Northwest Atlantic Fisheries Organization

Serial No. N6730 **NAFO SCR Doc. 17/061**

NAFO/ICES WG *PANDALUS* ASSESSMENT GROUP—September 2017

Applying a stochastic surplus production model (SPiCT) to the East Greenland Stock of Northern Shrimp

by

Frank Rigét

and

Nanette Hammeken Arboe

Pinngortitaleriffik, Greenland Institute of Natural Resources
Box 570, 3900 Nuuk, Greenland

Greenland Institute of Natural Resources
Box 570, 3900 Nuuk, Greenland

Summary

A stochastic surplus production model (SPiCT) was applied to the East Greenland stock of *Pandalus borealis*. Input data were composed of catch and survey and commercial CPUE indices. Different combinations of input data and time periods were explored. The model was relative stable when CPUE was prolonged back to 1980 and the perception was that the relative biomasse and fishing mortality were within safe biological limits.

Introduction

The SPiCT model is a stochastic surplus production model in continuous time (Pedersen & Berg, 2016). No analytical assessment has so far been performed for the stock of *Pandalus borealis* in East Greenland waters. 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.

Material and Methods

The input data was catch and CPUE indices from 1980 to 2017, and a survey index covering the period 2009-2016 (Siegstad 2016). The first year (2008) of the survey index series was not included in the analysis, as less or no experience exist at that time with fishing in this difficult area and the results were quite different from the following years. Unfortunately no survey was carried out in 2017. The catch and standardised CPUE of the Greenlandic fleet was estimated by GLM. Compared to the CPUE index in Hammeken Arboe (2017) the series was prolonged backward to begin in 1980. Only vessels with a minimum of 3 years fishing in the area was included in the GLM. The logbook coverage in the early years of the fishery was poor. As a consequence there is only one vessel included in the GLM from 1980 to 1984. 4 vessels are included in the GLM in 1985 and 16 vessels in 1986. A total of 83 vessels were included in the GLM.

Results and Discussion

The SPiCT model were applied to combinations of the catch with the CPUE and survey index (Catch & Index, Catch & CPUE and Catch & Index & CPUE) and using to different time periods of the CPUE (1980-2017 and 1987-2017) (Table 4). In some cases the model was only able to converge or give more reasonable confidence limits of the reference points, if the parameter n was fixed to a value of 2 (symmetric Schaefer production curve). Using the survey index as the only index resulted in a quite different perception of the stock status than when the CPUE index was included. The survey index series is relative short and showing a gradually decrease since 2009, while the CPUE series is relative long and fluctuating during time, which explain the different outputs when used alone. Comparing of two runs both using survey index and CPUE index with and without fixing n to 2 showed very similar temporal patterns but the confidence limits were very large when n was estimated. The model using both survey and CPUE indices and with a fixed n (n=2) was elected for the final analysis described below.

Model residuals and diagnostic are shown in Fig. 2. The One Step Ahead (OSA) residuals were not significant different from zero and therefore not biased (above figure row). Testing of multiple lags (here 4) and the individual lags show no significant autocorrelation of the residuals (ACF). The residuals were significantly different from being normal distributed in case of the catch, which may be caused by the very low catch in recent years.

Table 2 show the correlations between model parameters. The correlations were high in-between the log value of carrying capacity (K) and the catchabilities (q's) showing that these parameters are not well separated. Also the correlation between B_{MSY} and F_{MSY} was high (-0.79).

Fig. 3 show the relative fishing mortality (F_t/F_{MSY}) and the relative biomass (B_t/B_{MSY}). F_t/F_{MSY} has been well below 1 except in a short period around 1990 with high catches, where it was above 1. The relative biomass (B_t/B_{MSY}) has mostly been above 1 except in the years from late 1980s to mid 1990s and in recent years. However in 2017 B_t/B_{MSY} is again above 1 (1.54). During the period the relative biomass and fishing mortality has mostly been in the green square ($F_t/F_{MSY}<1$ and $B_t/B_{MSY}>1$) and from 2016 to 2017 it has moved from the yellow square ($F_t/F_{MSY}<1$ but $B_t/B_{MSY}<1$) to the green square.

Retrospective plots shortened by the 1 to 4 of the last observations (Fig. 4) show low consistency in case of biomass and fishing mortality, whereas the relative biomass and the relative fishing mortality were rather robust.

Table 3 show the stochastic reference points from the SPiCT model. MSY is estimated to 12,089 T, B_{2017}/B_{MSY} to 1.54 and F_{2017}/F_{MSY} to 0.014, however, the confidence limits are relative broad. The predicted catch in 2018 at F = F_{2017} amount to 457 T.

Forecast for the year 2018 is shown in Table 4. Six forecast scenarios are presented. The B_{2017}/B_{MSY} are above 1 in all scenarios and the F_{2017}/F_{MSY} are below 1 in all scenarios except for fishing at F_{MSY}. The B increase in all scenarios except with fishing at F_{MSY}.

Conclusion

The SPiCT model was run with the assumption of a symmetric Schaefer production curve. The model was sensitive of removing last years data (retrospective plots) and with some violation of the model assumption (normal distribution of the residuals in case of catch). The results indicated that F_{2017}/F_{MSY} is well below 1 and B/B_{MSY} is above 1, however the confidence limits were large. The results are therefore only indicative. The SPiCT model may be more applicable in the future, especially when more years of survey data is obtained.

References

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Table 1. Comparison of the SPiCT output using different input data.

East Greenland	MSY	B_MSY	F_MSY	B/Bmsy 2017	F/Fmsy 2017	Catch 2018	Fixing n	Converge
Survey								NO
Survey	930	3,567	0.026	0.056	5.150	266	x	
CPUE 1980	9,485	52,618	0.203	1.349	0.018	469		YES
Survey+CPUE 1980	8,993	57,513	0.179	1.273	0.020	475		YES
Survey+CPUE 1980	12,089	44,050	0.278	1.544	0.014	457	x	YES
CPUE 1987								NO
CPUE 1987								NO
Survey+CPUE 1987								NO
Survey+CPUE 1987							x	unrealistic

Table 2. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn
logm	1.0000000000	0.6008779181	-0.6058609352	-0.6176757761	7.060414e-04
logK	0.6008779181	1.0000000000	-0.9587250549	-0.9705114811	-2.216854e-04
logq	-0.6058609352	-0.9587250549	1.0000000000	0.9872046340	1.232658e-04
logq	-0.6176757761	-0.9705114811	0.9872046340	1.0000000000	1.098495e-04
logn	0.0007060414	-0.0002216854	0.0001232658	0.0001098495	1.000000e+00
logsdb	0.1775995933	-0.4169967019	0.3983948152	0.3911491474	3.495859e-04
logsdf	0.0031970667	-0.1131983616	0.1212232926	0.1186209373	5.799802e-05
logsdi	0.0217091729	-0.1134126270	0.1158049990	0.1095167255	1.274845e-04
logsdi	-0.0575381411	0.2792730149	-0.2953260803	-0.2769832433	-3.623948e-04
logsdc	0.0494576880	0.1384698552	-0.1431808422	-0.1448274637	-3.115452e-05
	logsdb	logsdf	logsdi	logsdi	logsdc
logm	0.1775995933	3.197067e-03	0.0217091729	-0.0575381411	4.945769e-02
logK	-0.4169967019	-1.131984e-01	-0.1134126270	0.2792730149	1.384699e-01
logq	0.3983948152	1.212233e-01	0.1158049990	-0.2953260803	-1.431808e-01
logq	0.3911491474	1.186209e-01	0.1095167255	-0.2769832433	-1.448275e-01
logn	0.0003495859	5.799802e-05	0.0001274845	-0.0003623948	-3.115452e-05
logsdb	1.0000000000	9.779773e-02	0.1948461335	-0.5198881224	-7.804304e-02
logsdf	0.0977977320	1.000000e+00	0.0734873320	-0.1626222509	-3.986801e-01
logsdi	0.1948461335	7.348733e-02	1.0000000000	-0.3459844002	-8.981413e-03
logsdi	-0.5198881224	-1.626223e-01	-0.3459844002	1.0000000000	3.920863e-02
logsdc	-0.0780430444	-3.986801e-01	-0.0089814133	0.0392086321	1.000000e+00

Table 3. Results from the SPiCT model including parameter estimates, reference points and predictions of East Greenland stock of northern shrimp

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Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 54.4892831
Euler time step (years):  1/16 or 0.0625
Nobs C: 38,  Nobs I1: 8,  Nobs I2: 38

Priors
     logn  ~  dnorm[log(2), 0.001^2] (fixed)
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp     log.est
 alpha1 7.881865e-01 4.141411e-01 1.500064e+00  -0.2380205
 alpha2 3.564619e-01 9.889110e-02 1.284899e+00  -1.0315280
 beta   8.065650e-01 3.841166e-01 1.693619e+00  -0.2149708
 r      6.068918e-01 2.516681e-01 1.463505e+00  -0.4994047
 rc     6.068911e-01 2.516684e-01 1.463501e+00  -0.4994059
 rold   6.068903e-01 2.516675e-01 1.463502e+00  -0.4994072
 m      1.520092e+04 7.649311e+03 3.020769e+04   9.6291113
 K      1.001887e+05 3.332499e+04 3.012089e+05  11.5148111
 q1     6.254360e-02 1.828700e-02 2.139063e-01  -2.7718911
 q2     1.620000e-05 4.800000e-06 5.430000e-05 -11.0294980
 n      2.000002e+00 1.996086e+00 2.003926e+00   0.6931484
 sdb    3.246273e-01 2.228940e-01 4.727938e-01  -1.1250776
 sdf    4.631238e-01 2.852496e-01 7.519158e-01  -0.7697608
 sdi1   2.558669e-01 1.403326e-01 4.665191e-01  -1.3630980
 sdi2   1.157172e-01 4.066170e-02 3.293143e-01  -2.1566056
 sdc    3.735395e-01 2.502037e-01 5.576724e-01  -0.9847317

Deterministic reference points (Drp)
           estimate        cilow        ciupp   log.est
 Bmsyd 5.009439e+04 1.666250e+04 1.506046e+05 10.821664
 Fmsyd 3.034455e-01 1.258342e-01 7.317503e-01 -1.192553
 MSYd  1.520092e+04 7.649311e+03 3.020769e+04  9.629111
Stochastic reference points (Srp)
           estimate        cilow        ciupp   log.est rel.diff.Drp
 Bmsys 4.405014e+04 1.487271e+04 1.304681e+05 10.693084  -0.13721314
 Fmsys 2.779426e-01 1.104099e-01 6.996842e-01 -1.280341  -0.09175614
 MSYs  1.208926e+04 6.152286e+03 2.375544e+04  9.400073  -0.25739026

States w 95% CI (inp$msytype: s)
                    estimate        cilow        ciupp    log.est
 B_2017.00      6.799752e+04 2.132963e+04 2.167718e+05 11.1272266
 F_2017.00      3.893400e-03 1.031400e-03 1.469690e-02 -5.5484674
 B_2017.00/Bmsy 1.543639e+00 1.014911e+00 2.347814e+00  0.4341428
 F_2017.00/Fmsy 1.400800e-02 4.543200e-03 4.319060e-02 -4.2681267

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2018.00      8.425122e+04 2.622157e+04 2.707034e+05 11.3415583
 F_2018.00      5.338400e-03 1.276500e-03 2.232590e-02 -5.2328247
 B_2018.00/Bmsy 1.912621e+00 1.047964e+00 3.490693e+00  0.6484746
 F_2018.00/Fmsy 1.920690e-02 5.751000e-03 6.414600e-02 -3.9524840
 Catch_2018.00  4.568675e+02 1.556977e+02 1.340597e+03  6.1243934
 E(B_inf)       8.023310e+04           NA           NA 11.2926915
```

Table 4. Forecast with six scenarios of the East Greenland stock of northern shrimp.

```
Observed interval, index:  1980.00 - 2017.00
Observed interval, catch:  1980.00 - 2018.00

Fishing mortality (F) prediction: 2019.00
Biomass (B) prediction:           2019.00
Catch (C) prediction interval:    2018.00 - 2019.00

Predictions
                           C       B     F B/Bmsy F/Fmsy perc.dB perc.dF
1. Keep current catch   522.4 88716.7 0.006  2.014  0.022     5.3    13.9
2. Keep current F       456.9 86857.3 0.005  1.972  0.019     3.1     0.0
3. Fish at Fmsy       21314.3 69793.3 0.278  1.584  1.000   -17.2  5106.5
4. No fishing             0.5 87223.5 0.000  1.980  0.000     3.5   -99.9
5. Reduce F 25%         342.8 86948.8 0.004  1.974  0.014     3.2   -25.0
6. Increase F 25%       570.8 86765.9 0.007  1.970  0.024     3.0    25.0

95% CIs of absolute predictions
                         C.lo    C.hi    B.lo     B.hi  F.lo  F.hi
1. Keep current catch  284.1   960.5 26942.5 292128.3 0.001 0.025
2. Keep current F      156.4  1334.7 26427.8 285464.0 0.001 0.029
3. Fish at Fmsy       8073.9 56267.5 16923.7 287826.4 0.051 1.511
4. No fishing            0.2     1.3 26642.6 285555.7 0.000 0.000
5. Reduce F 25%        117.3  1002.1 26481.5 285486.4 0.001 0.022
6. Increase F 25%      195.5  1666.5 26374.3 285441.9 0.001 0.036

95% CIs of relative predictions
                      B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo F/Fmsy.hi
1. Keep current catch       NaN       NaN     0.008     0.060
2. Keep current F         1.599     2.431     0.005     0.073
3. Fish at Fmsy           0.918     2.736     0.265     3.780
4. No fishing             1.621     2.419     0.000     0.000
5. Reduce F 25%           1.605     2.428     0.004     0.054
6. Increase F 25%         1.594     2.434     0.006     0.091
```

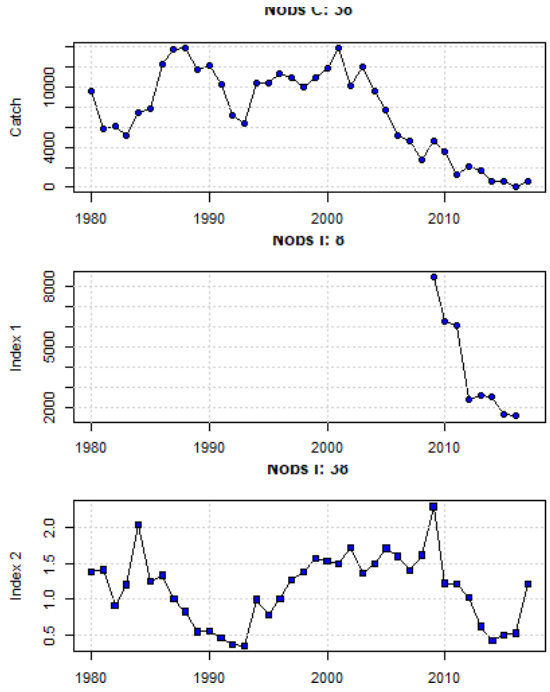

Fig. 1. Input data for the SPiCT models of East Greenland stock of northern shrimp. Top: Catch, Mittel: Survey index, Bottom: CPUE index.

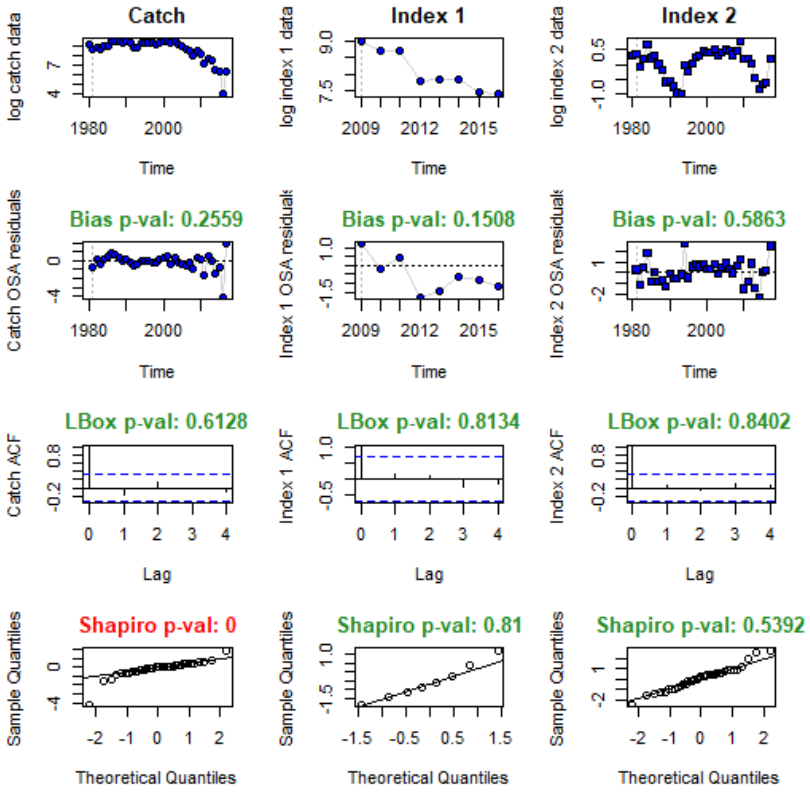

Fig. 2 Diagnostics. First column show log of the input data series; catch, survey index and CPUE. Second column "one-step ahead" (OSA) residuals and a test for bias, Third column show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth column test for normality of the residuals.

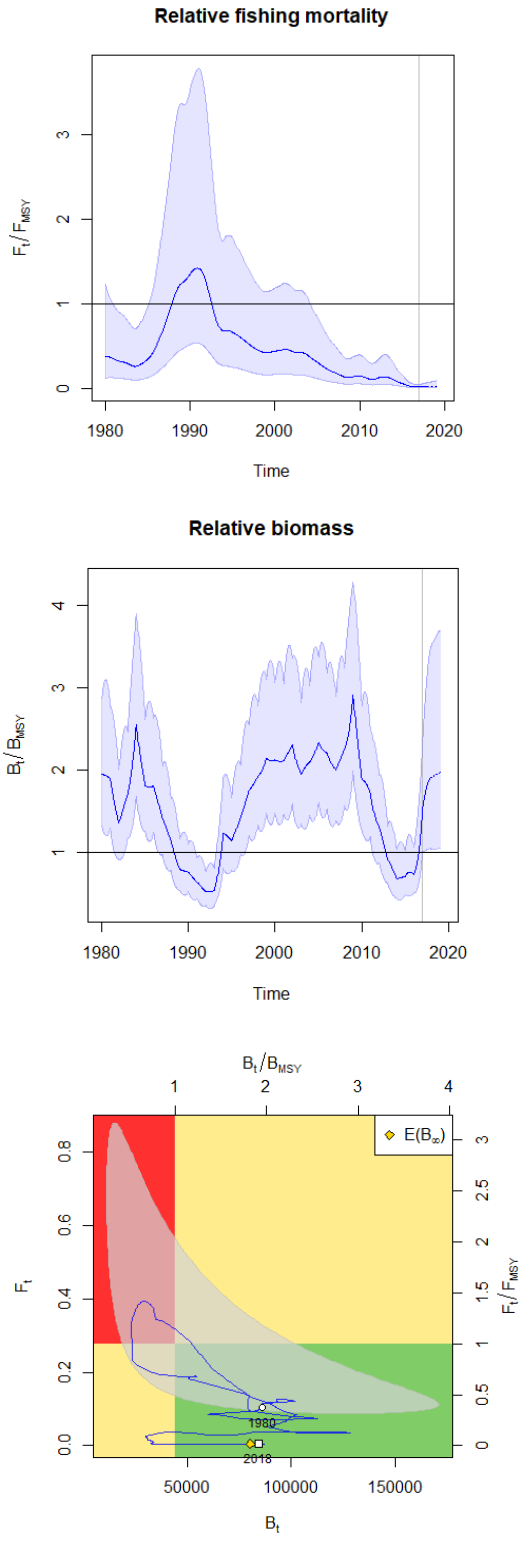

Fig. 3. Plot of the estimated relative fishing mortality (F_t/F_{MSY}) and relative biomass (B_t/B_{MSY}) trough time of East Greenland stock of northern shrimp.

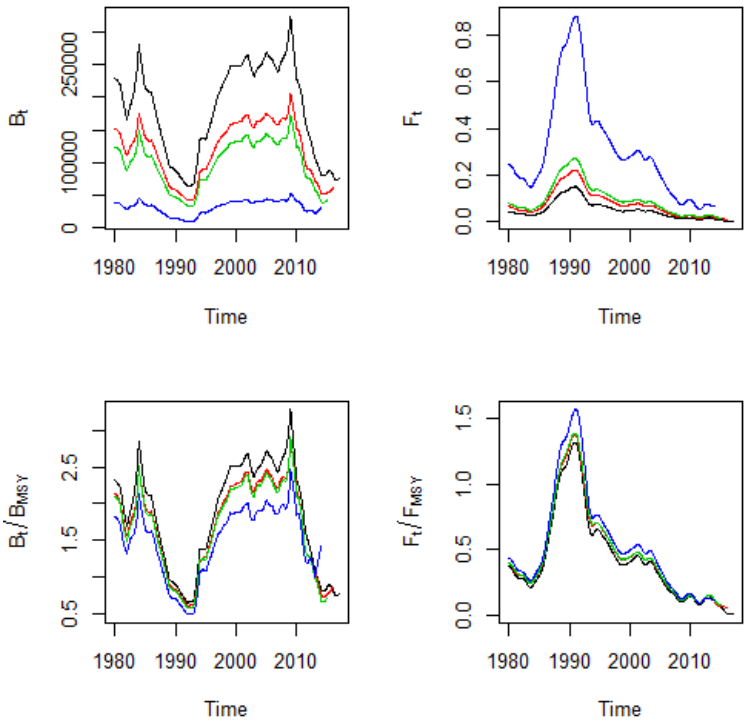

Fig. 4. Retrospective plots of fishing mortality and fishable biomass with 4 scenarios where the time-series of catch, survey and CPUE are shortened by the 1 to 4 last observations of the East Greenland stock of northern shrimp.