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# Estimation of the cod biomass by SAM and its implication for the assessment of Northern Shrimp (*Pandalus borealis*) in West Greenland.

by

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## *Introduction*

The West Greenland stock of *P. borealis* is assessed annually using a quantitative surplus-production model. The stock dynamics of the model include a term for predation by cod, which is considered to vary with changes in the biomass of the offshore cod stock and its distributional overlap with the stock of shrimps. Four separate indices of the cod biomass was included in the shrimp cod assessment model (Kingsley, 2014). An early virtual population analyse (Buch et al. 1994), a ground fish research trawl survey carried out by German (Fock 2014) and two Greenland research time series using different gears. The overlaps between these indices were used to develop a continuation of the VPA series called the 'true cod biomass' as VPA is sought of as represent the 'real' cod biomass. The true cod biomass was then multiplied by an 'overlap factor' (Global Index of Collocation, Bez & Rivoirad, 2000) to calculate an 'effective cod biomass' (Kingsley, 2014).

In 2019 the cod biomass estimated by the Greenland trawl survey increased by a factor of 14 from 29 Kt in 2018 to 268 Kt in 2019 (Figure 1). The high biomass estimate was derived from two hauls (one in NAFO division 1D and one in 1E), which accounted for 90% of the total biomass (Figure 2). The occurrence of one or two hauls driven the estimate of the total biomass is a well-known problem in stock estimation especially for shoaling species. Cod is known to have an occasionally shoaling behavior. The consequences of the high cod biomass, at only two stations in 2019, is not only a high model estimated predation of shrimp in 2019, but also for the catch level predictions for 2020 as it is a normal practice to assume a cod biomass in 2020 at same level as in 2019. In 2016 a similar but opposite situation happen with the survey estimate as the cod biomass decreased from 140 Kt to about 20 Kt that together with an unusual low overlap factor resulted in a very low effective cod biomass. At that time it was considered unwise to apply such a low effective cod biomass in the predictions (Kingsley, 2016).

Here we present an estimation of the West Greenland cod stock biomass applying a state-space assessment model (SAM) (Nielsen & Berg, 2014). SAM is an accepted and widely used assessment model within ICES and is applied at the assessments of West Greenland inshore cod stock and the East Greenland + NAFO Div. 1F cod stock (ICES, 2019). The actual assessment of the West Greenland cod stock is visible at stockassessment.org (GreenCod1976West). SAM is an age-based model, which besides including research survey catch-at-age data also include catch-at-age data of the commercial fishery. By including fishery data in addition to survey data, it is expected that the SAM estimates of the West Greenland cod stock are less sensitive to fluctuating research survey estimates than the estimates made within the shrimp stock production model.

### *Materials and methods*

<u>Input data</u>
The period from 1976 to 2019 is included in the SAM model, same period as in the shrimp production model. Yearly catch-at-age and mean weight-at-age for age 0 to 10+ of the fishery based on regular sampling of the landings are the basic input. Data for 2019 are preliminary by using last year age-length key on preliminary catch and length distribution data. The landing fraction was assumed to be one, meaning no discard of the catch. Tagging experiments has showed that West Greenland cod emigrate to East Greenland and Iceland (Hansen & Hermann, 1953; Storr-Paulsen et al. 2004; ICES, 2018). It is a challenge to quantify the emigration. The emigration to East Greenland/Iceland is reflected in the model by increasing the natural mortality to 0.25 at age 5, 0.3 at age 6, 0.35 at age 7 and kept constant at 0.4 for ages 8+, corresponding to an emigration of about 20% of the 5 years old in the following 5 years.

<u>Model configuration</u>
Fishery before spawning were set to zero assuming spawning takes place 1 January. The Greenland and German surveys in West Greenland age 0 to 10+ were applied for tuning. From 1992 to 2004, when no commercial fishery occurred no age-disaggregated catch data were available.

*Catchabilities*: The catchabilities in the two surveys were estimated separately for ages 0 to 8, and for ages 9 and 10+ the catchability was coupled.

*Selectivity*: Fishing mortalities was set to be uniquely estimated for ages 3 to 8, and for ages 9 and 10+ a common selectivity parameter was estimated.

*Correlation of fishing mortality:* An autoregressive model of order 1 was applied. the main fishery is a trawl fish fishery and some autocorrelation across ages can be expected. This improved the model considerably judged by the reduction of AIC compared to independent estimation of the fishery mortality of each age class.

*Variance*: The process variance parameters for the log(N)-process were separated for age 0 and age 1 as they may be estimated with more uncertainty. For age 2-10 the variance parameter was coupled.

The variance parameters for the observations (catch and surveys) were set similar for all ages but separately for the catch and each of the surveys.

*Covariance and correlation*: The covariance structure for each fleet (catch and surveys) was set to be independent as no knowledge was available to suggest another structure. Similarly, it was assumed that there was no coupling of correlation parameters in the surveys. No correlation of the fishing mortality across ages was assumed.

### *Results and Discussion*

In the following, focus is given to the results of the estimated cod biomass and not so much to other results from the SAM model such as fishing mortality (F), spawning stock biomass and recruitment.

<u>Model diagnostics</u>
The model give a relative good fit to the catch data except in the late 1980ies (Figure 3). During these years, the cod stock was totally dominated by the relative large 1984 year-class, which is known to have Icelandic origin and migrated out of West Greenland when they become mature (Hovgård & Wieland, 2008).

*Residuals:* No apparent patterns are observed in the catch and surveys residuals except positive residuals dominate in the latest years in the Greenland survey and negative dominate in the latest year in the German survey (Figure 4 upper). Relative high process residuals are found both in case of numbers (N) and F but appear to be random without any clear patterns (Figure 4 lower).

*Weight of observations*: Figure 5 shows that the reciprocal variance of the catch is larger than in case of the two surveys, which are rather similar. This means that the SAM assessment gives relatively higher weight to the catch data than to the two surveys.

*Retrospective plot*: A 5 years retrospective plot shows that there are a tendency of overestimate the spawning stock biomass as the biomass decrease when a new year of data become available (Figure 6).

*Cod stock biomass:* The trajectory of the total cod stock biomass estimated as the "True cod biomass" by the shrimp production model and by SAM ("Cod biomass") with and without including an estimate of emigration is shown in Figure 7. The "True cod biomass", estimated by the shrimp model, trajectory show large year to year variation with large peaks in 1988-1989 and again around 2014-2015 and latest here in 2019. The trajectory estimated by SAM differ essentially with a gradually decrease in cod stock biomass from the late 1970s to the beginning of the 1990s where it practical disappears. From the mid-2000s the cod stock gradually increase again. The reasons for these differences are, in addition to different approaches, also that the shrimp production model is mainly based on research survey data while the estimation by SAM beside the research surveys also include catch at age data.

*Retrospective plot of the shrimp biomass:* A five-year retrospective plot of the shrimp stock biomass estimated by the shrimp production model using cod biomass estimated by SAM is shown in Figure 8. The plot do not give rise to concerns and trajectories appear very stable and without any bias.

## ***Conclusions***

The cod stock biomass estimation has essential importance for the shrimp stock assessment as it is used in risk analysis for future shrimp catch levels. Highly fluctuating cod biomass as estimated by the shrimp production model has large consequences for estimating future catch levels of shrimps and thereby the advised TAC. This is especially problematic when the cod stock are increasing which also was a concerned pointed out by Kinsley (2014). The SAM model include catch-at-age data from the commercial fishery in addition to research survey data and result in a much more stable development of the cod stock. It is therefore recommended to apply the cod stock estimated by SAM as input to the shrimp production model.

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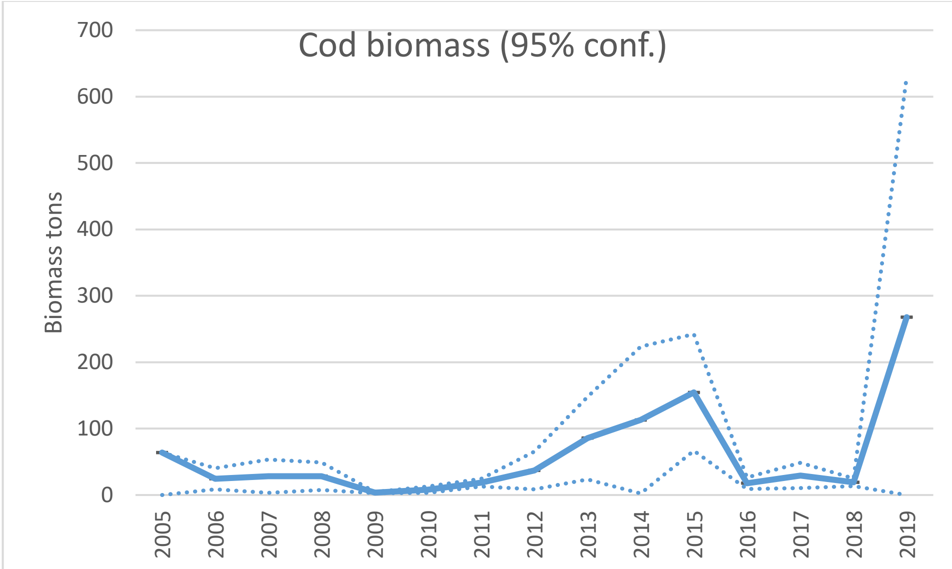


**Figure 1.** Estimated cod biomass (tons) from Greenland research trawl survey

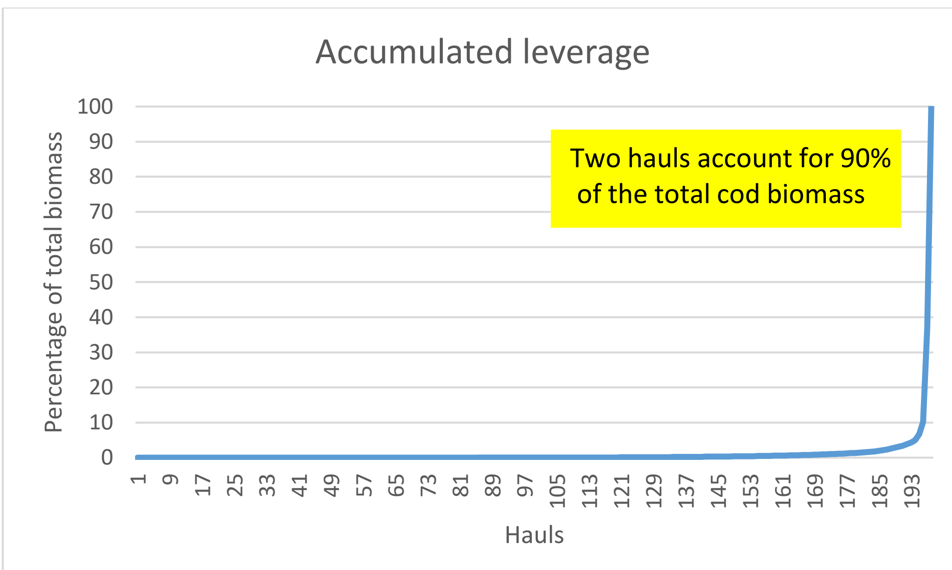


**Figure 2.** Accumulated importance of trawl hauls for the estimated total biomass of cod.

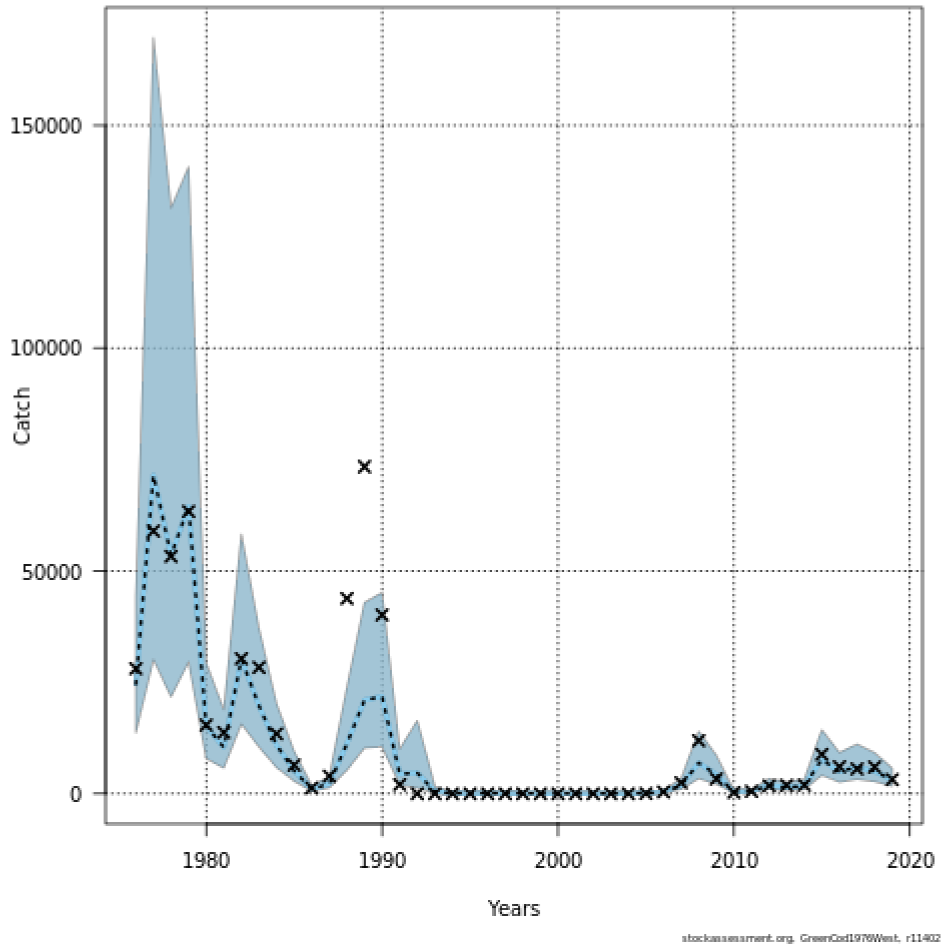


**Figure 3.** Estimated catch and with observed catch shown as crosses. Note the period 1992-2004 with zero catches because no age disaggregated catch data were available.

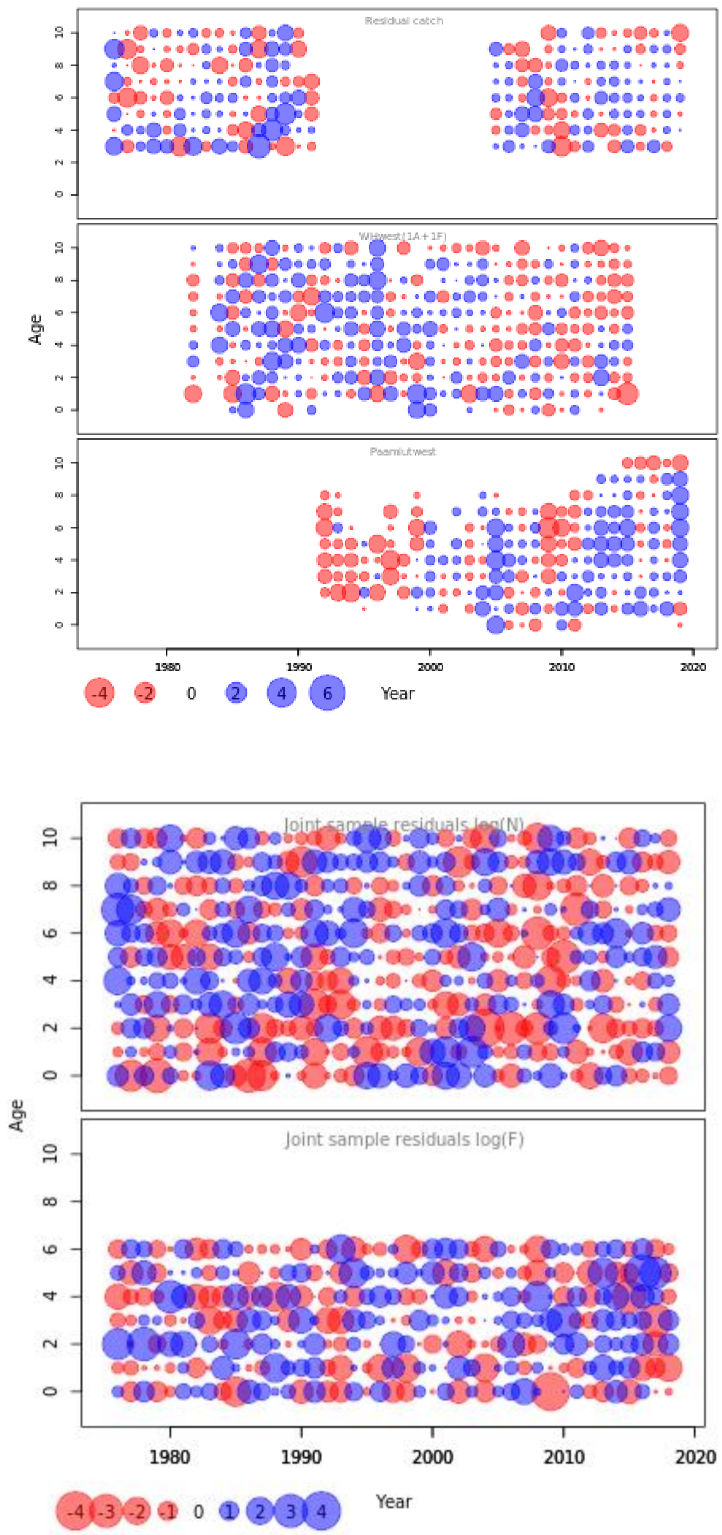


**Figure 4.** Upper: Normalized residuals derived from the SAM run in the observations series. Lower: Residuals for the estimates of stock numbers and F. Blue circles indicate positive residuals (observation larger than predicted) and filled green circles indicate negative residuals.

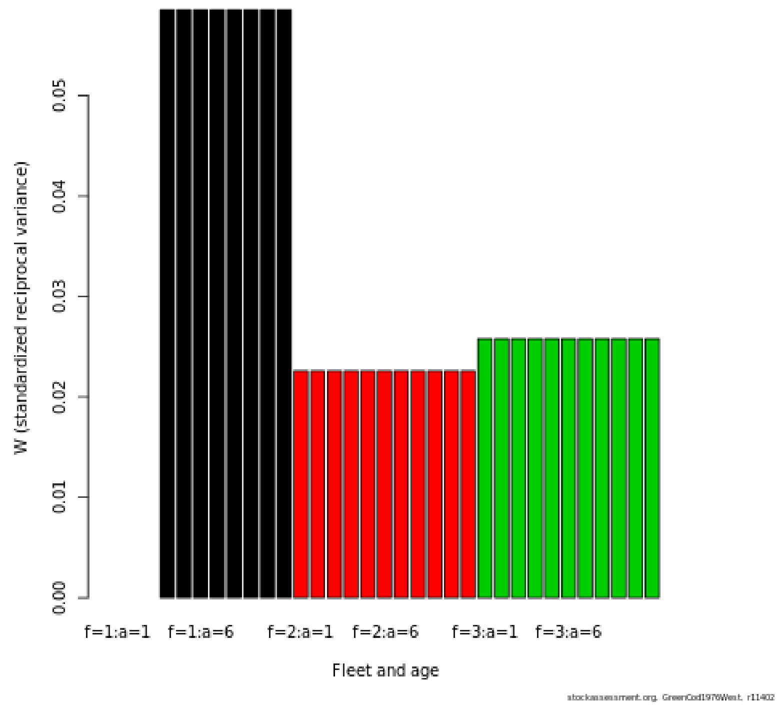


**Figure 5.** Standardized reciprocal variance (weight) of the catch (black), Greenland survey (red) and German survey (green).

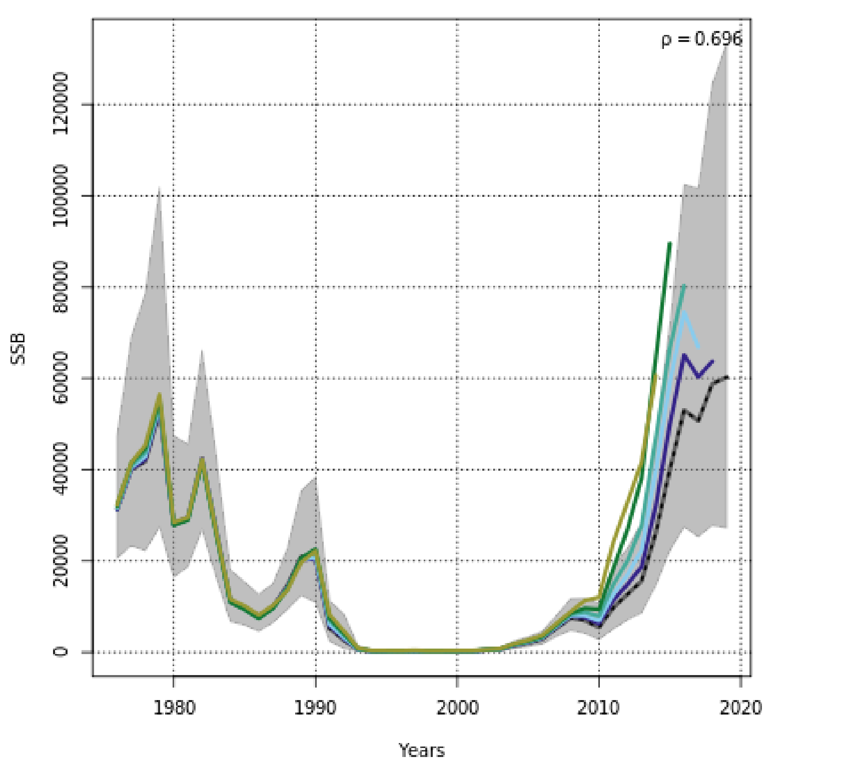


**Figure 6.** Retrospective plot of spawning stock biomass

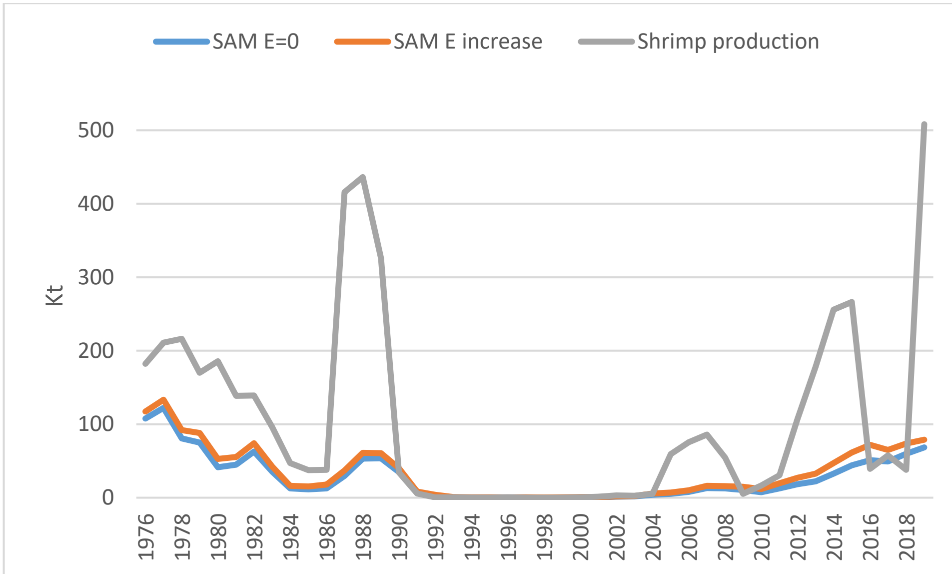


**Figure 7.** Cod biomass estimated by the shrimp production model (gray) and estimated by SAM without an emigration out of West Greenland (blue) and by SAM including an emigration out of West Greenland (orange).

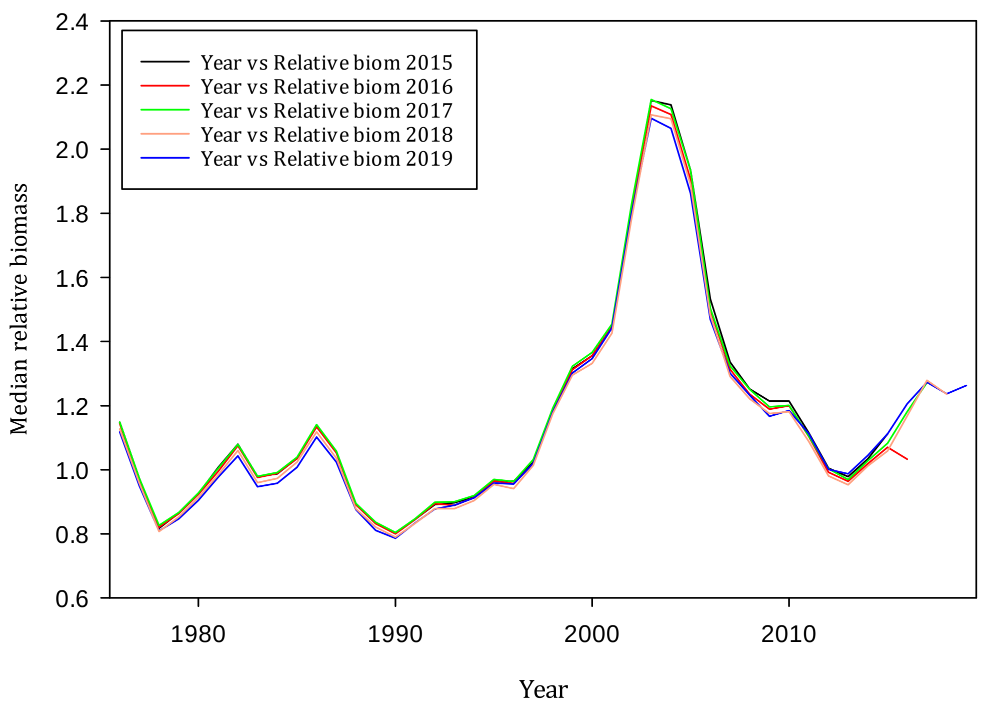


**Figure 8.** Retrospective plot of the shrimp biomass estimated by the shrimp production model using cod biomass estimated by SAM.