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2021 Assessment of Yellowtail Flounder in NAFO Divisions 3LNO using a Stock Production Model in a Bayesian Framework.

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Abstract

A surplus production model in a Bayesian framework was introduced for the 2018 assessment of the stock. For the 2021 assessment, the same model formulation, catch series and indices that were used in the last assessment model were also input to a surplus production model in a Bayesian framework with series updated to 2020. Canadian and Spanish surveys show the stock size increased from when the moratorium on directed fishing was declared in 1994 until about 1999 or 2000. Although there was some variability, estimates remained high until about 2012 and 2011, respectively. Canadian spring and Spanish spring survey estimates then declined substantially to 2016. Estimates from Canadian fall surveys have remained high, however. Relative estimates from the Bayesian production model indicates that biomass remains high in 2021 (1.4 times B_{msy}) and fishing mortality remains low (F_{2020}=0.12). Projections in the short and medium term were conducted and results are presented in a precautionary approach framework.

Fishery and Management

A. TAC Regulation

The stock has been under TAC regulation since 1973, when an initial level of 50 000 tons was established. In 1976, the TAC was lowered to 9 000 tons, following a series of high catches (Fig. 1; Table 1) and a reduction in stock size. From 1977 to 1988, the TAC varied between 12 000 tons and 23 000 tons and was unchanged at 15 000 tons for the last 4 years of that period. The TAC was set at 5 000 tons in 1989 and 1990, following sharp declines in stock size after the large catches in 1985 and 1986, then increased to 7 000 tons in 1991-94. However, NAFO Fisheries Commission decided that no directed fisheries would be permitted for this stock and some other groundfish fisheries (cod, American plaice and witch flounder) on the Grand Bank during 1994. From 1995 to 1997, the TAC was set at zero and a fishery moratorium was imposed. Following an increase in survey biomass, Scientific Council in 1997 recommended a re-opening of the yellowtail flounder fishery with a precautionary TAC of 4 000 tons for the 1998 fishery. With the cessation of the moratorium, other management measures were imposed, such as delaying the re-opening until August of 1998 to allow the majority of yellowtail flounder spawning in that year to be completed, and restricting the fishery to Div. 3N and 3O. For the 1999 fishery, a TAC was set at 6 000 tons and again restricted to Div. 3N and 3O, but there were no restrictions on the time period. In the absence of aging for this species, stock production models have been used as the basis for Scientific Council's TAC recommendations. From 2000-2015 a stock production model incorporating covariance (ASPIC) was employed, and in 2018 a stock production model in a Bayesian framework became the basis for advice. In 2000, TAC was set at 10 000 tons, increased to 13 000 tons in 2001. TACs increased to 14 500 tons, 15 000 tons, and 15 500 tons in 2003, 2005, and 2007 respectively. In assessments since 2008, Scientific Council noted that this stock was well above B_{msy}, and recommended any TAC option up to 85% F_{msy} for 2009-2021. TAC was been set to 17 000 tons for 2009 to 2021.

B. Catch Trends

The nominal catch increased from negligible amounts in the early 1960s to a peak of 39 000 tons in 1972 (Table 1; Fig. 1). With the exception of 1985 and 1986, when the nominal catch was around 30 000 tons, catches were in the range of 10 000 to 18 000 tons from 1976 to 1993, the year before the moratorium.
During the moratorium (1994-97), catches decreased from approximately 2 000 tons in 1994 to around 300 - 800 tons per year, as by-catch in other fisheries (Table 1). Since the fishery re-opened in 1998, catches have increased from 4 400 tons to a high of 14 100 tons in 2001. Overall, catches exceeded the TACs during 1985 to 1993 and again from 1998-2001, by about 10% in the latter period (Table 1; Fig. 1). Since 2002 the catches have been below the TAC. Corporate restructuring and labour disputes, in 2006, prevented the Canadian fleet from prosecuting the Yellowtail flounder fishery, and Canadian catch was only 177 tons. The nominal catch in that year was only 930 tons, well below the TAC of 15 500 tons. In 2007, the participation in the fishery increased by Canadian fleet, but was still low at 3 673 tons, and the nominal catch was 4 617 tons. Catch increased in 2008 to 11 400 tons. Catches from 2009- 2020 were lower than the TAC ranging from 3 100 to 14 800 tons (2020 value) taken of the 17 000 ton TACs. Reduction in the effort by the Canadian fleet in from 2006-2018 was the result of industry-related factors.

In some years, small catches of yellowtail have been reported from the Flemish Cap, NAFO Div. 3M. STACFIS previously noted that these catches were probably errors in reporting or identification, as the reported distribution of yellowtail flounder does not extend to the Flemish Cap.

Table 2 shows a breakdown of the Canadian catches by year, division and gear. Since the fishery reopened in 1998, Canadian catches have fluctuated from less than 200 tons (2006) to over 13,000 tons (2005). With the exception of 1991-1993, when Canadian vessels pursued a mixed fishery for plaice and yellowtail flounder in Div. 3O, the majority of catches have been taken in Div. 3N. The most important gear is otter trawl, and catches by other gears have been less than 10 tons annually after 2002. The Canadian catch reported in 2020 was 13 480 tons. In 2011 and 2012, most of the catch was taken in April to June (Table 3), whereas the fishery operated mostly year-round in other years from 2008-2020.

C. The 2019 and 2020 Fisheries by Non-Canadian Vessels (SCS 21/05,06,09,13)

Sampling of size composition from commercial catches of yellowtail flounder in the Canadian directed fishery (with minimum codend mesh size in the Canadian fleet of 145 mm) for yellowtail were available for 2018-2020. The mode was about 33cm in all 3 years (Figure 2).

In fisheries by other countries for Greenland halibut and skate in the NRA of Div. 3NO, some sampling of yellowtail flounder was available, and lengths are plotted in Figure 3. Spain uses a minimum of 130 mm mesh size when fishing for Greenland halibut and 280mm in the skate fishery.

II. Research Survey Data

A. Canadian Stratified-random Surveys Spring and Fall Surveys

Stratified-random research vessel surveys have been conducted in the spring in Divs. 3L, 3N and 3O since 1984 and in the fall since 1990. Up until 1994, the surveys were conducted using an *Engel* 145' high-rise groundfish trawl whereas the 1995-2017 surveys were carried out with a much more efficient *Campelen 1800* shrimp trawl. There have been a number of problems with the survey vessels in recent years, and as a result, surveys in the autumn of 2014 and spring of 2006 and 2015 did not cover the entire stock area and estimates from these surveys are not considered representative of the stock. Due to COVID-19 related restrictions, no survey was conducted in spring of 2020. Descriptions of the history of the Canadian survey and problems with coverage in recent surveys are given in and Rideout *et. al.* (2021).

Abundance and biomass trends

Tables 4 and 5, and Figure 4 show the population abundance and biomass estimates of yellowtail flounder in the Canadian spring and autumn surveys. Detailed descriptions of trends in yellowtail flounder from both surveys are contained in Maddock Parsons *et al.* (2021). Until recently, survey indices showed similar trends in both series. The fall survey indicates that the upward trend in stock size started in 1993 while the spring survey showed the trend starting in 1995. The spring series showed a marked decline in biomass and abundance from 2012 to 2016, with a slight increase from 2017 to 2019. The fall survey index did not shown the same sharp decline and although estimates remains relatively high, there is an overall decreasing trend from 2007 to 2020.

Figure 5 shows the result of a regression of the biomass estimates from the spring and fall time series. A linear relationship is evident with 62% of the variation being explained by the model. Different time regimes seem to be evident: 1990-1995, when the stock was at its lowest and estimates were more in agreement, and subsequent to then, when the stock was increasing the estimates were more variable and less in agreement . Catchability estimates from the stock production model indicate *q's* from the Campelen surveys are around 2, and therefore swept-area stock-size is likely being overestimated in the spring and fall surveys.

Size composition and growth

Figure 6 shows the length composition of survey catches from spring and fall surveys by year for Div. 3LNO (combined sexes). More small fish were present in the survey catches beginning in the fall of 1995 onward due to the increased efficiency of the new Campelen survey gear over the Engel gear. Annual shifts in modes could be evidence of year classes moving through the time series.

In the years when the spring survey indicated that the stock size was very low (1995-1996 for example), length distributions were bimodal, and the smaller size mode (in the range of 20-25cm) can be tracked from year to year, although growth appears slow (the mode is about the same for 2000 and 2001). As the stock size increased, the distribution became dominated by fish in one major mode (25 to 35 cm) and it is probably made up of a number of different age classes. Smaller peaks of fish less than 20cm are evident from about 2006 or 2007-2011 and then merge into the modal peak in following years. Shifts in this size mode from 1996-1998, 1999-2002, and 2010-2013 seem to track recruitment pulses (Fig. 6). In 2017, a peak of small fish (about 10 cm) was observed and seemed strong. This peak tracked through 2018 and 2019 length frequencies and another peak of small fish was evident in 2019.

In the fall surveys, multi-modal peaks are more common and unlike the spring surveys, were evident in many surveys from 2001-2020 (Fig. 6). From 2011-2013, frequencies were largely unimodal and peaked at about 35cm. After 30-32 cm, growth slows and becomes almost negligible between years. This is consistent with the growth curves constructed using ages from thin-sectioned otoliths (Dwyer *et al*., 2003). The 2015 autumn survey indicated smaller fish were present (about 8 and 12 cm cm) which tracked to larger sizes from 2016 to 2019. Another mode at about 8 cm was observed in 2017 and this appeared in subsequent surveys at larger sizes. A large mode of small fish (<10cm) was evident in the 2019 survey and is also represented at larger size in the 2020 survey. These are indications that recruitment could be strong in recent years.

Figure 7 shows survey abundance less than 22 cm (ages 0-3) from Canada (population number at length) and Spain (total numbers) for the period 1996-2020 as a proxy for recruitment. At that size, yellowtail flounder are not recruited to any of the regulated fisheries. The 2014 fall, 2006 and 2015 spring surveys were incomplete and no recruitment proxies are shown for those survey years. There were no surveys in spring of 2020 by either Canada or Spain, due to pandemic related restriction. The trends in spring and fall abundance < 22 cm are generally similar between series with the exception of the 2004 and 2005 Canadian fall surveys which had increased abundance of small fish compared to either the Canadian spring or Spanish spring surveys. From 2006 to 2012 Canadian survey estimates of small fish abundance have been near or slightly below the time series average. Estimates of abundance of small fish in the Canadian spring and autumn surveys were at or above average from 2017 to 2020, and in the Spanish survey series, values have been lower than normal since 2007.

B. Spanish Stratified-random Spring Surveys in the Regulatory Area, Div. 3NO (SCR Doc. 20/009; 19/018)

Beginning in 1995, Spain has conducted stratified-random surveys for groundfish in the NAFO Regulatory Area (NRA) of Div. 3NO. These surveys cover a depth range of approximately 45 to 1 300 m. In 2003, after extensive comparative fishing between the vessel, C/V *Playa de Menduiňa* and Pedreira trawl with the replacement vessel, C/V *Vizconde de Eza*, using a Campelen 1800 shrimp trawl as the new survey trawl, all data have been converted to Campelen units (Paz *et al*., 2003, 2004). In 2006, an error in the estimation method was corrected and all survey estimates were re-calculated (González-Troncoso *et al*., 2006).

The biomass of yellowtail in the Div. 3NO of the NRA increased sharply up to 1999, and then showed a similar annual fluctuation pattern seen in the Canadian spring surveys of Div. 3LNO until 2016 (Fig. 4 and 8). The survey index rapidly declined after 2016 and in 2019 was near the lowest in the times series. Most (85%) of the biomass comes from strata 360 and 376 similar to other years. Length frequencies in the recent Spanish surveys showed modes around 32-34 cm (Fig. 6). As in the Canadian spring surveys, this survey showed a similar progression of the peak in the length frequencies from 1998 to 2003. From 2007-2010, there was is some evidence of a recruitment pulse in recent years similar to the Canadian spring survey results, and in 2017 a mode of fish at about 10cm is observed in this survey, which is evident at larger sizes in the 2018 and 2019 surveys, similar to both of the Canadian surveys (González-Troncoso *et al*., 2019, 2020). No survey was conducted in 2020 due to COVID-19 related restrictions.

C. Stock Distribution

Yellowtail flounder are mainly found in water depths <183m and are concentrated mainly in Div. 3N, particularly on the Southeast Shoal, and areas immediately to the west and to a lesser extent the border of Div. 3LN. No change in distribution of the stock has been noted in recent years, and the stock continues to occupy more northern areas, and while variable, the proportion of yellowtail flounder north of 45 degree latitude has been stable around levels seen in the mid-80s (about 40%). Plots of distributions from Canadian spring and autumn surveys can be found in Maddock Parsons (2011) and previous descriptions of yellowtail flounder in Canadian surveys (Maddock Parsons *et al*. 2015, 2018 and 2021).

Correlation of spatial distribution in the surveys to temperature has not been updated for this assessment. In a previous assessment, a steady increase in the abundance of yellowtail flounder was seen to coincide with a northward expansion of the stock from 1995 up to 2005 and also coincided with increasing bottom temperatures (Walsh and Brodie, 2006). Small amounts of yellowtail were sometimes found in deep water.

D. Biological Studies

Information used to estimate maturity, weight at length and to calculate an index of female spawning stock biomass (SSB) comes from biological sampling of yellowtail flounder conducted on the Canadian Spring surveys of NAFO Divs. 3LNO. In 2019 there was a reduction in both the number of sets conducted and the amount of biological sampling undertaken during the survey in an attempt to improve survey efficiency and maximize survey coverage. As a result, there was a notable reduction in sampling of yellowtail flounder in Divs. 3L and 3N in 2019. There was no survey in spring of 2020 due to emerging COVID-19 pandemic.

Maturity

Maturity at size by year was estimated using Canadian spring research vessel data from 1984-2019 (there was no survey in spring of 2020). Estimates were produced using a probit model with a logit link function and a binomial error structure (McCullagh and Nelder, 1983). L50 has shown a general decline in males from the beginning of the time series to about 2000 after which it was relatively stable to 2015. It declined sharply to 2017 but increased again in 2018 and 2019 to be in range of the previous levels in the 2000's. L50 for males was around 26 cm in 2019 compared to 30 cm in the mid 1980's. Female L50 generally declined from the mid 1990's to the late 2000s and has been relatively stable since. The current L50 is about 32 cm compared to 34 cm at the beginning of the time series (Fig. 13). There was significant inter-annual variation in the proportion mature at length for both males and females (generalized linear models: males χ^2=602.1, df=35, p<0.0001, females χ^2=566.7, df=35, p<0.0001). In general, for both males and females, proportion mature at length in the last 10 years (2009-2019) was less than that of the first 10 years.

Weight at length

Log length – log weight regressions were fit for females for each year from the Canadian spring survey data from 1990-2019. The specific length weight relationships are given in Table 13. Annual length weight relationships were unavailable prior to 1990 so for those years a relationship produced using data from 1990-1993 is given. There was a decline in weight at length from 1996 to 2003 and then stability at a lower level since. This can be best seen in the largest size range plotted, the 50.5 cm grouping. For this size group weight declined by about 0.10 Kg (9%) from 1996 to 2003 (average 1990-96 compared to average 2003-2019 Fig. 14).

Female SSB

Estimates of female proportion mature at length, population numbers at length, and annual length weight relationships were used to produce an index of female SSB from the spring survey. Female SSB declined from 1984 to 1992 (Fig. 15). It increased substantially from 1995 to 2009. Since then it declined substantially to 2016 but increased slightly to 2018.

III. Assessment Results

In 2018, a stock production model using a Bayesian formulation was accepted to assess 3LNO yellowtail flounder, replacing the previous stock production model using ASPIC (Maddock Parsons, 2018).

For the 2021 assessment model, the Schaefer (1954) form of a surplus production model was used:

$$P_t=[P_{t-1}+ r\bullet P_{t-1} (1 - P_{t-1})- C_{t-1}/K]\bullet \eta_t$$

Where:

P_{t-1} is exploitable biomass (as a proportion of carrying capacity) for year t-1
C_{t-1} is catch for year t-1
(Meyer and Millar, 1999a, 1999b).
K is carrying capacity (level of stock biomass at equilibrium prior to commencement of a fishery)
r is the intrinsic rate of population growth
η_t 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, 1999b).

An observation equation is used to relate the unobserved biomass, P_t, to the research vessel survey indices:

$$I_t=q\bullet P_t \bullet \varepsilon_t$$

Where:

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

Input data are given in Table 7 and shown in Figure 12 scaled to each series mean. The model formulation is given in Appendix 1 and uses the same specifications as in 2018, with the exception that the number of chains for this assessment was 3, compared to 2 in the previous assessment and the number of iterations was increased from 200 000 to 500 000. The priors on r and initial population size were uninformative, with a uniform distribution ranging from 0.01 to 1 and 0.5 to 1, respectively. The prior for K was also intended to be uninformative, with a mean of 150 and very large CV (1000%) .

Priors used in the model were:

Initial population size	Pin~dunif(0.5, 1)	uniform(0.5 to 1)
Intrinsic rate of natural increase	r ~ dunif(0.01,1)	uniform (0.01 to 1)
Carrying capacity	K~dlnorm(2.703,0.2167)	lognormal (mean, precision)
Survey catchability	q ~dgamma(1,1)	gamma(shape, rate)
Process error	sigma ~ dunif(0,5) isigma2= $sigma^{-2}$	uniform(0 to 5)
Observation error	tau~dgamma(1,1) itau2 = 1/tau	gamma(shape, rate)

The model fit and convergence diagnostics were good for all surveys with no apparent trend in process error (see Figures 13-17, Table 11 and Appendix 2). Posteriors for r and K are updated from their priors (Fig. 15). The production model estimated that an *MSY* of 18 730 tons can be taken from a biomass of 89 790 tons at a fishing mortality of 0.21. Intrinsic rate of natural increase is estimated to be 0.42 and carrying capacity 180 000 tons. The relative biomass and fishing mortality estimates from the model are given in Figure 18. Biomass showed a continuous decline from the late 1960s to the mid-1970s, stabilized through to the mid-1980s, before declining further until about 1994, when the moratorium was imposed. The analysis showed that relative biomass (B_t/B_{msy}) was below the level at which *MSY* can be produced from 1973 to 1997, and at its minimum in 1992 the ratio was about 0.4. Since then, the stock increased rapidly to a point where B_t/B_{msy} >1.0, and at the beginning of 2021, the relative biomass B_t/B_{msy} is estimated to be 1.44 (90% CL = 0.98, 2.01).

The relative fishing mortality rate (F_t/F_{msy}) was high during most of the historical fishery (Fig. 18), in particular during the mid to late 1980s to the early 1990s when landings were often double the TAC (Fig.1). Since the fishery re-opened in 1998, the fishing mortality rate gradually increased and since 2001 the *F*-ratios were lower than half of F_{msy}. If catches are similar to recent levels (10 900t) in 2021, the *F*-ratio is estimated to be 0.40 (90% CL = 0.27, 0.63). Catches since 2014 have been lower than the estimated surplus production, however catch in 2020 is very near that value (Fig. 19).

The model results and diagnostics from this Bayesian formulation are similar to those from the 2018 assessment of this stock (Table 8).

Precautionary Approach Framework

The surplus production model outputs indicate that the stock is presently 1.4 times B_{MSY} and F is below F_{MSY} (Fig. 20). 30% B_{MSY} is considered a suitable limit reference point (B_{lim}) for stocks where a production model is used. At present, the risk of the stock being below B_{lim} = 30% B_{msy} or F> F_{MSY} is very low (<1%). The stock is, therefore, in the safe zone as defined in the NAFO Precautionary Approach Framework (NAFO 2004).

Projections

Medium-term projections were carried forward to the year 2025 under two catch scenarios for 2021. One set of projections assumed the catch in 2021 equalled the average of the last two years of catch (13 800 tons) and the other scenario assumed catch in 2021 was equal to the TAC (17 000 tons). Constant fishing mortality was applied from 2022-2025 at several levels of F (F=0, $F_{status\ quo}$=0.0978, 2/3 F_{MSY}, 85% F_{MSY}, and F_{MSY} =0.21) for both scenarios. Projected trends in relative biomass and fishing mortality are shown in Figures 21-24.

Fishing at F_{MSY} would first lead to a considerable yield in 2022, but yields are then projected to decline in the medium term with catch at 2/3 F_{MSY}, 85% F_{MSY}, and F_{MSY} (Table 9). At the end of the projection period, the risk of biomass being below B_{lim} is less than 1% in all cases.

The probability that $F > F_{lim=}\ F_{MSY}$ in 2022-2024 was less than 0.04 for the $F_{status\ quo}$ projections in both scenarios (Table 10). At 2/3 F_{MSY}, the probability that F > F_{lim} was between 0.07 and 0.10 in the medium term for the $Catch_{2021}$ scenario, and between 0.8 and 0.11 for the scenario where $Catch_{2021}$= TAC (17 000 tons). Projected at the level of 85% F_{lim}, the probability that F > F_{lim} is between 0.26 and 0.30 and for F_{msy} projections, this probability increased to 0.50 (for both scenarios). For biomass projections, in all scenarios for 2021-2025, the probability of biomass being below B_{lim} was less than 0.01. For the $Catch_{2021}$=13 800 ton scenario, the probability that biomass in 2025 is greater than B_{2021} is 0.50, 0.42, 0.33 and 0.27 for $F_{status\ quo}$, 2/3 F_{msy}, 85% F_{msy}, and F_{msy} respectively. For the $Catch_{2021}$=TAC projections, P(B_{2025}>B_{2021}) for the same levels of F are 0.48, 0.41, 0.32 and 0.26. The projections with no fishing after 2021 (F=0) are the only projections to predict growth of the stock and the P(B_{2025}>B_{2021}) was 83% and 82% for the two scenarios examined.

Concerns have been raised that the projections from the stock production model may be optimistic as ecosystem and fish productivity conditions have shown decline while the entire process error distribution (i.e. representative of both positive and negative conditions) is carried forward in the projections and risk-based advice.

Summary

The assessment model indicates that Div. 3LNO yellowtail flounder stock size estimates remain high, at 1.4X B_{MSY}. There are also indications that recruitment has been above average in recent years. Fishing mortality is estimated to be below 2/3 F_{MSY}, and well below the limit reference point (F_{LIM} = F_{MSY}), and at levels of F between 2/3 F_{MSY} and 85% F_{MSY}, the stock is not projected to decrease below B_{LIM} in the medium term (to 2025).

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Table 1. Nominal catches by country and TACs (tons) of yellowtail in NAFO Divisions 3LNO.

Year	Canada	France	USSR/Rus.	S.Korea[a]	Other [b]	Total	TAC
1960	7	-	-	-	-	7	
1961	100	-	-	-	-	100	
1962	67	-	-	-	-	67	
1963	138	-	380	-	-	518	
1964	126	-	21	-	-	147	
1965	3075	-	55	-	-	3130	
1966	4185	-	2,834	-	7	7026	
1967	2122	-	6,736	-	20	8878	
1968	4180	14	9146	-	-	13340	
1969	10494	1	5,207	-	6	15708	
1970	22814	17	3,426	-	169	26426	
1971	24206	49	13087	-	-	37342	
1972	26939	358	11929	-	33	39259	
1973	28492	368	3,545	-	410	32815	50000
1974	17053	60	6,952	-	248	24313	40000
1975	18458	15	4,076	-	345	22894	35000
1976	7910	31	57	-	59	8057	9000
1977	11295	245	97	-	1	11638	12000
1978	15091	375	-	-	-	15466	15000
1979	18116	202	-	-	33	18351	18000
1980	12011	366	-	-	-	12377	18000
1981	14122	558	-	-	-	14680	21000
1982	11479	110	-	1,073	657	13319	23000
1983	9085	165	-	1,223	-	10473	19000
1984	12437	89	-	2,373	1836 [b]	16735	17000
1985	13440	-	-	4,278	11245 [b]	28963	15000
1986	14168	77	-	2,049	13882 [b]	30176	15000
1987	13420	51	-	125	2718	16314	15000
1988	10607	-	-	1,383	4166 [b]	16158	15000
1989	5009	139	-	3,508	1551	10207	5000
1990	4966	-	-	5903	3117	13986	5000
1991	6589	-	-	4156	5458	16203	7000
1992	6814	-	-	3825	123	10762	7000
1993	6747	-	-	-	6868	13615	7000
1994	-	-	-	-	2069	2069	7000
1995	2	-	-	-	65	67	0
1996	-	-	-	-	232	232	0
1997	1	-	-	-	657	658	0
1998	3739	-	-	-	647	4386	4000
1999	5746	-	96	-	1052 [b]	6894	6000
2000 [c]	9463	-	212	-	1486	11161	10000
2001 [c]	12238	-	148	-	1759	14145	13000
2002 [c]	9959	-	103	-	636	10698	13000
2003 [c]	12708	-	184	-	914 [e]	13806	14500
2004	12575	-	158	-	621	13354	14500
2005	13140	299	8	-	486	13933	15000
2006	177	-	1	-	752	930	15000
2007	3673	-	76	-	874	4623	15500
2008	10217	384	143	-	659	11403	15500
2009	5416	87	3	-	662	6168	17000
2010	8070	580	101	-	628	9379	17000
2011	3946	338	82	-	863	5229	17000
2012	1795	321	84	-	1483	3683	17000
2013	7999		166	-	2597	10762	17000
2014	6750	6	85	-	1095	7936	17000
2015	5581			-		5581	17000
2016	6327	322	81	-	2597	9327	17000
2017	6262	280	85	-	2329	8956	17000
2018	7134		83	-	1477	8694	17000
2019	11535	338	82	-	880	12835	17000
2020	13478	329	84	-	913	14804	17000

[a] South Korean catches ceased after 1992
[b] includes catches estimated from Canadian surveillance reports
[c] provisional
[d] no directed fishery permitted
[e] Includes catches averaged from a range of estimates

Table 2. Canadian catches (tons) by NAFO Division from 1973 to 2020. Data are preliminary from Canadian ZIF statistics and may be slightly different from STATLANT or CESAG data.

	OTTER TRAWL				
YEAR	3L	3N	30	3LNO	OTHER GEARS
1973	4188	21470	2827	28475	17
1974	1107	14757	1119	16983	70
1975	2315	13289	2852	18456	2
1976	448	4978	2478	7904	6
1977	2546	7166	1583	11295	0
1978	2537	10705	1793	15035	56
1979	2575	14359	1100	18034	82
1980	1892	9501	578	11971	40
1981	2345	11245	515	14105	17
1982	2305	7554	1607	11466	13
1983	2552	5737	770	9059	26
1984	5264	6847	318	12429	8
1985	3404	9098	829	13331	9
1986	2933	10196	1004	14133	35
1987	1584	10248	1529	13361	59
1988	1813	7146	1475	10434	173
1989	844	2407	1506	4757	252
1990	1263	2725	668	4656	310
1991	798	2943	2284	6025	564
1992	95	1266	4633	5994	820
1993	0	2062	3903	5965	782
1994	0	0	0	0	0
1995	0	0	0	0	2
1996	0	0	0	0	0
1997	0	1	0	1	0
1998	0	2968	742	3710	29
1999	0	5636	107	5743	3
2000	1409	7733	278	9420	43
2001	183	8709	3216	12108	130
2002	22	7707	2035	9764	195
2003	28	8186	4482	12696	1
2004	2760	7205	2609	12574	3
2005	284	10572	2283	13139	1
2006	-	176	-	176	1
2007	5	2053	1615	3672	1
2008	985	6976	2249	10210	6
2009	224	3228	1958	5410	3
2010	113	5584	2372	8069	2
2011	166	2850	930	3946	1
2012	199	1171	424	1795	0
2013	82	6073	1844	7999	0
2014	2	5815	932	6750	0
2015	2	3148	2431	5581	0
2016	24	5622	681	6327	0
2017	0	5180	1082	6262	0
2018	9	5704	1421	7134	0
2019	9	11474	52	11535	0
2020	1	12397	1071	13469	0

Table 3. Monthly catch (t) of yellowtail flounder by Canadian vessels in NAFO Divs. 3LNO from 2010-2020.

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
2010	288	274	431	1345	1420	1147	0	68	486	993	766	855
2011	343		221	917	1109	1306	50	1				
2012				398	382	506	0			49	390	70
2013	329	529	1316	478	829	830		278	1058	1074	849	431
2014	559	778	824	802	721	1002			168	418	1152	325
2015		241	39	352	879	535		228	284	721	1500	802
2016	774	340			390	1209	247	122	825	884	902	634
2017	271	313	4	442	894	1140	592		590	537	682	797
2018	107	88		21	800	1459	518	0	605	1548	1249	739
2019	581	373	523	533	806	1758	520	0	371	2108	2015	1060
2020	776	406	71	882	1890	614	191	313	1251	2388	1766	2920

Table 4. Estimates of Abundance (000s), mean number, biomass (000t) and mean weight (kg) per tow for Canadian Spring surveys of NAFO Divisions 3LNO 1984-2019. Surveys in 2006 and 2015 did not cover the entire stock area and estimates are not considered representative. There was no survey in 2020.

	Abundance (millions)				Mean number per tow				Biomass ('000t)				Mean weight (kg) per tow			
	3L	3N	3O	3LNO	3L	3N	3O	3LNO	3L	3N	3O	3LNO	3L	3N	3O	3LNO
1984	45.4	435.3	63.5	544.2	22.1	189.7	25.8	79.9	21.9	167.7	28.2	217.7	10.7	73.1	11.4	32.0
1985	49.9	240.1	84.1	374.1	9.4	104.6	34.2	37.1	21.1	88.2	37.5	146.8	4.0	38.4	15.2	14.6
1986	26.9	229.5	70.1	326.5	5.3	100.0	28.5	33.3	12.6	95.1	30.5	138.2	2.5	41.5	12.4	14.1
1987	12.3	291.0	90.9	394.2	2.4	128.1	36.9	40.2	5.8	77.5	41.2	124.6	1.1	34.1	16.7	12.7
1988	8.1	135.3	59.7	203.1	1.6	58.9	24.2	20.7	3.7	51.4	25.8	81.0	0.7	22.4	10.5	8.2
1989	7.9	478.3	46.7	532.9	1.6	208.4	18.9	54.3	4.0	78.3	21.5	103.8	0.8	34.1	8.7	10.6
1990	4.7	305.5	57.3	367.4	0.9	133.1	23.9	37.7	2.2	75.7	25.1	103.1	0.4	33.0	10.5	10.6
1991	2.2	268.1	50.0	320.3	0.4	111.7	19.7	32.5	1.1	69.1	23.3	93.4	0.2	28.8	9.2	9.5
1992	0.3	189.2	28.0	217.4	0.1	79.3	11.0	21.2	0.2	49.6	11.6	61.4	0.0	20.8	4.6	6.0
1993	0.2	145.0	101.1	246.3	0.0	60.4	39.8	24.0	0.1	50.8	42.4	93.3	0.0	21.1	16.7	9.1
1994	0.1	126.4	21.9	148.4	0.0	51.5	8.5	14.1	0.0	46.3	9.2	55.6	0.0	18.9	3.6	5.3
1995	0.0	158.8	28.5	187.4	0.0	66.1	11.2	18.2	0.0	57.9	12.7	70.6	0.0	24.1	5.0	6.9
1996	2.5	475.3	161.7	639.4	0.5	198.0	63.3	62.2	1.1	103.9	70.6	175.6	0.2	43.3	27.6	17.1
1997	1.2	554.9	139.4	695.5	0.2	233.2	54.6	67.7	0.5	121.3	53.2	174.9	0.1	51.0	20.8	17.0
1998	1.6	577.2	154.5	733.3	0.3	240.4	60.5	69.9	0.5	143.7	58.0	202.2	0.1	59.8	22.7	19.3
1999	55.4	965.4	269.1	1289.9	9.6	402.1	105.4	120.4	28.5	238.5	98.7	365.7	5.0	99.3	38.7	34.1
2000	40.7	695.3	186.5	922.5	7.6	289.6	73.1	89.6	17.5	197.3	72.1	287.0	3.3	82.2	28.3	27.9
2001	11.5	1119.9	197.2	1328.5	2.1	466.4	77.3	126.6	4.4	297.9	63.6	366.0	0.8	124.1	24.9	34.9
2002	1.6	528.3	161.0	690.9	0.3	220.0	63.1	66.5	0.6	147.3	51.6	199.5	0.1	61.4	20.2	19.2
2003	92.0	914.9	243.2	1250.1	16.9	381.0	95.3	120.2	34.7	280.2	72.0	386.9	6.4	116.7	28.2	37.2
2004	38.7	690.1	237.9	966.7	7.0	287.4	93.2	92.0	15.3	216.7	75.8	307.9	2.8	90.3	29.7	29.3
2005	115.6	822.0	227.1	1164.8	21.7	342.4	89.0	113.2	43.6	263.7	81.5	388.8	8.2	109.8	31.9	37.8
2006	251.5	1035.0	295.9	1582.4	47.1	660.7	169.8	183.0	85.7	319.1	99.1	503.8	16.0	203.7	56.9	58.3
2007	177.5	953.5	309.7	1440.7	33.3	397.1	121.4	140.0	60.9	292.8	89.3	443.0	11.4	121.9	35.0	43.0
2008	115.3	1114.6	250.6	1480.4	22.6	467.5	98.2	147.5	43.2	330.4	83.3	456.9	8.5	138.6	32.6	45.5
2009	47.0	751.6	117.9	916.4	8.8	313.0	46.2	89.0	13.2	213.5	44.4	271.2	2.5	88.9	17.4	26.3
2010	110.3	950.9	272.2	1333.3	21.0	396.0	106.7	130.8	28.6	276.9	89.2	394.7	5.5	115.3	35.0	38.7
2011	160.3	967.3	298.6	1426.1	29.7	402.9	117.7	137.9	55.8	266.9	100.2	422.9	10.3	111.1	39.5	40.9
2012	238.5	1184.6	269.1	1692.1	46.3	496.9	105.4	167.8	88.6	315.3	85.6	489.4	17.2	132.2	33.6	48.5
2013	210.6	955.5	196.5	1362.6	39.5	397.9	77.0	132.4	66.3	274.9	56.2	397.3	12.4	114.5	22.0	38.6
2014	101.0	773.6	204.7	1079.3	18.9	322.2	80.2	104.9	34.5	232.4	65.2	332.1	6.5	96.8	25.5	32.3
2015	10.5	433.8	213.3	657.6	3.4	180.7	83.6	82.2	4.0	144.3	71.8	220.2	1.3	60.1	28.1	27.5
2016	11.6	347.9	115.0	474.5	2.2	144.9	45.8	46.3	1.8	101.3	30.4	133.4	0.3	42.2	12.1	13.0
2017	76.5	552.5	111.5	740.5	54.9	231.8	43.7	117.0	18.3	167.9	27.9	214.1	13.1	70.4	10.9	33.8
2018	68.2	769.1	190.4	1027.6	13.9	320.3	74.6	104.4	21.4	222.9	59.1	303.4	4.4	92.8	23.2	30.8
2019	85.2	521.8	150.7	757.7	16.0	217.3	59.5	73.8	16.1	127.6	38.0	181.7	3.0	53.2	15.0	17.7
2020																

Table 5. Estimates of Abundance (000s), mean number, biomass (000t) and mean weight (kg) per tow for Canadian Autumn surveys of NAFO Divisions 3LNO 1990-2020. The survey in 2014 did not cover the entire stock area and estimates are not considered representative.

	Abundance (millions)				Mean number per tow				Biomass ('000t)				Mean weight (kg) per tow			
	3L	3N	3O	3LNO	3L	3N	3O	3LNO	3L	3N	3O	3LNO	3L	3N	3O	3LNO
1990	4.4	148.5	39.5	192.5	0.8	65.9	16.1	19.3	2.1	46.5	17.3	65.8	0.4	20.6	7.0	6.6
1991	2.1	212.3	82.7	297.1	0.4	92.1	33.1	29.3	1.0	50.9	30.5	82.4	0.2	22.1	12.2	8.1
1992	2.0	158.0	55.8	215.9	0.4	86.4	22.7	22.4	0.9	44.1	19.4	64.5	0.2	24.1	7.9	6.7
1993	2.6	327.7	41.6	371.9	0.5	137.7	16.4	37.4	1.1	94.2	17.5	112.8	0.2	39.6	6.9	11.3
1994	0.1	259.3	28.5	287.9	0.0	108.0	11.2	28.0	0.0	95.5	10.9	106.4	0.0	39.8	4.3	10.4
1995	3.6	509.0	79.6	592.2	0.7	212.0	31.2	57.3	1.2	102.8	25.7	129.8	0.2	42.8	10.1	12.6
1996	6.7	380.6	59.9	447.1	1.1	158.5	24.2	39.8	2.2	92.6	20.0	114.9	0.4	38.6	8.1	10.2
1997	6.1	685.8	135.2	827.1	1.0	285.6	53.3	73.1	1.3	190.3	53.7	245.3	0.2	79.3	21.2	21.7
1998	13.1	450.1	170.4	633.6	2.1	171.8	64.2	54.4	5.2	134.0	47.5	186.7	0.8	51.1	17.9	16.0
1999	20.6	743.1	176.5	940.3	3.5	312.4	71.4	87.8	9.6	193.0	48.4	250.9	1.6	81.1	19.6	23.4
2000	37.9	860.3	254.1	1152.3	6.1	320.3	91.5	98.8	12.5	252.8	69.7	335.0	2.0	94.1	25.1	28.7
2001	74.5	1314.7	262.7	1651.9	11.7	489.5	95.3	139.8	25.5	368.9	81.4	475.8	4.0	137.3	29.5	40.3
2002	33.1	971.3	170.4	1174.8	5.2	361.7	61.4	99.3	13.6	272.7	53.5	339.7	2.1	101.5	19.3	28.7
2003	58.9	869.6	334.1	1262.6	9.2	364.8	127.1	110.9	18.6	252.0	97.7	368.3	2.9	105.7	37.2	32.3
2004	63.4	1158.6	209.1	1431.0	13.4	485.5	81.9	147.8	22.2	291.6	60.9	374.7	4.7	122.2	23.9	38.7
2005	38.8	1146.7	190.8	1376.3	6.6	446.1	68.7	122.7	14.1	261.5	67.1	342.7	2.4	101.7	24.2	30.6
2006	61.9	814.1	172.5	1048.5	10.2	339.1	68.1	95.4	21.2	232.3	52.0	305.5	3.5	96.7	20.5	27.8
2007	91.0	1414.2	252.0	1757.2	15.3	526.6	90.8	154.0	28.0	377.8	76.5	482.4	4.7	140.7	27.6	42.3
2008	81.9	787.1	300.2	1169.2	15.3	327.8	117.6	113.6	27.8	214.8	79.4	322.0	5.2	89.5	31.1	31.3
2009	45.1	709.9	145.0	900.0	7.6	282.7	52.6	80.2	16.5	180.7	40.7	237.8	2.8	72.0	14.7	21.2
2010	135.7	1335.9	184.7	1656.3	22.0	558.4	72.4	149.1	35.9	336.4	44.9	417.2	5.8	140.6	17.6	37.5
2011	103.0	759.2	176.5	1038.7	19.4	316.2	69.2	101.2	35.3	217.7	57.4	310.4	6.7	90.7	22.5	30.2
2012	93.4	827.5	342.1	1262.9	17.5	344.6	134.1	122.7	25.8	218.7	112.9	357.4	4.8	91.1	44.2	34.7
2013	103.2	901.9	180.2	1185.4	19.2	375.7	70.6	114.9	36.4	251.9	57.8	346.1	6.8	104.9	22.7	33.5
2014	57.9	0.0	0.0	57.9	9.7	0.0	0.0	9.7	19.8	0.0	0.0	19.8	3.3	0.0	0.0	3.3
2015	96.7	821.1	143.6	1061.4	18.1	342.0	56.2	103.1	29.7	241.8	35.9	307.4	5.6	100.7	14.1	29.9
2016	109.0	793.8	189.6	1092.5	20.4	330.6	74.8	106.3	34.6	197.3	54.8	286.7	6.5	82.2	21.6	27.9
2017	101.5	888.1	239.5	1229.1	19.0	369.9	94.3	119.6	32.2	218.7	71.3	322.2	6.0	91.1	28.1	31.3
2018	137.7	682.4	215.4	1035.4	25.9	284.2	84.4	100.9	38.7	186.2	53.7	278.6	7.3	77.6	21.0	27.2
2019	68.4	740.4	155.8	964.6	12.8	308.4	61.0	93.7	22.4	165.8	42.2	230.4	4.2	69.0	16.5	22.4
2020	82.0	915.5	244.9	1242.4	15.4	382.9	96.0	120.8	19.1	225.7	61.3	306.1	3.6	94.4	24.0	29.8

Table 6. Length weight relationships used to produce an index of female SSB from the spring survey. The relationships are of the form log(weight)=(*a**log(length))+*b*)

Year	*a*	*b*
prior to 1990	3.10	-5.19
1990	3.19	-5.33
1991	3.05	-5.12
1992	3.02	-5.06
1993	3.11	-5.20
1994	3.09	-5.19
1995	3.10	-5.20
1996	3.09	-5.15
1997	3.09	-5.17
1998	3.05	-5.11
1999	3.15	-5.27
2000	3.17	-5.32
2001	3.09	-5.20
2002	3.08	-5.20
2003	3.09	-5.22
2004	3.12	-5.24
2005	3.17	-5.32
2006	3.09	-5.21
2007	3.25	-5.46
2008	3.22	-5.42
2009	3.14	-5.30
2010	3.10	-5.23
2011	3.14	-5.30
2012	3.23	-5.43
2013	3.16	-5.34
2014	3.16	-5.32
2015	3.13	-5.27
2016	3.11	-5.26
2017	3.07	-5.20
2018	3.21	-5.39
2019	3.12	-5.26

Table 7. Nominal catch (000t) and survey series included in the assessment of yellowtail flounder in 2021. Canadian surveys in 2006 and 2015 spring and 2014 autumn were incomplete and results may not be comparable to other years. There were no surveys in spring 2020 by either Canada or Spain.

Year	Nominal catch (000 t)	Yankee survey (000 t)	Russian survey (000 t)	Campelen spring (000 t)	Campelen fall (000 t)	Spain survey (000 t)
1965	3.1					
1966	7.0					
1967	8.9					
1968	13.3					
1969	15.7					
1970	26.4					
1971	37.3	96.9				
1972	39.3	79.2				
1973	32.8	51.7				
1974	24.3	40.3				
1975	22.9	37.4				
1976	8.1	41.7				
1977	11.6	65.0				
1978	15.5	44.3				
1979	18.4	38.5				
1980	12.4	51.4				
1981	14.7	45.0				
1982	13.3	43.1				
1983	10.5					
1984	16.7		132.0	217.7		
1985	29.0		85.0	146.8		
1986	30.2		42.0	138.2		
1987	16.3		30.0	124.6		
1988	16.2		23.0	81.0		
1989	10.2		44.0	103.8		
1990	14.0		27.0	103.1	65.8	
1991	16.2		27.5	93.4	82.4	
1992	10.8			61.4	64.5	
1993	13.6			93.3	112.8	
1994	2.1			55.6	106.4	
1995	0.1			70.6	129.8	9.3
1996	0.2			175.6	114.9	43.3
1997	0.7			174.9	245.3	38.7
1998	4.4			202.2	186.7	122.6
1999	6.9			365.7	250.9	197.0
2000	11.2			287.5	335.0	144.7
2001	14.2			366.0	475.8	182.7
2002	10.7			199.5	339.7	148.5
2003	13.8			386.5	368.3	136.8
2004	13.4			307.9	374.7	170.0
2005	13.9			388.8	342.7	156.5
2006	0.9			★	305.5	160.1
2007	4.6			443.0	482.4	160.7
2008	11.4			456.9	322.0	160.1
2009	6.2			271.2	237.8	183.4
2010	9.4			394.7	417.2	189.7
2011	5.2			422.9	310.4	203.8
2012	3.7			489.4	357.4	195.6
2013	10.7			397.3	346.1	188.0
2014	8.0			332.1	★	136.5
2015	6.9			★	307.4	140.8
2016	9.3			133.4	286.7	153.7
2017	9.0			214.1	322.2	95.9
2018	8.7			303.4	278.6	107.7
2019	12.8			181.7	230.4	42.6
2020	14.8			★	306.1	★

Table 8. Assessment results for Divs 3LNO yellowtail flounder: the accepted 2021 surplus production model in a Bayesian framework, compared to the 2018 assessment.

Run	2018 Assessment	2021 Assessment
Prior on r (mean, sd)	uniform 0.01-1	uniform 0.01-2
Prior on K (mean,sd)	normal(150,1500)	normal(150,1500)
B_{msy}	87.63 kt	89.79 kt
MSY	18.76 kt	18.7 kt
F_{msy}	0.214	0.2085
K	175 kt	180 kt
r	0.43	0.42
q.Fall	2.29	2.18
q.Russian	0.83	0.80
q.Spanish	0.95	0.87
q.Spring	2.16	2.07
q.Yankee	0.65	0.62
Pin	0.77	0.77
deviance	1038	1099
sigma	0.12	0.13
tau.Fall	0.04	0.03
tau.Russian	0.19	0.19
tau.Spanish	0.20	0.22
tau.Spring	0.07	0.07
tau.yankee	0.03	0.03

Table 9. Two scenarios (Catch$_{2021}$= average 2019 and 2020=13 800t and Catch$_{2021}$=TAC=17 000t) for medium-term projections for yellowtail flounder. Median and 90% confidence limits around relative biomass B/B_{msy}, are shown, for projected F values of F=0, $F_{\text{status quo}}$, 2/3 F_{msy}, 85% F_{msy} and F_{msy}.

Projections with catch in 2021= avg catch 2019-2020 (13 800 t)		
Year	Yield ('000t) median	Projected relative Biomass(B/B_{msy}) median (90% CL)
	F=0	
2022	0.00	1.43 (0.95, 2.01)
2023	0.00	1.59 (1.06, 2.21)
2024	0.00	1.72 (1.15, 2.34)
2025		1.8 (1.24, 2.42)
	$F_{status\ quo}$ = 0.112	
2022	14.35	1.43 (0.95, 2.01)
2023	14.31	1.43 (0.93, 2.03)
2024	14.29	1.43 (0.91, 2.02)
2025		1.43 (0.89, 2.03)
	2/3 F_{MSY} = 0.139	
2022	17.81	1.43 (0.95, 2.01)
2023	17.27	1.39 (0.9, 1.98)
2024	16.93	1.36 (0.85, 1.96)
2025		1.35 (0.81, 1.95)
	85% F_{MSY} =0.177	
2022	22.68	1.43 (0.95, 2.01)
2023	21.12	1.34 (0.85, 1.92)
2024	20.16	1.28 (0.77, 1.86)
2025		1.23 (0.7, 1.84)
	F_{MSY} =0.21	
2022	26.73	1.43 (0.95, 2.01)
2023	24.10	1.29 (0.81, 1.87)
2024	22.46	1.2 (0.7, 1.79)
2025		1.14 (0.61, 1.75)

Projections with catch in 2021= TAC=17 000 t)		
Year	Yield ('000t) median	Projected relative Biomass(B/B_{msy}) median (90% CL)
	F=0	
2022	0.00	1.39 (0.92, 1.97)
2023	0.00	1.56 (1.03, 2.18)
2024	0.00	1.69 (1.13, 2.32)
2025		1.78 (1.22, 2.41)
	$F_{status\ quo}$ = 0.112	
2022	13.99	1.39 (0.92, 1.97)
2023	14.06	1.4 (0.91, 2)
2024	14.12	1.41 (0.89, 2.01)
2025		1.42 (0.88, 2.02)
	2/3 F_{MSY} = 0.139	
2022	17.36	1.39 (0.92, 1.97)
2023	16.98	1.37 (0.87, 1.96)
2024	16.73	1.35 (0.83, 1.94)
2025		1.33 (0.8, 1.94)
	85% F_{MSY} =0.177	
2022	22.11	1.39 (0.92, 1.97)
2023	20.77	1.31 (0.83, 1.9)
2024	19.92	1.26 (0.75, 1.85)
2025		1.22 (0.69, 1.83)
	F_{MSY} =0.21	
2022	26.05	1.39 (0.92, 1.97)
2023	23.70	1.27 (0.79, 1.85)
2024	22.20	1.19 (0.68, 1.78)
2025		1.13 (0.59, 1.75)

Table 10. Yield (000 t) and risk (%) of B_y<B_{msy} and F_y>F_{msy} (F_{lim}=F_{msy}) at projected F values of $F_{status\ quo}$, 2/3 F_{msy}, 85% F_{msy} and F_{msy} for two catch scenarios in 2021: $Catch_{2021}$=average 2019 and 2020=13 800t and $Catch_{2021}$=TAC=17 000t.

	Yield ('000t)			**P(F>F_{lim})**				**P(B<B_{lim})**				**P(B<B_{MSY})**				
$Catch_{2021}$=13 800t	**2022**	**2023**	**2024**	**2022**	**2023**	**2024**	**2025**	**2022**	**2023**	**2024**	**2025**	**2022**	**2023**	**2024**	**2025**	**P(B_{2025}>B_{2021})**
F=0	0.00	0.00	0.00	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	7%	3%	2%	1%	83%
$F_{status\ quo}$ = 0.112	14.35	14.31	14.29	2%	3%	3%	3%	<1%	<1%	<1%	<1%	7%	8%	9%	9%	50%
2/3 F_{MSY} = 0.139	17.81	17.27	16.93	8%	8%	10%	10%	<1%	<1%	<1%	<1%	7%	10%	12%	14%	42%
85% F_{MSY} =0.177	22.68	21.12	20.16	26%	27%	28%	29%	<1%	<1%	<1%	<1%	7%	13%	18%	23%	33%
F_{MSY}=0.209	26.73	24.10	22.46	50%	50%	50%	50%	<1%	<1%	<1%	<1%	7%	16%	25%	32%	27%

	Yield ('000t)			**P(F>F_{lim})**				**P(B<B_{lim})**				**P(B<B_{MSY})**				
$Catch_{2021}$=17 000t	**2022**	**2023**	**2024**	**2022**	**2023**	**2024**	**2025**	**2022**	**2023**	**2024**	**2025**	**2022**	**2023**	**2024**	**2025**	**P(B_{2025}>B_{2021})**
F=0	0.00	0.00	0.00	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	9%	4%	2%	1%	82%
$F_{status\ quo}$ = 0.112	13.99	14.06	14.12	2%	3%	3%	4%	<1%	<1%	<1%	<1%	9%	9%	10%	10%	48%
2/3 F_{MSY} = 0.139	17.36	16.98	16.73	8%	9%	10%	11%	<1%	<1%	<1%	<1%	9%	11%	13%	15%	41%
85% F_{MSY} =0.177	22.11	20.77	19.92	27%	28%	29%	30%	<1%	<1%	<1%	<1%	9%	14%	20%	24%	32%
F_{MSY}=0.209	26.05	23.70	22.20	50%	50%	50%	50%	<1%	<1%	<1%	<1%	9%	18%	27%	34%	26%

Table 11. Convergence criteria and diagnostics for 2021 yellowtail flounder Bayesian surplus production model.

		Stats (miniter=1 maxiter=45000 sample=45000) Bin size for caculating Batch SE and (Lag 1) ACF=50									Geweke convergence diag. fraction in 1st window 0.1 fraction in last window 0.5 (between -2 and 2 is good)		Brooks, Gelman, and Rubin Convergence diagnostics (near 1 is good)		
	Chain	Mean	SD	Naïve SE	MC Error	Batch SE	Batch ACF	0.025	0.5	0.975	z-score	p-score	Potential Scale Reduction Factors	Multivariate SRF	Corrected SRF
K	1	188.604	45.953	0.217	1.156	0.949	0.147	128.400	179.400	302.600	1.3053	0.1918	1.001204	1.001816	0.975
	2	187.775	44.782	0.211	1.087	0.929	0.157	128.800	179.000	299.503	0.5990	0.5492			x 1.002253 1.005563
	3	189.405	46.014	0.217	1.144	0.981	0.209	129.100	180.300	306.103	-0.0098	0.9922			
r	1	0.419	0.096	0.000	0.002	0.002	0.105	0.235	0.417	0.614	-1.2049	0.2283	1.000837	1.001266	0.975
	2	0.420	0.095	0.000	0.002	0.002	0.139	0.238	0.418	0.615	-0.6617	0.5082			x 1.000841 1.003146
	3	0.417	0.096	0.000	0.002	0.002	0.177	0.233	0.415	0.613	0.1362	0.8917			
Sigma	1	0.135	0.035	0.000	0.000	0.000	0.052	0.075	0.131	0.213	0.0951	0.9242	0.9999883	0.9999935	0.975
	2	0.135	0.036	0.000	0.000	0.000	0.145	0.075	0.133	0.212	1.6576	0.0974			x 1.000013 1.000041
	3	0.135	0.036	0.000	0.000	0.000	0.089	0.074	0.132	0.214	-0.1196	0.9048			
q.Can Spr	1	2.072	0.431	0.002	0.009	0.008	0.129	1.237	2.070	2.933	-1.1186	0.2633	1.001067	1.001611	0.975
	2	2.075	0.431	0.002	0.010	0.008	0.135	1.239	2.073	2.932	-0.8551	0.3925			x 1.001088 1.00401
	3	2.062	0.430	0.002	0.010	0.008	0.180	1.222	2.059	2.913	0.1986	0.8426			
q.Can Fall	1	2.185	0.456	0.002	0.010	0.008	0.129	1.301	2.184	3.093	-1.0727	0.2834	1.000971	1.001467	0.975
	2	2.187	0.454	0.002	0.010	0.008	0.132	1.309	2.182	3.093	-0.9095	0.3631			x 1.000982 1.003648
	3	2.173	0.454	0.002	0.010	0.009	0.181	1.290	2.172	3.077	0.1344	0.8931			
q.Russia	1	0.817	0.219	0.001	0.004	0.003	0.123	0.440	0.800	1.292	-0.9950	0.3198	1.000652	1.000988	0.975
	2	0.819	0.220	0.001	0.004	0.003	0.129	0.442	0.802	1.304	-1.1428	0.2531			x 1.000763 1.002574
	3	0.815	0.219	0.001	0.004	0.003	0.178	0.434	0.800	1.295	0.1917	0.8480			
q.Yankee	1	0.624	0.174	0.001	0.004	0.003	0.117	0.307	0.619	0.989	-1.1595	0.2463	1.000465	1.000708	0.975
	2	0.625	0.173	0.001	0.004	0.003	0.136	0.310	0.618	0.985	-0.8984	0.3690			x 1.000514 1.001823
	3	0.622	0.174	0.001	0.004	0.003	0.203	0.302	0.615	0.982	0.3837	0.7012			
q.Spanish	1	0.880	0.199	0.001	0.004	0.003	0.121	0.509	0.871	1.292	-1.0379	0.2993	1.000938	1.001418	0.975
	2	0.881	0.198	0.001	0.004	0.003	0.123	0.514	0.874	1.291	-1.1634	0.2447			x 1.000947 1.003525
	3	0.875	0.197	0.001	0.004	0.003	0.170	0.502	0.868	1.278	0.1185	0.9057			

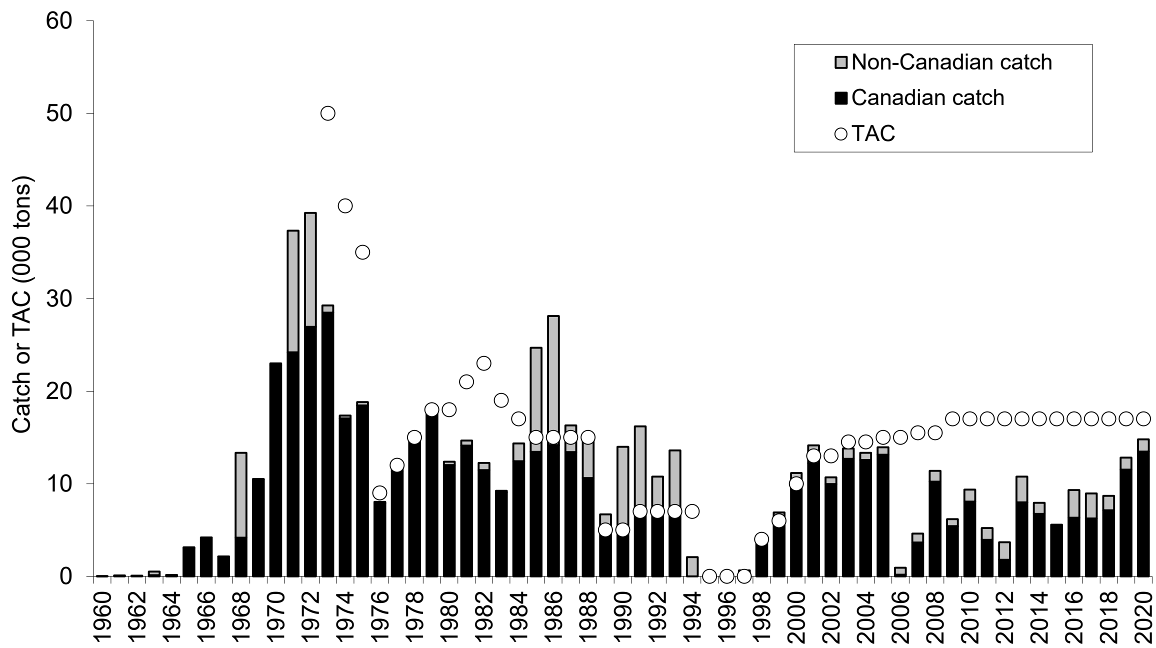


Figure 1. Catch (000t) and TAC of yellowtail flounder in NAFO Divisions 3LNO.

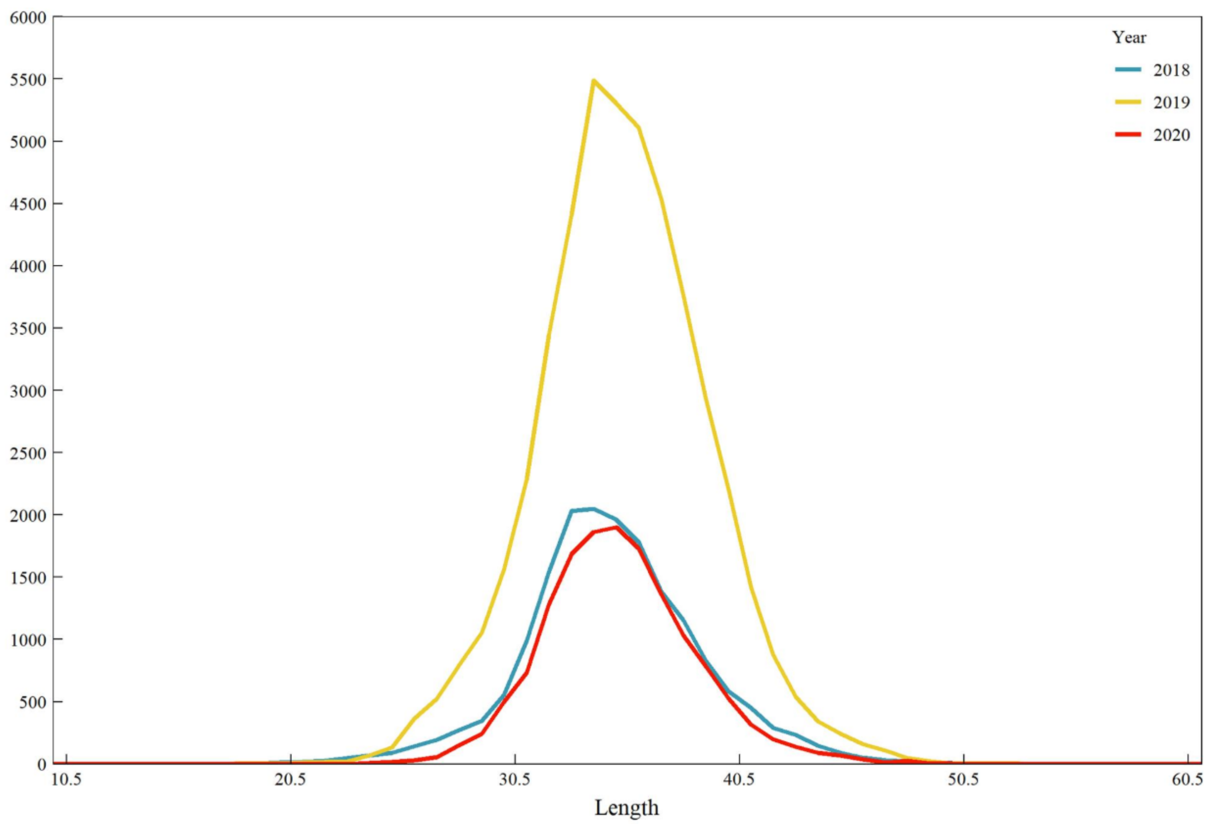


Figure 2. Length frequencies from the Canadian commercial ottertrawl fishery on Yellowtail Flounder in NAFO divs 3LNO from 2018-2020.

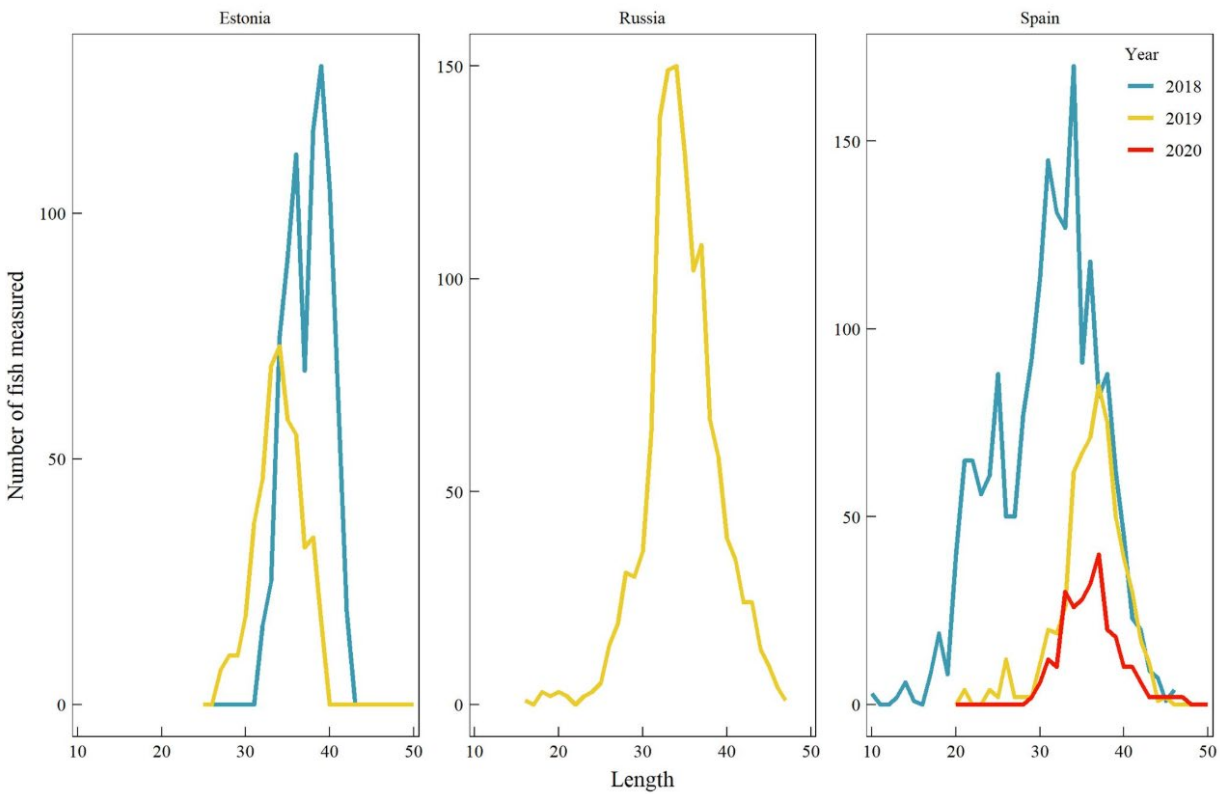


Figure 3. Length frequencies from commercial fisheries in the NRA of Divs 3NO conducted by Estonia, Russia, and Spain in 2018, 2019 and 2020.

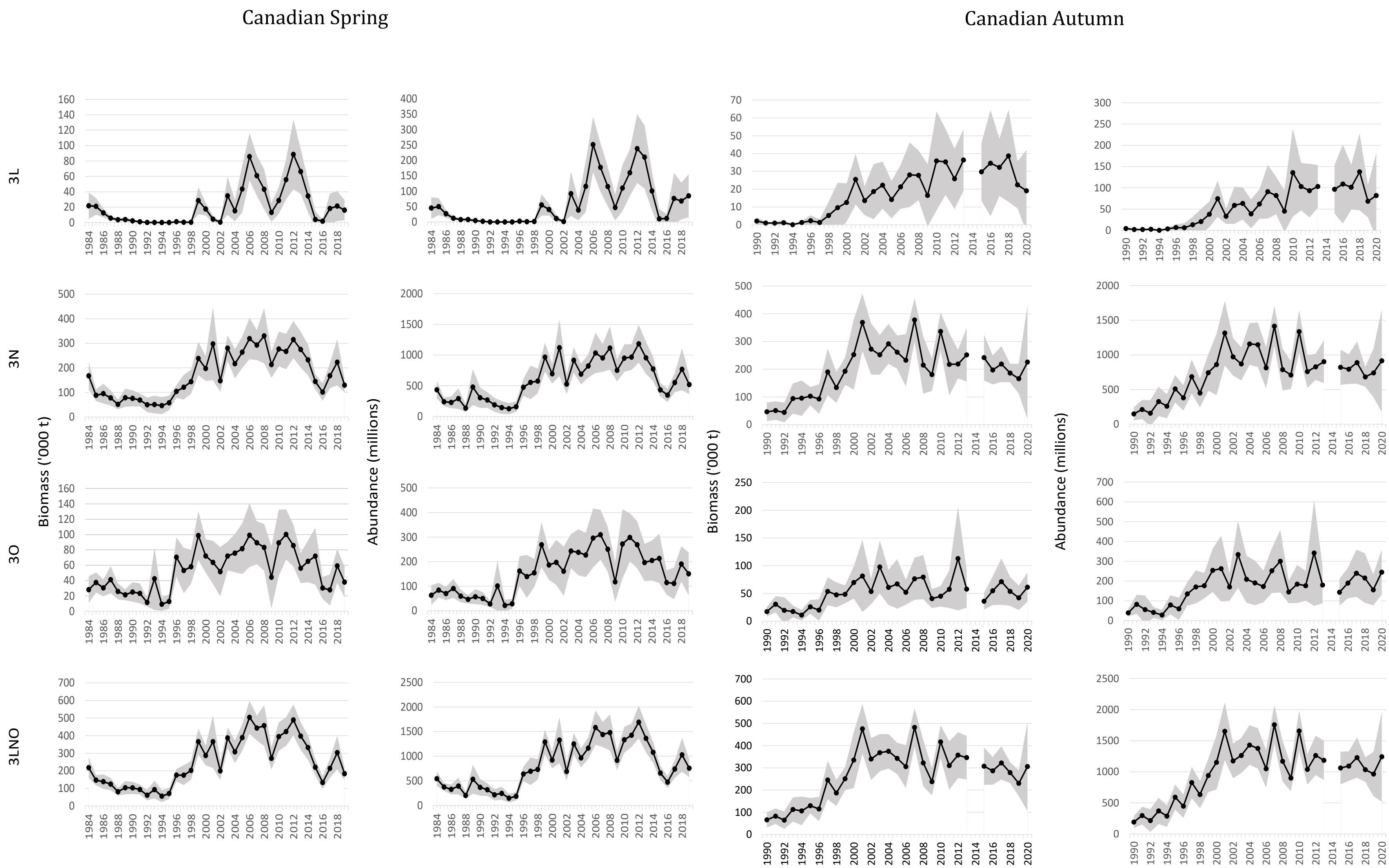


Figure 4. Estimates of biomass and abundance for yellowtail flounder in NAFO Divisions 3LNO from the Canadian spring and autumn surveys.

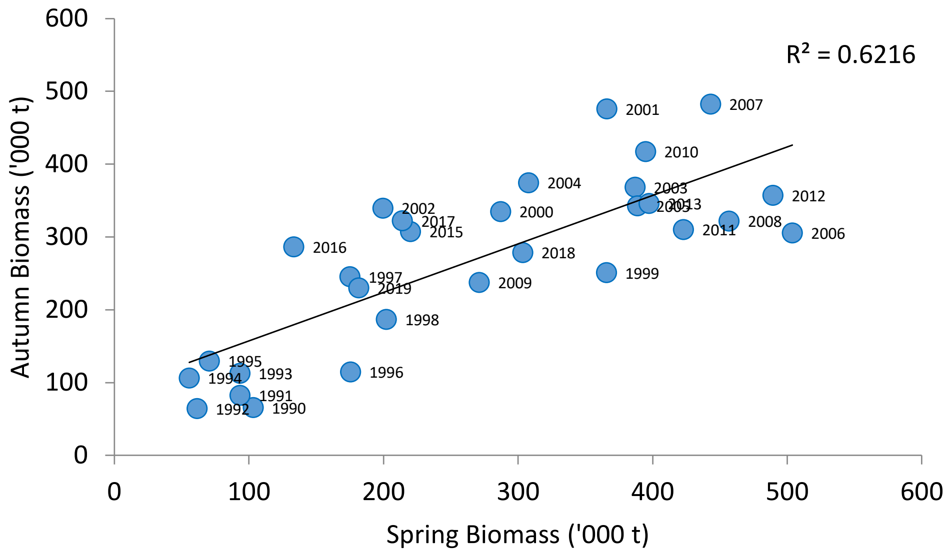


Figure 5. Regression of Canadian spring and autumn estimates of yellowtail flounder biomass in Divs. 3LNO, 1990-2019. Surveys in 2006 and 2015 spring, and 2014 autumn were incomplete; there was no spring survey in 2020.

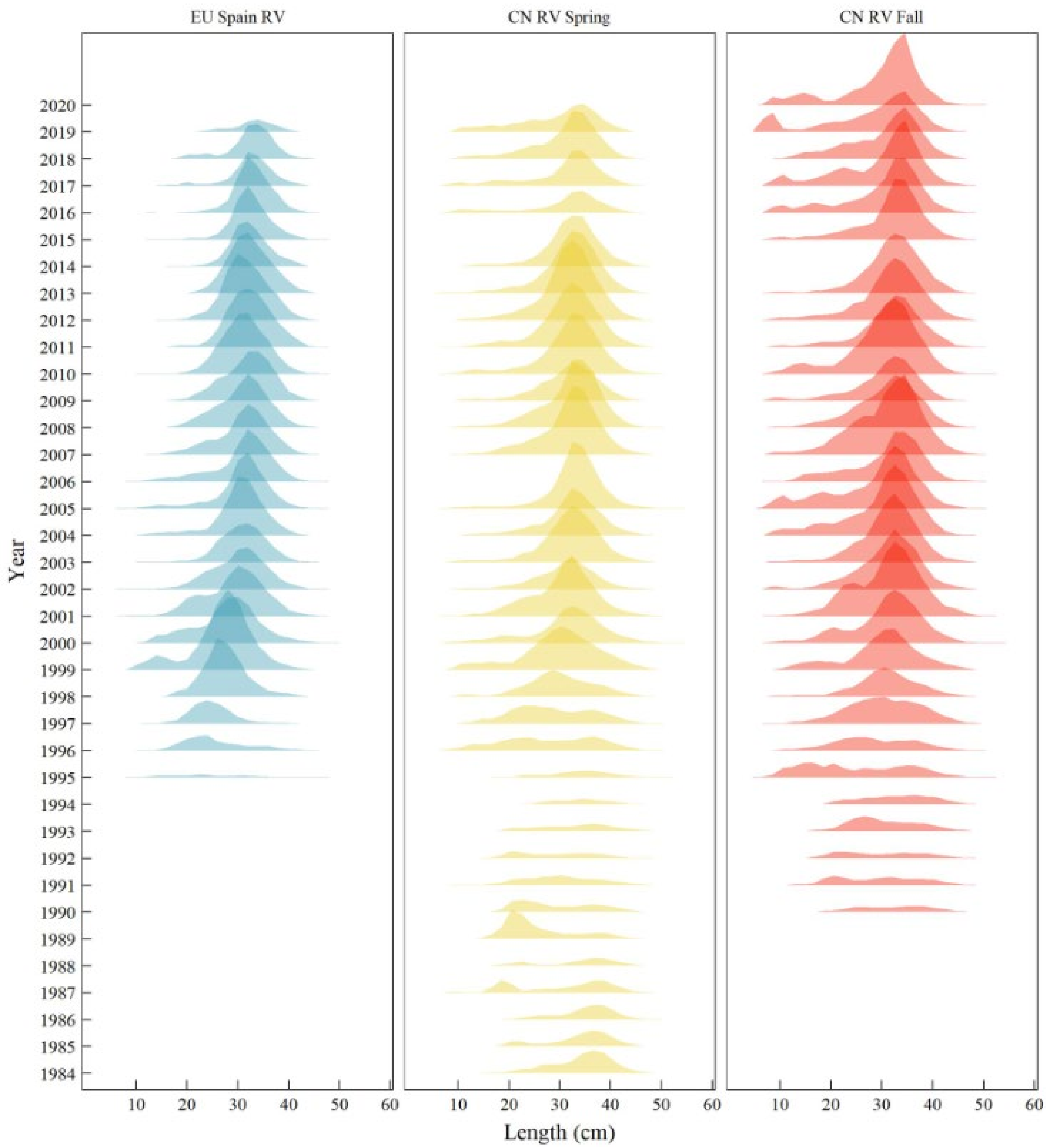


Figure 6. Abundance at length of yellowtail flounder in NAFO Divisions 3LNO from the Canadian spring and autumn surveys, and the Spanish survey of 3NO from 1984-2020. Canadian spring surveys for 2006 and 2015 and Canadian autumn survey of 2014 were incomplete. There were no surveys in spring of 2020 for Canada and Spain.

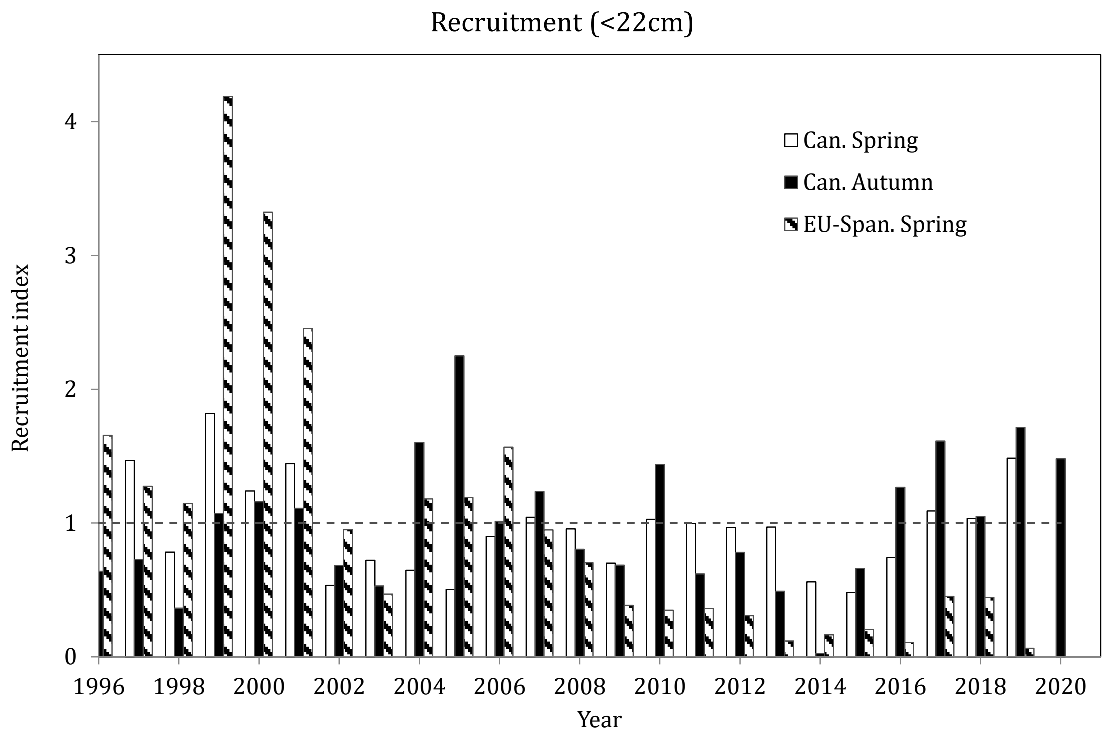


Figure 7. Population numbers (scaled to the means of 1996-2020) of yellowtail flounder less than 22cm in the Canadian spring and autumn surveys in NAFO Divisions 3LNO and the Spanish survey in the NRA.

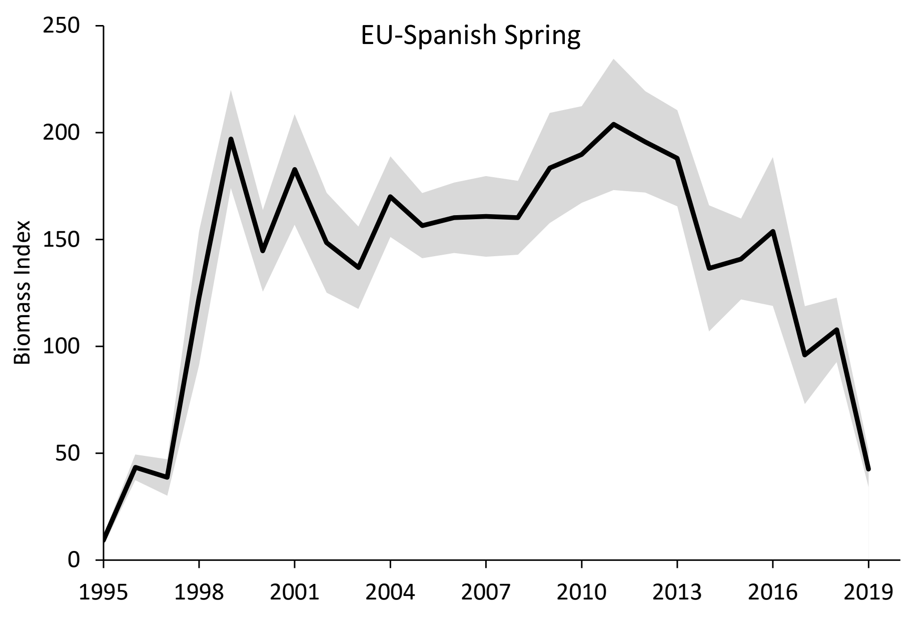


Figure 8. Converted biomass estimates (Campelen equivalents) from Spanish surveys in the NRA of NAFO Divisions 3NO. Error bars are ± 1 SD. There was no survey in 2020.

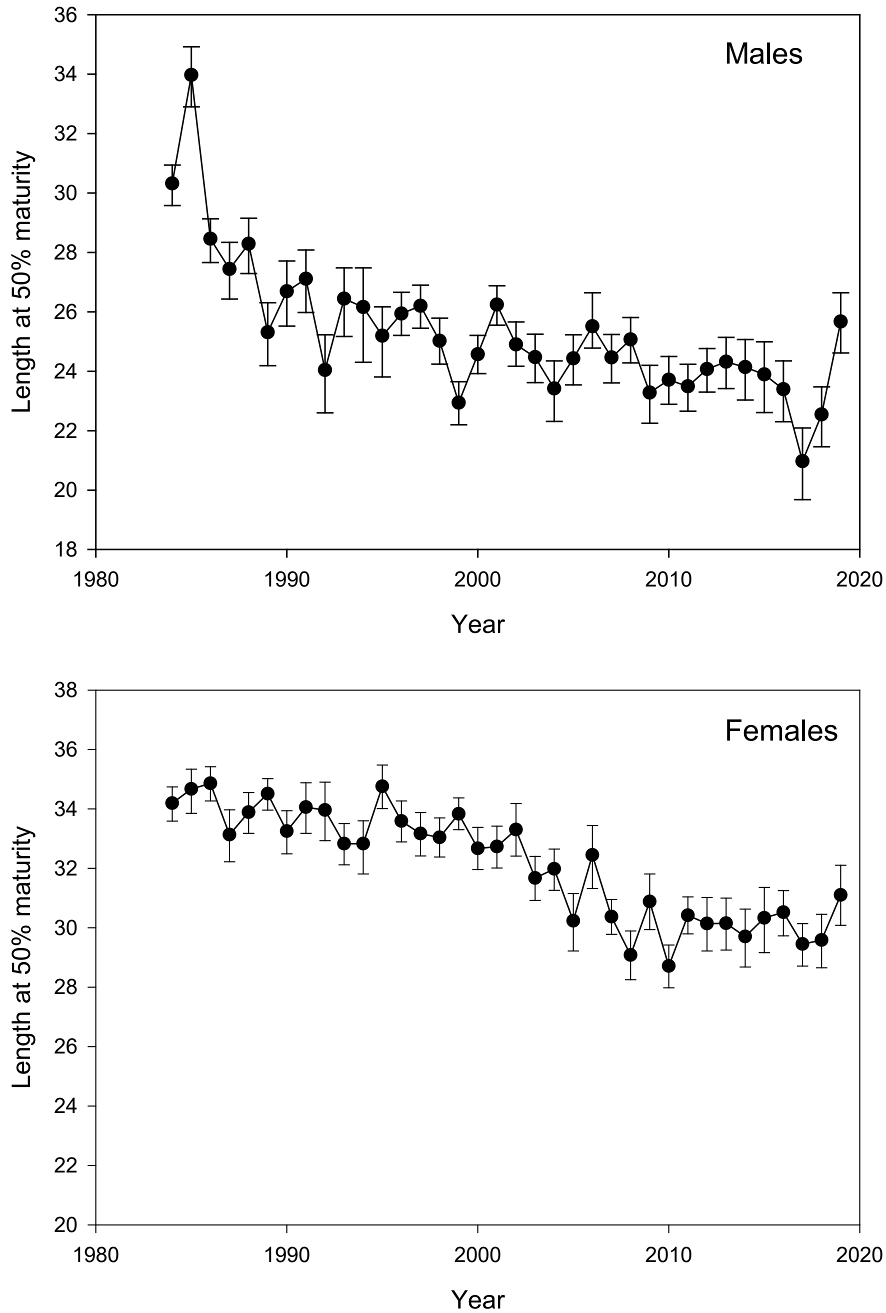


Figure 9. Length at 50% maturity of male and female yellowtail flounder from annual Canadian research vessel surveys of Div. 3LNO from 1984 to 2019.

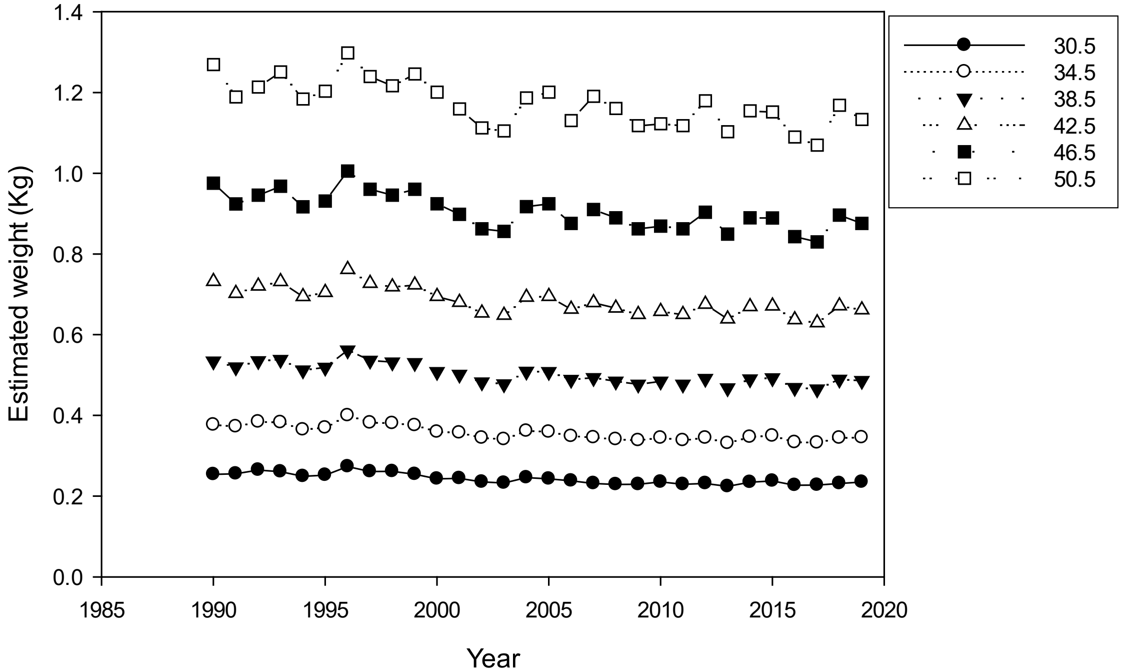


Figure 10. Estimated weight (Kg) at length (cm) for selected length groups for female yellowtail flounder in Div. 3LNO from Canadian spring surveys from 1990-2019.

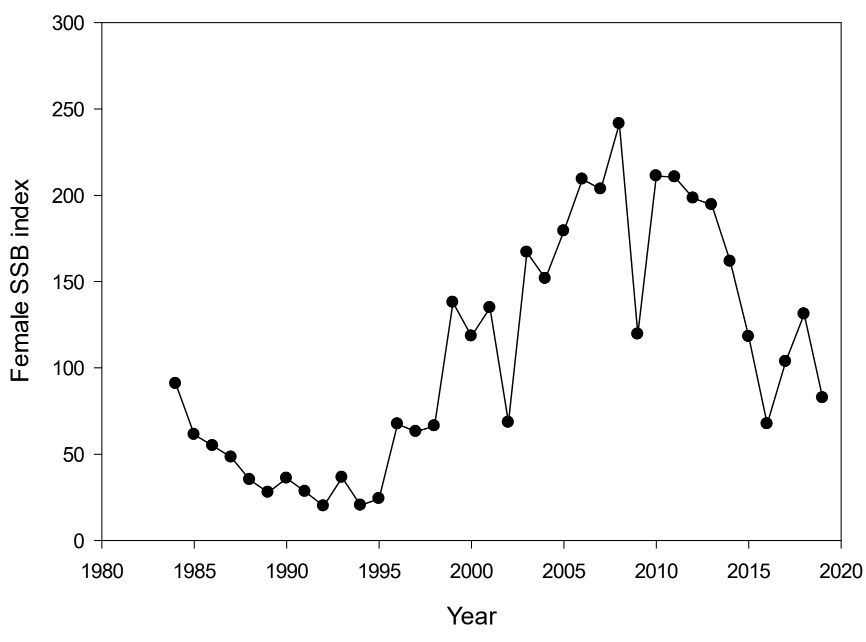


Figure 11. Index of female spawning stock biomass ('000t) for Div. 3LNO yellowtail flounder as calculated from Canadian spring research vessel surveys from 1984-2019 (the surveys in 2006 and 2015 were not considered representative; no survey in 2020).

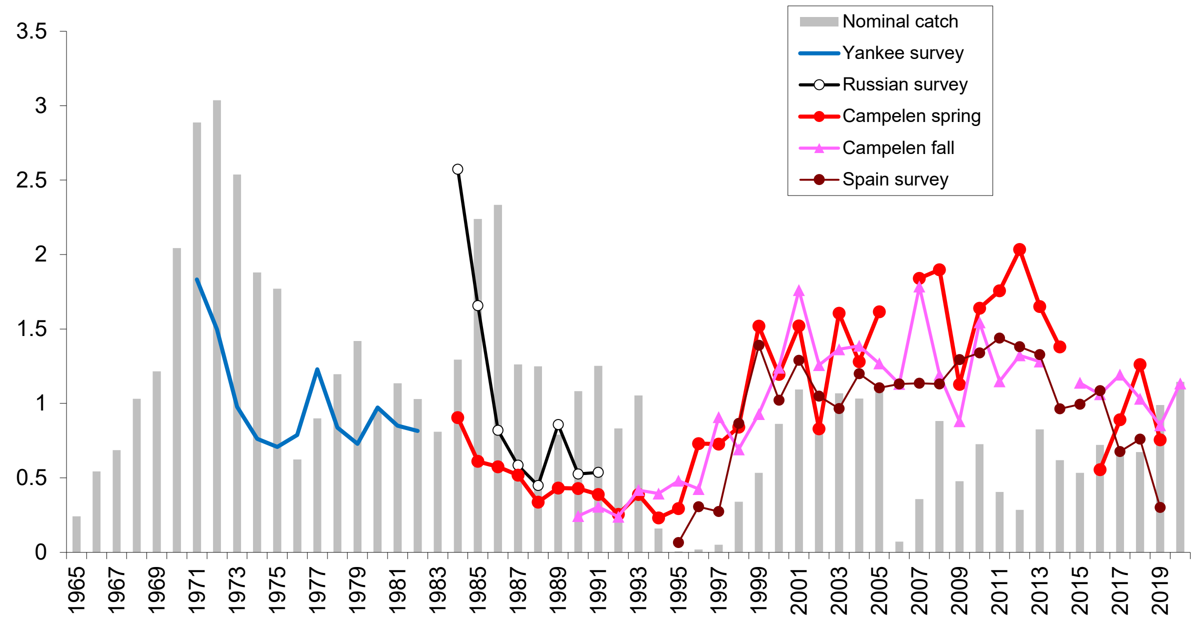


Figure 12. Nominal catch and survey series scaled to the mean for each of the indices used in the 2021 assessment of yellowtail flounder.

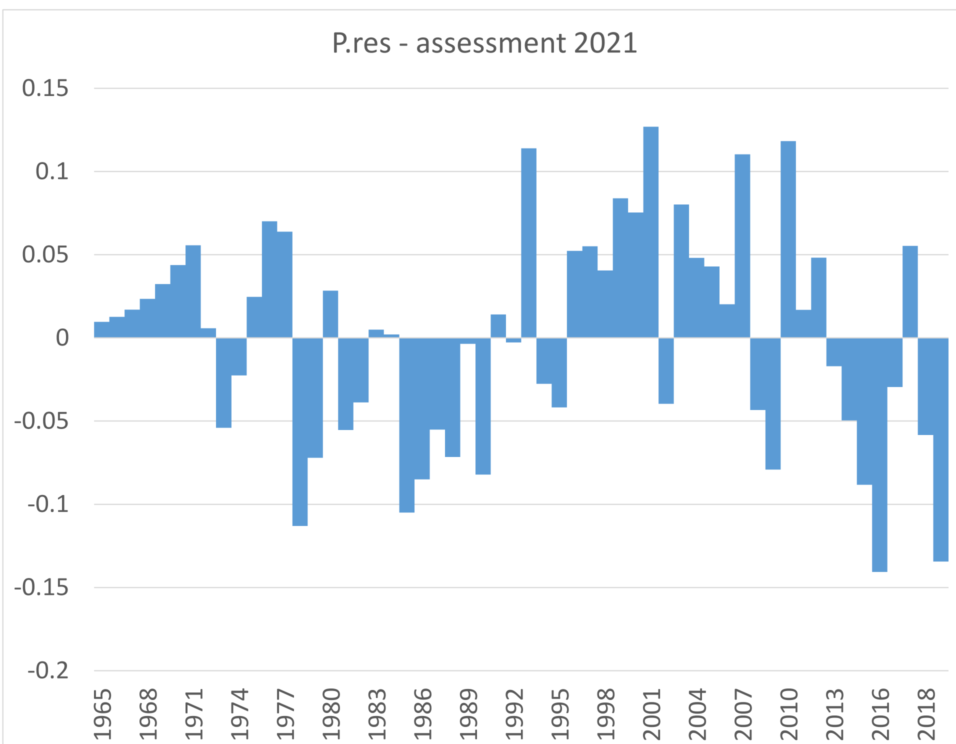


Figure 13. Process residuals for the 2021 assessment of Divs. 3LNO yellowtail flounder in a Bayesian framework.

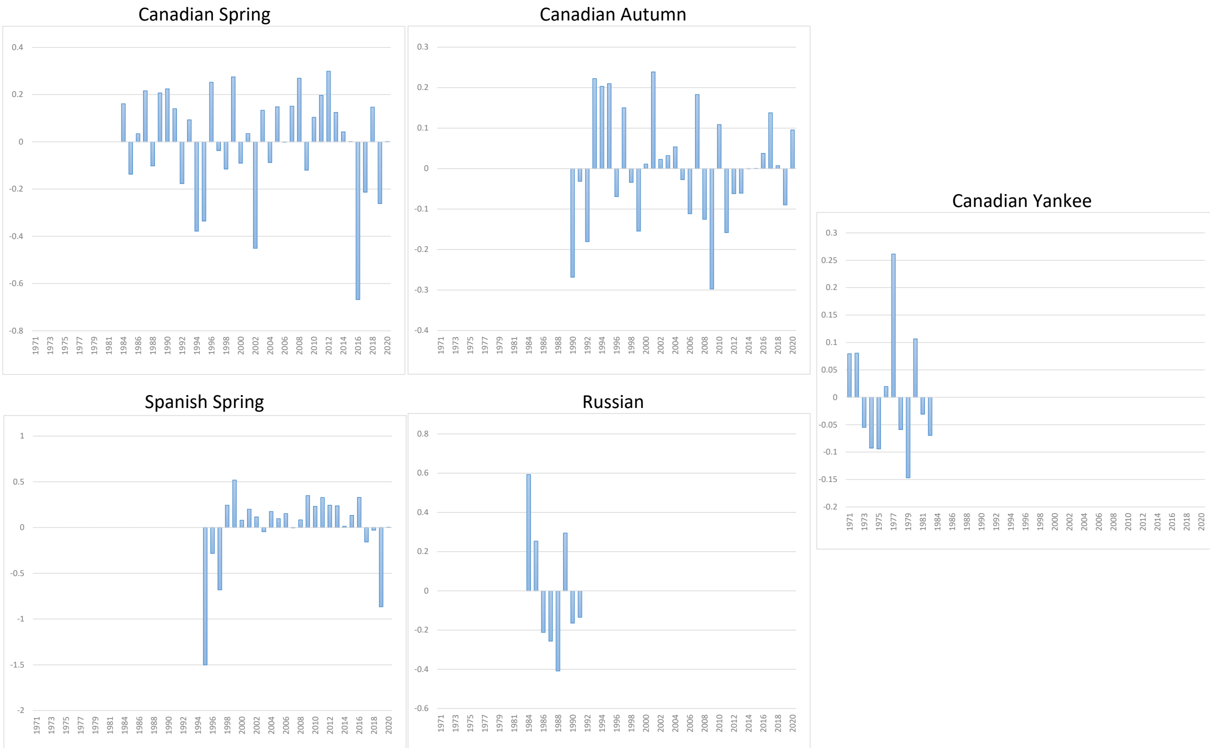


Figure 14. Residual plots for the survey indices from the surplus production model in a Bayesian framework for the assessment of yellowtail flounder in NAFO Divs. 3LNO.

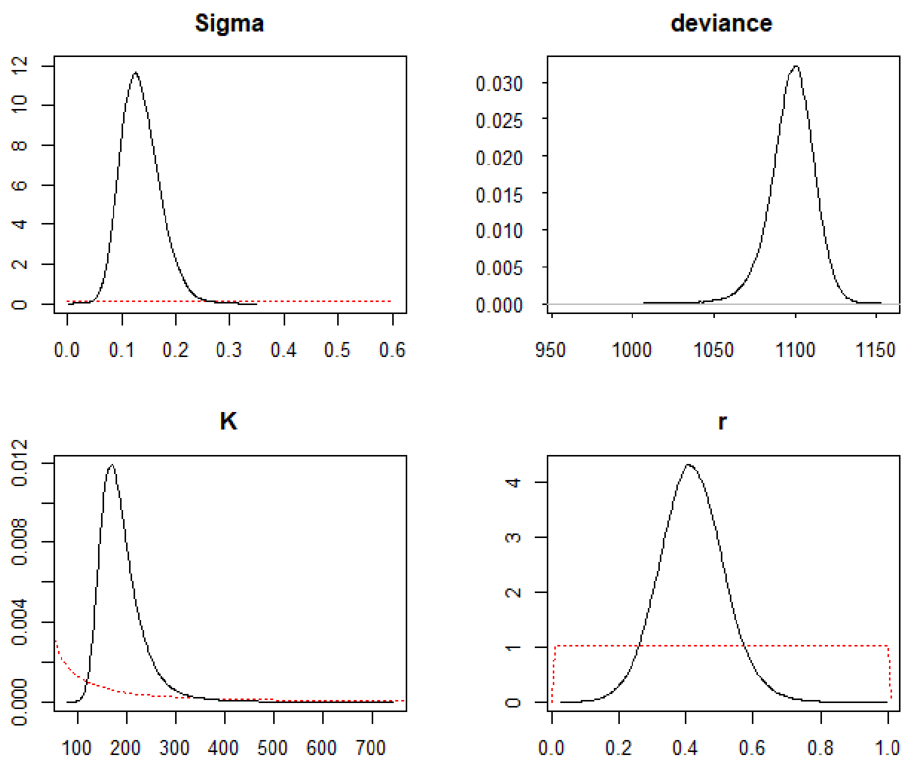


Figure 15. Priors (red line) and posteriors (black line) for sigma (process error), deviance, carrying capacity (K) and intrinsic rate of growth (r) for the 2021 yellowtail flounder surplus production model (Bayesian).

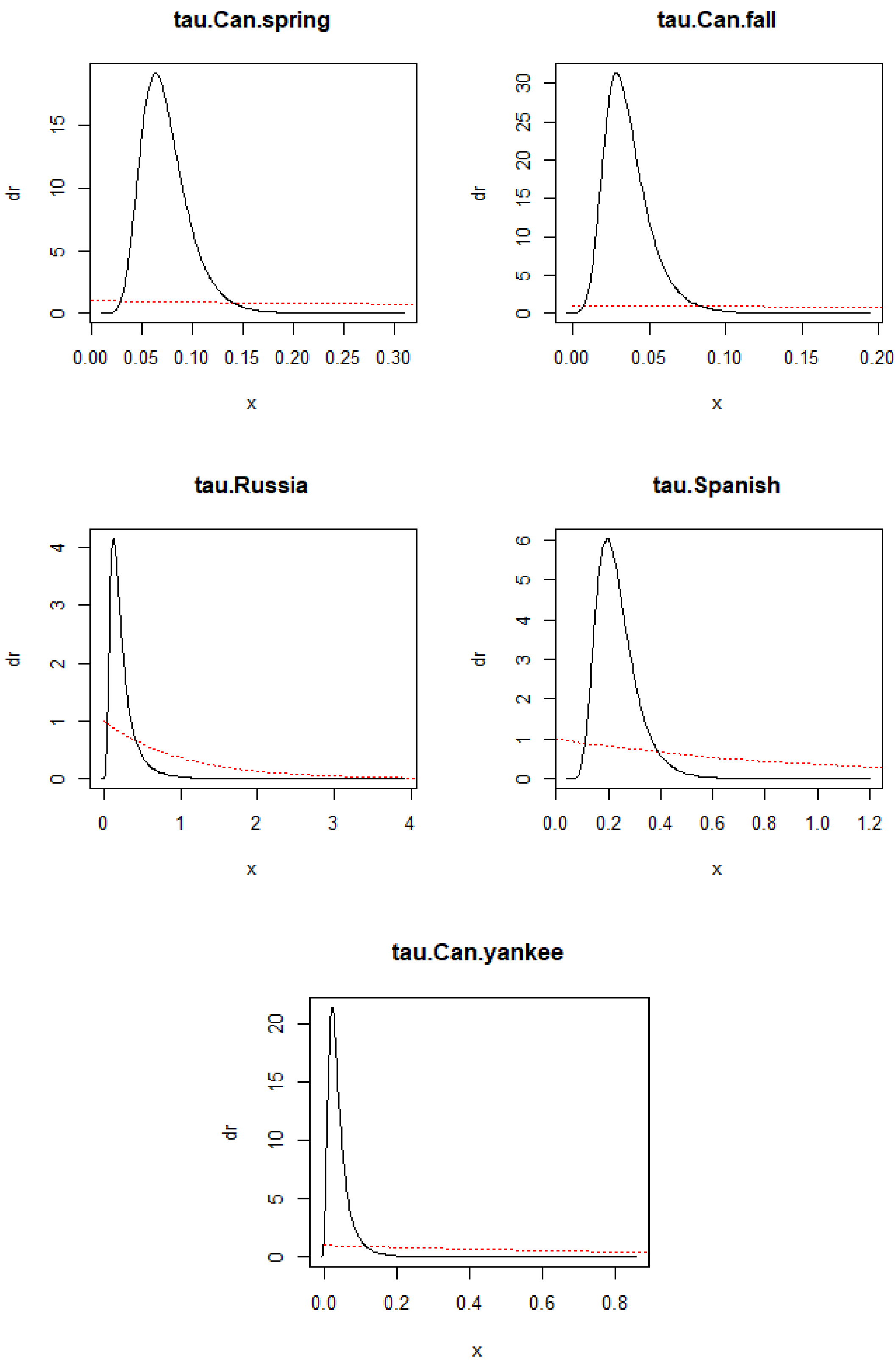


Figure 16. Priors (red line) and posteriors (black line) fop observation error of surveys used in the 2021 Yellowtail flounder Bayesian surplus production model.

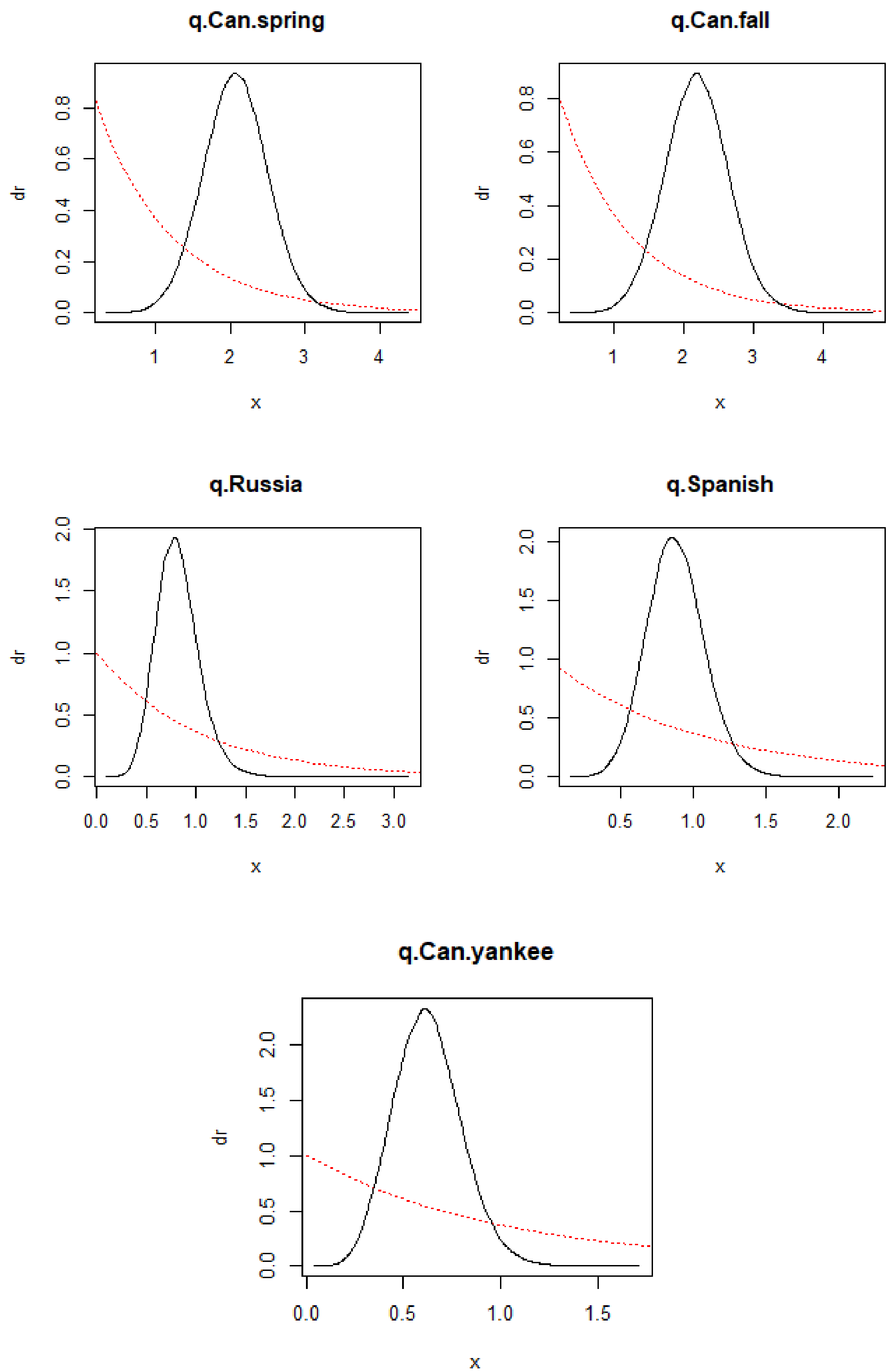


Figure 17. Priors (red line) and posteriors (black line) for the q estimated for each survey used in the 2021 yellowtail flounder Bayesian surplus production model.

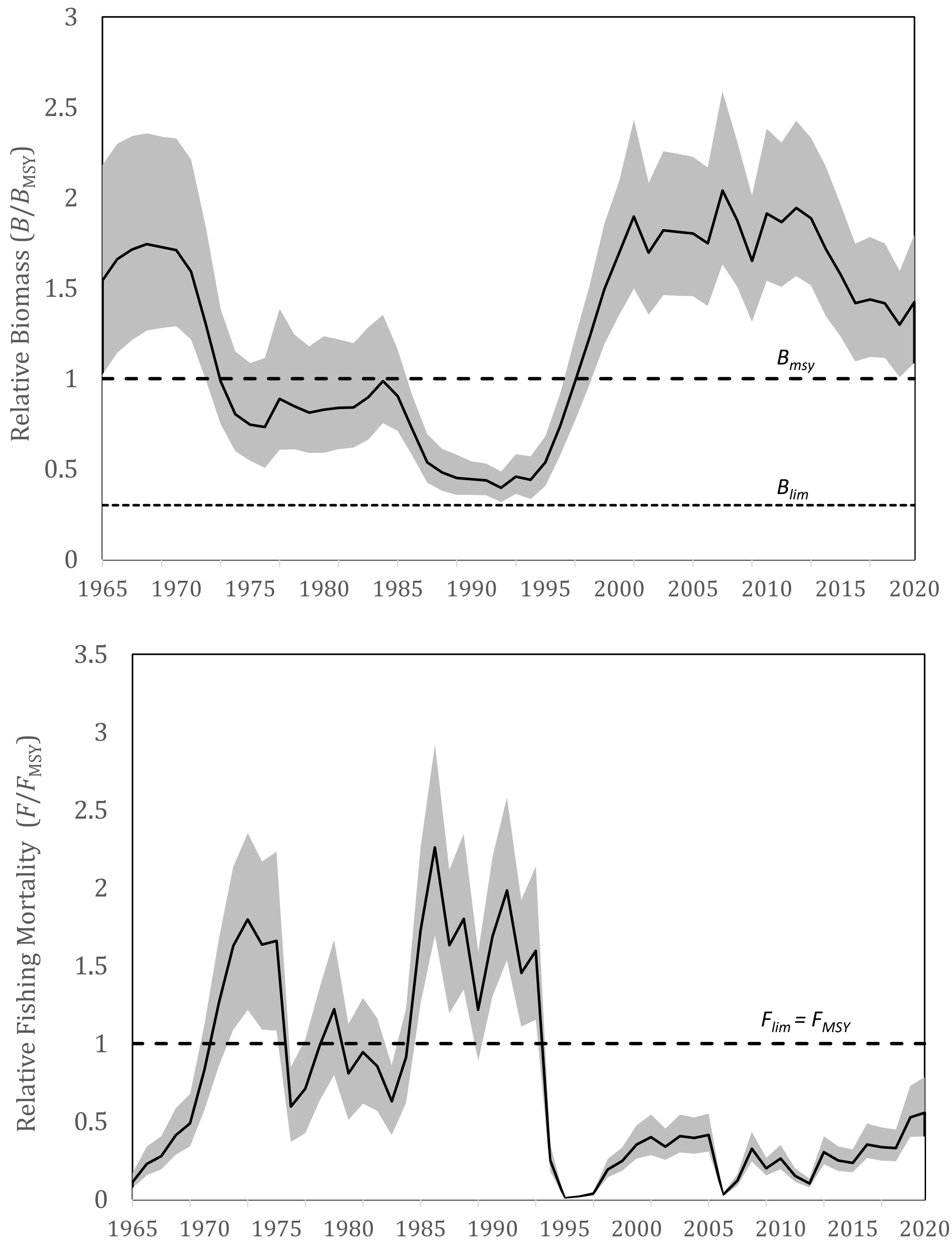


Figure 18. Yellowtail flounder in NAFO Divisions 3LNO: Relative biomass (B/B_{msy}) and relative fishing mortality (F/F_{msy}) estimates from a surplus production model in a Bayesian framework used for the 2021 assessment. 90% confidence intervals are shown.

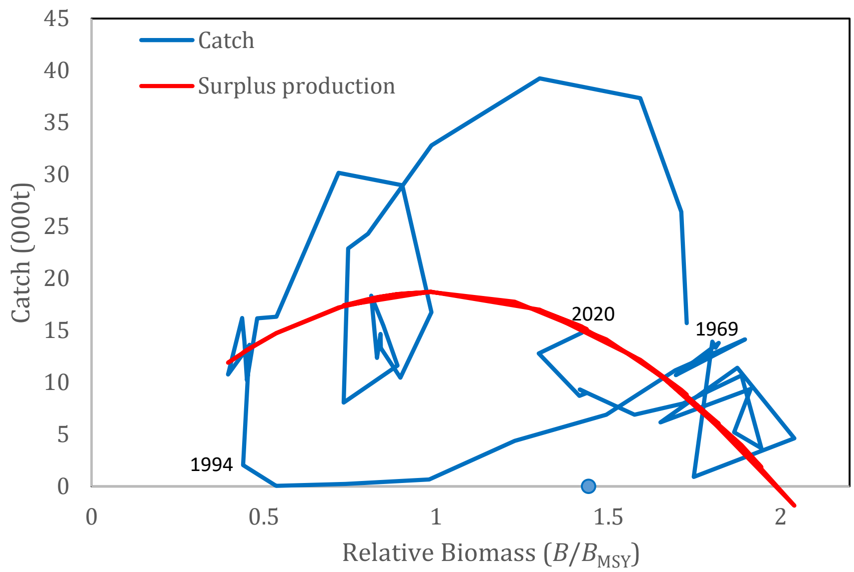


Figure 19. Catch and estimated surplus production (‘000 t) plotted against relative biomass (B/B_{msy}) of yellowtail flounder in NAFO Divs. 3LNO.

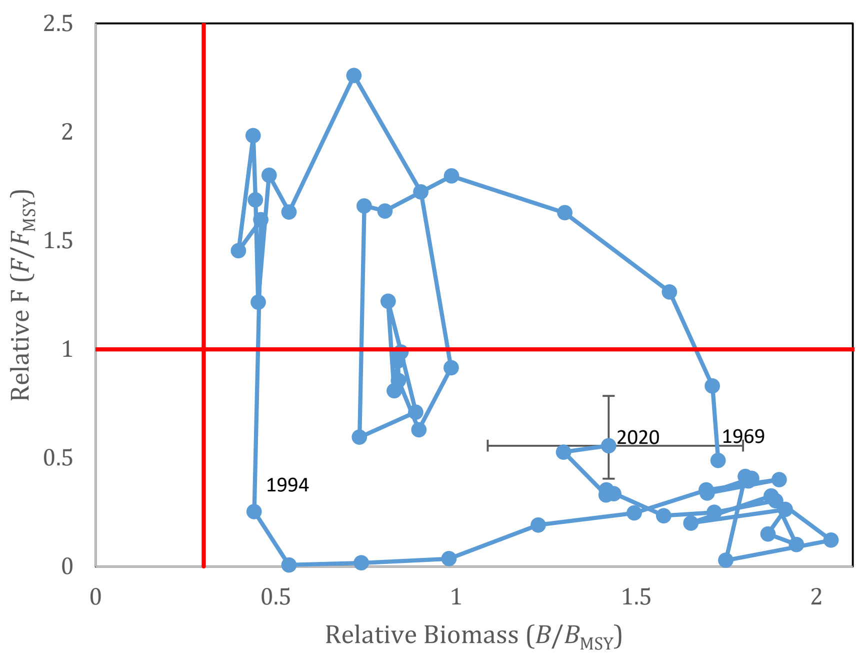


Figure 20. Yellowtail flounder in Div. 3LNO: stock trajectory estimated in the surplus production analysis, under a precautionary approach framework. Error bars on estimate in final year are 90% confidence limits.

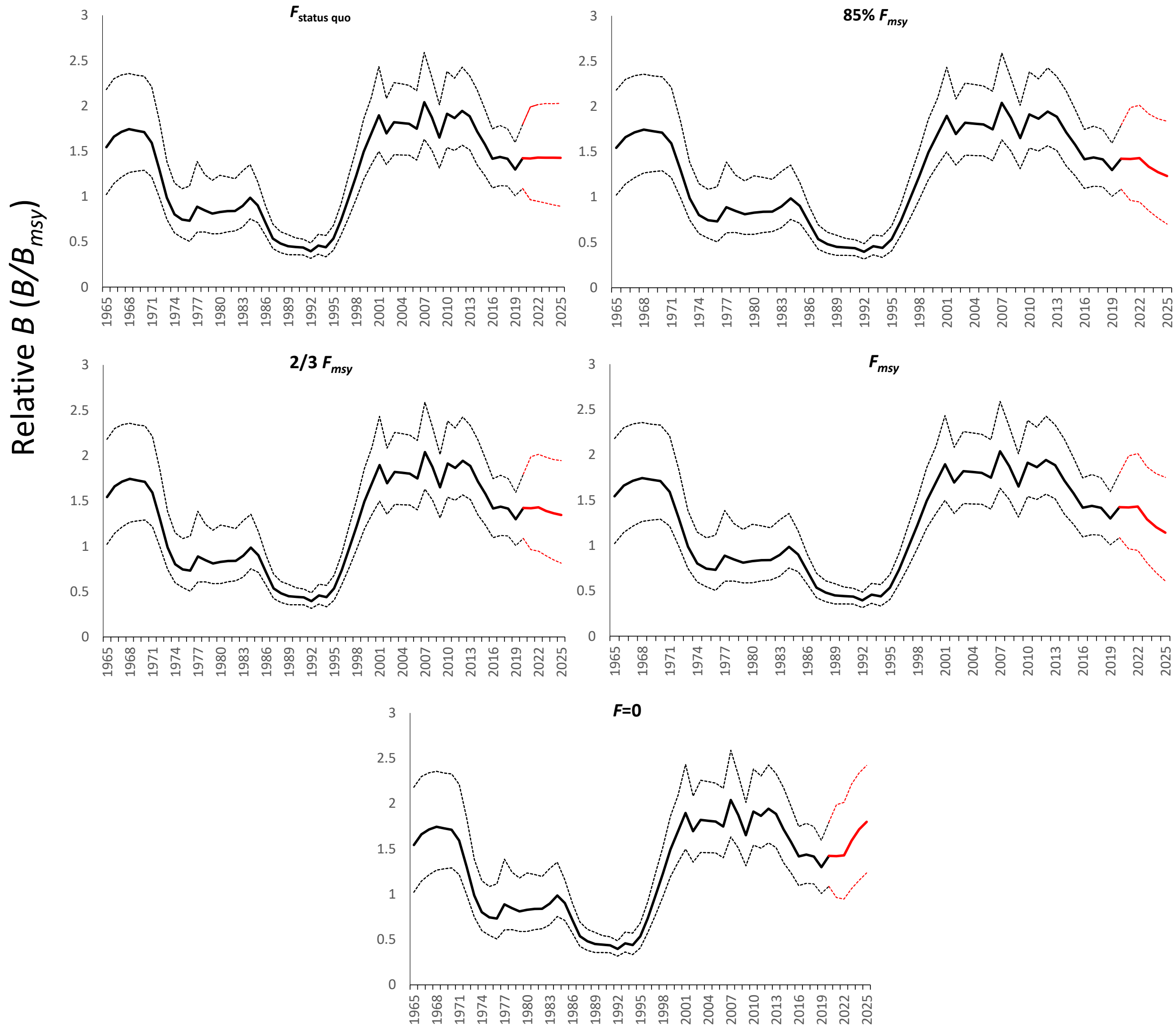


Figure 21. Yellowtail flounder in Div. 3LNO: trends in relative biomass and projections for 2021-2025 (catch in 2021 average of 2019-2020=13 800 tons) at 5 levels of F (F=0, $F_{status\ quo}$, 2/3 F_{msy}, 85% F_{msy} and F_{msy}). Results are derived from a surplus production model in a Bayesian framework. Median and 90% confidence intervals.

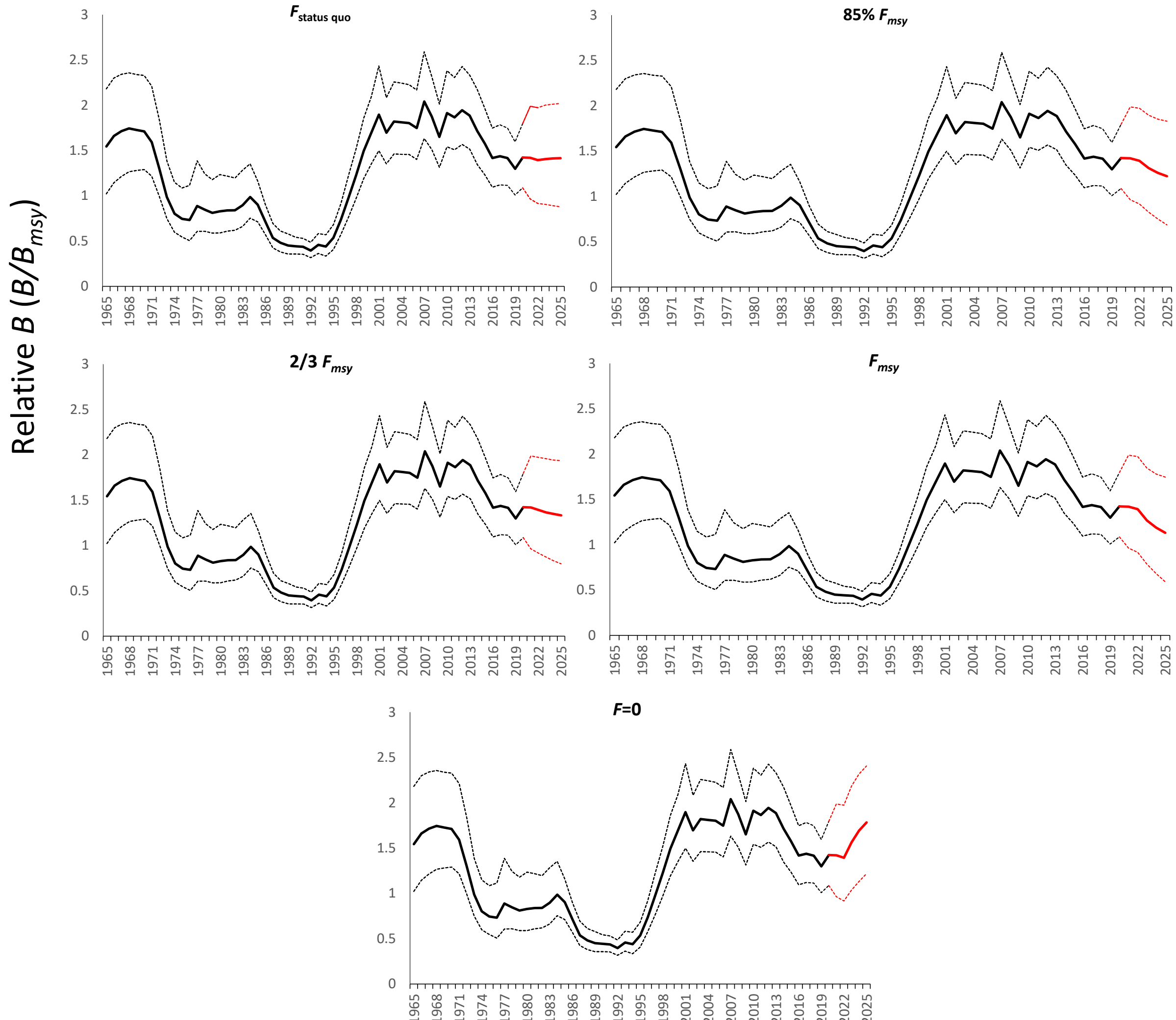


Figure 22. Yellowtail flounder in Div. 3LNO: trends in relative biomass and projections for 2021-2025 (catch in 2021 = TAC= 17 000 tons) at 5 levels of F (F=0, $F_{\text{status quo}}$, 2/3 F_{msy}, 85% F_{msy} and F_{msy}). Results are derived from a surplus production model in a Bayesian framework. Median and 90% confidence intervals.

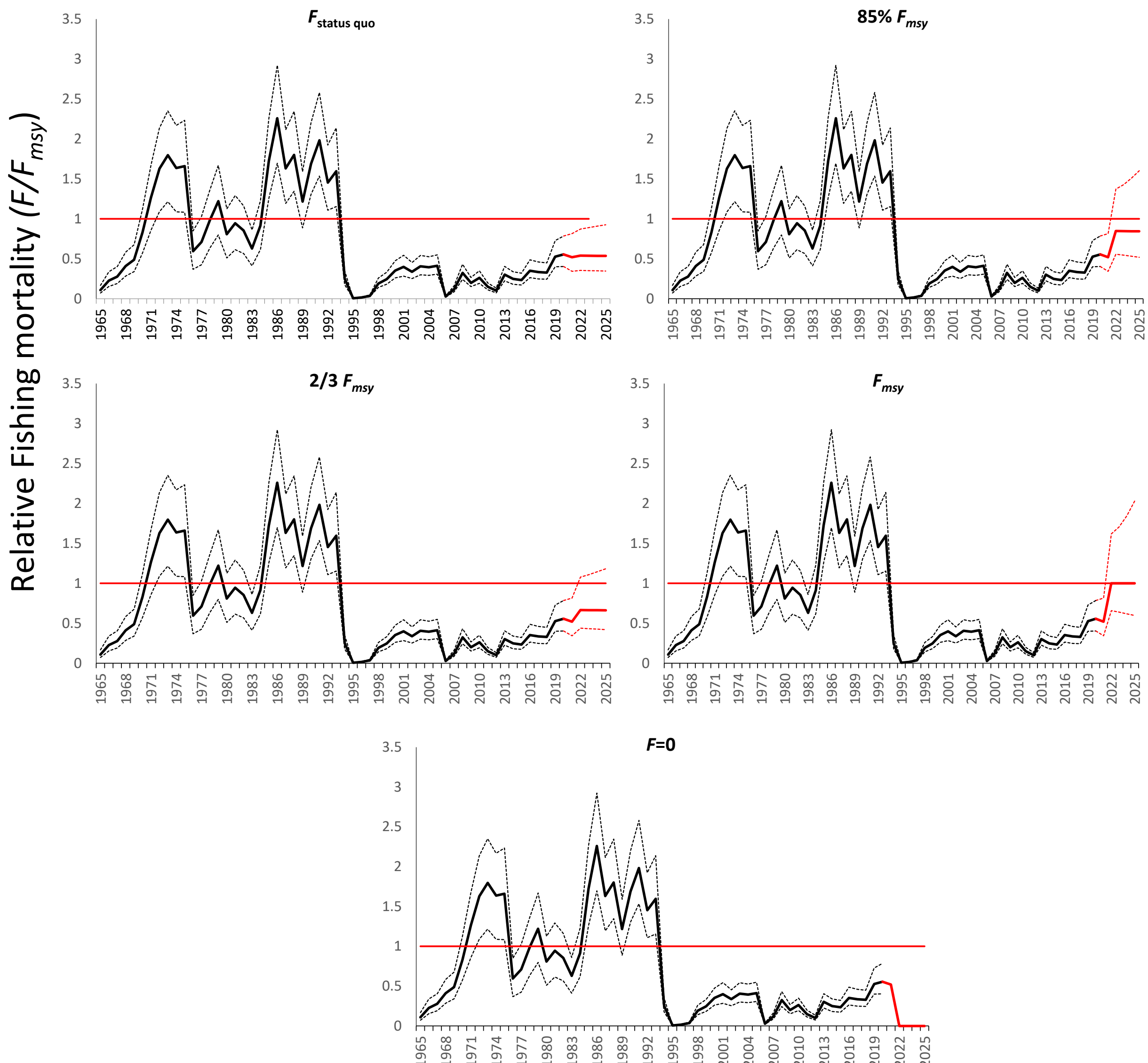


Figure 23. Yellowtail flounder in Div. 3LNO: trends in relative fishing mortality (F/F_{msy}) and projections for 2021-2025 (catch in 2021 average of 2019-2020 = 13 800t) at 5 levels of F (F=0, $F_{\text{status quo}}$, 2/3 F_{msy}, 85% F_{msy} and F_{msy}). Results are derived from a surplus production model in a Bayesian framework. Median and 90% confidence intervals.

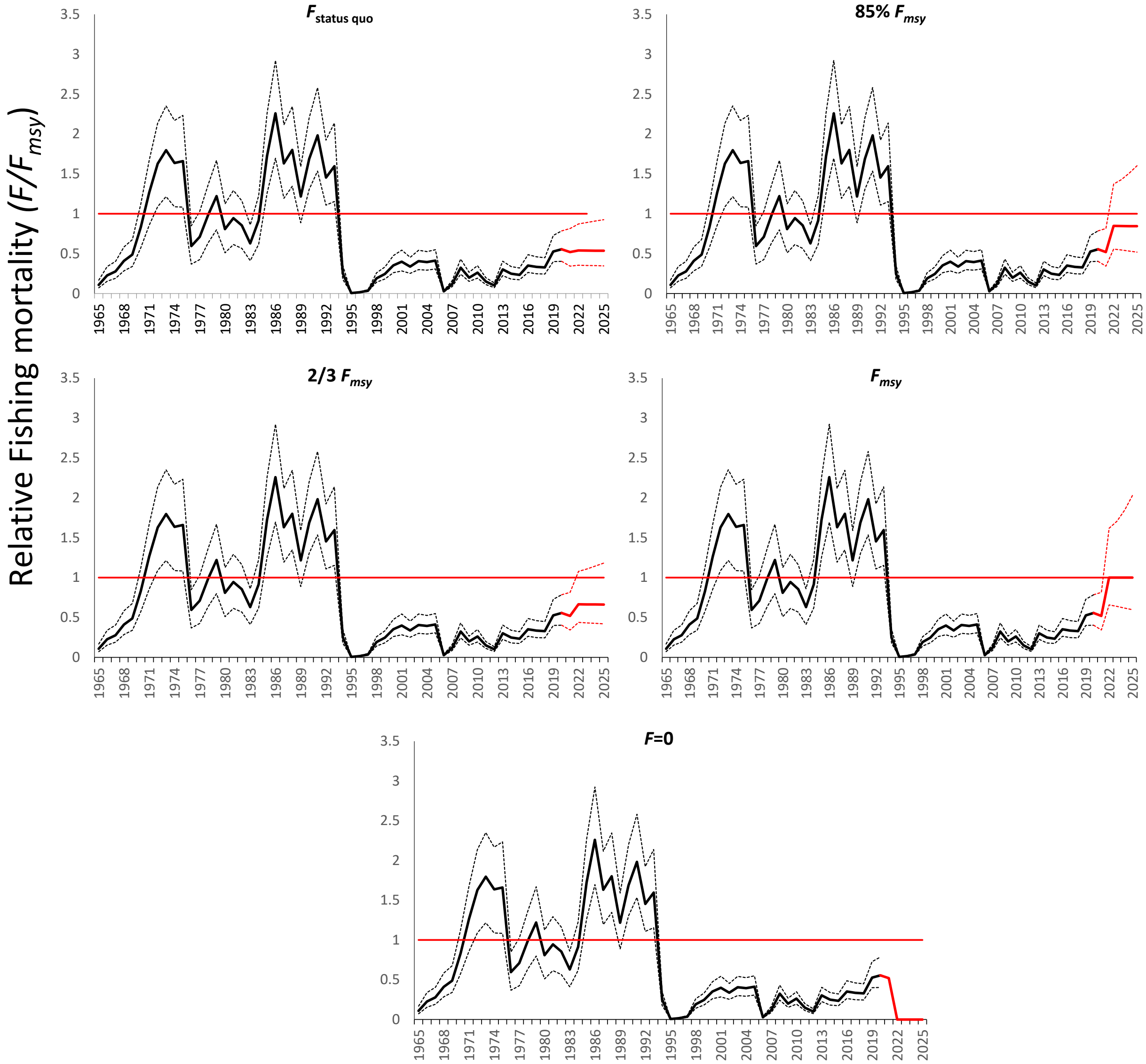


Figure 24. Yellowtail flounder in Div. 3LNO: trends in relative fishing mortality (F/F_{msy}) and projections for 2021-2025 (catch in 2021 average of 2019-2020 = 17 000t) at 5 levels of F (F=0, $F_{\text{status quo}}$, 2/3 F_{msy}, 85% F_{msy} and F_{msy}). Results are derived from a surplus production model in a Bayesian framework. Median and 90% confidence intervals.

APPENDIX 1

Script for 2021 assessment of yellowtail using a surplus production model in Bayesian framework (original coding J. Bailey)

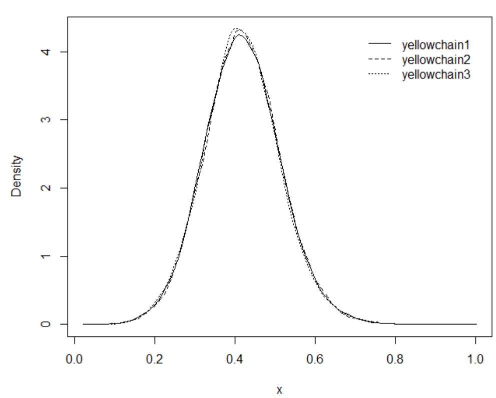
```
model
{
#prior for r mean 0.3 std 0.1
r ~ dunif(0.01,1)
# prior distribution of K
#mean 150,sd 25 run1 cv was 42% in normal scale
#this run mean of 150 and sd of 1500 CV 1000%
K~dlnorm(2.703,0.2167)
# prior distribution of q's
q.Spring~dgamma(1,1)
q.Fall~dgamma(1,1)
q.Russian~dgamma(1,1)
q.Spanish~dgamma(1,1)
q.Yankee~dgamma(1,1)

# Prior for process noise, sigma
sigma ~ dunif(0,5)
isigma2 <- pow(sigma, -2)

# Prior for observation errors, tau.
tau.Spring~dgamma(1,1)
itau2.Spring <- 1/tau.Spring
tau.Fall~dgamma(1,1)
itau2.Fall <- 1/tau.Fall
tau.Russian~dgamma(1,1)
itau2.Russian<- 1/tau.Russian
tau.Spanish~dgamma(1,1)
itau2.Spanish <- 1/tau.Spanish
tau.Yankee~dgamma(1,1)
itau2.Yankee <- 1/tau.Yankee

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

# State equation - SP Model.
for (t in 2:(56))   {
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
for (t in 20:(N)) {
Springm[t] <- log(q.Spring* K * P[t])
Spring[t] ~ dlnorm(Springm[t], itau2.Spring)
}
for (t in 26:(N)) {
Fallm[t] <- log(q.Fall* K * P[t])
Fall[t] ~ dlnorm(Fallm[t], itau2.Fall)
}
for (t in 31:(N)) {
Spanishm[t] <- log(q.Spanish* K * P[t])
Spanish[t] ~ dlnorm(Spanishm[t], itau2.Spanish)
}
for (t in 7:(18)) {
Yankeem[t] <- log(q.Yankee* K * P[t])
Yankee[t] ~ dlnorm(Yankeem[t], itau2.Yankee)
}
for (t in 20:(27)) {
Russianm[t] <- log(q.Russian* K * P[t])
Russian[t] ~ dlnorm(Russianm[t], itau2.Russian)
}
# Output. Using the proportion and K to estimate biomass, B.
for(t in 1:N) {
B[t] <- P[t] * K
F[t]<-L[t]/B[t]
}
#Biomass Ratio: Showing what percent the stock would be at if fished at MSY for a given year, t
for(t in 1:N) {
Bratio[t] <- B[t]/BMSY
}
#F Ratio: indicates the ratio of fishing mortality to that estimated for FMSY.
#e.g. 1.65=65% higher than that estimated for FMSY
for(t in 1:N) {
Fratio[t] <- F[t]/FMSY
}
# further management parameters and predictions:
MSY <- r*K/4;
FMSY<-r/2
BMSY<-K/2
#Replicate data sets code below here
#generate replicate data sets
for (i in 7:18){
        Yankee.rep[i] ~ dlnorm(Yankeem[i],itau2.Yankee)
        p.smaller.Yankee[i] <- step(log(Yankee[i])-log(Yankee.rep[i]))
#residuals of log values of replicate data
        res.Yankee.rep[i] <- log(Yankee[i])-log(Yankee.rep[i])
}
#generate replicate data sets
for (i in 20:N){
        Spring.rep[i] ~ dlnorm(Springm[i],itau2.Spring)
        p.smaller.Spring[i] <- step(log(Spring[i])-log(Spring.rep[i]))
#residuals of log values of replicate data
        res.Spring.rep[i] <- log(Spring[i])-log(Spring.rep[i])
}
#generate replicate data sets
for (i in 26:N){
        Fall.rep[i] ~ dlnorm(Fallm[i],itau2.Fall)
        p.smaller.Fall[i] <- step(log(Fall[i])-log(Fall.rep[i]))
#residuals of log values of replicate data
        res.Fall.rep[i] <- log(Fall[i])-log(Fall.rep[i])
}
#generate replicate data sets
for (i in 31:N){
        Spanish.rep[i] ~ dlnorm(Spanishm[i],itau2.Spanish)
        p.smaller.Spanish[i] <- step(log(Spanish[i])-
log(Spanish.rep[i]))
#residuals of log values of replicate data
        res.Spanish.rep[i] <- log(Spanish[i])-log(Spanish.rep[i])
                }
#generate replicate data sets
for (i in 20:27){
        Russian.rep[i] ~ dlnorm(Russianm[i],itau2.Russian)
        p.smaller.Russian[i] <- step(log(Russian[i])-
log(Russian.rep[i]))
#residuals of log values of replicate data
        res.Russian.rep[i] <- log(Russian[i])-log(Russian.rep[i])
                }

            } ## END
```

APPENDIX 2

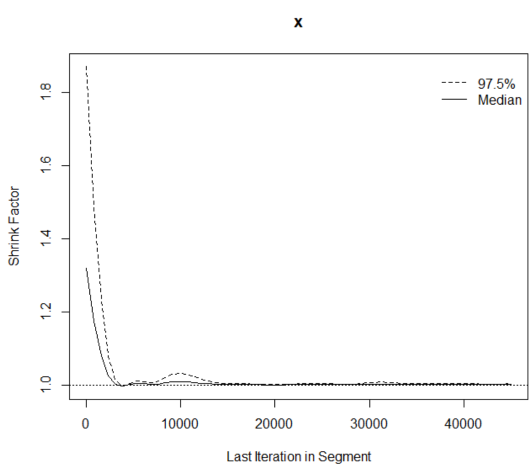
Diagnostics and Fit Criteria by factor

r: Intrinsic rate of growth

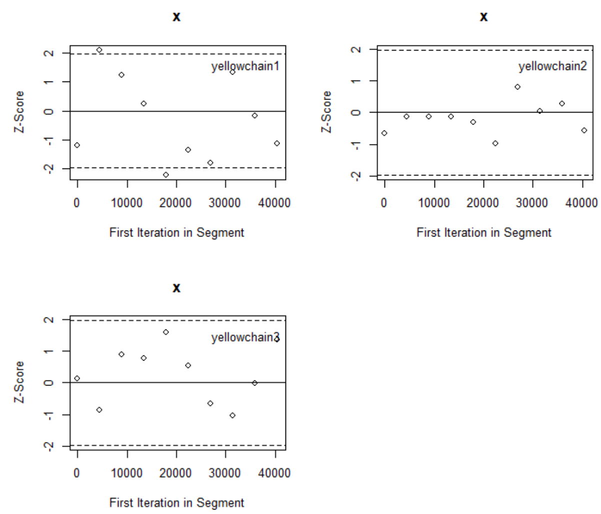
Estimated Posterior Density



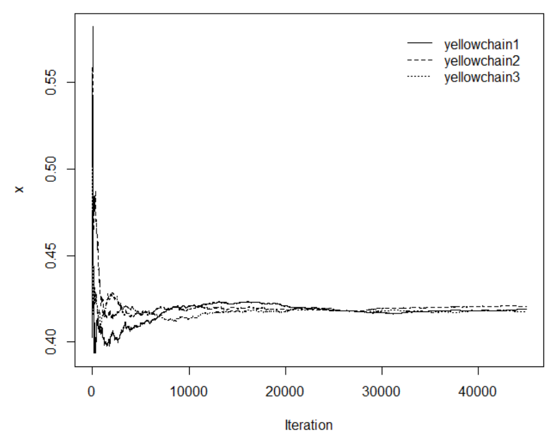
Gelman & Rubin Shrink Factors



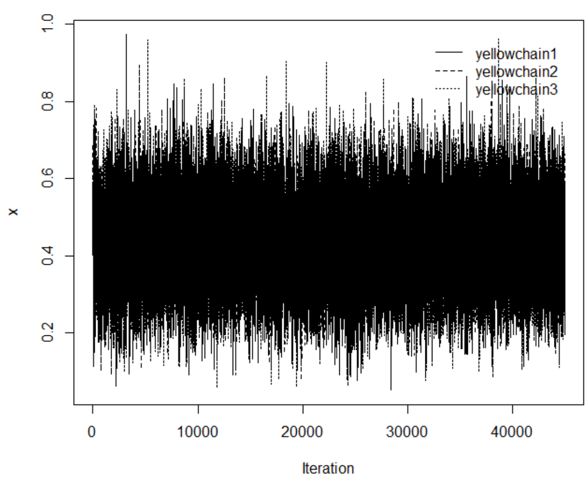
Geweke Convergence Diagnostic



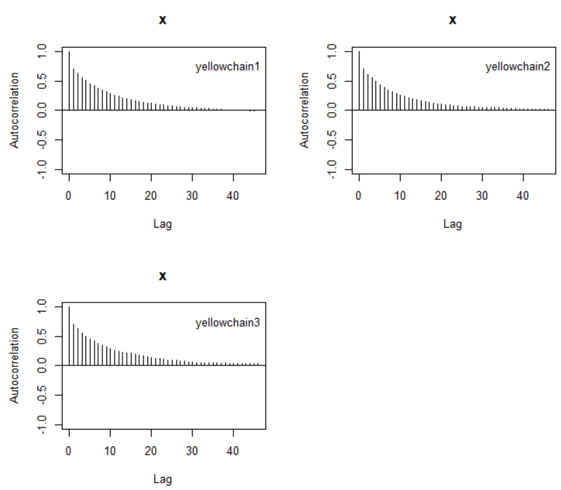
Sampler Running Mean



Sampler Trace

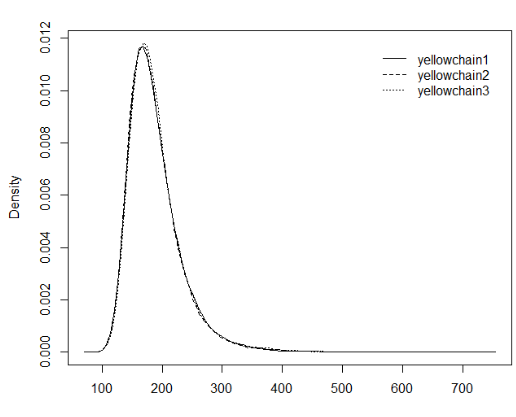


Sampler Lag-Autocorrelations

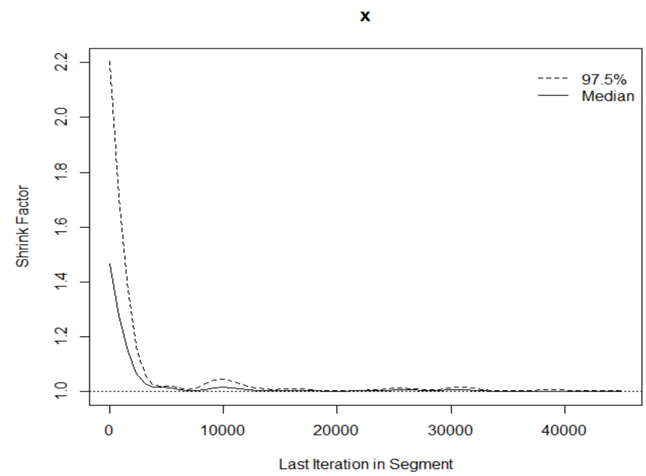


K: Carrying capacity

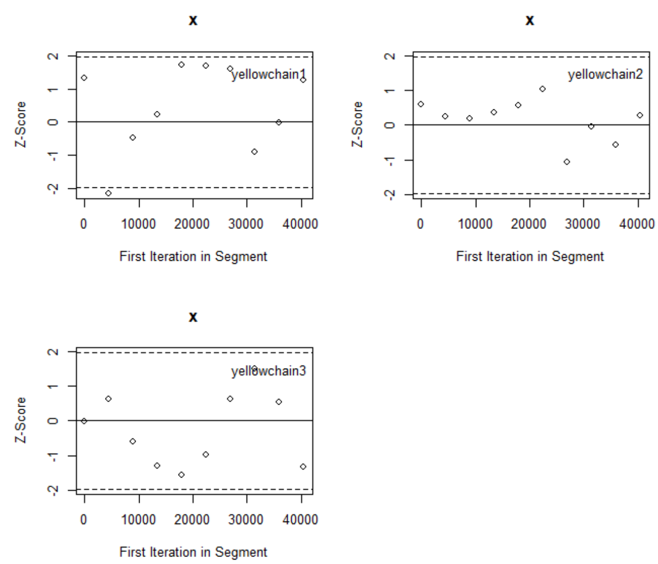
Estimated Posterior Density



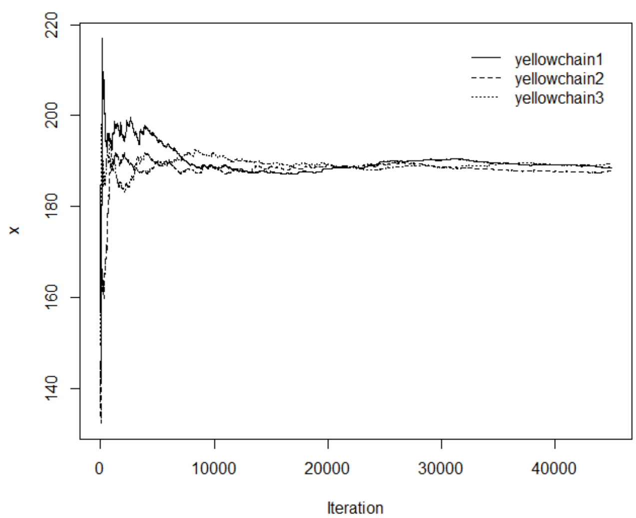
Gelman & Rubin Shrink Factors



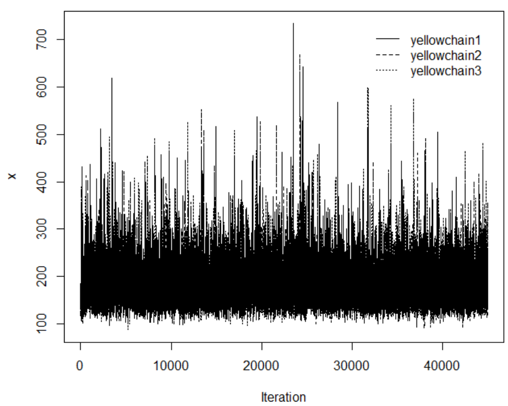
Geweke Convergence Diagnostic



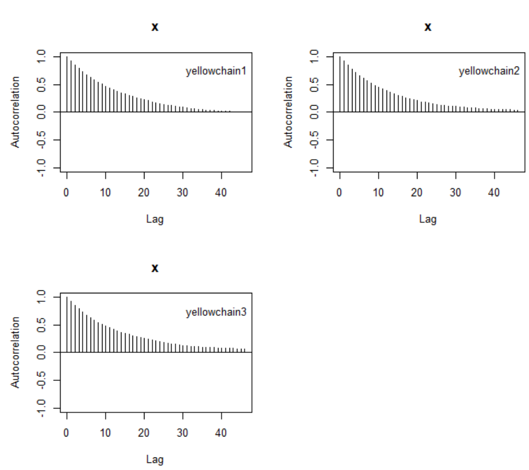
Sampler Running Mean



Sampler Trace

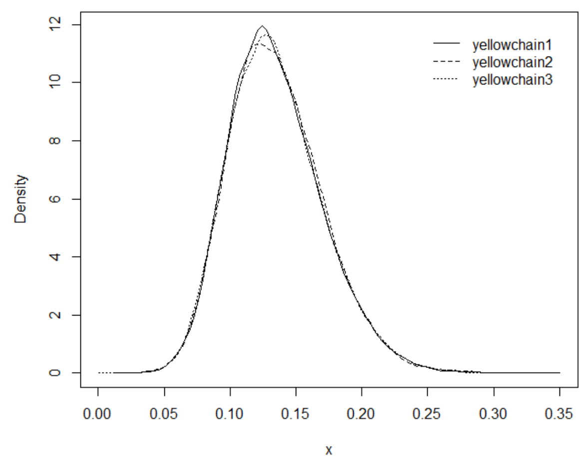


Sampler Lag-Autocorrelations

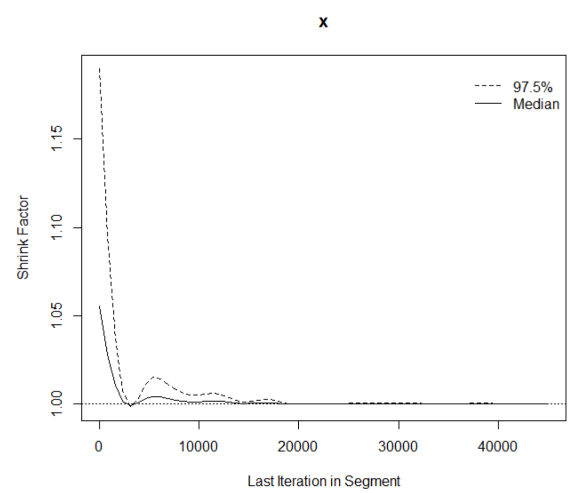


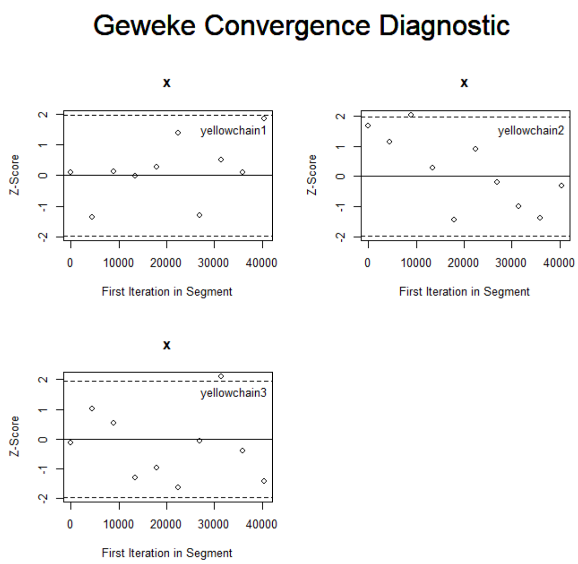
SIGMA: Process Error

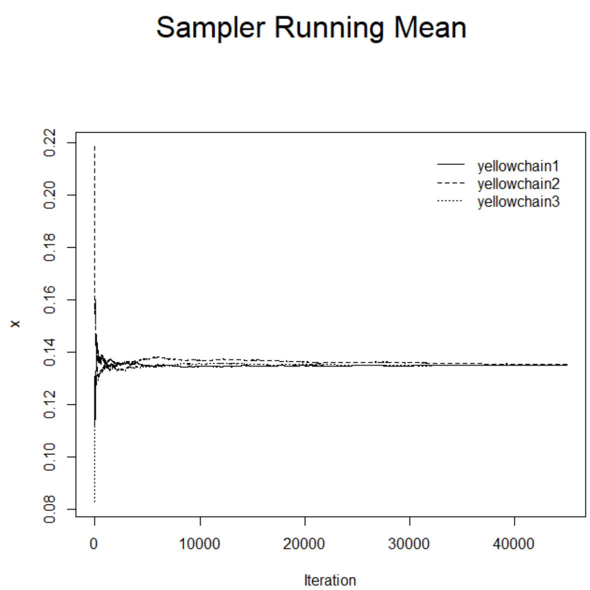
Estimated Posterior Density

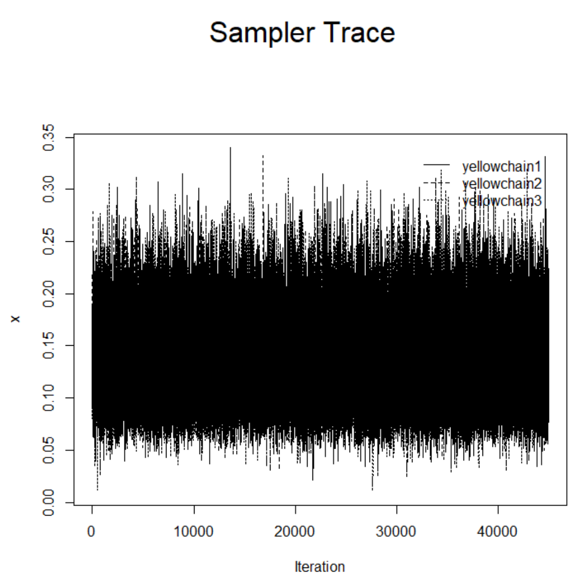


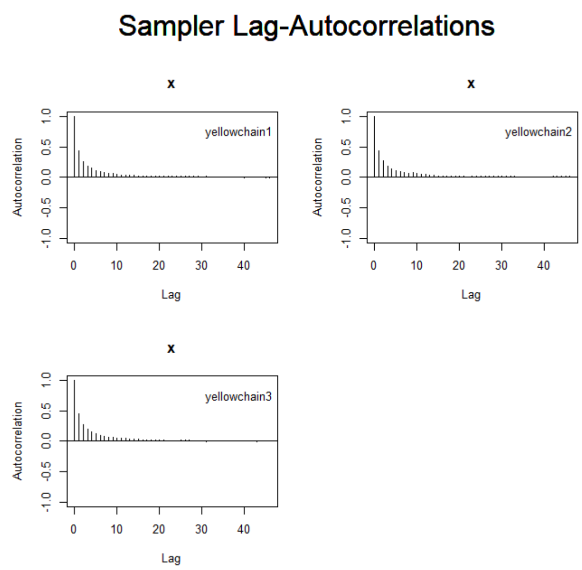
Gelman & Rubin Shrink Factors



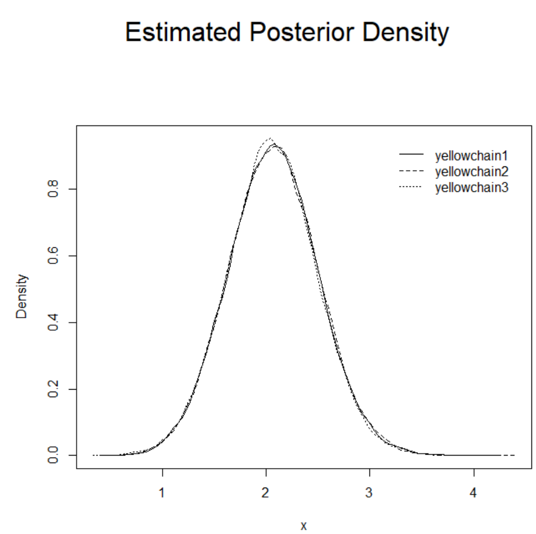




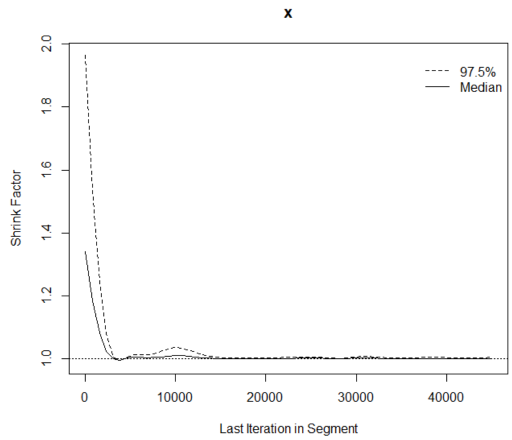




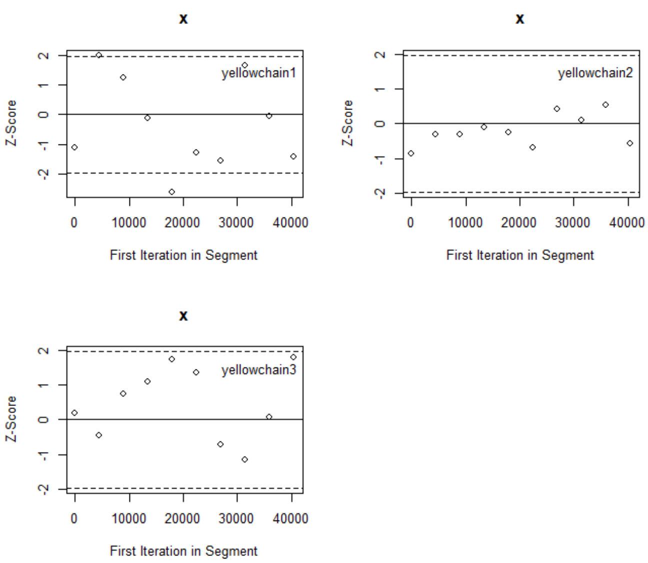
q: Canadian spring survey



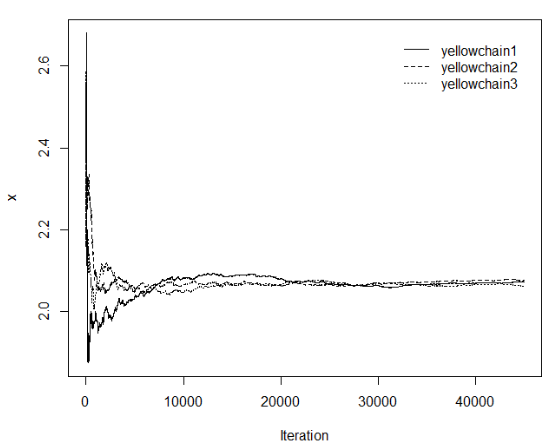
Gelman & Rubin Shrink Factors



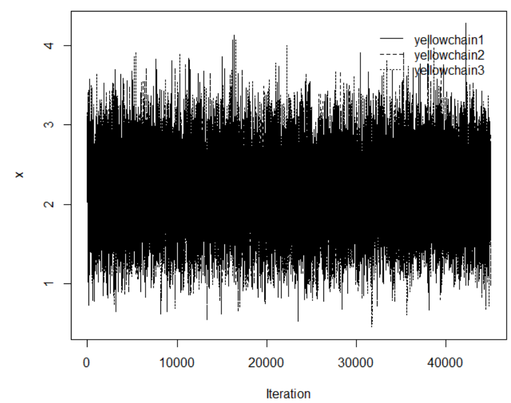
Geweke Convergence Diagnostic



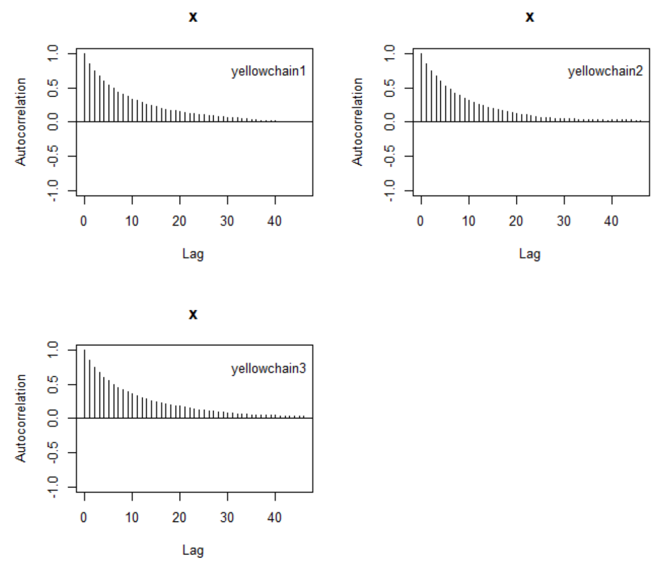
Sampler Running Mean



Sampler Trace

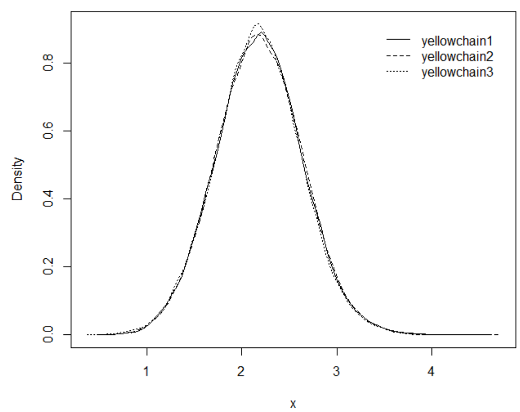


Sampler Lag-Autocorrelations

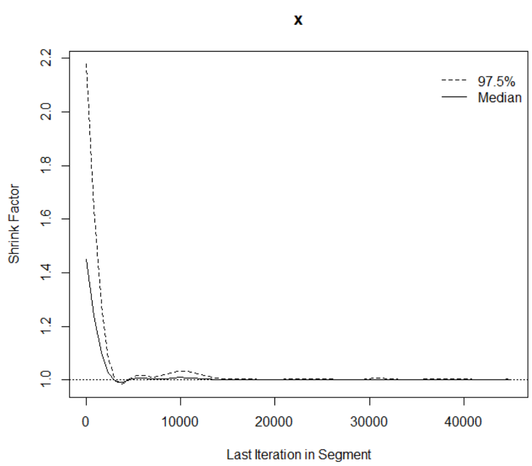


q: Canadian autumn survey

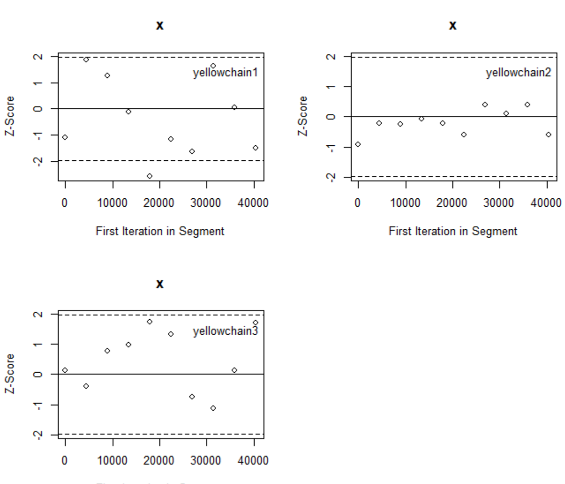
Estimated Posterior Density



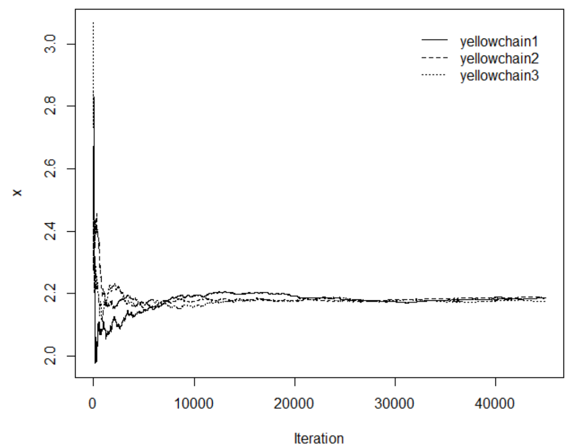
Gelman & Rubin Shrink Factors



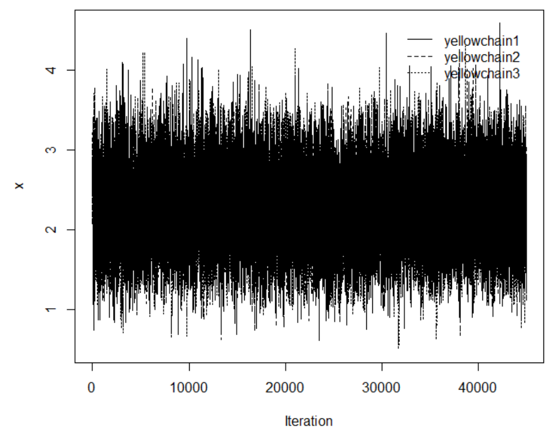
Geweke Convergence Diagnostic



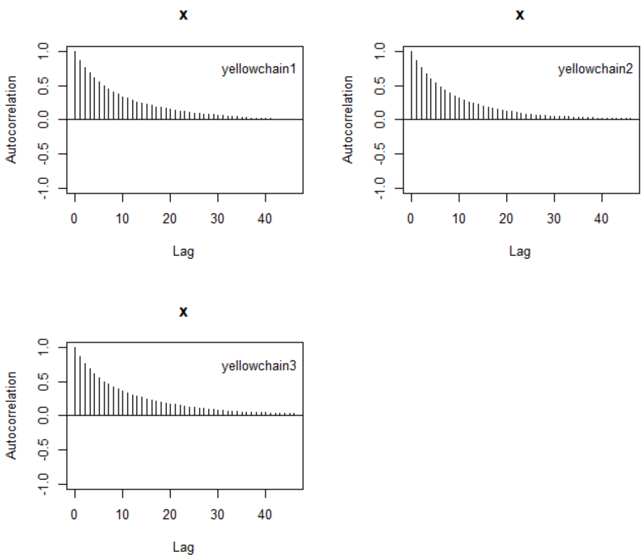
Sampler Running Mean



Sampler Trace

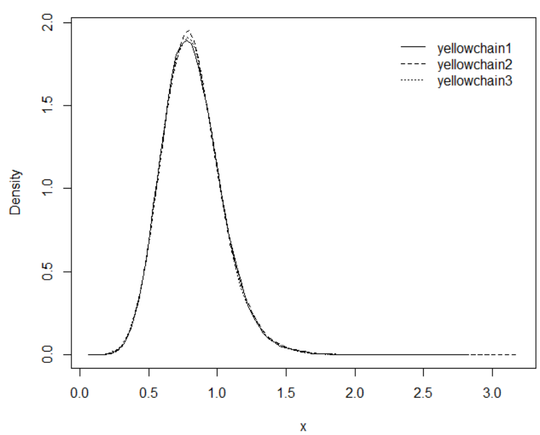


Sampler Lag-Autocorrelations

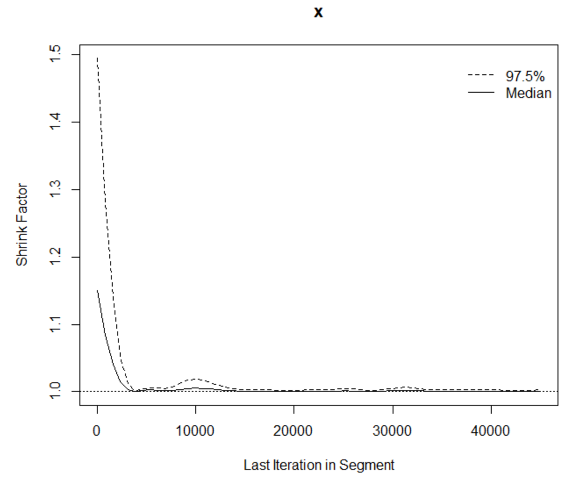


q: Russian survey

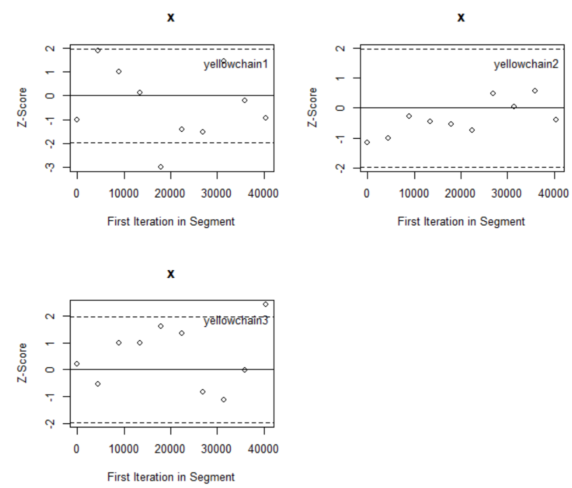
Estimated Posterior Density



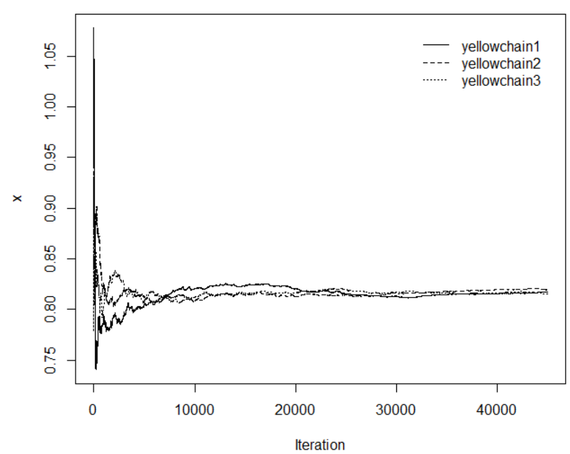
Gelman & Rubin Shrink Factors

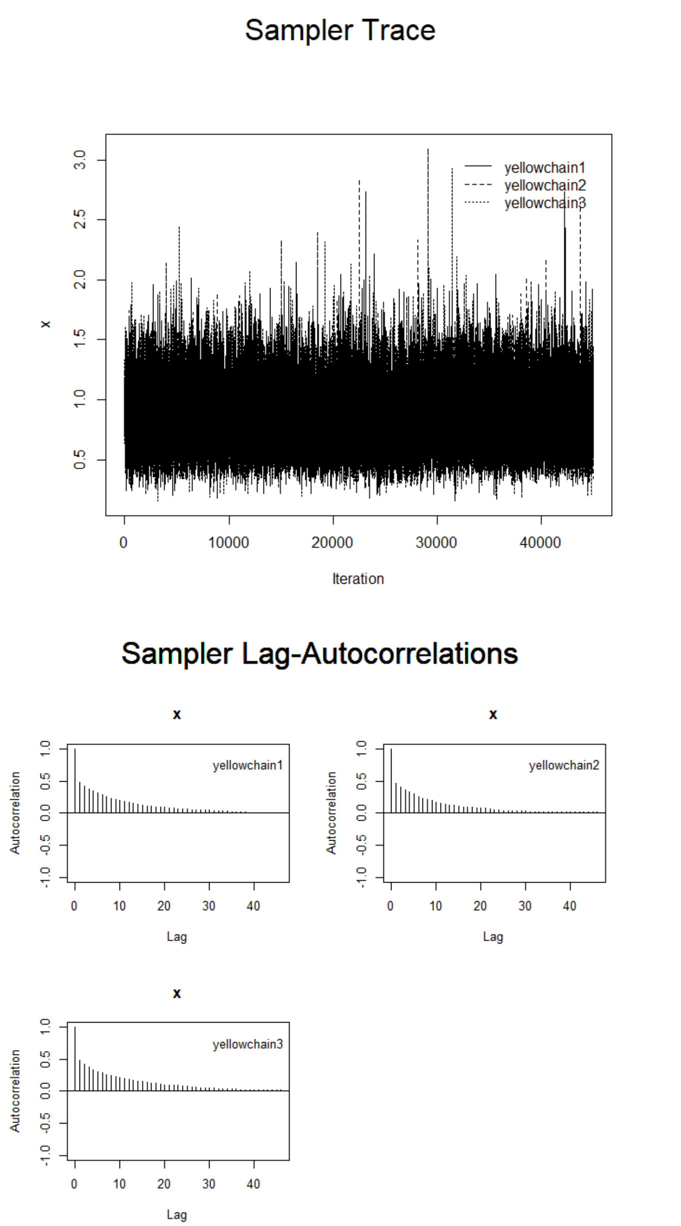


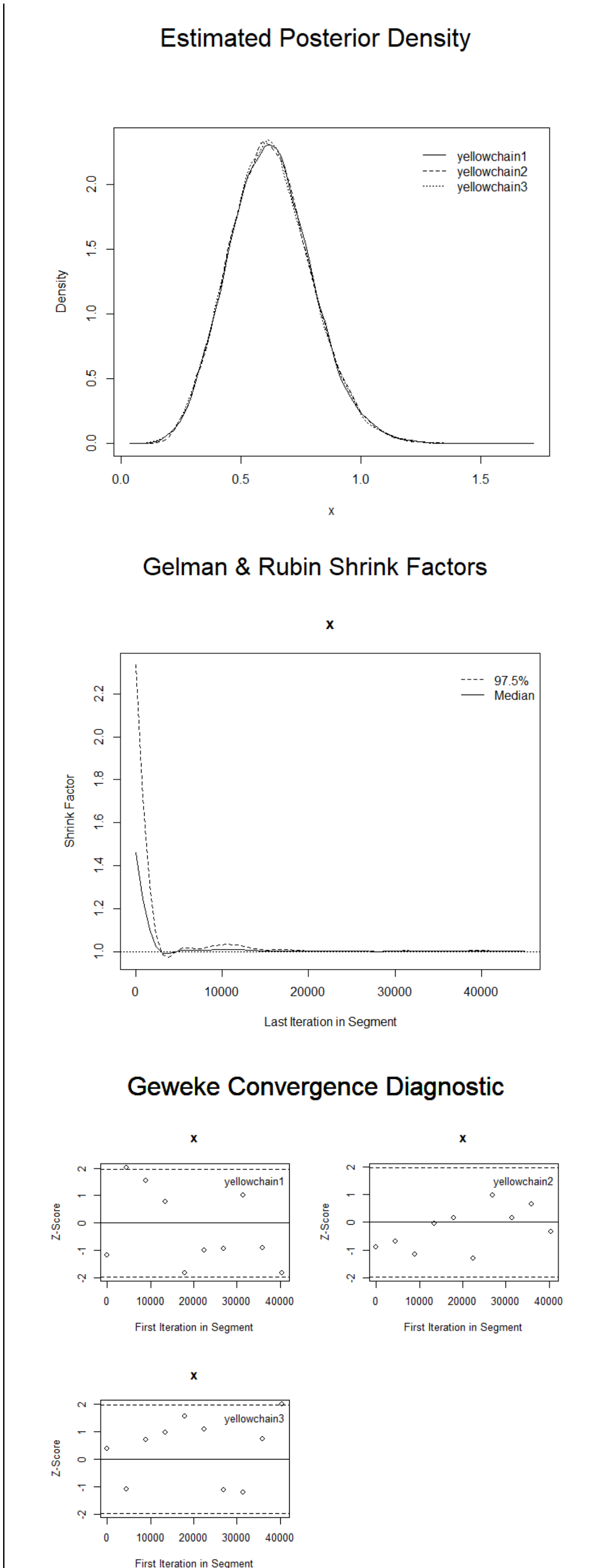
Geweke Convergence Diagnostic



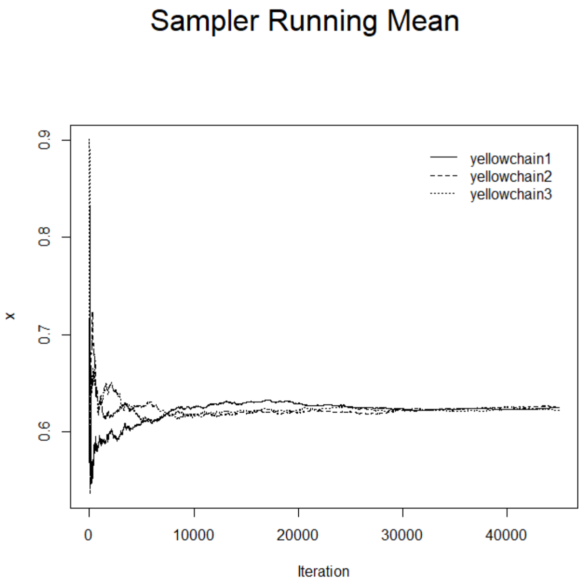
Sampler Running Mean

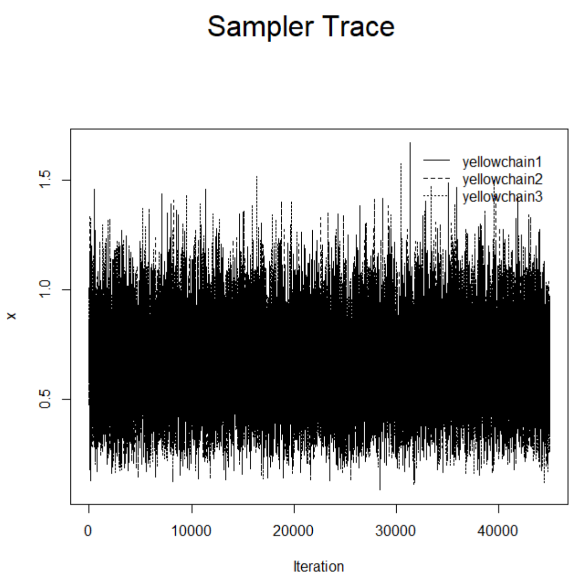


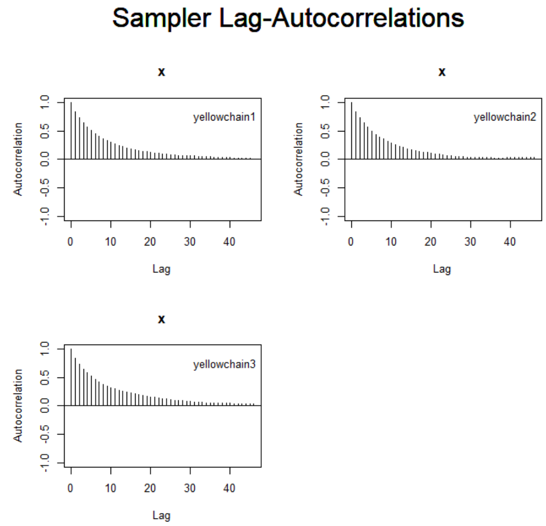




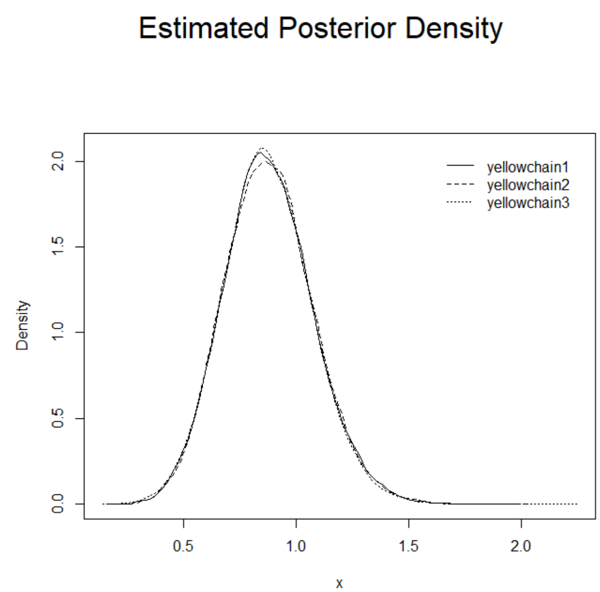
q: Canadian Yankee survey

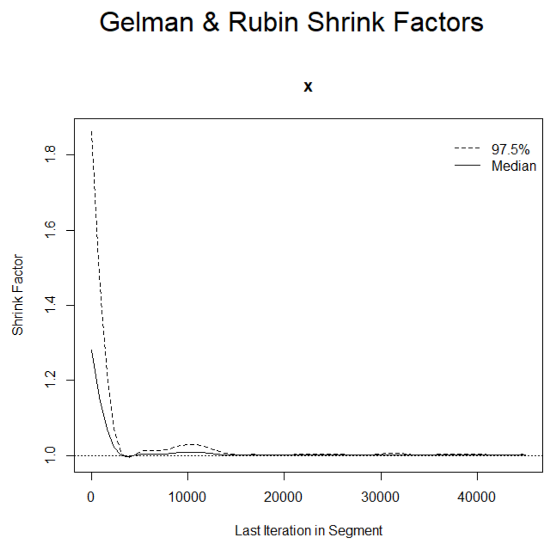


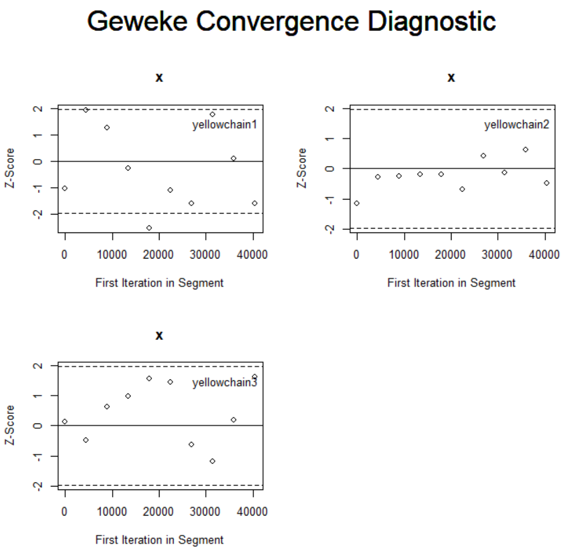


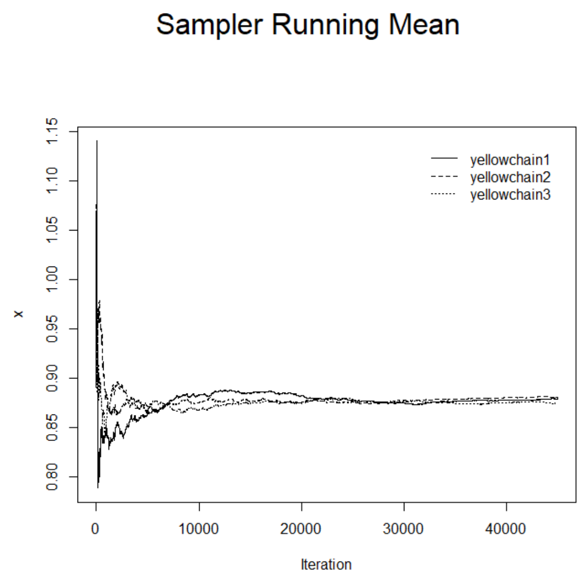


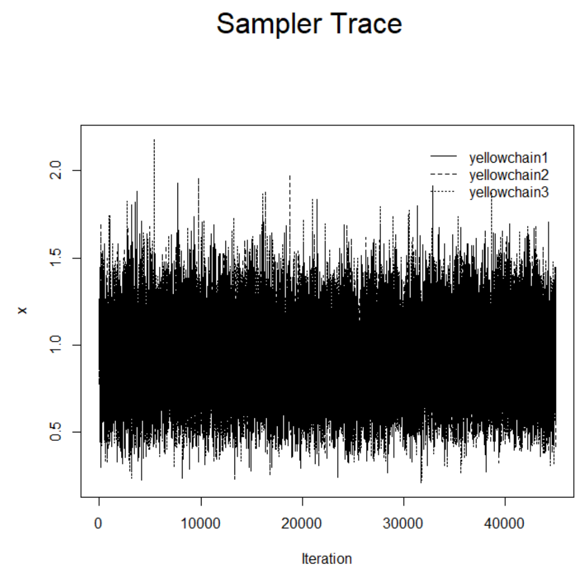
q: Spanish survey

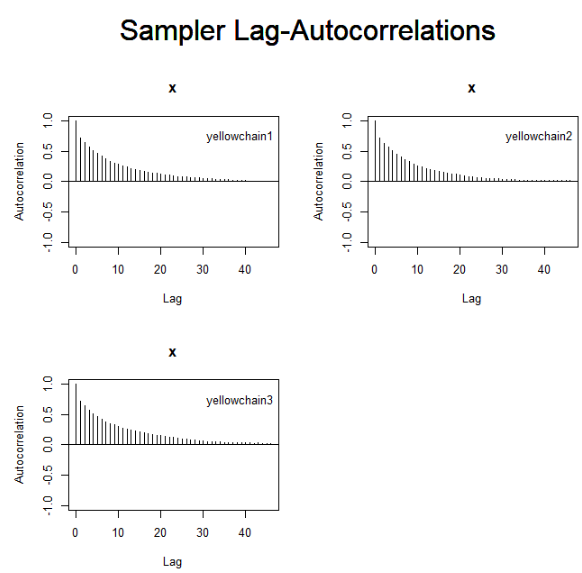



Gelman & Rubin Shrink Factors
x
97.5%
Median
Shrink Factor
1.0
1.2
1.4
1.6
1.8
0
10000
20000
30000
40000
Last Iteration in Segment


Geweke Convergence Diagnostic
x
yellowchain1
yellowchain2
yellowchain3
Z-Score
First Iteration in Segment
0
10000
20000
30000
40000


Sampler Running Mean
yellowchain1
yellowchain2
yellowchain3
x
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
0
10000
20000
30000
40000
Iteration


Sampler Trace
yellowchain1
yellowchain2
yellowchain3
x
0.5
1.0
1.5
2.0
0
10000
20000
30000
40000
Iteration


Sampler Lag-Autocorrelations
x
yellowchain1
yellowchain2
yellowchain3
Autocorrelation
Lag
0
10
20
30
40