A comparison study of North Pacific albacore (*Thunnus alalunga*) age and growth among various sources [1]

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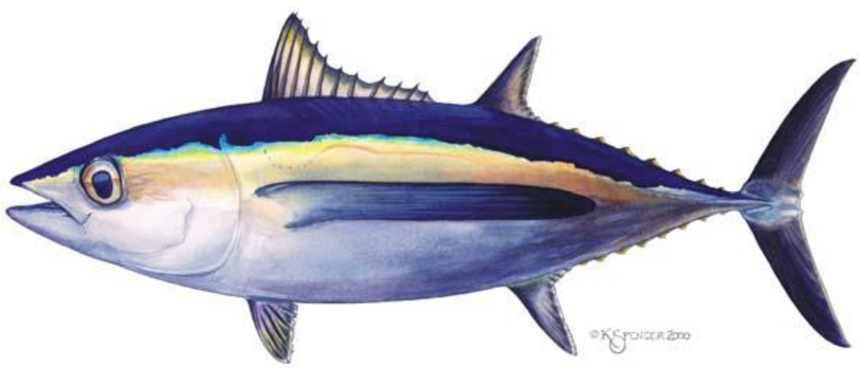

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ABSTRACT

The objectives of this working paper are to: 1) review two recent studies (Chen et al. 2012 and Wells et al. 2013) on the age and growth of North Pacific albacore (*Thunnus alalunga*), 2) provide a series of best available sex-specific and sex-combined growth model parameters for the 2014 assessment based on the conditional age-at-length data from these two studies, and 3) compare the size of fish sampled by these studies with commercial catch composition data. We calculated the von Bertalanffy growth parameters (L_{inf}, K and t_0) using conditional age-at-length data derived from otolith samples from Chen et al. (2012) and Wells et al. (2013). The resulting growth models suggest differences in the growth of male and female albacore as well as between the different regions of the North Pacific. Male albacore growth is faster than females after age 7-8 and results in a larger L_{inf} of approximately 119 cm fork length (FL) (based on combined Chen/Wells dataset), compared to 106 cm for female albacore. Most of the biggest fish were collected in the central Pacific Ocean, and were either male or of unknown-sex. We also studied the size composition of albacore sampled by Wells et al. (2013) relative to the US longline deepset fishery. The results suggest that Wells et al. (2013) samples were likely biased towards larger fish from this fishery, which may have resulted in more male albacore being sampled since larger fish tend to be male. This in turn may have biased the resulting sex-combined growth model because of the higher proportion of male fish in the samples of large fish. Based on these results, we suggest the ALBWG consider using sex-specific growth models with reasonable growth parameters, or estimate growth parameters within the stock assessment model.

INTRODUCTION

The capacity of a fish to grow is a key aspect of fish stock assessment. In age or length structured models, growth is modeled explicitly and age-growth relationships can be highly influential on assessment results. Age and growth relationships were a key source of uncertainty in the last stock assessment of North Pacific albacore by the ISC Albacore Working Group (ALBWG) (ISC 2011). Subsequent to the last assessment, two age and growth studies have been published by Chen et al. (2012) and Wells et al. (2013), providing important information to help resolve these uncertainties.

The objectives of this working paper are to: 1) review two recent studies (Chen et al., 2012 and Wells et al., 2013) on the age and growth of North Pacific albacore, 2) provide a series of best available sex-specific and sex-combined growth model parameters for the 2014 assessment based on the conditional age-at-length data from these two studies, and 3) compare the size of fish sampled by these studies with commercial catch composition data.

DATA AND METHODS

Chen et al. (2012) and Wells et al. (2013) kindly provided data from their respective studies, including estimated ages, measured fork lengths (cm), sampling dates, and sampling regions. Samples from Chen et al (2012) were collected in the western and central Pacific Ocean over 2001-2008, while samples from Wells et al. (2013) were collected across the western (WPO), central (CPO) and eastern Pacific Ocean (EPO) from 1990-2012 (Table 1). All data collected by Chen et al. (2012) included the sex of sampled fish (Female: n=125, Male: n=148). However, only a quarter of data from Wells et al. (2013) specified the sex of the sampled fish, while the rest of the samples were not sex-specific (Female: n=34, Male: n=92, Unknown sex: n=360). Details about age estimation procedures using otoliths collected at the time of biological sampling can be found in the associated references.

The length-at-age data were fitted to the following von Bertalanffy growth model using non-linear least squares,

$L_t = L_{inf}[1-e^{-k(t-t0)}]$,

where L_t is body fork length (FL cm), L_{inf} (cm FL) is the mean asymptotic length, K ($year^{-1}$) is the Brody growth parameter, and t_0 (year) is the length at age-0.

We fitted sex-specific and sex-combined growth models using data from both studies. Chen et al. (2012) did not report a sex-combined growth model but the ALBWG may use a sex-combined model for the 2014 stock assessment. A sex-combined model can be obtained by fitting all the data from both sexes in Chen et al. (2012). However, this might lead to a biased growth model due to the larger number of male samples, which have a different growth from female albacore. Therefore, an 'averaged' sex-combined growth curve was obtained by averaging the male and female growth curves from the sex-specific models. In contrast, most of the data from Wells et al. (2013) were of unknown sex and Wells et al. (2013) reported a sex-combined growth curve by fitting all the available age and size data, including sex-specific and sex-unspecified data. This may have biased the reported growth curve due to the larger sizes of adult male albacore. Preliminary models indicated that reasonable sex-specific growth curves were difficult to estimate from the limited sex-specific data from Wells et al. (2013). Therefore, we estimated sex-specific growth curves by fitting the sex-specific data from both Chen et al. (2012) and Wells et al. (2013). Subsequently, we estimated 'averaged' sex-combined growth curves by averaging the male and female growth curves from the sex-specific models. In addition, we estimated the SD and CV of each age from both data.

Length composition data from albacore fisheries in the North Pacific were provided to the ISC Albacore WG for the 2014 assessment, which were compared with the samples taken by the age studies mentioned above. In addition, the residuals of the fit to length composition data in the stock assessment model (SS3) (Methot Jr & Wetzel 2012) were also examined as an additional indicator of the L_{inf} parameter.

RESULTS

Estimated sex-specific and sex-combined growth curves based on data from Chen et al. (2012) and Wells et al. (2013) are shown in Figure 1. The male, female, and sex-combined growth curves based on the combined data from both studies are shown in Figure 2. Parameters of all growth models are shown in Table 2.

As shown in Table 1, the majority of samples from Chen et al. (2012) came from the WPO, with the sample size of CPO fish being smaller than WPO and EPO fish (Figure 3). The data from Wells et al. (2013) come from all 3 regions, although the majority came from the EPO. Spatio-temporal patterns were apparent in these data. Most of the largest fish from Wells et al. (2013) were collected in the CPO during 2010 (Figure 3).

The age-specific SD and CV from the Wells/Chen-sex-combined data are listed in Table 3. Age-1 data has a larger CV of 10%. The averaged CV is about 4%.

Most of the CPO samples of large fish from Wells et al. (2013) were either male or of unknown sex, with only 2 samples from large female fish. A peak in length compositions from commercial fisheries in the US deepset longline fishery was apparent at around 100 cm FL. However, a modal peak was apparent around 110 cm in the biological samples from Wells et al. (2013), with a higher proportion of fish around 120-130 cm (Figure 4).

Since there might have been time-varying growth, we compared the size of fish in the Wells et al. (2013) samples taken during 2010-2011, with the US deepset longline size compositions over the same period. In 2010, Wells et al. (2013) sampled predominantly from larger fish (120-130 cm) but smaller fish (90-100 cm) were sampled in 2011 (Figure 5).

DISCUSSION

Age and growth was identified as a key source of uncertainty in the previous stock assessment, with a substantial need for future research (ISC 2011). Data from Chen et al. (2012) and Wells et al. (2013) provide key new size-at-age information for the current assessment.

The oldest male in this study was 15 years old, and the oldest females were nearly 12 years old. The females sampled by Wells et al. (2013) were generally older than those of Chen et al. (2012). The opportunistic sampling by Wells et al. (2013) coupled with fitting a sex-combined growth curve may have resulted in a biased growth curve. The samples collected by Wells et al. (2013) in 2010 appeared to be of particularly large fish relative to the fishery catch and to those collected in 2011. Since larger fish appear to be disproportionately male (i.e., male albacore have a higher L_{inf}), these samples are likely male and limited samples with identified sex show that these samples were almost entirely male. Therefore, fitting to the entire dataset likely resulted in a male-biased growth curve resulting in a higher than expected L_{inf}.

The Stock Synthesis assessment model was fit to length composition catch data from the US deep-set longline fleet to look for patterns in the residuals, which can provide independent indications of L_{inf} and identify the presence of age-cohorts in catch data. Patterns of three or more continuous Pearson residuals greater than 1 cm FL appeared between size bins 116-118 and 118-120 cm FL from 2001-2003 (Figures A1 & A2). The L_{inf} implied by this pattern is consistent with that from the Wells/Chen-Male growth curve. Cohorts are also evident in the Japanese EPO longline length compositions. The first cohort appears around 1985 and the size of the largest fish stabilizes between 1992-1995, between the 118-120 and 120-122 cm FL size bins. A second cohort from the same fishery is also evident during 2000-2012, with the largest fish appearing at 2012 within the 114-116 cm FL bins (Figure A3). A cohort also appears in the Japanese large longline fleet between 1992-1996, with the largest fish falling in the 118-120 cm FL bin, and a mean falling within the 116-118 cm FL bin, which is comparable to the other two fleets (Figure A4).

In light of this information, several growth model alternatives should be considered by the ALBWG. The currently available data indicates that North Pacific albacore appear to exhibit sex- and region-specific growth. Firstly, the ALBWG should consider whether to use sex-specific growth models within the stock assessment model. Secondly, the ALBWG should consider whether to use the growth models based on the Chen et al. (2012) study or to use the growth models based on the combined Wells/Chen dataset. Alternatively, the ALBWG may also choose to estimate the growth parameters within the stock assessment model.

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TABLES

Table 1. Sample sizes collected by North Pacific sampling regions.

Study/Region	Female	Male	Unspecified	Total
Chen et al. 2012	125	148		273
Central	11	17		28
Western	114	131		245
Wells et al. 2013	34*	92*	360**	486
Central	15	62	65	142
Eastern			295	295
Western	19	30		49
Total	159	240	360	759

*All samples with sex were provided by Japanese longline.

**All samples through market were not sexed due to market restrictions.

Table 2. von Bertalanffy growth parameters from published studies, and analysis of combined data in this study.

Study	Data Source	Sex	Fitting Method	L_{inf} (cm)	K ($year^{-1}$)	t0	Abbreviation
Wells et al. 2013	Wells et al. 2013	Sex-combined	Fit to data	124.1	0.164	-2.239	Wells-published
Chen et al. 2012	Chen et al. 2012	Male	Fit to data	114.0	0.253	-1.01	Chen-Male
Chen et al. 2012	Chen et al. 2012	Female	Fit to data	103.5	0.340	-0.53	Chen-Female
This study	Chen et al. 2012	Sex-combined	Averaged*	108.4975	0.2922	-0.7683	Chen-Sex-combined
This study	Both	Male	Fit to data	119.1499	0.2077	-1.4530	Wells/Chen-Male
This study	Both	Female	Fit to data	106.5704	0.2976	-0.7627	Wells/Chen-Female
This study	Both	Sex-combined	Averaged*	112.3794	0.2483	-1.0979	Wells/Chen-Sex-combined

*Averaged between male and female growth curves.

Table 3. Mean length, SD and CV of Wells/Chen-Sex-combined data

Age	Mean Length(cm)	SD	CV
1	54.763	5.849	0.107
2	64.006	3.219	0.050
3	74.248	4.543	0.061
4	84.409	4.064	0.048
5	90.130	4.291	0.048
6	94.609	3.805	0.040
7	97.885	3.346	0.034
8	101.594	2.668	0.026
9	103.054	2.975	0.029
10	106.513	4.110	0.039
11	109.486	3.022	0.028
12	112.265	2.690	0.024
13	117.313	4.625	0.039
14	119.483	5.701	0.048
15	128.000	N/A	N/A
Mean			0.044
Median			0.039

FIGURES

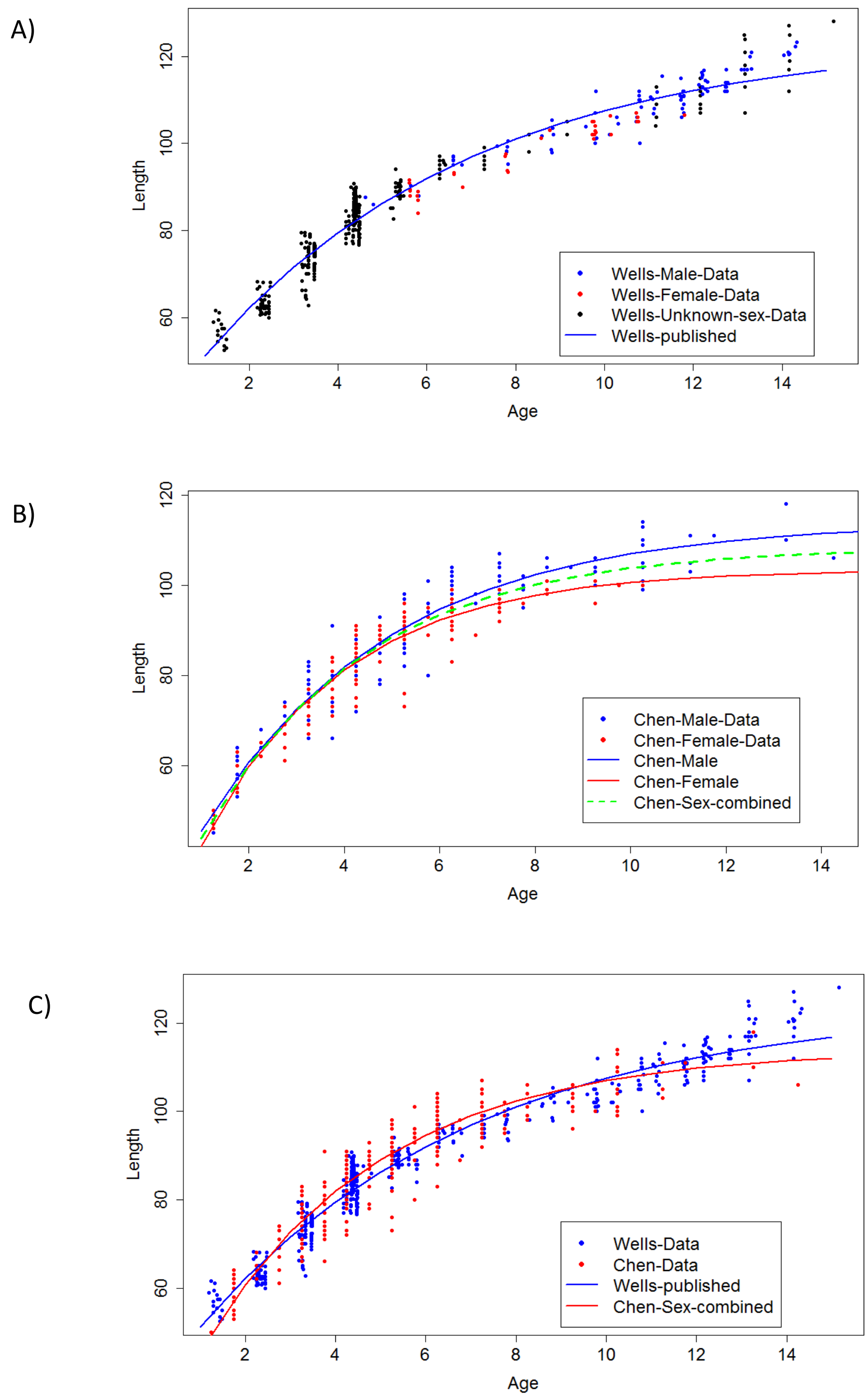


Figure 1. von Bertalanffy growth models fit to A) Wells et al. (2013), B) Chen et al. (2012) and C) each sex-combined dataset. Growth model parameters are listed in Table 1. Length in cms; age in years.

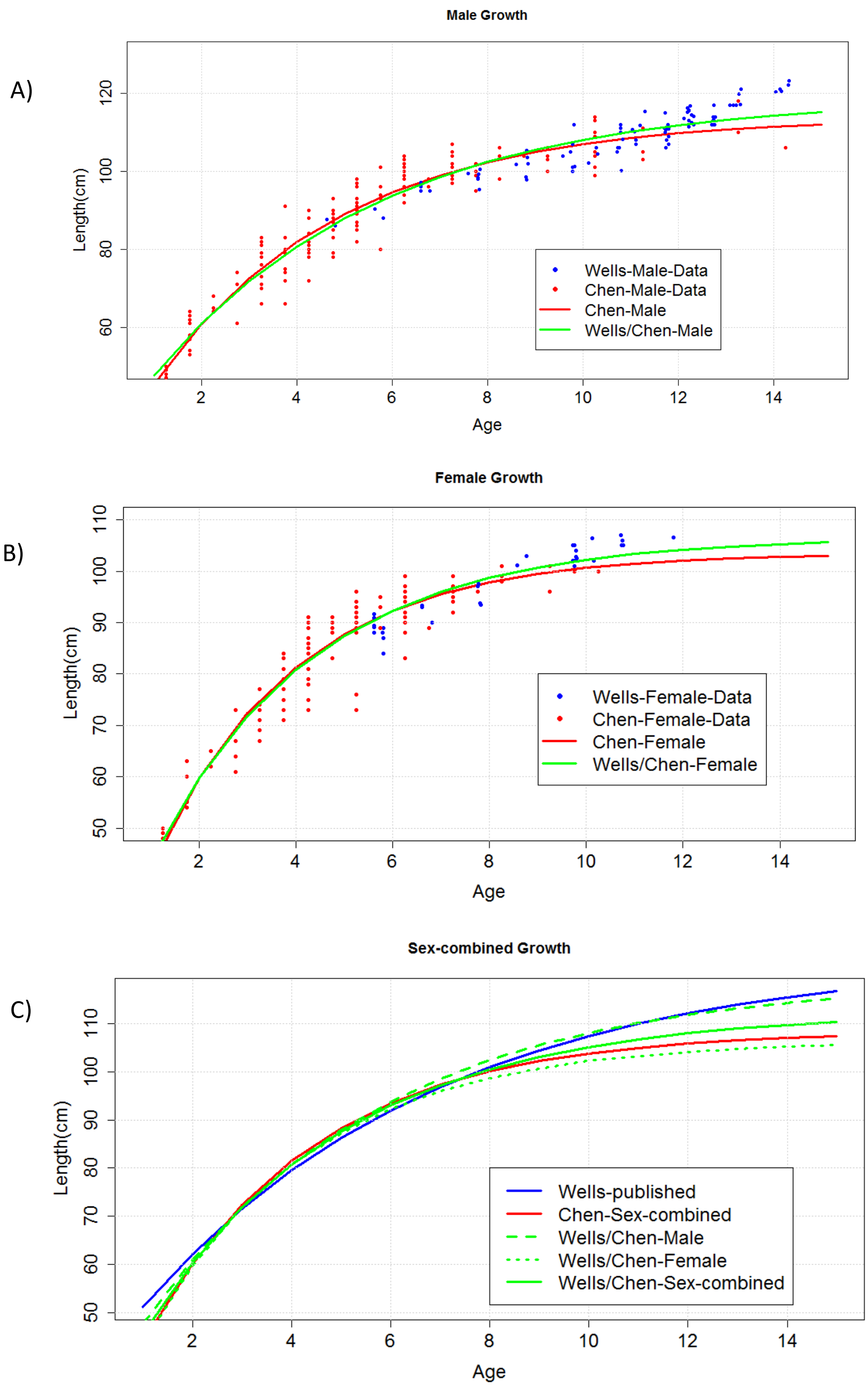
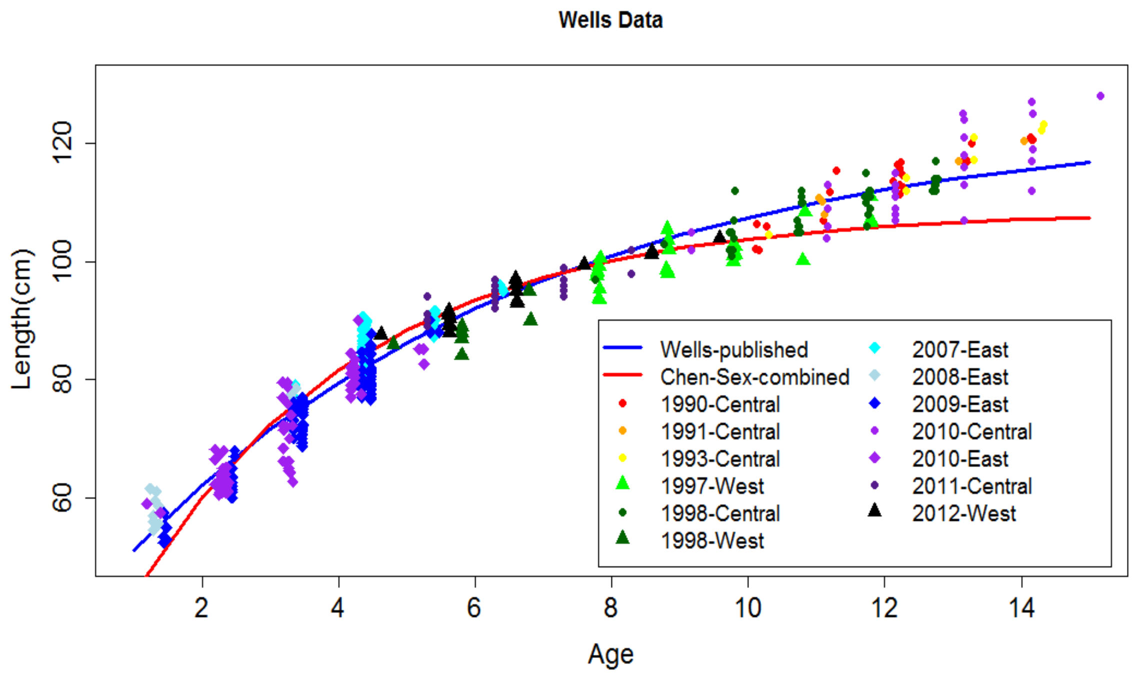


Figure 2. Sex-specific growth model for A) males from both studies, B) females from both studies, and C) sex-combined from both studies. Age in years.

A)



B)

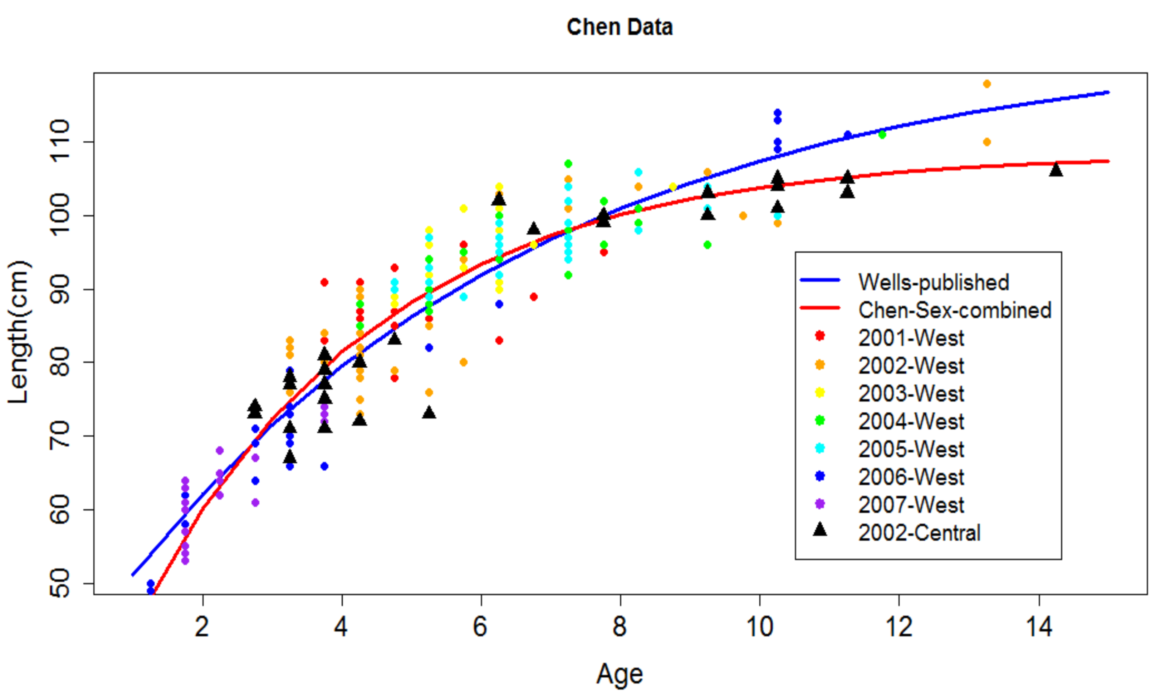


Figure 3. Comparison of A) Wells et al. (2013) and B) Chen et al. (2012) data by sampling year and region to curves fitted to Wells-published and Chen-Sex-combined curves. Age in years.

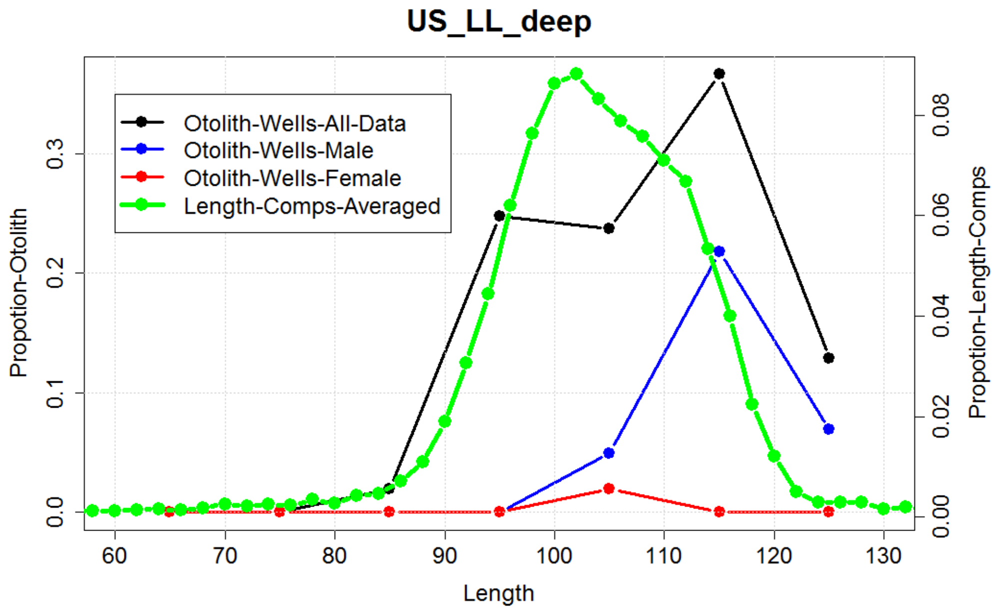


Figure 4. Comparison of proportion at length of biological samples taken by Wells from the US deep-set longline fleet and the length (cm) compositions from catches available from the same fleet for the ISC's North Pacific albacore stock assessment in 2014.

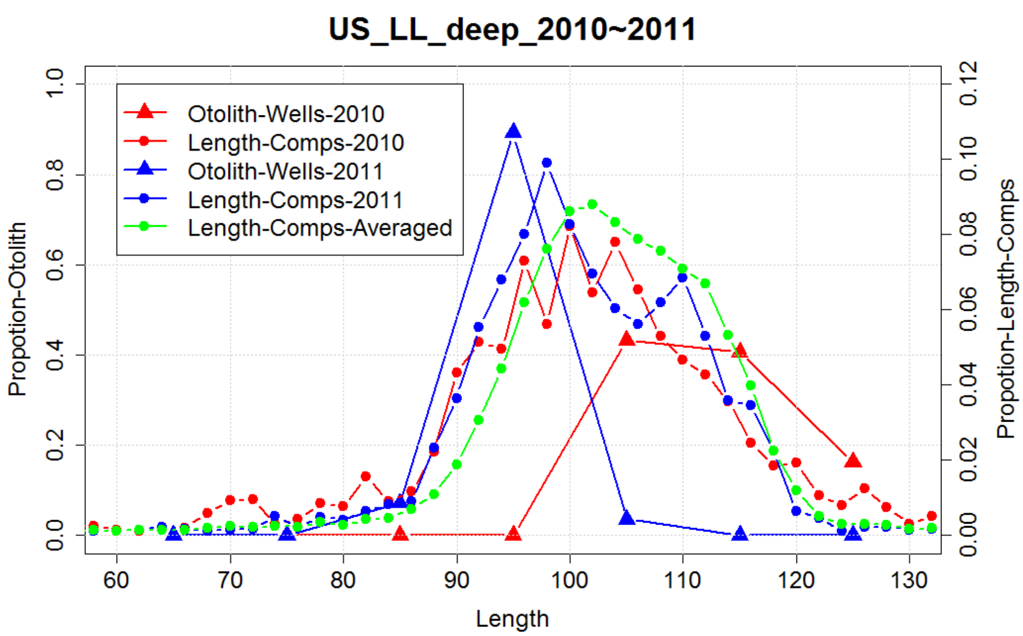


Figure5. Time-varying length (cm) compositions between biological samples from Wells and catch samples during 2010 and 2011.

APPENDIX

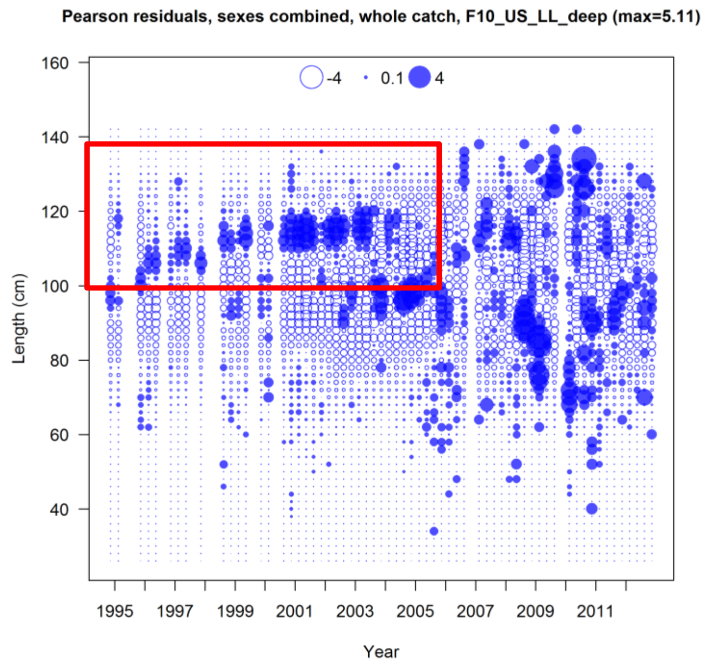


Figure A1. Pearson residuals from SS3 model fit to sex-combined catch from the US deep-set longline fleet.

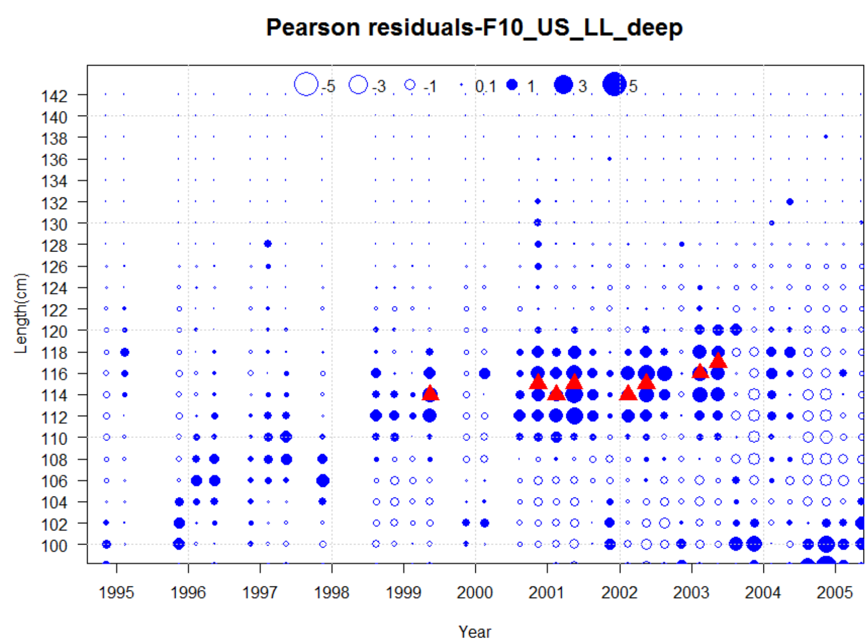


Figure A2. Pearson residuals from SS3 model fit to sex-combined catch from the US deep-set longline fleet. Red triangles depict patterns of three or more consecutive residuals equal to or greater than 1 cm.

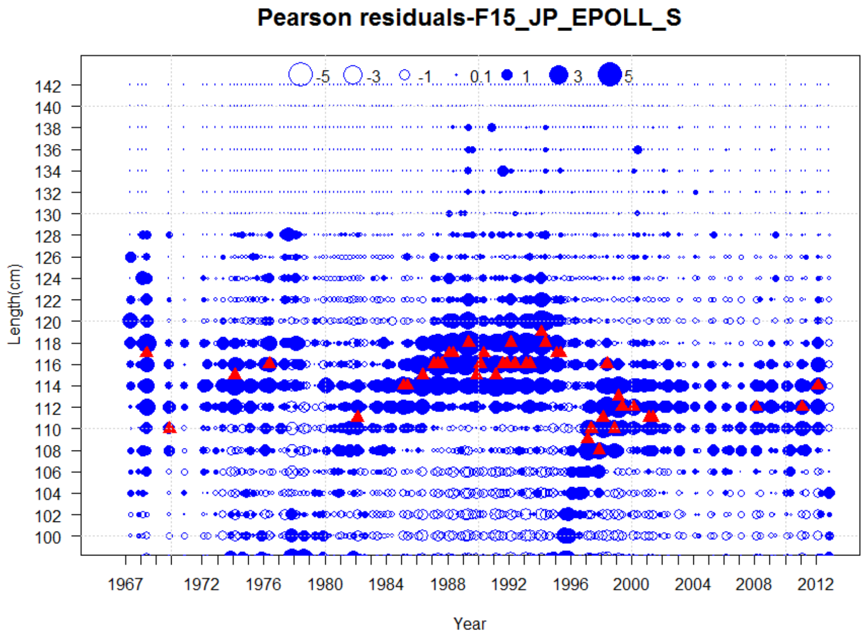


Figure A3. Pearson residuals from SS3 model fit to sex-combined catch from the Japanese EPO longline fleet. Red triangles depict patterns of three or more consecutive residuals equal to or greater than 1 cm.

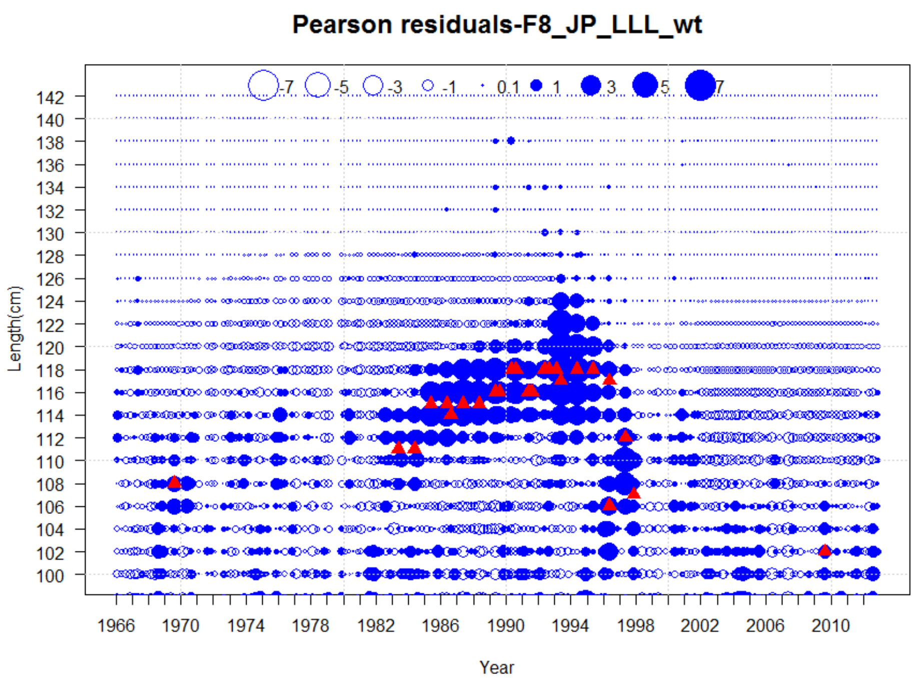


Figure A4. Pearson residuals from SS3 model fit to sex-combined catch from the Japanese large longline fleet. Red triangles depict patterns of three or more consecutive residuals equal to or greater than 1 cm.