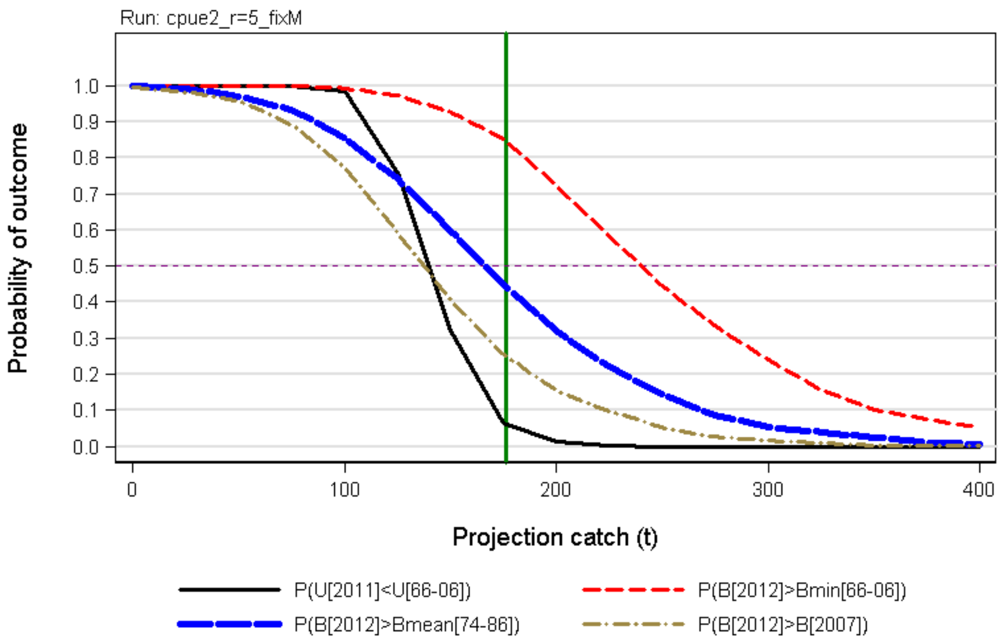


Figure D.49. Cumulative probabilities for four performance measures for the last year of five projection years over a range of constant catch strategies for the 3CD5AB split CPUE series | $r = 5$ | fix M model based on a sample of 2,000 points from the chain. Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

Appendix E. REVISIONS TO DECISION TABLES PRESENTED IN DFO (2007)

Introduction

A preliminary version of this assessment was presented to the Groundfish Subcommittee of Pacific Stock Assessment Review Committee in January 2007 (DFO 2007). This version of the of the stock assessment contained the error that is described in Appendix D. The stock assessment was accepted with revisions by the Subcommittee (DFO 2007) and the subsequent report contained a set of decision tables that were based on the assessment model which contained the error. The error has been corrected in this version of the English sole assessment presented and this Appendix compares the output of the decision tables presented in DFO (2007) with those in Tables D.6 to D.11, comparing, for each run (Table E.1), the four performance indicators presented in Appendix D.

Results

The results from the revised 5CD assessment are very similar to the assessment presented in January 2007 for each of the four performance indicators across all six 5CD assessment runs, with the probability functions from each iteration of the assessment lying on top of each other in most cases. In a few instances, the previous assessment was slightly more optimistic than the revised current assessment (e.g., indicator $\mathrm{P}\left(B_{2012} > \mathrm{mean}\left\{B_t\right\}_{t=1978}^{1988}\right)$: Figure E.4, Figure E.5 and Figure E.6). However, the differences are slight and do not suggest that they require a revision of the previous conclusions because they all occur in the upper righthand quadrant of the graphs.

PSARC accepted Run "2" from the single CPUE series (`r=5 and estimate M`, Table E.1) and Run "5" from the split CPUE series (`r=5 and estimate M`, Table E.1). The single CPUE series Run "2" shows no change at all in any of the four performance indicators (Figure E.2) while the split CPUE series Run "5" shows a slight shift in the 50% probability in surpassing the 1978–88 reference from about 1000 t to 900 t of annual removals (Figure E.5). Both levels are above the 2006 TAC for this stock.

The results from the revised 2009 3CD5AB assessment also show almost no change from the previous 2006 assessment for each of the four performance indicators across the four assessment runs. The two probability functions lie on top of in almost every instance, with only slight divergences at the righthand end of the functions (e.g., indicator $\mathrm{P}\left(\tilde{B}_{2012} > \min\left\{B_t\right\}_{t=1966}^{2006}\right)$: Figure E.7 and Figure E.10).

As for the 5CD assessment, the differences are small and do not suggest that they require a revision of the previous conclusions because they all occur in the upper righthand quadrant of the graphs. PSARC accepted Run "7" from the single CPUE series (`r=5 and estimate M`, Table E.1) and Run "9" from the split CPUE series (`r=5 and estimate M`, Table E.1). The only shift in the single CPUE series Run "7" is in the 50% probability of exceeding the minimum observed biomass which moves slightly to the right of the value presented in 2007 of 200 t (Figure E.7). The split CPUE series Run "9" shows no changes in any of the four performance indicators, with the current probability functions lying effectively on top of the equivalent functions derived from the previous version of the assessment (Figure E.10).

Table E.1. List of runs investigated in the English sole stock assessment [Appendix D and DFO (2007)] showing the run descriptors, the region assessed and the numbering scheme used in this Appendix. Refer to Appendix D for a more complete description of the assumptions which underlie each of these runs.

Run Number	**Assessment Region**	**Run description**
Run 1	5CD	single CPUE series | $r = 4$ | est M
Run 2	5CD	single CPUE series | $r = 5$ | est M
Run 3	5CD	single CPUE series | $r = 5$ | fix M
Run 4	5CD	split CPUE series | $r = 4$ | est M
Run 5	5CD	split CPUE series | $r = 5$ | est M
Run 6	5CD	split CPUE series | $r = 5$ | fix M
Run 7	3CD5AB	single CPUE series | $r = 5$ | est M
Run 8	3CD5AB	single CPUE series | $r = 5$ | fix M
Run 9	3CD5AB	split CPUE series | $r = 5$ | est M
Run 10	3CD5AB	split CPUE series | $r = 5$ | fix M

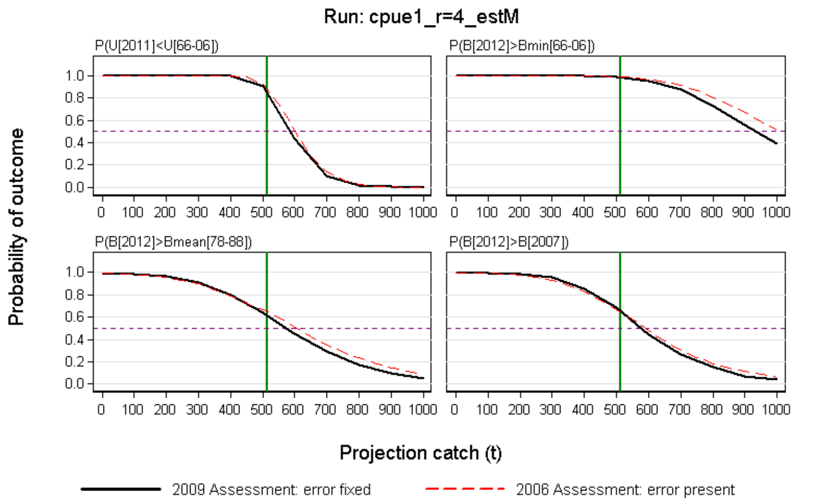


Figure E.1. Comparison between the 2009 and 2006 5CD English sole assessments of the trajectories from four performance indicators derived from Run “1” (Table E.1). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

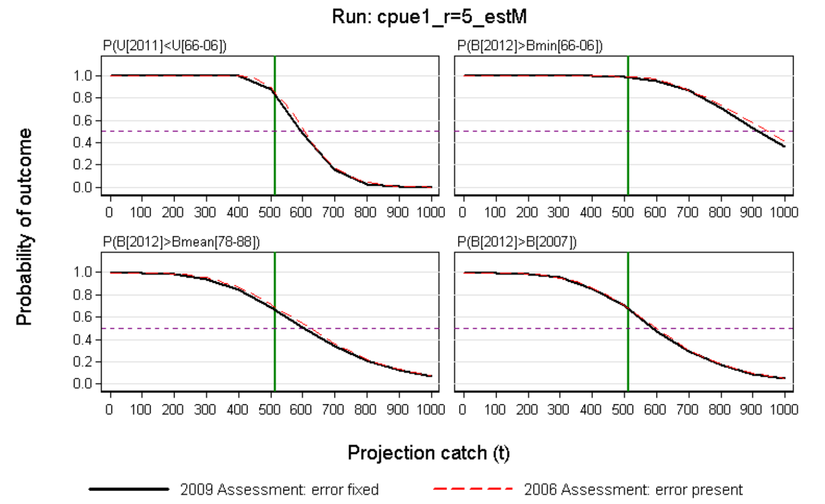


Figure E.2. Comparison between the 2009 and 2006 5CD English sole assessments of the trajectories from four performance indicators derived from Run “2” (Table E.1). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

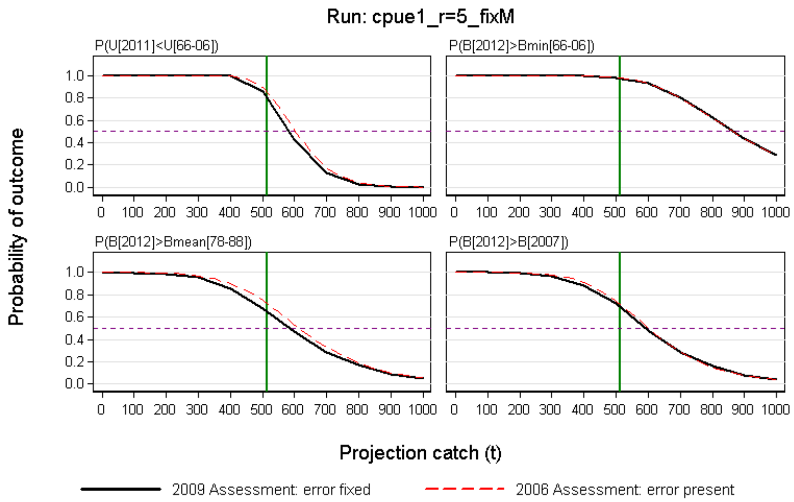


Figure E.3. Comparison between the 2009 and 2006 5CD English sole assessments of the trajectories from four performance indicators derived from Run “3” (Table E.1). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t).

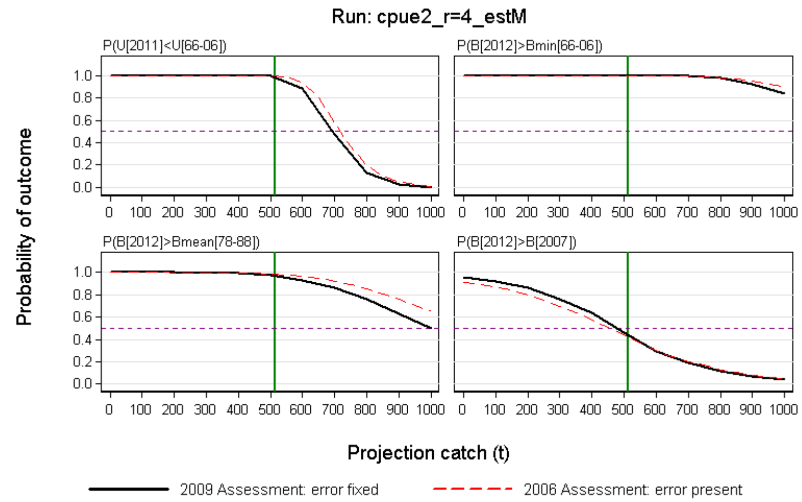


Figure E.4. Comparison between the 2009 and 2006 5CD English sole assessments of the trajectories from four performance indicators derived from Run “4” (Table E.1). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t).

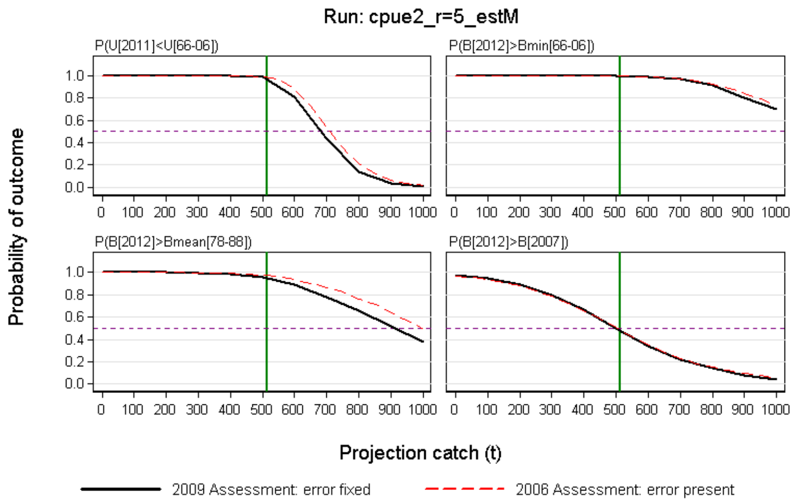


Figure E.5. Comparison between the 2009 and 2006 5CD English sole assessments of the trajectories from four performance indicators derived from Run "5" (Table E.1). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t)

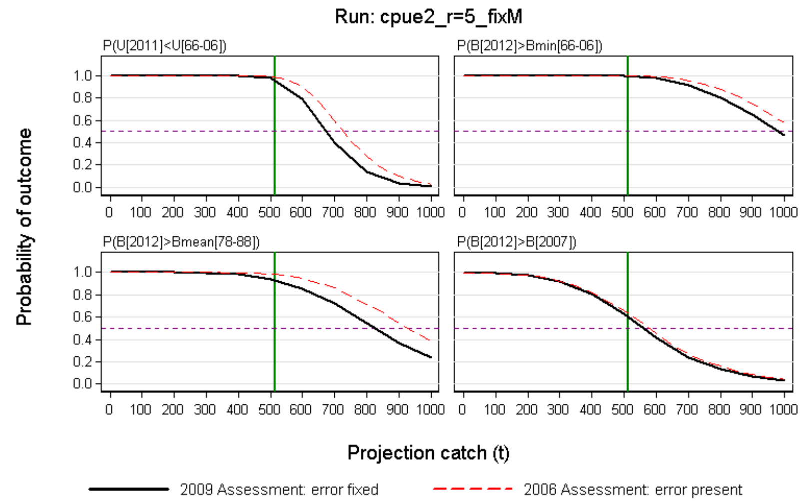


Figure E.6. Comparison between the 2009 and 2006 5CD English sole assessments of the trajectories from four performance indicators derived from Run "6" (Table E.1). Vertical line marks the equivalent female landings for the 5CD English sole TAC (514 t).

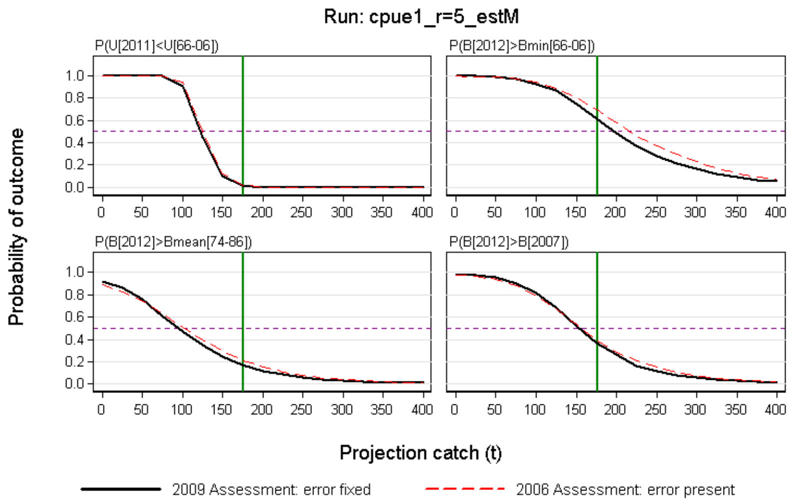


Figure E.7. Comparison between the 2009 and 2006 3CD5AB English sole assessments of the trajectories from four performance indicators derived from Run “7” (Table E.1). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

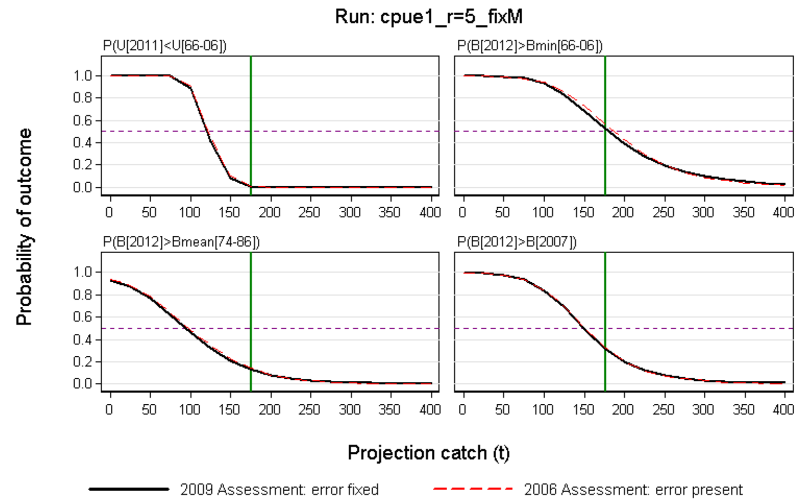


Figure E.8. Comparison between the 2009 and 2006 3CD5AB English sole assessments of the trajectories from four performance indicators derived from Run “8” (Table E.1). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

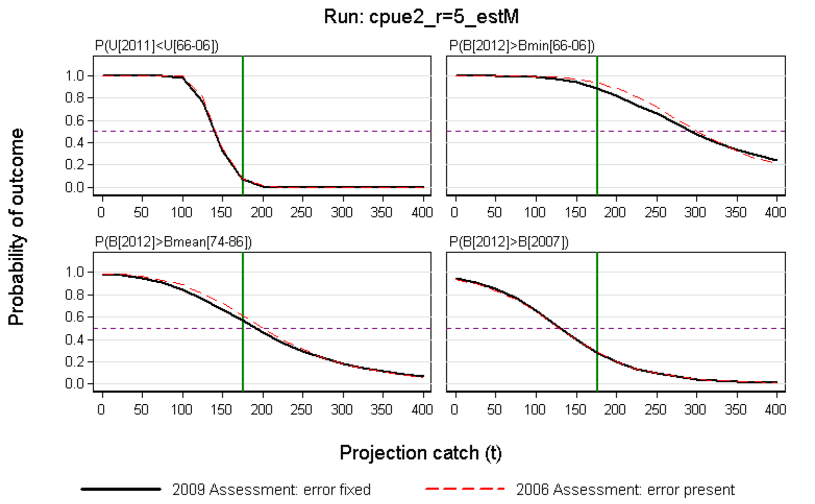


Figure E.9. Comparison between the 2009 and 2006 3CD5AB English sole assessments of the trajectories from four performance indicators derived from Run “9” (Table E.1). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

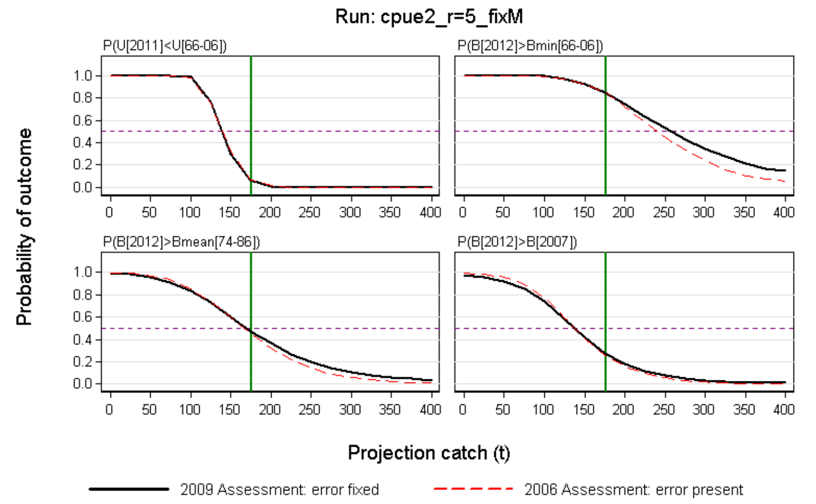


Figure E.10. Comparison between the 2009 and 2006 3CD5AB English sole assessments of the trajectories from four performance indicators derived from Run “10” (Table E.1). Vertical line marks the equivalent female landings for the 3CD5AB English sole TAC (176 t)

Appendix F. PSARC REQUEST FOR WORKING PAPER[1]

Date Submitted:

August 2006

Regional sector requesting advice:

(FAM, OHEB, Policy, Science)

Proposed PSARC Presentation Date:

Fall 2006 or January 2007

Subject of paper (title if developed):

English (Lemon) Sole Assessment

Science lead author:

Rob Kronlund / Paul Starr

Resource Management lead author:

Diana Trager

Rationale for request:

(What is the issue, what will it address, importance, etc.)

Over the past several years, fishermen have reported changes in English sole abundance in all management areas, to the point where species avoidance has become difficult and may limit industry's ability to maximize harvest opportunities for other groundfish species commonly caught with English sole.

Objective of working paper including assessment of environment/climate impacts:

(To be developed by FAM, OHEB, Policy, Science)

To provide assessments of the English sole populations in the waters off Vancouver Island and Queen Charlotte Sound (Areas 3C, 3D, 5A and 5B) and Hecate Strait (Areas 5C and 5D). These assessments will provide estimates of stock status relative to agreed target reference points as well as recommendations for levels of removals which will allow these populations to reach these targets. The assessments should include all available information, including surveys, biological sampling, catch records, logbooks, observer reports. These assessments will provide the basis for the management of the 2007/08 fisheries for English sole in the designated management areas.

Question(s) to be addressed in the working paper:

(To be developed by initiator)

1. What is the status of the English sole populations in 3CD5AB and 5CD relative to agreed target reference points?

2. What levels of catch in 2007/08 and beyond will allow these populations to reach these target reference points in XX years?

[1] Science – append approved RFWP to working paper.
Sector initiator – send approved RFWP to PSARC after sign off, and before significant work begins on the paper.

Stakeholders affected:

Commercial groundfish harvesters

How advice may impact the development of a fishing/recovery plan:

The advice will be used in the development of annual integrated fishery management plans to ensure sustainable harvest levels on a stock/area specific basis.

Timing issues related to when advice is necessary:

Advice required by January 2007 in time for inclusion is the development of the 2007/08 integrated groundfish management plans.

Initiating sector approval:

Regional Director/Designated Authority: ________________________

Date:_______________________