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Applying a stochastic surplus production model (SPiCT) for Greenland halibut in 0+1 offshore

by

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Abstract

A Stochastic Surplus Production Model in Continuous Time (SPiCT) was applied to the Greenland halibut Subareas 0+1 offshore stock. Input data for the tuning model included catches in Subarea 0+1 offshore from 1991 to 2023 and a combined index produced with Delta-GAM for the biomass of fish > 35 cm from the deep surveys indices in Divisions 0A+1CD and the shallow survey in Divisions 1A-F (1991-2023). Priors were used 1) to fix the shape parameter (n) at 2 (Schaefer curve), 2) for the intrinsic population growth rate and 3) for the process error of the biomass. The model was reviewed and accepted to provide advice.

Introduction

The SPiCT model is a stochastic surplus production model in continuous time (Pedersen & Berg, 2016). The model was accepted for assessment of the Greenland halibut in SA 0+1 offshore. Previously, no analytical assessment of the Greenland halibut Subareas 0+1 offshore stock had been used as basis for NAFO to provide advice for the stock.

The model assumptions are:

1. The intrinsic growth rate represents a combination of natural mortality, growth, and recruitment.
2. The biomass refers to the exploitable part of the stock.
3. The stock is closed to migration.
4. Age and size-distribution are stable in time.
5. Constant catchability of the gear used to gather information for the biomass index.

The generic assumption for most analytical stock assessment models is that the stock is a closed entity with no emigration or immigration to neighboring areas. Recent studies of stock structure for Greenland halibut in the entire North Atlantic show that the 0+1 offshore stock is a rather robust entity and tagging experiments show that migration mainly appears in individuals < 30 cm which is not part of the exploitable biomass. Only 2,5 % of the total recaptures (1.5%) migrated to different areas (Vihtakari et al. 2022)

Material and Methods

Catch data have been available since 1965 (Nogueira and Hedges, 2023) but we decided to truncate the time-series to 1991. Much information suggests that the ecosystem shifted in the early 90´s to less productivity, with the collapse of Atlantic cod and decrease of most of demersal fish species (Hamilton et al., 2000, Sejr et al., 2021). We considered the years 1991 and 1992 more uncertain than the rest by multiplying by 2 the standard deviation of the catches in those years.

Two fisheries-independent biomass indices are available. A shallow survey was conducted in NAFO Div. 1A-F (50-600m) for the period 1991-2004 with trawl gear Skjervoy and 2005-2023 with trawl gear Cosmos (no survey was conducted in 2021) (Nygaard and Nogueira, 2023). The second biomass index is a combined index from the Canadian and Greenland deep water surveys in 0A-1CD (years 1999, 2001, 2004, 2008, 2012, 2014-2017, 2019 with a bottom trawl gear Alfredo, and 2022-2023 with a bottom trawl gear Bacalao) covering depth of 400-1500 m (Nogueira and Hedges, 2024). Both survey indices cover the main distribution of the stock. The biomass of fish > 35 cm (considered as the exploitable part of the stock) from the two indices was combined with Delta-Lognormal Generalized Additive Model (Delta-GAM). The model produces a standardized index (Berg and Nogueira, 2024) that was used as input for the SPiCT model.

The research survey in NAFO Div. 1A-F is conducted in June and the deep surveys in 0A and 1CD are in the autumn (September-November), and therefore, the biomass data from June are shifted in time by adding 0.5 year. The input the biomass index is shown in Figure 2.

We used a prior of n = 2 , for fix the classic Shaefer curve, a prior for the standard deviation for the biomass(sdb = 0.1) to have a realistic process error, and a prior for the population growth rate (r = 0.25) (www.fishbase.com) (Table 1).

Results and Discussions

The outcome of the SPiCT model is shown in Table 2 and Annex1. The intrinsic population growth rate (r) was estimated to be 0.26 CI(95%)= (0.18; 0.36), and it is considered to be a reasonable range. The r estimated from the Greenland halibut stock in ICES Subareas 5,6,12 and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland) is r =0.16 (ICES, 2022). The carrying capacity (K) is estimated to 499 913 t and B_{msy} was 248 041 t. Given the rule of thumb that B_{lim} is equal to 30% of B_{msy}, B_{lim} is estimated to 74 412 t. The present relative biomass in relation toB_{msy} is 1.3, e.g. well above Bmsy, while the present relative fishing mortality is 0.8 in relation to Fmsy, e.g., well below Fmsy.

The main results of the model, the absolute biomass and absolute fishing mortality together with the relative biomass and fishing mortality, are shown in Figure 2. There are high uncertainties associated with population estimates, especially for fishing mortality.

Diagnostics of the model are shown in Figure 3. The residuals for the catches are rather large in the early years of the time series but otherwise do not show any bias or blocks. The survey index is not biased. However, overall the model formulation seems appropriate. One Step Ahead (OSA) residuals were not significantly different from zero and therefore not biased (Figure 3, second row). Testing of multiple lags (here 4) found no significant autocorrelation in the residuals (ACF) of catches or the combined index. The normality of the catch and the index residuals has p-value > 5% (Figure 3, fourth row).

Table 3 shows correlations between model parameters for fixed effects. Most of the parameters are well separated i.e., relatively low correlations. The highest correlations were between K and m (deterministic MSY), q (catchability) and m, and q and K.

Parameter estimates should not be influenced by initial values (Millenberger et al. 2019), which appears to be the case in the present assessment (Table 4).

Retrospective plots of fishing mortality and fishable biomass over five years show a consistent underestimation of biomass and a consistent overestimation of fishing mortality. However, all peels are within the confidence limits. Mohn's rho are -6.5% and 16.9% for B/B_{msy} and F/F_{msy} , respectively). (Figure 4). These values are in ICES context acceptable within the limits of +-20%. Since the bias is conservative in an advisory context (underestimation of ESB and overestimation of F) it causes less concern.

Conclusion:

The model was accepted as a valid tool for the stock assessment of Greenland halibut in 0+1 offshore.

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Table 1. Priors used in the model:

logn ~ dnorm[log(2) , 2^2] (fixed)
logr ~ dnorm[log(0.025), 0.25^2]
logsdb ~ dnorm[log(0.1) , 0.5^2]

Table 2. Population parameters estimated by the SPiCT model.

	Estimate	CI lower	CI upper	log.est
alpha2 (noise term for survey, α = SDIndex/SDBiomass)	2.70	1.22	5.97	0.99
beta (β = SDCatch/SDF)	0.44	0.22	0.85	-0.83
r (intrinsic population growth rate)	0.26	0.18	0.36	-1.36
m (deterministic MSY)	32228	18778	55311	10.38
K (Carrying capacity)	499913	252217	990865	13.12
q1 (Catchability for survey)	0.07	0.02	0.19	-2.72
sdb (Standard deviation, biomass)	0.06	0.03	0.11	-2.83
sdf (Standard deviation, fishing mortality)	0.14	0.10	0.20	-1.97
sdi (Standard deviation, Survey)	0.16	0.12	0.22	-1.84
Sdc (Standard deviation, catch)	0.06	0.04	0.10	-2.81
B (Biomass end of 2023)	322570	105264	988479	12.68
F (Fishing mortality end of 2023)	0.10	0.03	0.31	-2.28
Relative reference points				
B/Bmsy, end current year (proj.) (%)	1.30	0.76	2.22	0.26
F/Fmsy, end current year (proj.) (%)	0.80	0.28	2.25	-0.23

Table 3. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logsdb	logsdf	logsdi	logsdc
logm	1.00000000	0.868646999	-0.93453593	0.074859437	0.15809673	-0.063593254	-0.05091516
logK	0.86864700	1.000000000	-0.93511992	-0.009668063	0.04952964	0.007480997	-0.01250956
logq	-0.93453593	-0.935119921	1.00000000	-0.017705498	-0.11033206	0.020990401	0.03363581
logsdb	0.07485944	-0.009668063	-0.01770550	1.000000000	0.07750947	-0.264976025	-0.04536103
logsdf	0.15809673	0.049529641	-0.11033206	0.077509466	1.00000000	-0.117122556	-0.20407908
logsdi	-0.06359325	0.007480997	0.02099040	-0.264976025	-0.11712256	1.000000000	0.03164498
logsdc	-0.05091516	-0.012509556	0.03363581	-0.045361028	-0.20407908	0.031644979	1.00000000

Table 4. Checking the influence of initial values on parameter estimates with 20 random selected initial values. Distance from the estimated parameter vector to the base run parameter vector (should be close to 0).

	Distance	m	K	q	sdb	sdf	sdi	sdc
Basevec	0.00	32227.80	499913.3	0.07	0.06	0.14	0.16	0.06
Trial 1	0.14	32227.81	499913.2	0.07	0.06	0.14	0.16	0.06
Trial 2	0.40	32227.79	499912.9	0.07	0.06	0.14	0.16	0.06
Trial 3	0.40	32227.81	499912.9	0.07	0.06	0.14	0.16	0.06
Trial 4	0.37	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 5	0.37	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 6	0.03	32227.81	499913.3	0.07	0.06	0.14	0.16	0.06
Trial 7	0.34	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 8	0.34	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 9	0.35	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 10	0.08	32227.82	499913.2	0.07	0.06	0.14	0.16	0.06
Trial 11	0.33	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 12	0.33	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 13	0.55	32227.80	499912.8	0.07	0.06	0.14	0.16	0.06
Trial 14	0.44	32227.80	499912.9	0.07	0.06	0.14	0.16	0.06
Trial 15	6765327.47	563498.57	7244348.6	0.00	0.09	0.11	0.16	0.36
Trial 16	0.34	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 17	0.47	32227.80	499912.8	0.07	0.06	0.14	0.16	0.06
Trial 18	0.07	32227.81	499913.3	0.07	0.06	0.14	0.16	0.06
Trial 19	0.34	32227.80	499913.0	0.07	0.06	0.14	0.16	0.06
Trial 20	0.49	32227.80	499912.8	0.07	0.06	0.14	0.16	0.06

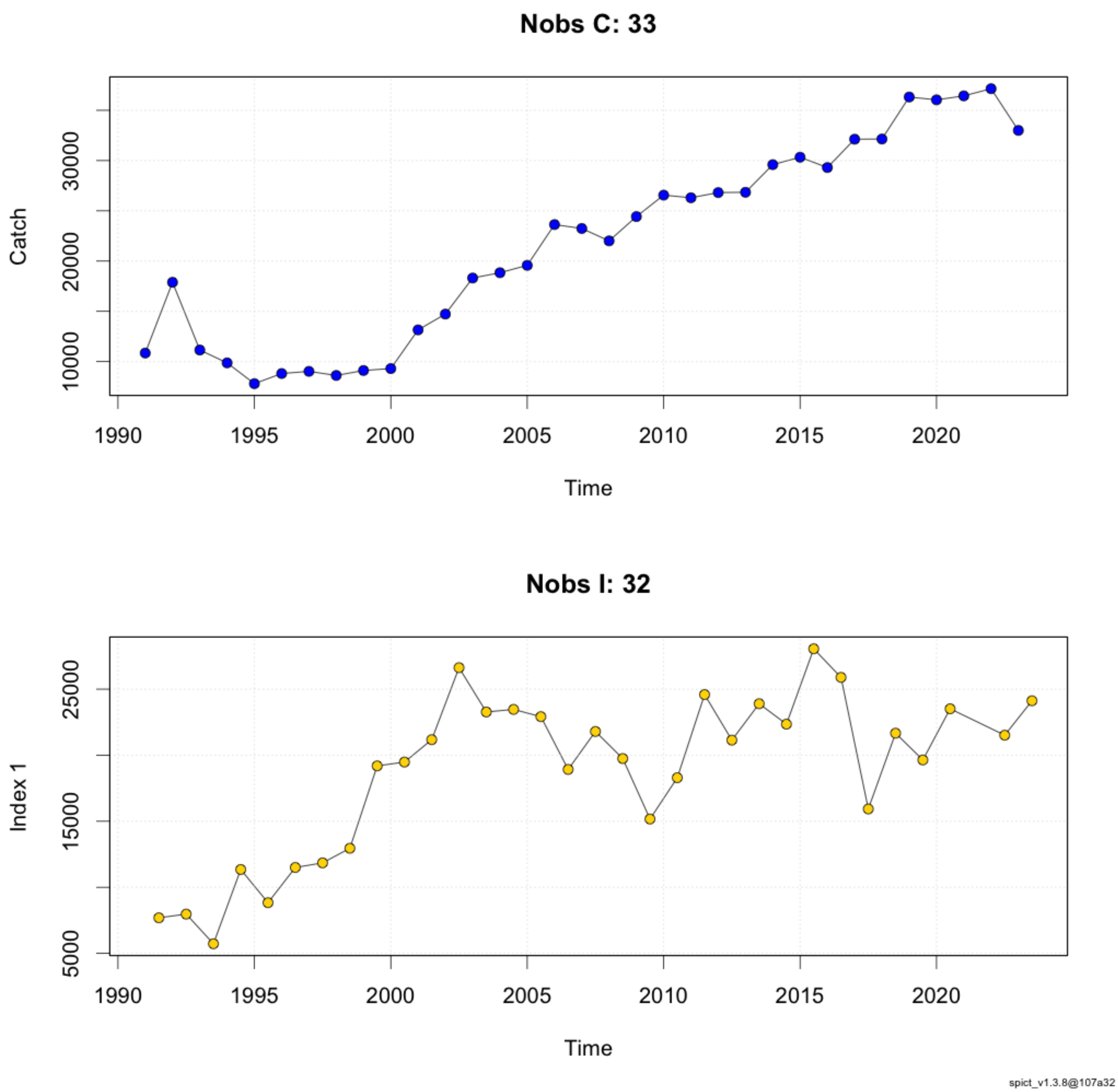

Figure 1. Input data for SPiCT models of the Greenland halibut Subareas 0+1 offshore stock. Top: Catch, middle: 0A-1CD combined index, Bottom: 1AF Survey index (biomass > 35 cm).

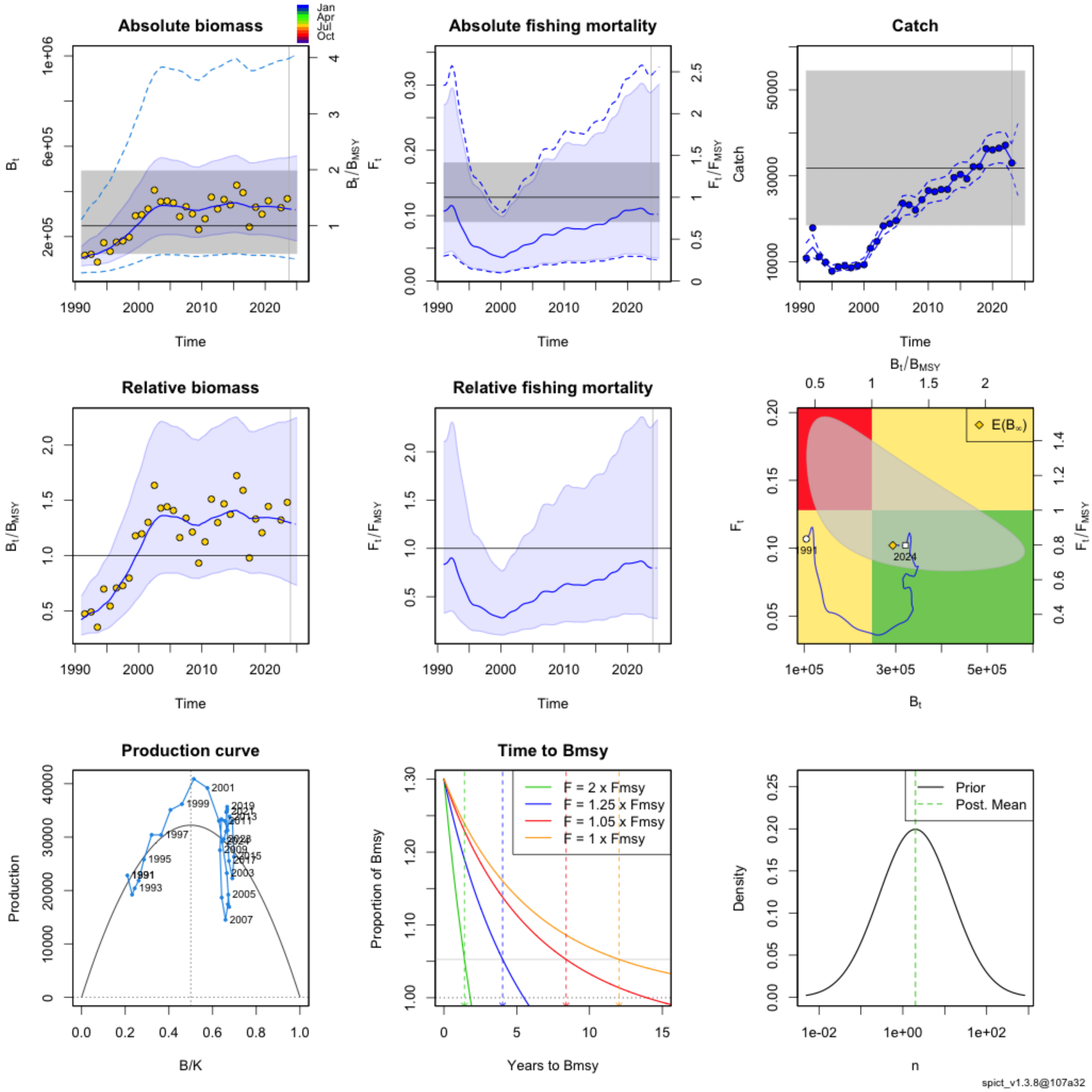

Figure 2. Main results of the model.

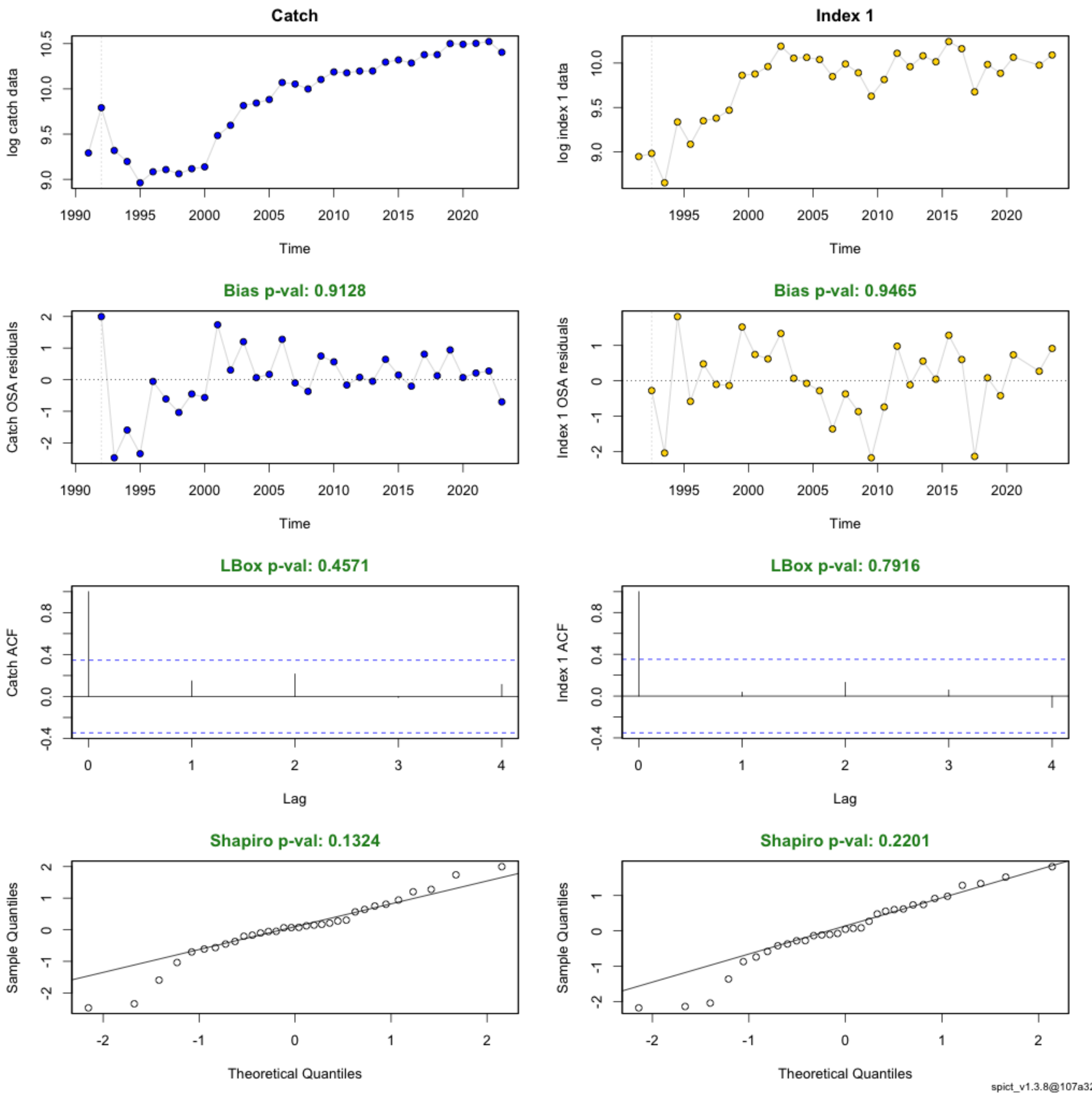

Figure 3. Diagnostics. First row show log of the input data series; catch, combined survey index 1AF-0A1CD. Second row "one-step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row show the results of Shapiro test for normality of the residuals.

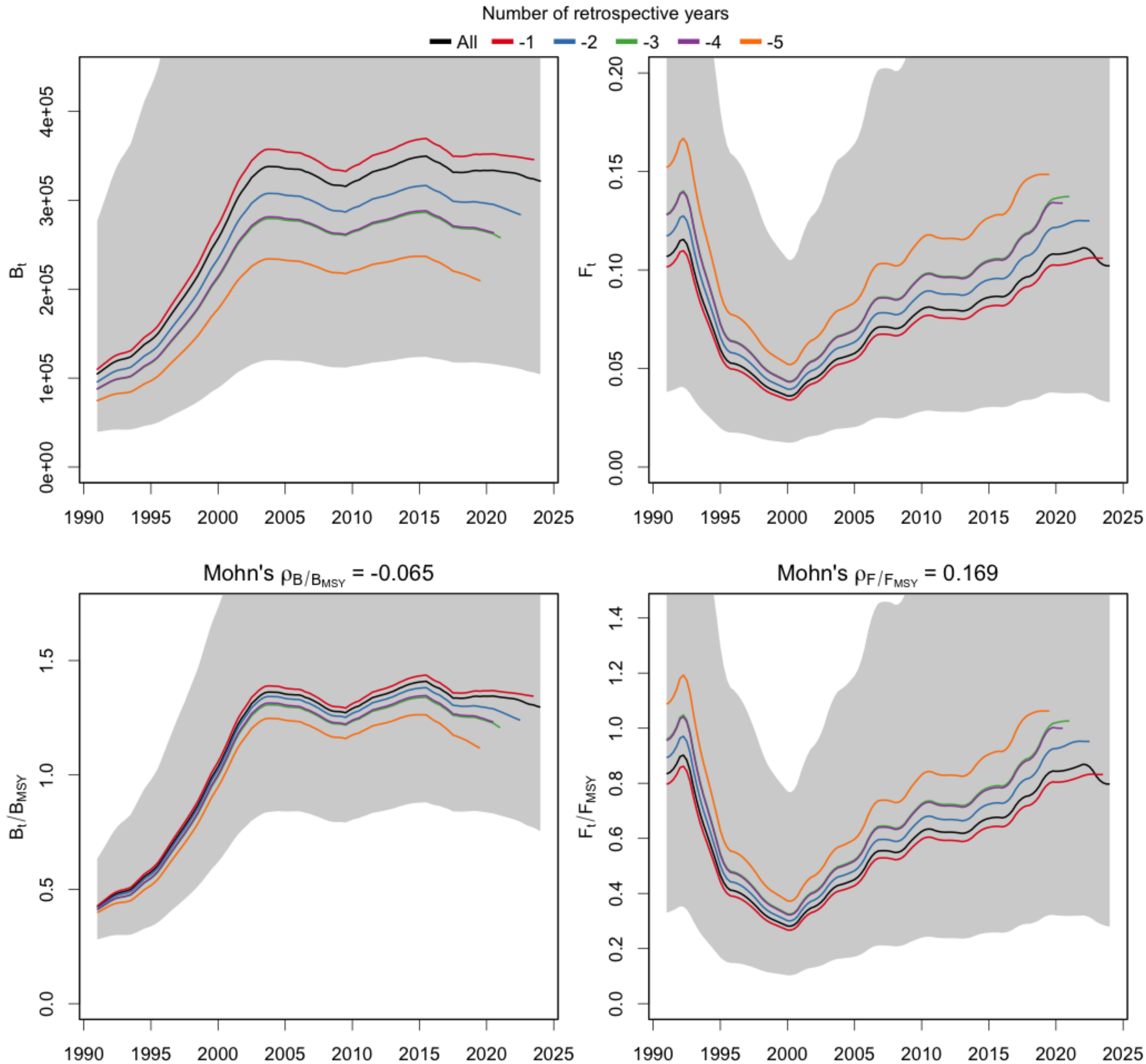

Figure 4. Five-year retrospective plots of fishing mortality and fishable biomass.95% confidence limits for the final year is indicated.

Annex 1. Results from SPiCT:

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Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: -6.7299936
Euler time step (years):  1/4 or 0.25
Nobs C: 33,  Nobs I1: 32

Residual diagnostics (p-values)
    shapiro   bias    acf   LBox shapiro bias acf LBox
 C   0.1324 0.9128 0.2249 0.4571       -    -   -    -
 I1  0.2201 0.9465 0.4655 0.7916       -    -   -    -

Priors
   logn  ~  dnorm[log(2), 2^2]
   logr  ~  dnorm[log(0.25), 0.25^2]
 logsdb  ~  dnorm[log(0.1), 0.5^2]

Fixed parameters
   fixed.value
 n           2

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha  2.695825e+00 1.218338e+00 5.965071e+00  0.9917042
 beta   4.345524e-01 2.209657e-01 8.545931e-01 -0.8334387
 r      2.578671e-01 1.829482e-01 3.634659e-01 -1.3553108
 rc     2.578671e-01 1.829482e-01 3.634659e-01 -1.3553108
 rold   2.578671e-01 1.829482e-01 3.634659e-01 -1.3553108
 m      3.222780e+04 1.877789e+04 5.531140e+04 10.3805848
 K      4.999133e+05 2.522174e+05 9.908647e+05 13.1221900
 q      6.560550e-02 2.310080e-02 1.863170e-01 -2.7240964
 sdb    5.880960e-02 3.057740e-02 1.131085e-01 -2.8334506
 sdf    1.389071e-01 9.586270e-02 2.012794e-01 -1.9739499
 sdi    1.585403e-01 1.163460e-01 2.160369e-01 -1.8417464
 sdc    6.036240e-02 3.679910e-02 9.901370e-02 -2.8073886

Deterministic reference points (Drp)
           estimate        cilow        ciupp   log.est
 Bmsyd 2.499567e+05 1.261087e+05 4.954324e+05 12.429043
 Fmsyd 1.289336e-01 9.147410e-02 1.817330e-01 -2.048458
 MSYd  3.222780e+04 1.877789e+04 5.531140e+04 10.380585
Stochastic reference points (Srp)
           estimate        cilow        ciupp   log.est rel.diff.Drp
 Bmsys 2.480415e+05 1.253003e+05 4.910169e+05 12.421351 -0.007721330
 Fmsys 1.280730e-01 9.075140e-02 1.807431e-01 -2.055155 -0.006719318
 MSYs  3.176577e+04 1.854254e+04 5.441887e+04 10.366145 -0.014544948

States w 95% CI (inp$msytype: s)
                    estimate        cilow        ciupp    log.est
 B_2023.75      3.225701e+05 1.052642e+05 9.884791e+05 12.6840758
 F_2023.75      1.021239e-01 3.315420e-02 3.145697e-01 -2.2815684
 B_2023.75/Bmsy 1.300469e+00 7.621222e-01 2.219091e+00  0.2627246
 F_2023.75/Fmsy 7.973881e-01 2.821410e-01 2.253582e+00 -0.2264138

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2025.00      3.180093e+05 1.005349e+05 1.005918e+06 12.6698358
 F_2025.00      1.021240e-01 3.183980e-02 3.275552e-01 -2.2815680
 B_2025.00/Bmsy 1.282081e+00 7.302843e-01 2.250811e+00  0.2484847
 F_2025.00/Fmsy 7.973885e-01 2.700847e-01 2.354181e+00 -0.2264133
 Catch_2024.00  3.269875e+04 2.519819e+04 4.243195e+04 10.3950922
 E(B_inf)       2.938508e+05           NA           NA 12.5908273
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