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Ideas for future sampling programs of North Pacific albacore (*Thunnus alalunga*)[1]

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Abstract

Age and growth parameters have been identified as a key uncertainty in the albacore stock assessment. Addressing this uncertainty requires that additional samples be collected. Any new sampling program needs to be scientifically rigorous and to consider potential biases, resource requirements, logistics, and the questions being addressed. Three sampling programs are outlined here as options for future sampling, noting that these are not the only options: 1) age-stratified, 2) proportional, and 3) random. The current length-at-age data were analyzed to inform potential future sampling for both the proportional and age-stratified designs. Mean lengths-at-age were used to define appropriate length bins: 0-60 cm fork length (FL), 60-70 cm, 70-80 cm, 80-90 cm, 90-100 cm, 100-110 cm, and >110 cm. These length bins were used to determine the number of samples that need to be collected for an age-stratified sampling program. These options could be applied at various scales from one-time collection to annual, fleet-specific operational ageing. Current programs should be reviewed to leverage sampling already in place as a starting point prior to starting any new sampling program.

Introduction

The relationship between age and growth remains a key uncertainty for the North Pacific albacore stock assessment (ISC 2011, 2014, 2017). Based on the currently available age and growth data, the stock assessment is using the best available science (Xu et al. 2014, reviewed in James et al. 2020). However, the current length-at-age data have gaps in ages and sex information across regions, years, and fishing fleets (James et al. 2020). If these gaps are to be filled in, a well-designed sampling program is required to obtain the samples needed to improve the age and growth information to better inform future stock assessments. Any such sampling program should aim to address regional, temporal, and sex-specific differences, and ensure adequate sample sizes are collected.

One option to minimize the number of otoliths that need to be aged is the generation of an age-length key (ALK). An accurate ALK can be generated using as few as 10 fish aged per bin (Kritzer et al. 2001; Coggins et al. 2013). The ALK is then applied to 500-1000 measured (cm FL) fish (Coggins et al. 2013). The determination of appropriate bins to sample is of utmost importance as any overlap in length bins among ages will introduce bias to the ALK (Westrheim and Ricker 1978). Sampling with length-based bins biases the ages collected particularly when the bins have maximum quotas (Goodyear 1995; Gwinn et al.

2010). This will in turn bias the ALK or growth parameters derived from the data (Kimura 1977; Goodyear 1995; Gwinn et al. 2010; Coggins et al. 2013; Goodyear 2019). Since there is strong overlap of lengths among ages for North Pacific albacore (James et al. 2020) the sampling program should be designed to mitigate this bias to more accurately reflect the fished population. At this point no fishery-independent biological samples are available, therefore we can cannot know the magnitude that our fishery-dependent samples differ from the wild population.

Given that albacore exhibit sex-specific growth, future sampling programs will need to collect sex information (Chen et al. 2012; Xu et al. 2014; James et al. 2020). Sex determination at time of collection is often difficult as fish are gutted before landing. Methods to obtain the sex of each fish include purchasing the whole fish or using a genetic technique in development for albacore (Chiba et al. 2019; Suda et al. 2019; Craig and Hyde 2020). The latter would be an invaluable tool for collecting sex-specific information either dockside or through observer programs with just a fin clip.

Sampling programs to fill data gaps in age and growth parameters could take many forms from focused, one-time sampling to annual operational ageing. No matter the form, several factors need to be considered to create a scientifically rigorous plan including potential sampling biases, resource requirements, logistics of sampling, and the ultimate goal of the sampling. The objective of this working paper is to outline some potential sampling programs that would fill data-gaps and improve age and growth data for future North Pacific albacore stock assessments.

Materials and Methods

Three potential sampling program designs were explored in this working paper including age-stratified, proportional and random. The structure of both the age-stratified and proportional sampling programs was informed using the data from Chen et al. (2012) and Wells et al. (2013). The mean lengths-at-age (James et al. 2020) calculated from these datasets were used to define appropriate length bins. Ultimately, the determination of length bins was a balance of between the mean length-at-age and reduction of number of length bins to facilitate sampling.

For the age-stratified approach it is necessary to calculate the number of samples that need to be collected per length class which is used as a proxy for age during sampling. Ageing 10 fish per age class is sufficient to accurately generate an age-length key (ALK) (Kritzer et al. 2010; Coggins et al. 2013). To determine the number of fish that need to be collected in each length bin to achieve 10 fish in each age class, the age distribution in each 10 cm length bin was calculated, each percent multiplied by 10, and each length bin scaled by a multiplier so the sum of each age class was at least 10 (Figure 1). The number in each age class was summed by length bin. The number to be collected in each length bin was doubled (except when this was performed with sexes separate) to attain 10 fish of each sex in each age class (Figure 1). This assumed a collection sex ratio of 1:1.

Results

For both the age-stratified and proportional sampling programs the length bins were 0-60 cm, 60-70 cm, 70-80 cm, 80-90 cm, 90-100 cm, 100-110 cm, and 110+ cm (Figure 2). For the age-stratified program, the number of fish to collect in each length bin to achieve 10 fish of each sex in each age bin is shown in Table 1. The sample size is provided for sexes combined with fish of unknown sex, sexes combined without fish of unknown sex, and females and males separately. Sample numbers were also determined for each fishing fleet with sexes combined including fish of unknown sex (Table 2). For sexes combined scenarios a sex ratio of 1:1 was assumed. If sex cannot be determined during sample collection or the sex ratio is not 1:1 then the number of samples to be collected need to be increased so 10 of the less common sex (generally females at large size classes) would be successfully collected.

Some age classes required disproportionately high multipliers because they represented a very small percent of the sample. These age classes are not represented with 10 fish in Tables 1 and 2. Age 8 is represented with 8.6 samples for sexes combined without fish of unknown sex, 7.5 samples in the Taiwanese Longline, and 9 samples in the US deep Longline. Age 15 is represented by 0.6 samples for the sexes combined with fish of unknown sex and 1 sample in the US deep Longline fishery because only 1 fish was assigned an age of 15. Age 14 was represented by 8.4 samples for male sampling and 1.8 samples in the Taiwanese Longline. Age 11 is represented by 3.5 samples for female sampling as only 1 female was assigned this age.

Discussion

Future sampling should be statistically rigorous and consider potential sampling biases, resource requirements, sampling logistics, and define the ultimate goal of the sampling plan. Analyses on current age and growth data can be used to inform future sampling programs. Here we explore just three different sampling programs designs, 1) age-stratified, 2) proportional, and 3) random. The number of samples in each program represent the number of otoliths to be collected and aged.

The following sampling programs were developed as potential options. They can be instituted at different levels depending on available resources. At one level operational aging could be used to develop annual (or seasonal) and fleet-specific ALKs, if this level of detail is deemed necessary (for example, if albacore age-length keys vary over short/small durations of space and time) or they could be scaled back depending on the scientific need and resource availability. If age-length keys turn out to be non-variable over space and time, there is not a strong need for operational ageing. Given the broad range of albacore across the North Pacific, a population-wide understanding of age and growth will require multinational participation and implementation using standardized methods in a coordinated sampling program. A summary of some pros and cons of each of the three suggested sampling plans are available in Table 3.

Program 1 – Age-stratified sampling:

The objective of age-stratified sampling is to develop ALKs and improve length-at-age relationships, while avoiding biases introduced by length-based sampling. However, age-stratified sampling cannot be practically executed because length, but not age, are determined during sampling, therefore this program will sample length bins in proportion to ages. Sample sizes for each length bin reflect the number needed to have 10 samples of each age and each sex (Tables 1 and 2). For basin-wide sampling, if sex determination can be made at the time of sampling then the sampling plan with sexes separate should be used, however there was no difference between male and female length-at-age for ages 1-5 (James et al. 2020), therefore the sex-combined plan may be used for these ages (Table 1). If sex is determined after sampling (Chiba et al. 2019; Suda et al. 2019; Craig and Hyde 2020) then the sexes combined sampling plan must be used (Table 1). For fleet-specific sampling (Table 2), sex-specific sampling could also be used for some fleets, but others require more sex data, therefore sexes combined sampling by fishing fleet is presented here (Table 2).

Age-stratified sampling has a number of advantages. This program minimizes bias typically associated with length-based sampling. This sampling program is likely the least resource-intensive of the three programs described in this paper because at minimum 432 fish could be collected for the entire Pacific Ocean across different fishing fleets that have complementary size distributions. Additionally, this sampling program does not require close monitoring of fishery landings; sampling is not intended to represent landings. This program would be successful with participation of the fewer fishery components (e.g. flag, gear, area, season, year) than the other sampling programs. Fleet-specific sampling would generally be less than 432 fish each because most fishing fleets do not collect all age classes (Table 2). A scaled down version of age-stratified sampling could sample for a limited amount of time (e.g. several years or once every few years) or only 432 fish for the entire Pacific Ocean.

Program 2 – Proportional sampling:

The objective of proportional sampling is to develop ALKs described above through fishery-representative sampling of albacore. Every x^{th} fish in a length bin will be collected to represent a fixed percent of each fishery component. The value of x depends on the size of the fishery component and will likely vary between them to proportionally reflect albacore landings. The total number of fish collected could be altered depending on available resources. There will be no maximum bin quotas as this is known to bias an ALK and growth parameters (Kimura 1977; Goodyear 1995; Gwinn et al. 2010; Coggins et al. 2013; Goodyear 2019). The length bins defined above would be used.

Of the three programs described in this paper, this method is the most straightforward to implement in practice. Depending on the magnitude of sampling effort, the resources required to run this program would vary, but landings have to be closely monitored to ensure every x^{th} fish is being sampled. The resources required could be very high if sampling sought to accurately represent each fishery component throughout a year. This program would benefit from the ALBWG prioritizing certain fishery components. Proportional sampling will, however, introduce the most bias into ALKs, as it is based on length bins. Scaled down versions of proportional sampling could include sampling a limited number of fishery components, or sampling for a limited amount of time (e.g. several years, once every few years, etc.).

Program 3 – Random sampling:

The objective of a random sampling program is to obtain a representative sample of the sex- and age-distribution caught by a particular fishery component. The goal would be to collect and age a fixed percent of fish from each fishery component. This percent could be altered to reflect available resources. This method of sampling circumvents bias from sampling using length bins by being a random sample of landed albacore. This sampling program does not use length bins. This program could be executed by generating a list of random numbers for sampling sequentially as fish are landed. The span of numbers to be covered (e.g. 1000, 5000) would depend on an average number of landings for each fishery component or a reasonable, predesignated percent of the total landings for each fishery component.

This method would result in fleet- and sex-specific age distributions that would be less likely to have bias. However, it is also likely that this sampling program would require the most resources (time and money) if it is to accurately represent each fishery component throughout a year. Each fish landed would have to be counted to apply the list of random numbers. Given that resources are often limiting for full-scale random sampling, some options to scale down this sampling program are: prioritizing certain fishery components for this sampling program, or the sampling could occur for a limited amount of time (e.g. several years, once every few years, etc.).

Thoughts on Choosing a Sampling Program

One key consideration in deciding on a sampling plan is resource availability. If sufficient resources were available, operational ageing with annual and fleet-specific sampling would be the most comprehensive option for future sampling. Each of these three programs could be executed at the operational ageing level. However, one major benefit of operational ageing is if the age composition of the fishery and/or stock is changing over short temporal and/or spatial scales. If this is not true for albacore, then operational ageing will not yield much additional information beyond a reduced sampling program such as sampling once every few years, or for a few years at a time then stopping. Since resources are likely limiting, the sampling plan that requires the fewest samples collected from the fewest fishery components is the age-stratified program. This plan also introduces less bias than the proportional sampling program. This can be executed on an ocean-wide basis, or by fishery component.

As we contemplate sampling program options, it is worth determining how the existing sampling in the North Pacific could be built-upon to reach the magnitude and scientific rigor of one of these suggested programs. In the eastern North Pacific, the Southwest Fisheries Science Center (SWFSC) has partnered with industry to sample albacore landed in the eastern Pacific Ocean surface fishery. SWFSC has been collecting these samples since 2009 and otoliths from 2009 and 2010 were included in Wells et al. (2013). These fish are a nonrandom sample as they are collected by members of industry during normal fishing operations and average 50 samples a year. The samples are part of ongoing albacore life history research. Scaling up this sampling would require additional funds, and additional staff time and resources to process and analyze samples.

To improve the North Pacific albacore stock assessment, additional information is needed on sex- and region-specific length-at-age. The available information and past sampling regimes were not systematically coordinated across the Pacific Ocean or between fleets and consequently do not provide the information to address these questions (James et al. 2020). As we move forward, any sampling program, including those suggested above, would benefit from a coordinated effort among different countries and fisheries.

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Table 1. Number of samples to be collected in each length bin for an ocean-wide age-stratified sampling program. Depending on the ability to determine sex during sampling or post-sampling use the sex-specific sampling or the sexes combined, respectively.

Length Bin (cm FL)	Sexes Combined w/unknowns	Sexes Combined w/o unknowns	Females	Males
> 60	15	0	7	0
60-70	30	50	15	30
70-80	20	20	10	10
80-90	20	20	10	10
90-100	41	40	35	20
100-110	178	120	70	71
> 110	120	182		71
Total	424	432	147	212

Table 2. Number of samples to be collected in each length bin for an age-stratified sampling program for each fishing fleet. These are the fishing fleets that are represented in the current age and growth data from Chen et al. (2012) and Wells et al. (2013): Japanese Pole and Line (JPN PL), eastern Pacific Ocean Surface Fishery (EPO SF), Taiwanese Longline (TW LL), US deep longline (US LL), and Japanese Longline (JPN LL). These are only displayed with sexes combined and do include fish of unknown sex.

Length Bin (cm FL)	JPN PL	EPO SF	TW LL	US LL	JPN LL
> 60	0	19	12		
60-70	45	30	60		
70-80	20	20	20		
80-90		20	20	0	100
90-100		100	60	200	50
100-110			120	240	101
> 110			100	100	50
Total	65	189	392	540	301

Table 3. Pros and cons of each of three proposed sampling programs.

Sampling Program	Introduce age bias into assessment	Sampling of albacore is representative of…	Total resources required
Age-stratified	Likely No	Age	Least
Proportional	Likely Yes	Fishery	Variable
Random	Likely No	Fishery	Most

Length bin (cm FL)	Number of fish aged in each length bin	Age 1	2	3
0-60	24	24		
60-70	17	9	8	
70-80	3			3

Number of fish in each age class and length bin

Length bin (cm FL)	Number of fish aged in each length bin	Age 1	2	3
0-60	24	1.00		
60-70	17	0.53	0.47	
70-80	3			1.00

Percent of fish in each age class and length bin

Length bin (cm FL)	Number of fish aged in each length bin	Age 1	2	3
0-60	24	10.00		
60-70	17	5.30	4.70	
70-80	3			10.00
	Total	**15.30**	**4.70**	**10.00**

Percent of fish multiplied by 10 in each age class and length bin and summed in each age class

Determine and apply a multiplier to each length bin that would sample at least 10 fish in each age class. Sum across age classes for each length bin. Finally multiply the sum by 2 for the total number to be collected. This accounts for 10 males and 10 females in each age class (assuming a 1:1 sex ratio).

Length bin (cm FL)	Number of fish aged in each length bin	Age 1	2	3	Multiplier	Sum of each length bin	Total number to be collected
0-60	24	0.00			0	0.00	0
60-70	17	11.93	10.58		2.25	22.50	45
70-80	3			10.00	1	10.00	20
	Total	**11.93**	**10.58**	**10.00**			**65**

Figure 1. Method description of the determination of the total number to sample in each length bin for the age-stratified sampling program. The example is the Japanese Pole and Line fishery with sexes combined.

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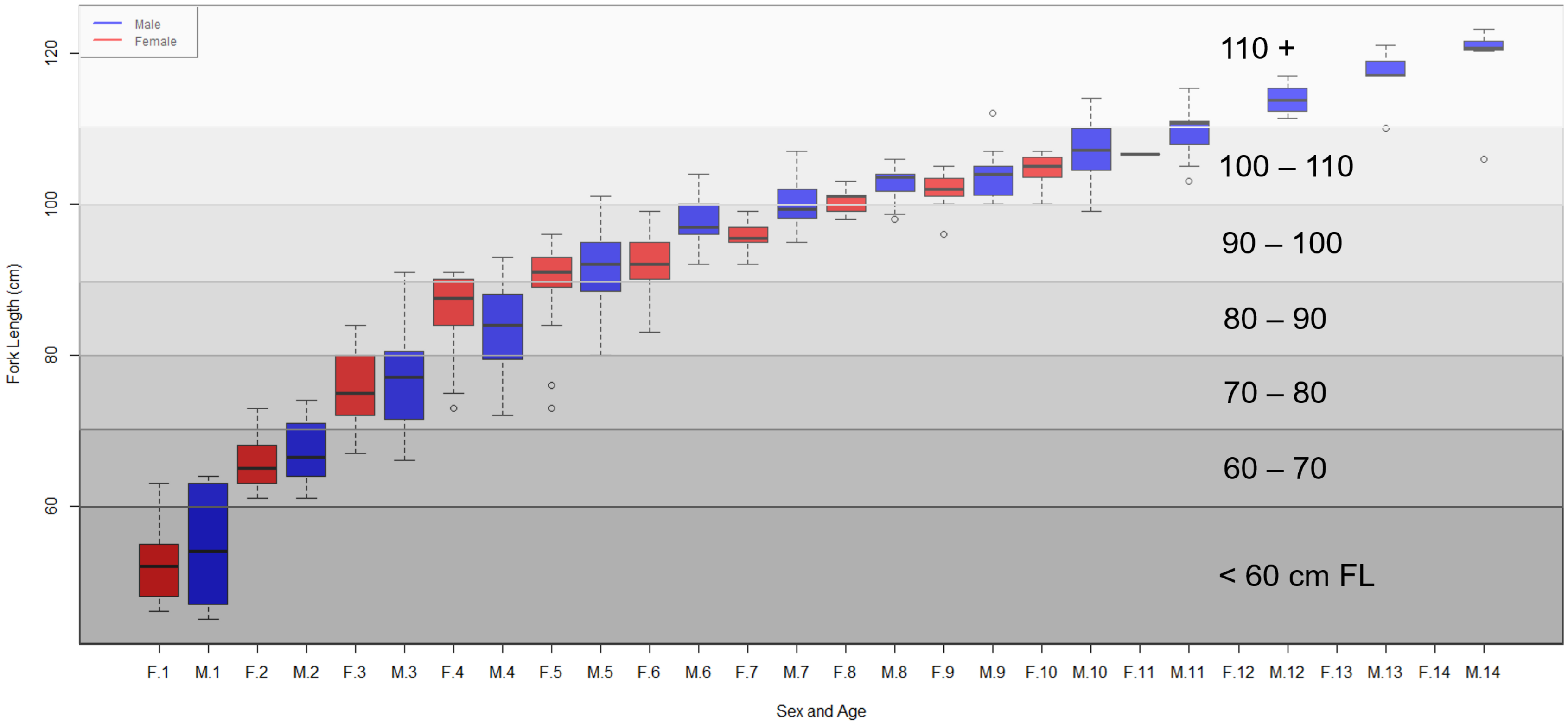

Figure 2. Boxplot of female and male mean length-at-age from James et al. (2020) with length bins overlaid in shades of gray.