Northwest Atlantic Fisheries Organization

SERIAL NO. N5452 **NAFO SCR DOC. 07/67**

NAFO/ICES WG *PANDALUS* ASSESSMENT GROUP – OCTOBER/NOVEMBER 2007

Effect of Changing the Cod Series on a Bayesian Production Model for West Greenland Shrimp.

by

Michael C.S. Kingsley

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

Abstract

A quantitative model of the dynamics of the West Greenland stock of *Pandalus borealis*, fitted to observation data by Bayesian methods, has been developed and taken into use for assessments of the stock. The dynamic equation includes a term for predation by Atlantic cod, and the data used includes a long series of cod-stock biomass estimates and a short series of cod predation estimates. The model was found to be sensitive to the cod biomass series, producing aberrant results when the series was changed. Systematic investigation traced the problem to an adjustment made to the predation data so that it would fit the cod biomass series originally used. The treatment of the predation term in the model was slightly modified so that the adjustment of the predation data was unnecessary, and the predation estimates were coupled with the cod biomass estimates on which they had originally been based, which were added to the data series used by the model. The estimates of the basic shrimp stock-dynamic parameters, such as MSY, from the revised model were found to be much less sensitive to changes in the cod-stock series, which, however, by altering the parameters of the cod-shrimp predation relationship, did have an effect on predictions of the shrimp stock trajectory under different scenarios for the development of the cod stock.

Introduction

A stock-production model has been developed for the West Greenland stock of Northern Shrimp *Pandalus borealis* (Hvingel 2006). The model considers production, net of natural mortality, to be related to stock size by a quadratic function (convex upwards), zero at zero stock size and zero again at 'carrying capacity'. Removals from the stock occur by fishery catches and by predation. The Atlantic cod (*Gadus morhua*) is considered the most significant predator from the modelling point of view, because the West Greenland cod stock is (has been) capable of large fluctuations in size, and at high stock sizes cod can eat a lot of shrimp with a significant effect on the dynamics of the stock. The inclusion of cod predation as an element in the model greatly improved its ability to track past fluctuations in indices of the size of the shrimp stock.

The model uses the following input data series:

- annual catches from the stock (since 1955);
- annual CPUE indices from the commercial fishery, starting in 1976;

- biomass indices from a stratified-random research trawl survey carried out annually since 1988;

- biomass estimates for Atlantic cod—a significant predator capable of reaching large stock sizes in W. Greenland waters and of exerting significant predation pressure on shrimp—since 1955;

- direct estimates of predation by cod on the West Greenland shrimp stock in 1989–1992 based on a Ph.D. thesis on cod feeding (Grunwald 1998).

The model steps forward from year to year adding production, which is calculated from stock size and fitted stock-dynamic parameters, and subtracting catch and cod predation, to calculate a predicted biomass (relative to MSYL) in the next period. The true biomass is then allowed to deviate from the prediction by a multiplicative log-normal error. Catches are assumed to be known exactly from the data; the cod stock size is assumed known exactly, but fitted, uncertain, predation-rate parameters are used to calculate predation from stock sizes of both shrimp and cod. The four-year series of predation estimates is assumed known. Stock size indices—CPUE and survey—are both assumed to be only indicators, not true values, and are related to stock size by fitted scale parameters (‘catchabilities’). In this formulation, there are thus two data series that are used without scaling: one is the catch data, and the other is the cod predation data. The others are scaled either directly by a catchability coefficient (CPUE and survey indices), or indirectly by the scaling of effects on the stock by a predation-rate parameter.

The model considers all error terms to be multiplicative and homoscedastic in log. space.

The model is fitted to the data by Bayesian methods using the WinBUGS platform (Hvingel and Kingsley 2006). This model and its fitting methods have been accepted by NAFO for use in the assessment of the West Greenland shrimp stock (NAFO 2003).

The series of cod biomass estimates does not consist of a single homogeneous series, but of estimates that have been assembled from different sources, with evidently some uncertainty about the earlier values. There has therefore been some discussion of the series and different ones have been proposed (Wieland and Storr-Paulsen 2004; Storr-Paulsen and Wieland 2005). More recently, as some increase in the density of cod has been recorded, especially in the southern part of the shrimp-fishing grounds, there has been evidence that limited overlap in the distribution of the two species reduces the average predation rate; i.e. where the density of shrimp is high, it is observed to form a large proportion of the contents of cod stomachs, but in the areas where most of the cod are now, the density of shrimp is low and not many shrimps are found in cod stomachs (Storr-Paulsen et al. 2006). The implication is that using the total cod biomass in the model as a measure of predation pressure might be too simple, and that some modification of the cod biomass series to reflect the varying overlap of the two species might be in order (Wieland and Sünksen 2006).

As first constructed, the model ran in quite an orderly way to give reasonable values for the MSY—considered in the light of the catches that have been sustained in recent years—and for the biomass trajectory as a fraction of the MSYL. The biomass trajectory is mostly dictated by the two biomass index series, which are in moderately good agreement with one another, and the fitted biomass trajectory agreed well with them.

When the cod series that was originally used was replaced by an ‘effective’ cod biomass series proposed by Wieland and Sünksen (2006) the estimated parameters of the population dynamics and the trajectory of biomass changed quite drastically: estimates of MSY, carrying capacity and biomass became much larger (Table 1), and the trajectory of relative biomass moved into regions where it was much above *carrying capacity* for periods of time (Fig 1).

The apparent sensitivity of the estimates of the shrimp population-dynamic parameters to what appeared to be relatively small changes in the cod biomass series was of some concern, and this document reports the results of an investigation into the problem.

Methods

In the following text, the ‘Original’ cod series was that derived by Hvingel and reported in Hvingel and Kingsley (2006), and the ‘Wieland’ series is that headed ‘effective’ cod biomass in Table 1 of Wieland and Sünksen (2006).

At the start it was not clear where, in the 50-year series, to look for the cause of the problem. The initial approach, therefore, was to cut up the two cod series and stick different pieces together. Thus, the model was first run with the first 26 years of the Original cod series and the last 26 years of the Wieland series; then vice versa. The two series were then cut up into quarters, i.e. 13-year sequences, for the next round of trials, and so on to finer divisions. The results of these trials (Table 2) showed that—regardless of which series was used in other periods—if the Wieland series was used in 1987–1993, the model estimated a high MSY (300 Kt/yr) and stock sizes in 2006 above carrying capacity, and whenever the Original cod series was used for those years the model estimated a lower MSY (130 Kt/yr) and present stock sizes about 75% of carrying capacity. The period 1987–1993 spanned the years (1989–1992) for which cod predation data was available from the Grunwald thesis. The significance of this was checked by inserting the Wieland cod biomass values *only* for the years covered by the Grunwald cod predation data (Table 1), when the effect—very high MSY estimate—was similar, and by using the Wieland series for all years except those for which there was predation data, when again the MSY was reasonable. It looked therefore as though a mismatch between the Grunwald consumption data and the Wieland series of cod biomass data was responsible for the aberrant behaviour of the model.

The next series of trials was carried out with the Grunwald cod predation data simply removed from the model. It then made little difference which cod series was used: the results obtained were closely the same. This appeared to confirm that it was a mismatch between the cod stock size estimates in the Wieland series for 1989–92 and the data on predation for the same years that caused the aberrant results when using the Wieland series.

When the cod predation estimates for the 'Grunwald years' (1989–1992) obtained by running the model without any direct predation data were compared with the cod predation data that was input to the model, it was found that when the 'Original' cod series was used the estimated predation was similar to the input data; but the predation estimated when the Wieland series was used was much lower than the input data. The difference was because the Wieland series had much lower cod biomass levels for those years.

Since the Grunwald-based predation data was used in the model as though it was an absolute, when it was present in the model with the Wieland cod series, the fitting process had to find some way to close the gap between the inputs and the estimate from the Wieland data: i.e. to get high predation values in the absence of a cod stock. The only way the model could fit this was to generate a much larger shrimp stock biomass for those years, and to do this it had to create a shrimp stock that was both very large, with high carrying capacity, and also very productive, with high MSY. The resulting highly productive shrimp stock—with an MSY near 300.000 t/yr—when released from predation by the final collapse of the cod stock in the early '90s and subjected only to catches of the order of 100.000 t/yr exploded in size, increasing to over twice the estimated MSYL.

Once this basic reason for the behaviour of the model had been identified, a closer examination of the input predation data showed that the consumption estimates for the 'Grunwald years' from runs using the 'original' cod stock fitted the input Grunwald data so well because the latter had in fact been adjusted from Grunwald's original published estimates to take account of differences between cod biomass estimates used in her thesis and the cod biomass estimates in the 'original' cod series. That was a large part of the reason why the output using the 'original' cod series agreed so well with the input Grunwald data, while the Wieland series could not fit it.

Including the Grunwald data improved the precision of estimates of cod consumption (Figure. 2). Without the Grunwald data, cod consumption was inferred as the residual series of differences after production was added to, and catch subtracted from, the reduction in stock size, and production and stock size are not precisely estimated. And since the Grunwald data had been adjusted to the 'original' cod series, the improvement was then especially marked.

Resolution

Details of the slight modifications made to the model are given in an Appendix. The model was modified by including Grunwald's published consumption estimates in the input data with no adjustment for differences in estimates of cod biomass, but also, when making estimates from her data, using as data in the model the same cod-stock estimates that she used to estimate the consumption. However, this research series was now kept separate from the estimates of the main cod predation series, only entering as a contributor to the estimation of the predation-rate parameters. The cod predation estimates now formed a homogeneous series, since none of them were represented by data values, and could be used as a term in the stock-dynamic equation, replacing the previously used prediction values.

This modification should mean that the model can be flexibly used with different estimates of the cod biomass series without the same instability that it showed before. Preliminary results indicate that the choice of cod series has little effect on the estimates of the intrinsic dynamics of the shrimp stock—MSY and Bmsy—which seem to be largely determined by its trajectory in the years for which good CPUE and survey data have been available, which are also years when the cod has largely been absent. However, it does affect the estimates of the predation parameters, which are more influenced by what happened in the years when there was a large cod stock. Using a different series of past cod-stock biomass values therefore influences the shrimp biomass trajectories estimated under *future* trajectories for the cod stock, especially those for which significant growth of the stock is being considered.

Including Grunwald's cod predation data in the model has som effect on the estimates of the parameters of the predation relationship between cod and shrimp. This is natural, as the predation data itself consists of estimates of predation rates. The amounts of shrimp consumed do not change much, as they tend to remain scaled by the catches (i.e. the sum of cod predation and catch, on average, has to remain equal to net production). So including the predation data alters the estimate of the MSYL, which is not well defined by the model in the absence of predation data. The change due to including the predation data set is a decrease in the median estimate of MSYL by about 11½%. The median MSY hardly changes at all, remaining near the values of recent catches which have been approximately sustainable in the absence of a large cod stock; therefore the estimated productivity of the stock increases, median estimate of Zmsy by about 6.4%.

A more significant effect of including the cod predation data is greatly to increase the precision with which the MSY itself is estimated. With predation data included, SD and IQR are both reduced by about 30%. However, in spite of this we cannot predict future trajectories of the shrimp stock much more accurately with cod predation data in the model than without it (Fig. 2)

The changed treatment of the cod predation data, i.e. including it as a contributor to the estimation of the parameters of the predation relationship, but not as directly setting the predation quantity for those years, and also including in the stock-dynamic state equation an estimated rather than predicted predation value, increases the estimated MSY from about 139 Kt to about 144 Kt (median estimates) and the productivity of the stock at MSY level from 16.6% to 19.2% (median estimates).

Conclusions

The shrimp biomass dynamics model was sensitive to changes in the cod series because a short series of data on predation by cod, based on a research project, had been adjusted to fit the main cod biomass series with which the model was originally run. When the model was run with other cod biomass series that were incompatible with this adjustment, aberrant results were obtained.

Without the input predation data, the model was capable of deducing predation-rate estimates from the joint histories of the cod biomass, the shrimp biomass, and the shrimp catches, and was not sensitive to using a different cod series.

A modification of the coding of the production model that couples the research estimate of the amount of predation to its own series of cod biomass estimates and uncouples it from the main cod biomass series has made the model estimates of shrimp population-dynamic parameters less sensitive to the cod biomass estimates used as the main series.

References

GRUNWALD, E.M. 1998. Nahrungsökologissche Untersuchungen an Fischbeständen im Seegebiet vor Westrgrönland. Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel. Kiel. 208 pp.

HVINGEL, C. 2006. Construction of biological advice for the management of a Northern Shrimp fishery—the West Greenland example. Thesis, Dr. scient. Norwegian College of Fishery Science, U. of Tromsø. 72 pp.

HVINGEL, C. and M.C.S. KINGSLEY. 2006. A framework to model shrimp (*Pandalus borealis*) stock dynamics and quantify risk associated with alternative management options, using Bayesian methods. ICES J. Marine Sci. 63(1): 63–82.

NORTHWEST ATLANTIC FISHERIES ORGANISATION. 2003. Scientific Council Reports 2002; Part C, Scientific Council Meeting 6–13 Nov. 2002, Appendix I. Dartmouth, N.S.

STORR-PAULSEN, M. and K. WIELAND. 2005. A preliminary estimate of cod (*Gadus morhua*) biomass in West Greenland offshore waters (NAFO Subarea 1) in 2005. NAFO SCR Doc. 05/73 Ser. No. N5178. 7 pp.

STORR-PAULSEN, M., J. CARL and K. WIELAND. 2006. The importance of Atlantic Cod (*Gadus morhua*) predation on Northern Shrimp (*Pandalus borealis*) in Greenland waters 2005. NAFO SCR Doc. 06/68. Ser. No. N5318. 16 pp.

WIELAND, K. and M. STORR-PAULSEN. 2004. A comparison of different time series of Atlantic Cod (*Gadus morhua*) biomass at West Greenland and their potential use for the assessment of Northern Shrimp (*Pandalus borealis*) in NAFO Subarea 1. NAFO SCR Doc. 04/71 Ser. No. N5051. 9 pp.

WIELAND, K. and K. SÜNKSEN. 2006. A preliminary estimate of Atlantic Cod (*Gadus morhua*) biomass in west Greenland offshore waters (NAFO Subarea 1) for 2006 and recent changes in the spatial overlap with Northern Shrimp (*Pandalus borealis*). NAFO SCR Doc. 06/57 Ser. No. N5305. 11 pp.

Table 1. Mean and median estimates for the parameters of a stock-production curve for northern shrimp in West Greenland fitted, by the original Bayesian model, to data including 2 different series of biomass values for Atlantic cod.

	'Original' cod		'Wieland effective' cod	
	Mean	Median	Mean	Median
MSY (Kt/yr)	156.1	139.4	319.1	298.2
Carrying cap. (Kt)	3137	1954	5131	4060
MSYL of biomass (Kt)	1569	977	2565	2030
MSY level of mortality (/yr)	0.1432	0.1443	0.1478	0.1483
Biomass w.r.t. MSYL in 2006	1.59	1.583	2.116	2.137

Table 2. MSY and final biomass ratios estimated by the original Bayesian stock-production model for *Pandalus borealis* off West Greenland using two different cod-stock biomass series combined in different ways.

Cod series used for years:					Median estimates	
1955–1967	1968–1980	1981–1986	1987–1993	1994–2006	MSY	Biomass ratio in 2006
O[a]	O	K	K	O	332	2.206
O	O	K	K	K	330	2.237
K	K	K	K	O	310	1.995
K	K	O	K	K	301	2.129
K	K	K	K	K	298	2.137
O	O	O	O	O	139.4	1.583
O	O	O	O	K	135.8	1.612
K	K	O	O	O	134.6	1.526
K	K	K	O	K	133.6	1.533
K	K	K	O	K	132.1	1.557
1955–1988	1989–1992	1993–2006				
O	K	O			340	2.194
K	O	K			132.6	1.546

[a] O is 'Original' cod (Hvingel and Kingsley 2006); K is 'Wieland effective' series (Wieland and Sünksen 2006)

Table 3. Estimates of cod biomass and cod predation on shrimp in 1989–1992; original model

	MSY[1] (Kt/yr)	Predation estimates (Kt)			
		1989	1990	1991	1992
Input data (Grunwald modified by Hvingel/Kingsley)		84.75	8.46	0.983	2.282
Estimated from model runs (mean of exp(Vmed)):					
'Original' cod series	139.4	46.22	11.85	1.473	2.03
'Wieland effective' cod series	298.2	124.2	6.907	1.176	0.33
'Original' series with 'Wieland' estimates in 89–92	340.0	126.1	7.011	1.183	0.34
'Wieland' series with 'Original' estimates in 89–92	132.6	47.47	12.22	1.532	2.10
Predation estimated from model runs with Grunwald predation data left out					
'Original' cod series	142.2	42.27	11.97	1.516	1.99
'Wieland effective' cod series.	140.8	40.07	2.164	0.372	0.104
Cod biomass series:		Cod biomass estimates (Kt)			
'Original' (Hvingel/Kingsley)		191.6	57.5	7.4	8.4
'Wieland effective'		138.8	7.87	1.135	0.329

[1] median of the Bayes posterior distribution

Table 4. Estimates of cod biomass and cod predation on shrimp in 1989–1992; revised model

	MSY[1] (Kt/yr)	Predation estimates (Kt)			
		1989	1990	1991	1992
Input predation data (Grunwald unmodified)		213.7	27.8	2.7	0.8
Estimated from model runs (mean of V):					
'Original' cod series	145.2	41.81	14.24	1.873	2.574
'Wieland effective' cod series	142.8	33.42	2.077	0.371	0.103
Input cod biomass data series:		Cod biomass estimates (Kt)			
'Original' (Hvingel/Kingsley)		191.6	57.5	7.4	8.4
'Wieland effective'		138.8	7.87	1.135	0.329
Grunwald		470.9	184.1	19.8	2.9

[1] median of the Bayes posterior distribution

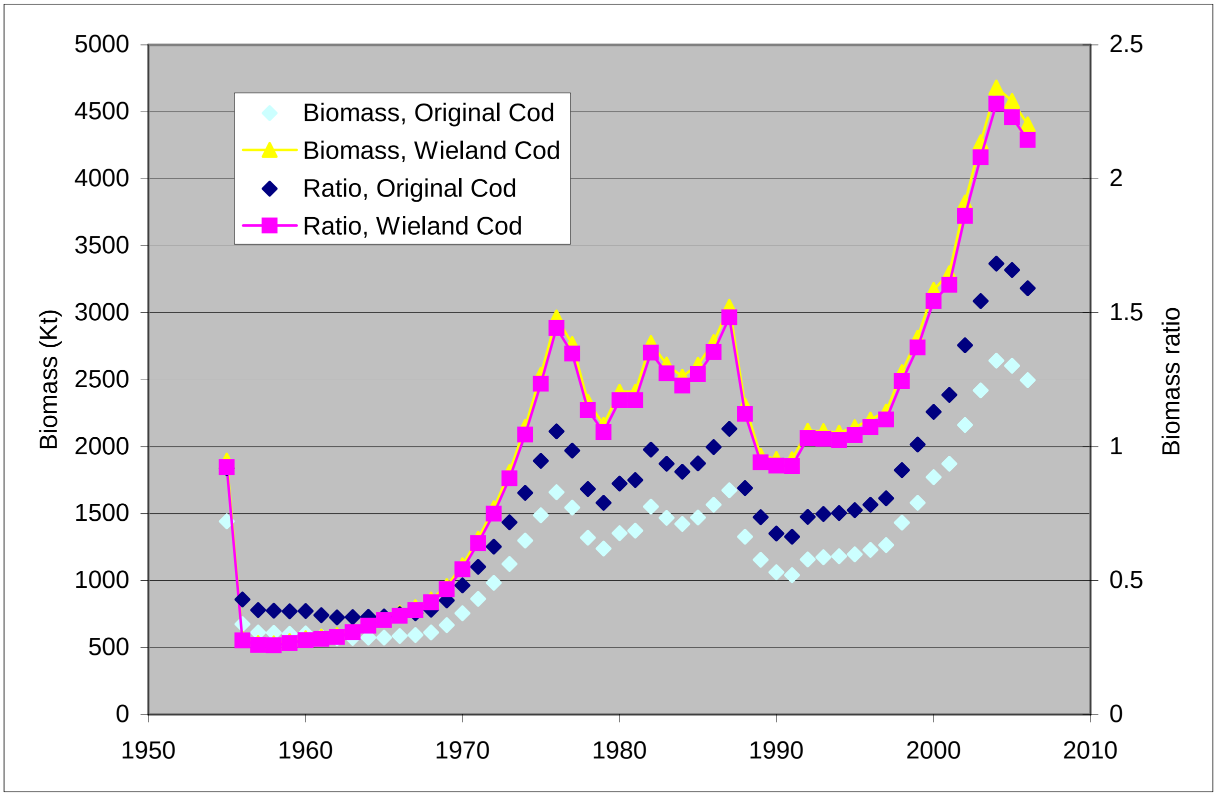
Table 5. Parameters of the shrimp stock dynamics estimated by the revised stock-dynamic model with different treatments of cod biomass and Grunwald predation data.

	Median values (i.q.r.)					
	'Original' cod w. predation data		'Wieland effective' cod, w. predation. data		'Original' cod w/o predation data	
MSY (Kt/yr)	145.2	(34.8)	142.8	(31.0)	147.2	(44.7)
Survey catchability (%)	39.8	(26.5)	43.8	(22.2)	35.9	(28.5)
P50.sqr[1]	4.81	(3.41)	3.84	(2.53)	5.15	(4.46)
O_{max}[2] (kg/kg/yr)	3.00	(0.43)	3.00	(0.42)	3.01	(0.42)
CV[3] (p) (%)	10.21	(3.76)	8.82	(3.11)	10.55	(3.67)
B_{msy} (Kt)	757	(452)	760	(387)	855	(785)
Z_{msy} (%)	19.0	(8.4)	19.0	(6.8)	17.8	(10.4)
CV[3] (G)	76.2	(39.8)	74.1	(35.4)	NA	NA
Mean biomass frac. 1960–2006 (%)	70.8	(26.3)	73.5	(31.2)	72.5	(33.3)
Deviance	94.3	(30.6)	91.6	(27.9)	67.5	(31.7)
DIC	14		50		-108	

[1] O_{max}/P50.sqr gives an index of cod predation rates at low shrimp biomass levels;

[2] O_{max} is an index of cod predation rates at high biomass levels;

[3] Coefficients of variation of predictions; CV(p) is the cv of prediction of shrimp biomass ratio from the previous year's value; CV(G) is the cv of prediction of Grunwald's cod predation values from the associated cod biomass estimates.



F

Figure 1. Estimated trajectories of W. Greenland shrimp biomass and biomass ratio—relative to the MSYL—when modelled with 2 different series of cod biomass estimates, using the original model and data.

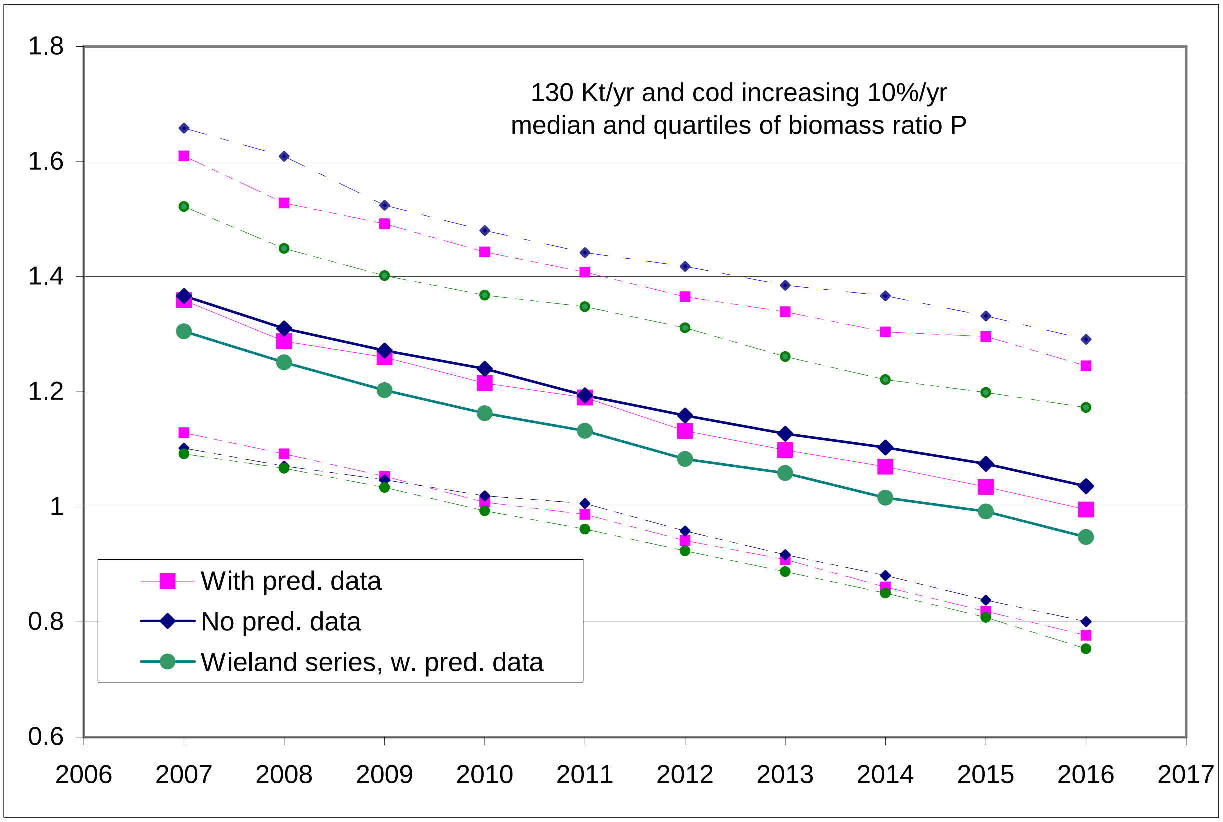


Fig. 2. Median estimate and quartiles of biomass ratio to Bmsy for 10-year predictions made after fitting stock-dynamic parameters using 2 different series of past cod biomass and including and omitting exogenous predation-rate data. N.B. when using the Wieland ‘effective’ cod series, future cod is *‘effective’* cod; when using the ‘original’ series, future cod is *total* cod. Cod biomass is 22.7 Kt in 2007 increasing by 10%/yr.

Appendix[1]

In the original formulation of the model, there was considered to be a series of values of cod predation (*V*). They were stochastically predicted from the cod biomass values and the parameters of the predation relationship in the following lines of code.

```
#       V is cod predation; Omax and P50.sqr
#       are parameters of the predation relationship; P[i] is shrimp biomass
#       relative to MSYL

for (yr in 1:Present) {
P.sqr[yr]  <-   P[yr]*P[yr]
Vmed[yr]  <-   log(cod[yr]*Omax*P.sqr[yr]/(P.sqr[yr]+P50.sqr)))
V[yr]  ~  dlnorm(Vmed[yr],precV)
}
```

The research series of predation values was entered as data values of *V* for the applicable years and contributed to the estimation of the predation parameters. The (many) years for which there was no data on cod predation were simply treated as having missing data. The *V* series thus had four values that were fixed data values while the rest were stochastically estimated from the cod biomass and the predation parameters, with a variance that was derived largely from the fitting of the four research-series values.

Because the *V* series contained two different types of value, the stock-dynamic equation used instead the predicted values, which were a homogeneous series, but whose uncertainty reflected only the uncertainty in the parameters of the predation realationship:

```
Pmed[yr]  <-   log(P[yr-1]-(Catch[yr-1]+exp(Vmed[yr-1]))/Bmsy+ Zmsy*P[yr-1]*(2 - P[yr-1]))
P[yr]  ~  dlnorm(Pmed[yr],precP)
```

In the revised coding, the estimation of predation values *V* from cod biomass was unchanged, but the research series no longer entered as a set of value of *V*. Instead, values predicted from the predation parameters were fitted to those obtained in the research project, using a separate series of cod biomass values that had been used in the same research project:

```
for (i in First.Research.Yr:Last. Research.Yr) {
        log.Research.Predation.predicted[i]  <-   log(Research.cod[i]*Omax*P.sqr[i]/(P.sqr[i]+P50.sqr))
        Research.Predation[i]  ~  dlnorm(log. Research.Predation.predicted[i],precR)
        }
```

and the stock-dynamic equation used a homogeneous series of *fitted* values of *V*:

```
Pmed[yr]  <-   log(P[yr-1]-(Catch[yr-1]+V[yr-1])/Bmsy+ Zmsy*P[yr-1]*(2 - P[yr-1])
```

instead of the predicted values.

---

[1] In this BUGS code, ~ means ‘is distributed as’, <- means ‘receives the value’. Variables are: *P* is shrimp biomass relative to *Bmsy*, the MSYL; *Omax* and *P50.sqr* are parameters of the Holling type III predation relationship, *Catch* and *Cod* explain themselves, *Zmsy* is shrimp stock productivity at the MSY level. dlnorm(x,p) is a log.-Normal distribution with mean x and variance $1/p$ in log. space.