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

by

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Summary

A stochastic surplus production model (SPiCT) was applied to the West Greenland stock of *Pandalus borealis*. Input data composed of survey fishable biomass, catch and commercial CPUE indices. Different combinations of input data and time periods were explored. The model was stable and the perception was that the relative biomasse and fishing mortality were within safe biological limits. In general, model output was similar to the output of the stock-dynamic model used for assessing the Shrimpp stock in NAFO Division 0A.

Introduction

The SPiCT model is a stochastic surplus production model in continuous time (Pedersen & Berg, 2016). The model was tried in order to compare the output with that of the stock-dynamic model of the West Greenland Northern shrimp stock (Burmeister and Rigét, 2017b) used in recent years. 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 a thirty years' time period (1988-2017), identical with the corresponding input data to the stock-dynamic model used in the assessment of the West Greenland stock of northern shrimp (Burmeister and Rigét 2017a) (Fig. 1). The input composed of catches as a proxy for the catches, survey fishable biomass abundance index and a commercial CPUE index (Burmeister & Rigét 2017b; Hammeke 2017).

Results and Discussion

The SPiCT model were applied to combinations of the catch with the CPUE and survey fishable biomass index (Catch & Index, Catch & CPUE and Catch & Index & CPUE). In all cases the model was stable and converged. Using the survey fishable biomass index as the only index or the CPUE index as the only index resulted in quite different perceptions of the stock status. The survey fishable biomass index has a marked peak in the period 2003 to 2006, whereas the CPUE index is gradually increasing from about 2005 to 2008. The difference of the two indices cause the discrepancy of the model output when the indices are applied alone. The model using both catch, survey fishable biomass, and CPUE indices 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) show no significant autocorrelation of the residuals (ACF) in case of catch and CPUE time-series but significant for the survey fishable biomass index. Also in case of individual lags (lag 1 and 2) of the survey index. The residuals were not significantly different from being normal distributed in any case.

Table 1 show the correlations between model parameters. The correlations were relatively high in several occasions meaning that the parameters are not well separated. E.g. are the log value of maximum sustainable yield (m), carrying capacity (K) and the catchabilities (q) highly inter-correlated. Also the correlation between B_{MSY} and F_{MSY} was high (-0.98).

Fig. 3 show the relative fishing mortality (F_t/F_{MSY}) and the relative biomass (B_t/B_{MSY}) derived from the SPiCT model. F_t/F_{MSY} has decreased steadily since the early 1990s and is in recent years at a historical low level. The relative biomass (B_t/B_{MSY}) has since 2003 been above or close to one, and in the last 4 to 5 years been increasing. The development of biomass and fishing mortality since 1988 have moved from the yellow/red square (F_t/F_{MSY}>1 and B_t/B_{MSY}<1) to the green square (F_t/F_{MSY} <1 and B_t/B_{MSY}>1).

Retrospective plots of fishing mortality and fishable biomass with 4 scenarios with catch, survey and CPUE time series are shortened by the 1 to 4 last observations, show high consistency between the scenarios (Fig. 4), especially in case of the relative fishing mortality and biomass.

Table 2 show the stochastic reference points from the SPiCT model. B_{MSY} is estimated to 158 Kt, B_{2017}/B_{MSY} to 1.25 and F_{2017}/F_{MSY} to 0.45. However, the confidence limits are relative broad. Compared to the output from the stock-dynamic model the B_{MSY} is similar, B_{2017}/B_{MSY} (1.45) and F_{2017}/F_{MSY} (Z_{2017}/Z_{MSY} = 0.57) are somewhat smaller. The predicted catch in 2018 at F = F_{2017} amount to 90 Kt.

Forecast for the year 2018 is shown in Table 3. 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 no fishing and fishing at F_{MSY}. The B increase in all scenarios except with fishing at F_{MSY} and with a 25% increase of F.

Table 4 compare the output of the above described results with runs using different combinations of input data and with using the total catch series back to 1970. When only using the catch data and survey index, B_{2017}/B_{MSY} are below 1 and F_{2017}/F_{MSY} above 1. Using only catch data and the CPUE index, the results are similar to those using both CPUE index and survey index. When the catch data going back to 1970 is applied MSY decrease with about 30 Kt and B_{2017}/B_{MSY} decrease to 1.14 and F_{2017}/F_{MSY} increase to 0.63.

Conclusion

The SPiCT model appears stable and give the perception of the stock being exploited well bellow F_{MSY} and that the biomass is well above B_{MSY}. In general, the output from the SPiCT model and the stock-dynamic model are consistent and support each other.

References

BURMEISTER, AD., F.F RIGET. 2017a. The West Greenland trawl survey for *Pandalus borealis*, 2017, with reference to earlier results. *NAFO SCR Doc*. 017/051, Ser. No. N6720. 39 pp.

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Table 1. Correlation matrix for the estimated SPiCT model parameters

	logm	logK	logq	logq	logn
logm	1.0000000000	0.805240205	-0.8555477426	-0.8582002811	0.762910453
logK	0.8052402047	1.000000000	-0.9875600171	-0.9906218609	0.411168673
logq	-0.8555477426	-0.987560017	1.0000000000	0.9968897448	-0.514272535
logq	-0.8582002811	-0.990621861	0.9968897448	1.0000000000	-0.515866969
logn	0.7629104533	0.411168673	-0.5142725349	-0.5158669694	1.000000000
logsdb	0.1017495100	-0.077743424	0.0372569937	0.0373725109	0.173356136
logsdf	-0.0009598998	-0.011799562	0.0095425632	0.0095721497	0.007238227
logsdi	0.0028765868	-0.001186700	0.0005861477	0.0005879801	0.003427963
logsdi	-0.0399197594	0.045374499	-0.0288439804	-0.0289334131	-0.096324834
logsdc	-0.0290578423	0.007129401	0.0018014219	0.0018070055	-0.046377617

	logsdb	logsdf	logsdi	logsdi	logsdc
logm	0.10174951	-0.0009598998	0.0028765868	-0.03991976	-0.029057842
logK	-0.07774342	-0.0117995616	-0.0011867004	0.04537450	0.007129401
logq	0.03725699	0.0095425632	0.0005861477	-0.02884398	0.001801422
logq	0.03737251	0.0095721497	0.0005879801	-0.02893341	0.001807006
logn	0.17335614	0.0072382268	0.0034279634	-0.09632483	-0.046377617
logsdb	1.00000000	0.0277061590	0.0193360365	-0.41771689	-0.133054429
logsdf	0.02770616	1.0000000000	0.0035193340	-0.08150334	-0.384654618
logsdi	0.01933604	0.0035193340	1.0000000000	-0.03381426	-0.003904784
logsdi	-0.41771689	-0.0815033411	-0.0338142596	1.00000000	0.087683356
logsdc	-0.13305443	-0.3846546175	-0.0039047845	0.08768336	1.000000000

Table 2. Results from the SPiCT model including parameter estimates, reference points and predictions

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Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: -37.5249224
Euler time step (years):  1/16 or 0.0625
Nobs C: 30,  Nobs I1: 30,  Nobs I2: 30

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

Model parameter estimates w 95% CI
            estimate       cilow        ciupp    log.est
 alpha1    4.1667953   2.7798745    6.2456715  1.4271472
 alpha2    0.2330528   0.0339926    1.5978072 -1.4564901
 beta      0.3459845   0.1196911    1.0001184 -1.0613614
 r         1.3080325   0.2991374    5.7196098  0.2685241
 rc        0.3062691   0.1188250    0.7894027 -1.1832912
 rold      0.1734395   0.0601861    0.4998040 -1.7519263
 m       171.8129850 102.5947033  287.7312461  5.1464066
 K      1491.0827679 441.4619145 5036.2845530  7.3072578
 q1        0.2687962   0.0683630    1.0568784 -1.3138019
 q2        0.0018293   0.0004672    0.0071624 -6.3038069
 n         8.5417208   1.6926090   43.1056405  2.1449625
 sdb       0.0722506   0.0523766    0.0996656 -2.6276152
 sdf       0.1026015   0.0701001    0.1501719 -2.2769028
 sdi1      0.3010533   0.2340074    0.3873087 -1.2004680
 sdi2      0.0168382   0.0028726    0.0987000 -4.0841054
 sdc       0.0354985   0.0150966    0.0834724 -3.3382642

Deterministic reference points (Drp)
           estimate       cilow        ciupp   log.est
 Bmsyd 1121.9740424 284.5006279 4424.6853191  7.022845
 Fmsyd    0.1531345   0.0594125    0.3947014 -1.876438
 MSYd   171.8129850 102.5947033  287.7312461  5.146407
Stochastic reference points (Srp)
         estimate       cilow        ciupp   log.est rel.diff.Drp
 Bmsys 1105.14467 283.8815586 4302.3038905  7.007732  -0.01522821
 Fmsys    0.14336   0.0491463    0.4181821 -1.942396  -0.06818182
 MSYs   158.26903 109.8819329  227.9636582  5.064296  -0.08557549

States w 95% CI (inp$msytype: s)
                   estimate       cilow        ciupp    log.est
 B_2017.00      1382.3839889 354.1973143 5395.2568691  7.2315648
 F_2017.00         0.0651936   0.0168202    0.2526840 -2.7303937
 B_2017.00/Bmsy    1.2508625   1.0834129    1.4441927  0.2238333
 F_2017.00/Fmsy    0.4547546   0.3088796    0.6695223 -0.7879973

Predictions w 95% CI (inp$msytype: s)
                 prediction       cilow        ciupp    log.est
 B_2018.00      1388.7440064 367.1892371 5252.3596022  7.2361550
 F_2018.00         0.0649401   0.0168116    0.2508507 -2.7342906
 B_2018.00/Bmsy    1.2566174   1.0553763    1.4962316  0.2284235
 F_2018.00/Fmsy    0.4529859   0.3047224    0.6733875 -0.7918943
 Catch_2018.00    90.3367080  74.2728918  109.8748226  4.5035439
 E(B_inf)       1351.1656653          NA           NA  7.2087230
```

Table 3. Forecast with six scenarios.

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Observed interval, index:  1988.00 - 2017.00
Observed interval, catch:  1988.00 - 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  90.0 1392.6 0.065  1.260  0.451     0.3    -0.3
2. Keep current F      90.3 1393.1 0.065  1.261  0.453     0.3     0.0
3. Fish at Fmsy       193.5 1314.6 0.143  1.189  1.000    -5.3   120.8
4. No fishing           0.1 1455.5 0.000  1.317  0.000     4.8   -99.9
5. Reduce F 25%        68.2 1409.0 0.049  1.275  0.340     1.5   -25.0
6. Increase F 25%     112.2 1377.1 0.081  1.246  0.566    -0.8    25.0

95% CIs of absolute predictions
                       C.lo  C.hi  B.lo   B.hi  F.lo  F.hi
1. Keep current catch  84.3  96.1 374.8 5173.9 0.017 0.244
2. Keep current F      74.3 109.9 374.8 5177.8 0.017 0.255
3. Fish at Fmsy       160.0 234.0 325.5 5308.8 0.037 0.562
4. No fishing           0.1   0.1 416.2 5090.2 0.000 0.000
5. Reduce F 25%        55.9  83.1 385.2 5153.9 0.012 0.191
6. Increase F 25%      92.5 136.2 364.5 5202.9 0.021 0.318

95% CIs of relative predictions
                      B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo F/Fmsy.hi
1. Keep current catch     1.045     1.520     0.307     0.664
2. Keep current F         1.041     1.526     0.290     0.707
3. Fish at Fmsy           0.989     1.430     0.641     1.560
4. No fishing             1.050     1.652     0.000     0.001
5. Reduce F 25%           1.046     1.554     0.218     0.530
6. Increase F 25%         1.035     1.500     0.363     0.883
```

Table 4. Comparison of the SPiCT output using different input data.

West Greenland	MSY	B_MSY	F_MSY	B/Bmsy 2017	F/Fmsy 2017	Catch 2018	
Survey	149.876	355,944	0.421	0.430	1.370	100,633	Catch 1970-2017, Survey 1988-2017, CPUE 1987-2017
CPUE	126,347	1,187,607	0.107	1.137	0.627	91,515	Catch 1970-2017, Survey 1988-2017, CPUE 1987-2017
Survey+CPUE	126,182	1,179,524	0.107	1.140	0.626	91,509	Catch 1970-2017, Survey 1988-2017, CPUE 1987-2017
Survey	144,678	280,408	0.516	0.519	1.172	99,836	Same period as Assessment Model 1988-2017
CPUE	158,492	1,107,490	0.143	1.252	0.454	90,333	Same period as Asessment Model 1988-2017
Survey+CPUE	158,269	1,105,145	0.143	1.251	0.453	90,337	Same period as Assessment Model 1988-2017

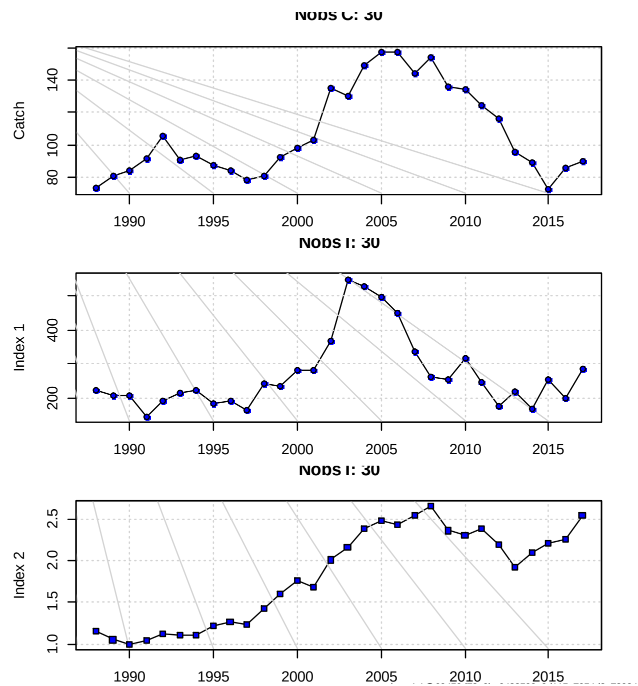

Fig. 1. Input data for the SPiCT models of West Greenland stock of northern shrimp.
Top: Catch, Mittel: Survey index, Bottom: CPUE index.

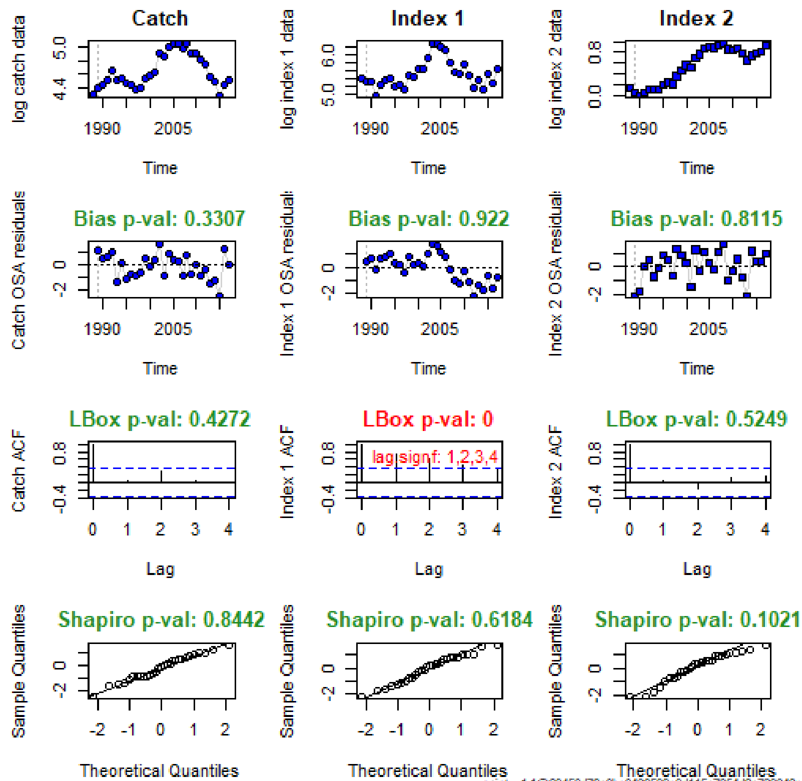

Fig. 2. Diagnostics. First column show log of the input data series; catch, survey index and CPUE. Second column "one-step ahead" (OSA) residuals and a test for bias, Third column show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth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

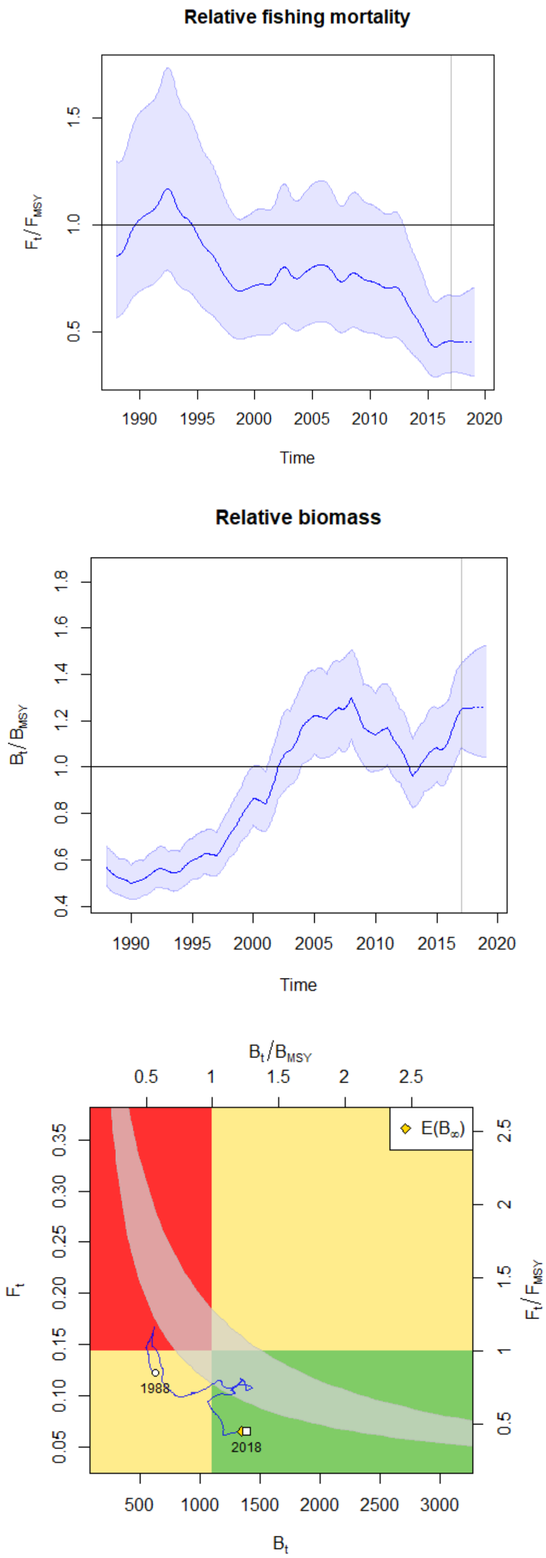

Fig. 3. Plot of the estimated relative fishing mortality (F_t/F_{MSY}) and relative biomass (B_t/B_{MSY}) trough time.

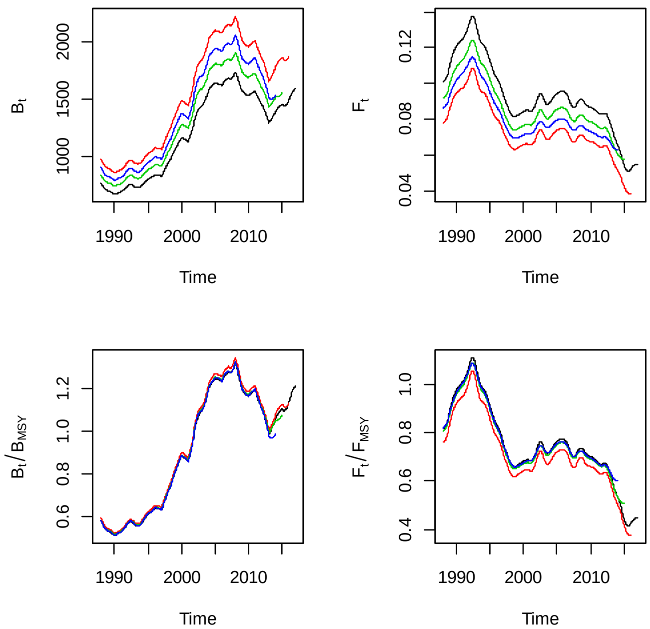

Fig. 4. Retrospective plots of fishing mortality and fishable biomass with 4 scenarios where the time-series of catch, survey and CPUE are shortened by the 1 to 4 last observations