NPFC-2021-SSC BFME02-WP01

Small Working Group on NPA and SA - Summary for 2021

The Small Working Group on NPA and SA (SWG NPA-SA) met four times during 2021. The group was tasked with eight items:

1. Review available data for stock assessment, examining data quality and sharing data for NPA and SA.
2. Formulate TORs for stock assessment for NPA and SA, and potentially for adaptive management of SA
3. Review and recommend data-limited stock assessment methods for NPA and SA
4. Decide who (one Member / all Members / an external consultant) will conduct the stock assessments if possible
5. Discuss plans determining stock status and potentially for rebuilding stocks
6. Discuss environmental factors affecting abundance and recruitment
7. Develop plans for holding a workshop with other RFMOs managing stocks of NPA, SA and other related species, possibly under the framework of the FAO Deep Sea Fisheries Project
8. Revise (NPA) or develop (SA) species summary document

Item 1. Appendix 1 contains the data availability table developed by the SWG.

Item 2. The terms of reference for Data Limited Approach to Stock Assessment for NPA and SA were developed. Terms of reference were not developed for adaptive management of SA. The Terms of Reference for a Data Limited Approach to Stock Assessment for NPA and SA are:

1. The same initial approach to data, analysis and assessment will be used for both North Pacific Armorhead and Splendid Alfonsino

2. Given the limited data available to assess NPA and SA a data limited approach that utilizes life-history information (size, maturity and age data) will be explored to generate population status for the two species
3. The SWG NPA and SA members will collaborate on the analyses
4. All members with bottom fish fisheries will contribute any available data on size, maturity and age of NPA and SA in accordance with the data sharing protocols and in the format provided in the accompanying table
5. The provided data will be used for the data-limited approach to NPA and SA stock assessment and will not be shared, distributed or used for other purposes without the consent of the data provider

Item 3. A review of the potential data limited approaches was provided to the group in a written report from Dr. Merrill Rudd (presented by Canada to the group). There were discussions around this topic that served as the basis for the approach described in the Terms of Reference above. The report can be found in Appendix 2.

Item 4. It was decided that the Small Working Group participants (and other interested participants) would conduct the initial stock assessment (with leadership from Japan) as indicated in the terms of reference.

Item 5. After discussion it was decided that the decisions about rebuilding and stock status would be addressed after the data limited stock assessments were completed.

Item 6. An analysis of the relationship between environmental covariates and recruitment for NPA was presented and discussed by the SWG. A summary of the analysis can be found in NPFC-2021-

SSC BFME02-WP02. The paper looked at relationships between recruitment and large (basin) scale factors, such as the Pacific Decadal Oscillation and the Arctic Oscillation and local-scale factors, such as the sea surface temperature experienced by eggs and larvae predicted by Lagrangian drift with surface currents. An attempt was made to incorporate these indices into a stock-recruit model, however these were determined to be not useful, as the number of degrees of freedom of the model was quite low and the credible intervals around predicted recruitment was very large.

Item 7. The group discussed the question of having a workshop on the assessment of bottom fish species with other RFMOs and what the priority for this would be, given the timeline of FAO. In general, it was agreed that this workshop would be useful, but may be a lower priority than some of the other work that the group is currently addressing. It was agreed since the workshop was a good idea, but a low priority that we would look for opportunities to do this in the future and consider them.

Item 8. Species Summary documents for NPA and SA were developed, reviewed and additional comments provided inter-sessionally. These comments were incorporated into the final documents, presented under Agenda Items 3.4.2 and 4.2.2 of SSC BF-ME02.

Appendixes:

Appendix 1 – Data availability for SWG NPA-SA

Appendix 2 – Potential Data-Limited Approaches to North Pacific Armorhead and Splendid Alfonsino Stock Assessment in the North Pacific

Appendix 1

Data availability for SWG NPA-SA

North Pacific Armorhead

Category and data sources	Description (including spatial or temporal resolution, if possible)	Years with available data	Average sample size/ year or data coverage	Potential issues to be reviewed
Japan				
Catch statistics				
Trawl Catch - Japan	Annual catch	1969-present	100% coverage	
Gillnet Catch - Japan	Annual catch	1990-present	100% coverage	
Trawl Catch - Korea	Official statistics, reports from annual report	Official statistics: 2004-2019	100% coverage	Catches are collected by electronic reporting system since 2015. Catches before 2015 are from the fishing catch provided by the fishery company
Trawl Fishery - Russia	Official statistics, scientific surveys, observer data	1970-1987; 1997; 2001-2002; 2005-2006; 2011; 2013	100% coverage	Data coverage details to be reviewed
Size, age, composition data				

Length and body depth measurements, Fishery (gillnet and trawl) - Japan	Scientific observer data	June 2009-present-	ca. 11,000 fish per year	Protocol revised (see NPFC-2018-SSC BF01-WP03)
Length and body depth measurements, Survey (trawl) - Japan	Monitoring survey data	2019-present	ca. 800 fish per year	
Length and body depth measurements - Japan	Laboratory measurement data (observer sample, monitoring sample, on-board survey sample, R/V Kaiyo-maru sample)	2012-present	ca. 1,200 fish per year	
Length measurements, Fishery (trawl) – Korea	Measured by observers while onboard	2013-2019	80-1600 fish/year	Data coverage review
Length measurements - Russia	scientific surveys, observer data	1970-1987; 1997; 2011; 2013	Coverage=100%	Data coverage details to be reviewed
Body depth measurements - Russia	scientific surveys, observer data	1970-1987; 1997; 2011; 2013	Coverage=100%	Data coverage details to be reviewed
Aging - Japan	NA			A preliminary daily ring analysis for ca. 300 fish
Aging - Korea	Samples by observers	2013-2019	80-300 fish/year	Details to be reviewed
Catch at age (CAA) - Korea	Estimate CAA from the above data	2013-2019	Age-length key are to be developed	
Maturity - Japan	Gonad mass/ GSI (Observer sample measured in the laboratory)	2013-present	ca. 1,200 fish per year	

Maturity - Japan	Maturity stage from histological analysis (Observer sample analyzed in the laboratory)	2017, 2019	ca. 60 fish per year	
Maturity - Korea	Maturity measured by observers	2013-2019	80-300 fish/year	Data coverage review
Sex and maturity – Russia	scientific surveys, observer data Maturity stage, sex (gender) composition.	1970-1987; 1997; 2011; 2013	Coverage=100%	Data coverage details to be reviewed
Abundance indices (survey)				
Catch data, trawl - Japan	Monitoring survey data	2019-present	16 tows in 2019, 4 tows in 2020	Preliminary surveys in 2018 not included
Effort data, trawl - Japan	Monitoring survey data	2019-present	16 tows in 2019, 4 tows in 2020	Preliminary surveys in 2018 not included
Catch data - Russia Effort data - Russia	scientific surveys, observer data	1970-1987; 1997;		Data coverage details to be reviewed
Abundance indices (commercial)				
Catch data, trawl - Japan	Scientific observer data, shot-by-shot	June 2009-present	100% coverage	Possible impact by misreporting (NPFC-2018-TCC03-Final Report)

Effort data, trawl – Japan	Scientific observer data, shot-by-shot	June 2009-present	100% coverage	
Catch data, gillnet - Japan	Scientific observer data, shot-by-shot	2018-present	100% coverage	
Catch data, gillnet - Japan	Scientific observer data, daily	June 2009-2017	100% coverage	
Effort data, gillnet - Japan	Scientific observer data, shot-by-shot	June 2009-present	100% coverage	
Catch data, trawl - Japan	Logbook data, daily	1970-present	100% coverage since 1992, uncertain in older period	Digitization of old (before 1989) data has not been completed
Effort data, trawl - Japan	Logbook data, daily	1970-present	100% coverage since 1992, uncertain in older period	Digitization of old (before 1989) data has not been completed
Catch data, gillnet - Japan	Logbook data, daily	2008-present	100% coverage	
Effort data, gillnet - Japan	Logbook data, daily	2008-present	100% coverage	
Trawl - Korea	Log book data available	2013-2019	Coverage =100%	One fishing vessel. Standardization?
Catch data, gear 1 - Russia Effort data, gear 1 - Russia	Official statistics, observer data	2001-2002; 2005-2006; 2011; 2013		Data coverage details to be reviewed

Splendid Alfonsino

Category and data sources	Description (including spatial or temporal resolution, if possible)	Years with available data	Average sample size/ year or data coverage	Potential issues to be reviewed
Japan				
Catch statistics				
Trawl - Japan	Annual catch	1969 to present	100% coverage	
Gillnet - Japan	Annual catch	1990 to present	100% coverage	
Trawl - Korea	Official statistics, reports from annual report	Official statistics: 2004-2019	Coverage=100%	Catches are collected by electronic reporting system since 2015. Catches before 2015 are from the fishing catch provided by the fishery company
Trawl Fishery - Russia Fishery B	Official statistics, scientific surveys, observer data	1969-1988; 2002; 2005; 2006; 2010; 2011; 2013; 2019	Coverage=100%	Data coverage details to be reviewed
Size, age, composition data				

Length measurements - Japan	Scientific observer data using punch cards	June 2009 to present-	ca. 37,000 fish pr year	see NPFC-2018-SSC BF01-WP03 Appendix
Length measurements - Japan	Monitoring survey data	2019	ca. 400 fish	SA not caught in 2020 monitoring surveys
Length measurements - Japan	Laboratory measurement data (observer sample, monitoring sample, on-board survey sample, R/V Kaiyo-maru sample)	2013 to present	ca. 1,400 fish per year	
Length measurements - Korea	Measured by observers while onboard	2013-2019	10-2000 fish/year	Data coverage review
Length measurements - Russia	scientific surveys, observer data	1969-1988; 2010; 2011; 2013; 2019	Coverage=100%	Data coverage details to be reviewed
Aging - Japan	Otolith annual rings (Observer and other samples analyzed in the laboratory)	2013 to present	ca. 900 fish per year	Need to correct the difference in reading protocols
Aging - Korea	Samples by observers	2013-2017, 2019	10-380 fish/year	Details to be reviewed
Catch at age (CAA) - Japan	NA			CAA can be estimated by creating age-length key from aging data
Catch at age (CAA) - Korea	Estimate CAA from the above data	2013-2017, 2019	Age-length key are to be developed	
Maturity - Japan	Gonad mass/ GSI (Observer sample measured in the laboratory)	2013 to present	ca 1,400 fish per year	

Maturity - Japan	Maturity stage from histological analysis (Observer and other samples analyzed in the laboratory)	2017 to present	ca. 45 fish per year	
Maturity - Korea	Maturity measured by observers	2013-2017, 2019	10-2000 fish/year	Data coverage review
Sex and maturity – Russia	scientific surveys, observer data Maturity stage, sex (gender) composition.	1969-1988; 2010; 2011; 2013; 2019	Coverage=100%	Data coverage details to be reviewed
Abundance indices (survey)				
Catch data - Japan	Monitoring survey data	2019 to present	16 tows in 2019, 4 tows in 2020	0 catch of SA in 2020 monitoring surveys Preliminary surveys in 2018 not included
Effort data - Japan	Monitoring survey data	2019 to present	16 tows in 2019, 4 tows in 2020	0 catch of SA in 2020 monitoring surveys Preliminary surveys in 2018 not included
Catch data - Russia Effort data - Russia	scientific surveys, observer data	1969-1988; 2010; 2019	Coverage=100%	Data coverage details to be reviewed
Abundance indices (commercial)				
Catch data, trawl - Japan	Scientific observer data, shot-by-shot	June 2009 to present	100% coverage	Possible impact by misreporting (NPFC-2018-TCC03-Final Report)

Effort data, trawl – Japan	Scientific observer data, shot-by-shot	June 2009 to present	100% coverage	
Catch data, gillnet - Japan	Scientific observer data, shot-by-shot	2018 to present	100% coverage	
Catch data, gillnet - Japan	Scientific observer data, daily	June 2009 to 2017	100% coverage	
Effort data, gillnet – Japan	Scientific observer data, shot-by-shot	June 2009 to present	100% coverage	
Catch data, trawl – Japan	Logbook data, daily	1970-present	100% coverage since 1992, uncertain in older period	Digitization of old (to 1988) data has not been completed
Effort data, trawl – Japan	Logbook data, daily	1970-present	100% coverage since 1992, uncertain in older period	Digitization of old (before 1989) data has not been completed
Catch data, gillnet - Japan	Logbook data, daily	2008-present	100% coverage	
Effort data, gillnet - Japan	Logbook data, daily	2008-present	100% coverage	
Trawl – Korea	Log book data available	2013-2019	Coverage=100%	One fishing vessel. Standardization?

Appendix 2

Potential Data-Limited Approaches to North Pacific Armorhead and Splendid Alfonsino Stock Assessment in the North Pacific

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3 March 2021

1. Introduction

North Pacific Armorhead (NPA) and Splendid Alfonsino (SA) are captured by Japanese, Korean, and Russian bottom trawl and bottom gillnet fisheries in the North Pacific Ocean Emperor Seamounts. These fisheries in international waters are managed by the North Pacific Fisheries Commission (NPFC), a Regional Fisheries Management Organization (RFMO). NPA and SA are NPFC priority species and have shown signs of overharvest via recruitment overfishing and declining catches over the last few decades. However, there is no estimate of stock status to guide a sustainable harvest.

Phase I of this project was to identify data availability and data gaps from existing sources such as literature, approaches of other RFMOs, and historic catch and effort and biomass survey data from Japanese, Korean, and USA sources. This work was completed and delivered as a report by the U.S. and Canada to the NPFC Science Committee in November 2020.

This report addresses Phase II of this project. The objective of Phase II is to identify approaches that could be taken to address sustainability for NPA and SA stocks. This report evaluates the data available for analysis, identifies data gaps directly related to stock assessment analyses, reviews previously documented research, and identifies major sources of uncertainty to identify data-limited approaches to stock assessment that could be applied for NPA and SA to bring them in to compliance with a precautionary approach to management.

2. Data available

2.1. Shared datasets

2.1.1. Catch and effort time series

The literature review from Phase I of this project reported a total catch and effort time series for North Pacific Armorhead and Splendid Alfonsino on the Emperor Seamounts from 1967 to 2019. The early portion of the time series represents the start of commercial fishing on NPA with the initiation of the Russian trawl fishery in 1967. Data prior to 2001 is held by Members (Russia and Japan). Recent data starting in 2001 is reported to the NPFC by gear type and Member (Japan, Korea, and Russia). Spatially-explicit catch and effort data by seamount and gear is reported to NPFC from 2017-2019. Seamount where gear was deployed by Japanese fleets (lacking specific catch and effort statistics) is available from 1969-2001.

Catch data from 1969 are described in Nishimura and Yatsu (2008), which describes a surplus production model for Splendid Alfonsino on the Southern Emperor-Northern Hawaiian Ridge (SE-NHR). However, catch and effort data for NPA and SA on the SE-NHR come from the same datasets as they are caught together in bottom trawl, longline, and gillnet fisheries. The dominant catch has been SA, but NPA abruptly increases in years of high recruitment. Variable targeting depending on NPA recruitment leads to issues calculating CPUE for both species.

Data sources

a) 1967-2001: Total catch (tons) and effort (number of hours fished) from the Japanese and Russian bottom trawl fishery (data held by Japan and Russia)

    i) Reported catch (thousand tonnes) for North Pacific deepwater fisheries 1968-1977 with amount for NPA and % bycatch species in Shotton (2016), Table 19

b) 1967-2001: Seamount where gear was deployed (data held by Japan)

c) 2001-2019: Total catch and effort (number of fishing days, number of vessels) for the Russian longline and bottom trawl fleets (reported to NPFC)

d) 2002-2019: Total catch and effort (number of fishing days, number of vessels) for the Japanese gillnet and bottom trawl fleets (reported to NPFC)

e) 2004-2019: Total catch and effort (number of fishing days, number of vessels) for the Korean longline and bottom trawl fleets (reported to NPFC)

f) 2017-2019: Total catch and effort by seamount by gear by Member (reported to NPFC)

Potential uses for these data

In general, total catch is informative of the scale of the population, particularly when considered alongside other data types that would inform population productivity. For example, if catch is consistently under-estimated, population models will under-estimate the amount of harvest the population could sustain given productivity estimates from sources that inform rates of change. Catch data alone do not provide information on population changes, since catch may be influenced by fishers' decisions on where to fish unrelated to species availability (e.g. management or safety concerns, dynamics of other target species, etc.). Combined with some measure of fishing effort or fishery-independent surveys, catch data may be useful to understand population size and distribution.

Effort data paired with catch data, however, provides information on stock productivity. In its simplest form, catch-per-unit effort (CPUE) serves as a better indicator of stock abundance (i.e. an abundance index) than catch alone because there is important information on the amount of effort that was exerted to catch the reported amount. For example, a small amount of catch may have occurred because there was a small amount of fishing for the target species in a particular area or month, and thus the low catch was not necessarily indicative of lack of presence. However, CPUE must still be used with caution as fishing distribution is not random, but targets areas known to be efficient fishing grounds for the target species. In this case, CPUE may not be proportional to catchability and CPUE may remain high while the stock is actually contracting in space over time. Furthermore, technological advances or changes in gear type would change catchability over time, further influencing CPUE as an accurate abundance index. CPUE standardisation may be used to account for observation error in CPUE by month, area, fishing vessel, or other relevant factors, but would still be hindered by changes in catchability over time. In the case of NPA, CPUE is the primary data available that could be used to assess stock status.

A CPUE index may be used in indicator approaches, of which there are various types. Indicator approaches are often used to combine "quasi-assessments" with management action, assuming the indicator is representative of the state of the stock in some way (see Section 4.3.2). In a data-limited case, CPUE may be used as an indicator of abundance. Standardized CPUE could be used as a single indicator or in a multiple indicator framework such as a hierarchical decision tree. CPUE could be standardized across the multiple fleets, gear types, and seamounts that characterize the NPA stock and attempt to account for confounding variables to decouple the relationship between CPUE and abundance. However, the relationship between CPUE and abundance is more difficult to decouple with variable targeting of the species over space and time.

The catch and effort data could also be used to determine species composition, and interesting patterns that could work in an indicator approach. For example, catch of NPA and SA, as well as other species caught in bottom trawl, gillnets, and longline, are available from Members during the early years and during years where catch and effort data are reported to the NPFC. Years with high NPA recruitment had lower SA catches, and vice versa. Sawada et al. (2017) used various methods for standardising CPUE in the multispecies context of the Emperor Seamounts bottom fisheries, using standardised CPUE as a multispecies indicator. The resulting directed CPUE indices could be used in species-specific model-based assessments, and the CPUE indices for each species could be used as species-specific abundance indicators or together when considering ecosystem-level changes in abundance over time. The methods of Sawada et al. (2017) for directed CPUE series seem useful moving forward for multi-species CPUE standardisation and for use as abundance indices in a variety of contexts. Nishimura and Yatsu (2008) ran surplus production models for SA using unadjusted and adjusted CPUE abundance indices based on Japanese catch and effort data, where the adjusted series assumed SA annual catch aggregated across seamounts was proportional to log-transformed ratio of SA catch to aggregated SA and NPA catch due to differential depth ranges of the two species.

Catch-only data-limited assessment methods typically require catch from the start of fishing, some additional biological information, and priors on relative stock status at a specific point in time. Catch-only methods are highly uncertain in estimating stock status and often deemed unreliable due to the sensitivity to accurate inputs. In some cases, catch-only methods may be the best available science for informing mandated catch limits when no other data types are available to inform stock productivity. Due to the availability of reliable effort data paired with removal data and the highly variable recruitment patterns of NPA, we would likely not consider any catch-only methods for these stocks unless it was in comparison to another approach that includes the CPUE index.

Catch and effort data by seamount may be particularly useful to estimate population size in different fishing areas, assuming the populations at each seamount are closed (negligible movement of demersal NPA between seamounts) and that catch and effort data are available throughout the fishing season. Given the unique life history of NPA leading to highly variable recruitment to seamounts assumed to be independent of current spawning biomass at seamounts and the catch and effort data available by seamount, depletion analysis is a good candidate as a stock assessment approach given the outputs meet the management goals. Depletion analysis is particularly useful for species with rapid growth rates, short life-spans, little generational overlap, and weak or no stock-recruitment relationships. The key assumptions of depletion analysis are high steepness, a closed population, and no within-season natural mortality. Depletion analysis regresses CPUE against cumulative catch through the season, where the slope of the regression estimates catchability. Depletion analysis estimates biomass at the start of the season, and could be used to limit the season or total catch. Somerton and Kikkawa (1992) used depletion analysis to estimate biomass of the vulnerable stock at the summit of the Southeast Hancock Seamount. The closed population assumption is not necessarily applicable to SA stocks, as there may be more migration by SA between seamounts and thus catch and effort may need to be aggregated across a broader spatial scale to meet the closed population assumption.

Total catch data are commonly used alongside an abundance index (fishery-dependent, such as CPUE, or fishery-independent, such as an acoustic survey) in a surplus production model. Yonezaki et al. (2012) ran a surplus production model for NPA, but results were highly uncertain due to highly uncertain early catch data. Uncertain early catch data would lead to high uncertainty in the initial biomass parameter (i.e. carrying capacity), which would also lead to high uncertainty in the intrinsic growth rate due to uncertainty in how fast the population may have become depleted with high rates of fishing in the early years. However, a state-space surplus production model may be useful for a species with highly variable recruitment such as NPA. A state-space model better accounts for observation error in catch or CPUE series and process error, for which highly variable recruitment could be considered (Wetherall and Yong, 1986). The state-space formulation of a surplus production model could better tease apart uncertainty due to measurement (i.e. catch) or general stochasticity in the environment (i.e. recruitment). A state-space surplus production model may be useful in tandem with other approaches such as depletion analysis or a multi-indicator approach at the seamount-level.

Nishimura and Yatsu (2008) ran a surplus production model for SA on the SE-NHR, but results were also uncertain due to several potential assumption violations discussed later in this report.

2.1.2. Biological data to inform life history parameters and composition time-series

Catch lengths, maturity information, ages, and weights have been collected by scientific observers on Japanese fishing vessels in the Emperor Seamounts. The observer program started in 2009 as an interim measure and the NPFC continued to fund the program for conservation and management purposes (Sawada et al., 2018). Fish measurements are a mandatory item for observers. For the primary target species (including NPA and SA, as well as oxeye oreo), observers sample fish from the catch of one tow per day if the species is caught. For SA, observers randomly sample 100 individuals and measure fork length (FL) to nearest 0.5 cm using fish measurement boards and punch cards designed for fish measurement. Prior to 2012, SA were measured only when SA were the primary catch of the day (larger than NPA and others). Since 2013, observers measure SA on all fishing days.

Data source

a) 2009-2020: Scientific observer program on Japanese fishing vessels (data held by Japan)

Potential uses for these data

The observer data program provides length composition, which may be particularly useful for SA stock assessment (less useful for NPA stock assessment since NPA have already reached their maximum size at the time of settlement to seamounts and thus length composition data would not be as informative on stock status). However, the observer data could provide a reliable fat index based on body width and condition that could be used in place of length composition for NPA. Samples could be used for aging for NPA and SA, which would improve characterization of the length-at-age curve (SA) and fat index-at-age relationship (NPA). Paired length and weight measurements would be particularly useful to inform a local length-weight relationship for SA, which seem to be more widely available in regions outside the SE-NHR. Maturity at length or age would also be useful from the biological sampling data, particularly for SA. Maturity information for NPA for this survey would be useful to confirm at what body width on the fat index NPA likely become sexually mature (i.e. somewhere between a “fat” and “intermediate” designation).

2.1.3. Fishery-independent surveys: species identification and distribution

The acoustic survey available from Matsuura et al. (2018) focused on determining the vertical and horizontal distributions of NPA and SA for better species identification and density distribution in future surveys.

Data sources

a) 2014-2020: Acoustic survey of seamounts for NPA, data held by Japan (Matsuura et al., 2018). Acoustic surveys use a quantitative echosounder for NPA, SA, and prey organisms. This acoustic survey can determine the density distribution of fish using the backscattering strength of fishing measured along the echosounder transect lines and the target strength of the target species. Species identification is vital for estimates of density distribution, and can be done by understanding the horizontal and vertical distributions of the target species. This acoustic survey focused on determining the distribution and habits of NPA and SA since 2016 (although the survey has been occurring since 2014).

Potential uses for these data

In general, acoustic surveys may be used to provide presence/absence data, absolute or relative abundance at fine spatial or temporal scales (e.g. day and night, by month, by seamount, etc.), size and/or body condition distributions, and/or spatial extent of the stock across seamounts. Results of acoustic surveys may be used in a single or multi-indicator approach where scientists and managers could decide a threshold below which various indicators would limit fishing. For example, acoustic surveys could theoretically estimate the absolute abundance by species by seamount to help the fishery prepare for NPA or SA as the target species, or potentially closing fishing at certain seamounts with low recruitment that year. With more years of data, these fishery-independent acoustic surveys could be used as an abundance index similar to a fishery-dependent CPUE time series in indicator or model-based analyses (e.g. surplus production model, depletion analysis if acoustic surveys are conducted within-season by seamount). Acoustic surveys would likely be designed differently for the objective of density distribution once there is more certainty in species identification from this study. To build off of this study, estimates of absolute or relative abundance and species composition may be possible for future acoustic surveys.

2.2. North Pacific Armorhead

2.2.1. Fishery-independent surveys: abundance indices

Based on literature review from Phase I and review of the literature, there is indication the following sources could inform fishery-independent estimates of absolute abundance or abundance indices for NPA. Because NPA and SA are often caught together, it is possible SA are represented in the surveys as well. However, more information is needed for both of the following sources to determine if usable information is available to use either as an index of SA abundance.

Data sources

a) 1985-1990: Bottom longline and trawl surveys (n=10) of SE Hancock Seamounts specifically designed for NPA by USA (Somerton and Kikkawa, 1992). Bottom longline better accounted for NPA on the steep slopes of the seamount as well as the flat tops, while bottom trawls could only operate along the flat tops. The use of bottom longline allowed the entire seamount population to be sampled. It is possible that SA were observed in this survey, but Somerton and Kikkawa (1992) does not mention the handling of other species when discussing this NPA-focused survey.

b) 2005-2007: Trawl survey of major seamounts (Colohan, Milwaukee, Kimmei, Koko Seamounts, data likely held by Korea, need more information on this survey).

Potential uses for these data

Bottom longline and trawl surveys conducted by the US of SE Hancock Seamounts were used to develop fishery-independent abundance estimates for NPA (Somerton and Kikkawa, 1992). Biomass was then estimated based on longline catch per hook, using the mean individual weight of NPA caught during the sampling period and the catchability of longlines, as estimated via depletion analysis using fishery-dependent cumulative catch and CPUE data. This survey in particular was targeting NPA. These data could be used as an example for future fishery-independent surveys, or provide absolute abundance of NPA for these particular seamounts in future integrated models that may date back to the 1980s. Further examination of the data would be helpful to determine whether there is useful information for SA as well.

2.2.2. Fat index

The unique life history and growth patterns of NPA have led to a fat index (FI) to characterize NPA growth post-settlement. After arriving at seamounts, NPA decrease in body width and weight either due to the rigor of spawning or inability to obtain sufficient prey, eventually becoming emaciated (Somerton and Kikkawa, 1992). The FI is defined as body depth divided by fork length and NPA are often categorized as "fat", "intermediate", and "lean" referring to their state along the FI. "Fat" types are bluish-gray, sexually immature, and infrequently captured at the SE-NHR seamounts (Kiyota et al., 2016). NPA transform rapidly to the "intermediate" type upon settlement to seamounts, which includes a change of coloration with the use of fat reserves. "Intermediate" and "lean" types are brownish in color and the dominant fat types on seamounts.

Data sources

a) 2018, 2019 and modified in 2020: Monthly monitoring survey from Japanese fishing vessels in specific spatial blocks to assess recruitment (NPFC data source, need more information on this survey)

b) 1985-1990: Bottom longline and trawl surveys (n=10) of SE Hancock Seamounts by USA (Somerton and Kikkawa, 1992). Bottom longline better accounted for NPA on the steep slopes of the seamount as well as the flat tops, while bottom trawls could only operate along the flat tops. The use of bottom longline allowed the entire seamount population to be sampled.

Potential uses for these data

FI can be used as an index of post-recruitment age. The FI may be conveyed as a frequency distribution, which often displays 2-3 distinct modes similar to modes within a length-frequency distribution. Modes are assumed to represent annual cohorts of fish because NPA recruitment to seamounts is seasonal, therefore being used as a recruitment index. When modes in the FI distribution are distinct, they can be followed through time from "fat" to "lean", and thus could be used in a similar manner as a catch curve with length frequency data to estimate the natural mortality rate, M. This is how the FI was used in the 1985-1990 bottom longline and trawl surveys.

However, FI can also be used alongside aging data as a proxy for the way length-at-age and length composition are typically used. An aging study to develop a function for fat index-at-age could help transform FI into compositional data that could be used in age-structured assessments.

2.2.3. Biological information

2.2.3.1. Length-weight relationship

Typically, the length-weight relationship of fish is described using an allometric equation, $W = aL^b$. However, NPA decrease in weight after their settlement to seamounts, therefore requiring an alternate relationship to represent their decrease in weight and body depth while length remains the same.

Data sources

a) Somerton and Kikkawa (1992) published a relationship between weight, body depth, and fork length from fishery-independent trawl surveys at the SE Hancock seamounts. Using bottom longline gear, these surveys were representative of the entire demersal stock (see Section 2.2.1).

b) Updated local information from 2009-2020 observer program on Japanese fishing vessels (see Section 2.1.2) could be used to update the relationship published in Somerton and Kikkawa (1992).

Potential uses for these data

Length-weight information is used to convert between numbers and biomass, and may be used as a proxy for fecundity assuming the amount of eggs increases with increasing female weight. Both biomass and fecundity are often used in calculating the spawning potential ratio, a commonly used metric to describe the proportion of the spawning population available, particularly useful when

MSY-based reference points are not possible to calculate due to a lack of information on the scale of the population.

2.2.3.2. Maturity

Maturity information is often used to approximate the spawning biomass, which is then often used as a reference point to estimate stock status. Age at first maturation for NPA has been approximated to 2-3 years (25-33 cm FL) based on biological surveys from the Fisheries Agency of Japan.The SE-NHR seamounts are believed to be the largest spawning grounds for NPA, with a spawning season between November and February. While "fat" type NPA are sexually immature and quickly transition to the "intermediate" category upon recruitment to seamounts, it is likely that the fat reserves are likely used rapidly as NPA transition to the mature "intermediate" state (Humphreys et al., 1989).

Data sources

a) Maturation and reproductive cycle described in Yanagimoto and Humphreys (2005)

b) Description of maturation data relative to fat index described in Humphreys et al. (1989)

c) Updated local information from 2009-2020 observer program on Japanese fishing vessels (see Section 2.1.2).

Potential uses for these data

Proportion of the population mature is often used as a key indicator, assuming the stock status would be related to the proportion mature. For example, if the mean length of the catch drops below the length at maturity, that would be an indication that fish are caught before they are able to reproduce and a size limit or limit on fishing should be instated. However, this is less likely applicable for NPA if all individuals recruited to the seamount are sexually mature. Fat index appears to be a better index of recruitment than the mean length of capture relative to the length at maturity. A higher proportion of NPA categorized as "fat" would mean a higher recruitment year, and presumably more spawning at the particular seamount, since NPA do not remain in the fat state for very long. A higher proportion of NPA categorized as "lean" would mean that spawning has already occurred or there were not as many recruits in that year (depending on the timing of the survey). Ongoing studies of maturity related to the fat index would be useful for use of the fat index as a recruitment index, rather than the typical comparison of length to length at 50% maturity.

2.2.3.3. Natural mortality and maximum age

The best estimate for M is 0.54/year (Somerton and Kikkawa, 1992). M was estimated from the change in relative abundance over time during a period with no commercial fishing using the weighted average between two cohorts. There were differences in M between sexes that were statistically significant, and the potential for sampling bias of females was ruled out. This estimate is higher than previous studies that had assumed NPA are semelparous and die soon after spawning.

There was a previous estimate of M of 0.25/year based on age data that was likely biased because the age range of 7 years is likely high when compared with fat index histograms which indicate a demersal age range of 4-5 years. Also, the mean age of the catch did not decrease during the developing fishery, which goes against expectation.

Data sources

a) Bottom longline surveys estimating relative abundance over time for two cohorts (Somerton and Kikkawa, 1992)

Potential uses for this data

An estimate or assumption about natural mortality is required for life history-based indicators, risk assessment, and most model-based approaches. *M* is a key parameter for age- and length-based models to determine the rate at which individuals in the population die annually. However, age- and length-based models would not be used for NPA because the maximum size occurs at settlement and thus cohorts cannot be distinguished by the size composition of catch (Kiyota et al., 2016).

For NPA, *M* will most likely be useful in general life history-based indicators or risk assessment. However, estimates of *M* are quite uncertain because the data are outdated. It is usually helpful to examine *M* using a variety of empirical relationships to consider uncertainty, but estimates of growth are also unreliable for NPA which would limit these comparisons. Using the measured, in situ estimate of *M* will be the best approach for NPA, but will likely not be used in age- or length-structured models.

2.2.3.4. Length-at-age

Body length ranges at seamounts are very narrow, indicating that NPA body growth ceases by the time they recruit to the seamount (Humphreys et al., 1989; Kiyota et al., 2016; Takahashi and Sasaki, 1977). Age determination has successfully used check marks on sagittal otoliths to represent annuli, but age determination of older fish becomes more difficult due to smaller width with age (Humphreys, 2000; Kiyota et al., 2016).

Data sources

a) Aging data associated with Humphreys (2000)

b) Updated local information from 2009-2020 observer program on Japanese fishing vessels (see Section 2.1.2).

Potential uses for this data

Typically, length composition data, combined with a length-at-age function with relatively low uncertainty, can be used to differentiate across cohorts. This information can be used to either 1) estimate biological parameters depending on the population from which lengths were sampled, 2) identify recruitment cohorts, and 3) estimate fishing mortality rates, based on assumptions above asymptotic length, natural mortality, and either an assumed or estimated selectivity-at-length relationship. However, due to unique growth and weight trends of NPA, length composition data cannot be used in this manner.

However, a relationship of fat index-at-age could be used to replace the information typically provided by length-at-age (Kiyota et al., 2016). This would require an updated age determination study with recent samples of NPA by fat index category.

2.3. Splendid alfonsino

2.3.1. Length composition of the catch

Data sources

b) 2009-2020: Scientific observers onboard Japanese fishing vessels in the Emperor Seamounts (see Section 2.1.2).

Potential uses for these data

Unlike NPA, SA continue to grow once recruited to the fishery, therefore it is possible to collect representative samples of different sizes and ages to define a von Bertalanffy length-at-age function. Conveniently, SA recruitment has been observed to be generally constant over time. Many length-based assessment methods assume recruitment is constant over time, and use length composition or mean length over time to estimate fishing mortality rates and selectivity of the fishing gear. Because SA below their asymptotic length are recruited to the fishing gear, length compositions may be informative of stock status so long as the lengths are representative of the fished stock. Mean length or length composition relative to the length-at-maturity may also be used as life-history based indicators as simple assessments of the reproductive potential in the population.

2.3.2. Biological information

2.3.2.1. Length-weight relationship

The commonly-used allometric equation to represent the length-weight relationship of fish, $W = aL^b$, has been applied for SA populations around the world.

Data sources

a) Updated local information from 2009-2020 observer program on Japanese fishing vessels (see Section 2.1.2). This would ideally be the relationship to use as it would be recent and local.

b) Parameter estimates from various studies worldwide available in Table 36 of Shotton (2016)

Potential uses for these data

Length-weight information is used to convert between numbers and biomass, and may be used as a proxy for fecundity assuming the amount of eggs increases with increasing female weight. Length-weight is a common input for age- and length-based stock assessment models.

2.3.2.2. Maturity

Maturity information is available from many studies over time and SA fisheries. Unfortunately many classification systems exist for characterizing SA maturation, which leads to variability in the definition of maturation between studies (Shotton, 2016). Stock assessment models typically require the proportion of the population mature by age or length, commonly described using a logistic function with length at 50% and 95% maturity. This ogive can be developed by classifying fish as either immature or mature along with their length and/or age. For example, a fish classified as “immature”, “resting”, or “developing” could be classified as immature and “ripe”, “spawning”, and “spent” could be classified as mature (Shotton, 2016).

Data sources

a) Updated local information from 2009-2020 observer program on Japanese fishing vessels (see Section 2.1.2). This would ideally be the relationship to use as it would be recent and local.

b) Age and length at 50% maturity from studies around the world are collected in Table 38 of Shotton (2016).

Potential uses for these data

Proportion of the population mature is often used as a key indicator, assuming the stock status would be related to the proportion mature. For example, if the mean length of the catch drops below the length at 50% maturity, that would be an indication that fish are caught before they are able to reproduce and a size limit or limit on fishing should be instated. Some approaches also compare the maturation function or parameters with length percentiles of the catch as a more specific life history indicator of overfishing. Maturity-at-age or length is also used in age- and length-based stock assessments to estimate the spawning biomass, which is commonly used to assess stock status relative to a reference point.

2.3.2.3. Natural mortality and maximum age

Natural mortality (*M*) is very difficult to measure in practice, and is often estimated using a variety of empirical and life history-based relationships. Natural mortality may be calculated from von Bertalanffy growth parameters, maximum age, catch curves, and temperature when it cannot be measured directly from tagging studies or fishery-independent sampling from unfished areas.

Data sources

a) Estimates of natural mortality by sex and overall for five studies from Chile based on empirical relationships are available in Table 40 of Shotton (2016).

b) Estimates of natural mortality by sex using multiple models for New Zealand stocks available in Table 41 of Shotton (2016) from Massey and Horn (1990)

c) Estimates of M from the Emperor Seamounts calculated empirically from local estimates of von Bertalanffy growth parameters using empirical estimator of *M* from Then (2015): $M = 4.118k^{0.73}Linf^{-0.33}$, where estimates of von Bertalanffy parameters were Linf = 52.602 and k = 0.092 to obtain an M = 0.195 (Sawada and Yonezaki, 2019).

d) Takahashi (2018) assumed M = 0.2 using the estimator by Djabali et al. (1994)

e) Maximum ages from various studies are described in Sawada et al. (2018) (around 20 years in the North Pacific).

f) Could be updated locally using relationships with local growth parameters or temperature; see the Natural Mortality Tool from Cope (2021) which includes many empirical estimators including that proposed by Then et al. (2015).

Potential uses for these data

Age- and length-based models and many life history-based indicators and risk assessments would require an estimate of natural mortality. However, estimates of *M*, particularly based on empirical relationships with other estimated parameters, are very uncertain. This would be an excellent use of the Natural Mortality Tool, which allows the user to input all information used in empirical relationships with natural mortality (e.g. von Bertalanffy growth parameters, temperature, estimates of maximum age, etc.) and develops a distribution for *M* considering all approaches. This better accounts for uncertainty in an important population parameter than assuming only a single empirical equation, requiring parameter inputs that are already uncertain themselves.

2.3.2.4. Length-at-age

Local, recent estimates of von Bertalanffy growth parameters are ideal for use in stock assessments. However, it is very important to consider uncertainty in these estimates because stock assessment results are very sensitive to values of Linf and k.

Data sources

a) Takahashi (2018) estimated parameters of von Bertalanffy growth function for body weight (g) at age (t) of SA in the Emperor Seamounts using a wide size range of individuals collected through the NPFC scientific observer program: $W_t = 1852.35(1-e^{-0.148(t+2.926)})^3$ (Sawada and Yonezaki, 2019), where Linf = 52.602 cm and k = 0.092/year.

Potential uses for these data

I could not find the raw data for these estimates, but if available, it would be great to check back particularly to determine the assumption or estimate of t_0 and make sure that the analysis was based on recent aging and length data. Furthermore, it would be important to determine how much uncertainty there is around this average growth function. Length or weight-at-age assumptions are vital to age- and length-based models. When using length composition in particular, estimates of fishing mortality and stock status will be very sensitive to assumptions about Linf. If the Linf is assumed to be higher than the truth, we would not see many individuals nearing Linf in the length data and fishing mortality would be estimated to be higher than the truth (i.e. large individuals had been fished out). If Linf is assumed to be lower than the truth, we would end up seeing many individuals close to Linf and estimates of fishing mortality would be lower than the truth. Thus, seeing the data from which these von Bertalanffy parameters arise and getting a better understanding of uncertainty in these estimates is important if an age or length-based model will be pursued, as well as any other life history-based indicator.

2.3.2.4. Fecundity

Data on fecundity-at-age or length is used to estimate the spawning biomass. Fecundity is often simply assumed to be proportional to the weight-at-age. However, due to the increase in the number and potentially quality of eggs for older, fatter females, a fecundity-at-age or length relationship may more accurately characterize the spawning stock than any assumption about how fecundity changes related to age and weight.

Data sources

a) Studies have found that SA exhibit asynchronous oocyte development, meaning that batch spawning (i.e. multiple spawning per reproductive season) is likely to occur (Alekseev et al., 1986)

b) Lehodey (1997) estimated an allometric relationship between fork length and fecundity, where $E = 0.00067 * FL^{5.62}$, where E = eggs, FL = fork length in cm, corresponding to 700,000 eggs for 40 cm FL. The allometric relationship describes the number of oocytes, and does not consider batch fecundity.

c) Spawning season varies geographically, and is likely to be summer in the Emperor Seamounts from larvae collection in July 1984 at the SE Hancock seamount based on back-calculation of daily otolith increments and seasonal patterns in the gonadosomatic index (Sawada et al., 2018; Takahashi, 2018).

Potential uses for these data

Fecundity-at-length or age would be used in any age- or length-based model. The specific relationship is not required if the analyst is comfortable making the assumption that fecundity is proportional to weight-at-age or length, but estimates of spawning biomass would be improved with a specific fecundity relationship.

3. Data gaps and uncertainty

3.1. North Pacific Armorhead

While several data types typically used in stock assessment are "missing" for NPA (e.g. growth parameters, stock-recruit relationship), their life history and population dynamics make these types of data very difficult to collect and information of these types would not be very informative of stock status if collected. The below data uncertainties focus on information that would be very useful for NPA assessment and management if collected or determined.

3.1.1. Fishery-independent surveys designed to estimate biomass for an absolute or relative index

Initial acoustic surveys focused on understanding diurnal migration patterns within a seamount. This initial study helps groundtruth accurate species identification of NPA and SA on seamounts. With this initial study and information to improve accuracy of species identification, future acoustic surveys could be developed for the purposes of estimating absolute or relative abundance for NPA and SA by seamount. An absolute estimate of abundance or relative index over time would drastically improve uncertainty in stock status.

3.1.2. Continued data collection to inform fat index

Continued collection of body weight, body depth, length, and age data would inform the fat index for use as a recruitment index and potentially substitute information typically provided by length composition data. The fat index shows the most potential for identifying recruitment events and informing estimates of spawning biomass. Combined with age data, the fat index could be used in a similar way to length as “fat index-at-age” data and composition of the catch in either fishery-dependent or independent surveys. Due to high recruitment variability, biomass estimates of NPA populations at seamounts alone may not be indicative of reproductive potential, whereas the composition of NPA along the fat index would be indicative of that year’s population or the next few years’ population depending on how long NPA remain in an intermediate or lean state before dying. This information could also be used to plan for the NPA and SA fisheries, since SA are typically targeted during poor recruitment years for NPA. It is possible that the timing of these surveys would not align with recruitment and management for NPA, but regardless I still think some brainstorming of the best way to use the fat index would be the best way forward for understanding NPA population dynamics and to structure management and conservation of the fishery.

3.1.3. Early catch history

Uncertainty in early catch history is cited as one of the main reasons that previous attempts at running surplus production models were unreliable. Any possible collaboration or reconstruction to reduce uncertainties in the early catch history of NPA would be vital for reducing uncertainty during the period of high contrast, where NPA stocks were unfished and then were rapidly fished down. This part of the time series would be most informative of NPA productivity rates and to better understand the density levels that NPA could sustain at seamounts prior to heavy exploitation. Without an understanding of the early catch history and CPUE information, we are left with relatively low-contrast catch and CPUE information and do not have much information for estimating relative depletion in years after initial exploitation. If the early time series of catch and effort are indeed uncertain, stock assessments will not be able to relate to the pre-exploitation period. It is possible a more meaningful reference point could be developed that does not relate to an unfished state (e.g. if other elements of productivity in the system have shifted such that unfished levels would not be feasible even if fishing ceased).

3.1.4. CPUE uncertainty

CPUE series should be used with caution because NPA are only directly targeted during high recruitment years. However, years of high NPA recruitment are relatively easy to identify, and many options for CPUE standardization to account for this issue have been proposed. Specifically, Sawada et al. (2017) examined nominal, adjusted, directed, and declared CPUE as options that would account for differential targeting between NPA and SA, extending beyond the standardized CPUE that corrected the effects of seasons and areas in the NPA surplus production model in Yonezaki et al. (2012) and the adjusted CPUE used to assess SA in Nishimura and Yatsu (2008). Directed CPUE is a multi-species approach to calculating CPUE that relies on an “explanatory level” that helps classify the target species. Declared CPUE uses tows where the focal species targeted was declared. Directed and declared CPUE rely on the data collected by scientific observers. Directed and declared CPUE followed a similar pattern which was different from the trajectories as calculated by nominal and adjusted CPUE. While directed and declared CPUE likely better characterize CPUE for NPA and SA based on differential targeting, the CPUE series would only date back to the start of the scientific observer program in 2009, thus not starting in the initial years of the fishery.

3.1.5. Reference point development

A reference point should be developed or agreed upon by scientists, managers, and stakeholders in order to communicate and quantify stock status. Because recruitment is highly variable, many of the concepts that are typically used as reference points (e.g. MSY, comparison of spawning biomass to an unfished state) are not meaningful. Reference points could be based on single or multiple indicators. CPUE would not typically be used as a reference point, since this related to fishery goals with no consideration for sustainability concerns. The fat index, on the other hand, is currently used as a recruitment index and could meet both fishery and ecological sustainability goals. For example, further biological studies that could define a proportion of fat or intermediate individuals from the fat index that would represent adequate recruitment for a targeted fishery could help manage and plan the NPA fishery assuming the timing of the fat index availability is in line with the timing for use in estimating stock status and planning for the NPA fishing season.

Fishery-independent surveys, either in the form of acoustic, longline, or bottom trawl surveys could also serve to help estimate stock status and plan for the NPA fishing season. Acoustic surveys could potentially also be used to approximate a recruitment index or define a reference point before the fishery begins.

3.1.6. Size selectivity due to market demand

More information on market demand and resulting differential targeting of NPA along the fat index would be useful to determine size selectivity for the NPA fishery between and within years. This would be particularly helpful to inform the meaning behind estimates of relative biomass in depletion analysis and the annual fishery targeting dynamics between NPA and SA. For example, if NPA are still caught in the fishery in low recruitment years despite low market demand for “intermediate” or “lean” type individuals, then depletion analysis would still be useful to manage NPA during low recruitment years. However, if fishing dynamics change in low recruitment years due to lack of market demand for “intermediate” or “lean” NPA, this may affect the usefulness of depletion analysis to manage NPA stocks.

3.2. Splendid Alfonsino

3.2.1. Local life history parameter estimates

There are many biological studies of SA from stocks around the world, but fewer published studies from the Emperor Seamounts. The NPFC scientific observer program collecting biological data from 2009-2020 should be used to update SA life history information for the Emperor Seamounts similar to updates in the length-at-age curve by Takahashi (2018), such as the length-weight relationship, maturity-at-age or length, and fecundity-at-age or length. Updated, local estimates of these biological parameters would be very helpful since SA do appear to have a more typical life history for fish, thus making many types of model-based assessments feasible which often require accurate estimates of life history parameters.

3.2.2. CPUE uncertainty

Due to the longstanding collection of total catch and effort for NPA and SA on the Emperor Seamounts, the CPUE index would generally be considered the best piece of information to inform stock status. However, CPUE for SA on the Emperor Seamounts may be biased due to target shifting between SA and NPA depending on NPA recruitment. There is also the potential issue of hyperstability caused by SA aggregation, meaning that CPUE may remain high while the SA population decreases and that the catchability coefficient q is not directly proportional to CPUE to represent abundance. Further, CPUE will be influenced by the recent change in mesh size applied to the SA fishery on the emperor seamounts to reduce fishing pressure on small individuals.

Two studies have addressed CPUE standardisation for SA in the Emperor Seamounts. Nishimura and Yatsu (2008) ran a non-equilibrium surplus production model with observation error for the SA stock on the Emperor Seamounts using ASPIC (Prager, 1992), comparing results from unadjusted CPUE (Japanese annual SA catch divided by annual total Japanese fishing hours) and adjusted CPUE (Japanese annual SA catch divided by adjusted Japanese fishing hours). In this case, adjusted fishing hours were assumed proportional to log-transformed annual catch of SA to aggregated annual catch of SA and NPA. This comparison attempted to address the issue with differential targeting of SA and NPA. Sawada et al. (2017) criticized the lack of justification, comparison with other approaches, or validation of the adjusted CPUE approach in the Nishimura and Yatsu (2008) production model, and explored directed and declared CPUE in comparison which rely on the approximated or declared focal species targeted (a brief summary is provided in Section 3.1.4). While directed or declared CPUE may represent the abundance index of SA more accurately than nominal or adjusted CPUE, the series relies on data collected from the scientific observer program beginning in 2009. More work would be needed to either a) use multiple CPUE time series with the best assumptions possible dating back to the first years of fishing or b) ignore early CPUE altogether, relying on the CPUE abundance index beginning in 2009.

In addition to the targeting issues, hyperstability and change in selectivity will also affect CPUE. The issue of hyperstability may be addressed by acoustic or other fishery-independent surveys to determine the degree of hyperstability, statistical tests examining the best assumed relationship between the estimated catchability coefficient and CPUE. The change in selectivity would either need to be addressed via a) an age-structured model that explicitly accounts for the management change or b) fitting a surplus production model to separate CPUE series representing major changes in selectivity, the most recent of which would not be available until at least 5-6 years of CPUE information are collected under the new management measure.

3.2.3. Size at selectivity

The NPFC enacted an increase in the minimum mesh size for bottom trawlers in 2018. This decision was based on the observation of smaller individuals in the catch size composition over time from the biological sampling in the scientific observer program starting in 2009 (Sawada et al., 2018). Sawada and Yonezaki (2019) ran a yield-per-recruit (YPR) analysis as a first step towards quantitative assessment of SA on the Emperor Seamounts in relation to the size structure of the population. Due to uncertainty in how the mesh size regulation would affect selectivity of trawling, Sawada and Yonezaki (2019) calculated reference points for a wide range of parameter values for the earliest age of capture, amongst other key parameters. The sensitivity test found that the results of YPR are of course very sensitive to size selectivity and at the potential ages for initial entry to the fishery there is concern about growth overfishing. This uncertainty in size selectivity should be considered further via analysis on the length composition of the catch and updated biological parameters to obtain accurate estimates of spawning biomass and reference levels.

3.2.4. Stock structure

Sawada et al. (2018) summarizes studies on SA stock structure across the entire extent of the species. While there is a hypothesis of SA migration between Japan and the Emperor Seamounts region due to a long pelagic period (150-300 days) and mark-recapture studies identifying the potential for adult migration of more than 1,000 km, there has not yet been evidence to support this hypothesis. Sawada et al. (2018) recommends treating the Emperor Seamounts SA as a separate stock for precautionary reasons.

However, there seem to be some reasons to suggest that the Emperor Seamounts SA population may not be distinct. While multiple types of studies support that SA in Japanese waters represent a single population, there is the possibility of a meta-population for North Pacific SA. Reasons to support this would be 1) there is no genetic differentiation between North Pacific SA populations, 2) larvae can drift from Japanese waters to the SE-NHR, and 3) morphological characteristics can be affected by local environmental conditions (Shotton, 2016; Yanagimoto, 2004).

Assumptions of some stock assessment methods would be violated if there is indeed migration between the Emperor Seamounts and other SA populations. Further research on the stock structure to determine whether Emperor Seamounts population is indeed a closed, distinct population or not would improve stock assessment inference.

3.2.5. Early catch history

The same uncertainties associated with NPA reporting and targeting in the early years of the catch time series would affect the SA stock in the Emperor Seamounts (see Section 3.1.3).

4. Recommendations for data-limited approaches to assess stock status

My literature review was guided by the information provided in Phase I of this project and the stock assessment questionnaire of the FishPath decision support system. FishPath was developed by the Nature Conservancy with a collaborative team of fishery scientists and experts from around the world as an engagement tool to help managers, stakeholders, and scientists consider the biological, socioeconomic, and governance context of data-limited fisheries to develop a short-list of monitoring, assessment, and management options. I focused on the stock assessment module to guide my literature review, which included questions related to life history, data availability, fishing dynamics, and research capacity. These detailed questions developed by scientists and experts around the world expanded the types of strengths and caveats I would consider for the NPA and SA fisheries when weighing options for data-limited assessment approaches. Based on my consideration from the literature review and short-list of stock assessment options recommended by FishPath, the following section includes my recommendations for stock assessment options of NPA and SA. The following recommendations align with the review of biology and previous assessments discussed in Sawada and Ichii (2020) but go on to recommend indicator, life history, and risk assessment approaches that could be used in addition to or in place of model-based approaches.

4.1. Approaches for North Pacific Armorhead

There were two key limitations for data-limited stock assessment options for NPA: 1) violated assumptions of constant recruitment and 2) lack of differentiation in length composition data from the fishery. Many data-limited stock assessment methods assume constant recruitment, whereas variable recruitment is a key attribute of the NPA stock. Further, the majority of length- and age-based data-limited assessment options, including population models, empirical reference points, and simple approximations of life history parameters (e.g. relating von Bertalanffy growth to natural mortality) assume that fish either continue to grow or reach an asymptote as they become recruited or are recruited to the fishery, providing some contrast in the observed length composition data which could inform recruitment, fishing mortality, and selectivity parameters. NPA likely reach asymptotic length by the time they recruit to seamounts, declining in overall condition and weight after recruiting to the seamount. Other indicators, such as the fat index, are more useful than length composition data and growth information during the period when NPA are selected to the fishery at the seamount because the fat index is the only one of the three datasets that would be variable within or between fishing seasons. However, the fat index has not yet been thoroughly explored as a replacement for length composition data in the context of data-limited stock assessment. These two key attributes of NPA life history removed the option of many data-limited stock assessment methods that either rely on the assumption of constant recruitment, the availability of accurate von Bertalanffy growth parameters, or length composition data.

Because there seems to be negligible migration of NPA between seamounts and CPUE series are available, some data-limited assessment methods fit the NPA scenario quite nicely. Many data-limited stock assessment models assume closed populations, and while this is often violated for many fisheries it seems NPA meet this assumption within a fishing season.

4.1.1. Depletion analysis

Depletion analysis involves comparing CPUE and cumulative catch throughout the season, using linear regression to determine the total catch and length of the fishing season, with the slope of the regression representing the catchability coefficient. Depletion analysis does not require an assumption of linearity between CPUE and cumulative catch, but would require exponential, logarithmic, or arc-sine transformations to regress CPUE by cumulative catch. Key assumptions of depletion analysis are high steepness, a closed population, and no within-season natural mortality, and work best with little generational overlap. An issue with depletion analysis is it does not explicitly consider uncertainty. Depletion analysis could be used to estimate start-of-season biomass and depletion by the end of the season, linking well with decision rules such as catch limits and adjustment of the length of the fishing season based on the depletion estimates throughout the season relative to a reference point (Hilborn and Walters, 1992).

NPA meets the requirements of depletion analysis due to its high recruitment variability, weak stock-recruit relationship, and minimal immigration or emigration at seamounts within a fishing season. However, it is important to be aware that there may be natural mortality within-season, and/or NPA may live on the seamount for more than one fishing season (i.e. there is generational overlap). Cumulative catch and CPUE from the fishery, which may target only "fat" individuals due to market demand, may not be affected by generational overlap since NPA transition within the fishing season to "intermediate" or "lean" stages. In this case, the depletion analysis would reflect the depletion of the "fat" stock targeted by the fishery. Other caveats include the use of fishery-dependent CPUE with extreme caution due to variable targeting of NPA and other species, although perhaps this would not be as much of an issue in a single fishing season. Cumulative catch and CPUE from a fishery-independent survey may represent initial biomass and depletion of the seamount population more accurately, but also may be more impacted by the violated assumption of generational overlap.

4.2. Approaches for Splendid Alfonsino

SA life history is more typical of other fish species, making it possible to apply classic stock assessment approaches for SA in the Emperor Seamounts once the data are properly processed. Further, and very unlike NPA, SA recruitment is assumed to be relatively constant over time opening up many data-limited stock assessment options if model-based approaches are rejected as the data are collected and processed. The key issues holding back full stock assessments for SA at this point largely include recent changes in selectivity due to a change in mesh size in 2019, uncertainty in the CPUE series due to variable targeting of SA and NPA and potential hyperstability, and lack of published datasets for length composition and biological parameters that could be available from the NPFC scientific observer surveys on the Emperor Seamounts from 2009-2020. The availability of length composition, local and recent biological parameter estimates, an agreed-upon approach to CPUE series development, and accounting for a change in selectivity would allow for a statistical catch-at-age model such as Stock Synthesis or custom-built software to be used. The following recommendations consider uncertainties in biological parameters, CPUE series, and availability of length composition data.

4.2.1. Statistical catch-at-age models

Statistical catch-at-age (SCAA) models estimate annual abundance at age from catch-at-age (or catch-at-length) data, an abundance index (e.g. CPUE and/or fishery-independent surveys), and biological information (e.g. growth, maturity, recruitment, mortality). SCAA models estimate or derive fishing mortality, abundance, survey and fishery catchabilities, and reference points (e.g. MSY-based reference points or fraction of unfished biomass). SCAA typically includes measurement error in catch-at-age or catch-at-length data and abundance indices to account for observation uncertainty. SCAA models are very flexible to account for constant or time-varying selectivity, natural mortality, and various assumptions on the spawner-recruit relationship. Stock Synthesis (SS) is an example of a program with many features for customizing an SCAA model (Methot and Wetzel, 2013).

While the possibility of an SCAA model such as SS may seem daunting due to the many data requirements, SS has been tested with many different data availability scenarios ranging from catch-only via Simple Stock Synthesis (Cope, 2013), catch with an abundance index via Extended Simple Stock Synthesis (Cope et al., 2015), and most recently catch with length composition data and no abundance index (Rudd et al. *in prep*). SS is an integrated modeling framework which allows all information available to be considered, and has produced unbiased results with data of limited types or number of years. One benefit of the integrated approach of SS is that data uncertainties may be addressed explicitly as they are prepared for the use in the model, and that data may be included as they become available.

Simple Stock Synthesis (SSS): The first step would be to gather the best estimates of life history parameter values (e.g. maturity, natural mortality, von Bertalanffy growth parameters, fecundity, recruitment compensation, recruitment variability, and the length-weight relationship). The next step would be to use the time series of removals that have been used for surplus production models without much issue (Nishimura and Yatsu, 2008). This most data-poor application of SS would require accurate assumptions about the selectivity-at-age curve, for which there are ongoing uncertainties particularly due to the recent change in the mesh size. However, because SSS includes the many features of SS, it could account for the multiple fleets fishing on SA as well as selectivity blocks to account for the change in selectivity.

Extended Simple Stock Synthesis (XSSS): With consensus on the best approach to CPUE standardization (e.g. directed or declared CPUE), the CPUE index could be included in the SS model in addition to the time series of removals and biological information.

Stock Synthesis with catch and length (SS-CL): If length composition data become available prior to consensus on the best approach for CPUE standardization, length compositions by fleet could be included in the SS model in addition to removals and biological information. This approach was recently approved by the U.S. Pacific Fishery Management Council for use in data-moderate assessments particularly for U.S. West Coast nearshore stocks.

Just like any of the data-limited stock assessment approaches, SCAA model results will only be as reliable as the data inputs and assumptions. For example, if there are uncertainties in the CPUE series relating to the target species or hyperstability, those uncertainties would need to be addressed before using the CPUE series in a data-limited indicator approach or more data-rich SCAA model. As uncertainty associated with each input is addressed in ongoing and future research, they may be added to the SS model for a fully age-structured stock assessment of SA.

4.2.2. Length-based models

Due to uncertainty in the early catch history and CPUE series but the availability of length composition of the catch from an observer program beginning in 2009, it may be useful to explore length-based models as an alternative to relying on the catch and CPUE series.

Inconsistent targeting of SA could also be an issue for length composition data due to changes in catchability over time. While it is not an eliminating factor for using length-based models, analysts should use caution when interpreting temporal trends in SPR estimates and focus more on independent estimates. Length-based approaches do not typically consider sex-specific life history characteristics that may be applicable to SA. In this case, it is generally recommended to use female life history parameters to best represent the spawning stock in the relative reference points.

Length-based spawning potential ratio (LB-SPR)

LB-SPR estimates spawning potential ratio (SPR), the ratio of reproductive potential of a fished relative to unfished population. LB-SPR requires at least one year of length composition, an estimate for the ratio of natural mortality to the von Bertalanffy growth coefficient (*M/k*), the asymptotic size (Linf), the coefficient of variation around Linf (CV), and information on the size-at-maturity which is used to calculated SPR. The underlying length-based model used in LB-SPR uses *M/k* under the assumption that this value is less variable across stocks and species than *M* or *k* independently. LB-SPR assumes equilibrium conditions (i.e. constant recruitment and fishing mortality rates). When more than one year of length data is available, LB-SPR runs independently for each year to calculate the estimated parameter *F/M* separately by year with the option to run a smoother between them so that *F* does not vary unrealistically between years. However, by treating each year as independent, time-varying selectivity is not as large of a concern as in integrated approaches.

LB-SPR would be well-suited as a data-limited stock assessment option for SA if length composition from scientific observer surveys are available. Particular benefits are that recruitment of SA has been observed to be relatively constant, matching a key LB-SPR assumption. Further, SA length composition may be impacted by changing selectivity over time, but this is not a major issue since LB-SPR treats each year independently. Length composition data would require thought to weighting of samples across each gear type, as LB-SPR would estimate the SPR for the population as a whole without regard to multiple fleets. The selectivity function would then represent an average across all fleets. If selectivity is thought to be dome-shaped (i.e. larger individuals are not selected to the fishing gear) then LB-SPR estimates of SPR would be lower than the truth.

Analysis of sustainability indicators based on length-based reference points (LBRP)

Cope and Punt (2009) developed length-based reference points (LBRP) that expand on the three simple size indicators proposed by Froese (2004): P_{mat}, the percent of mature fish in the catch with 100% as a target, P_{opt}, the percent of individuals of optimum length in the catch with 100% as a target, and P_{mega}, the percentage of “mega-spawner” fish in the catch, with 0% as a target. Cope and Punt (2009) showed that the three indicators may not adequately reflect sustainable fishing practices without considering selectivity, adding the indicator P_{obj}, defined as the sum of the P_{mat}, P_{opt}, and P_{mega}, in a decision tree to determine whether a stock’s biomass is below a target or limit reference point based on the three Froese (2004) indicators, P_{obj}, and the ratio of the length at maturity relative to the optimum length. The output of LBRP is a measure of relative stock status. The LBRP approach assumes constant recruitment (which aligns with SA life history). However, LBRP, like other indicator-based approaches, does not explicitly consider uncertainty.

4.2.3. Life history-based reference points

Yield per recruit

Yield per recruit (YPR) analysis is used to determine the maximum yield per recruit from a fishery. It uses an underlying age-structured model to determine the size or age at initial capture where the yield is maximized and corresponding fishing rate (F_{max}). F_{max} is always greater than F_{MSY} and should be considered a limit rather than a target since it is a theoretical measure to maximize yield. With information on maturity, YPR can calculate the spawning biomass per recruit (SBPR) at any given fishing level. YPR assumes the fishery is in equilibrium. YPR may be useful to determine other fishing mortality-based reference points besides F_{max} (e.g. $F_{0.1}$, the fishing mortality rate where YPR is 10% of an unfished population). Outputs of YPR include F_{max} and age at first capture, or spawning biomass-based reference points when including maturity information in SBPR.

Because YPR only uses life history parameters, it can be used as a preliminary analysis to guide management as data time series are considered and/or developed, or to develop reference points that could be used when examining outputs from other assessment approaches that use time series such as catch, CPUE, and/or length composition.

Demographic F_{MSY}

The demographic F_{MSY} approach estimates F_{MSY} using life history-based methods for estimating the intrinsic rate of growth (*r*) in surplus production models. This approach was developed for when catch data are uninformative in estimating the intrinsic rate of growth in a surplus production model (i.e. little variation in the catch time series). This could be useful as catch in recent years has been low for both SA and NPA. While demographic, life history-based *r* is defined slightly differently from *r* used in surplus production models, McAllister et al. (2001) showed that *r* from this approach was more useful than relying solely on a non-informative catch time series. This approach uses estimates of natural mortality, the maturity-at-length, and von Bertalanffy growth parameters to estimate F_{MSY} and improve prior distributions on the intrinsic growth rate used in surplus production models. Thus, demographic F_{MSY} could be a useful approach to improve inference in any future applications of surplus production models.

4.3. Approaches for both North Pacific Armorhead and Splendid Alfonsino

4.3.1. Production model

Production models (e.g. Schaefer, Fox, Pella-Tomlinson) account for population biomass rather than the age-structure of a population. These models consider the total biomass, the biomass that is caught, and the "surplus production" that is either added back (or removed) through reproduction, recruitment, growth, and mortality. Different formulations of production models adjust the parameterizations or assumptions about the relationship between carrying capacity and MSY. Data inputs include total catch and at least one abundance index. Major parameters include carrying capacity (*K*), interpreted as the unfished biomass or maximum size of the population, and the intrinsic growth rate (*r*), which includes reproduction, recruitment, growth, and mortality processes.

Process error, measurement error, and the catchability coefficient can be assumed or estimated. Production models will be very sensitive to the accuracy of catch and abundance index inputs, as well as the accuracy of the assumed relationship between the abundance index and catchability coefficient. Production models also do not perform well when there is a lack of contrast in catch or the abundance index, as there is then little information to inform the intrinsic growth rate and carrying capacity. There are many formulations of surplus production models, but it is currently best practice to use Bayesian inference for improved representation of process and observation error. Key outputs of surplus production models are abundance over time and approximations of MSY through assumptions of the relationship between MSY and the estimated parameters (Winker et al., 2020, 2018). Due to the ability to estimate and update MSY-based reference points and requirement of total catch as an input, production models link well with decision rules such as catch and effort limits relative to biomass-based reference points.

There are some important caveats for application for NPA. Production models may have poor behavior or difficulty fitting to species with highly variable recruitment, such as NPA. Further, CPUE should be used with extreme caution due to the changes in targeting between years. It is also possible that the selectivity has changed over time, which is an issue for surplus production models as this can not be directly accounted for. Further, production models assume carrying capacity is stationary over time, which may be difficult to account for due to the wide-ranging seamounts where NPA inhabit.

4.3.2. Multi-indicator approaches

The following indicator approaches could be used for both NPA and SA. The benefit of using these indicators for both NPA and SA is to include both stocks in the same management framework, where quasi-assessments could be used to guide decision rules for both stocks. This may work naturally due to the multispecies nature of the fishery.

Hierarchical decision trees

Hierarchical decision trees are a type of multi-indicator approach that is not based on an underlying population dynamics model. This approach combines the assessment and management action in a series of intermediate steps. The most important criteria is the first part of the tree, where an indicator is used to determine a preliminary stock status estimate that corresponds to a decision rule. The decision rule is then adjusted based on a series of subsequent decision branches according to one or more sets of secondary indicators, which may update the estimated stock status. This is not a formal stock assessment approach, but is helpful when multiple indicators are available but a model-based stock assessment assuming underlying population dynamics is not possible given the data, life history, or research capacity circumstances. The major output of a hierarchical decision tree is an indirect approximation of stock status across multiple "quasi" assessments (Dowling et al., 2015; Prince et al., 2011).

NPA could use the fat index as the first part of the decision tree. If the proportion of fat or intermediate individuals at the start of the season is too low, this would trigger the decision to target SA instead of NPA that year assuming there was little recruitment. CPUE index could be used as a lower-level indicator to make adjustments to the management decision (or adjust the order of the fat and CPUE indices in the hierarchical decision tree). Knowledge of the fishery dynamics in the ecosystem makes the hierarchical decision tree particularly useful for NPA. Potential caveats include uncertainty in the CPUE series if there are impacts due to differential targeting or changing selectivity over time. Another major caveat is that the hierarchical decision tree approach does not explicitly consider uncertainty.

Traffic lights

The traffic light approach is another multi-indicator approach. Color-based categories are assigned to certain conditions based on the indicator values are either "safe" (green), "dangerous" (red), or somewhere in between. These types of indicators could be incorporated into hierarchical decision trees described above, or used independently. For example, a primary control rule may be based on an upper-level indicator (e.g. no fishing if the proportion of "fat" individuals is below a certain amount at the beginning of the season), and CPUE could be used as an indicator to determine the length of the fishing season at a particular seamount or overall catch or effort limits. The main challenge of this approach is determining the threshold that would be categorized as "safe" or "dangerous" (Caddy, 2009, 2004; Caddy et al., 2005).

Species composition data, CPUE data, and the fat index could be useful indicators in a traffic light system for NPA. Uncertainty in the CPUE series and any potential changes in selectivity should be considered when using this approach. Like other indicator-based approaches, uncertainty is not explicitly considered. However, this approach could be helpful based on the improvement of the fat index as an indicator, the consideration of species composition, and if reference points can be well-defined.

Sequential trigger framework

Similar to traffic lights, a sequential trigger framework is a multi-indicator approach that can be used separately or in conjunction with hierarchical decision trees. The trigger system evaluates indicators relative to reference values (i.e. triggers). The triggers do not need to be directly related to stock status, but could correspond to a state of the fishery that requires a management response, ranging from biomass proxies, fishing mortality targets or limits, or another situation using expert judgment. The framework can use single or multiple indicators. Like the other indicator approaches, a major drawback is the lack of consideration of uncertainty in the indicator and the trigger itself.

Typically there are three trigger levels: 1) proxy limit reference point below which fishing would stop, 2) a trigger that invokes a response requiring more data collection or other response before further fishing could occur and 3) a level above which catch or fishing could increase. Trigger #2 typically recommends further data collection, in which case the sequential trigger framework would eventually not be used anymore if another option was available with improved data collection.

Triggers for NPA could be related to the fat index, CPUE index, or an index related to species composition of the catch.

Triggers for SA could be the CPUE index or using the length at 50% maturity relative to the mean length of the catch or other important percentile of the length composition of the catch.

5. Conclusions and recommendations

5.1. North Pacific Armorhead

Depletion analysis has already been used for the Southeast Hancock Seamounts. Somerton and Kikkawa (1992) applied depletion analysis for each fishing season from 1978-1984 when US observers onboard Japanese trawlers conducted 10 fishing trips to SE Hancock Seamount. The depletion analysis used the daily average catch (kg) per hour of fishing, the cumulative catch of NPA up to the beginning of the particular fishing day, and estimated the catchability coefficient and initial biomass from the regression of CPUE and cumulative catch. The analysis also tested whether the initial biomass estimates at the start of the season represented total biomass or only the fishable portion of the stock (i.e. corrected Leslie estimates). Variances were estimated using equations described in the appendix of Somerton and Kikkawa (1992).

Depletion analysis could be repeated by coding the depletion analysis using Bayesian priors on initial biomass and the catchability coefficient to propagate estimates of uncertainty in the estimates of depletion (Stewart et al., 2019). I would recommend this approach if within-season management or seamount-specific depletion estimates were desirable with management goals.

A production model was already applied (Yonezaki et al., 2012), although I have not been able to find the study to review methods and conclusions. The Phase I review of previous stock assessments noted that the surplus production model was attempted but results were highly uncertain, attributing the uncertainty to large uncertainties in fisheries data from the initial exploitation phase and significant variation in recruitment. With investigation into the early catch uncertainty, it is possible that surplus production models would be useful to represent either stock status and MSY by seamount or for the NPA population as a whole. However, if a surplus production model was applied to the NPA population as a whole, it would be difficult to allocate catch by seamount given recruitment and population dynamics could vary widely between seamounts. Perhaps it would be possible to code a surplus production model where carrying capacity K varied by seamount but the intrinsic growth rate r and catchability coefficient q are shared across seamounts (or other meaningful combinations of shared parameters). In this case, approximations of MSY could be calculated by seamount. However, further discussion on reference points and management objectives for NPA would be required before undertaking this task, as it may include more modeling and assumptions than its worth if a simpler approach would be useful for management due to the highly variable nature of NPA.

Indicator approaches may be the best option for NPA with current data available for tying quasi-assessments with decision control rules. These could serve as proxy assessments while further research is conducted into how to potentially use the fat index in place of length composition data. At that point, the fat index could either be used as an improved indicator relative to the proportion of population mature (comparing fat index composition relative to maturity indicators) or relative to length-based (or "fat index-based") reference points (Babcock et al., 2013; Cope and Punt, 2009).

5.2. Splendid Alfonsino

While indicator approaches may be useful for NPA due to the unique life history and high recruitment variability, there is less of a need to rely on them for SA because the life history of SA is more typical and recruitment is generally constant. The limiting factor to SA stock assessment seems to be uncertainty in the data inputs such as the CPUE series, biological parameter estimates, and lack of extensive use of the length composition from the observer program. These data uncertainties would need to be addressed before using an indicator-based approach, in which case they might as well be used in a model-based assessment to more formally estimate stock status and develop decision rules. In the case where a model-based assessment is developed for SA, the data inputs could still be used in any indicator-based approach applied to NPA for comparison and determine whether the approaches would lead to the same management recommendation.

YPR was applied to SA in the SE-NHR by Sawada and Yonezaki (2019), repeating the analysis of Takahashi (2018). The preliminary analysis identified that growth overfishing was likely before the implementation of a higher mesh size in 2019, as individuals less than 2 years old accounted for most of the catch and the age at capture was less than 1 year. However, maximum yield occurs at an age at capture much higher than 2 years. The increase in mesh size was implemented in 2019 to conserve spawning biomass and obtain higher economic value as indicated by the YPR results. As noted by Sawada and Yonezaki (2019), the YPR analysis could be improved by considering whether a knife-edge selectivity function is appropriate for the SA fishery on the Emperor Seamounts or whether an alternative selectivity function should be used. The YPR analysis should at least be extended to include maturity information for a spawning biomass per recruit (SBPR) analysis which would evaluate how the spawning stock changes at various ages at selectivity and fishing pressure. This YPR analysis did consider uncertainty in estimates of *M,* but could be repeated with other updates to local life history parameters as a result of continued collection of biological information.

Further review of the data may be helpful to narrow down whether a model-based stock assessment, such as an SCAA or surplus production model, would be appropriate given uncertainties in the early catch time series, CPUE series, and availability of length composition data from the scientific observer program. These data uncertainties have held back stock assessment of SA thus far. Unfortunately, these same data uncertainties would also apply for data-limited, indicator-based approaches that would be the alternative to a model-based assessment. The best opportunity to improve SA assessment would be to rely on or improve the scientific observer program collecting length composition and biological data for updating life history parameters. There are several life history-based indicators and length-based models that could be useful to assess relative stock status of SA that would avoid issues relating to uncertainties in the early catch history or issues with the CPUE series related to targeting and potential hyperstability.

6. Follow-up

6.1. Questions sent to Members

1) Are catch and effort data available by seamount for NPA and SA for all Member fleets?

- If so, for which years?
- Are these data also available by month?

2) It was mentioned in personal communication that the early catch time series (e.g. 1967-2001) may be uncertain for some fleets.

- Has any work been done to reduce uncertainty in and/or reconstruct the early catch time series?
- Are there any other years or fleets that may not be representative of total catch besides from 1967-2001?

3) Literature review and the report presented under item a) of the November meeting mention a scientific observer program collecting biological information (lengths, weights, maturity, ages) for Japanese and Korean fleets. Methods used on Japanese vessels are summarised in Sawada et al. (2018) and seem to have been used to update biological parameter estimates by Takahashi (2018) but I could not find other reports on where these data might be held or used.

- Which fleets have been participating in the collection of these biological data via scientific observer programs?
- Are NPA and SA both included in the biological sampling?
- Do these data exist in a form that could be used to update biological parameters, use length composition data in assessments (SA), or continue development of the fat index (NPA)?

6.2. Summary of data sources

The following is the full list of data sources to be obtained for stock assessment of NPA and SA. Section 2 separates these data sources by category and discusses their potential use in stock assessment. Some of the following data sources could be used for more than one assessment input (e.g. biological data from the scientific observer program could inform the NPA fat index and update life history parameter estimates for both NPA and SA).

1) Total catch and effort (NPA and SA)
   a) 1967-2001: Total catch (tons) and effort (number of hours fished) from the Japanese and Russian bottom trawl fishery (data held by Japan and Russia)
   b) 1967-2001: Seamount where gear was deployed (data held by Japan)
   c) 2001-2019: Total catch and effort (number of fishing days, number of vessels) for the Russian longline and bottom trawl fleets (reported to NPFC)
   d) 2002-2019: Total catch and effort (number of fishing days, number of vessels) for the Japanese gillnet and bottom trawl fleets (reported to NPFC)
   e) 2004-2019: Total catch and effort (number of fishing days, number of vessels) for the Korean longline and bottom trawl fleets (reported to NPFC)
   f) 2017-2019: Total catch and effort by seamount by gear by Member (reported to NPFC)
2) Biological data to inform life history parameters and composition time-series (NPA and SA)
   a) 2009-2020: Scientific observer program on Japanese fishing vessels (data held by Japan)
3) Fishery-independent surveys: species identification and distribution (NPA and SA)
   a) 2014-2020: Acoustic survey of seamounts for NPA, data held by Japan (Matsuura et al., 2018). Acoustic surveys use a quantitative echosounder for NPA, SA, and prey organisms. This acoustic survey can determine the density distribution of fish using the backscattering strength of fishing measured along the echosounder transect lines and the target strength of the target species. Species identification is vital for estimates of density distribution, and can be done by understanding the horizontal and vertical distributions of the target species. This acoustic survey

focused on determining the distribution and habits of NPA and SA since 2016 (although the survey has been occurring since 2014).

4) Fishery-independent surveys: abundance indices (NPA only)
    a) 1985-1990: Bottom longline and trawl surveys (n=10) of SE Hancock Seamounts specifically designed for NPA by USA (Somerton and Kikkawa, 1992). Bottom longline better accounted for NPA on the steep slopes of the seamount as well as the flat tops, while bottom trawls could only operate along the flat tops. The use of bottom longline allowed the entire seamount population to be sampled. It is possible that SA were observed in this survey, but Somerton and Kikkawa (1992) does not mention the handling of other species when discussing this NPA-focused survey.
    b) 2005-2007: Trawl survey of major seamounts (Colohan, Milwaukee, Kimmei, Koko Seamounts, data likely held by Korea, need more information on this survey).
5) Biological information: NPA
    a) Length-weight: Somerton and Kikkawa (1992) published a relationship between weight, body depth, and fork length from fishery-independent trawl surveys at the SE Hancock seamounts. Using bottom longline gear, these surveys were representative of the entire demersal stock (see Section 2.2.1).
    b) Maturity
        i) Maturation and reproductive cycle described in Yanagimoto and Humphreys (2005)
        ii) Description of maturation data relative to fat index described in Humphreys et al. (1989)
    c) Natural mortality and maximum age: Bottom longline surveys estimating relative abundance over time for two cohorts (Somerton and Kikkawa, 1992)
    d) Length-at-age: Aging data associated with Humphreys (2000)
6) Biological information: SA
    a) Length-weight: Parameter estimates from various studies worldwide available in Table 36 of Shotton (2016)
    b) Maturity: Age and length at 50% maturity from studies around the world are collected in Table 38 of Shotton (2016)
    c) Natural mortality and maximum age
        i) Estimates of natural mortality by sex and overall for five studies from Chile based on empirical relationships are available in Table 40 of Shotton (2016).

ii) Estimates of natural mortality by sex using multiple models for New Zealand stocks available in Table 41 of Shotton (2016) from Massey and Horn (1990)

iii) Estimates of M from the Emperor Seamounts calculated empirically from local estimates of von Bertalanffy growth parameters using empirical estimator of *M* from Then (2015): $M = 4.118k^{0.73}Linf^{-0.33}$, where estimates of von Bertalanffy parameters were Linf = 52.602 and k = 0.092 to obtain an M = 0.195 (Sawada and Yonezaki, 2019).

iv) Takahashi (2018) assumed M = 0.2 using the estimator by Djabali et al. (1994)

v) Maximum ages from various studies are described in Sawada et al. (2018) (around 20 years in the North Pacific).

d) Length-at-age: Takahashi (2018) estimated parameters of von Bertalanffy growth function for body weight (g) at age (t) of SA in the Emperor Seamounts using a wide size range of individuals collected through the NPFC scientific observer program: $W_t = 1852.35(1-e^{-0.148(t+2.926)})^3$ (Sawada and Yonezaki, 2019), where Linf = 52.602 cm and k = 0.092/year.

e) Fecundity

i) Studies have found that SA exhibit asynchronous oocyte development, meaning that batch spawning (i.e. multiple spawning per reproductive season) is likely to occur (Alekseev et al., 1986)

ii) Lehodey (1997) estimated an allometric relationship between fork length and fecundity, where $E = 0.00067*FL^{5.62}$, where E = eggs, FL = fork length in cm, corresponding to 700,000 eggs for 40 cm FL. The allometric relationship describes the number of oocytes, and does not consider batch fecundity.

iii) Spawning season varies geographically, and is likely to be summer in the Emperor Seamounts from larvae collection in July 1984 at the SE Hancock seamount based on back-calculation of daily otolith increments and seasonal patterns in the gonadosomatic index (Sawada et al., 2018; Takahashi, 2018).

7. References

Alekseev, F.E., Alekseev, E.I., Trunov, I.A., Shlibanov, V.I., 1986. Macroscale water circulation, ontogenetic geographical differentiation and population structure of alfoncino, Beryx splendens Lowe, in the Atlantic Ocean (No. ICES CM 10).

Babcock, E.A., Coleman, R., Karnauskas, M., Gibson, J., 2013. Length-based indicators of fishery and ecosystem status: Glover’s Reef Marine Reserve, Belize. Fisheries Research.

https://doi.org/10.1016/j.fishres.2013.03.011

Caddy, J.F., 2009. Practical issues in choosing a framework for resource assessment and management of Mediterranean and Black Sea fisheries. Mediterranean Marine Science. https://doi.org/10.12681/mms.124

Caddy, J.F., 2004. Current usage of fisheries indicators and reference points, and their potential application to management of fisheries for marine invertebrates. Canadian Journal of Fisheries and Aquatic Sciences. https://doi.org/10.1139/f04-132

Caddy, J.F., Wade, E., Surette, T., Hebert, M., Moriyasu, M., 2005. Using an empirical traffic light procedure for monitoring and forecasting in the Gulf of St. Lawrence fishery for the snow crab, Chionoecetes opilio. Fisheries Research. https://doi.org/10.1016/j.fishres.2005.06.003

Cope, J.M., 2021. Natural Mortality Estimators [WWW Document]. The Barefoot Ecologist's Toolbox. URL http://barefootecologist.com.au/shiny_m.html (accessed 21).

Cope, J.M., 2013. Implementing a statistical catch-at-age model (Stock Synthesis) as a tool for deriving overfishing limits in data-limited situations. Fisheries Research. https://doi.org/10.1016/j.fishres.2012.03.006

Cope, J.M., Punt, A.E., 2009. Length-Based Reference Points for Data-Limited Situations: Applications and Restrictions. Marine and Coastal Fisheries. https://doi.org/10.1577/c08-025.1

Cope, J.M., Thorson, J.T., Wetzel, C.R., DeVore, J., 2015. Evaluating a prior on relative stock status using simplified age-structured models. Fisheries Research. https://doi.org/10.1016/j.fishres.2014.07.018

Djabali, F., Mechailia, A., Koudil, M., Brahmi, B., 1994. A reassessment of equations for predicting natural mortality in Mediterranean teleosts. Naga 17, 33–34.

Dowling, N.A., Dichmont, C.M., Haddon, M., Smith, D.C., Smith, A.D.M., Sainsbury, K., 2015. Empirical harvest strategies for data-poor fisheries: A review of the literature. Fisheries Research. https://doi.org/10.1016/j.fishres.2014.11.005

Froese, R., 2004. Keep it simple: three indicators to deal with overfishing. Fish Fish 5, 86–91.

Hilborn, R., Walters, C.J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman & Hall, London.

Humphreys, R.L., 2000. Otolith-based assessment of recruitment variation in a North Pacific seamount population of armorhead (Psudopentaceros wheeleri). Marine Ecological Progress Series 204, 213–223.

Humphreys, R.L., Winans, G.A., Tagami, D.T., 1989. Synonymy and life history of the North Pacific pelagic armorhead, Pseudopentaceros wheeleri,, Hardy (Pisces: Pentacerotidae). Copeia 1, 142–153.

Kiyota, M., Nishida, K., Murakami, C., Yonezaki, S., 2016. History, Biology, and Conservation of Pacific Endemics 2. The North Pacific Armorhead, Pentacerous wheeleri (Hardy, 1983) (Perciformes, Pentacerotidae). Pac. Sci. 70, 1–20.

Lehodey, P., Grandperrin, R., Marchal, P., 1997. Reproductive biology and ecology of a deep-demersal fish, alfonsino (Beryx splendens) over the seamounts off New Caledonia. Mar. Biol. 128, 17–27.

Massey, B.R., Horn, P.L., 1990. Growth and age structure of alfonsino(Beryx splendens)from the lower east coast, North Island, New Zealand. New Zealand Journal of Marine and Freshwater Research. https://doi.org/10.1080/00288330.1990.9516407

Matsuura, T., Hasegawa, K., Sawada, K., Yonezaki, S., Kiyota, M., 2018. Report of the scientific survey in the southern Emperor Seamounts (southern ES) area in 2017: Results of the acoustic data analysis (No. NPFC-2018-SSC-BF01-WP04). North Pacific Fisheries Commission.

McAllister, M.K., Pikitch, E.K., Babcock, E.A., 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Canadian Journal of Fisheries and Aquatic Sciences. https://doi.org/10.1139/f01-114

Methot, R.D., Wetzel, C.R., 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research. https://doi.org/10.1016/j.fishres.2012.10.012

Nishimura, A., Yatsu, A., 2008. Application of surplus-production models to splendid alfonsino stock in the Southern Emperor and Northern Hawaiian Rdige (SE-NHR) (No. Appendix C).

Prager, M.H., 1992. A Surplus-Production Model Incorporating Covariates. Collective Volumes of Scientific Papers, International Commission for the Conservation of Atlantic Tunas 28, 218–229.

Prince, J.D., Dowling, N.A., Davies, C.R., Campbell, R.A., Kolody, D.S., 2011. A simple cost-effective and scale-less empirical approach to harvest strategies. ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsr029

Sawada, K., Ichii, T., 2020. Blast from the past: a brief summary on the past studies for bottom fish stocks in the Emperor Seamounts area (No. NPFC-2020-SSC BFME01-WP05). North Pacific Fisheries Commission.

Sawada, K., Nishida, K., Yonezaki, S., Kiyota, M., 2018. Review of biology and fisheries of splendid alfonsino (Beryx splendens), especially in the Emperor seamounts area (No. NPFC-2018-SSC BF01-WP03). North Pacific Fisheries Commission.

Sawada, K., Nishida, K., Yonezaki, S., Kiyota, M., 2017. Application of the directed CPUE method to the multispecies bottom fisheries in the Emperor Seamounts region, for the monitoring of stock status and fishing activity (No. NPFC-2017-SSC NPA02-WP02 (Rev. 1)). North Pacific Fisheries Commission.

Sawada, K., Yonezaki, S., 2019. Yield-per-recruit analysis of splendid alfonsino in the Emperor Seamounts (No. NPFC-2019-SSC BF02-WP01). North Pacific Fisheries Commission.

Shotton, R., 2016. Global review of alfonsino (Beryx spp.), their fisheries, biology, and management (No. FAO Fisheries and Aquaculture Circular No. 1084).

Somerton, D.A., Kikkawa, B.S., 1992. Population dynamics of pelagic armorhead (Pseudopentaceros wheeleri) on Southeast Hancock Seamount. Fish. Bull. 90, 756–769.

Stewart, D.R., Butler, M.J., Johnson, L.A., Cajero, A., Young, A.N., Harris, G.M., 2019. Efficacy of depletion models for estimating abundance of endangered fishes in streams. Fisheries Research. https://doi.org/10.1016/j.fishres.2018.09.026

Takahashi, Y., 2018. A study on age, growth, and harvest strategy of the alfonsino (Beryx splendens) in the Emperor seamounts water (Masters Thesis). Tokyo University of Marine Science and Technology.

Takahashi, Y., Sasaki, T., 1977. Trawl fishery in the central North Pacific Seamounts (Kita Taiheiyo cyubu kaizan ni okeru tororu gyogyo), Northern waters groundfish fishery data (No. 3). Far Seas Fisheries Research Laboratory, Japan.

Then, A.Y., Hoenig, J.M., Hall, N.G., Hewitt, D.A., Jardim, H.E.E., 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsu136

Wetherall, J.A., Yong, M.Y.Y., 1986. Problems in assessing the pelagic armorhead stock on the central North Pacific Seamounts (No. NOAA Tech. Repo. NMFS 43). Department of Commerce.

Winker, H., Carvalho, F., Kapur, M., 2018. JABBA: Just Another Bayesian Biomass Assessment. Fisheries Research. https://doi.org/10.1016/j.fishres.2018.03.010

Winker, H., Carvalho, F., Thorson, J.T., Kell, L.T., Parker, D., Kapur, M., Sharma, R., Booth, A.J., Kerwath, S.E., 2020. JABBA-Select: Incorporating life history and fisheries' selectivity into surplus production models. Fisheries Research. https://doi.org/10.1016/j.fishres.2019.105355

Yanagimoto, T., 2004. Groundfish fisheries and the biological properties of alfonsino (Beryx splendens) Lowe in the Emperor Seamounts. Fisheries Biological and Oceanography Kuroshio 5, 99–109.

Yanagimoto, T., Humphreys, R.L., 2005. Maturation and reproductive cycle of female armorhead (Pseudopentaceros wheeleri) from the southern Emperor-northern Hawaiian Ridge Seamounts. Fish. Sci. 71, 1059–1068.

Yonezaki, S.T., Okuda, T., Kiyota, M., 2012. Application of the non-equilibrium surplus-production models to North Pacific armorhead in the Southern Emperor and Northern Hawaiian Ridge (SE-NHR) seamounts. Document submitted to the Second Intergovernmental Meeting on Establishment of New Mechanism for Management of High Seas Bottom Trawl Fisheries in the North Western Pacific Ocean Armorhead WA 2012 Doc-2-Re2, 22.