Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2012/152

Newfoundland and Labrador Region

Document de recherche 2012/152

Région de Terre-Neuve et du Labrador

Reference points and assessment update for American Plaice (*Hippoglossoides platessoides*) in NAFO SA2 + Div. 3K and Subdiv. 3Ps

Points de référence et mise à jour de l'évaluation de la plie canadienne (*Hippoglossoides platessoides*) de la sous-zone 2 de l'OPANO, division 3K et de la sous-division 3Ps

M.J. Morgan, K.S. Dwyer, and P.A. Shelton

Fisheries and Oceans Canada
PO Box 5667
St. John's, NL, A1C 5X1
Canada

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

Correct citation for this publication:

Morgan, M.J., Dwyer, K.S., and Shelton, P.A. 2013. Reference points and assessment update for American Plaice (*Hippoglossoides platessoides*) in NAFO SA2 + Div. 3K and Subdiv. 3Ps. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/152. iii + 64 p.

ABSTRACT

Survey indices from research vessel (RV) and landings information were updated for Subarea (SA) 2 + Div. 3K and Subdiv. 3Ps American Plaice (*Hippoglossoides platessoides*). Limit reference points (LRP) were determined for these two stocks and stock status updated relative to these points.

In SA2 + Div. 3K the stock declined to very low levels by the early 1990s. Total mortality due to all causes, including fishing, has been decreasing on more recent cohorts but, stock biomass remains at only 10% of the values of the mid-1980s. An empirical biological LRP was determined from examining stock recruit data from the research vessel survey. Generally recruitment has been impaired when the survey spawning stock biomass (SSB) index is below 70,000 t and therefore this was chosen as the LRP. The 2009 estimate of survey spawning stock biomass (SSB; the most recent year for which age data are available) indicates that the stock is at 24% of the LRP. It was not possible to determine an upper reference point or a removals (F-based) reference point for this stock.

In Subdiv. 3Ps a Bayesian Surplus Production Model was applied to landings data from 1960 to 2010 and survey data from 1980 to 2010. Consistent with the Fisheries and Oceans Canada (DFO) Precautionary Approach (PA) policy B_{lim} is 40% B_{msy}, the upper stock reference is 80% B_{msy} and F_{lim} is F_{msy}. Stock status relative to these reference points was estimated from the model. Stock size estimated from the surplus production model decreased fairly steadily from the late 1960s to reach a low in 1993 of less than 10% of B_{msy}. Stock size has been increasing slowly since 1993; however, current biomass is 50% of B_{lim} and therefore the stock is in the critical zone. The probability of being below B_{lim} is high (0.94). Current fishing mortality is estimated to be 64% of F_{lim}. The probability of being above F_{lim} is 0.2.

RÉSUMÉ

Les indices des relevés provenant du navire de recherche (NR) et les renseignements sur les débarquements ont été mis à jour pour la plie canadienne (*Hippoglossoides platessoides*) de la sous-zone 2, division 3K et de la sous-division 3Ps. On a déterminé les points de référence limites (PRL) pour ces deux stocks et on a mis à jour l'état de ces stocks en fonction de ces points.

Dans la sous-zone 2, division 3K, le stock a diminué à des niveaux très bas vers le début des années 90. La mortalité totale, attribuable à l'ensemble des causes, y compris la pêche, a diminué pour les cohortes plus récentes, mais la biomasse du stock demeure à seulement 10 % des valeurs du milieu des années 80. Un PRL empirique biologique a été déterminé à partir de l'examen des données sur les recrues du stock tirées du relevé du navire de recherche. En règle générale, le recrutement s'était détérioré quand l'indice du relevé de la biomasse du stock reproducteur (BSR) est inférieur à 70 000 t et, par conséquent, ceci a été choisi comme le PRL. L'estimation de 2009 de la biomasse du stock reproducteur (BSR; l'année la plus récente pour laquelle les données sont disponibles) indique que le stock est à 24 % du PRL. Il n'a pas été possible de déterminer un point de référence supérieur ni un point de référence d'exploitation (fondé sur le taux de mortalité par la pêche) pour ce stock.

Un modèle bayésien de production excédentaire a été appliqué aux données de débarquements entre 1960 et 2010 et aux données des relevés effectués entre 1980 et 2010. Conformément à la politique de l'approche de précaution (AP) de Pêches et Océans Canada (MPO), le B_{lim} est établi à 40 % de la B_{rms}, le point de référence supérieur du stock est établi à 80 % de la B_{rms} et le F_{lim} correspond au F_{rms}. L'état du stock par rapport à ces points de référence a été estimé à partir du modèle. La taille du stock estimée à partir du modèle de production excédentaire a connu un déclin assez constant à partir de la fin des années 60 pour atteindre son point le plus bas en 1993 avec moins de 10 % de la B_{rms}. La taille du stock augmente lentement depuis 1993, toutefois, la biomasse actuelle est à 50 % de la valeur du B_{lim} et, par conséquent, la valeur du stock est dans la zone critique. La probabilité que la valeur du stock soit inférieure à la valeur du B_{lim} est élevée (0,94). La mortalité actuelle par la pêche est estimée à 64 % de la valeur du F_{lim}. La probabilité qu'elle soit supérieure à la valeur du F_{lim} est de 0,2.

INTRODUCTION

Ecosystem and Fisheries Management (EFM) has requested identification of reference points for Subarea (SA) 2 + Div.3K and Subdiv. 3Ps American Plaice (*Hippoglossoides platessoides*) stocks in order to apply the Fisheries and Oceans Canada (DFO) Precautionary Approach (PA) framework (DFO 2009). The limit reference point (LPR) and the upper stock reference will be used to define the Critical, Cautious, and Healthy Zones.

The American Plaice stock in SA2 + Div. 3K was last fully assessed in 2003 and the Subdiv. 3Ps stock was assessed in 2005. This paper provides an update on survey indices and landings (bycatch) for both stocks. Based on fishery and survey data, biomass and removal reference points (upper, limit) are attempted for each stock.

There are number of methods for determining LRPs for fish stocks. These may range from simple empirical techniques to more-involved modeling approaches. Methods were attempted for both stocks, and from this, the status of each stock was provided relative to the reference point given.

ASSESSMENT UPDATE

FISHERY

SA2 + Div. 3K

Landings (from Zonal Interface Format File – ZIFF) increased steadily throughout the 1960s, peaking at 12,686 t in 1970 (Table 1, Fig. 1) and were well below total allowable catch (TAC) quotas for all years since 1982 to 1997. After the declaration of the 200-mile-limit in 1977, catches by non-Canadian fleets were greatly reduced, with the result that the total landings from the stock exceeded 2,000 t on only two occasions after 1981. Reported landings from 1994 to 1999 were less than 30 t per year mostly as by-catch in gillnet fisheries and these are the lowest in the time series. This is due to a large reduction in the TAC (Fig. 1), as well as the moratorium in 1994 on directed fishing (a by-catch TAC remained in place until 1997) and limited fisheries on northern cod (Div. 2J3KL), which, after 1992, essentially eliminated a major source of American Plaice by-catch. The main source of by-catch of American Plaice since 2000 has been in the Greenland Halibut gillnet fishery, and in recent years, the otter trawl fishery for this species. In 2010 and 2011, the total reported landings of American Plaice were 22 t and 17 t, respectively. In both years, 97% of the American Plaice by-catch (in tonnes) came from the Greenland halibut otter trawl fishery, mostly in Div. 3K.

Discards of American Plaice in the shrimp fishery in SA2 + Div. 3K are estimated to be about 13 t to 27 t in the most recent years for which there are results (2006-2009) (Orr 2010). This is based on analysis of observer data collected at sea on the large and small vessel shrimp fleets. These estimates may not be accurate because the minimum measurement of a sample is 1 kg (thus numbers are an overestimate). In addition, shrimp fishing areas do not overlap Northwest Atlantic Fisheries Organization (NAFO) areas exactly. Finally, the timing of the shrimp fishery is from April 1 to March 31. All of these factors will have an impact on the actual estimate of by-catch. The shrimp fishery incidentally takes American Plaice that are less than 30 cm, with large peaks in numbers of some years at 15 cm. Thus the number of small plaice taken in the shrimp fishery is not accurately known.

Subdiv. 3Ps

Landings (ZIFF) from this stock were highest from 1968 to 1973, exceeding 12,000 t on three occasions in this period (Table 2, Fig. 2). Since 1977 only Canada and France have been involved in this fishery. After the implementation of the 200-mile limit in 1977, landings ranged between 2,000 t to 4,000 t up to 1992. Landings averaged just under 4,000 t during the 1980s but rapidly declined after 1991. Subsequently there has been a moratorium on direct fishing of American Plaice in Subdiv. 3Ps since September 1993. Since then, there has been only by-catch of American Plaice in other fisheries, which increased substantially since 1995, and was over 1,000 t in each year from 2001 to 2003. However, by-catch has been declining since then and is 402 t and 273 t in 2010 and 2011, respectively.

Data from the Newfoundland reported catch statistics (ZIFF) were examined to determine which fisheries were taking the greatest portion of the American Plaice by-catch. The by-catch of American Plaice is taken in two main fisheries, the directed cod and Witch Flounder fisheries. In 2010, 50% of the total Newfoundland catch (t) came from the Witch Flounder otter trawl fishery and 30% was taken from the cod gillnet fishery. In 2011, this was somewhat different: 25% of the by-catch of American Plaice was taken in the Witch Flounder otter trawl fishery and 40% was taken in the cod gillnet fishery.

RESEARCH VESSEL (RV) SURVEY

SA2 + Div. 3K

Abundance and Biomass

DFO has conducted stratified random bottom trawl surveys in Div. 2G, 2H, 2J, and 3K since the late 1970s, although not annually in Div. 2GH. In 1995, the survey trawl was switched from an Engel 145 Hi-lift trawl with bobbin footgear to a Campelen 1800 shrimp trawl with rockhopper footgear (McCallum and Walsh 1996). The Campelen trawl is more effective in capturing small fish. A comparative fishing experiment was carried out to quantify the differences, and the results are found in Warren (1996). Morgan and Brodie (2000) converted the results of surveys in Div. 2J and 3K from 1978 to 1994 into Campelen-equivalent units for American Plaice. The surveys in Div. 2GH were not converted.

From 1995 to 2011, the fall surveys covered Subarea 2 + Div. 3KLMNO although the coverage was not comparable in all years, particularly in Div. 2G and inshore Div. 3K. Inshore strata were added in Div. 3K in 1996 and Div. 2H was surveyed in 1996-1999, 2001, 2004, 2006, 2008, and 2010-2011. Div. 2G was last surveyed in 1999.

Biomass and abundance estimates in Div. 2H, although low, have been increasing over the Campelen time series (beginning in 1996) (Table 3, Fig. 3).

Biomass and abundance declined in the late 1980s in Div. 2J3K to a low level in 2002. Since then, both biomass and abundance have increased slightly. Abundance in 2011 is highest since 1994, when the moratorium was instituted (Table 3, Fig. 4). However, current biomass in Div. 2J3K is at 10% and abundance at 25% of the average of the mid-eighties.

Ageing of American Plaice in Div. 2J3K has not been updated since 2009. However, length frequency plots from 2009 to 2011 indicate that there is a large peak in numbers of American Plaice at 20 cm in 2011 (Fig. 5).

A comparison of the expanding symbol plots of numbers/tow in Subarea 2 + Div. 3K in 1981 and the most recent years also indicate a decline in abundance (Fig. 6-8). In addition, fewer fish are found on the banks and nearshore in recent years, compared to the 1980s, coinciding with a shift to deeper water that occurred during that time period (Dwyer et al. 2003).

Mortality

A general linear model was fit to survey data for years 1978-2009 (equivalent to catch curve analysis). The model estimates total mortality (Z) based on the slope of the log of the survey numbers at age for fish in a cohort. Younger American Plaice are not fully selected by the survey gear as illustrated in Fig. 9. Because of this the decision was made to omit data for ages 0 to 6 from the analysis on the basis that these ages are not fully selected to the survey gear.

$$\log(I_{a,c}) = \text{int} + \text{age} + \text{age*cohort}_c$$

Where $I_{a,c}$ is the survey index at age *a* for cohort$_c$, int is the intercept, age is the age effect (slope) and age*cohort$_c$ is the interaction term between age and cohort (separate slope for each cohort) where cohort is a categorical variable.

The equation for the estimate of the mortality rate for a cohort from this model is

$$Z_c = \text{age} + \text{age*cohort}_c$$

Estimates of Z_c are plotted in Fig. 10.

Because cohorts at the beginning and end of the survey series are incomplete these were trimmed from the output before plotting and only data for cohorts 1966 to 1998 are included. Because age-disaggregated survey data for Div. 2J3K has been completed only up to 2009, this means that the 1998 cohort estimate of Z is based only on data for ages 7-11. There was a significant difference between cohorts indicating change in Z over time ($F = 19.02$, $df = 39$, $P < 0.0001$). Z increased progressively on cohorts that arose from 1970 onwards, reaching a peak of over 1.4 on the 1983 cohort. Thereafter Z showed a decreasing trend reaching a value of <0.2 on the most recent cohorts for which there are sufficient information to reliably compute a mortality rate.

Maturity

Age and length at 50% maturity were produced from DFO survey data. Estimates were produced by sex and cohort for each population using generalized linear models with a logit link function and binomial error.

There was a significant effect of cohort on proportion mature at age for males ($\chi^2 = 618$, $df = 34$, $P < 0.0001$) and females ($\chi^2 = 1838$, $df = 40$, $P < 0.0001$) and also on proportion mature at length for males ($\chi^2 = 945$, $df = 36$, $P < 0.0001$) and females ($\chi^2 = 3377$, $df = 41$, $P < 0.0001$). In SA2 + Div.3K, age at 50% maturity (A50) has declined from just under 11 years to around 7 years of age for females (Fig. 11). For males, A50 has declined from around 7 years to just over 4 years of age. There has been some increase in A50 for males of recent cohorts, but such a short term increase has been seen in the time series previously and this will need to continue before it can be considered a reversal of the decline. Length at 50% maturity (L50) has also declined for both sexes in SA2 + Div. 3K (Fig. 12). For males, L50 was about 22 cm at the beginning of the time series and for recent cohorts is about 18 cm. Female L50 declined from about 38 cm at the beginning of the time series to about 31 cm recently.

Spawning Stock Biomass

An index of spawning stock biomass was calculated from the survey by multiplying estimated maturity at age by abundance at age and weight at age in the survey. The spawning stock biomass (SSB) index declined rapidly after 1982 and reached its lowest level in 2003. There was some increase after 2006 but the average of 2007 to 2009 is only 15% of the average over the 1978 to 1982 period (Fig. 13). Ageing data has not been completed since 2009; hence the time series ends in 2009.

Recruitment

For SA2 + Div. 3K a relative recruitment index was estimated from DFO survey data using a general linear model applied to ages 3-5, in the same fashion as in Dwyer et al. (2003). Only those cohorts that were observed at least twice in the data were used in the estimation. Relative cohort strengths were estimated using the following model:

$$\log(N_{a,y}) = \mu + A_a + Y_y + \varepsilon_{a,y} ,$$

where:

μ = intercept

a = age subscript, age 3 to 5

y = cohort subscript

N = survey index (abundance in millions)

A = age effect

Y = cohort effect

ε = error.

There was a significant cohort effect, that is a significant difference in cohort strength ($F = 4.7$, $df = 31$, $P < 0.0001$). In SA2 + Div. 3K recruitment declined from the mid-1980s to the late 1990s. There has been an increase in recruitment to approximately 40% of the average recruitment estimated prior to the mid-1980s (Fig. 14).

Stock Recruit

As the survey occurs in the fall the SSB index in year y was taken as giving rise to recruits in year y+1. A segmented regression was fit to the stock recruit data using the Julious algorithm and maximum likelihood (Julious 2001). The stock recruit data with the fit from the Julious algorithm are shown in Fig. 15. The data do not seem to be well described by the segmented regression. The two methods of fitting the model give very different results with different estimated break points. However, there is a relationship between recruitment and SSB index with recruitment increasing with SSB index. Generally recruitment is at a lower level when the SSB index is below 70 and this could serve as a LRP for this stock. The 2009 estimate of survey SSB indicates that the stock is at 24% of the LRP. Estimates are not yet available for 2010 and 2011; however, there has been limited increase in total biomass from the survey and the stock is very unlikely to have increased above B_{lim}, the biomass limit reference point.

Subdiv. 3Ps

Abundance and Biomass

Stratified-random surveys have been conducted by DFO in Subdiv. 3Ps in each year from 1972 to 2011. Coverage prior to 1980 was poor. There were two surveys in 1993, one in February and one in April. Most of the surveys prior to 1993 were in February/March, while those since 1993 have been in April. The data can be split into three time periods based on the trawl used in each period: 1971-1982 was Yankee 36, 1983-1995 was Engel 145, and 1996-2011 was Campelen 1800 (see McCallum and Walsh (1996) for a description of the various trawls). There is a conversion between the second and third survey gears (Morgan et al. 1998) but not the first and third. Only Campelen and Campelen-equivalent units are discussed in this section.

Inshore strata were added in Placentia Bay in 1994 and more were added in Fortune Bay in 1997.

Biomass and abundance indices from 1983 to 2011 are shown in Fig. 16. From the mid-1980s to 1990 there was a large decline in both biomass and abundance indices. Stock size was lowest in the early 1990s. There has been an increase over the 1992-2011 period for both biomass and abundance indices but current biomass is at 25% and abundance at 52% of the average of the mid-1980s.

Age data for American Plaice in Subdiv. 3Ps has not been updated since 2009. However, length frequency plots from 2009 to 2011 indicate that there is a large peak in numbers at 10 cm in 2009 (likely age 2) that can be followed to a peak at 20 cm in 2011 (Fig. 17).

American Plaice are distributed (numbers/tow) throughout Subdiv. 3Ps (Fig. 18-20). For comparison, a year in which the index was in Engel units (non-converted) (1983) was provided (Fig. 18). This showed American Plaice catches in that year were distributed throughout the Halibut Channel and onto St. Pierre Bank. In the more recent time period (2007-2011) there tend to be fewer fish in the Halibut Channel and there are now some larger sets on southern St. Pierre Bank (Fig. 19-20). There are also some larger catches in Fortune Bay.

Mortality

The same general linear model as used in SA2 + Div. 3K was fit to survey data for Subdiv. 3Ps for years 1983 to 2009. Younger American Plaice are not fully selected by the survey gear as illustrated in Fig. 21. Because of this the decision was made to omit data for ages 0 to 6 from the analysis on the basis that these ages are not fully selected. Estimates of Z_c are shown in Fig. 22.

Because cohorts at the beginning and end of the survey series are incomplete these were trimmed from the output before plotting and only data for cohorts 1973 to 1998 are included. Because age-disaggregated survey data for Subdiv. 3Ps are only available up to 2009, this means that the 1998 cohort estimate of Z is based only on data for ages 7-11. There was a significant difference between cohorts indicating change in Z over time ($F = 11.31$, $df = 34$, $P < 0.0001$). Z increased progressively on cohorts that arose from the mid-1970s onwards, reaching a peak of nearly 1.2 on the 1979 cohort. Thereafter Z showed a generally decreasing trend reaching except for those cohorts of the early 1990s that were subject to the higher catches of the early 2000s. Z has reached values of just below 0.3 on the most recent cohorts for which there are sufficient information to reliably compute a mortality rate (Fig. 22).

Maturity

Age and length at 50% maturity were produced from DFO survey data. Estimates were produced by sex and cohort for each population using generalized linear models with a logit link function and binomial error.

American Plaice in Subdiv. 3Ps show a similar decline in A50 and L50 as in SA2 + Div. 3K (Fig. 23 and 24). There was a significant effect of cohort on proportion mature at age for males ($\chi^2 = 595$, $df = 38$, $p < 0.0001$) and females ($\chi^2 = 943$, $df = 40$, $p < 0.0001$) and also on proportion mature at length for males ($\chi^2 = 1086$, $df = 40$, $p < 0.0001$) and females ($\chi^2 = 756$, $df = 41$, $p < 0.0001$). Male A50 has declined from about 7 years to less than 4.5 years, while female A50 has declined from about 11 years to just under 9 years. Male L50 has declined from about 27 cm to less than 19 cm and female L50 has declined from about 40 cm to around 36 cm.

Spawning Stock Biomass

An index of spawning stock biomass was calculated from the survey by multiplying estimated maturity at age by abundance at age and weight at age in the survey. The SSB index showed a major decline from the mid-1980s to the early 1990s and has shown some increase after 1997. The SSB index from 2007 to 2009 is 30% of the 1983-1987 average (Fig. 25). Ageing data has not been completed since 2009; hence the time series ends in 2009.

Recruitment

For Subdiv. 3Ps there was a pattern in the residuals when Campelen and equivalent data were used in the estimation of recruitment, so as in Morgan et al. (2005), a general linear model using Campelen and original Engel data was chosen which eliminated the pattern in the residuals. Only those cohorts that were observed at least twice in the data were used in the estimation. Relative cohort strengths were estimated using the following model:

$$\log(N_{s,a,y}) = \mu + Y_y + (SA)_{s,a} + \varepsilon_{s,a,y} ,$$

where:

μ = intercept

s = survey subscript, Engel or Campelen

a = age subscript, age 2 to 5

y = cohort subscript

N = survey index (abundance in millions)

Y = cohort effect

SA = Survey * Age effect, and

ε = error.

There was significant cohort strength variation (F = 3.66, df = 25, $p < 0.001$). Recruitment declined in Subdiv. 3Ps from 1980 until 1995 (Fig. 26). Since then it has increased fairly steadily to reach levels similar to the beginning of the time series.

Stock Recruit

A segmented regression was fit to the stock recruit data using the Julious algorithm and maximum likelihood. The stock recruit data with the fit from the Julious algorithm are shown in Fig. 27. Recruitment increases with SSB index and the data are better described by the segmented regression in Subdiv. 3Ps than for SA2 + Div. 3K. The two methods of fitting the model gave the same results with the break point occurring at an SSB index of 24.1.

CATCH/BIOMASS RATIOS

SA 2 + Div. 3K

Catch divided by the index of survey biomass (C/B) is a proxy for fishing mortality (F), and the time series of C/B for American Plaice in SA2 + Div. 3K is shown in Fig. 28. Biomass estimates are Campelen equivalents for Div. 2J and 3K combined, and the catches are the reported landings data for SA2 + Div. 3K combined. For much of the time period when surveys were available, a substantial part of the commercial landings occurred during the first quarter of the year. Thus the survey estimates of biomass, which were generally from November to December, were taken to represent the biomass on January 1 of the following year. The analysis shows that C/B ratios were all less than 4%, exceeding 3% on only two occasions. C/B increased after 1999, as landings increased and survey biomass declined, but still remained below 1% (Fig. 28). The C/B ratios for the past four years have been very low.

Subdiv. 3Ps

For American Plaice in Subdiv. 3Ps, the C/B ratio was examined from Campelen data from 1983 to 2011 (Fig. 29). C/B ratio increased steadily through the 1980s reaching a peak of 0.31 in 1990. It declined rapidly after that as catches decreased, and dropped to a minimum in 1995. C/B increased until 2002, after which there has been a gradual decline.

The biomass in the 1990 survey of Subdiv. 3Ps was low compared to 1989 and 1991. This may have artificially inflated the estimate of the C/B ratio in that year. If the biomass in 1990 is estimated to be between those of the adjacent years then the C/B ratio in that year would be 0.14.

SURPLUS PRODUCTION MODELLING

The Bayesian surplus production modelling was previously used in a recovery potential context for these stocks (Bailey 2012, Morgan et al 2011). Here it is explored in the context of an assessment for these stocks. The starting point was the models applied in the recovery potential assessment. Most of the exploration described here is of the effect of alternative priors on model fit.

The Schaefer (Schaefer 1954) form of a surplus production model used here is:

$$P_t = [P_{t-1} + r^*P_{t-1} (1 - P_{t-1}) - C_{t-1}/K] *\eta t$$

where P_{t-1} and C_{t-1} denote exploitable biomass (as a proportion of carrying capacity, K) and catch, respectively, for year t-1 (Meyer and Millar 1999a,b). K is the level of stock biomass at equilibrium prior to commencement of a fishery, r is the intrinsic rate of population growth, and ηt is a random variable describing stochasticity in the population dynamics (process error). The model utilizes biomass proportional to an estimate of K in order to aid mixing of the Markov Chain Monte Carlo (MCMC) samples and to help minimize autocorrelation between each state and K (Meyer and Millar 1999a,b).

An observation equation is used to relate the unobserved biomass, P_t, to the observations that have been made (e.g. through DFO RV surveys), I_t.

$$I_t = q^*P_t^*\varepsilon_t$$

where q is the catchability parameter, P_t is an estimate of the biomass proportional to K at time t, and ε_t is observation error.

Data explored were as follows (Table 5):

SA2 + Div.3K

(1) Landings – 1960-2010

(2) Canadian RV Survey Indices: Engels Trawl – 1978-1994

(3) Canadian RV Survey Indices: Campelen Trawl – 1995-2010

Subdiv. 3Ps

(1) Landings – 1960-2010

(2) Canadian RV Survey Indices: Engels Trawl – 1972-1995

(3) Canadian RV Survey Indices: Campelen Trawl – 1996-2010

Non-informative or vague priors were used for all parameters as the initial prior distributions (Table 6). Priors on the catchability (*q*) were uniform and broad. Uniform priors for observation error were limited to a lower bound equal to the coefficient of variation (CV) of each survey index. The upper bound was set at 3 times this CV (Swain et al. 2009). Priors on the process error were also broad and uniform.

Often, K is set to the stock biomass in the year prior to the onset of fishing (P_0; see Meyer and Millar 1999a). However, in the models used here, initial stock biomass was not assumed to be the virgin biomass as fishing began on these stocks prior to 1960. P_0 was allowed to vary between 0.5 and 1 (i.e. initial biomass was allowed to vary between K/2 and K). A lognormal distribution for K was specified here with a mean of 300 ('000t) and a standard deviation of 1000 ('000t) for both stocks. The upper and lower boundaries on K were large.

The prior for r was first based on the expert opinion that it is unlikely to vary greatly from that of cod in Newfoundland waters which has been estimated at 0.26 (Hutchings 1999). Previous work with the models (Bailey 2012) resulted in somewhat different priors for the two stocks. The prior for r was only vaguely informative, utilizing a mean with a very wide lognormal distribution about the mean. For SA2 + Div. 3K the initial prior on r was μ = 0.25 and std = 0.32 and for Subdiv. 3Ps the initial prior on r was set at μ = 0.15 and std = 1. 'For both stocks the posterior for r was restricted to values between 0.0001 and 3.

Starting with these initial models a series of models were fit where one prior at a time was changed. The model fit (including convergence criteria, residuals for predicted surveys, credible intervals and deviance information criteria (DIC)) and effect on parameter estimates were compared. A new model was then constructed based on these results. For SA2 + Div. 3K most model formulations were run for 200,000 iterations, a burn in of 100,000 iterations, and the results thinned to every 10th iteration. For Subdiv. 3Ps (which converged better than the SA2 + Div. 3K model) most formulations were run with 150,000 iterations, a burn in of 50,000 iterations, and the results thinned to every 10th iteration, although the final run had 300,000 iterations with 3 chains and a burn in of 200,000 iterations, and was thinned at every 20th interation.

RESULTS

SA2 + Div. 3K

Parameter estimates for SA2 + Div. 3K were influenced by the choice of prior for r. Use of a higher mean and more informative prior for r (mean = 0.4, std = 0.2, r ~ dlnorm (-1.03, 4.49)I(0.01,2)) resulted in a much higher estimate of r than for most runs (model 3) (Table 7). Use of the same mean but with a lower precision (model 4) resulted in an estimate more in keeping with the initial run. Any of the priors for r that were tested with a lower precision resulted in r less than 0.1, mostly near 0.05. The alternative priors tested for the error on the survey indices resulted in much lower DIC but resulted in a much higher process error relative to the observation error (equal to the observation error). The sensitivity of estimates to the choice of prior for r may mean that the utility of these models is less for SA2 + Div. 3K than for Subdiv. 3Ps (see below). A model was constructed using the tau on the surveys that gave the lowest DIC (from model 10 and 11). This gave a very low DIC (model 13) but there were concerns about the extremely small deviance and with the process error. In addition, the fishery is thought not to have been the main cause of the decline of the stock (Morgan et al. 2002) in which case a production model would not be expected to be a good description of stock history.

As a result of these concerns, the surplus production modeling was not thought to be a good indicator of stock status at this time and no further results are presented here.

Subdiv. 3Ps

Parameter estimates for Subdiv. 3Ps American plaice were relatively stable, particularly the median for maximum sustainable yield (MSY) which varied from 3,500 to 5,800 tons and for most models was between 4,000 and 5,000 tons (Table 8). All formulations show a similar stock history and show that the current stock size is well below the biomass giving maximum sustainable yield (B_{msy}). However, credible intervals on Fratio (F/fishing mortality giving the maximum sustainable yield, F_{msy}) become very large, indicating that this formulation would not be good for assessment purposes. Use of a higher mean and more informative prior for r (mean = 0.4, std = 0.2, r ~ dlnorm(-1.03,4.49)I(0.01,2)) resulted in a higher estimate of r than for most runs but did not result in much change in the DIC.

Survey coverage was poor in many years prior to 1980 and the Engel time series is converted from original Yankee trawl units from 1972 to 1980. Residuals revealed a poor model fit to the first part of the Engel time series. However, starting data during the Engel time series from 1983 results in very large credible intervals on Fratio (F/F_{msy}), indicating that this formulation would not be good for assessment purposes (Model 13). Therefore, model 18 (the model with the best combination of convergence statistics, DIC and credible intervals when run on all the data) was run with survey data extending only to 1980. This model formulation used landings from 1960 to 2010, Engel survey data from 1980 to 1995, and Campelen survey data from 1996 to 2010 (with the exception of 2006 when the survey was incomplete). Its priors are given in Table 9 and diagnostics/results in Fig. 30-46. The diagnostics indicate that the model has converged and that process error is low compared to observation error and with little trend over time. Posteriors were updated based on the priors although there may be some influence of the prior for K on its posterior. There should be further exploration of the effect of priors. The survey indices were reasonably predicted (i.e. residuals small and unpatterned). Convergence diagnostics (posterior density of chains, Gelman-Rubin shrink factors, sampler running means, sampler lag autocorrelations) all indicate acceptable convergence.

Production models estimate relative levels of biomass and fishing mortality more precisely than absolute levels. This means that the ratio of biomass to the B_{msy} (Bratio) and the ratio of fishing mortality to the F_{msy} (Fratio) are more precise than biomass and fishing mortality themselves. For this reason, stock trajectories and reference points are usually reported as these ratios and status determined relative to F_{msy} and B_{msy}, with the biomass limit reference point set as a percentage of B_{msy}. Consistent with the DFO PA policy (DFO 2009), B_{lim} is 40% B_{msy}, the upper stock reference is 80% B_{msy} and F_{lim} (the removals reference point) is F_{msy}. Stock status relative to these reference points was estimated from the model.

Stock size estimated from the surplus production model decreased fairly steadily from the late 1960s to a low in 1993 of less than 10% of B_{msy}. Biomass has been increasing slowly since 1993; however, current biomass is 50% of B_{lim} and therefore the stock is in the Critical Zone (Fig. 44). Taking uncertainty into account, the probability of being below B_{lim} is high (0.94). Fishing mortality reached a peak in 1991 after which it declined for several years. Fishing mortality increased again to above F_{msy} in the early 2000s when landings exceed 1000 t annually. It has since declined and current median fishing mortality is estimated to be 64% of F_{lim} (Fig. 45). The probability of being above F_{lim} is relatively low (0.2).

The trajectory of B/B_{msy} and F/F_{msy} are plotted together on the proposed PA framework in Fig. 46. When stock biomass was above B_{msy} and fishing mortality was below F_{msy} the stock increased. Fishing mortality was above F_{msy} for many years, resulting in a steady decline in stock biomass. In the last few years fishing mortality has been below F_{msy} and stock size has increased, although it remains well below B_{lim}.

CONCLUSIONS

Directed fisheries for American Plaice in SA2 + Div. 3K remain under moratorium, and biomass and abundance indices (from RV surveys) are at low levels. It was not possible to use an analytical model of population dynamics for American Plaice in SA2 + Div. 3K at this time. Therefore an empirical reference point based on stock/recruit (S/R) scatter from the RV survey indicate that the most recent estimate of survey SSB (2009) is at 24% of B_{lim}.

Similarly fisheries remain under moratorium for American Plaice in Subdiv. 3Ps as well, with an increase in biomass and abundance indices from 1992 to 2011; current biomass is at 25% and abundance at 52% of the average of the mid-1980s. A Bayesian Surplus Production Model was carried out using prior information on r and K and catch data from 1960 to 2010 and RV survey data from 1980 to 2012 to produce limit reference points, B_{lim} (40% B_{msy}), 80% B_{msy} (an upper stock reference point), and F_{lim} (F_{msy}). Stock size estimated from the surplus production model decreased fairly steadily from the late 1960s to a low in 1993; biomass has been increasing slowly since 1993; however, current biomass is 50% of B_{lim} and therefore the stock is in the Critical Zone of the DFO PA framework. Taking uncertainty into account, the probability of being below B_{lim} in the most recent year is high (0.94). F_{lim} has declined since the early 2000s and current median fishing mortality is estimated to be 64% of F_{lim}. The probability of being above F_{lim} is relatively low (0.2).

LRPs for American Plaice in SA2 + Div. 3K and Subdiv. 3Ps may be revised as more data become available. Estimates of SSB, recruitment and mortality from DFO surveys were not available beyond 2009 for this meeting due to a backlog in age interpretation of samples.

REFERENCES

Bailey, J.A. 2012. Bayesian Surplus Production modelling for American Plaice (*Hippoglossoides platessoides*). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/036 ii + 144 p.

DFO. 2009. A Fishery Decision-Making Framework Incorporating the Precautionary Approach (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm).

Dwyer, K.S., Brodie, W.B., and Morgan, M.J. 2003. An assessment of the American plaice stock in NAFO Subarea 2 and Division 3K. Can. Sci. Advis. Sec. Res. Doc. 2003/095. ii + 39 p.

Hutchings, J.A. 1999. Influence of growth and survival costs of reproduction on Atlantic cod, *Gadus morhua*, population growth rate. Can. J. Fish. Aquat. Sci. 56: 1612-1623.

Julious, S.A. 2001. Inference and estimation in a change point regression problem. The Statistician 50: 51-61.

Meyer, R., and Millar, R.B. 1999a. Bayesian stock assessment using a state-space implementation of the delay difference model. Can. J. Fish. Aquat. Sci. 56: 37-52.

Meyer, R. and Millar, R.B. 1999b. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56: 1078-1086

Morgan, M. J., Brodie, W.B., Bowering, W.R., Maddock Parsons, D., and Orr, D.C. 1998. Results of data conversions for American Plaice in Div. 3LNO from comparative fishing trials between the Engel otter trawl and the Campelen 1800 shrimp trawl. NAFO SCR Doc. No. 70. Serial No. N3062. 10 p.

McCallum, B.R. and Walsh, S.J. 1996. Groundfish survey trawls used at the Northwest Atlantic Fisheries Centre, 1971 to present. NAFO SCR Doc. 96/50.

Morgan, M.J. and Brodie, W.B. 2000. Results of data conversions for American plaice in Div. 2J and 3K from comparative fishing trials between the Engel otter trawl and the Campelen 1800 shrimp trawl. DFO Atl. Fish. Res. Doc. 00/132.

Morgan, M.J., Brodie, W.B., and Shelton, P.A. 2005. An assessment of American Plaice in NAFO Subdivision 3Ps. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/069. ii + 40 p.

Morgan, M.J., Bailey, J., Healey, B.P., Maddock Parsons, D., and Rideout, R. 2011. Recovery potential assessment of American Plaice (*Hippoglossoides platessoides*) in Newfoundland and Labrador. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/047. iv + 32 p.

Morgan, M.J., Brodie, W.B., and Kulka, D.W. 2002. Was over exploitation the cause of the decline of the American plaice stock off Labrador and northeast Newfoundland? Fisheries Research 57: 39-49.

Orr, D., Veitch, P., Sullivan, D. Firth J. Peters, C., and Inkpen, T. 2010. Groundfish by-catch within the northern shrimp fishery off the eastern coasts of Newfoundland and Labrador over the years 2007-2009. NAFO SCR Doc. 10/45.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bull. Inter.-Am. Trop. Tuna Comm. 1: 27–56.

Swain, D.P., Jonsen, I.D., Simon, J.E., and Myers, R.A. 2009. Assessing threats to species-at-risk using stage-structured state-space models: mortality trends in skate populations. Ecol. App. 19: 1347-1364.

Warren, W.G. 1996. Report on the comparative fishing trial between the *Gadus Atlantica* and the *Teleost*. NAFO SCR Doc. 96/28.

Table 1. Total reported catch (t) of American Plaice in SA2 + Div. 3K.

Year	Total Reported Catch (t)	Year	Total Reported Catch (t)
1960	16	1986	3018
1961	67	1987	1063
1962	64	1988	953
1963	1421	1989	4248
1964	3068	1990	1825
1965	5558	1991	510
1966	2949	1992	104
1967	3591	1993	77
1968	5951	1994	16
1969	6902	1995	28
1970	12686	1996	16
1971	5348	1997	9
1972	9121	1998	2
1973	5140	1999	7
1974	5620	2000	67
1975	5747	2001	137
1976	6107	2002	100
1977	7525	2003	34
1978	3522	2004	17
1979	2965	2005	30
1980	5040	2006	60
1981	7545	2007	23
1982	1900	2008	10
1983	1633	2009	10
1984	1175	2010	22
1985	753	2011	17

Table 2. Total reported catch (t) of American Plaice in Subdiv. 3Ps.

Year	Total Reported Catch (t)	Year	Total Reported Catch (t)
1960	887	1986	5130
1961	1455	1987	5331
1962	1024	1988	4406
1963	754	1989	2957
1964	1542	1990	4130
1965	2022	1991	4395
1966	3406	1992	2331
1967	4494	1993	751
1968	14280	1994	122
1969	6491	1995	85
1970	12328	1996	114
1971	7182	1997	243
1972	6538	1998	423
1973	14769	1999	654
1974	6598	2000	650
1975	4211	2001	1010
1976	5458	2002	1128
1977	4605	2003	1033
1978	3658	2004	818
1979	3666	2005	776
1980	2935	2006	539
1981	3217	2007	524
1982	2186	2008	533
1983	1726	2009	573
1984	2963	2010	469
1985	4220	2011	286

Table 3. Biomass (000 t) and abundance (millions) estimates for Div. 2H and Div. 2J3K from fall RV surveys. NC = not converted; NS = not surveyed

	Div. 2H		Div. 2J3K	
Year	Biomass	Abundance	Biomass	Abundance
1978	NC	NC	332.4	1711.3
1979	NC	NC	194.7	856.8
1980	NC	NC	232.0	792.4
1981	NC	NC	254.9	788.4
1982	NC	NC	308.1	1015.9
1983	NC	NC	305.5	885.3
1984	NC	NC	235.7	740.6
1985	NC	NC	175.8	598.7
1986	NC	NC	165.8	617.0
1987	NC	NC	114.9	445.9
1988	NC	NC	118.2	436.0
1989	NC	NC	127.5	533.2
1990	NC	NC	76.2	299.8
1991	NC	NC	44.5	218.1
1992	NC	NC	22.5	136.2
1993	NC	NC	25.2	180.8
1994	NC	NC	20.6	170.2
1995	NC	NC	13.4	127.3
1996	0.2	2.3	17.1	148.3
1997	1.0	4.7	16.6	127.9
1998	0.9	8.9	19.5	125.9
1999	1.1	17.2	16.6	91.4
2000	NS	NS	14.5	73.0
2001	0.7	8.8	12.1	56.3
2002	NS	NS	6.8	40.3
2003	NS	NS	8.0	51.5
2004	1.5	20.0	9.8	71.5
2005	NS	NS	11.5	65.9
2006	1.8	32.4	19.9	114.2
2007	NS	NS	31.6	144.2
2008	1.6	17.4	23.1	113.8
2009	NS	NS	25.9	100.8
2010	3.0	20.1	20.3	101.9
2011	4.1	42.1	24.9	174.9

Table 4. Biomass (000 t) and abundance (millions) estimates for Subdiv. 3Ps from spring RV surveys. NS = not surveyed.

	Subdiv. 3Ps	
Year	Biomass	Abundance
1983	119.6	519.0
1984	55.5	217.3
1985	125.4	312.8
1986	73.0	293.4
1987	77.9	289.0
1988	62.5	215.5
1989	38.5	149.2
1990	13.2	52.3
1991	32.9	159.0
1992	16.0	54.6
1993	11.3	41.5
1994	10.6	43.3
1995	12.5	49.8
1996	12.4	92.1
1997	8.6	45.5
1998	14.4	52.6
1999	14.6	69.2
2000	21.5	137.3
2001	18.3	82.0
2002	15.9	54.8
2003	17.2	70.1
2004	14.0	68.3
2005	24.2	118.5
2006	NS	NS
2007	22.4	107.0
2008	31.2	253.3
2009	20.4	167.2
2010	22.0	182.7
2011	25.0	181.5

Table 5. Data used in Bayesian surplus production modelling. Note that for Subdiv. 3Ps the accepted model used Engel data starting in 1980.

	SA2 + Div. 3K			Subdiv. 3Ps		
Year	Landings	Engel	Campelen	Landings	Engel	Campelen
1960	0.016			0.887		
1961	0.067			1.455		
1962	0.064			1.024		
1963	1.421			0.754		
1964	3.068			1.542		
1965	5.558			2.022		
1966	2.949			3.406		
1967	3.591			4.494		
1968	5.951			14.28		
1969	6.902			6.491		
1970	12.686			12.328		
1971	5.348			7.182		
1972	9.121			6.538	33.8	
1973	5.140			14.769	13.7	
1974	5.620			6.598	13	
1975	5.747			4.211	1.9	
1976	6.107			5.458	37.8	
1977	7.525			4.605	9.1	
1978	3.522	115.20		3.658	3.8	
1979	2.965	68.92		3.666	7.2	
1980	5.040	90.82		2.935	35.8	
1981	7.545	104.48		3.217	26	
1982	1.900	115.07		2.186	39.1	
1983	1.633	126.98		1.726	45.2	
1984	1.175	93.45		2.963	22.5	
1985	0.753	67.58		4.22	64.5	
1986	3.018	67.39		5.13	30.4	
1987	1.063	45.24		5.331	33.9	
1988	0.953	50.68		4.406	27.3	
1989	4.248	46.38		2.957	17	
1990	1.825	24.49		4.13	5.8	
1991	0.510	12.42		4.395	12.1	
1992	0.104	5.52		2.331	6.8	
1993	0.077	5.51		0.751	4.6	
1994	0.016	3.82		0.122	4.2	
1995	0.028		13.42	0.085	3.9	
1996	0.016		17.14	0.114		12.4
1997	0.009		16.63	0.243		8.6

Table 5 (cont). Data used in Bayesian surplus production modelling. Note that for Subdiv. 3Ps the accepted model used Engel data starting in 1980.

	SA2 + Div. 3K			Subdiv 3Ps		
Year	Landings	Engel	Campelen	Landings	Engel	Campelen
1998	0.002		19.49	0.423		14.36
1999	0.007		16.56	0.654		14.6
2000	0.067		14.52	0.65		21.5
2001	0.137		12.13	1.01		18.3
2002	0.098		6.82	1.128		15.9
2003	0.034		8.01	1.033		17.2
2004	0.017		9.81	0.818		14
2005	0.030		11.50	0.776		24.2
2006	0.060		19.92	0.539		
2007	0.023		31.59	0.524		22.4
2008	0.013		23.05	0.533		31.2
2009	0.010		25.87	0.512		20.4
2010	0.022		20.26	0.468		22

Table 6: Initial priors for parameters used in surplus production models for SA2 + Div. 3K and Subdiv. 3Ps.

NAFO	Parameter	Description	Prior Distribution
SA2 + Div. 3K	K	Carrying Capacity	normal (μ=300kt, std=1000kt)
	r	Population growth rate	normal (μ=0.25, std=0.32)
	logq.eng	Catchability, Canadian Engels Trawl Series	U (0,10)
	logq.cam	Catchability, Canadian Campelen Trawl Series	U (0,10)
	Sigma	Process error	U (0,10)
	tau.eng	Observation error, Canadian Engels Trawl	U (0.68,2.03)
	tau.cam	Observation error, Canadian Campelen Trawl	U (0.41,1.24)
Subdiv. 3Ps	K	Carrying Capacity	normal (μ=300kt, std=1000kt)
	r	Population growth rate	normal (μ=0.15, std=1)
	logq.eng	Catchability, Canadian Engels Trawl Series	U(0,10)
	logq.cam	Catchability, Canadian Campelen Trawl Series	U (0,10)
	Sigma	Process error	U (0,10)
	tau.eng	Observation error, Canadian Engels Trawl	U (0.79,2.38)
	tau.cam	Observation error, Canadian Campelen Trawl	U (0.39,1.17)

Table 7. Parameter estimates and Deviance Information Criteria (DIC) for models using different priors for SA2 + Div. 3K. Priors for initial model are given in table 6.

2+3K							
		r	K	Fmsy	Bmsy	MSY	DIC
1	Initial model	0.054(0.015-0.151)	148.1(102.1-527.1)	0.027(0.0075-0.07528)	74.05(51.04-263.5)	2.114(0.597-8.545)	245.005
2	r ~ dlnorm(-3.81,0.262)I(0.0001,3)	0.013(4.281E-4-0.089)	171.7(103.5-629.3)	0.0065(2.11E-4-0.045)	85.83(51.75-314.6)	0.6336(0.021-4.58)	244.419
3	r ~ dlnorm(-1.03,4.49)I(0.01,2)	0.1443(0.0718-0.2838)	138.0(101.2-450.9)	0.07213(0.0359-0.1419)	69.0(50.62-225.5)	5.281(2.231-18.6)	238.989
4	r ~ dlnorm(-1.91,0.51)I(0.0001,3)	0.0394(0.0053-0.1284)	153.7(102.4-536.2)	0.0197(0.0026-0.0642)	76.85(51.21-268.1)	1.633(0.228-7.242)	245.252
5	survey q's dunif(0,5)	0.054(0.015-0.1475)	148.4(102.0-527.8)	0.027(0.0075-0.074)	74.21(51.0-263.9)	2.15(0.6004-8.703)	245.663
6	K~dlnorm(6.21,0.3)I(100,1500)	0.051(0.0145-0.1437)	171.3(102.9-767.0)	0.026(0.0073-0.072)	85.67(51.45-83.5)	2.308(0.6163-11.17)	238.589
7	K~dlnorm(5.193,0.98)I(100,3000)	0.053(0.0149-0.1413)	156.6(102.2-508.8)	0.0260.0074-0.071)	78.29(51.11-254.4)	2.156(0.6241-8.444)	245.069
8	K~dlnorm(4.46,0.40)I(50,3000)	0.058(0.01568-0.161)	122.9(57.38-406.6)	0.02912(0.008-0.081)	61.46(28.69-203.3)	1.829(0.4762-6.923)	237.911
9	sigma ~ dunif(0,100)	0.053(0.01496-0.145)	150.2(102.2-538.5)	0.027(0.0075-0.0723)	75.11(51.09-269.3)	2.141(0.5932-8.704)	244.25
10	tau.eng~dunif(0.2,2.38)	0.057(0.01538-0.156)	157.8(102.3-530.9)	0.02841(0.008-0.0782)	78.88(51.15-265.5)	2.428(0.6076-8.817)	204.817
11	tau.cam~dunif(0.2,1.17)	0.056(0.01494-0.151)	170.2(102.6-638.9)	0.028(0.007-0.0757)	85.09(51.31-319.4)	2.542(0.639-9.893)	180.414
12	base with 3 chains more iterations	0.054(0.015-0.144)	145.6(101.8-489.6)	0.027(0.0075-0.07197)	72.81(50.89-244.8)	2.044(0.6003-8.345)	249.215
13	base but with tau from 10 and 11	0.0569(0.015-0.1537)	162.3(102.5-535.5)	0.02847(0.0075-0.07684)	81.15(51.25-267.7)	2.495(0.6172-8.963)	168.011

Table 8. Parameter estimates and Deviance Information Criteria (DIC) for models using different priors for Subdiv. 3Ps. Priors for initial model are given in Table 6.

3Ps							
		r	K	Fmsy	Bmsy	MSY	DIC
1	Initial model	0.1401(0.048-0.255)	114.9(100.5-285.1)	0.07007(0.024-0.1275)	57.47(50.23-142.6)	4.14(1.871-10.17)	281.783
2	r ~ dlnorm(-1.90,1)I(0.01,2)	0.1485(0.076-0.266)	114.9(100.5-230.2)	0.07425(0.03816-0.1328)	57.45(50.24-115.1)	4.357(2.546-9.86)	282.951
3	r ~ dlnorm(-1.03,4.49)I(0.01,2)	0.1938(0.1194-0.3436)	114.8(100.5-237.8)	0.09689(0.05972-0.1718)	57.42(50.24-118.9)	5.837(3.403-14.27)	281.401
4	survey q's dunif(0,5)	0.1401(0.048-0.255)	114.9(100.5-285.1)	0.07007(0.024-0.1275)	57.47(50.23-142.6)	4.14(1.871-10.17)	281.783
5	K~dlnorm(6.21,0.3)I(100,1500)	0.1383(0.02993-0.2598)	122.4(100.8-436.3)	0.06915(0.01497-0.1299)	61.22(50.38-218.1)	4.359(1.535-13.3)	276.777
6	K~dlnorm(4.46,0.40)I(50,3000)	0.1778(0.07753-0.322)	87.96(54.42-190.2)	0.08888(0.03876-0.161)	43.98(27.21-95.12)	3.923(2.008-7.596)	280.586
7	K~dlnorm(5.193,0.98)I(100,3000)	0.1416(0.0378-0.2585)	119.0(100.6-327.4)	0.07081(0.0189-0.1292)	59.51(50.32-163.7)	4.288(1.62-10.81)	279.325
8	sigma ~ dunif(0,100)	0.1433(0.04208-0.2611)	117.7(100.6-336.3)	0.07163(0.02104-0.1305)	58.83(50.3-168.2)	4.271(1.753-11.03)	279.357
9	tau.cam~dunif(0.2,2.38)	0.1377(0.0538-0.236)	114.5(100.5-273.7)	0.06887(0.02692-0.1181)	57.23(50.25-136.8)	4.033(2.051-9.086)	271.138
10	tau.eng~dunif(0.2,1.17)	0.1524(0.04618-0.295)	118.8(100.6-301.7)	0.07619(0.02309-0.1475)	59.42(50.3-150.8)	4.654(1.815-12.25)	278.761
11	new base with I(50,1500) on K						
	K~dlnorm(5.193,0.98) (X=300, std=400)						
	tau.cam~dunif(0.2,2.38)						
	tau.eng~dunif(0.2,1.17)	0.172(0.0754-0.3211)	92.92(55.64-242.0)	0.08599(0.0377-0.1606)	46.46(27.82-121.0)	3.954(2.062-9.487)	261.087
12	more iterations (200000)	0.172(0.07297-0.322)	93.48(56.15-250.8)	0.08608(0.03648-0.1608)	46.74(28.08-125.4)	3.988(2.069-9.568)	261.438
13	engels only to 1983	0.121(0.0067-0.225)	114.0(67.0-446.1)	0.0605(0.003366-0.1123)	56.98(33.5-223.0)	3.507(0.3854-8.08)	148.315
14	Same as new but K~dlnorm(4.46,0.4)	0.178(0.07998-0.34)	87.72(53.67-215.3)	0.08878(0.03999-0.1702)	43.86(26.83-107.7)	3.91(2.033-8.727)	263.357
15	Same as above but also old tau.cam	0.194(0.0769-0.369)	83.87(52.66-210.9)	0.09676(0.03842-0.1843)	41.94(26.33-105.5)	4.092(1.943-8.946)	276.225
16	Same as 14 but K I(35,1500)	0.1812(0.08341-0.3939)	86.97(43.11-191.8)	0.09062(0.0417-0.1969)	43.49(21.55-95.89)	3.894(1.947-8.028)	262.139
17	same as 14 but 3 chains	0.177(0.08141-0.3294)	88.39(53.69-199.0)	0.08845(0.04071-0.1647)	44.2(26.84-99.5)	3.926(2.063-7.865)	266.337
18	same as 17 but Engel data starting in 1980	0.1377(0.02761-0.2332)	101.4(63.51-241.7)	0.06884(0.0138-0.1166)	50.69(31.75-120.9)	3.576(0.9684-6.25)	185.166

Table 9. Priors for parameters used in 'preferred' formulation of the surplus production model for Subdiv. 3Ps.

NAFO	Parameter	Description	Prior Distribution
Subdiv. 3Ps	K	Carrying Capacity	normal (μ=300kt, std=400kt)
	r	Population growth rate	normal (μ=0.15, std=1)
	logq.eng	Catchability, Canadian Engels Trawl Series	U(0,10)
	logq.cam	Catchability, Canadian Campelen Trawl Series	U (0,10)
	Sigma	Process error	U (0,10)
	tau.eng	Observation error, Canadian Engels Trawl	U (0.2,1.17)
	tau.cam	Observation error, Canadian Campelen Trawl	U (0.2,2.38)

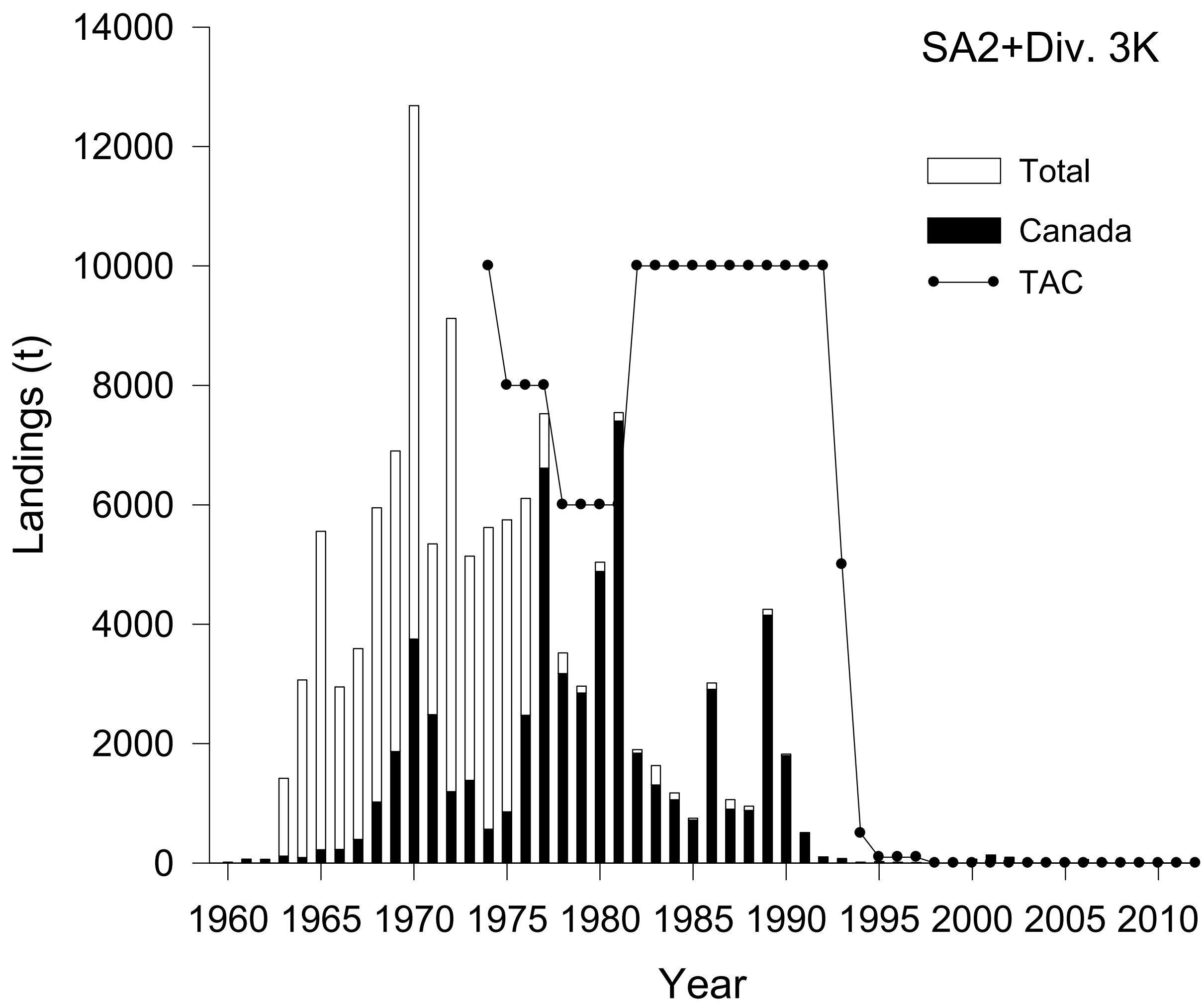


Figure 1. American Plaice landings (t) (1960-2011) and total allowable catch (TAC) (1974-2012) in SA2 + Div. 3K.

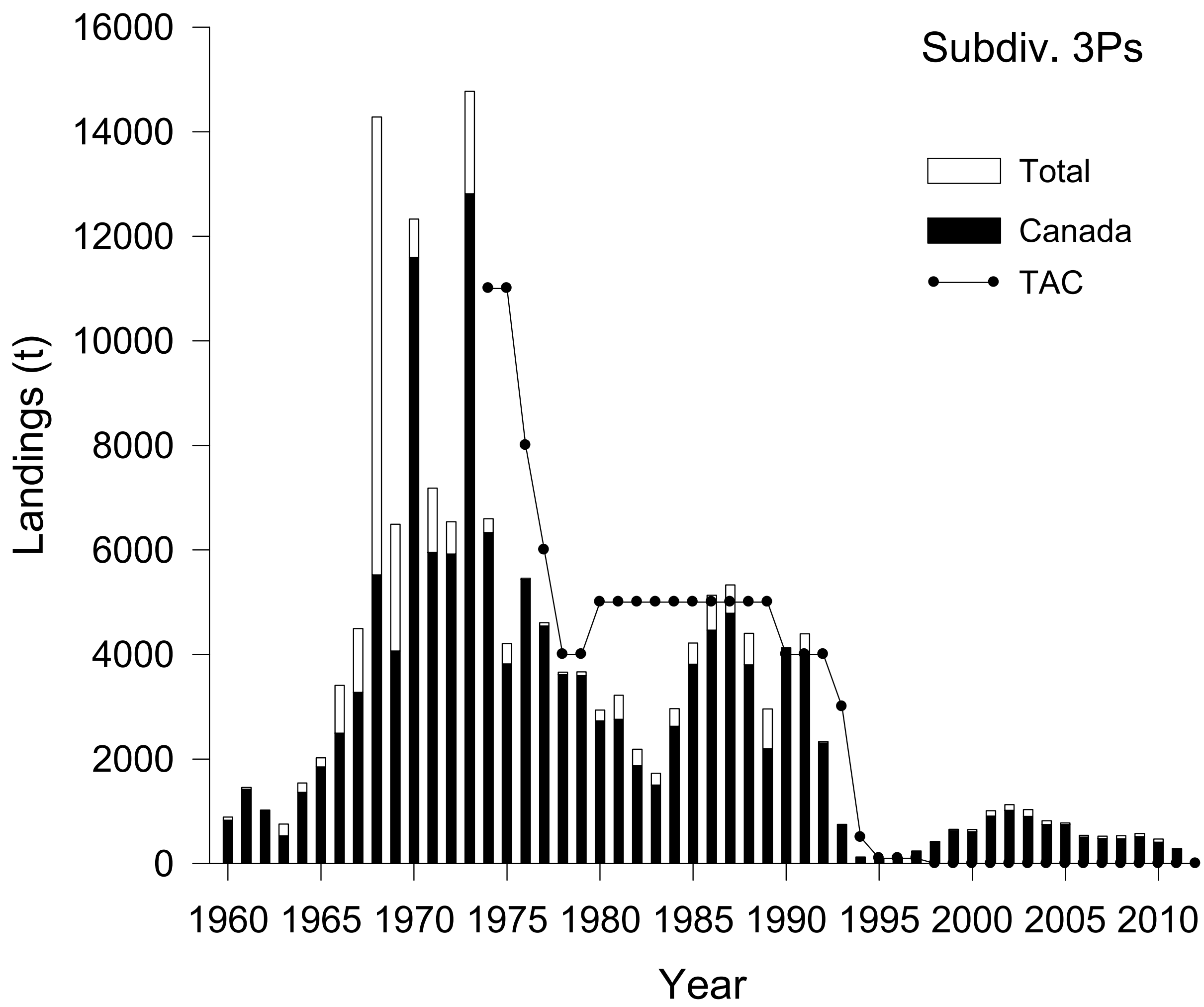


Figure 2. American Plaice catches (t) (1960-2011) and total allowable catch (TAC) (1974-2012) in Subdiv. 3Ps.

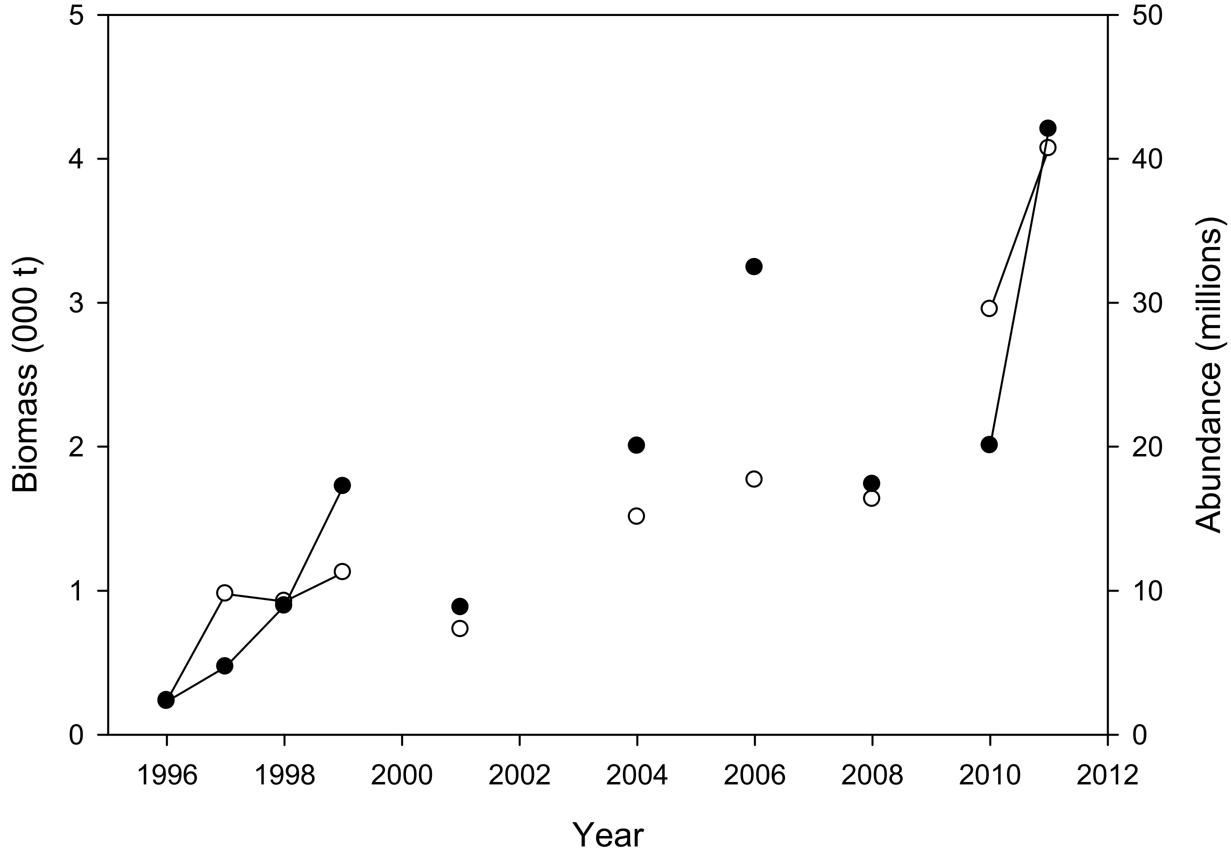


Figure 3. Biomass (000 t) and abundance (millions) indices of American Plaice from fall surveys, Div. 2H.

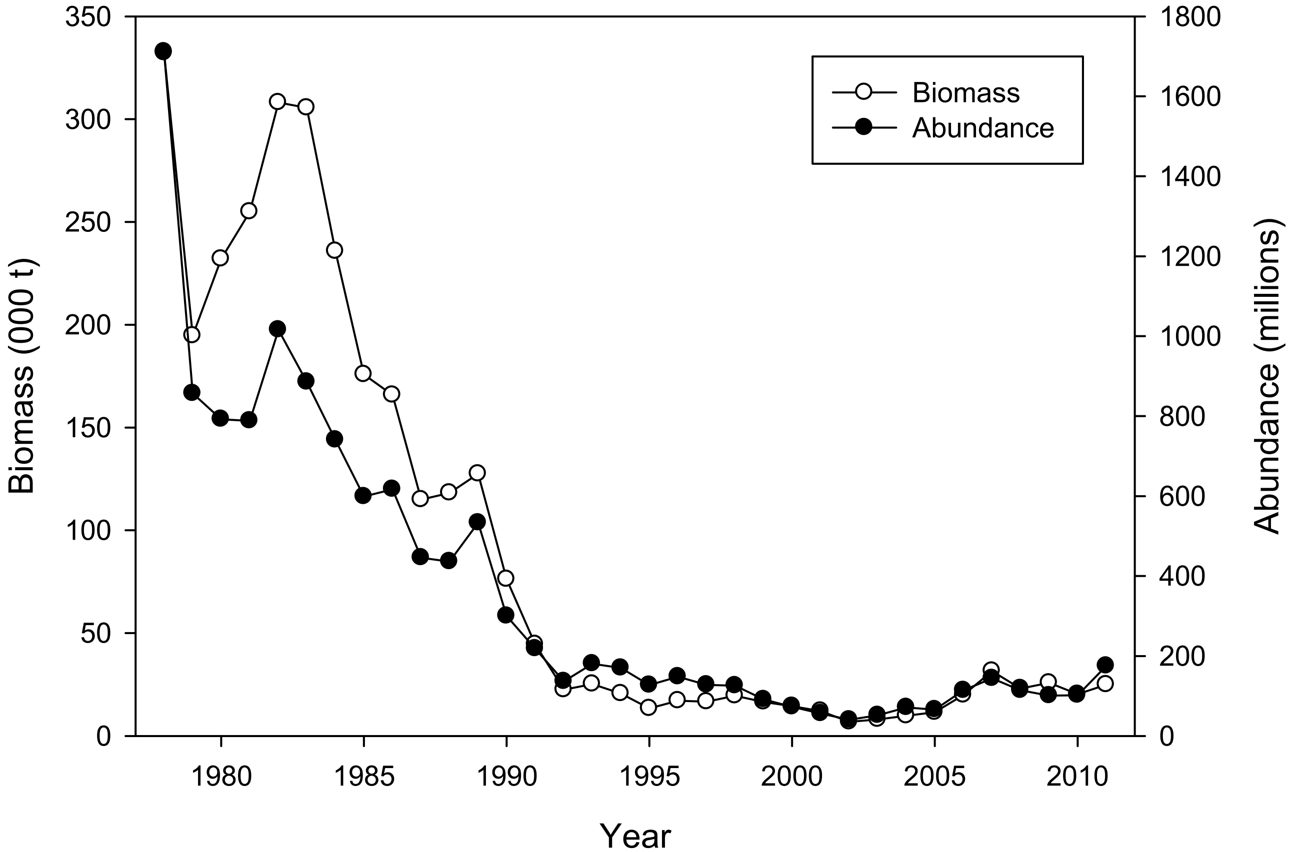


Figure 4. Biomass (000 t) and abundance (millions) indices of American Plaice from fall surveys, Div. 2J3K.

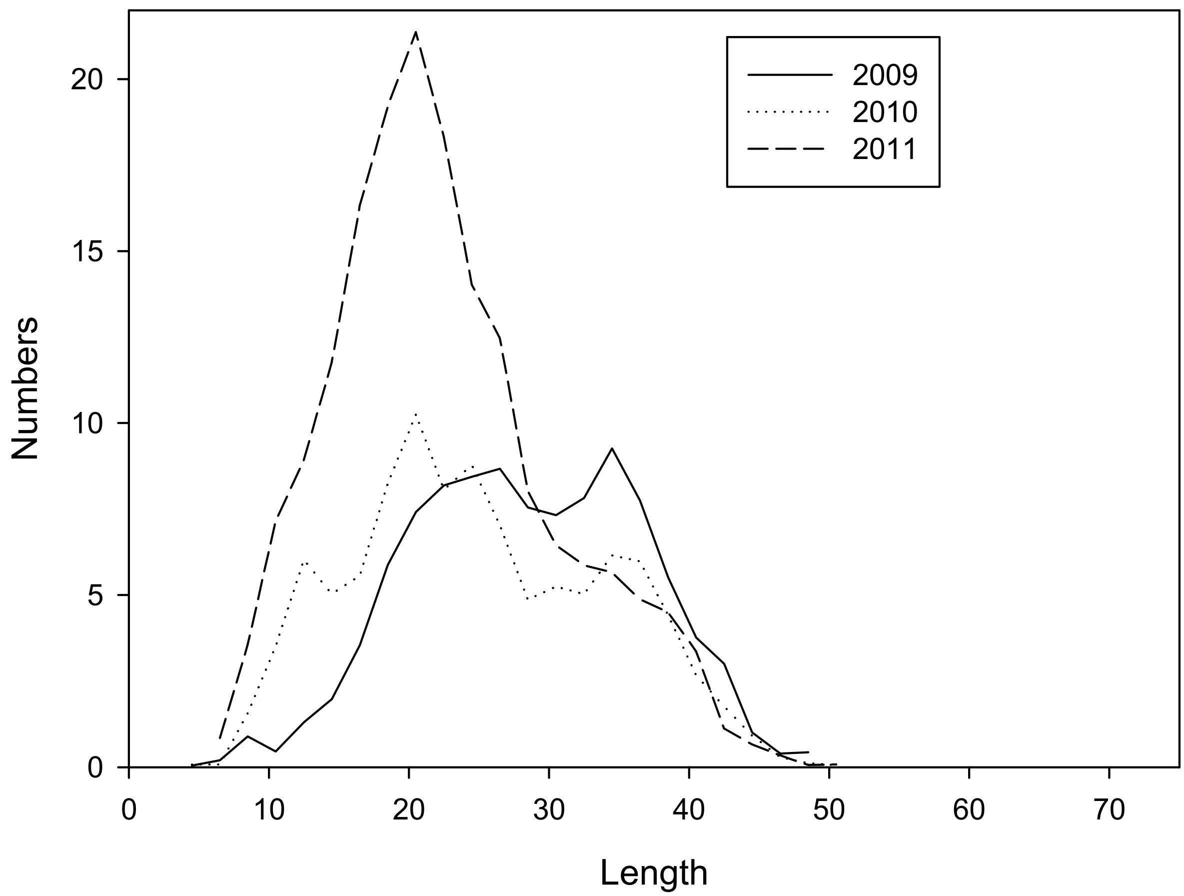


Figure 5. Numbers of American Plaice at length for 2009 to 2011 from fall surveys in Div. 2J3K.

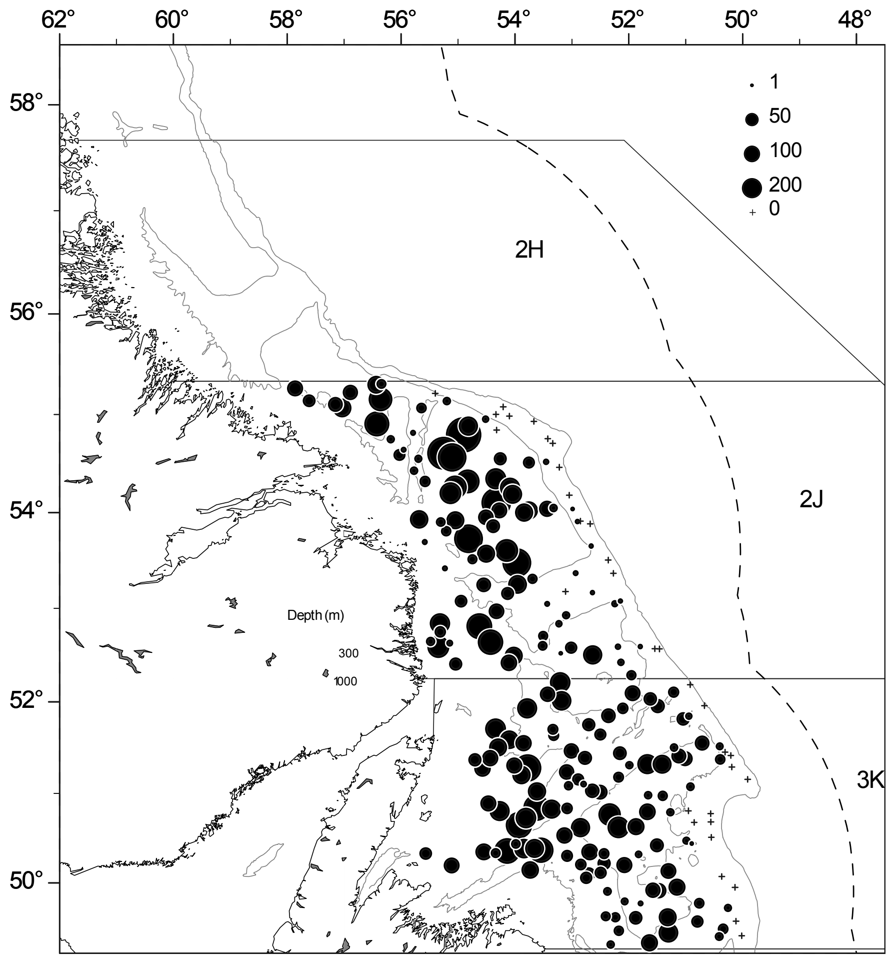


Figure 6. Distribution of American Plaice from the fall surveys in Div. 2HJ3K (number/tow) in 1981.

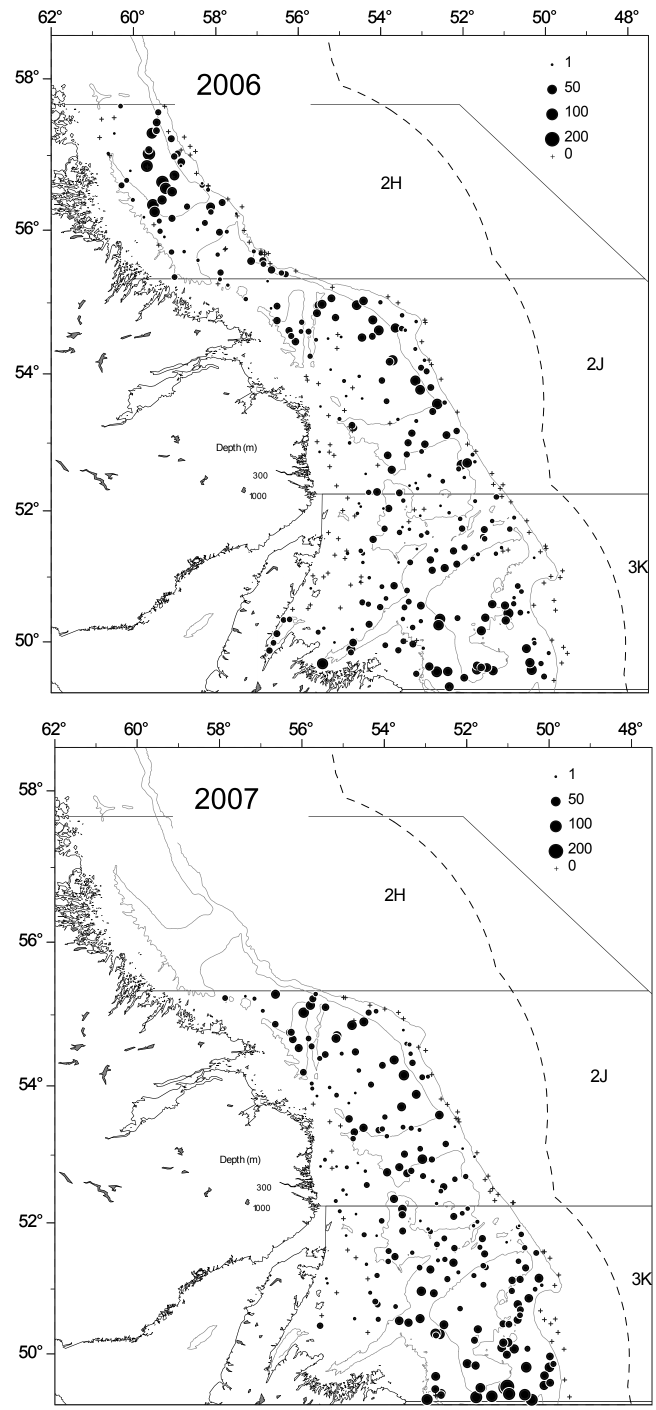
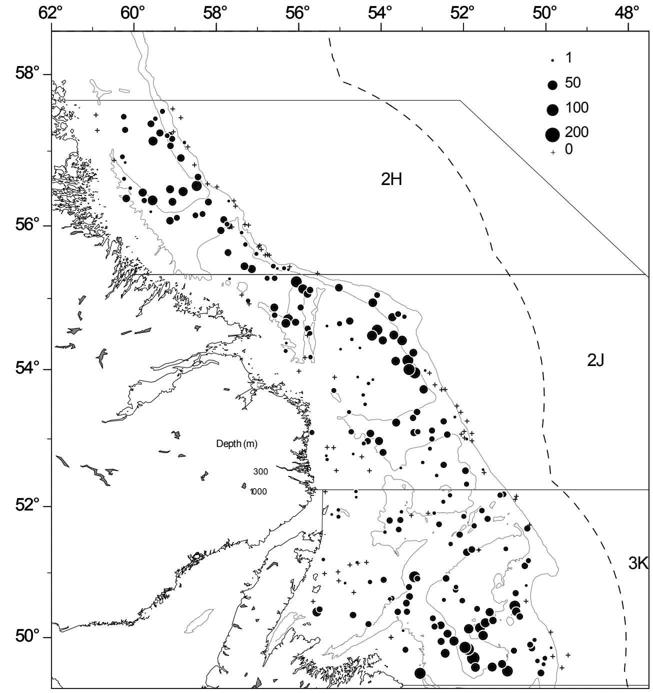


Figure 7a. Distribution of American Plaice from the fall surveys in Div. 2HJ3K (number/tow) from 2006 to 2009.

2008



2009

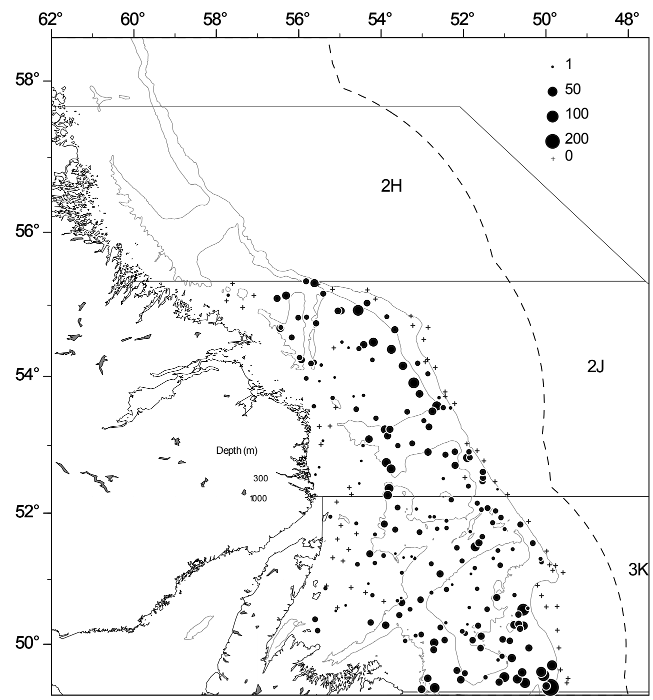
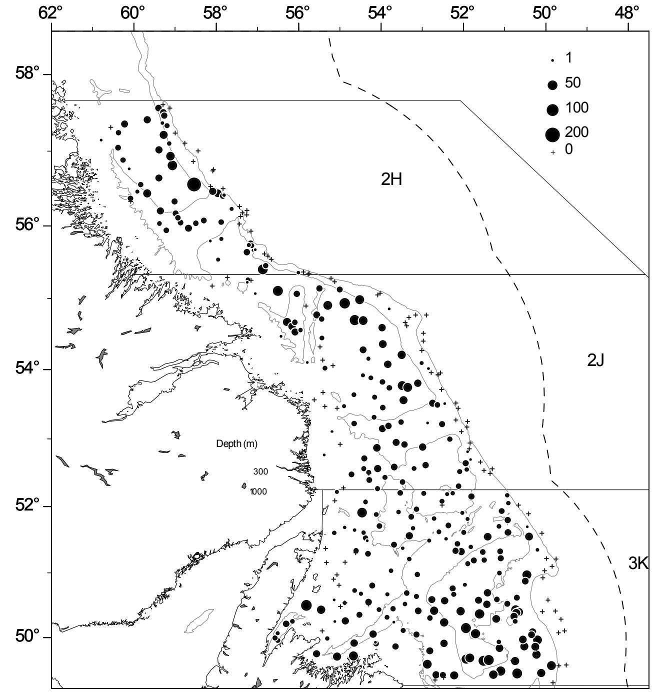


Figure 7b. Distribution of American Plaice from the fall surveys in Div. 2HJ3K (number/tow) from 2006 to 2009.

2010



2011

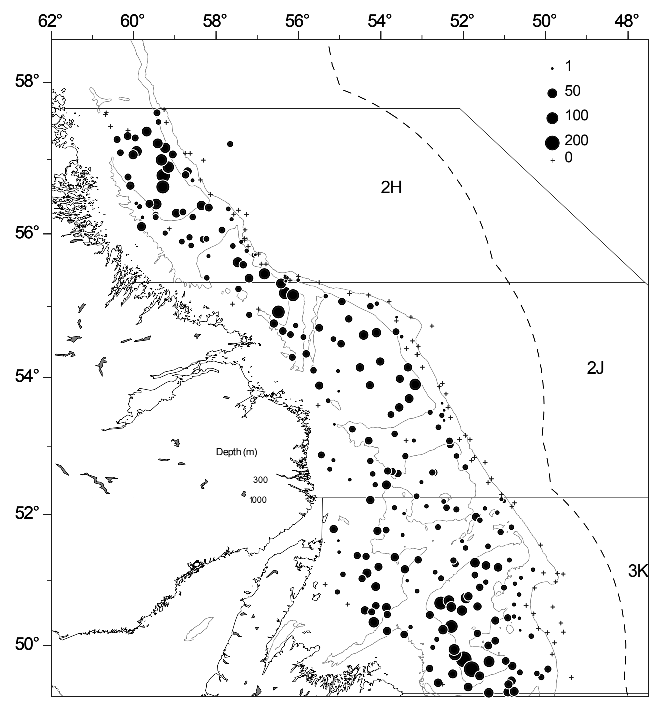


Figure 8. Distribution of American Plaice from the fall surveys in Div. 2HJ3K (number/tow) in 2010 and 2011.

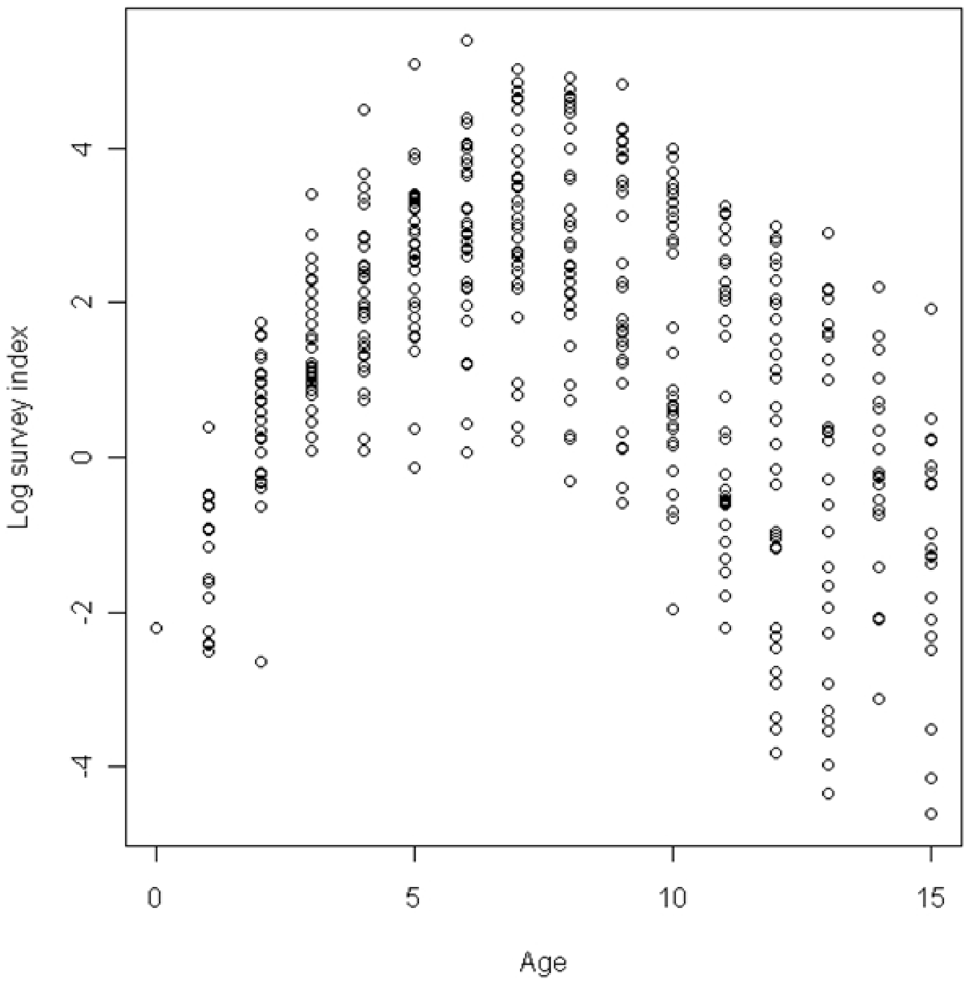


Figure 9. Plot of log survey index against age for ages 0 to 15 over the period 1978-2009 for American Plaice in SA2 + Div. 3K.

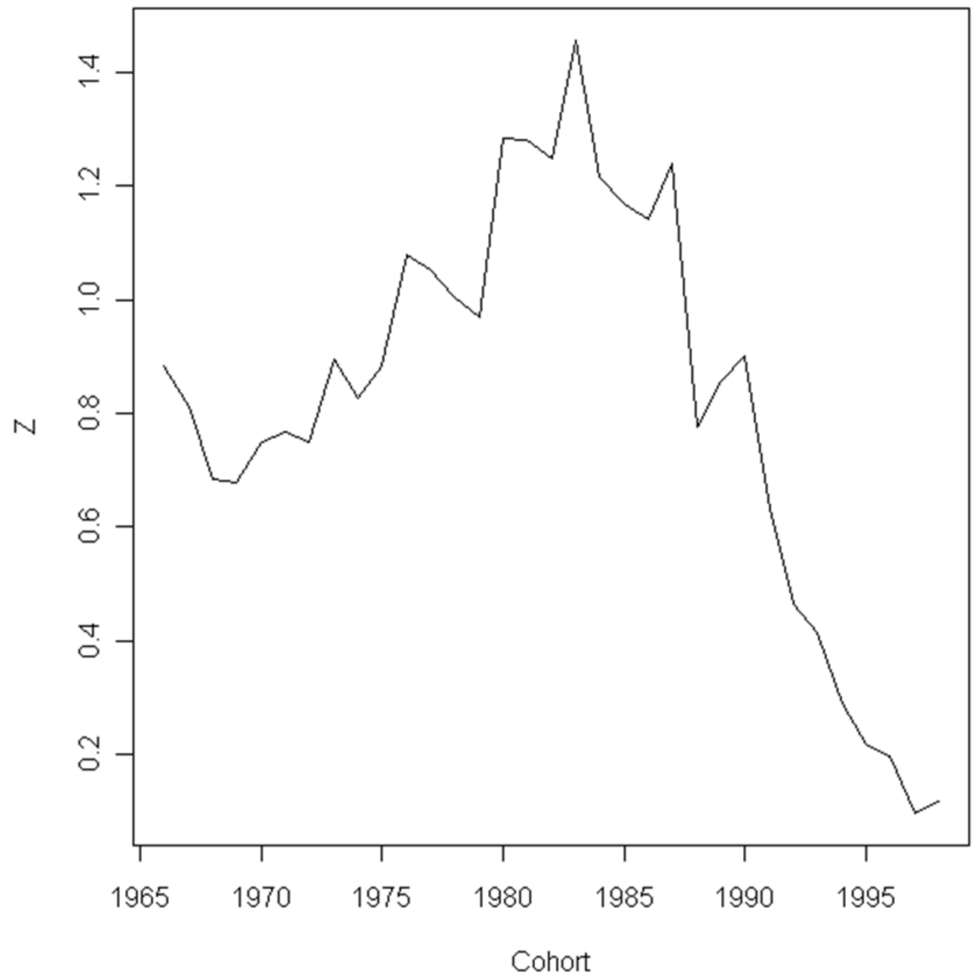


Figure 10. Estimates of cohort Z for SA2 + Div. 3K American Plaice based on the survey index. Estimates are negated so that higher values indicate increased mortality.

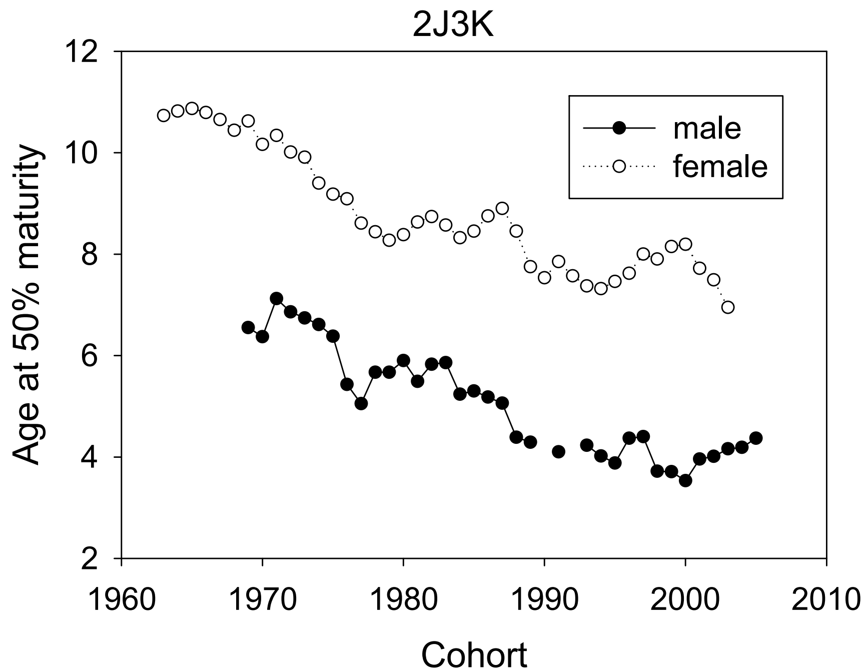


Figure 11. Age at 50% maturity for male and female American Plaice from SA2 + Div. 3K.

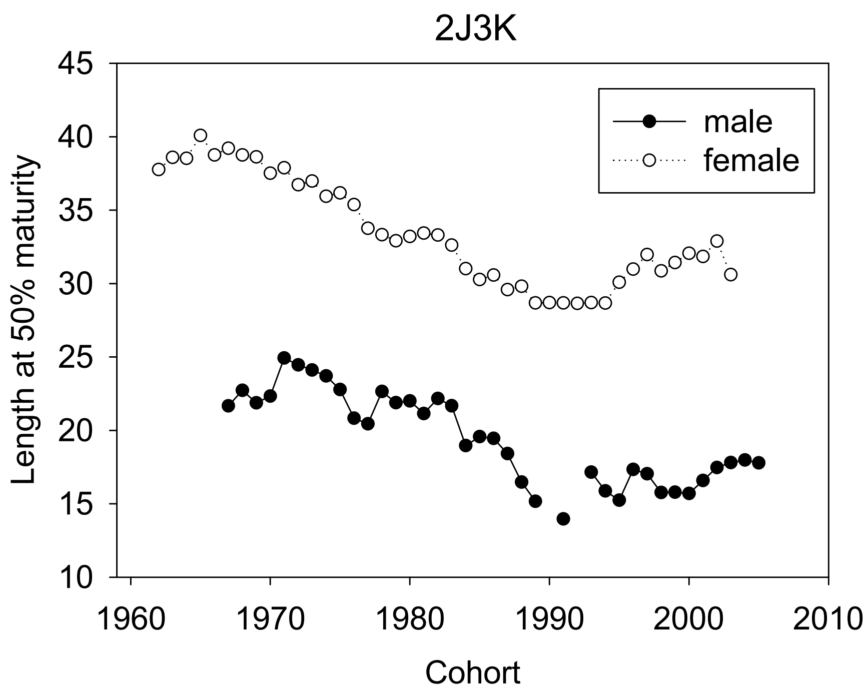


Figure 12. Length at 50% maturity for male and female American Plaice in SA2 + Div. 3K

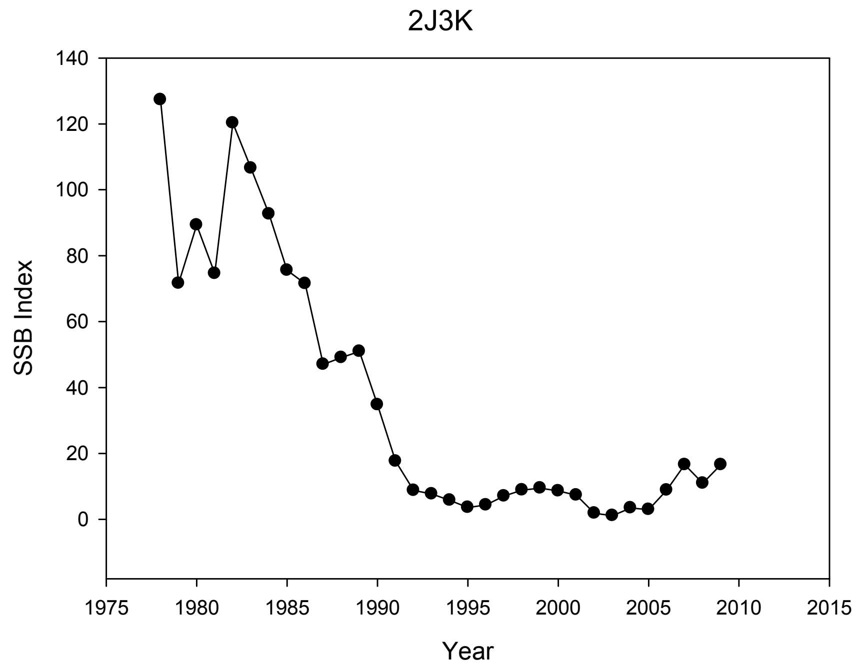


Figure 13. Index of spawning stock biomass derived from the research vessel surveys of SA2 + Div. 3K.

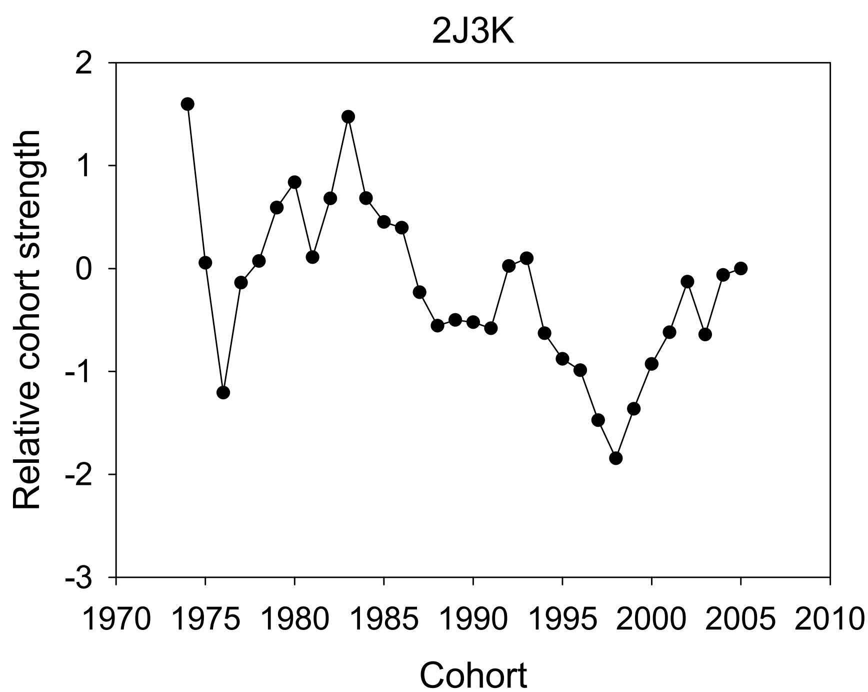


Figure 14. Recruitment as relative cohort strength from research vessel data for American Plaice in Div. 2J3K. Estimates are relative to the 2005 cohort.

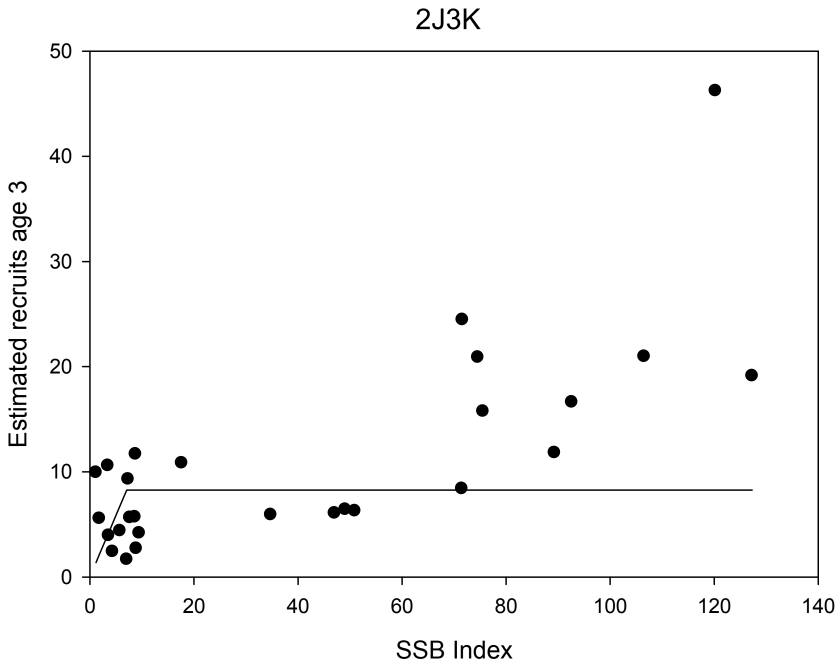


Figure 15. Recruitment and spawning stock biomass index estimated from the research vessel survey of SA2 + Div. 3K. The solid line gives the results of the segmented regression model fit to these data.

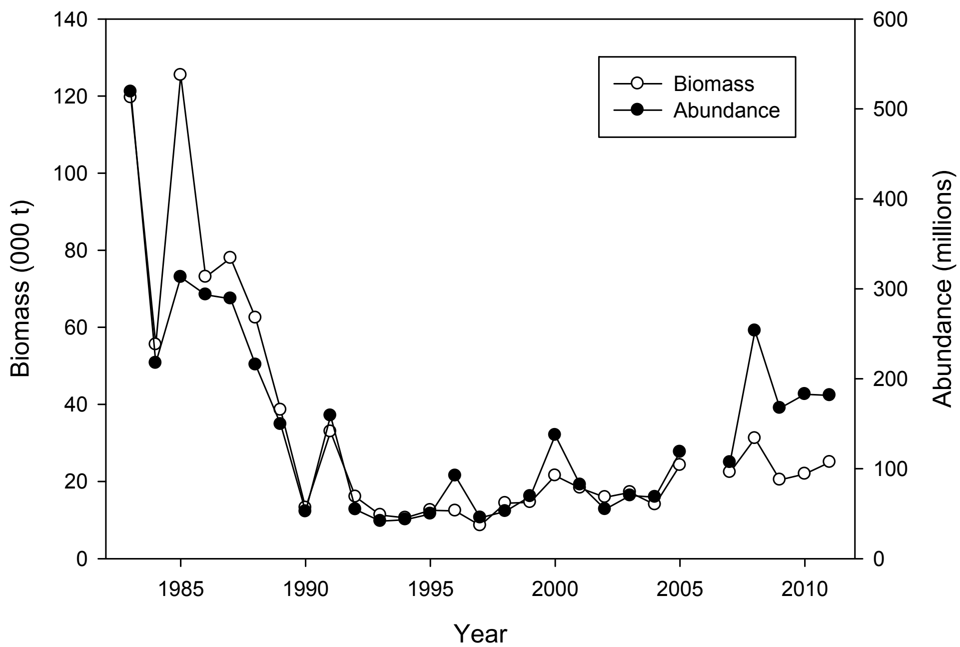


Figure 16. Biomass (000 t) and abundance (millions) indices of American Plaice from spring surveys, Subdiv. 3Ps.

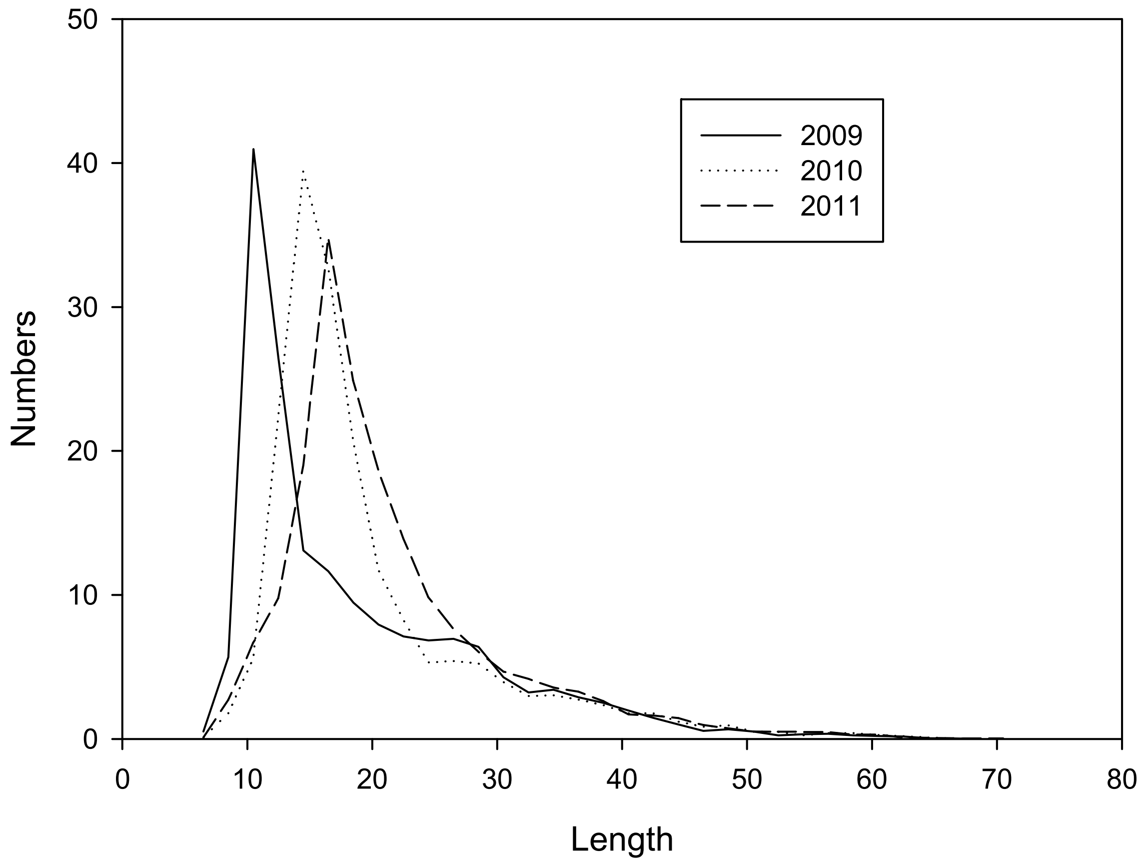


Figure 17. Numbers of American Plaice at length for 2009 to 2011 from spring surveys in Subiv. 3Ps.

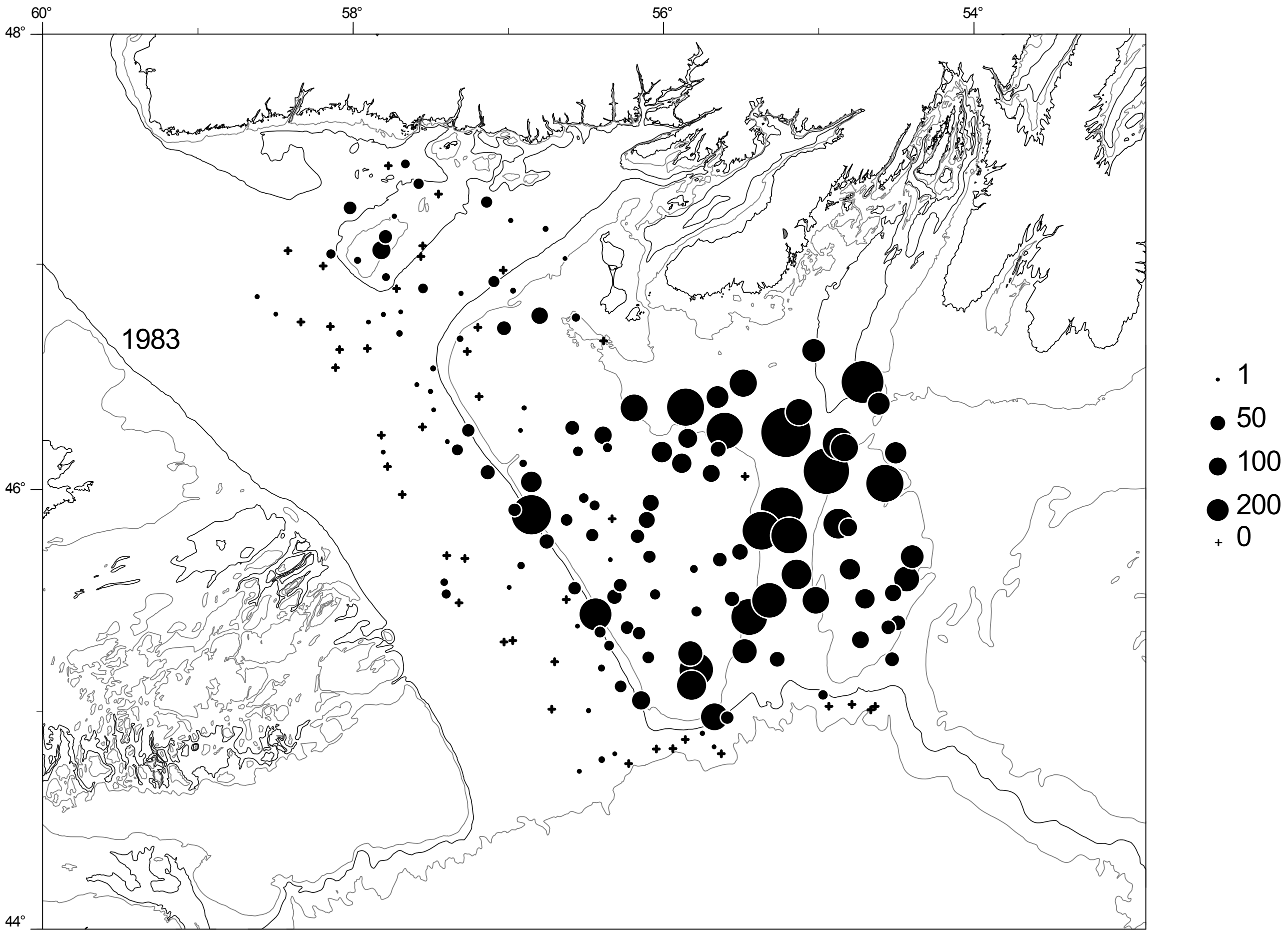


Figure 18. Distribution of American Plaice from the spring surveys in Subdiv. 3Ps (number/tow) in 1983.

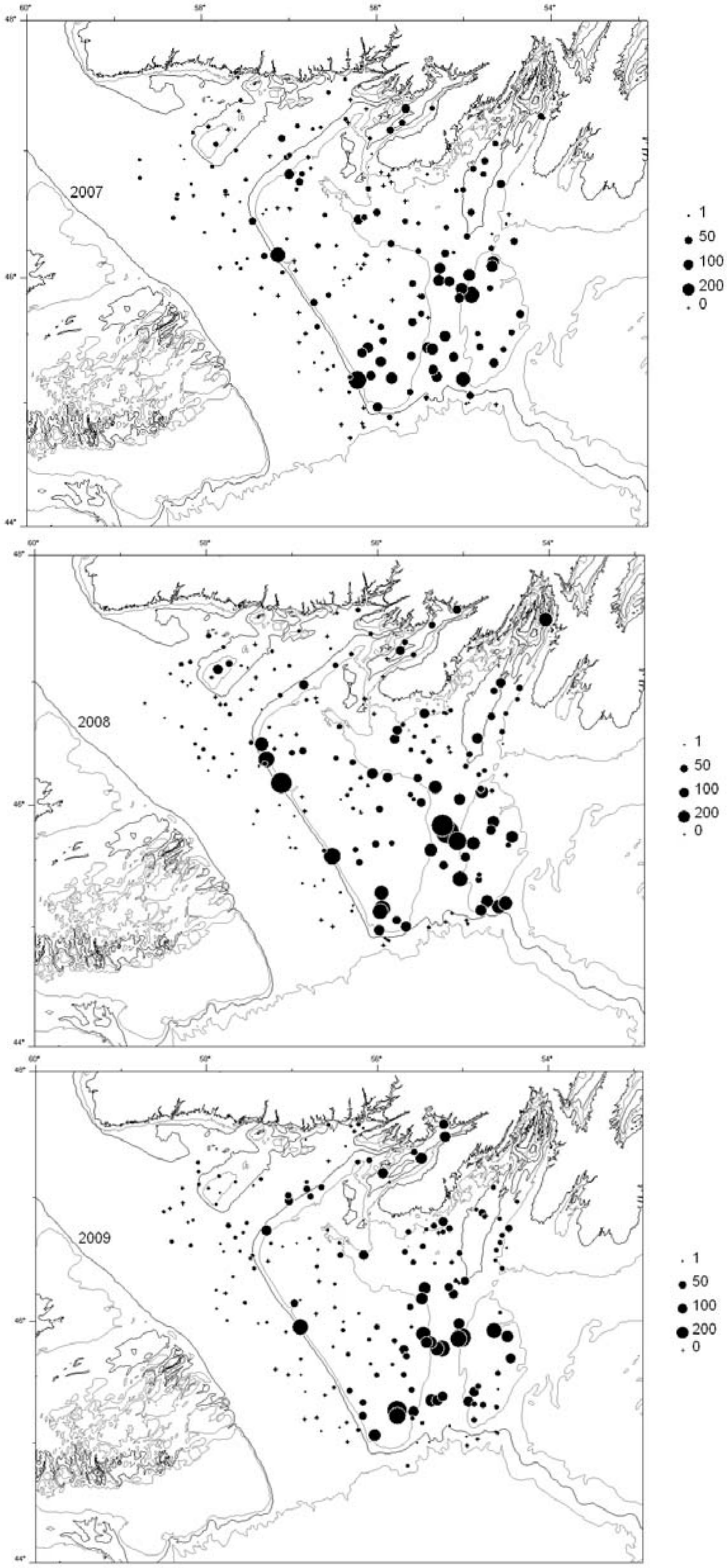


Figure 19. Distribution of American Plaice from the spring surveys in Subdiv. 3Ps (number/tow) for 2007 (top), 2008 (middle), and 2009 (bottom). Survey was cancelled in 2006.

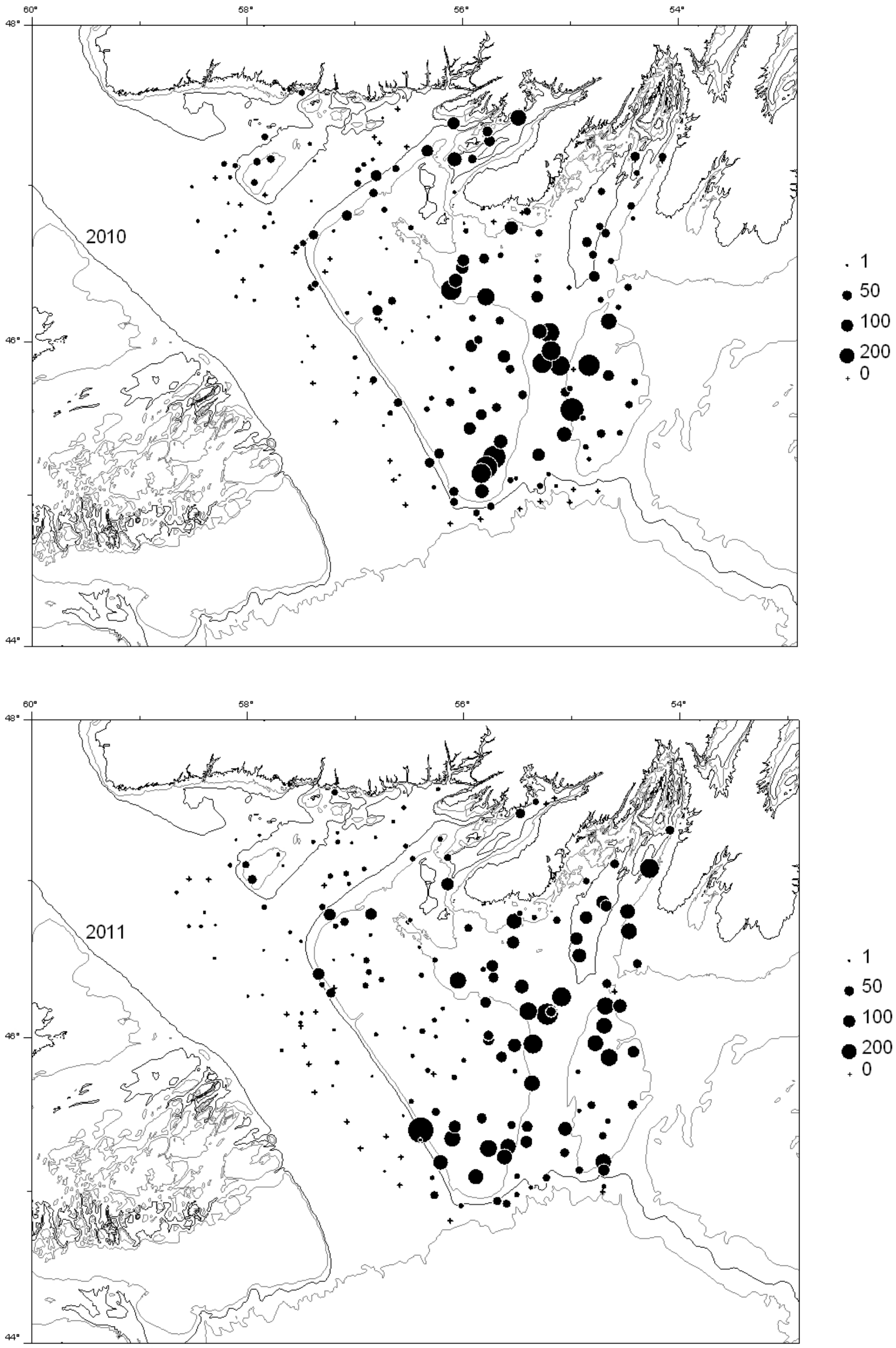


Figure 20. Distribution of American Plaice from the spring surveys in Subdiv. 3Ps (number/tow) in 2010 (top) and 2011 (bottom).

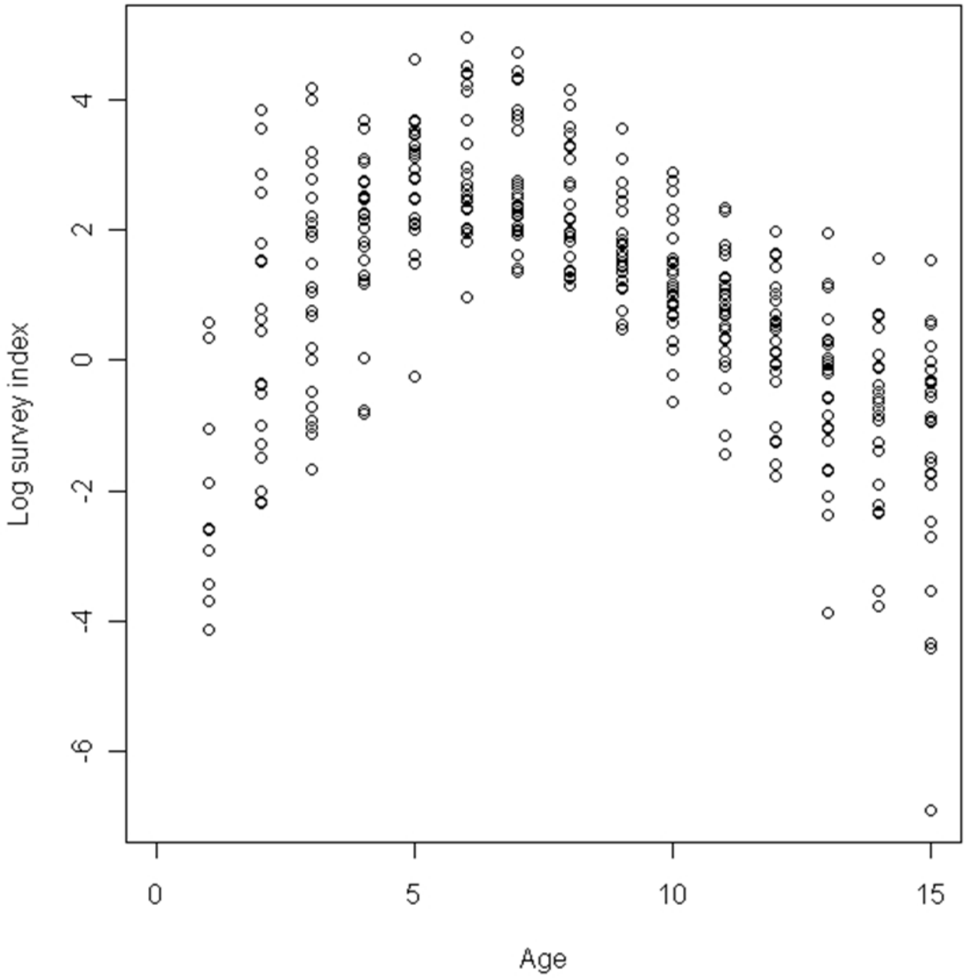


Figure 21. Plot of log survey index against age for ages 0 to 15 over the period 1983-2009 for Subdiv. 3Ps American Plaice.

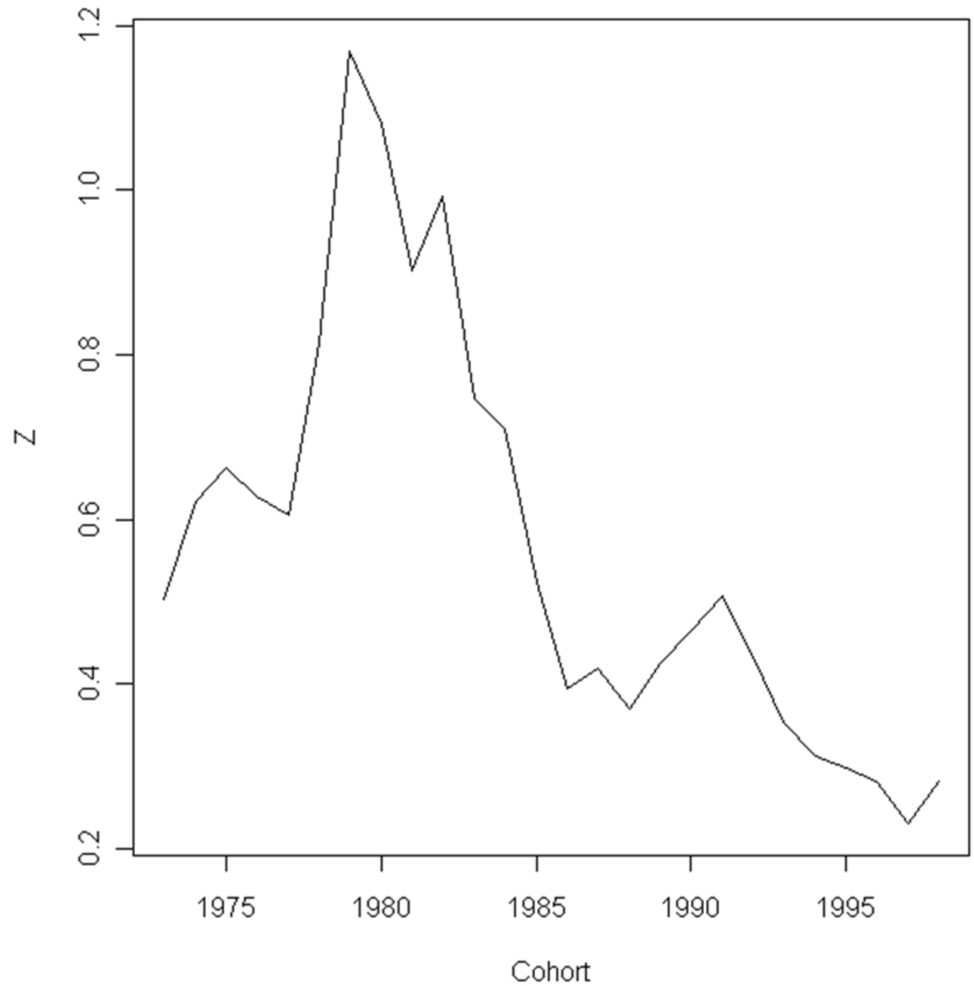


Figure 22. Estimates of cohort Z for Subdiv. 3Ps American Plaice based on the survey index. Estimates are negated so that higher values indicate increased mortality.

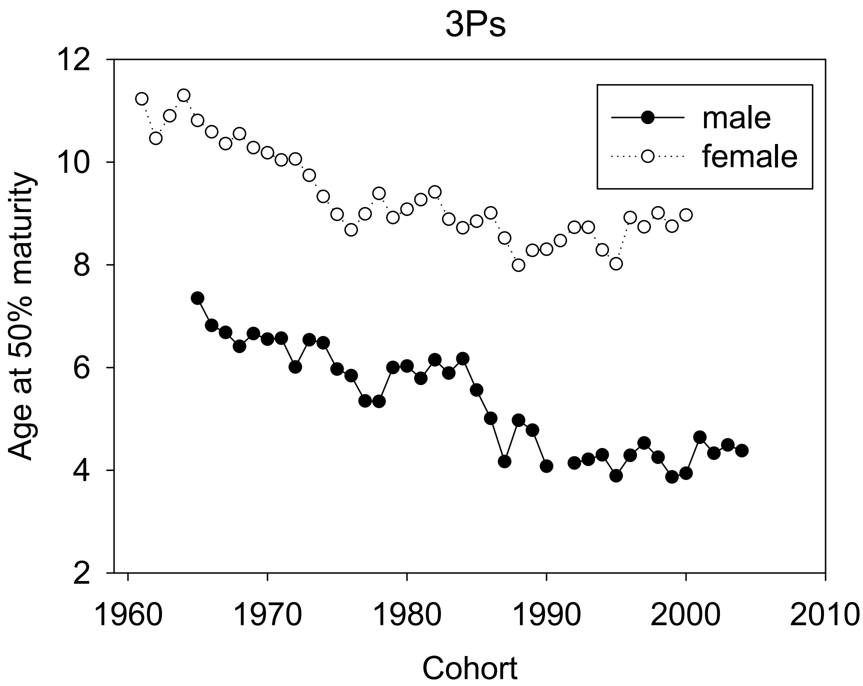


Figure 23. Age at 50% maturity for male and female American Plaice from Subdiv. 3Ps.

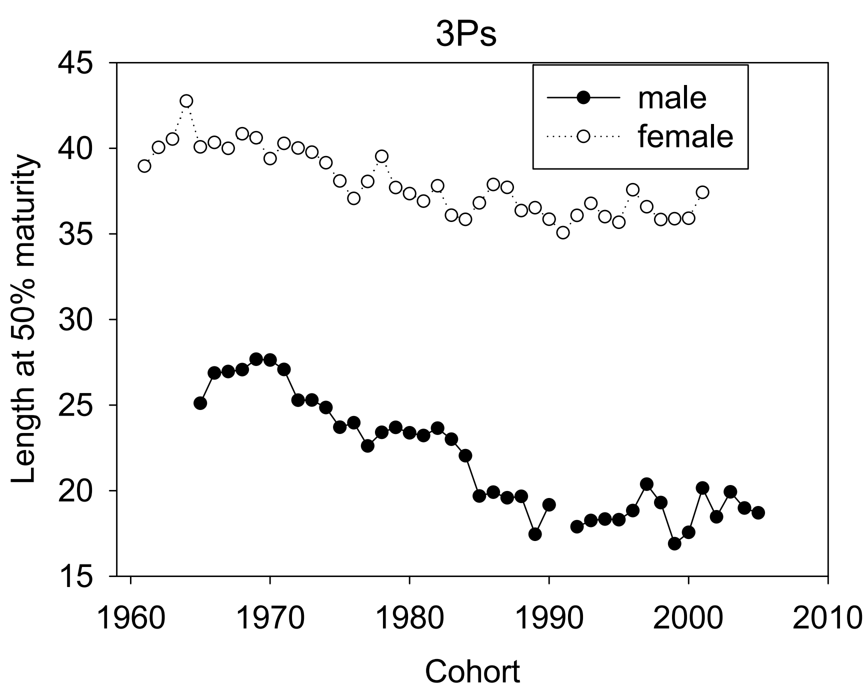


Figure 24. Length at 50% maturity for male and female American Plaice in Subdiv. 3Ps.

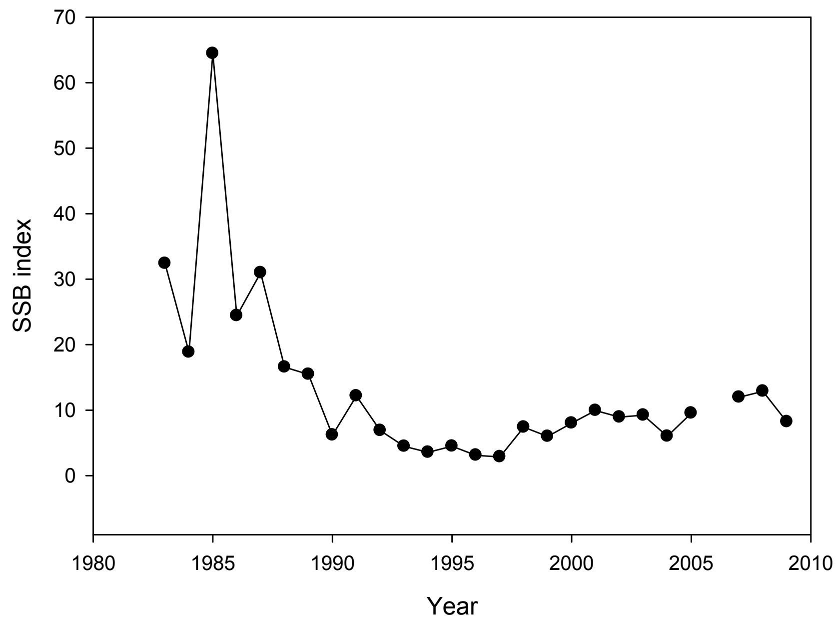


Figure 25. Index of spawning stock biomass derived from the research vessel surveys of Subdiv. 3Ps.

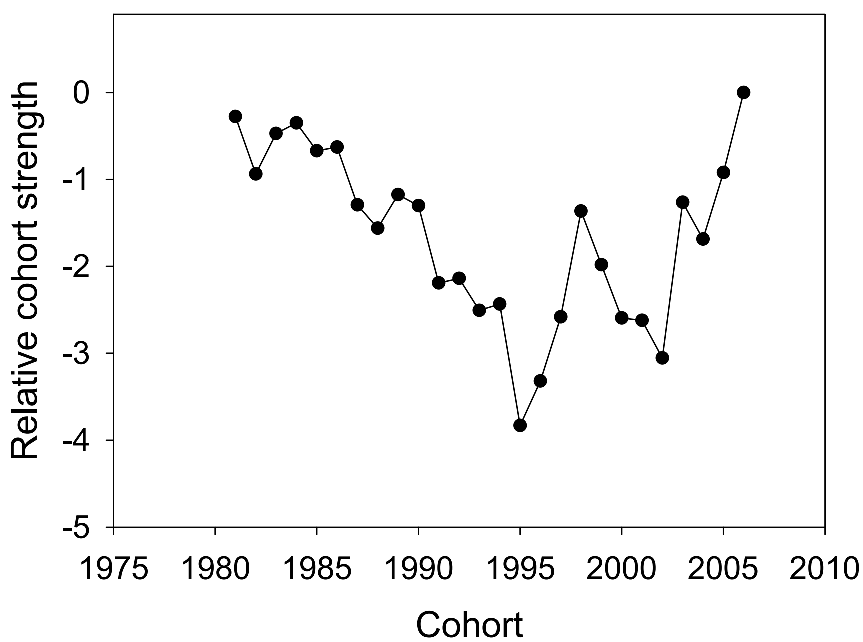


Figure 26. Recruitment as relative cohort strength from research vessel data for American Plaice in Subdiv. 3Ps. Estimates are relative to the 2005 cohort.

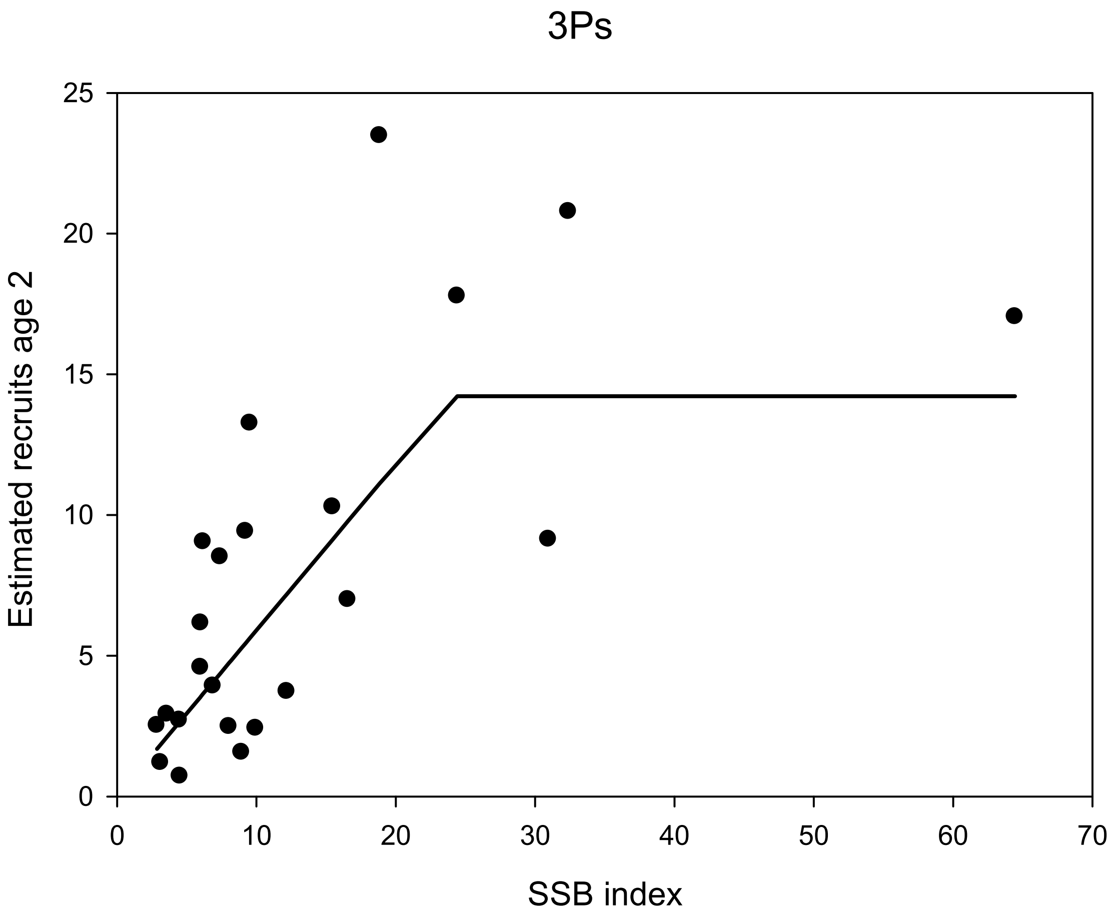


Figure 27. Recruitment and spawning stock biomass index estimated from the research vessel survey of Subdiv. 3Ps. The solid line gives the results of the segmented regression model fit to these data.

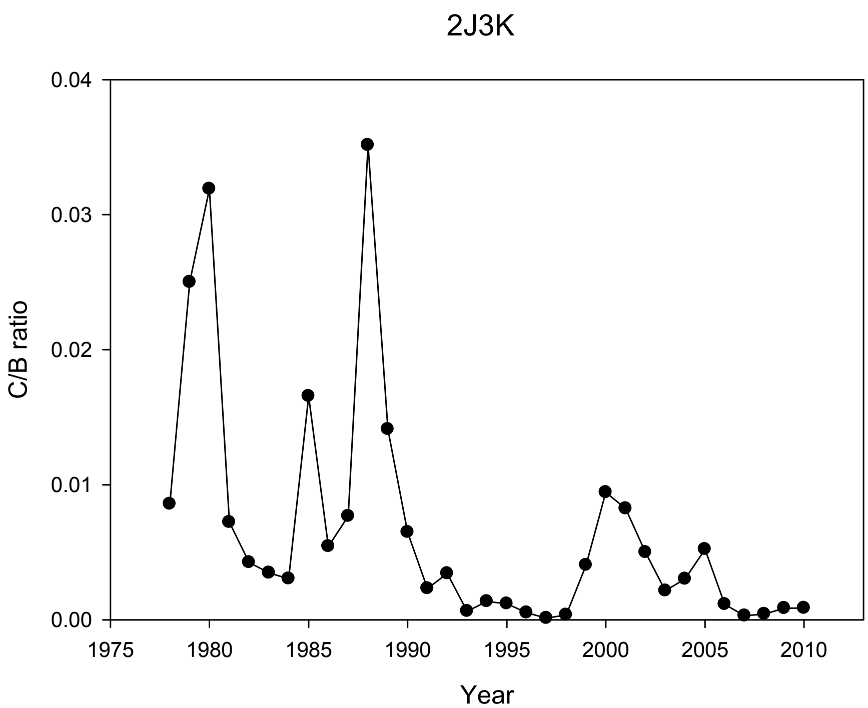


Figure 28. Ratio of reported catch to Campelen/Campelen-equivalent unit survey biomass indices for American Plaice in SA2 + Div. 3K.

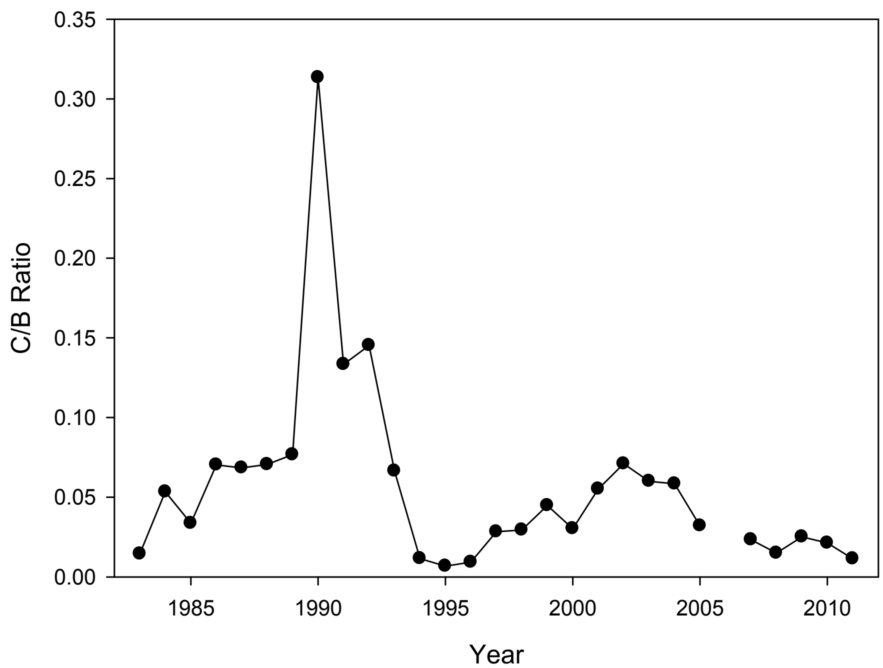


Figure 29. Ratio of reported catch to Campelen/Campelen-equivalent unit survey biomass indices for American Plaice in Subdiv. 3Ps.

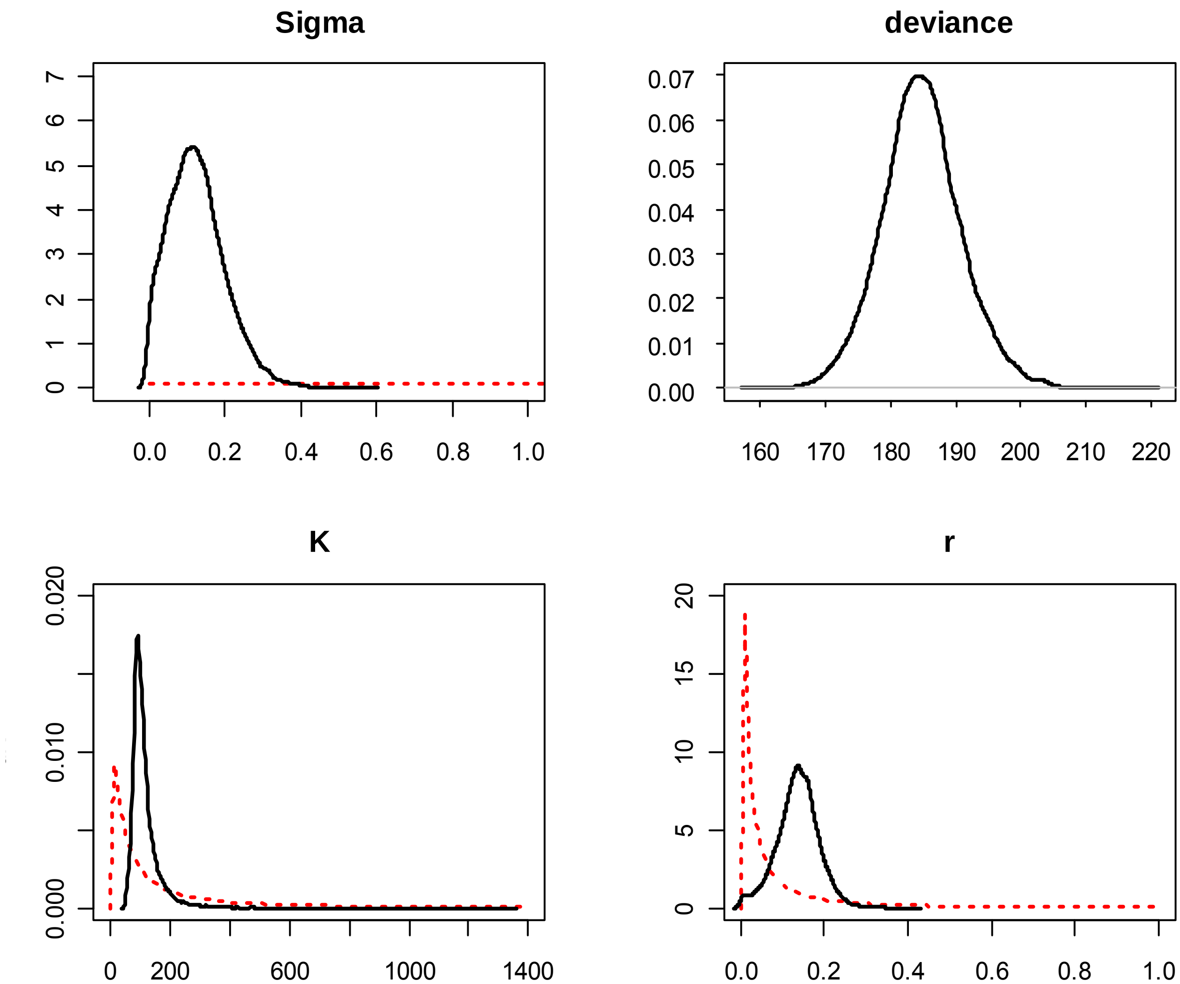


Figure 30. Prior and posterior distributions for sigma, K, and r and the distribution for deviance from the surplus production model for American Plaice in Subdiv. 3Ps.

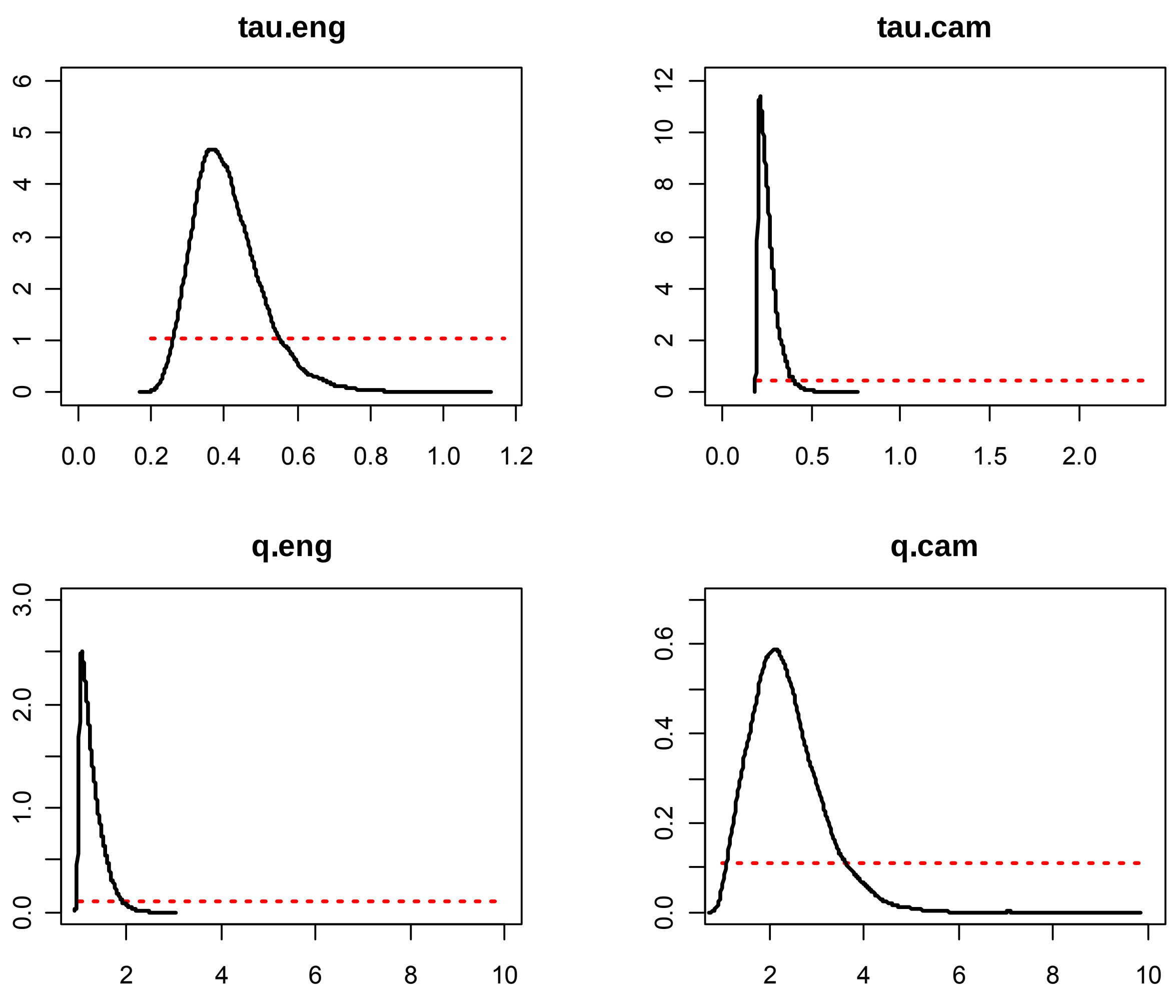


Figure 31. Prior and posterior distributions for the error and q for the survey indices from the surplus production model for American Plaice in Subdiv. 3Ps.

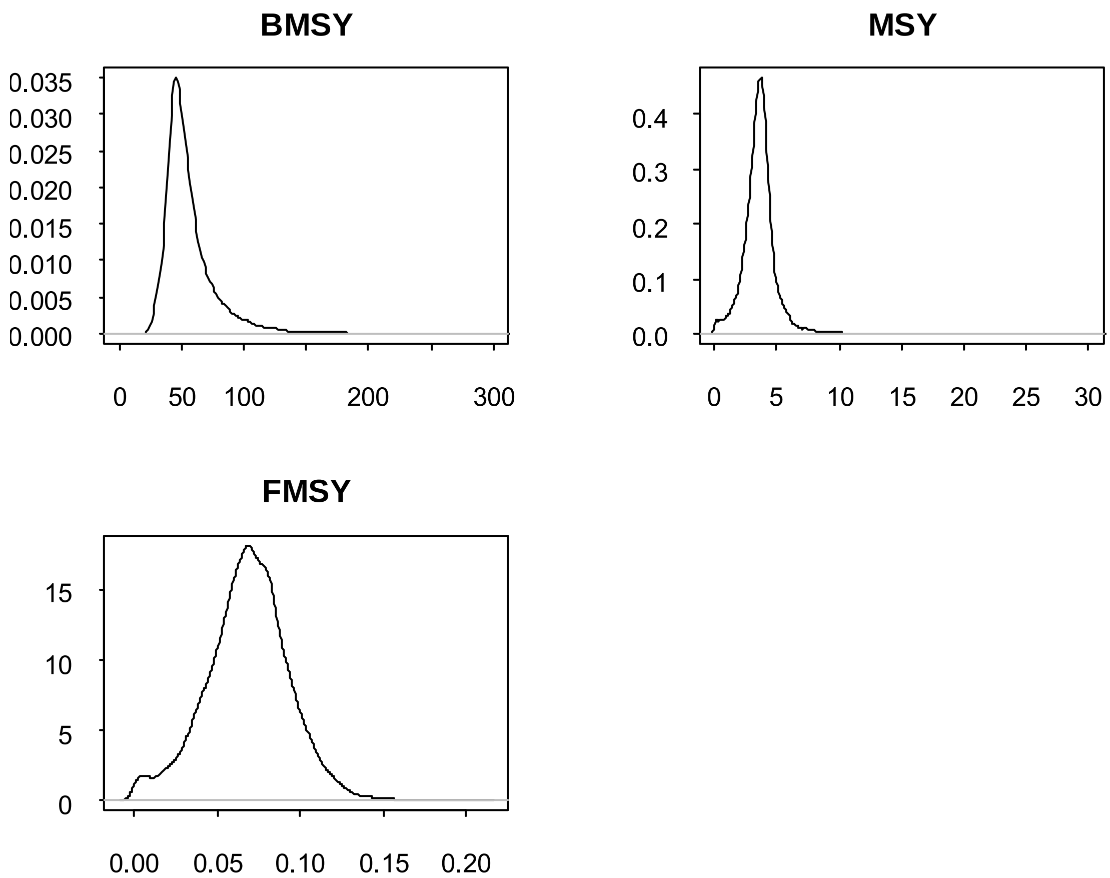


Figure 32. Posterior distributions of B_{msy}, MSY, and F_{msy} from the surplus production model for American Plaice in Subdiv. 3Ps.

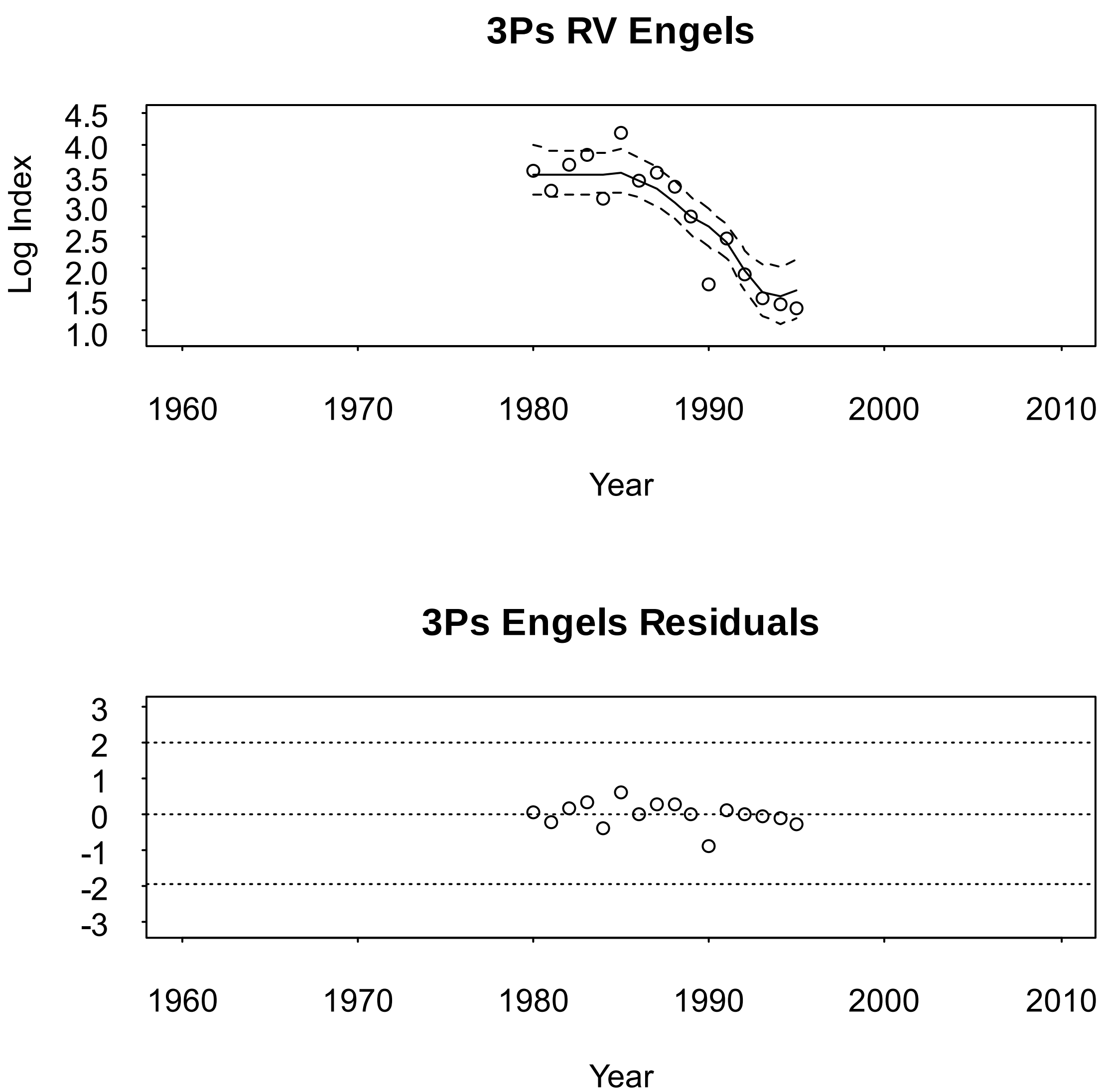
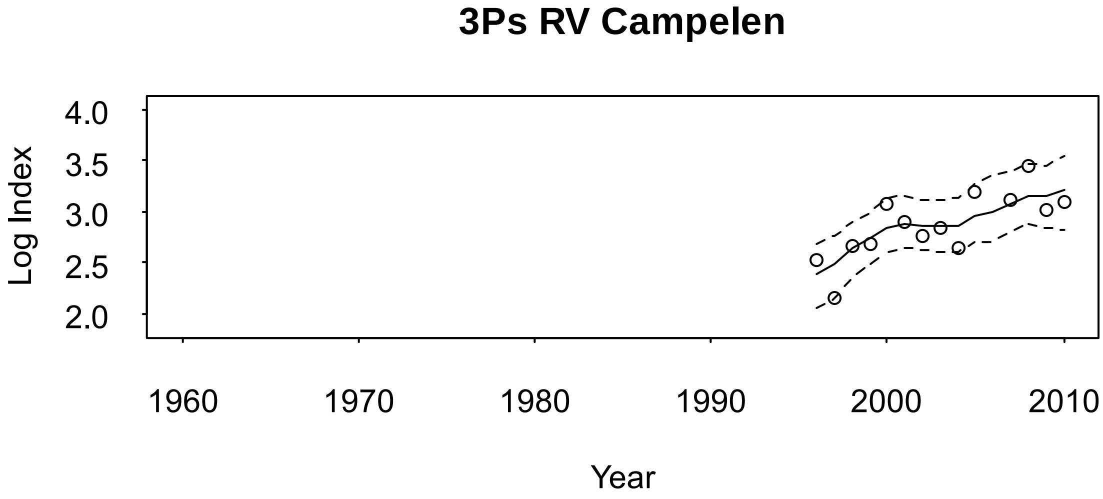


Figure 33. Observed and predicted Engel survey (top) and residuals (bottom) from the surplus production model for American Plaice in Subdiv. 3Ps.



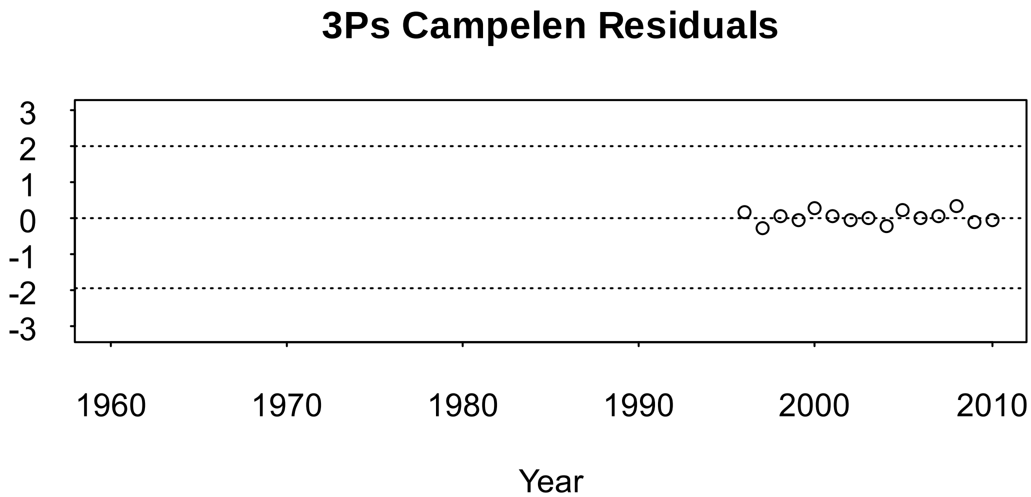
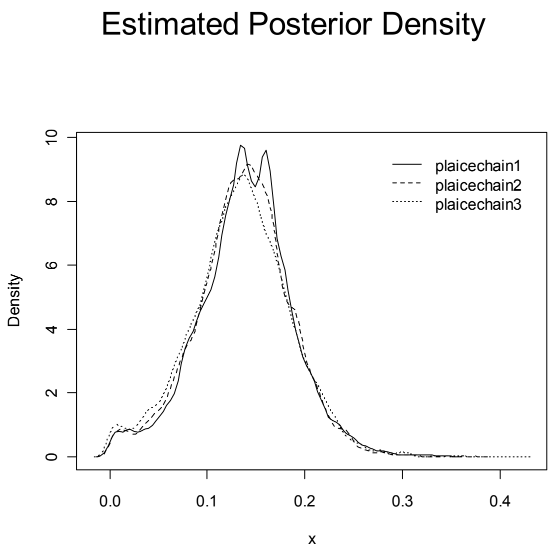
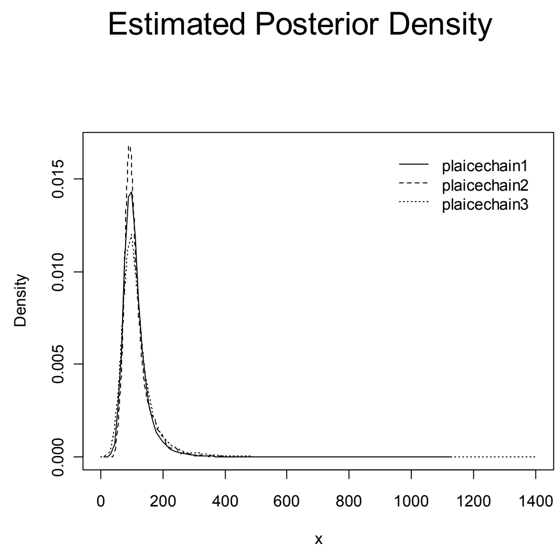


Figure 34: Observed and predicted Campelen survey (top) and residuals (bottom) from the surplus production model for American Plaice in Subdiv. 3Ps.

R



K



Sigma

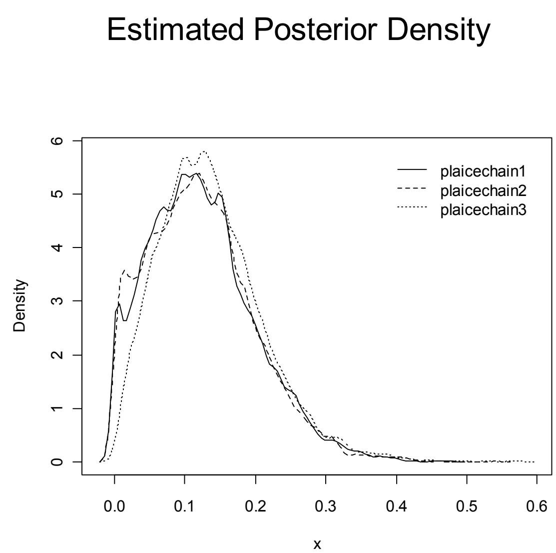
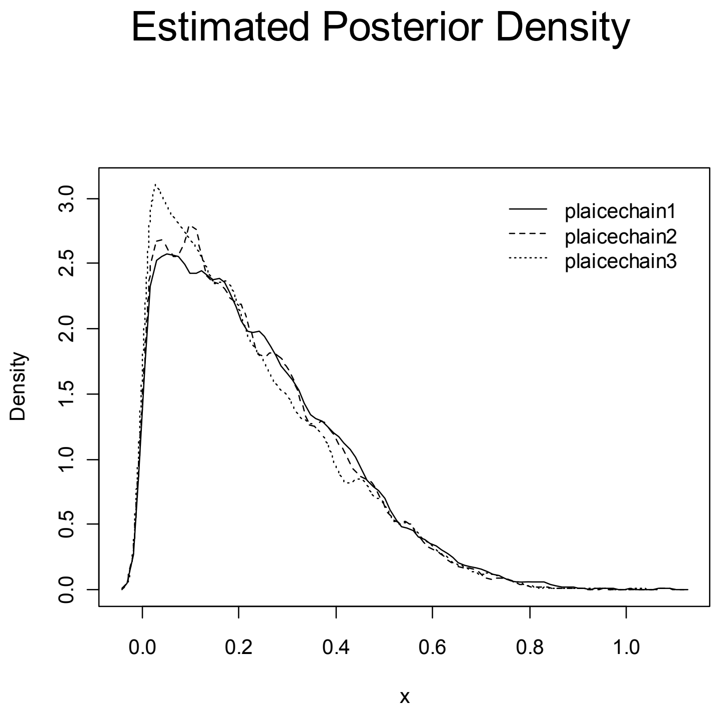


Figure 35. Posterior distribution from each chain for r, K and sigma from the surplus production model for American Plaice in Subdiv. 3Ps.

Logq.eng



Log.cam

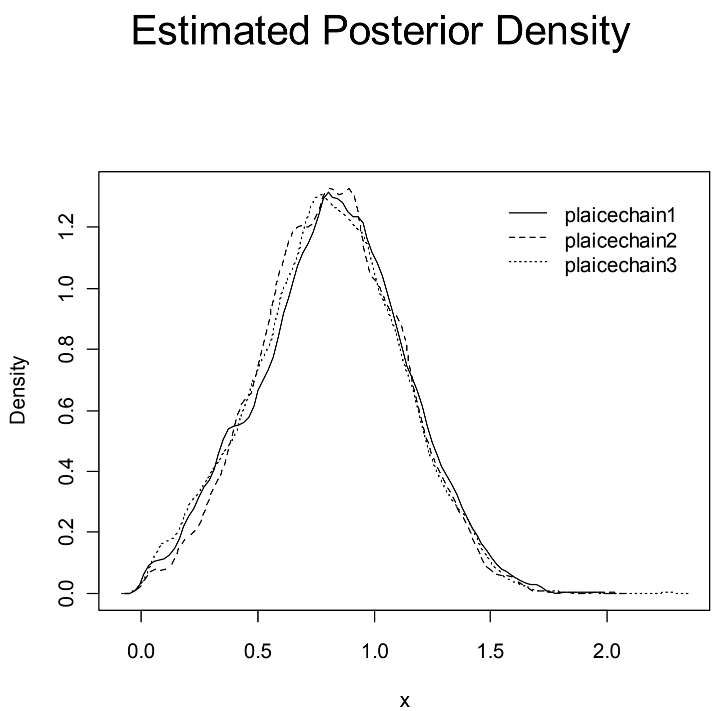
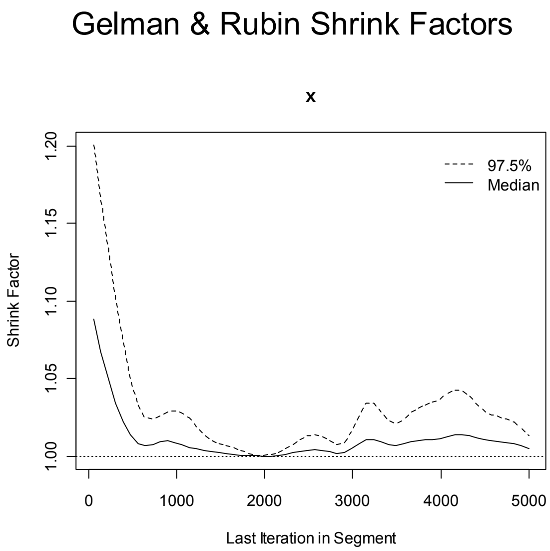
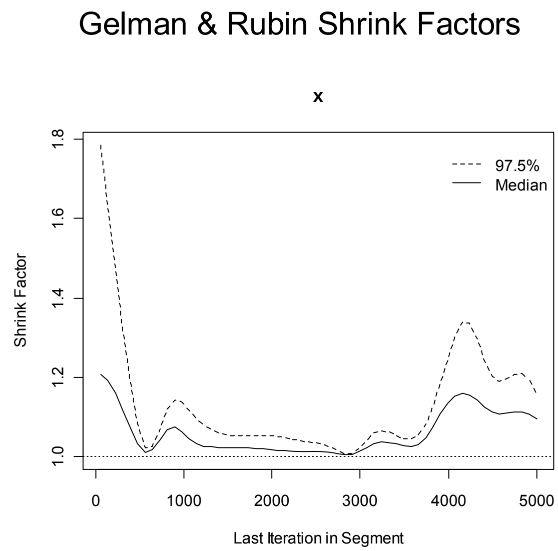


Figure 36. Posterior distribution from each chain for log q for the Engel survey and log q of the Campelen survey from the surplus production model of American Plaice in Subdiv. 3Ps.

R



K



Sigma

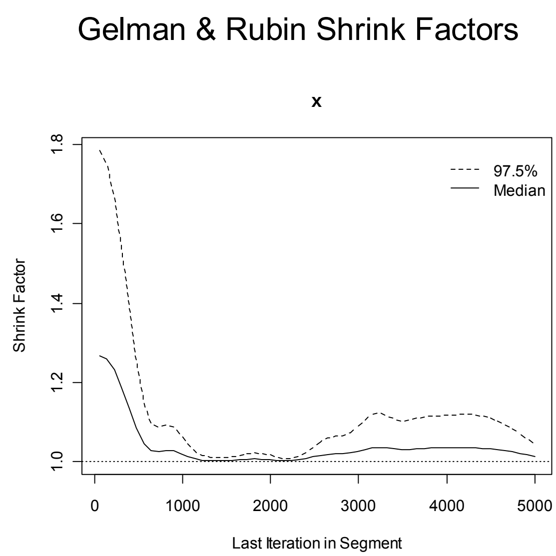
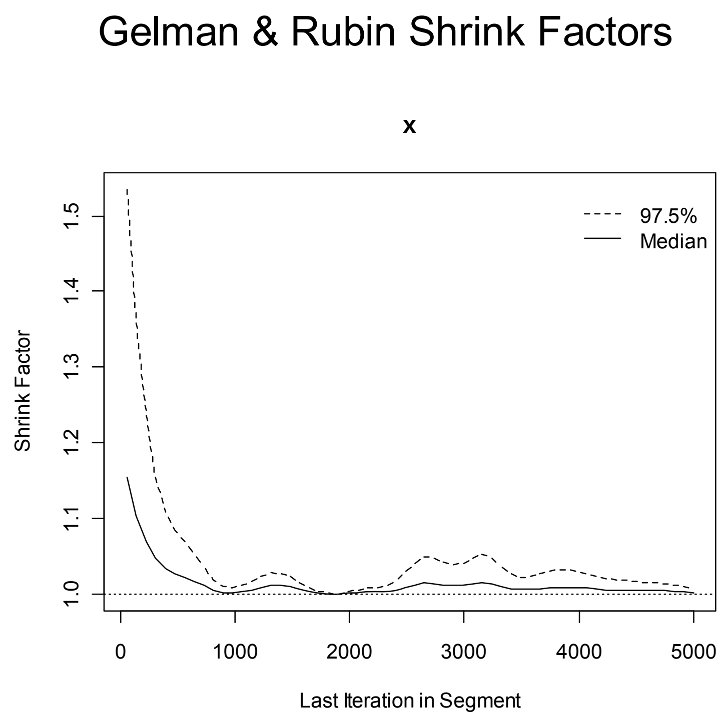


Figure 37. Gelman and Rubin convergence diagnostic for r, K, and Sigma from the surplus production model for American Plaice in Subdiv. 3Ps.

Logq.eng



Logq.cam

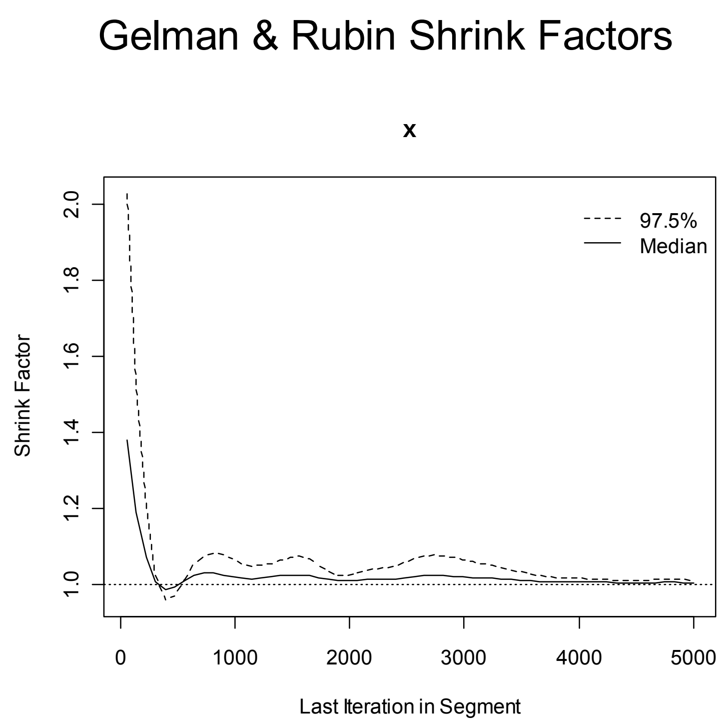
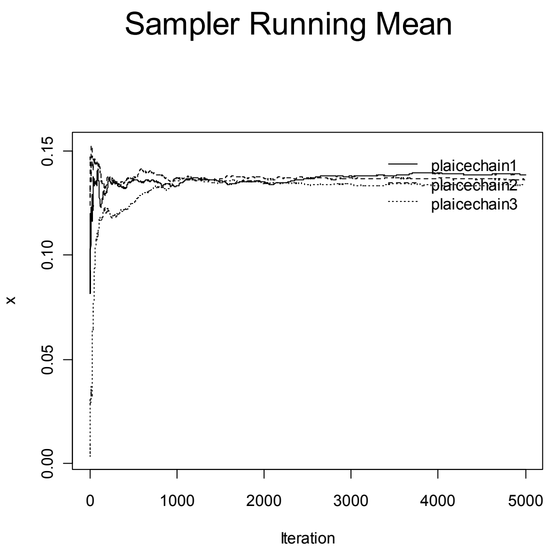
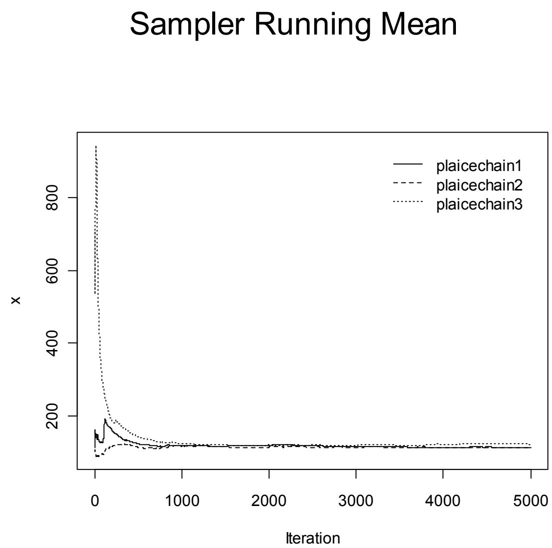


Figure 38. Gelman and Rubin convergence diagnostic for log q for the Engel survey and log q of the Campelen survey from the surplus production model of American Plaice in Subdiv. 3Ps.

R



K



Sigma

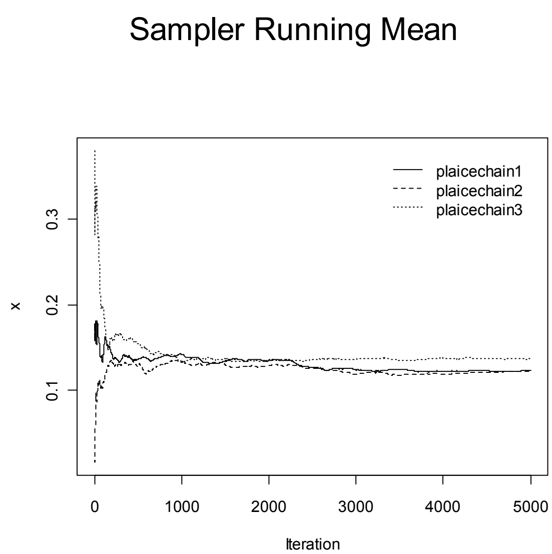
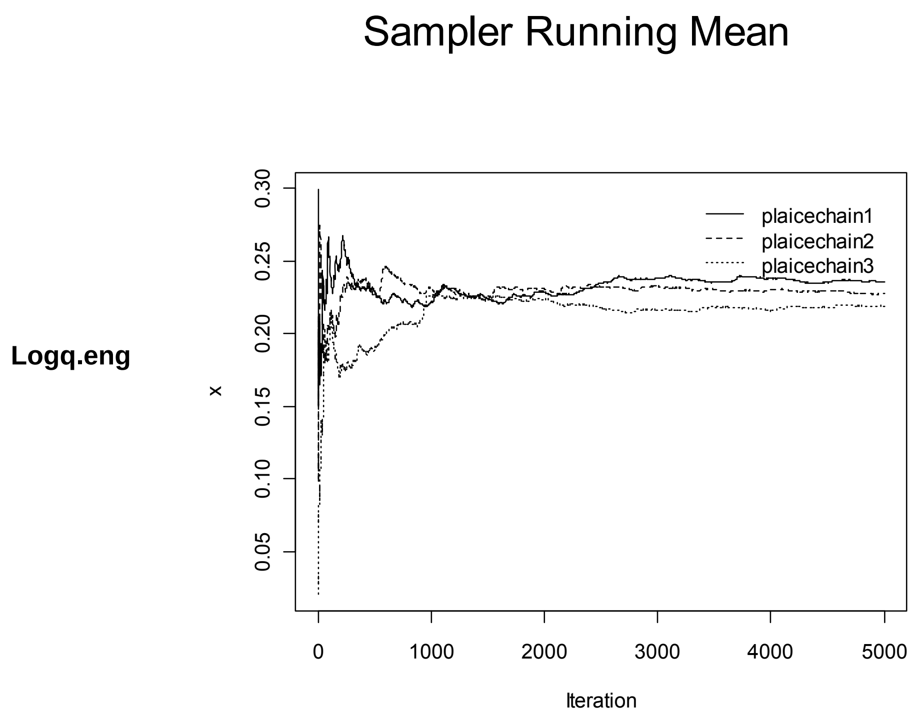


Figure 39. Running mean of each of 3 chains for r, K, and sigma from the surplus production model of American Plaice in Subdiv. 3Ps.



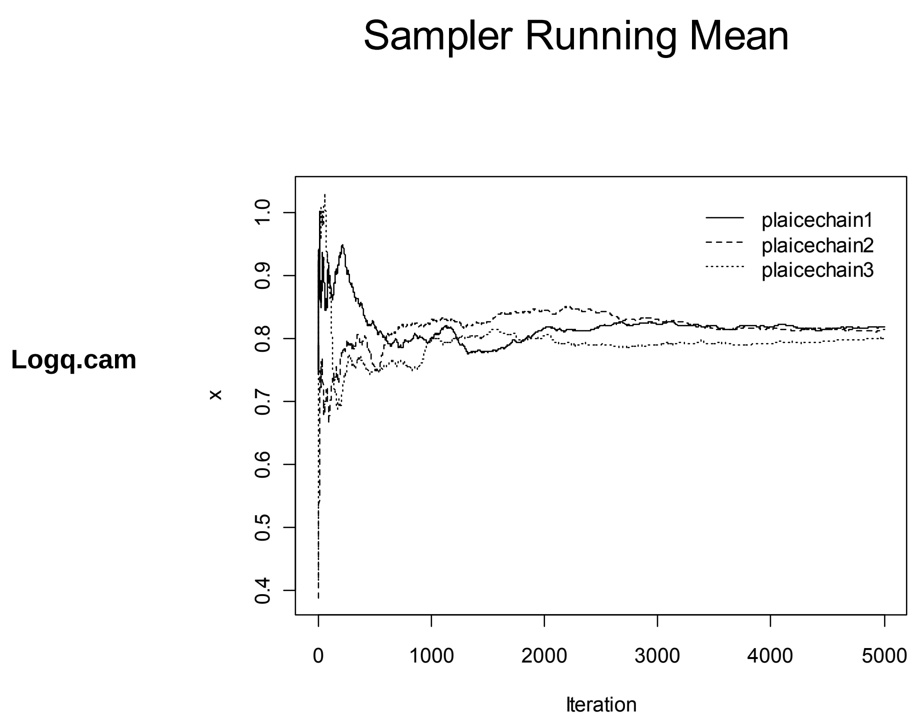
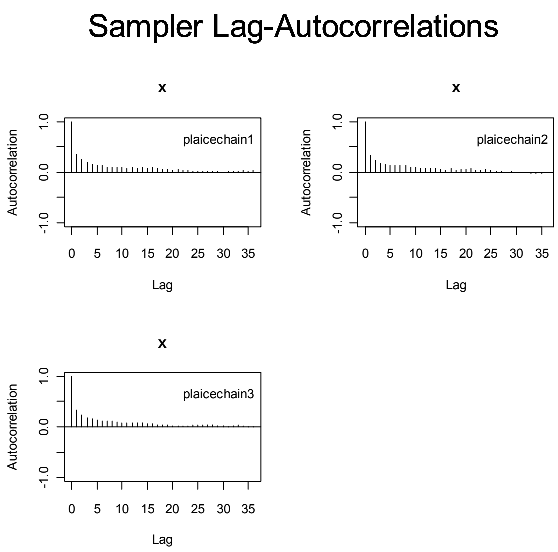
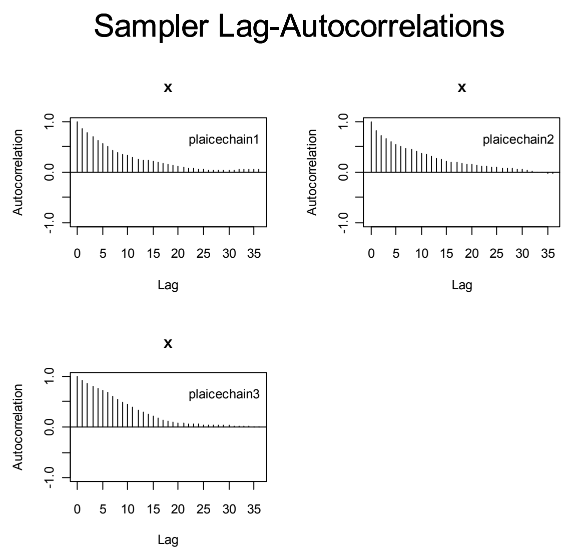


Figure 40. Running mean of each of 3 chains for log q for the Engel survey and log q of the Campelen survey from the surplus production model of American Plaice in Subdiv. 3Ps.

R



K



Sigma

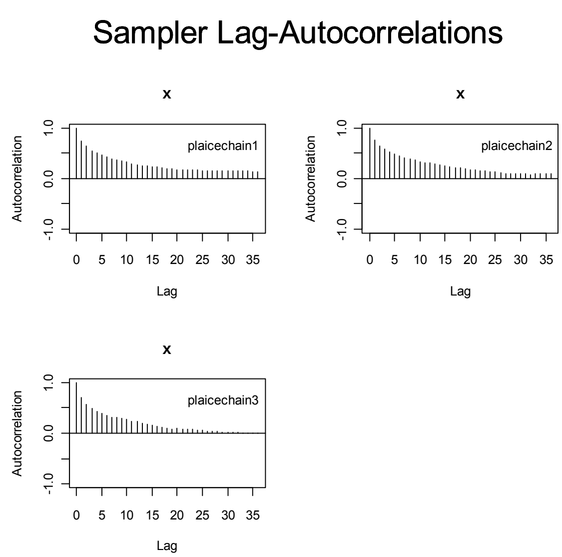
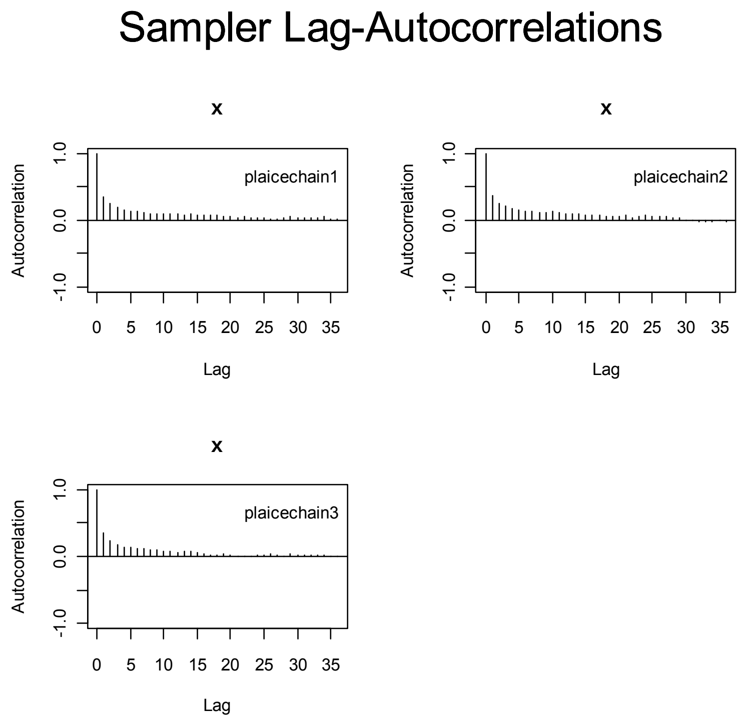
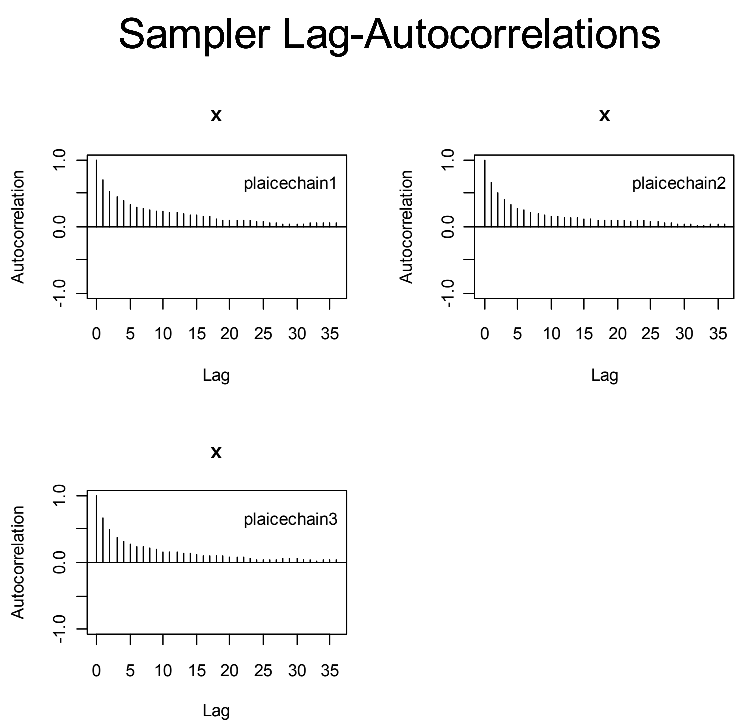


Figure 41. Autocorrelation for each of 3 chains for r, K, and sigma from the surplus production model of American Plaice in Subdiv. 3Ps.



Logq.eng



Logq.cam

Figure 42. Autocorrelation for each of 3 chains for log q for the Engel survey and log q of the Campelen survey from the surplus production model of American Plaice in Subdiv. 3Ps.

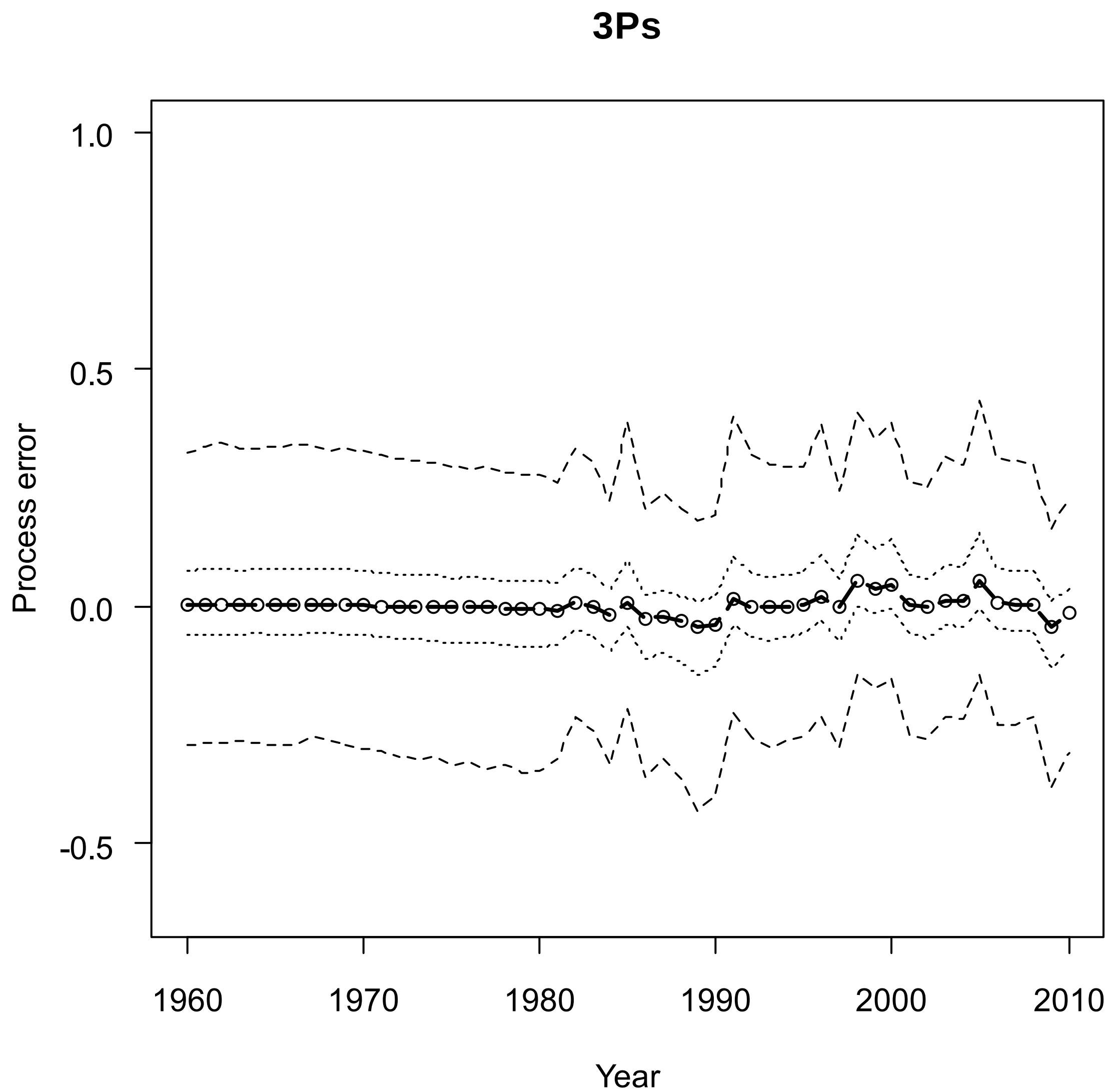


Figure 43. Median process error with 70 and 95% credible intervals from the surplus production model for American Plaice in Subdiv. 3Ps.

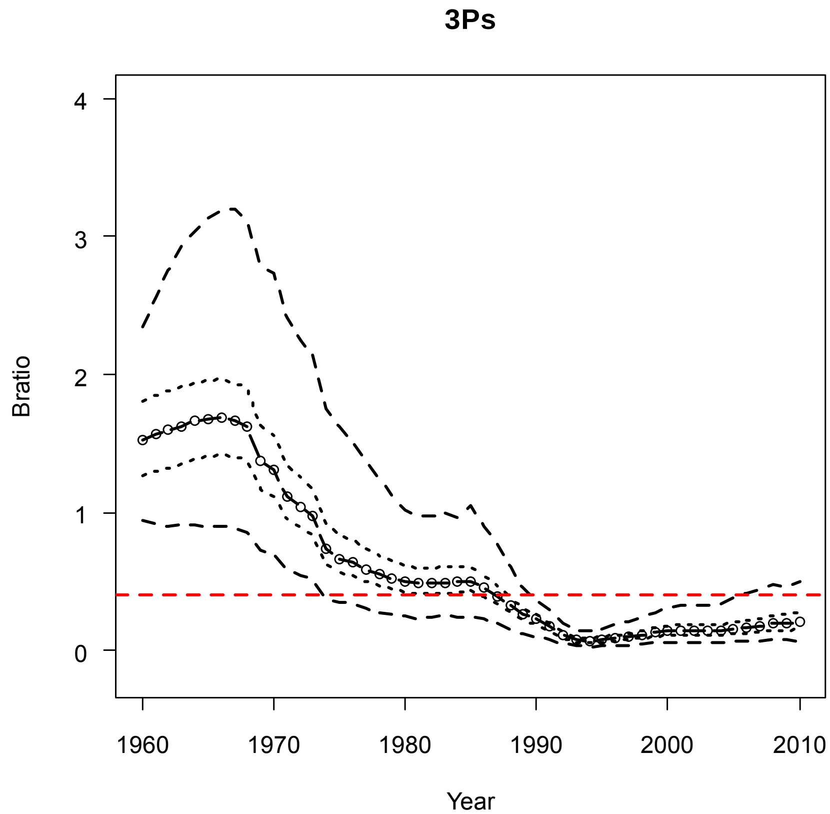


Figure 44. Ratio of biomass to B_{msy} from the surplus production model for American Plaice in Subdiv. 3Ps. The median, 70% and 95% credible intervals are shown. The red horizontal line is B_{lim} (where Bratio = 0.4).

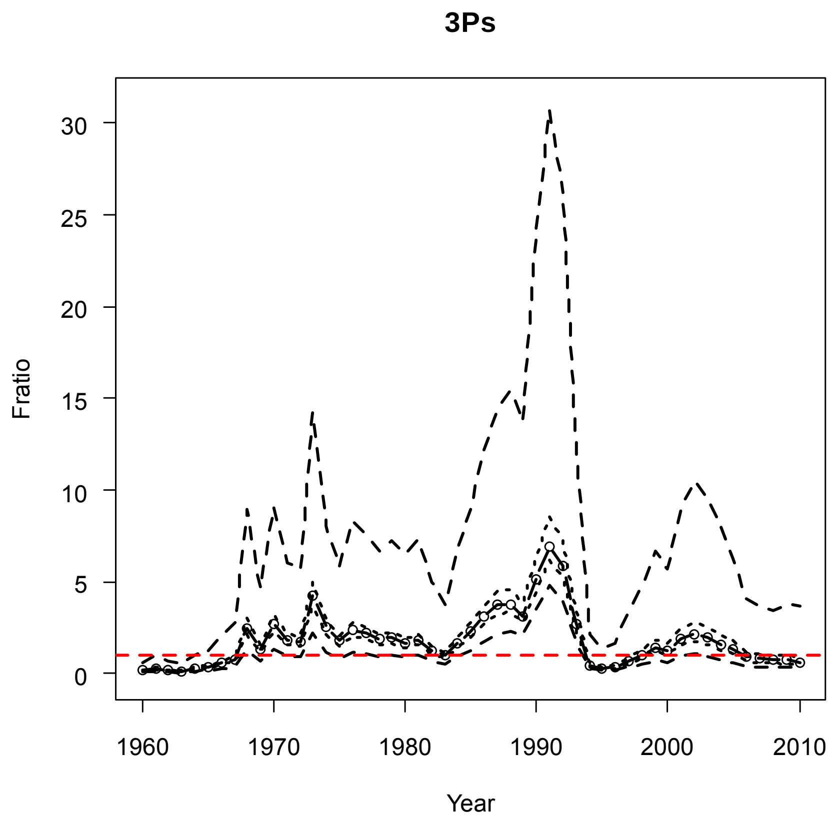


Figure 45. Ratio of fishing mortality to F_{msy} from the surplus production model for American Plaice in Subdiv. 3Ps. The median, 70% and 95% credible intervals are shown. The red horizontal line is F_{lim} (where Fratio=1).

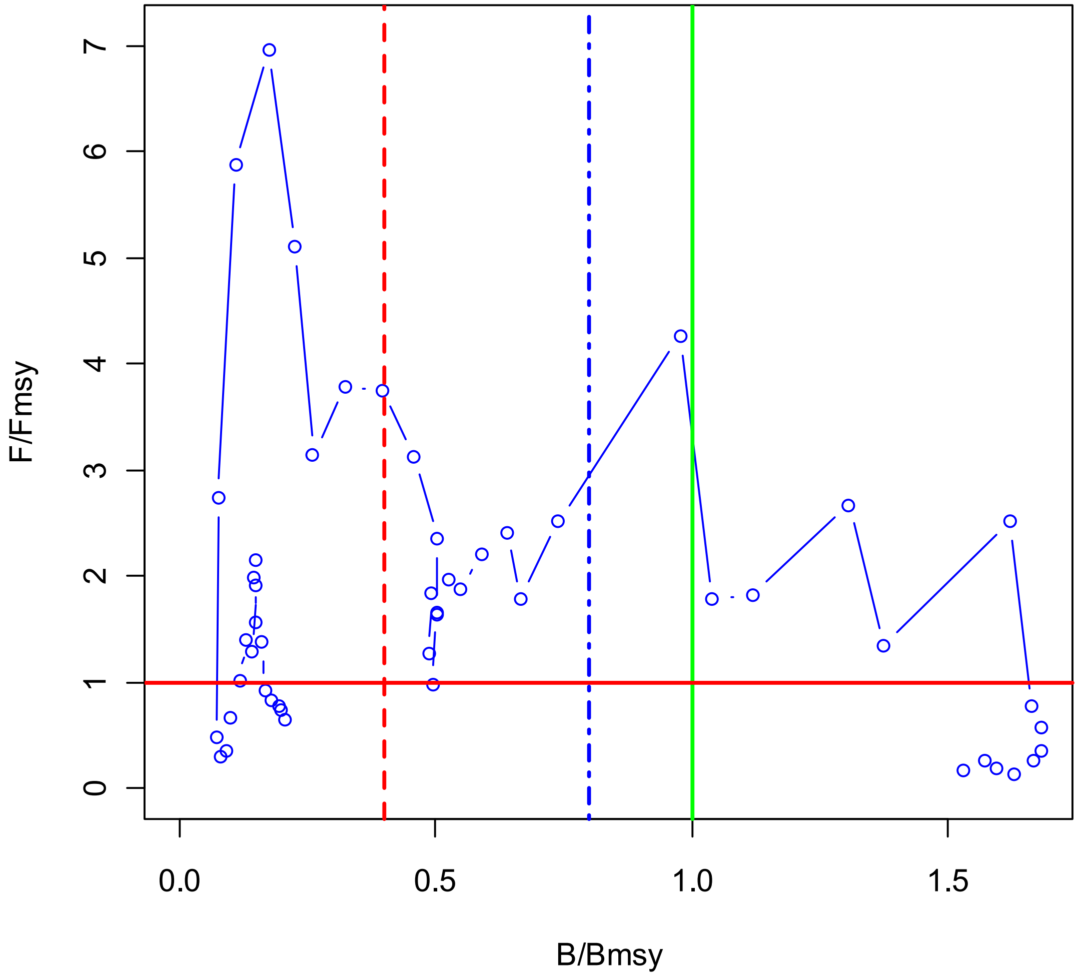


Figure 46. The ratio of F/F_{msy} and B/B_{msy} from the surplus production model for American Plaice in Subdiv. 3Ps in relation to stock reference points. The horizontal line is F_{lim}. The dashed vertical line is B_{lim}, the dashed and dotted vertical line is the suggested upper stock reference and the solid vertical line is where biomass equals B_{msy}.

APPENDIX 1
WINBUGS MODEL FOR PRODUCTION MODEL FOR SUBDIV. 3PS AMERICAN PLAICE

```
model

{

# Prior for intrinsic rate of increase(r)
r ~ dlnorm(-3.81,0.262)I(0.0001,3)

# prior distribution of q's
logq.eng~dunif(0,10)
q.eng<-exp(logq.eng)

logq.cam~dunif(0,10)
q.cam<-exp(logq.cam)

# prior distribution of K
K~dlnorm(4.46,0.40)I(50,1500)

# Prior for process error, sigma
sigma ~ dunif(0,10)
isigma2 <- pow(sigma, -2)

# Prior for observation errors, tau.
#tau.eng = Engels series; tau.cam=Campelen series
tau.eng~dunif(0.2,1.17)
itau2.eng <- pow(tau.eng, -2)
tau.cam~dunif(0.2,2.38)
itau2.cam <- pow(tau.cam, -2)

# Prior for initial population size as proportion of K, P[1]. Limited between 0.5*K and K.
Pin~dunif(0.5, 1)
Pm[1] <- log(Pin)
P[1] ~ dlnorm(Pm[1], isigma2)I(0.001,5)

#This parameter was used to track process error
P.res[1]<-log(P[1])-Pm[1]

# State equation - SP Model.
for (t in 2:(N))   {
Pm[t] <- log(max(P[t-1] + r*P[t-1]*(1-P[t-1]) - L[t-1]/K, 0.0001))
P[t] ~ dlnorm(Pm[t], isigma2)I(0.001,5)
P.res[t]<-log(P[t])-Pm[t]
}

# Observation equations, Engels and Campelen RV Series
for (t in 21:(36)) {
Iengm[t] <- log(q.eng*K * P[t])
Ieng[t] ~ dlnorm(Iengm[t], itau2.eng)
}
```

```
for (t in 37: N) {
Icamm[t] <- log(q.cam*K * P[t])
Icam[t] ~ dlnorm(Icamm[t], itau2.cam)
}

# Output. Using the proportion and K to estimate biomass, B.
for(t in 1:N) {
B[t] <- P[t] * K

#Calculating Fishery Exploitation
F[t] <- L[t]/B[t]

#Bratio calculation
Bratio[t] <- B[t]/BMSY
}

#F Ratio: indicates the ratio of fishing mortality to that estimated for FMSY.
for(t in 1:N) {
Fratio[t] <- F[t]/FMSY
}

#Calculation of Annual Surplus Production one less year than N
for(t in 1:50) {
ASP[t]<-(B[t+1]-B[t])+L[t]
}

# Surplus Production, FMSY, and BMSY calculations for SP Model
MSY <- r*K/4
FMSY<-r/2
BMSY<-K/2

#The section below is used for generating residuals
#generate replicate data sets for Engels and Campelen modeled values
for (i in 21:36){
	Ieng.rep[i] ~ dlnorm(Iengm[i],itau2.eng)
#p.smaller calculates the probability of the modeled value being lower than the actual value
	p.smaller.eng[i] <- step(log(Ieng[i])-log(Ieng.rep[i]))
#residuals of log values of replicate data
	res.eng.rep[i] <- log(Ieng[i])-log(Ieng.rep[i])
}

for (i in 37:N){
	Icam.rep[i] ~ dlnorm(Icamm[i],itau2.cam)
	p.smaller.cam[i] <- step(log(Icam[i])-log(Icam.rep[i]))
#residuals of log values of replicate data
	res.cam.rep[i] <- log(Icam[i])-log(Icam.rep[i])
}

} ## END
```