Gmacs Example Stock Assessment

The Gmacs development team

June 2015

Introduction

Gmacs is a generalized size-structured stock assessment modelling framework for molting crustacean species. Gmacs can make use of a wide variety of data, including fishery- and survey-based size-composition data, and fishery-dependent and -independent indices of abundance. Gmacs is coded using AD Model Builder.

Crab stocks of Alaska are managed by the North Pacific Fisheries Management Council (NPFMC). Some stocks are assessed with integrated size-structured assessment models of the form described in Punt, Huang, and Maunder (2013). Currenlty, each stock is assessed using a stock-specific assessment model (e.g. Zheng and Siddeek (2014)). The Gmacs project aims to provide software that will allow each stock to be assessed inside a single modelling framework.

Gmacs is used here to develop an assessment model for the Bristol Bay Red King Crab (BBRKC) stock. This document serves as a test-case for the development of Gmacs. The example assessment is intended to match closely with a model scenario presented to the Spring 2014 BSAI Crab Plan Team Meeting by Zheng and Siddeek (2014). The following summarizes the outcome of some comparisons between the existing BBRKC stock assessment model (Zheng and Siddeek 2014) and an emulated version using the Gmacs platform.

An important component of the Gmacs framework is the provision of software for plotting Gmacs model outputs. In what follows, we demonstrate the use of the `gmr` package to process the output of the Gmacs-BBRKC model and produce plots that can be used in assessment reports.

Together, the Gmacs-BBRKC model and this report serve as the first example of what should follow for other crab stocks: that is, direct model comparisons to (1) test the efficacy of Gmacs, and (2) determine whether Gmacs can be used in practice to closely match the outputs of existing ADFG stock assessment models.

Summary of analytical approach

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, the ADFG developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the BBRKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995. An alternative LBA (research model) was developed in 2004 to include small size groups for federal overfishing limits. The crab abundance declined sharply during the early 1980s. The LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a basic constant natural mortality during 1976-1993.

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). The model combines multiple sources of survey, catch, and bycatch data using a maximum likelihood approach to estimate abundance, recruitment, catchabilities, catches, and bycatch of the commercial pot fisheries and groundfish trawl fisheries.

Critical assumptions of the model include:

- The base natural mortality is constant over shell condition and size and was estimated assuming a maximum age of 25 and applying the 1% rule (Zheng 2005).
- Survey and fisheries selectivities are a function of size and were constant over shell condition. Selectivities are a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2013 based on modifications to the trawl gear used in the assessment survey.
- Growth is a function of size and did not change over time for males. For females, three growth increments per molt as a function of size were estimated based on sizes at maturity (1975-1982, 1983-1993, and 1994-2013). Once mature, female red king crabs grow with a much smaller growth increment per molt.
- Molting probabilities are an inverse logistic function of size for males. Females molt annually.
- Annual fishing seasons for the directed fishery are short.
- Survey catchability (q) was estimated to be 0.896, based on a trawl experiment by Weinberg et al. (2004) with a standard deviation of 0.025. Survey catchability was assumed to be constant over time. Some scenarios estimate q in the model.
- Males mature at sizes =120 mm CL. For convenience, female abundance was summarized at sizes =90 mm CL as an index of mature females. viii. For summer trawl survey data, shell ages of newshell crabs were 12 months or less, and shell ages of oldshell and very oldshell crabs were more than 12 months.
- Measurement errors were assumed to be normally distributed for size compositions and were log-normally distributed for biomasses.

Gmacs

The data and model specifications used in the Gmacs-BBRKC model are very similar to those used in the '4nb' scenario developed by Zheng and Siddeek (2014), herein referred to as the ADFG-BBRKC model.

Since the BBRKC model from Zheng and Siddeek (2014) treats recruits by sex along with sex-specific natural mortality and fishing mortality, results from the male components are compared with results from a Gmacs model implementation tuned to male-only data.

Parameter Number of estimated parameters Value Natural mortality 1 Males (1980-84) 1 Females (1980-84) 1 Females (1976-79; 1984-1993) 0.18 yr-1 Other years

Growth Transition matrix Pre-specified Molt probability (slope and intercept) (1975-78) Females? 2 Molt probability (slope and intercept) (1979+) Females? 2 Molt probability (slope and intercept) Males? Pre-specified

Recruitment Gamma distribution parameters 4 Annual deviations ??

Fishing mortality Mean fishing mortality (directed fishery) 1 Annual fishery deviations (directed fishery) ?? Mean fishing mortality (groundfish fishery) 1 Annual fishery deviations (groundfish fishery) ?? Mean fishing mortality (Tanner fishery) 1 Annual fishery deviations (Tanner fishery) ??

Fishery selectivity Directed fishery slope and intercept (by sex) 4 Groundfishery slope and intercept (both sexes) 2 Tanner crab fishery slope and intercept (both sexes) 4 Retention Slope, inflection point, asymptote 3 Initial conditions ?? Survey catchability 1 Survey selectivity NMFS Slope and intercept (1975-81) by sex 4 NMFS Slope and intercept (1982+) by sex 4 BSFRF selectivity Pre-specified BSFRF CV 1

Population Dynamics

Comparison tables of two different model approaches could be done by

Specification	Parameter	ADFG Value	Gmacs OneSex	Gmacs TwoSex
Start year	$t = 0$	1975	1953	1975

Specification	Parameter	ADFG Value	Gmacs OneSex	Gmacs TwoSex
End year	$t = T$	2014	2014	2014
No. sexes	s	2	1	2
No. shell condition	ν	2	2	2
No. maturity	m	2	1	1
No. size-classes	ℓ	20	20	20

Life History Trait	Parameter	ADFG Value	Gmacs Value	Comments
Natural Mortality	M	Fixed	Fixed	M is fixed in both models

Fishery Dynamics

Specification	Parameter	ADFG Value	Gmacs Value	Comments
No. Fleets		5	2	
No. Fleets		5	5	

File Description

- The `*.tpl` file is working, it builds and the `*.exe` file runs successfully.
- The main `*.dat` file is read in as expected (comments within).
- There is a second data file `rksize13s.dat` with sample sizes for various rows of size-comp data. See lines 81-87 of `*.tpl`.
- Input sample sizes appear to be capped to the constant numbers entered in the main data file under 'number of samples' or 'sample sizes' (variously).
- There is a third data file `tc7513s.dat` specifically for data from the tanner crab fishery (with red crab bycatch).
- There is a standard control file `*.ctl` with internal comments.
- There is an excel spreadsheet which can be used to read in the model output files and display related plots (it's a bit clunky).
- There are two batch files in the model directory: `clean.bat` and `scratch.bat`. The 'clean' batch file deletes files related to a single model run. The 'scratch' batch file deletes all files relating to the model build and leaves only source and data files.

Comparison of model results

The following plots summarize plots made using `gmr` based on output from Zheng and Siddeek (2014) and Gmacs. Two Gmacs models are provided, the OneSex model and the TwoSex model.

Fit to survey abundance indices

The model fit to survey biomass for males was better for the Zheng and Siddeek (2014) model (at least visually) than for either of the current implementations of Gmacs (Figure 1).
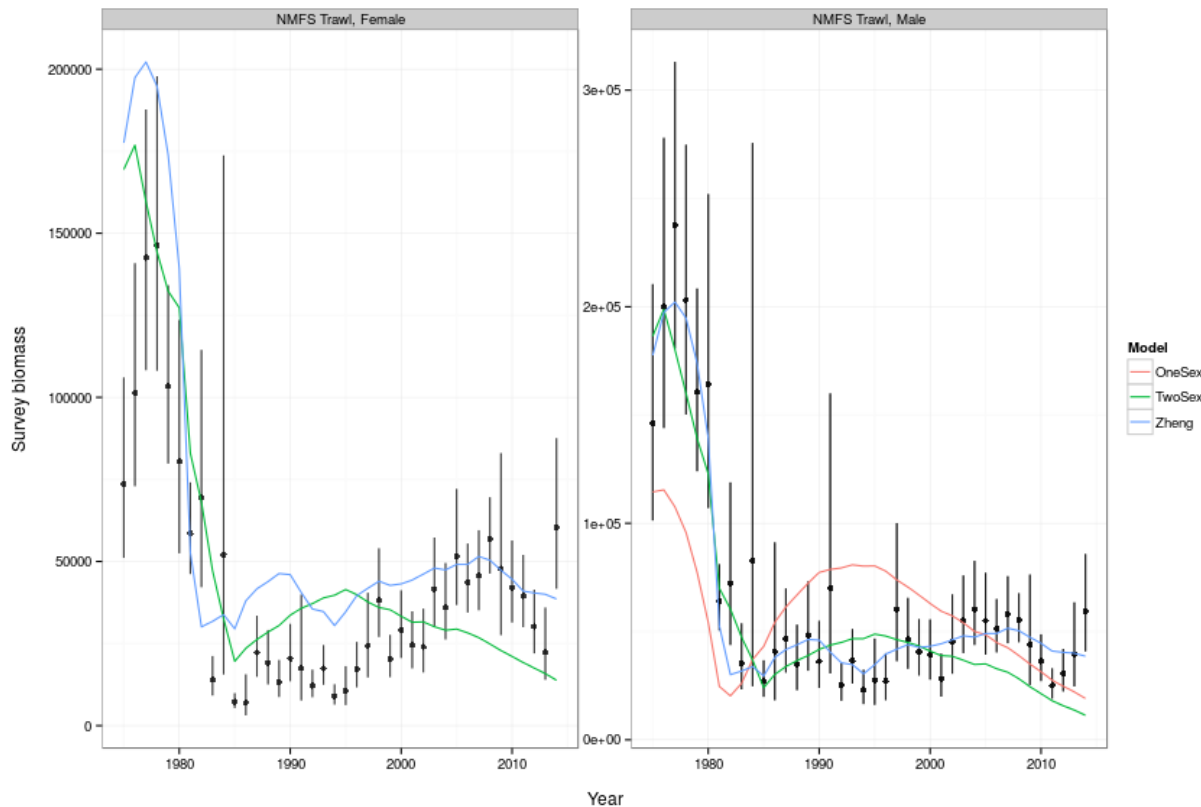

Figure 1: Model fits to NMFS trawl survey biomass.

Estimated retained catch and discards

The observed and predicted catches by gear type are summarized in (Figure 2). Data for discard fisheries were read in with 100% mortality (as clarified in Table 1 of Zheng and Siddeek (2014)).

Fit to size composition data

The fit of the Gmacs models to the BBRKC size composition data are given in the following plots. These include fits to the directed pot fishery for males (Figure 3), male crabs discarded in the directed pot fishery (Figure 4), female crabs discarded in the directed pot fishery (Figure 5), the groundfish trawl bycatch fisheries for males (Figure 6) and females (Figure 7), and the NMFS trawl survey (Figure 8).

Mean weight-at-length

The mean weight-at-length (w_ℓ) of crabs is defined in kg and the carapace length (ℓ, CL) in mm. The mean weight-at-length of males used in all models is nearly identical. The only difference between the Gmacs models and Zheng's is in the final length class (160mm) where the mean weight is greater in Zheng's model than in Gmacs (Figure 9). However, the pattern is very different for females. This difference is due to. . .
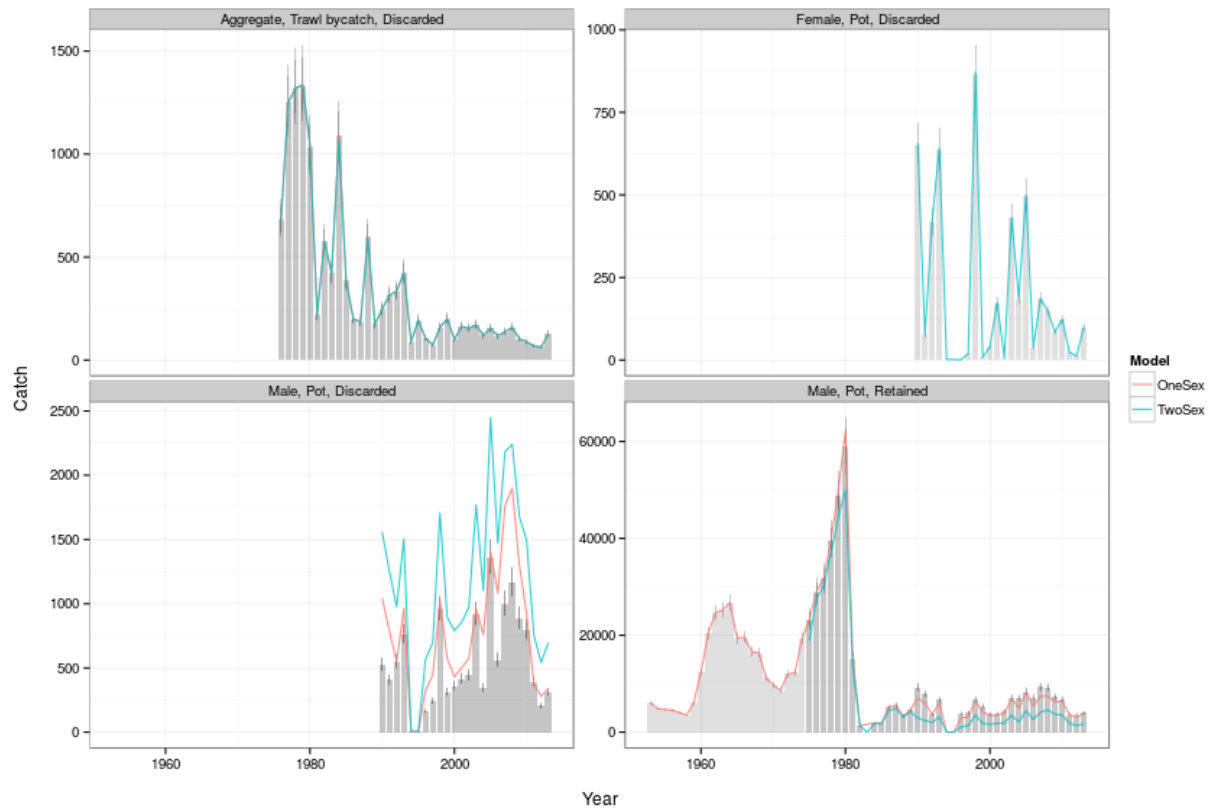
Figure 2: Observed and predicted catch by gear type for the Gmacs models.
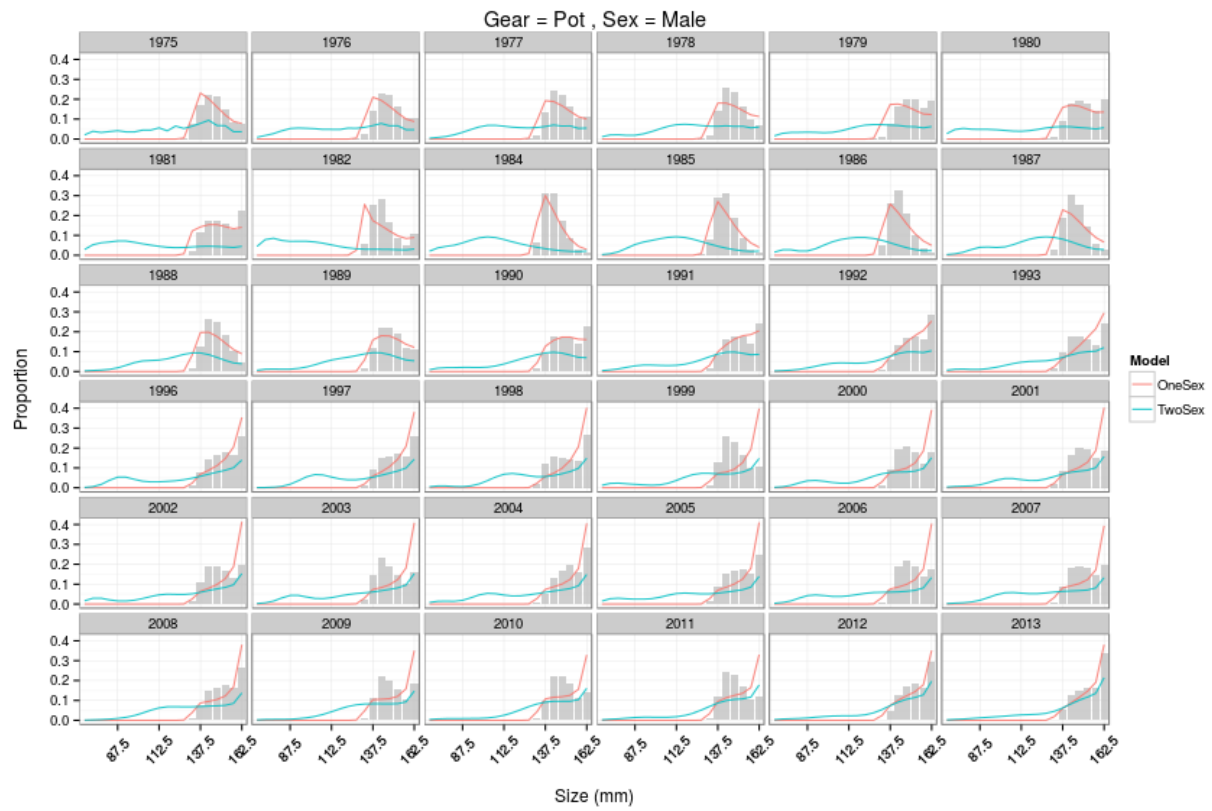
Figure 3: Observed and model estimated length-frequencies of male BBRKC by year retained in the directed pot fishery.
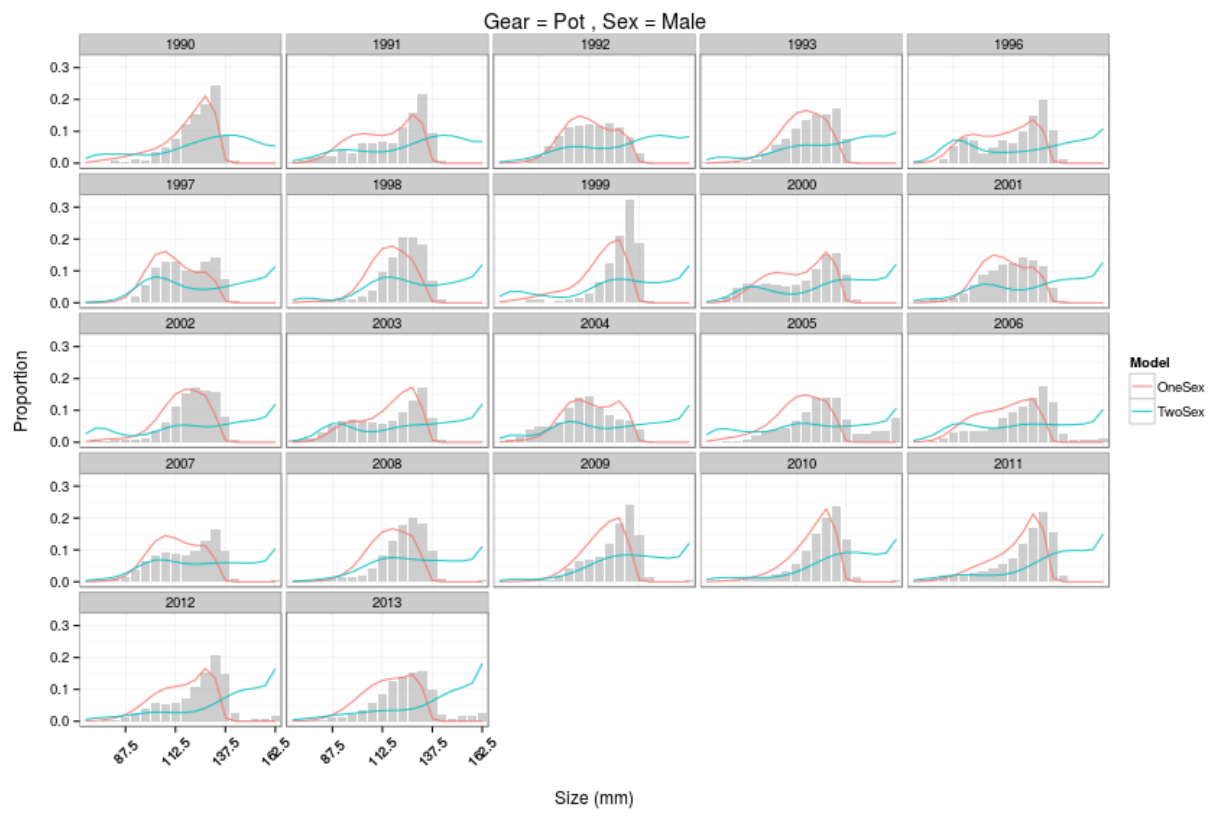
Figure 4: Observed and model estimated length-frequencies of male BBRKC by year discarded in the directed pot fishery.
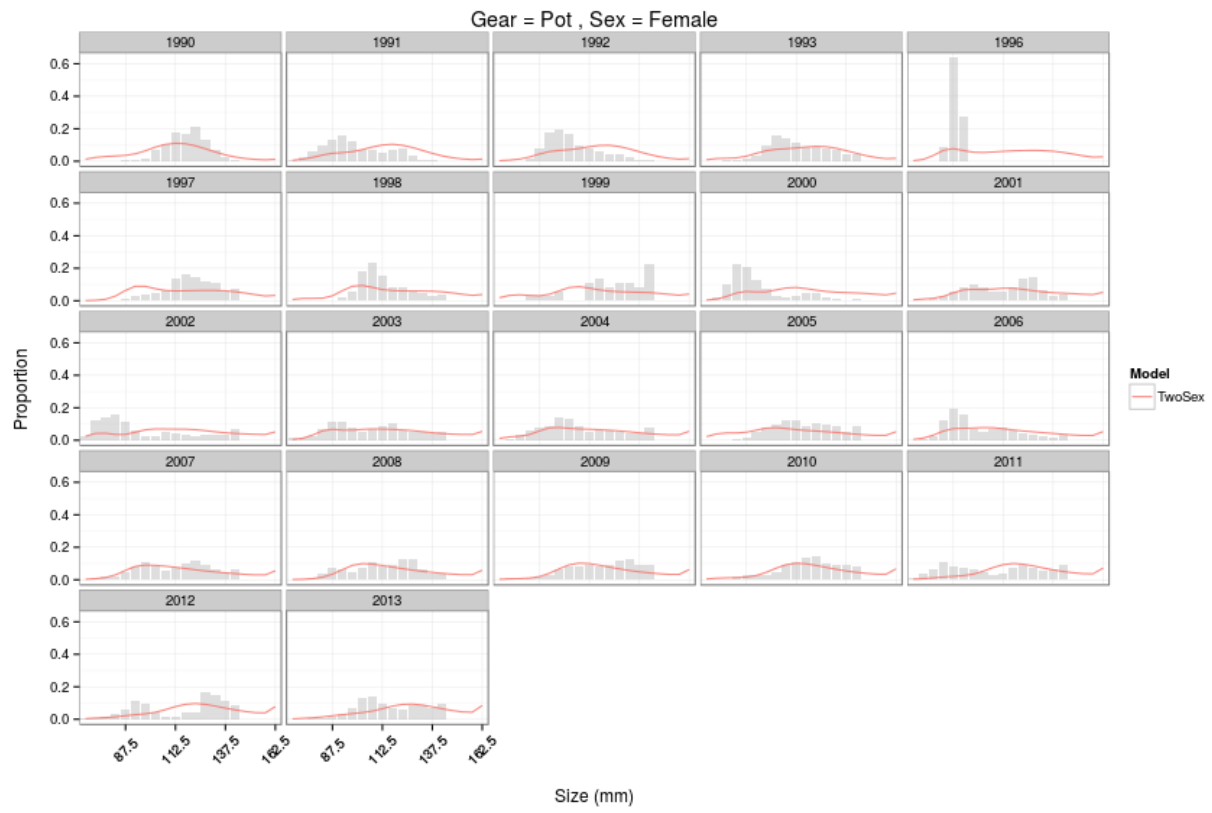
Figure 5: Observed and model estimated length-frequencies of female BBRKC by year discarded in the directed pot fishery.
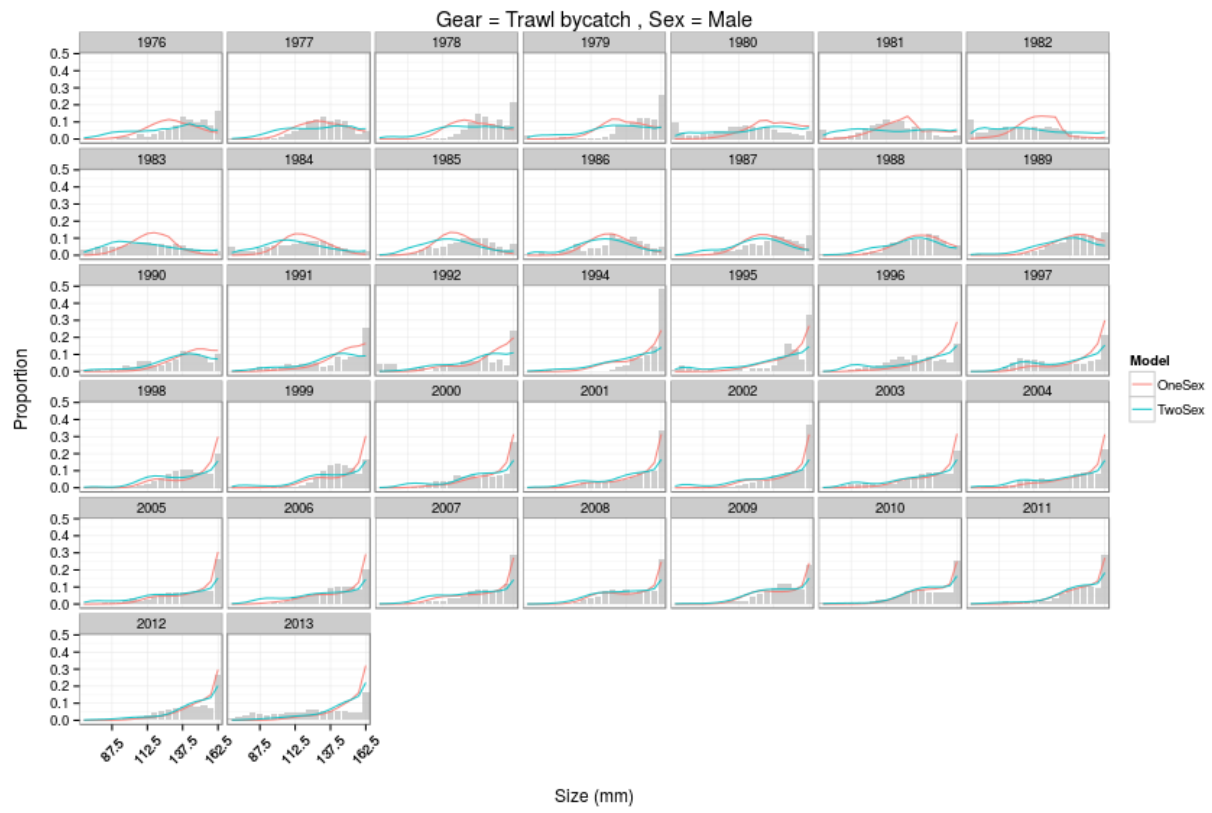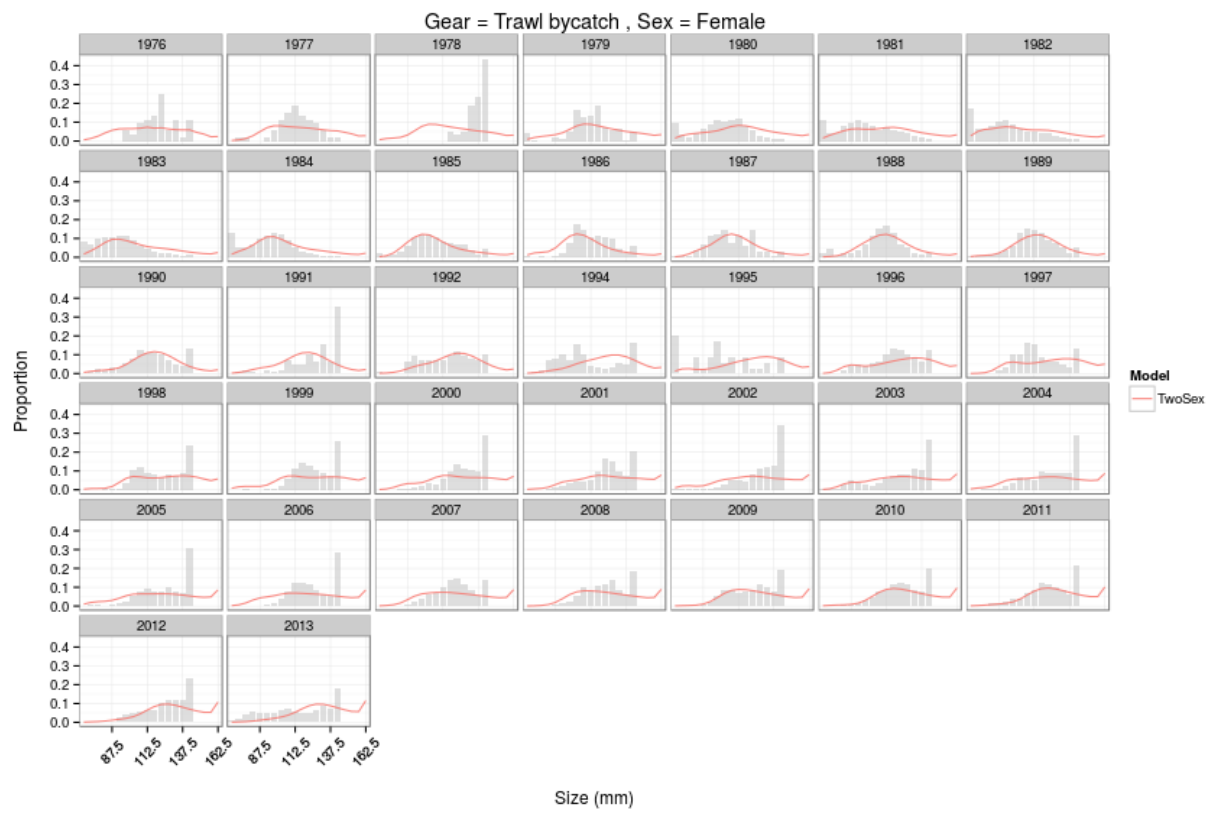
Figure 6: Observed and model estimated length-frequencies of male BBRKC by year in the groundfish trawl bycatch fisheries.

Figure 7: Observed and model estimated length-frequencies of female BBRKC by year in the groundfish trawl bycatch fisheries.
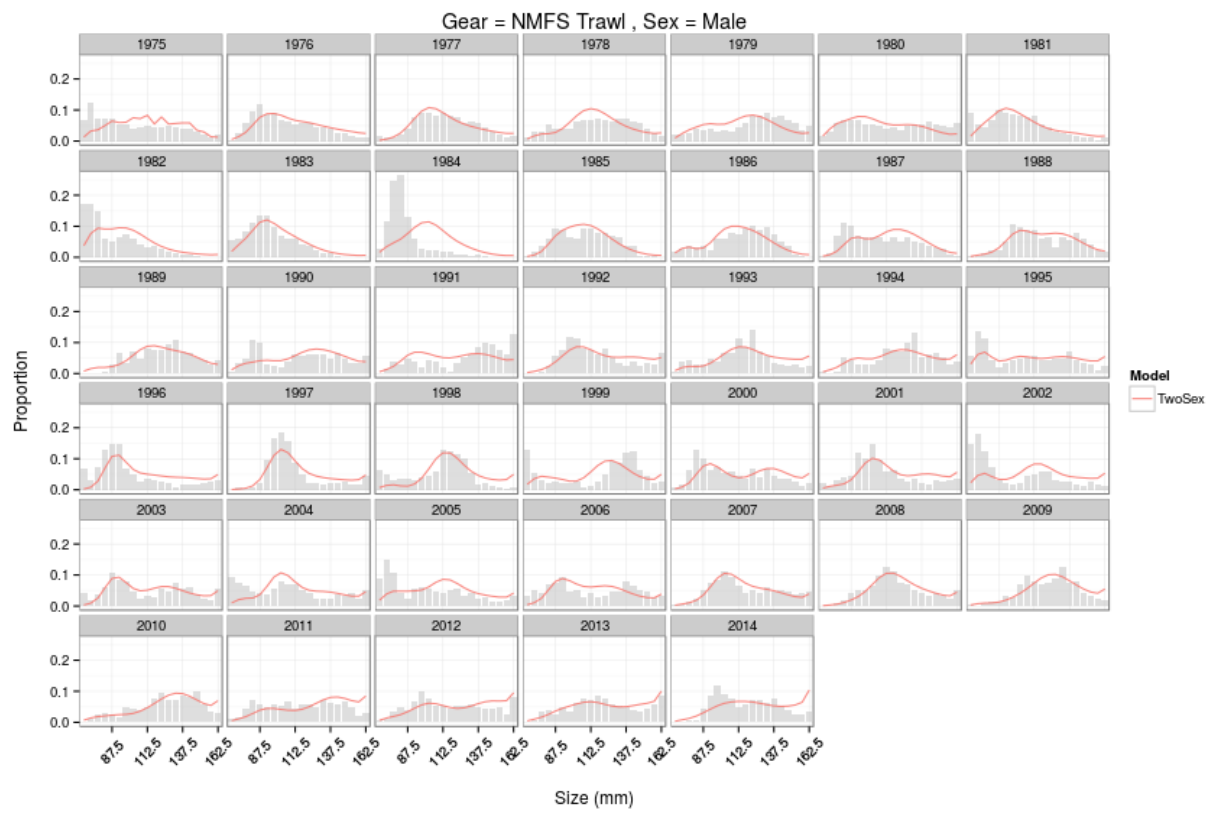
Figure 8: Observed and model estimated length-frequencies of male BBRKC by year in the NMFS trawl fishery.
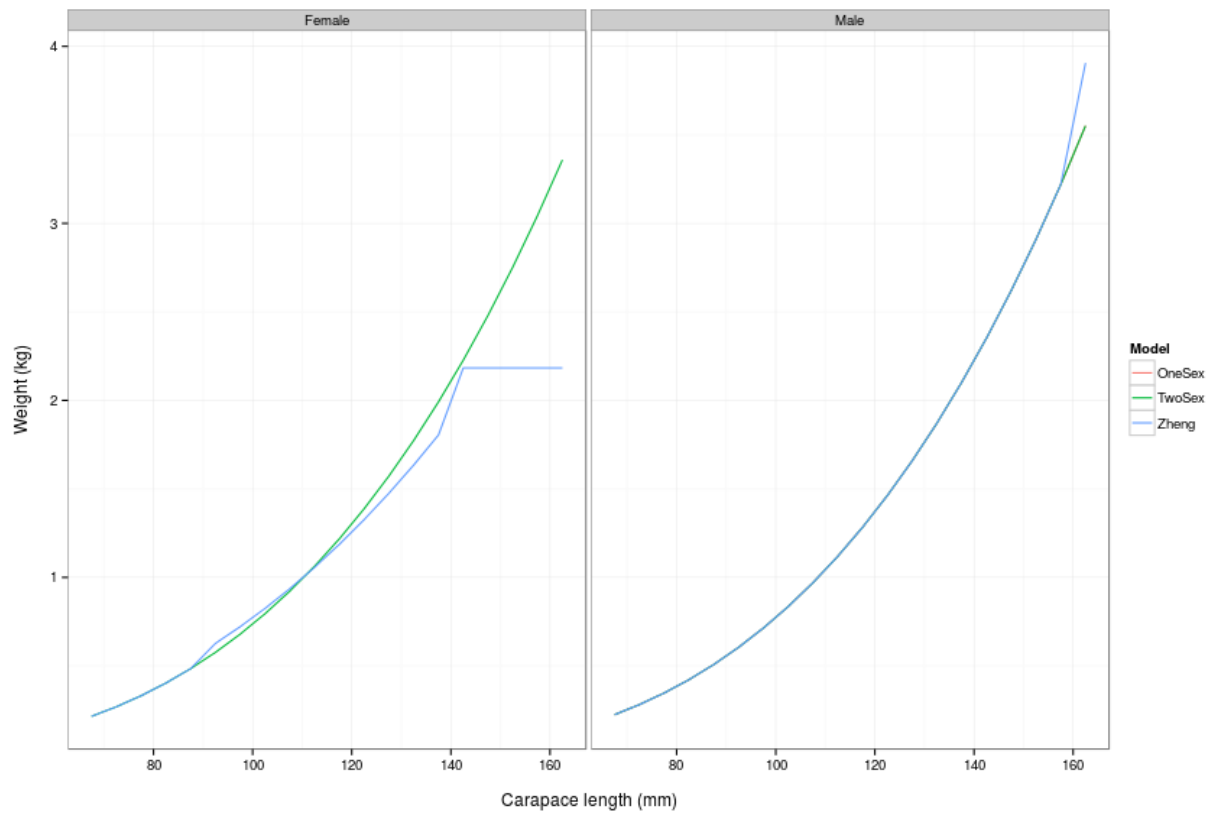
Figure 9: Relationship between carapace length (mm) and weight (kg) by sex in each of the models.

Initial recruitment size distribution

Gmacs was configured to match the Zheng and Siddeek (2014) model recruitment size distribution closely (Figure 10).
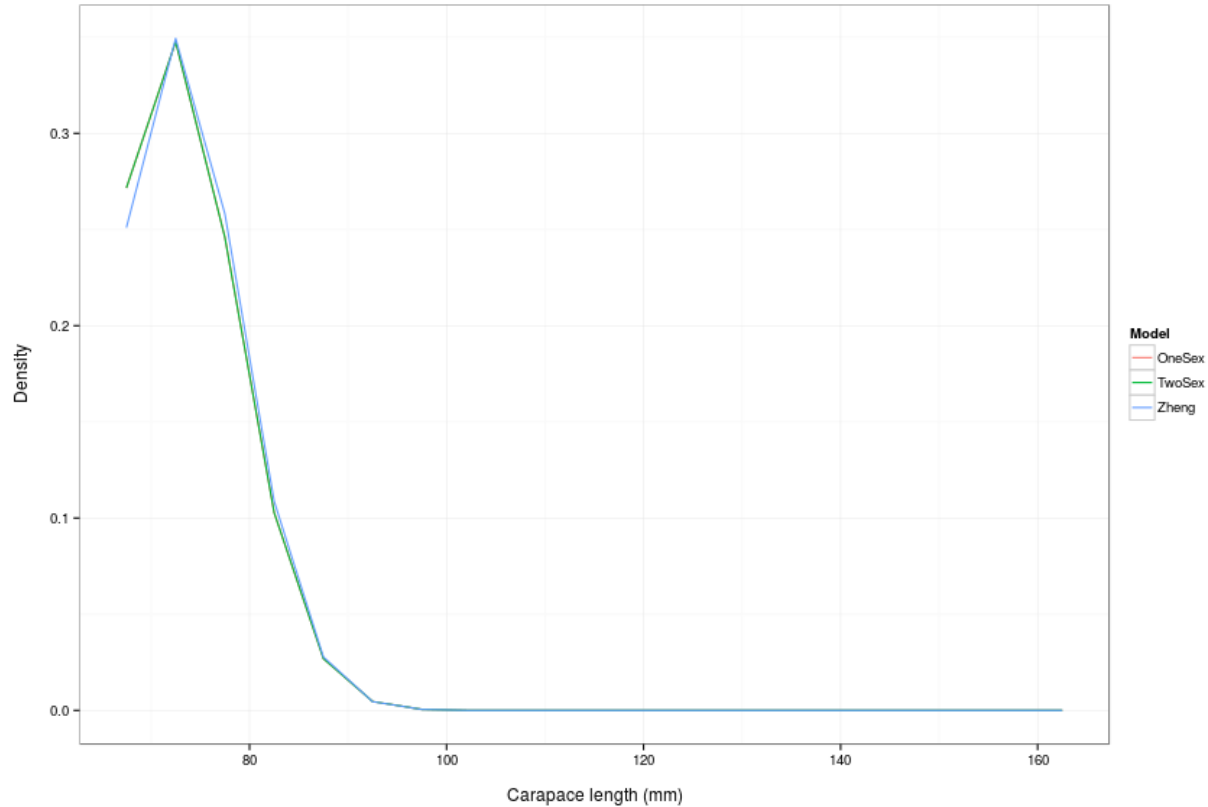
Figure 10: Distribution of carapace length (mm) at recruitment.

Molting increment and probability

Options to fit relationship based on data was developed but for the BBRKC system, a size-specific vector was used to determine molt increments as shown below (Figure 11). Fixed parameters in gmacs were set to represent that assumed from Zheng and Siddeek (2014) (Figure 12).

Transition processes

The first set of figures is the growth probabilities (for all crabs that molt) (Figure 13). The second set of figures is the combination of growth and molting and represents the size transition (Figure 14).

Numbers at length in 1975 and 2014

The number of crabs in each size class ($\mathbf{n}$) in the initial year ($t = 1$) and final year ($t = T$) in each model differ substantially (Figure 15). The scale of these results differ significantly and may be related to the interaction with natural mortality estimates and how the initial population-at-lengths were established (the BBRKC model assumes all new-shell).
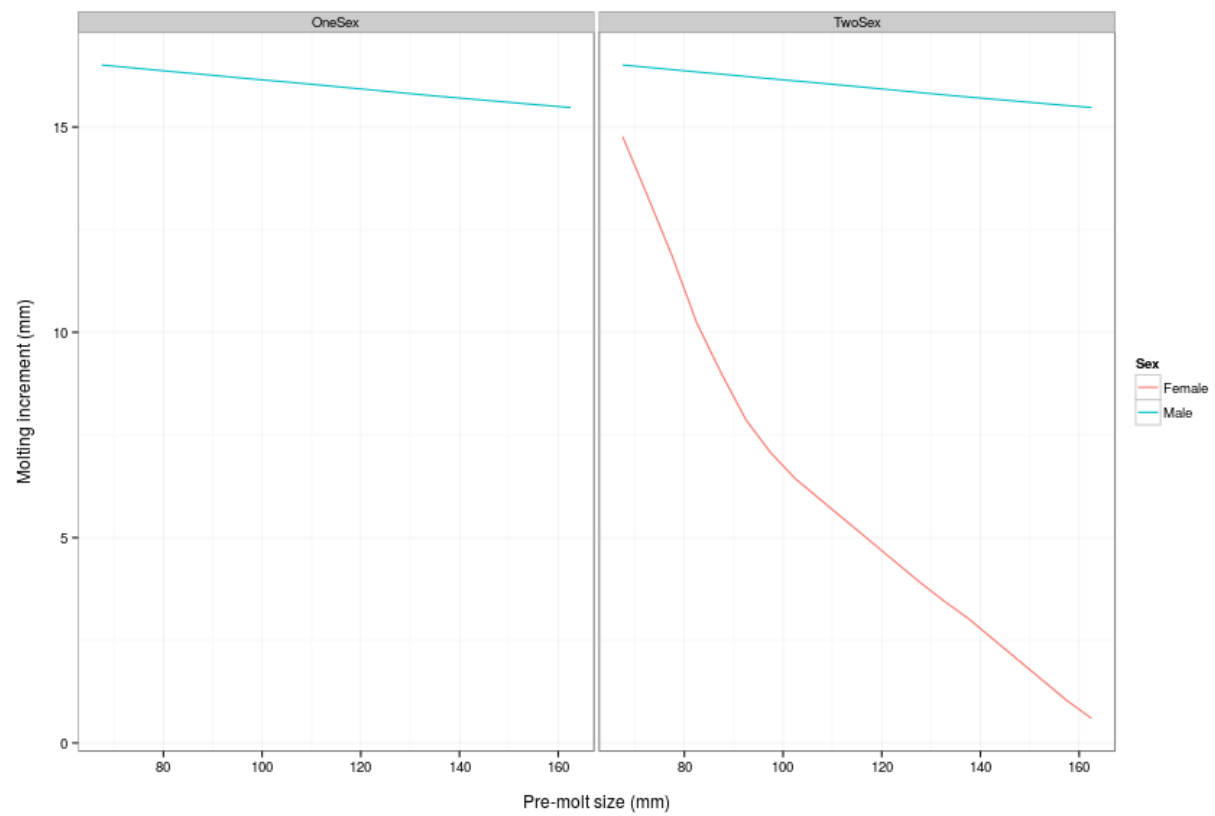
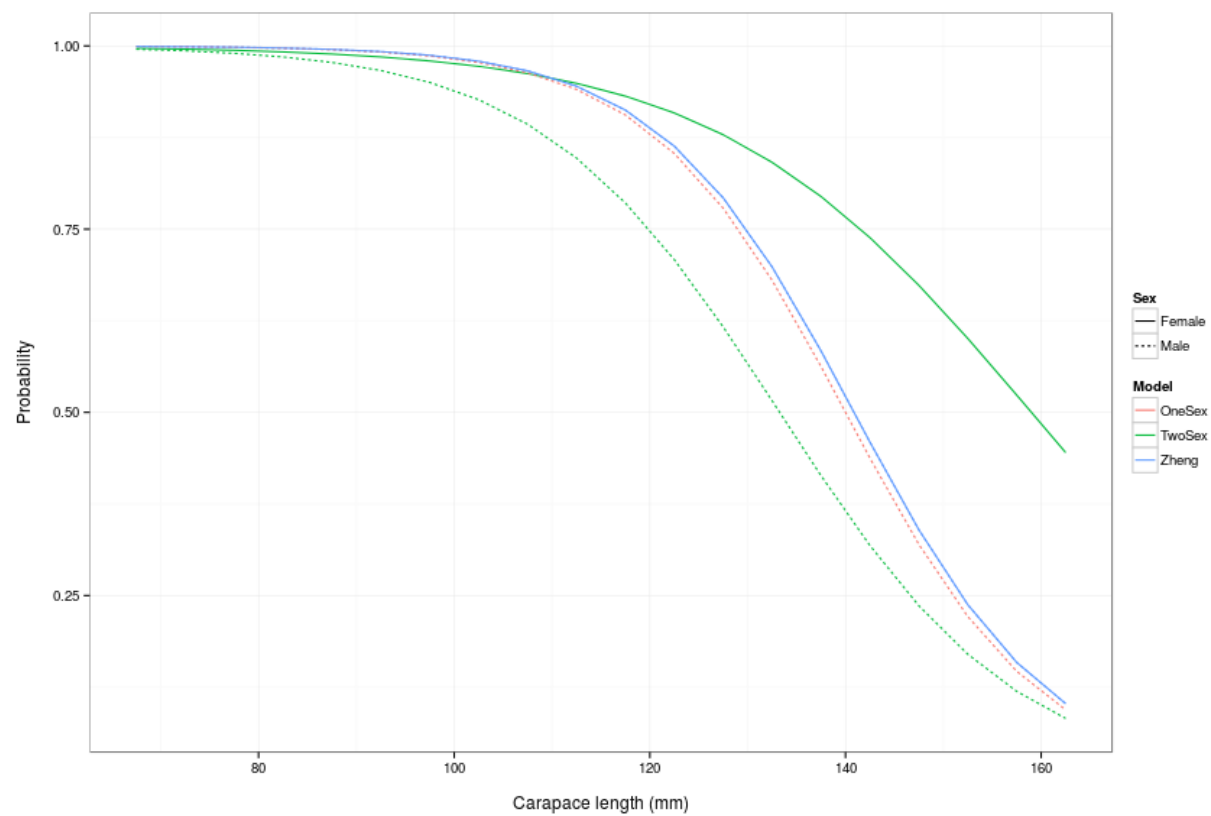Figure 11: Growth increment (mm).
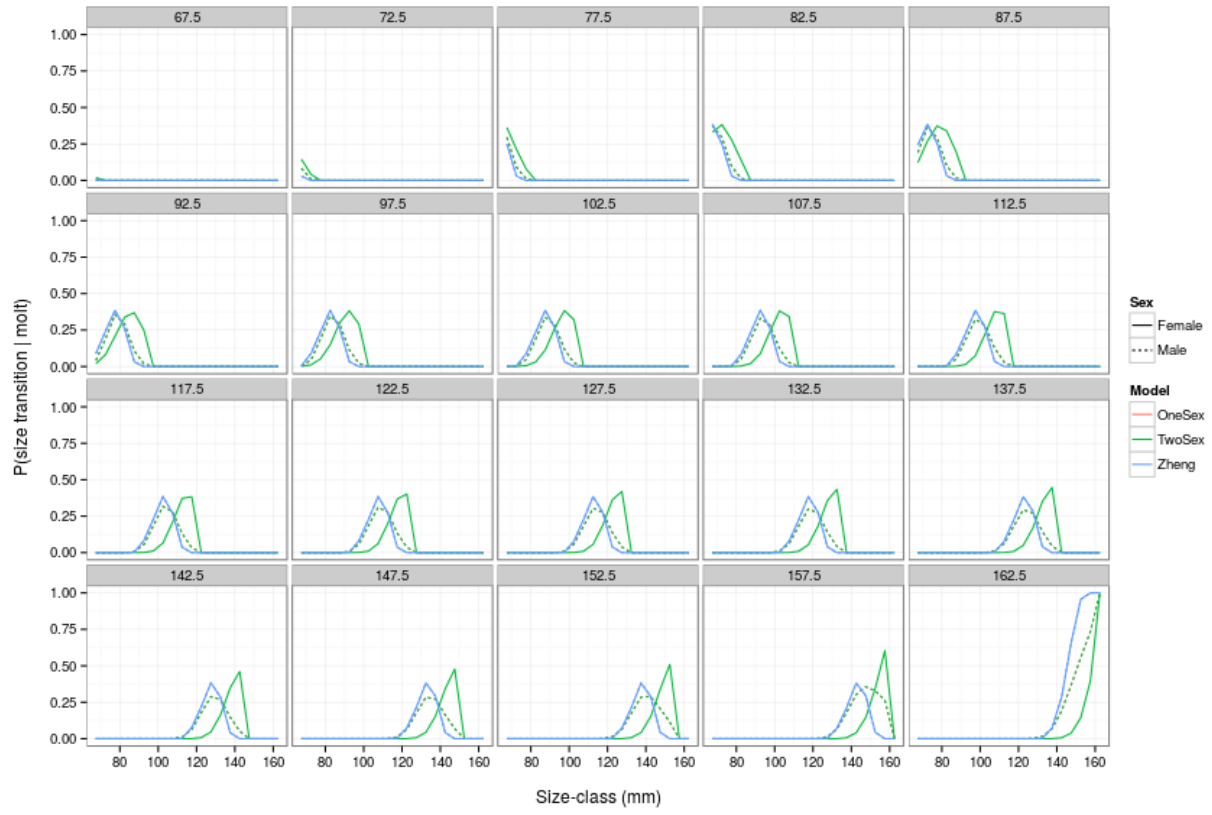
Figure 12: Molting probability.
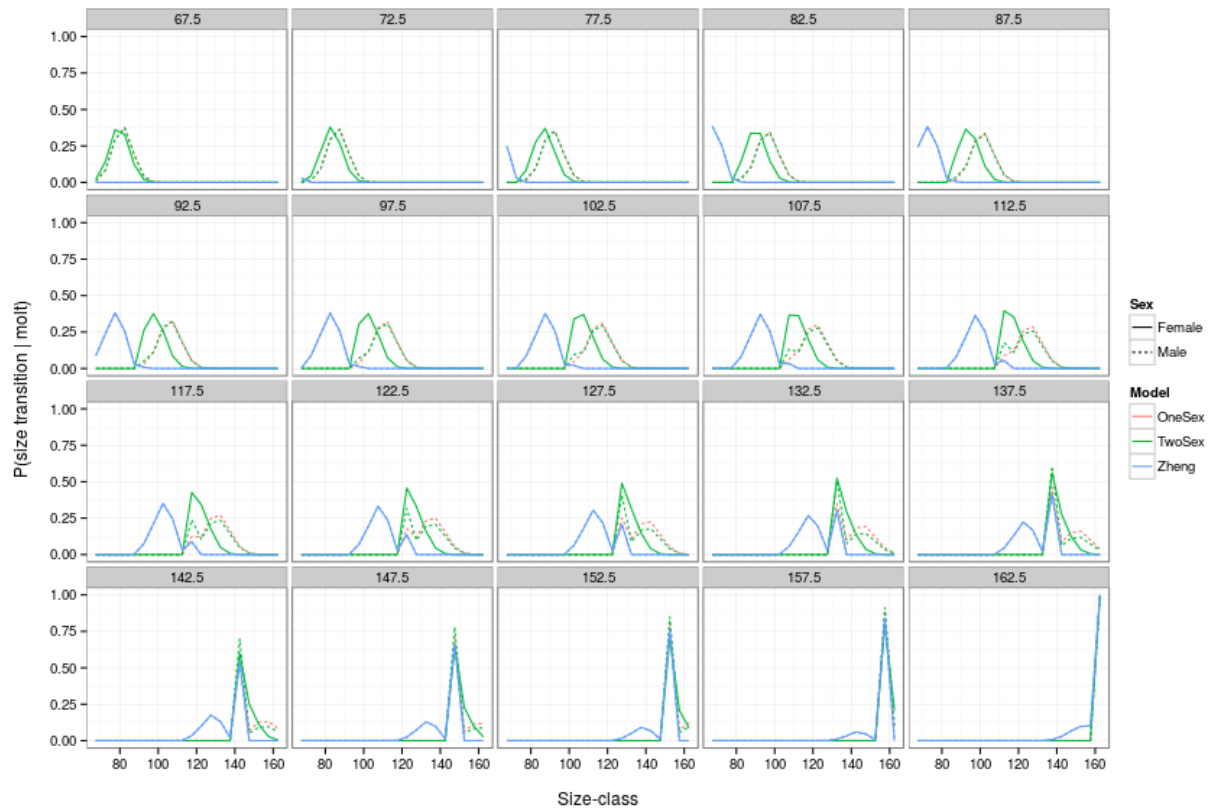
Figure 13: Growth transitions.
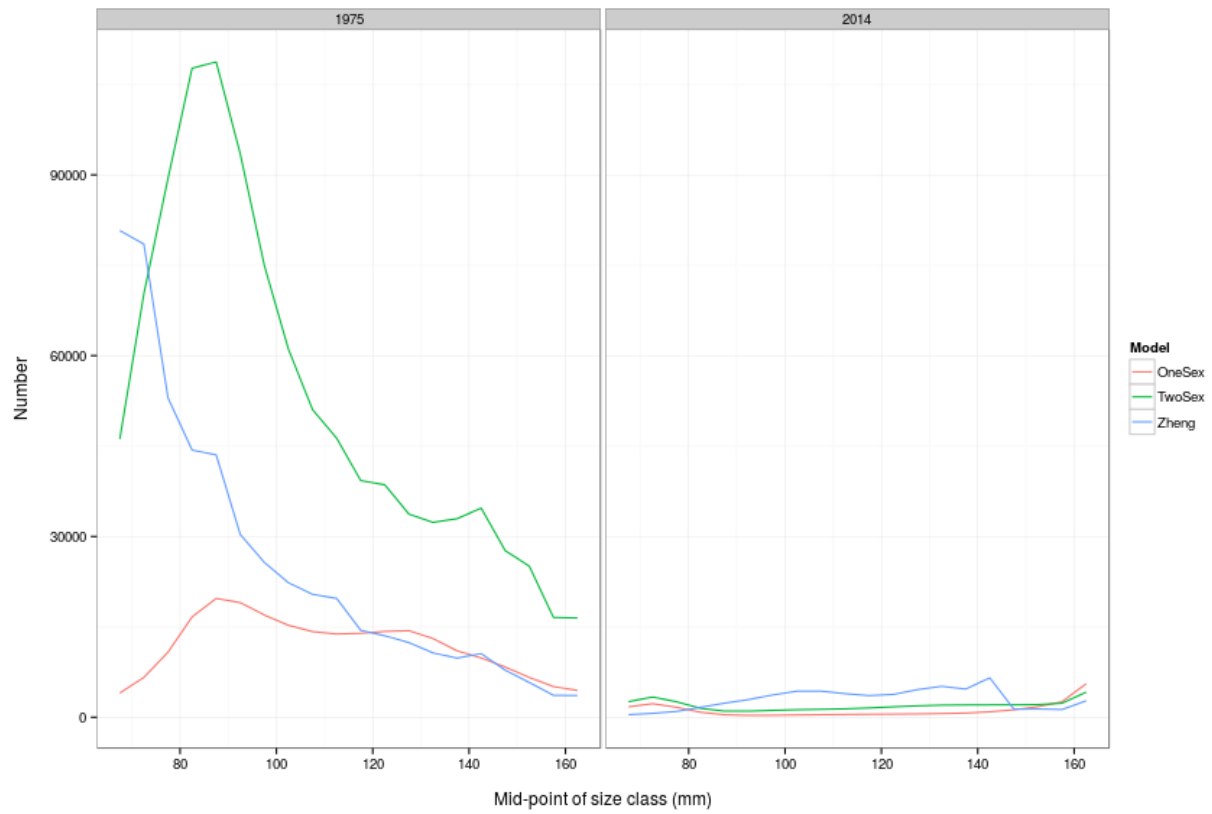
Figure 14: Size transitions.

Figure 15: Numbers at length in 1975.

Selectivity

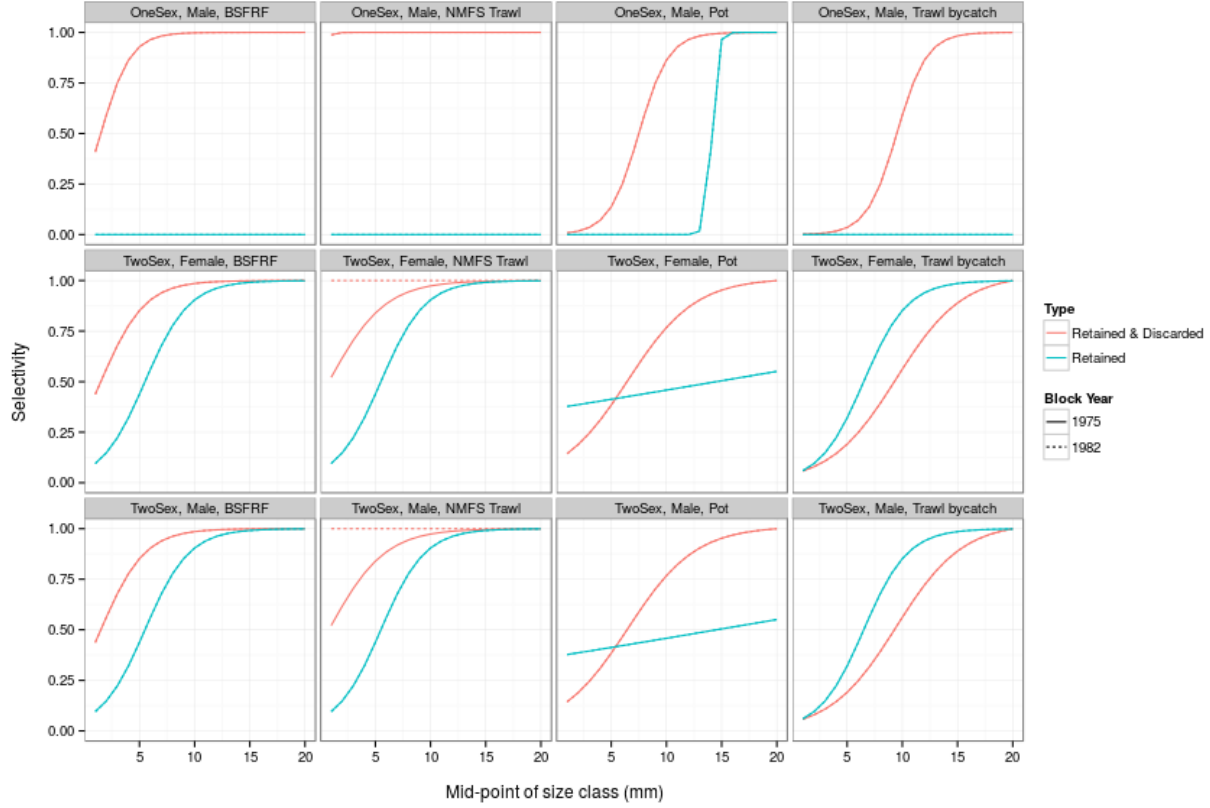The selectivity by length (S_ℓ) for each of the fisheries (Figure 16).

Figure 16: Estimated selectivity functions.

Natural mortality

The figure below illustrates implementation of four step changes in M_t (freely estimated) in gmacs relative to the estimates from Zheng et al. 2014 (Figure 17). In both the ADFG-BBRKC and Gmacs-BBRKC models, time-varying natural mortality (M_t) is freely estimated with four step changes through time. The years (t) that each of these steps cover are fixed a priori. The pattern in time-varying natural mortality is resonably similar between the two models (Figure 17), however the peak in natural mortality during the early 1980 is not as high in the Gmacs-BBRKC model.

Recruitment

Recruitment patterns are similar, but differences in natural mortality schedules will affect these matches. The figure below plots the values to have the same mean (Figure 18). Patterns in recruitment through time (R_t) estimated in the two models are similar, but differences in natural mortality schedules will affect these matches (Figure 18).
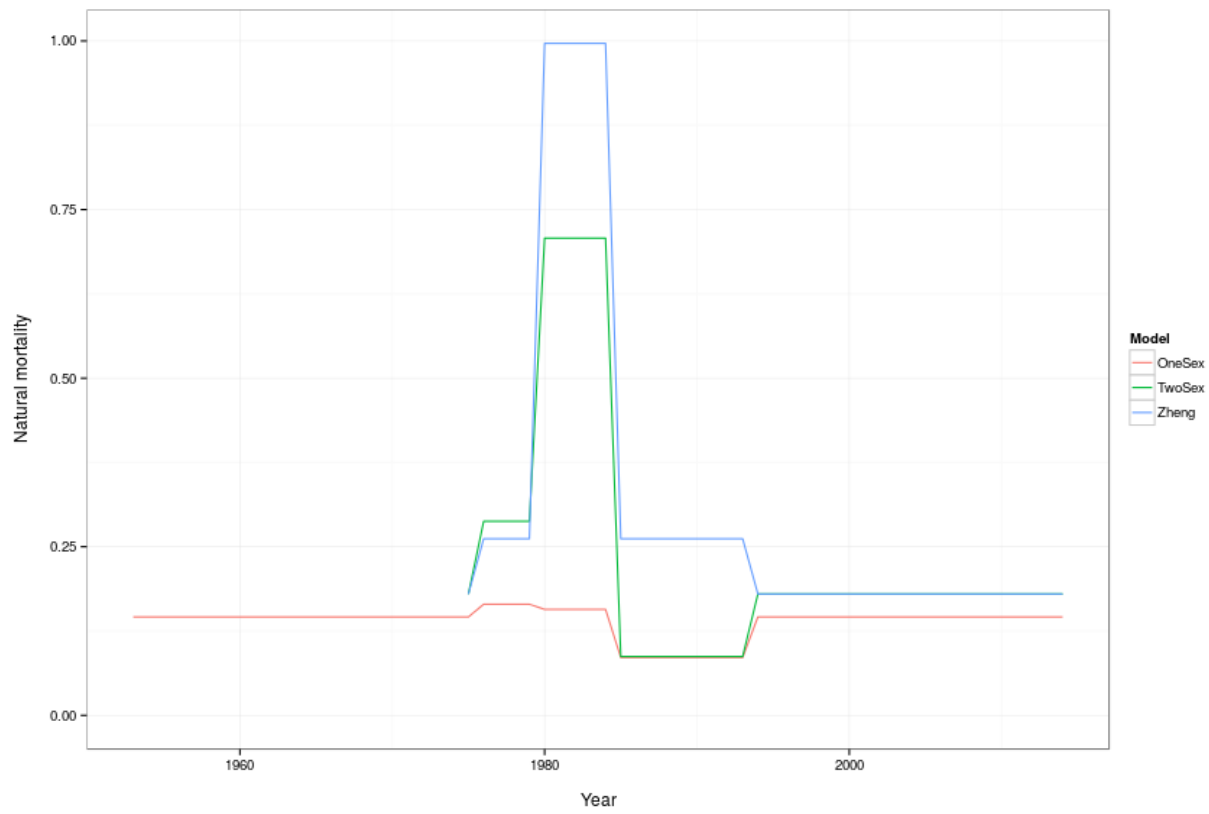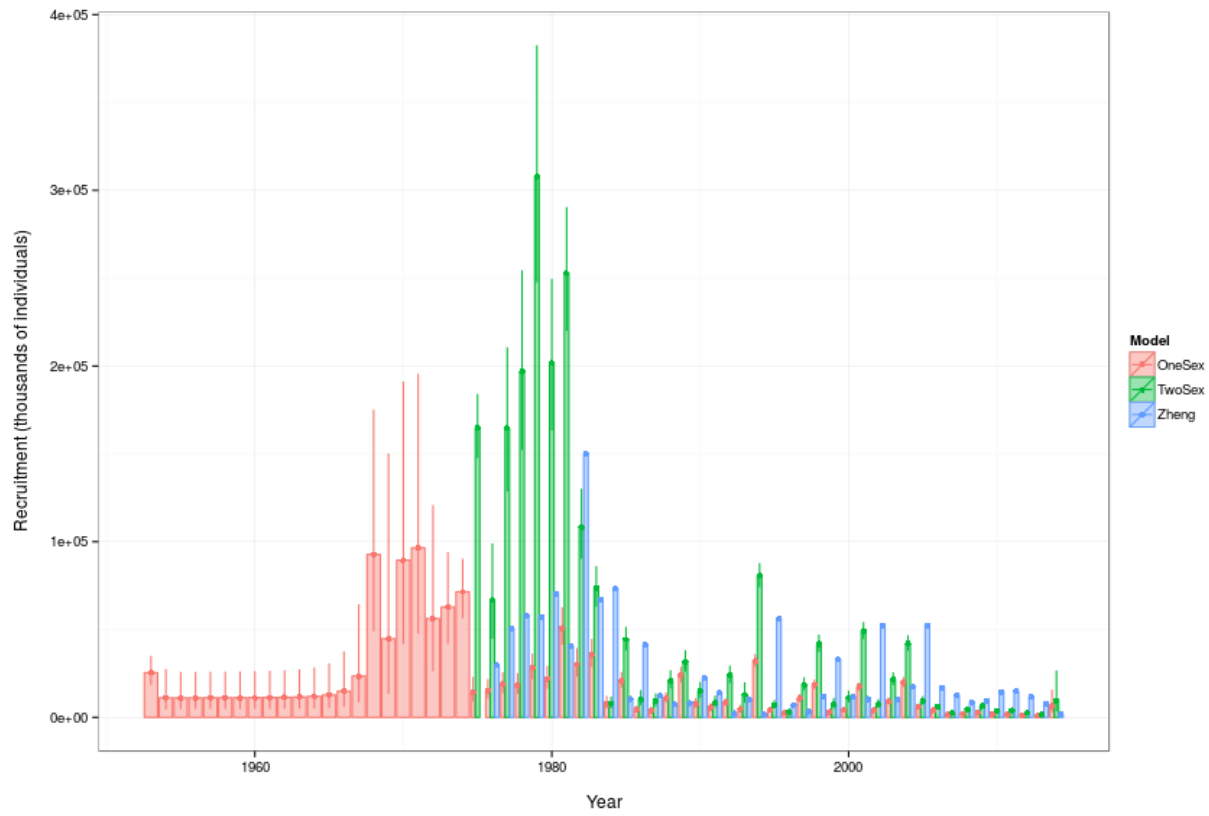
Figure 17: Time-varying natural mortality (M_t).

Figure 18: Estimated recruitment time series (R_t).

Mature male biomass (MMB)

The spawning stock biomass of mature males, termed the mature male biomass (MMB_t), also differs a lot bewteen the two models (Figure 19).
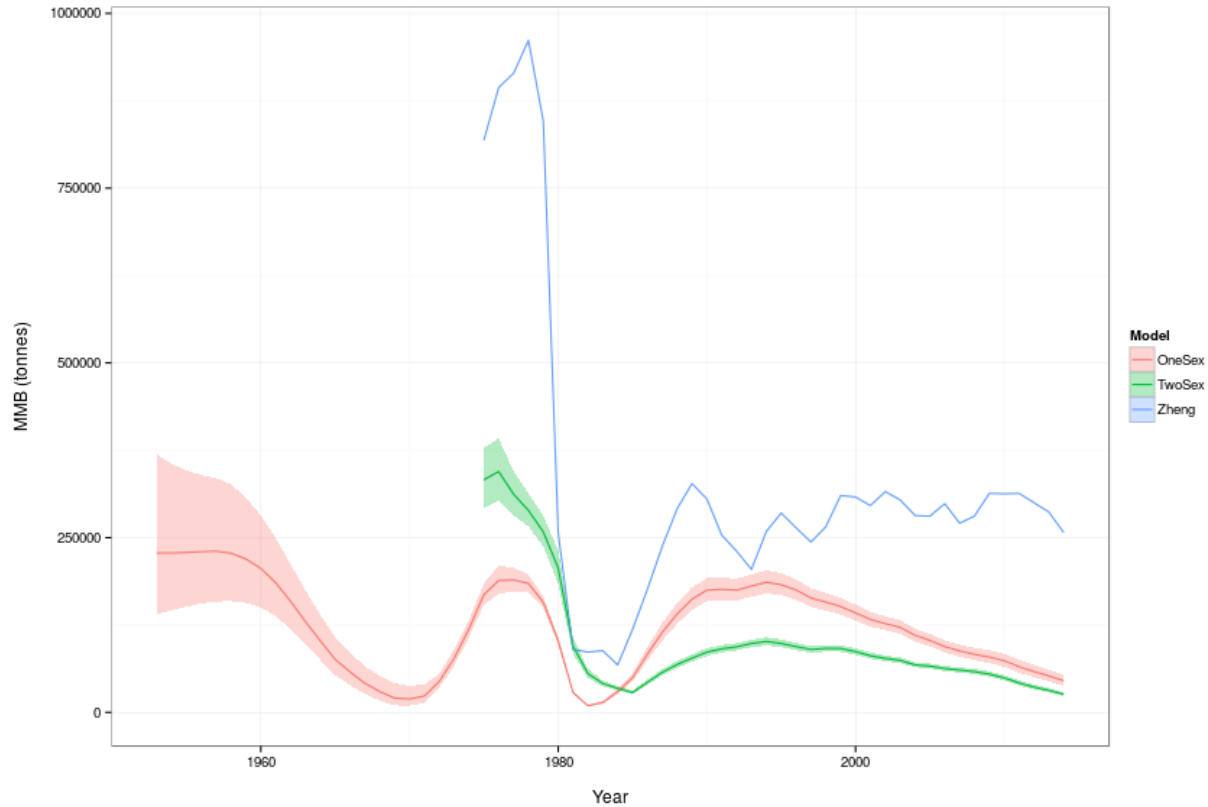

Figure 19: Mature male biomass (MMB) predicted in the two versions of the Gmacs model (OneSex and TwoSex) and the Zheng model.

Comparison of model results

The results of the ADFG-BBRKC model are compared here to the results of the Gmacs-BBRKC model.

Model	FSPR	BSPR	FOFL	OFL	RSPR
Gmacs (one sex)	0.28	32995.95	0.28	3373.93	8160.40
Gmacs (two sex)	0.21	22205.54	0.21	3030.39	16959.09

Gmacs results

We need to be able to produce a table of the comparative likelihoods (by component) of the alternative models. For best practice, just try and do what we do with SS models for SESSF stocks anyway. See the pink link report, and enter a section for each of those, and see if we can emulate a report of that type.

Discussion

Comparisons of actual likelihood function values and year-specific fits using the robust-multinomial would be the next step after selectivity issues are resolved. Subsequent to that, it would be worth exploring aspects of alternative model specifications (e.g., constant natural mortality over time, time-varying selectivity, etc) to evaluate sensitivities.

This discussion will focus on the challenges in developing a Gmacs version of the BBRKC model: those met, and those yet to be met.

References

Punt, A. E., T. Huang, and M. N. Maunder. 2013. "Review of Integrated Size-Structured Models for Stock Assessment of Hard-to-Age Crustacean and Mollusc Species." *ICES Journal of Marine Science* 70 (1) (January): 16–33. doi:10.1093/icesjms/fss185. http://icesjms.oxfordjournals.org/cgi/doi/10.1093/icesjms/fss185.

Zheng, J., and M.S.M Siddeek. 2014. "Bristol Bay Red King Crab Stock Assessment in Spring 2014." *Alaska Department of Fish and Game*: 149.