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Title

Prediction of Atlantic cod (*Gadus morhus*) biomass in West Greenland waters based on a regression approach

by

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Summary

Cod is included as predator in the assessment of northern shrimp (*Pandalus borealis*) in West Greenland. In order to predict the fishable biomass in the assessment year (year+1), the stock model should have as reliable an estimate of cod biomass as possible. Previously this cod biomass estimate has been based on expert judgement. It would be desirable with an objective way of estimating the cod biomass. Here we present and evaluate an approach based on linear regressions of the biomass of a given age group one year ahead.

Introduction

The northern shrimp (*Pandalus borealis*) scientific advice is generated by NAFO yearly in September. The advice procedure is based on a Baysian approach, and includes a predation term with cod biomass used as a proxy for shrimp removal. In order to predict the fishable biomass in the assessment year (i.e. y+1), the model should have as reliable an estimate of cod biomass as possible. This estimate is generated based on the Greenland Institute of Natural Resources yearly bottom trawl survey in West Greenland waters; the same survey that targets shrimp.

Cod data are available as age disaggregated data, but in the advisory year (i.e. y) the data are only available as an overall length distribution. Previously the cod biomass estimate in the assessment year (i.e. y+1) has been based on expert judgement. In this document we present a simple regression based approach to predict the cod biomass in the assessment year.

Material and Methods

Linear regressions

The calculations and predictions are based on the data presented in tables 1 and 2. We do not have reliable weight-at-age data for the period prior to 2005. For this period and in years with missing values, we use the time series average. The product of table 1 and 2 is the age specific biomass estimates. The gear does not catch age 0 well, and we do not use these data. The biomass from this age group is also negligible and will not affect the results.

As the predicted value is used without uncertainty in the northern shrimp assessment, we do not incorporate uncertainty into the prediction.

We use linear regressions to predict the biomass of a given age group one year ahead. We do regressions of the form:

Biomass at age y+1 = Biomass at age y.

Possible aurocorrelation was tested by Durbin-Watson test and showed significance ($p<0.05$) in case of age 4 vs age 3 and age 7 versus age 6. However we chose not to correct for autocorrelation as it appears not to be a general event.

Obtaining beta (incline) and alfa (interception) coefficients for each regression. We predict each age group forward one year as:

Biomass age x+1 = Biomass at age x * beta + alfa

There is no data to predict the number of 1 year olds. The recruitment pattern is apparently cyclic in recent times at age 1 (fig. 1). A peak in age 1 recruitment seems to be followed by a drastic decline the next year. The 2017 age 1 recruitment is based on observations from the 2017 survey. We multiply the abundance of fish smaller than 15 cm from 2017 survey by the average weight of 1-year olds in 2016.

By applying the 2016 age-length key and 2016 weight-at-age estimates we convert the observed 2017 length distribution from the 2017 survey to biomass-at-age. These estimates are then projected forward 1 year using the obtained regression coefficients from the entire dataset. The biomass of 1-year olds in 2018 is estimated as the average of the 2000-2016 1-year old recruitment (47.1 t)

Retrospective pattern

To evaluate the accuracy of the approach, the biomass was calculated retrospectively for the past ten years. This was done by using the regression coefficients from the full data set, and preforming the calculations on a reduced data set in yearly steps. The biomass of 1 year olds were not added to these estimate, but as it normally represents a very minor proportion of the biomass the error is negligible.

Results and Discussion

The Biomass-at-age vs. Biomass-at-age+1 regressions can be seen in fig. 2. The survey seems relatively consistent, and the predictive power of a single age-specific estimate is relatively high. There are single observations that fall noticeably outside the estimated regressions. For instance, in two years the survey fails to catch the one-year-olds, that are caught at age two. In a number of years, the relatively high catch of three-year-olds is not seen as a high number of four-year-olds. At older ages outliers are also present.

The retrospective pattern shows that the predictions follow the same trend as the observed biomass index, but the rate of change is not as great as in the observed values. Hence, the increase in index values from 2010 to 2015 results in a predicted index value that is 36% below the observed 2015 value. The most noticeable difference is the extremely low 2016 observed value which is not matched by a similar decline in the predicted value.

When estimating the 2018 cod biomass – the input needed for the shrimp assessment – by projecting the 2017 estimated biomass at age one year, we get an estimate of 23242 t. If we assume that the survey coefficient of variation on the abundance estimate (36.5% averaged over the past ten years) applies to the biomass, the biomass estimate is 6275-40209 t.

The shortcomings of the applied approach are:

- A survey with a relatively high uncertainty in predicting the biomass of a given yearclass one year in advance. This naturally translate into uncertainty in the prediction.
- The West Greenland area have few old fish. This means that survey hauls with old fish are rare but do happen making estimates are associated with high CV's. Since these older age groups contribute a lot to the biomass, this uncertainty affects the projections.
- The West Greenland area is currently a major nursery area for East Greenland and Iceland cod. When fish from these areas reach maturity at age 5-8 the migrate out of the area. This can lead to observation like that in 2016 where the observed biomass is considerably lower than the prediction. There is currently no basis for estimating such a massive migration event or a way to incorporate it into the approach presented here. This will ultimately lead to an overestimate of cod predation on shrimp, and a reduced shrimp advice, in years when this happens.

With these reservations, the approach does offer an objective way of estimating the cod biomass. In years when the survey follows a "expected" trend the estimations seem reasonable. It is unclear why the survey at a faster rate than the estimated biomass values during the positive development from 2012-2015. This could be related to an influx of adult cod from the inshore area, a result of the swept area calculations in connection with migration. It does not seem to be something with the suggested approach. Similarly, fish can immigrate to the area from the adjacent inshore area. When fish growing up inshore migrate towards spawning grounds, they will appear in the survey with being seen as younger fish. Such an event can explain the discrepancy between the predictions and the observed values in the 2013-2015 values – cod come from the inshore area, elevating the biomass, before eventually leaving the area in 2016 causing the massive biomass decline in that year.

Table 1: Age disaggregated abundance indices for Atlantic cod from the West Greenland bottom trawl survey

Year/age	0	1	2	3	4	5	6	7	8+
1992		0	221	126	123	63	10	3	1
1993		0	39	170	73	16	7	1	2
1994		0	10	126	22	8	1	0	0
1995		19	345	101	157	40	0	0	0
1996		0	14	203	78	3	0	0	0
1997		0	0	10	3	24	8	1	0
1998		0	17	25	20	0	0	0	0
1999		7	144	66	23	6	1	1	1
2000		90	711	363	92	13	52	0	0
2001		97	540	546	376	0	0	0	0
2002		0	603	2323	1078	245	0	4	0
2003		81	1416	1037	433	135	18	0	0
2004		1215	2812	1205	786	382	71	33	4
2005	3284	1348	38177	44685	10490	5595	4596	113	30
2006	244	6804	5826	42612	9722	1956	532	72	0
2007	224	295	12835	6348	29856	2708	166	69	16
2008	35	3516	2880	20921	8337	16047	1530	150	0
2009	0	308	10203	2295	1928	365	16	5	0
2010	208	3062	2720	13244	2314	1690	48	69	0
2011	18	4617	64111	5767	5346	452	450	64	25
2012	0	203	12621	42195	7046	7673	889	454	35
2013	0	2891	8948	15691	68091	18446	10230	666	190
2014	0	471	4810	8656	57698	51425	5145	2553	215
2015	0	2210	3957	15672	24870	43616	42750	2456	575
2016	0	2763	5919	3029	5758	3778	1832	1086	274

Table 2: Weight at age (kg) for West Greenland Atlantic cod.

Year/age	0	1	2	3	4	5	6	7	8
1992	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
1993	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
1994	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
1995	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
1996	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
1997	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
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2003	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
2004	0.003	0.025	0.124	0.326	0.624	1.094	2.067	2.876	3.947
2005	0.002	0.031	0.146	0.298	0.596	1.208	1.800	3.338	3.947
2006	0.004	0.025	0.120	0.338	0.477	0.680	2.581	2.714	3.947
2007	0.002	0.026	0.138	0.320	0.601	1.446	4.375	2.876	3.947
2008	0.006	0.025	0.098	0.239	0.497	0.939	1.774	2.742	3.947
2009	0.003	0.024	0.104	0.329	0.620	1.353	2.103	2.876	3.947
2010	0.003	0.017	0.136	0.291	0.683	1.191	1.952	3.066	3.947
2011	0.001	0.038	0.164	0.377	0.626	1.151	2.081	2.876	3.947
2012	0.003	0.019	0.137	0.419	0.763	1.200	1.371	3.396	3.947
2013	0.003	0.038	0.112	0.337	0.611	0.781	1.722	2.905	3.560
2014	0.003	0.014	0.133	0.300	0.675	0.977	1.708	2.704	4.108
2015	0.003	0.011	0.102	0.349	0.623	1.062	1.594	2.478	4.276
2016	0.003	0.028	0.094	0.314	0.711	1.145	1.742	2.542	3.844

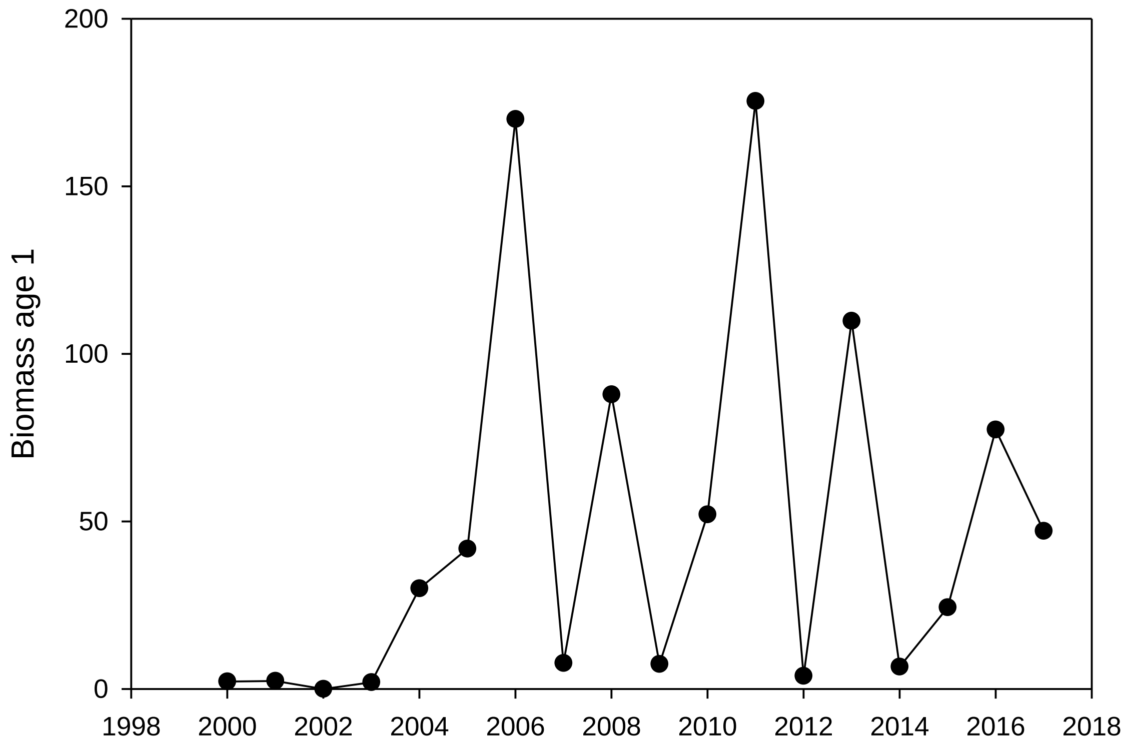

Fig. 1. Biomass of age 1 in the West Greenland bottom trawl survey.

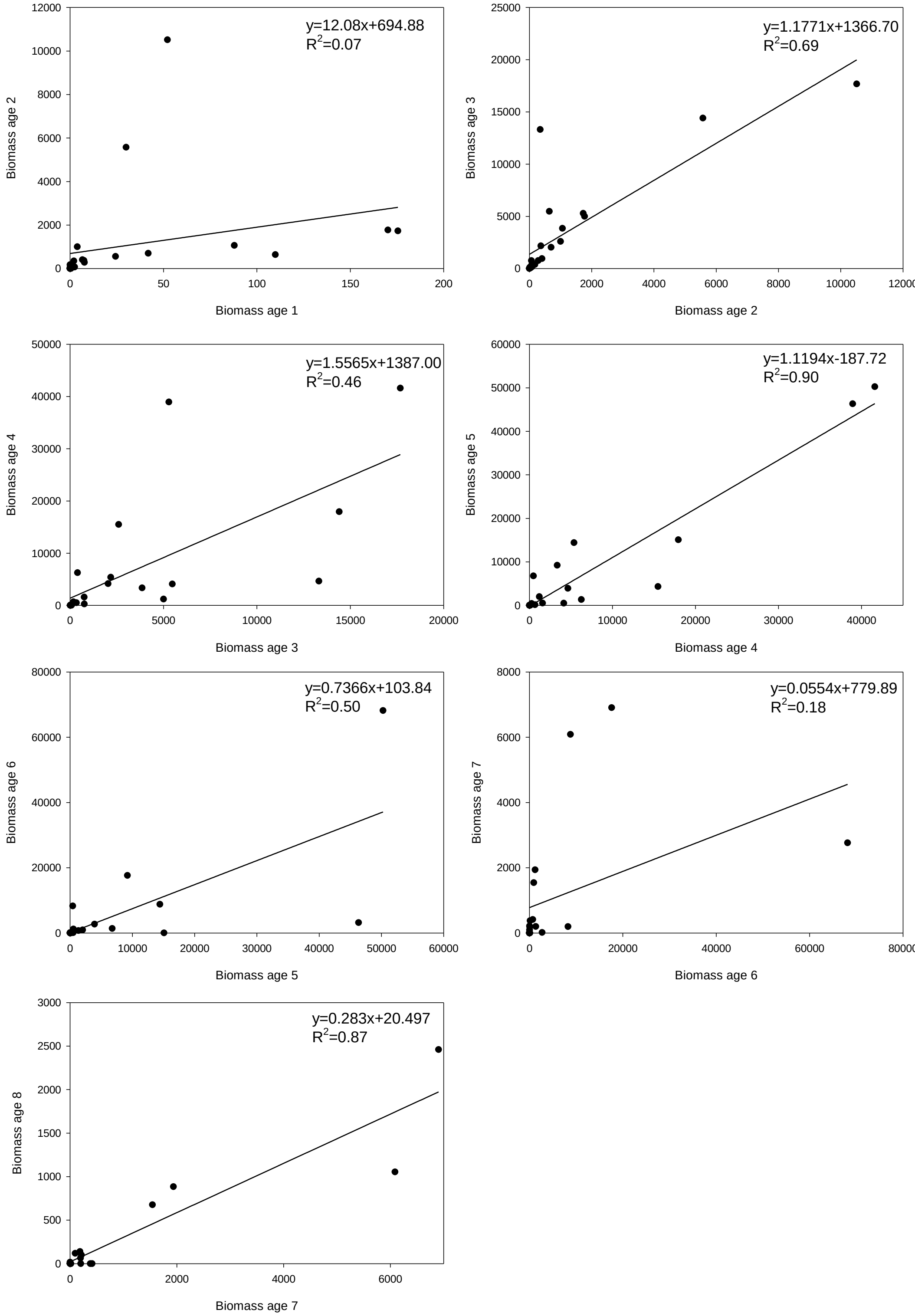

Fig. 2. Linear regressions of biomass at age against the same yearclass the following year.

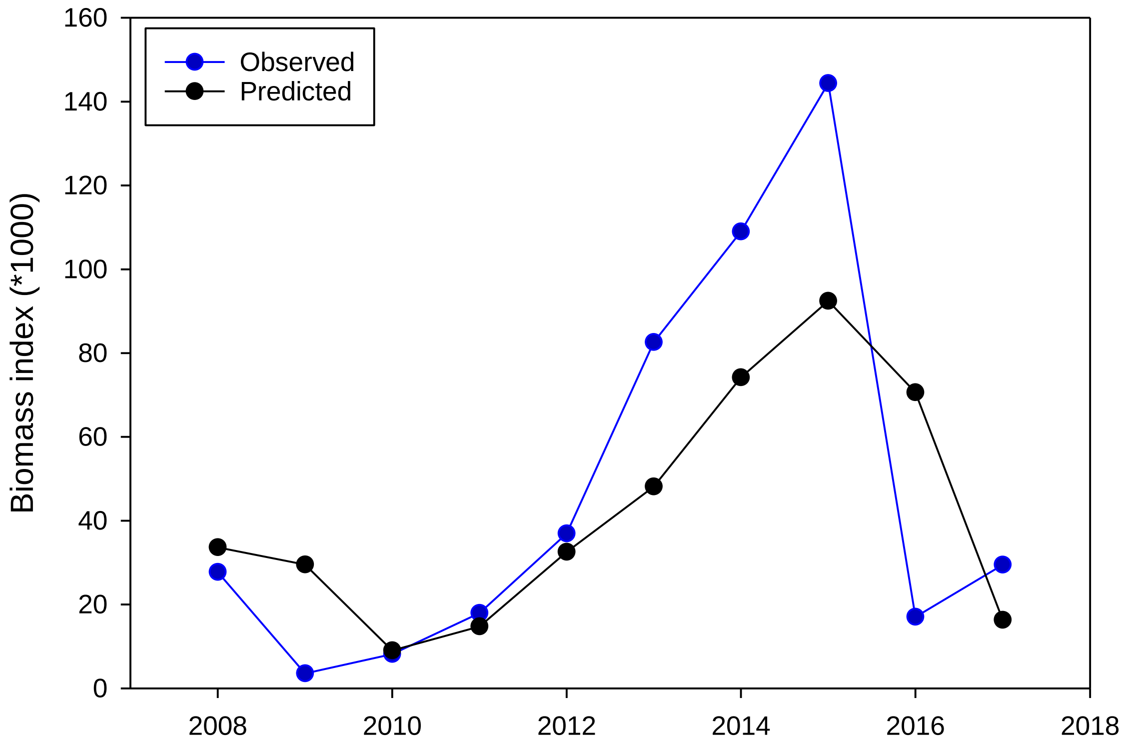

Fig. 3. The observed and predicted year specific Atlantic cod biomass in West Greenland (NAFO 1A-1F).