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Casal2 assessment for Antarctic krill in Subarea 48.1: a pilot model

Doug Kinzey and George M. Watters

Antarctic Ecosystem Research Division

Southwest Fishery Science Center

NOAA Fisheries

8901 La Jolla Shores Dr, La Jolla, CA 92037 USA Abstract

Abstract

Preliminary results from an integrated Casal2 assessment of Antarctic krill around the northern Antarctic Peninsula (in the area historically surveyed by the U.S. AMLR Program) and covering the years 1976-2021 are reported here. The assessment includes a 20-year forward projection. Data supplied to the model were fishery catches (1976-2021), acoustic biomass surveys (1996-2020), length-frequencies from the fishery (2011-2019) and length-frequencies from research surveys (1981-2011). Biomass estimates from fishing vessel and research vessel acoustic surveys were combined using Jolly-Hampton weightings (Table 2.4 in WG-EMM-2021-05r1). Unweighted length-frequencies from January and February were used from research surveys and the fishery. The 20-year projection demonstrates how the effect of future fishery catches on the population can be assessed. Two versions of the U.S. AMLR acoustic survey data, one using NASC converted to biomass and the other using NASC attributed to krill but not converted to biomass, produced similar population estimates when U.S. AMLR and fishing vessel survey catchabilities were estimated, process errors were assigned, and synoptic surveys conducted in 2000 and 2019 were assumed to provide estimates of absolute biomass. At the end of the 20-year projection with 620,000 metric tons caught per year, spawning biomass was about 64% of unexploited biomass. The current data, model configurations, and R plotting scripts are available at 'https://github.com/us-amlr/Casal2-krill-model'. Our results demonstrate that data are available to fit integrated models and make krill stock assessments consistent with assessments in other CCAMLR fisheries. The results also demonstrate that integrated assessment models provide a method to convert NASC estimates to biomass estimates without collecting length-frequency data during every acoustic survey and subsequently applying a target-strength model. We believe the Scientific Committee could design a data-collection plan for the krill fishery that facilitates application of integrated assessment models by combining frequent surveys that simply report NASC with occasional surveys during which length-frequency data are collected using research nets.

Introduction

Casal2 is a statistical framework originally developed by New Zealand's National Institute of Water and Atmospheric Research (NIWA) for modeling the population dynamics of marine species. It is currently used by CCAMLR to assess toothfish fisheries, but it is potentially applicable to any harvested population.

Statistical models such as Casal2 are fitted to data via a likelihood function and thus provide a quantitative measure of the uncertainty around the model estimates for a given set of data. Integrated models such as Casal2 allow direct comparison of alternative models for a combined dataset through a single score, the negative log-likelihood. Models with smaller negative log-likelihoods (larger likelihoods) are better predictors of the data than models with larger negative log-likelihoods. Comparison of negative log-likelihoods allow the best of different potential alternatives for configuring a model to be identified based on the data itself.

The Casal2 model for krill uses seven sources of time-series data:

1) fishery catches during 1976-2021 (obtained from CCAMLR Fishery Reports)

2) biomass estimates from acoustic surveys conducted by the U.S. AMLR Program during 1996-2011 ('WESJ' in Table 2.4 of CCAMLR WG-EMM-2021/05 Rev. 1)

3) biomass estimates from acoustic surveys conducted by fishing vessels during 2014-2016 and 2018-2020 (' WESJ' in Table 4 of CCAMLR WG-EMM-2021/05 Rev. 1)

4) biomass estimates from "synoptic" acoustic surveys conducted in 2000 and 2019 (' WESJ_syn' in Table 4 of CCAMLR WG-EMM-2021/05 Rev. 1)

5) length-frequencies of krill from U.S. AMLR surveys during 1992-2011 (U.S. AMLR database)

6) length-frequencies of krill from the fishery during 2011-2016, 2018-2019 (obtained from the CCAMLR Secretariat)

7) length-frequencies from German research surveys in 1981-1982 and 1984-1987 (provided by Volker Siegel)

Von Bertalanffy length-at-age and length-weight parameters were fixed using values from recent applications of the Grym (https://github.com/ccamlr/Grym_Base_Case/tree/Simulations) and treated as constants.

Methods and Results

The Casal2 model was constructed following the example files in 'https://github.com/NIWAFisheriesModelling/CASAL2/tree/master/Examples/Simple'. Model input configuration files are the 'estimation.csl2', 'observation.csl2', 'population.csl2', 'reports.csl2' and 'config.csl2' files available on GitHub. The first four of these should be placed in a directory called 'config' inside another directory containing 'config.csl2'. Casal2.exe will use 'config.csl2' to locate the input files.

Fishery catches were generally less than 150,000 metric tons (hereafter tons) before 2013 and a little over 150,000 tons from 2013-2021 (Figure 1). Projected catches for the 20-year period from 2022 to 2041 were at the CCAMLR 'trigger level' of 620,000 tons. We used 620,000 tons for the projection to indicate plausible outcomes if CM 51-07 is allowed to lapse and fishing is concentrated in the area to which the assessment applies.

Within the combined U.S. AMLR survey strata, total biomass from the synoptic surveys was 3,806,812 tons in 2000 and 5,378,204 tons in 2019 (Table 2.4 in WG-EMM-2021/05 Rev. 1). The unexploited population size in the model was initialized at 10 million tons and estimated to be 3,576,780 tons after fitting the model. Biomass estimates from U.S. AMLR and fishing vessel surveys ranged from about 9.5e+05 in 2002 to 2.1e+07 in 1997 (Figure 2A). The fitted biomasses from 1996-2020 smoothed through annual variability in the data (Figure 2). Different scalings between AMLR biomass and AMLR NASC (Figure 2B) were addressed using different process error weightings and estimates of catchability.

Catchabilities were estimated separately for the three different acoustic datasets: the synoptic surveys, fishing vessel surveys, and U.S. AMLR surveys. The model priors and process errors gave more weight to the synoptic surveys than to the fishery and AMLR surveys. Priors for the catchabilities in the synoptic surveys were assigned a mean of 1.0 with a CV of 1e-05. Priors for the fishing vessel and U.S. AMLR surveys had means of 0.51 with CVs of 1.0. Process errors were assigned as 0.1 for the synoptic surveys and 0.9 for the U.S. AMLR and fishing vessel surveys. Catchabilities estimated by the model were 1 for the synoptic surveys, 1.24 for the U.S. AMLR surveys, and 1.05 for the fishing vessel surveys.

The length-frequency data from U.S. AMLR surveys, the fisheries, and the German surveys (Figures 3A, 4A, and 5A, respectively) were fitted by the model to the average length at each of six ages from the von Bertalanffy relationship (Figures 3B, 4B, and 5B, respectively).

The estimated length-specific selectivities for the fishing vessel and U.S. AMLR acoustic surveys were 1.0 for krill longer than about 15 mm (Figure 6). The fishery was estimated to have knife-edge selectivity, increasing from zero below 32 mm to 1.0 by 34 mm. Selectivity for the U.S. AMLR net tows increased gradually from about 0.01 at 20 mm to 0.90 for the largest krill.

Future recruitment in the 20-year projection was modeled using recruitment multipliers estimated for the population during 1992-2011 (Figure 7). Estimated spawning biomass varied around the estimate of unexploited biomass without clear pattern before the projection with annual catches of 620,000 tons but then declined to 63.7% of unexploited spawning biomass by the end of the projection in 2041 (Figure 8). Reducing future annual catches to 450,000 tons produced a spawning biomass in 2041 that was 74.8% of unexploited spawning biomass.

The same model configuration was run using NASC attributed to krill (obtained by db-differencing) in place of biomass for the U.S. AMLR acoustic surveys (Table 1). The model estimates resulting from fitting the NASC values were very similar to the estimates using biomass. With the model fitted to NASC and future catches of 620,000 tons per year, projected spawning biomass declined to 64.4% of unexploited spawning biomass by 2041.

The estimated exploitation rates were below 0.05 before 2022 but ranged as high as 0.32 during the projection period (Figure 9).

The negative log-likelihood score for the model and data was -20952.3 using U.S. AMLR biomass estimates and -20949.8 using NASC. Since the data used in the two configurations were slightly different, these scores are not directly comparable. Alternative configurations were applied but none of those that converged (defined here as producing MCMC outputs without NAs for any numeric values) had smaller (better fitting for these data) negative log-likelihoods than the models presented here.

Discussion

An integrated, statistical modeling platform such as Casal2 allows population estimates to be made based on all the available data. The model tracks the population through time, and as additional data are collected the new data can be used to extend the temporal span of the model.

This study demonstrated that combining a few surveys that estimate krill biomass with frequent surveys that report krill NASC is feasible and can produce plausible population estimates. The synoptic biomass surveys provided scaling for surveys that reported NASC, and NASC can be used as a relative index of biomass. This reduces the need for scientific net tows to collect krill length-frequencies and apply a target strength model for during every survey. A data collection plan for the krill fishery could include occasional surveys with the full suite of research net samples together with frequent surveys that only report krill NASC.

The 20-year projection estimate of the Casal2 model for krill spawning biomass suggested CCAMLR's escapement rule might be violated if krill catches equal to the 620,000 trigger level were all taken from the area defined by the combined U.S. AMLR survey strata. This is a preliminary result as the Casal2 model for krill is still under development. One planned addition is to add R code applying the CCAMLR decision rules to the Casal2 outputs.

Table 1. NASC attributed to krill data values. These replaced the biomass values for '@observation AMLRsrv' in 'observation.csl2 in the second configuration of the model.

#year	obs	error_value(CV)
1996	34071199	0.2648
1997	59542637	0.2089
1998	38389789	0.1391
1999	9919447	0.2202
2000	25499693	0.1752
2001	5409218	0.1752
2002	3530670	0.2932
2003	28746004	0.1648
2004	4804882	0.2029
2005	7698221	0.4723
2006	7789939	0.299
2007	37292717	0.1965
2008	27985838	0.2161
2009	23077855	0.1089
2010	5439930	0.1256
2011	24551519	0.1671

Literature cited

CCAMLR, 2021. Results from the WG-ASAM intersessional e-group on krill biomass estimates from acoustic surveys. WG-EMM-2021/05 Rev. 1

Constable, A.J., 2011. Lessons from CCAMLR on the implementation of the ecosystem approach to managing fisheries. Fish and fisheries 12: 138-151

Fielding, S., J. Watkins, ASAM participants. 2011. The ASAM 2010 assessment of area 48 from the Scotia Sea CCAMLR 2000 synoptic survey. CCAMLR WG-EMM-11/20

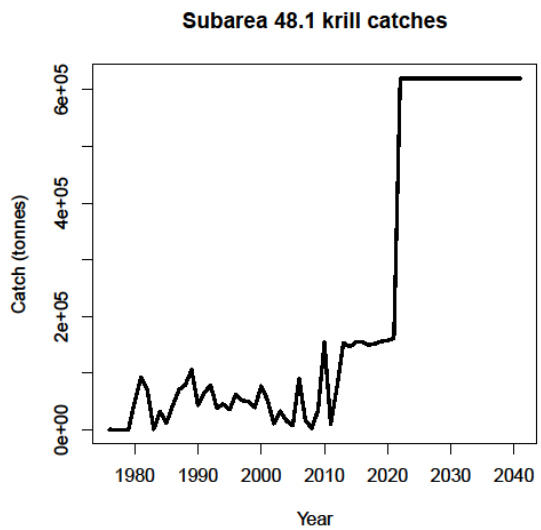

Figure 1. Krill catches from 1976 to 2021 for Subarea 48.1, and projected catches of 620,000 tons from 2022 to 2041 for the combined U.S. AMLR survey strata.

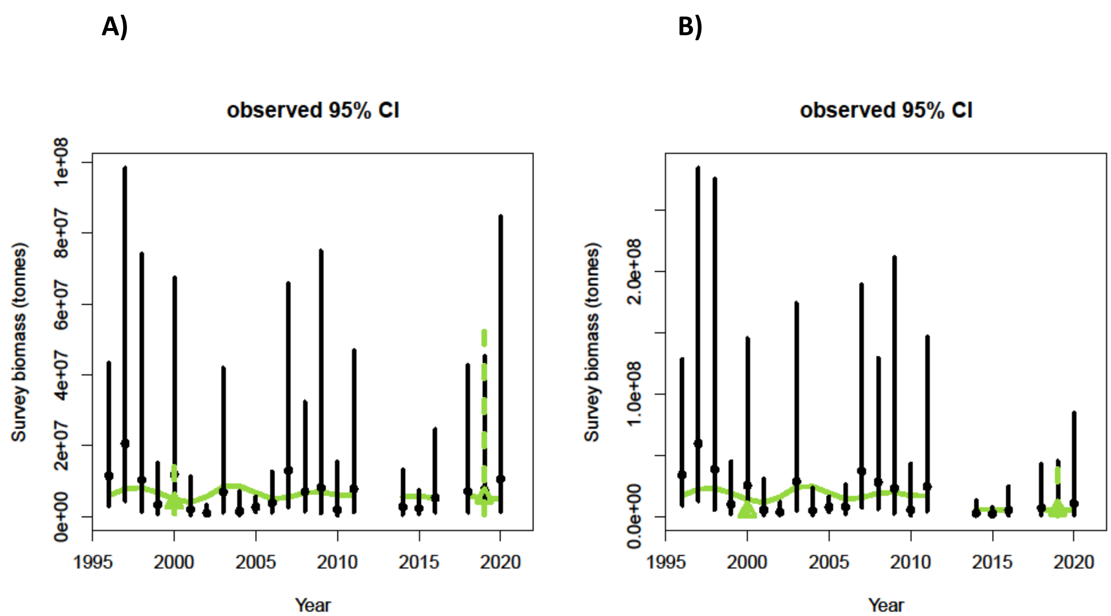

Figure 2. (**A**) Biomass estimates from U.S. AMLR (1996-2011) and fishing vessel (2014-2016, 2018-2020) acoustic surveys. Dark points represent annual mean biomasses with vertical dark line segments representing 95% lognormal CIs (WG-EMM-2021/05 Rev. 1). Green horizontal lines are the fitted values to the data. Green triangles and dashed vertical lines in 2000 and 2019 represent mean biomasses with 95% lognormal CIs from the synoptic surveys. (**B**) NASC attributed to krill from U. S. AMLR acoustic surveys (1996 to 2011). Fisheries and synoptic survey values remain as biomass.

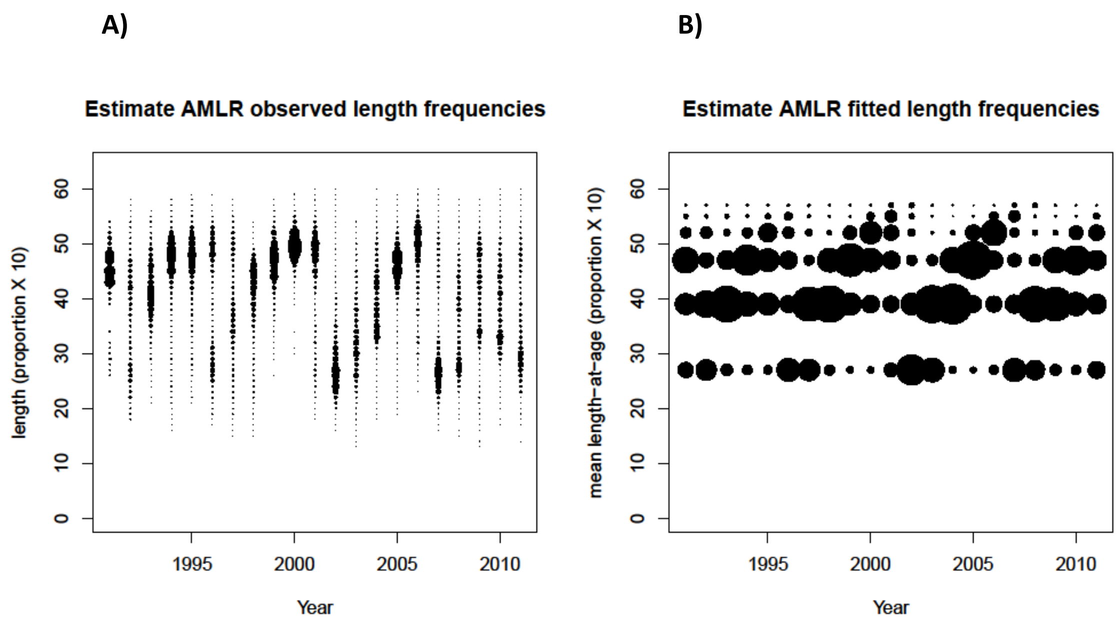

Figure 3. (**A**) Observed length-frequencies from U.S. AMLR surveys (1992-2011). (**B**) Casal2 fitted length-frequencies. The fitted frequencies are mean lengths-at-age from the von Bertalanffy growth curve for ages one to six.

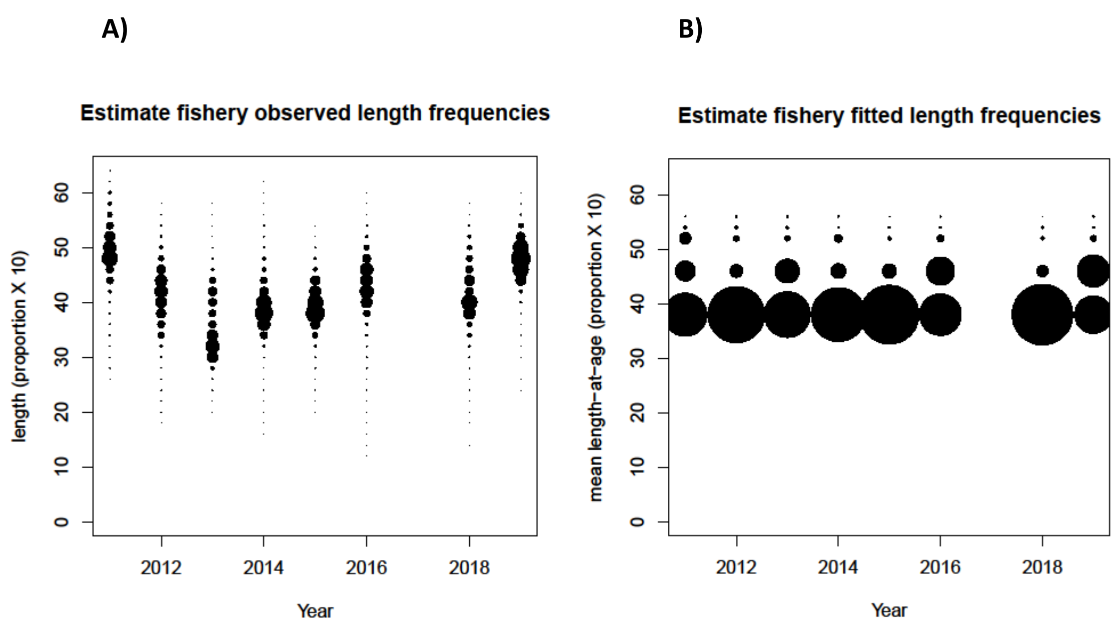

Figure 4. (**A**) Observed length-frequencies from the observer database for the fishery. (**B**) Casal2 fitted length-frequencies. The fitted frequencies are from the von Bertalanffy growth curve as in Figure 3.

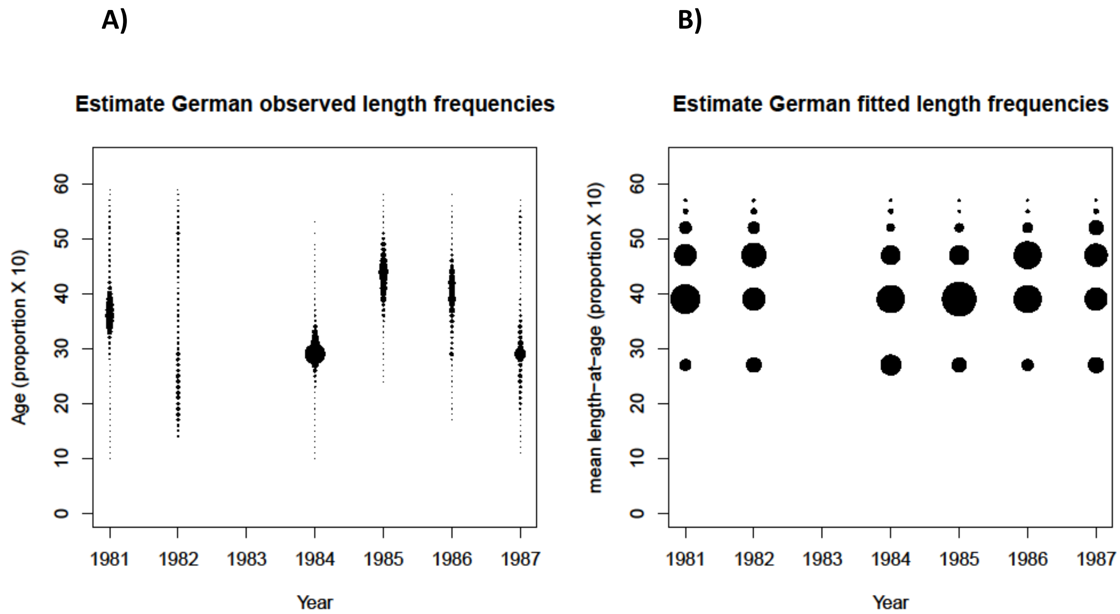

Figure 5. (**A**) Observed length-frequencies from German research surveys in 1981, 1982, and 1984-1987. (**B**) Casal2 fitted length-frequencies. The fitted frequencies are from the von Bertalanffy growth curve as in Figure 3.

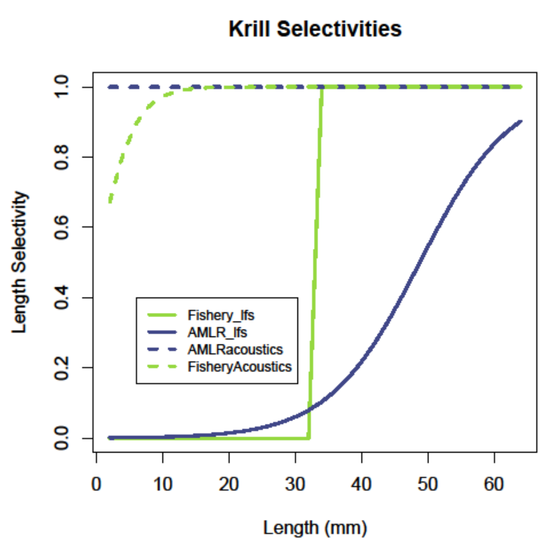

Figure 6. Estimated selectivities for acoustic surveys, U.S. AMLR net tows, and the fishery.

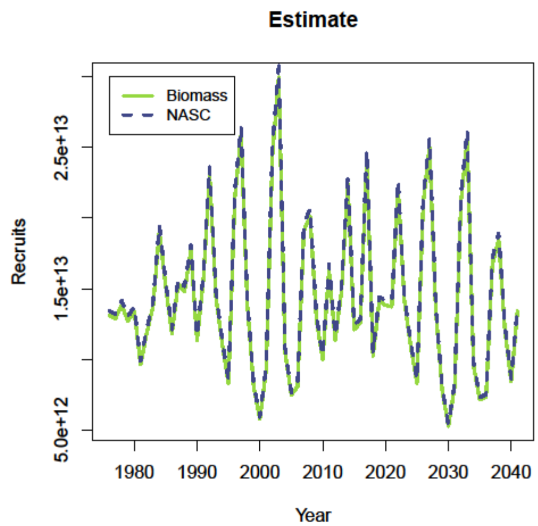

Figure 7. Recruitment estimates for 1976-2041. Recruitment for 2022-2041 is assigned based on standardized recruitment multipliers estimated for 1992-2011.

A) **B)**

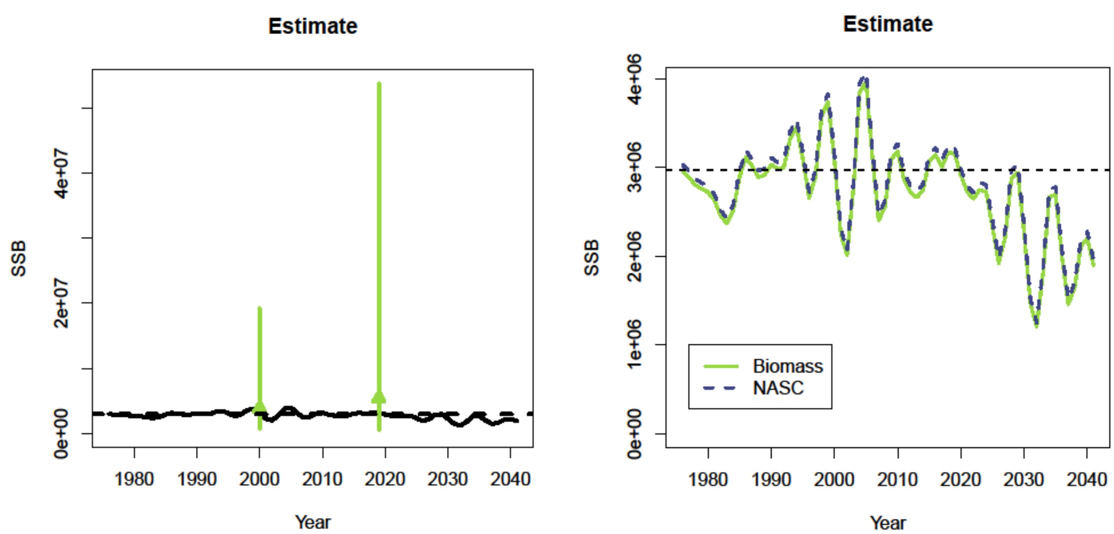

Figure 8. (**A**) Spawning biomass estimates during 1992-2021 and projected for 2022-2041 (based on annual catches of 620,000 tons) from the Casal2 model. Synoptic survey means (triangles) and 95% CIs (lines) are in green. Dashed line is unexploited spawning biomass. (**B**) Same spawning biomass estimates, without plotting synoptic surveys, using U.S. AMLR biomass and NASC as model inputs.

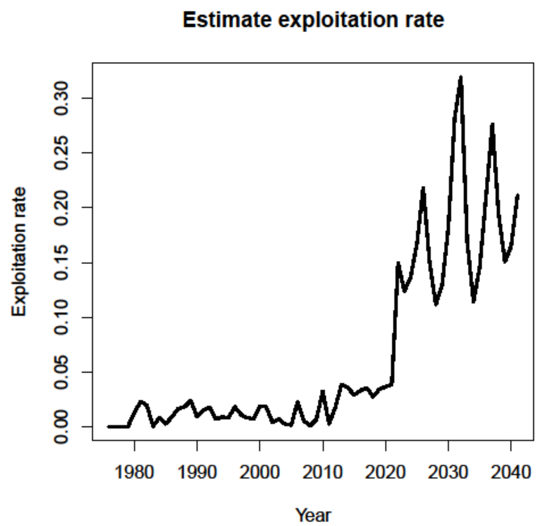

Figure 9. Estimated annual exploitation rates with historical catches and with annual future catches of 620,000 tons/year.