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Literature review and data availability for North Pacific Armorhead stock assessment

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Introduction

The North Pacific Armorhead (*Pentaceros wheeleri*) are captured in bottom trawl and bottom gillnet fisheries conducted by Japan, Korea and Russia in the Emperor Seamounts of the North Pacific Ocean. The fishery is conducted in International waters which are managed by the North Pacific Fisheries Commission (NPFC), a Regional Fisheries Management Organization (RFMO). Currently, there is no estimate of stock status made for these species that could guide a sustainable harvest. The North Pacific Armorhead (NPA) is a priority species for the NPFC in the Emperor Seamounts and has exhibited characteristics of overharvest (recruitment overfishing and declining catches over the last few decades). The Small Science Committee on Bottom Fish and Marine Ecosystems of the NPFC has committed to initiating a sustainable and precautionary approach to managing its bottom fish fisheries including the fishery for NPA as part of its five-year workplan (2020-2025).

Objectives

The objectives of this document are to briefly summarize the existing literature on NPA with regards to its important life history processes, to identify data availability for the stock in the NPFC Convention Area and to identify critical data gaps for assessing the status of the stock. The document is meant as a working paper that will form the basis of a common starting point from which to discuss appropriate management steps for the NPA in the NPFC Convention Area. The paper will be discussed at the 1st Bottom Fish and Marine Ecosystems Small Scientific Committee meeting (November 16-18, 2020).

Review of research on important life history processes

The North Pacific Armorhead are widely distributed over the subarctic central and eastern North Pacific at depths from 150-1500 m. They are primarily distributed as demersal adults on the

Emperor Seamounts and North Hawaiian Ridge, but they have been captured in continental slope waters both in the NW and NE Pacific Ocean. The NPA has supported a fishery in the NW Pacific Ocean since 1967. Their fishery, biology and management in the Emperor Seamounts has been summarized in numerous NPFC working and informational documents since 2008 (e.g. Kiyota et al., 2011, Kiyota et al., 2016, Sawada and Yonezaki 2019, Sawada and Ichii 2020). Here, we focus on summarizing the current knowledge that may be important for future management directions, including factors affecting recruitment, mortality and distribution, as well as any previous stock assessments that have been completed for the species.

Factors affecting recruitment

North Pacific Armorhead has an unusual life history that has confounded previous attempts at assessing stock status. The information in Table 1 presents an overview of studies to date on the early life history and recruitment of NPA. Spawning is believed to occur from November to March, with extended pelagic larval and juvenile stages. Pelagic juveniles are believed to drift eastward and north from the Emperor Seamounts to the Alaska gyre before returning, presumably via active swimming. Juveniles then settle, possibly in the spring of their 2nd year, to a demersal existence at between 1.5 and 4 years of age. Two other important features of the transition from pelagic to demersal life history stage are the transition from “fat” to “lean” morphotypes and the development of gonads. Recruitment has been shown to be extremely episodic for NPA with large year classes recorded in 1973, 1992, 2004, 2008, 2010, and 2012.

Based on their life history (extended spawn timing, followed by extended larval and juvenile stages before recruitment to the demersal stage), it is likely that NPA recruitment, as with similar species, might have complex relationships to the environment, where water temperature and currents would play a strong role in controlling recruitment. There have been attempts to link the growth and recruitment of NPA to oceanographic and atmospheric features, by using such methods as particle drift models and relationships of recruits to large scale ocean basin processes such as the Pacific Decadal Oscillation. These were most recently attempted by Yonezaki et al. (2017). None of these studies attempting to link recruitment to early life history processes has been fully successful at explaining recruitment variability. It is also important to note that year-class-strength in NPA appears to be independent of the spawning biomass.

Table 1. Summary of studies that examined recruitment processes for North Pacific Armorhead in the NW Pacific Ocean.

Relationship	Description	Source/citation
Recruitment and excessive initial catch	In the 1990s, there was continued low recruitment of the stock. Initial catch by Soviet and Japanese trawlers was excessive in the early 1970s, which may have	Wetherall & Yong, 1986

	driven spawning biomass down to critical, unrecoverable levels.	
	Recruitment since the 70s has exhibited significant year-to-year fluctuations. Recruitment is very low from 2013 on.	Kiyota, Nishida, Murakami & Yonezaki, 2016 Okuda & Kiyota, 2016
Timing and duration of recruitment	Recruitment to the seamounts is reported to occur within a short period from spring to summer. The recruitment peak estimated from Japanese trawl CPUE is suggested to be from April-May, with potential additional stretches in August and September. Recruitment is expected to mainly occur June to August. Seasonality of recruitment may differ year to year, as was reported between 1972-1973 when recruitment was high.	Kiyota *et al*., 2016 Boehlert & Sasaki, 1988 Humphreys *et al.*, 1993 Boehlert & Sasaki, 1988
Episodic recruitment and fluctuations	Annual fluctuations in population biomass and commercial catch are the result of the irregular episodic patterns that have been noted in NPA recruitment at the SE-NHR. To the southeast of the Hancock Seamount, recruitment was described as highly sporadic from 1978-	Kiyota *et al*., 2016 Somerton & Kikkawa, 1992

	1990. The total biomass in this region during this period therefore underwent significant changes. Japanese trawl CPUE data showed large fluctuations in the 1969-1977 period that was independent of spawning biomass (when biomass was at high levels). No clear correlation was found between recruitment and spawning stock biomass between 1980-1990, when the spanning biomass was significantly lower. Determination of the spawner-recruit relationship is challenging due to large-scale fluctuations in recruitment.	 Wetherall & Yong, 1986 Somerton & Kikkawa, 1992 Yonezaki *et al*., 2017
Recruitment and target species	In studied years (2010, 2012) where recruitment was strong, armorhead had a target species pattern, while alfonsino curves were characterized as bycatch species. The reverse pattern was found in 2019 where armorhead showed a bycatch curve pattern.	Sawada *et al.*, 2017
Recruitment and age	Recruits to the seamount may attain reproductive maturity in several months. Life span at the seamounts appears to be around 4-5 years but may be longer.	Somerton & Kikkawa, 1992 Somerton & Kikkawa, 1992

Recruitment and body size	Upon settlement to the seamount summits or continental slopes, recruits are adult size. FL of recruits were suggested to be within the range of 25-33 cm, and may differ between seamounts. FL 15-40 cm have been reported. At the southeast Hancock seamount region, mean body length of females was found to be negatively correlated with recruitment strength. 1989 was found to be a weak recruit year, with a lower variability but longer mean pelagic duration as well as longer body length. The study showed a general inverse size-recruitment-strength relationship. The relationship may be affected by density-dependent (proposed by Borets, (1997)) and density-independent factors.	Kiyota *et al*., 2016 Humphreys & Tagami, 1986; Humphreys *et al*., 1989 Humphreys, 2000
Recruitment and fat type	Historically, recruitment patterns could not be derived for NPA from length-frequency analyses like other fisheries, as monthly-frequency samples showed no increase in smaller size class. Different fat content morphotypes were used for temporal recruitment patterns. Gonad development through time (maturation) correlates with transformation	Boehlert and Sasaki, 1988

	from a “fat” to “intermediate” to “lean” morphotype.	
	A low relative abundance of “fat” type individuals during recruitment was noted at the SE-NHR seamounts due to a body depth transformation through time.	Humphreys *et al*., 1989
	While ocean fat types had a wide range, only adult lean, intermediate and fat types were present at the SE-NHR seamounts. The lean type at the SE-NHR had the widest range of physical condition. Individuals of an “ultra-lean” type were noted.	Humphreys *et al*., 1989
	New recruits after settlement had high body condition and higher fat index (FI).	Boehlert & Sasaki, 1988; Martin *et al*., 1992
	Higher FI corresponding to new recruits was proposed to be due to an absence of a monogenean parasite in demersal specimens. The parasite *Microcotyle macropharynx* is characterized by rapid infection rates and maturation in the demersal zone.	Humphreys *et al*., 1993
	Recruit cohorts were traced over time with success by FI (Hancock Seamount).	Somerton & Kikkawa, 1992
	Recruits’ significant amount of fat will be metabolized throughout the 3-4 last years of their lives.	Seki & Somerton, 1994

	A large proportion of “lean” type fish were found to have spent gonads, which points to an inability to recover from spawning. “Lean” fish were found to be deteriorating (skin). Given the estimations on spawning episodes timing, it was expected that catch proportions of lean fish would be high post-spawning episode. This was not found by research cruises in March 1981. Fat types did not appear to be separated by depth.	Uchida & Tagami, 1984 Kuroiwa, 1973 Uchida & Tagami, 1984
Oocyte development	Asynchronous oocyte development was reported.	Yanagimoto & Humphreys, 2005
Spawning episodes	Gonadal somatic index (GSI) was used to estimate that the spawning period at the SE-NHR is between November and March. GSI trends and ovarian histology were analysed and found to indicate spawning from November to February with a peak in December to January. Winter spawning timeline was described; beginning in early December, spawning peaked from late December to January and continued with a decline from February to March.	Sasaki, 1974 Yanagimoto & Humphreys, 2005 Bilim *et al.*, 1978

	Due to the absence of mature females in bottom trawls, water column spawning above the seamounts is suggested. Hatching was estimated (from otolith daily growth increments) to be between December and February. NPA has been suggested to be semelparous due to poor reported physiological condition and an absence of older fish within the population. It remains undetermined whether “lean” fish recover and spawn again.	Borets, 1975 Uchiyama & Sampaga, 1990; Murakami, Yonezaki, Suyama, Nakagami, Okuda & Kiyota, 2016 Humphreys & Tagami, 1986 Uchiyama & Sampaga, 1990
Productivity	Warm years are suggested to be more productive for the survival of young armorhead, due to a similar trend in zooplankton prey. Feeding conditions and interannual variability will affect larval and juvenile stages.	Fedosova, 1980
Ocean currents and atmospheric patterns	Recruitment strength may be influenced by ocean currents. Oceanographic processes were suggested to have an effect on recruitment fluctuations, however no studies exist to confirm this. Interannual variation in ocean currents, feeding, etc. affects NPA recruitment strength.	Boehlert & Sasaki, 1988 Somerton & Kikkawa, 1992 Boehlert & Sasaki, 1988

	Positions of climatic features such as the Aleutian Low (longitudinal) may affect surface currents through winter wind variations. Surface drift is affected by variability in features including this and the subtropical front, which will affect young NPA. If NPA is transported via drift to other regions, weak year classes due to later-life mortality may be resultant. Large annual fluctuations in recruitment suggested to be affected by a positive North Pacific Gyre Oscillation (NPGO) index. The relationship between armorhead and their marine environment was examined by a particle tracking experiment. A year with higher catch was found when the Pacific Decadal Oscillation index was negative. Recruitment strength may have been influenced by the central and northeast North Pacific ocean high surface water temperature.	Seckel, 1988 McNally, 1981; Boehlert and Sasaki, 1988 Boehlert & Sasaki, 1988 Murakami *et al*., 2016 Yonezaki *et al*., 2017
Seamount detection	The NPA recruitment mechanism is unknown, however effects of long-distance detection of	Boehlert & Sasaki, 1988

	seamounts is suggested to be important.	
Studies	While investigation of recruitment by characterizing survivors is often used, sampling of armorhead before recruitment remains a challenge due to the wide pelagic habitat and size range, isolation and expenses.	Humphreys, 2000

Factors affecting mortality

The factors affecting natural mortality for North Pacific Armorhead are generally unknown, but the available studies have been summarized in Table 2. Mortality in the pelagic early life history stages has not been studied. In the juvenile pelagic stages NPA have occasionally been found in the stomachs of whales. Natural mortality for demersal stages of NPA may be caused by predation from sharks and large piscivorous fishes, but causes are generally unknown. Because of their peculiar life history pattern, the maximum size occurs at settlement and somatic growth more or less ceases at that point. This means that maximum ages are unknown for the species and the species has a non-asymptotic growth curve. This makes natural mortality difficult to estimate using traditional analytical methods.

As a species that is relatively slow growing and reaches a fairly large body size and may live up to 30 years, it is expected that natural mortality would be relatively low. Natural mortality estimated by tracking cohorts has been estimated at 0.25 (Borets 1975) and 0.54 (Somerton and Kikkawa 1992). The Borets (1975) estimate has been discounted for a number of reasons including the unlikely pattern in mean age of fish at the beginning of the fishery (mean age increased rather than decreasing) and the age range used was considered excessive given the lengths observed.

Table 2. Summary of information on the mortality of North Pacific Armorhead within the NPFC region.

Relationship	Description	Source/citation
Natural predation	Predation on NPA is largely undescribed. NPA was discovered in *Balaenoptera brydei* stomach	Kiyota *et al*., 2016 Boehlert & Sasaki, 1988 (personal communication by

	content analysis. NPA was also reported in *Balaenoptera borealis* stomach contents. Likely, these predators consumed NPA in the pelagic stage. Demersal predation reports do not exist.	H. Kato) Chikuni, 1970; Kawamura, 1982 Kiyota *et al*., 2016
Longevity	Demersal fish are thought to survive after recruitment to the seamount for up to 4 years based on fork length distribution. NPA may die after one or two seasons, suggested by absences of individuals over age 3 on the seamounts. Reports of post-spawning emaciated individuals also indicate post-spawning mortality. Longevity and life histories may differ between different environments.	Somerton & Kikkawa, 1992 Uchiyama & Sampaga, 1989 Humphreys *et al*., 1984, Humphreys and Tagami, 1986 Uchiyama & Sampaga, 1990
SE-NHR fishing history	In 1967, large concentrations of armorhead were discovered over the SE-NHR. Exploitation followed throughout the Hawaiian archipelago. The Japanese commercial trawl fishery was established by the early 1970s. Between the Soviet Union and Japanese fleets, NPA suffered high exploitation rates in the area. From 1969-1976, seamounts	Uchida & Tagami, 1984 WPMFC, 2010 Uchida & Tagami, 1984

	differed in importance for catches. The Milwaukee Seamount group was the most productive.	
	The seamounts in the North Pacific fishing grounds differ from other trawling grounds and from each other in their features. 1972 trawl surveys showed differences in effective hauls and CPUE. Conditions were found to be difficult for trawling at, for example, Colahan Seamount compared to seamounts with sea beds that were easier to fish.	Kitani & Iguchi, 1974
	Between 1972-1976, Japanese trawl vessels caught an estimated 20,000-30,000 mt of NPA per year. While total estimated catch is unknown for the period for the Soviet Union, an estimation is that it was 100,000 mt from 1969-1970.	Gooding, 1980
	After 1977, catches declined drastically and remained at low levels in the years following.	Kiyota *et al*., 2016
	Nearly 1 million metric tonnes of NPA were harvested in the decade following the discovery by Soviet and Japanese trawlers.	Borets, 1975; Takahashi & Sasaki, 1977
	The Korean commercial fishery for NPA began in 2004.	Kiyota *et al*., 2016
	Russia’s commercial fishery ceased operations in the area after 2007. Korean trawl vessels and Japanese trawl	Kiyota *et al*., 2016

	and gill net vessels were operating through 2016. Sudden increases in catch (thus, biomass) are known to depend directly on recruitment. This was the case in 1992, when 14,000 tonnes was taken by the Japanese commercial fishery. Catches in 2004, 2008, 2010 and 2012 were large compared to other years. In 2012, Japanese catch was over 20,000 tonnes - which could be due to recruitment or stock recovery.	Kiyota *et al*., 2016

The distribution of North Pacific Armorhead

The distribution of North Pacific Armorhead appears to be limited to the Pacific Ocean. There are intermittent reports of catches of adult NPA in the California Current area, the Gulf of Alaska and off the southern Japan coast. However, the bulk of the adult population is believed to occur in the Northern Hawaiian Ridge and Emperor Seamounts. Table 3 summarizes the findings of studies on NPA distribution. During the pelagic phase, larval and juvenile fish have been captured throughout the North Pacific Ocean, but younger fish seem to be predominantly captured in the central North Pacific and nearer to the Emperor Seamounts. Pelagic stages of NPA are observed to aggregate in large schools near the surface, especially as juveniles. The older juvenile fish have been captured in “nursery” grounds in the NE Pacific (in the Gulf of Alaska), but also in other areas of the eastern Pacific (including south of the Hawaiian Islands), indicating that the dominant currents might exhibit a strong influence on the location where juvenile NPA are found.

After settling to demersal life stages, NPA are thought to have limited migration through the remainder of their lives, but no tagging studies have been attempted for this species. On seamounts NPA have been captured at depths from 150 to 1500 m. Within seamounts, diurnal feeding migrations have been observed, with NPA observed in aggregations at the summit or flanks of seamounts during the night and dispersing into the water column to feed during the daylight.

Table 3. Information on the distribution of North Pacific Armorhead from the literature at different spatial scales are included.

Relationship	Description	Source/citation
Global distribution	NPA was originally described as *Pentaceros richardsoni* Smith 1844 and was thought to be distributed worldwide, with high abundances in the North Pacific.	Fuji, 1986
	Before the discovery of NPA abundance at the SE-NHR, the centre of abundance of NPA was suggested to be around southern Japan. Fish found in the eastern North Pacific Ocean were thought to be transported away from the centre of abundance by the North Pacific current system.	Follett & Dempster, 1963; Kiyota *et al*., 2016
	Larvae and juveniles could have been distributed via the North Equatorial current to Japan.	Uda & Hasunuma, 1969
	NPA specimens may have been captured in the Kuroshio in 1986.	Boehlert & Sasaki, 1988
	This was previously opposed as juveniles had not been collected around Japan.	Zama *et al*., 1977
North Pacific: Occurrence and catch reports	NPA is characterized as a transboundary stock, but many populations of NPA are around the SE-NHR.	Boehlert & Sasaki, 1988
	Occurrence records show that NPA are widely distributed over the subarctic central and eastern North Pacific.	Boehlert & Sasaki, 1988

	The SE-NHR is thought to be the largest NPA spawning ground[1] due to various reports of sexually mature individuals in the region[2].	[1]Humphreys & Tagami, 1986; Boehlert & Sasaki, 1988. [2]Sasaki, 1974; Bilim *et al*., 1978; Yanagimoto & Humphreys, 2005
	Bottom trawl or deep-sea angling on Kyushu-Palau Ridge collected NPA.	Mochizuki, 1982
	Bottom longline caught NPA at depths range of 290-410 off the Ogasawara Islands.	Yanagimoto *et al*., 2008
	Rockfish trawl fishery collected three specimens (two having lengths of 250 mm and 338 mm SL) on the continental shelf (96-100 m deep) off of Oregon.	Wagner & Bond, 1961
	The trawl fishery of California reported one individual at 210 m deep[1], while another was collected by drag fishery off central California at 450 m deep and described[2].	[1]Smith, 1965; [2]Follett & Dempster, 1963
	Occurrences have not been reported from off Alaska or British Columbia, though extensive trawling surveys have been undertaken.	Hughes, 1981; Alton, 1986
	Juveniles were caught during the night (under deck lights) by dip net in the eastern North Pacific and reports of fishing by hand line by a Japanese whaling vessel from 1976-1979.	Kiyota *et al*., 2016
	A possible demersal specimen was reported off	Abe, 1969; Kiyota *et al*., 2016: (pers. Comm.: J,

	Hachijo Island and discovery of a “good” fishing ground for the species was reported in this area and to the east. A Japanese commercial fishery targeting NPA in the area however was not developed and catch remains incidental.	Yonezawa, Tokyo Metropolitan Fisheries Experimental Station.)
Depth range	Though there are many literature references to NPA depth range, its vertical distribution remains unknown. Early exploratory trawl data estimates for depth range and secondary literature citing these should be interpreted with caution. The depth range in commercial fishing was 150-1,500 m. Aggregations were described on flat crests of seamounts from 160-4000m in depth, as well as on upper seamount slopes to 800 m deep. 5°C-20° C was the estimated tolerable temperature range for NPA, while 8°C-15° C was the suggested optimum range. Depth distribution of reproductive fish is suggested to be from 200-500 m deep. In the Emperor seamounts, larger individuals were caught at depths of 300-390 m, compared to shallower (200-290m) or deeper (400-490 m).	Kiyota *et al*., 2016 Wagner & Bond, 161; Follett & Dempster, 1963; Smith, 1965 Borets, 1981 Takahashi & Sasaki, 1977
Ocean currents and climatic factors	Oceanographic conditions are proposed to regulate the	Boehlert, 1986

	distribution for NPA due to the interval between spawning and recruitment. Surface currents were calculated using OSCAR to show west-blowing wind and surface-layer water streamed to the east-southwest in the winter at the SE-NHR.	 Howell, Borgrad, Morishige, Seki & Polovina, 2012
Distribution: Eggs	Eggs are reported to float in surface waters. It was suggested that given Howell *et al.* (2012) findings, eggs and hatchlings would move eastward or south-eastward if they only depend on the winter surface-layer current for movement, and may not reach the nursery ground. However, due to the highly epipelagic nature of eggs and larvae at the topmost part of the ocean surface, wind might be the predominant determinant of their movement. Similarly, in particle dispersion study surface wind was suggested to be an important consideration in addition to ocean current. Eggs at the SE-NHR seamounts likely are transported by the east-northeast current to the nursery ground. The current at from 35° to 45°N, 180° longitude was examined. NPGO parameters were investigated.[1] Eggs and	Bilim *et al*., 1978 Murakami *et al*., 2016 Yonezaki *et al*., 2017 Murakami *et al*., 2016; Howard, 2013 [1]Di Lorenzo, Schneider,

	larvae are likely to be transported to the nursery ground from the SE-NHR when the current from the SE-NHR to the nursery east-northeast strengthens, the SE-NHR wind blows from the south and the nursery ground wind is directed west-southwest (NPGO index is positive).[2]	Cobb, Franks, Chhak, Miller, McWilliams, Borgrad, Arango, Curchitser & Powell, 2008; [2]Murakami *et al*., 2016
Distribution: Larvae/Juveniles	Larvae are in the surface waters over and adjacent to the SE-NHR seamounts. Juveniles and subadults are in the epipelagic layer of the subarctic North Pacific Ocean. Young fish are in the epipelagic layer for 2+ years up to 4.5 years. Pelagic occurrences of larvae and juveniles were summarized by season, area, sampling gear and abundance. Specimens were collected in the SE-NHR area from February to April. Pelagic samples occurred in a range of sea surface temperatures from 8.6° C to 15.0° C. Larvae are suggested to be neustonic as they were collected during sampling using surface net tows. Surface gill net, dip net, or hand line were used for juveniles and subadults, suggesting that they occur close to the surface.	Kiyota *et al*., 2016 Boehlert & Sasaki, 1988 Boehlert & Sasaki, 1988

	NPA are proposed to spend up to 7 years in the pelagic zone based on the determination that ages 6-8 years were 26-30 cm (no otolith analysis for this).	Borets, 1979
	The hypothesis that the pelagic phase lasts up to 4-5 years, based on FL of 25-30 cm, was referenced.	Uchida & Tagami, 1984
	Unpublished manuscript information on sagittal check mark analysis was used to suggest that the pelagic phase mostly occurs between ages 1.5 to 2.5 years.[1] Age of new recruits is proposed to be 18 to 30 months and most sampled specimens remained in epipelagic zone for 2 to 3 years.[2]	Uchiyama & Sampaga unpublished manuscript; [1]Boehlert & Sasaki, 1988; [2]Humphreys *et al*., 1989
	The pelagic phase for fish with average FL of 310 to 320 mm was suggested to last from 726 to 900 days (mean 848-891 days) at the SE Hancock seamounts (1980, 1986, 1989). Otolith analysis was used, and supports the 1.5-2.5 year-long migration theory of Boehlert and Sasaki (1988).	Humphreys, 2000
	In all years, pelagic captures were limited to the North Pacific (East)[1], however larvae and juveniles were found near seamounts in spawning locations[2] and in whale stomach content	[1]Boehlert & Sasaki, 1988; [2]Komrakov, 1970; [3]Boehlert & Sasaki (pers. Communication with H. Kato)

	analysis.[3]	
Distribution: Demersal stage	The SE-NHR seamounts host the largest known demersal population of NPA. Seamount tops are greater than 250 m in depth and greater in the northern seamounts. NPA habitat is on the summits, flat tops and upper slopes of the seamounts. Habitat limits are suggested; NPA proposed not to inhabit deeper seamounts to the north of 35° N[1] and to be low in abundance to the east of 180° W on shallow seamounts[2]. The range of NPA was confirmed by the commercial fishing grounds (from the Hancock seamounts to the Koko seamounts) in the 1980s, as well as U.S. NMFS Honolulu Laboratory surveys. NMFS surveys showed NPA in small numbers on slopes in Northwestern Hawaii Islands. Demersal NPA have been reported from Japan and off the western coast of North America.	Kuroiwa, 1973; Takahashi & Sasaki, 1977; Humphreys & Tagami, 1986 Kiyota *et al*., 2016 [1]Takahashi & Sasaki, 1977; [2]Kuroiwa, 1973 Kiyota *et al*., 2016 Boehlert & Sasaki, 1988
Spatial distribution: Aggregations	Surface sampling and cetacean stomach content analysis pointed to aggregating behaviour in pelagic juveniles. Based on sei whale feeding patterns, it was suggested that NPA	Chikuni, 1970

	schools in surface waters. Aggregations at seamounts are based on food sources from horizontal flux past the seamounts and from interception of vertically-migrating prey items. CPUE was found to have two maxima; one in the morning and one in the evening. This indicates diurnal changes in school density on seamount summits. Daytime aggregations are suggested to be not as dense as other time intervals based on appearances using a fish scanner.	 Kiyota *et al*., 2016; Tseytlin, 1985; Porteiro & Sutton, 2007; Clark *et al*., 2010 Kitani & Iguchi, 1974
Vertical distribution: Diurnal vertical migration	Existing literature points to demersal fishes undertaking diurnal vertical migrations at seamounts. Acoustic studies showed an upward movement in fish towards the thermocline during the day, followed by a return to the top of seamounts at night at Zapadnaya and Academian Berg seamounts. Sampling showed aggregations near the summit at night during maximum catch. A gradual decrease in catch correlated with fishes' movement upward into the water column in the morning. Analysis of trawl CPUE acoustic images gave a contrasting hypothesis; NPA was suggested to return to the seamount tops at night from their water column daytime position. The NPA night time position is	Kiyota *et al.*, 2016, Kitani & Iguchi, 1974 Komarakov, 1970 Kitani & Iguchi, 1974

	suggested to be farther down seamount slopes or deeper. The absence of NPA aggregations over seamount summits during the day were reported, while at night NPA was present. Acoustic surveys were undertaken and results differed between seamounts for day and night.	 Humphreys & Tagami, 1986 Matsuura, Hasegawa, Sawada, Yonezaki & Kiyota, 2018
Horizontal distribution: Migration	There have been no tagging studies for the migration of NPA. Estimates regarding migration patterns for NPA have been constructed using its geographic occurrence, its size composition of pelagic samples and from North Pacific basin oceanographic features. Observations of juveniles in the high-seas squid drift net fishery (1980s) represented occurrences to the east, which was suggested to represent a migration by young fish (of 20-32 cm FL) Two migration routes were hypothesized for pelagic larvae and juveniles; to move towards the Northeast and i) remain in the subarctic water and return to the SE-NHR directly or passively (eastward current up to Gulf or Alaska, westward in Alaskan stream, southward in its branch along Emperor or Komandorski Ridge) or ii) follow a southern route in the California Current and subtropical gyre towards the	Kiyota *et al*., 2016 Yatsu *et al*., 1993 Boehlert & Sasaki, 1988

	Hawaiian Islands. The normal migration route for NPA is suggested to be the northern route and a circuit will take 1.5 to 2.5 years to complete, compared to the longer southern route (potentially up to 4.5 years to complete). The longer southern route may explain the occurrence of larger and older specimens in Northwestern Hawaiian Islands. Age 0 armorhead are likely to depend on passive transport for migration, while age 2 fish (mean body length of 268 mm SL) may be capable of active swimming, potentially even against or across currents in returning to spawning areas.	 Murakami, Yonezaki, Suyama, Nakagami, Okuda & Kiyota, 2016
Horizontal distribution: Post-recruitment movement	Post-recruitment movement between seamounts is hypothesized to be unlikely, however no evidence was provided.	Humphreys, 2000
Body length distribution	Body length ranges at the SE-NHR seamounts are narrow. Milwaukee seamount NPA analysis showed narrow unimodal distribution with a peak at 30 cm FL. Fish with lengths below about 25 cm were absent, potentially due to settlement at the seamount at this length. At Kanmu, Colahan and Kinmea seamounts, a similar distribution was noted around 27 cm FL. A length range of 26-33 cm	Kiyota *et al*., 2016 Chikuni, 1971 Iguchi, 1973 Takahashi & Sasaki, 1977

	FL was sampled by trawl fishing from 1969-1976. In 1972, smaller fish in the range of 20-24 cm FL were caught on the Milwaukee Seamount.	
	Pelagic individuals have been found within the range of 18 to 26 cm FL. Small individuals are poorly represented due to sampling gear type.	Boehlert & Sasaki, 1988
	A range of 27-32 cm FL was reported.	Sasaki, 1986
	A range of 25-33 cm FL was found at time of seamount settlement.	Humphreys *et al*., 1989
	The largest fish was recorded at 54.7 cm FL with 8 or more sagittal check marks.	Uchiyama & Sampaga, 1990
	Females were reported by several sources to have greater body lengths than males.	Sasaki, 1974; Humphreys & Tagami, 1986; Uchiyama & Sampaga, 1990
	The difference in body length between sexes was small and not found in small samples.	Kiyota *et al*., 2016
	The difference between sexes in mean body length was suggested to be less than 15 mm.	Uchiyama & Sampaga, 1990; Humphreys & Tagami, 1986
	Near the SE-NHR seamounts, smaller fish were sampled than other regions of the North Pacific.	Boehlert & Sasaki, 1988
	In Northwestern Hawaiian Islands, large benthic specimens of over 460mm FL were collected.	Randall, 1980; Humphreys *et al.*, 1989 (unpubl. Data D.T. Tagami)

Information from previous stock assessments

Traditional model-based stock assessments will not work for NPA due to their unusual life history (Somerton and Kikkawa 1992, Yonezaki et al. 2012). A surplus production model was attempted but results were highly uncertain. There are many difficulties in assessing these stocks, but in general they suffer from being a low value fishery, with unusual life history, that occurs in distant waters and as such there is a dearth of quality data by which to assess the stocks. The primary data available for assessing the stock is CPUE data from the fishery. In addition, most stocks were overexploited during the development of their fisheries in international waters and the data from the initial period of exploitation is sparse at best and some assessments have indicated that catch reporting during the early periods of the fishery were low. Table 4 shows the results of previous attempts at assessing the NPA stock in the North Pacific Ocean.

Table 4. Information on previous stock assessments of NPA from around the world.

Area	Description	Source/citation
North Pacific	Conventional stock dynamics models are not effective for NPA stock status analysis. Size composition of the catch cannot be used to differentiate cohorts, thus an age-structured model cannot be used. Similarly, length or weight-based models cannot be applied due to growth and weight trends with age.	Kiyota *et al*., 2016
	NOAA ship Townsend Cromwell gathered information during 9 cruises from October 1976 to April 1981.	Uchida & Tagami, 1984
	Stock information was collected around the Southeast Hancock Seamount during research cruises from 1985-1993.	Tosatto, 2010
	Due to large recruitment fluctuations, an autoregression model was determined to be a poor fit.	Wetherall & Yong, 1986

	A surplus-production model was used. Fisheries data from the initial exploitation phase contained large uncertainties and the significant variation in recruitment provided a challenge to examination of the spawning and recruitment relationship.	Yonezaki *et al*., 2012
	Stock biomass was estimated from FI composition changes and CPUE using the DeLury method from Seber (1982).	Somerton & Kikkawa, 1992
	Dynamics of NPA stocks in the past were investigated. More data is required on recruitment fluctuations and NPA biology for adequate stock assessment.	Okuda & Kiyota, 2016

Data availability

The data on North Pacific Armorhead collected on the Emperor Seamounts are fairly extensive (Table 5). The data includes a fairly complete catch and effort history since the initiation of the trawl fishery by Russia in 1967. The recent data includes spatially explicit (by seamount) catch and effort available from the NPFC annual reports for each gear type and Member (Japan, Korea, and Russia). Historical catch data from Japan also appears to indicate catch and effort for individual seamounts, while the early data from Russia does not include a spatial component.

A number of surveys have been primarily targeting North Pacific Armorhead. These are summarized in Table 6.

There are associated biological data from fisheries catch and surveys since 2009 (Table 7), however, this data is likely part of the data holdings of individual NPFC Members. There are some biological data that can be inferred from previous stock assessments. These parameters as well as some other miscellaneous results are found in Table 8.

Table 5. Data available on the catch and effort history of North Pacific Armorhead (some inferred from publicly available reports where the catch data was previously summarized).

Data type	Members	Data description	Years available	Data source/holder
Catch - trawl	Japan, Russia, Korea	Total catch reported to NPFC	2002-2019 - Japan, 2004-2019 - Korea, 2001-2019 - Russia	NPFC
Catch - gillnet	Japan	Total catch reported to NPFC	2002-2019	NPFC
Catch - longline	Korea, Russia	Total catch reported to NPFC	2004 - Korea, 2001 - 2019 - Russia	NPFC
Effort - trawl	Japan, Russia, Korea	Number of fishing days, number of vessels	2001-2019	NPFC
Effort - gillnet	Japan	Number of vessels, number of fishing days	2002-2019	NPFC
Effort - longline	Korea, Russia	Number of fishing vessels, number of fishing days	2002-2019	NPFC
Seamounts fished	Japan, Korea, Russia	The seamounts where gear was deployed by gear type; trawl, longline, gillnet	2017-2019	NPFC
Effort- trawl	Japan, Russian	Number of hours fished	1967-2001	Japan, Russia
Catch - trawl	Japan, Russia	Total catch (tons)	1967-2001	Japan, Russia
Seamounts fished	Japan	The seamount where gear was deployed	1969-2001	Japan

Table 6. Surveys of Seamounts in the NPFC Convention Area and adjoining EEZ's. These surveys were conducted primarily targeting North Pacific Armorhead.

Survey type	Description	Years	Area surveyed	Data source
Acoustic survey	Acoustic survey of seamounts for NPA	2016-2020		Japan
Monitoring survey for NPA	Monthly monitoring survey from Japan fishing vessels to assess recruitment	2018-2019, modified in 2020	Specific spatial blocks	NPFC
Trawl survey	Bottom longline and trawl surveys (n = 10) of seamounts in southern Emperors for NPA	1985-1993	Hancock Seamount	USA (Somerton and Kikkawa 1992)
Trawl Survey	Trawl survey of major seamounts for NPA	2005-2007	Colohan, Milwaukee, Kimmei, Koko Seamounts	Korea?

Table 7. Biological data (age, length, sex ratios, weight) available for North Pacific Armorhead from studies and observers in the Emperor Seamounts.

Data type	Member nation	Data description	Years available	Data source/holder
Individual length and weight	USA	Lengths and weights collected by US observers on board Japanese fishing vessels on Hancock Seamount	1978-1984	PIFSC? (Somerton and Kikkawa 1992)
Catch lengths, maturity, ages, weights	Japan, Korea	Data collected by observers on fishing vessels	2009-2020	Japan, Korea

Table 8. A summary of biological parameters from assessments conducted for North Pacific Armorhead within the NPFC Convention Area.

Parameter	Description and conclusions	Source
Sex ratio	No clear difference from a 1:1 male to female ratio was found, and demersal samples varied between years.	Humphreys & Tagami, 1986; Uchiyama & Sampaga, 1990; Somerton & Kikkawa, 1992
Growth	The pelagic life stage is largely undescribed and little information exists on NPA growth.	Kiyota *et al*., 2016
	Sagittal otolith counts on pelagic specimens showed the following length ranges by year: age 0+=72-124 mm, age 1+= 174-222 mm, and age 2+= 233-279 mm.	Humphreys, 2000
	Vancouver aquarium specimens grew from 250 mm to 325 mm (almost 75 mm in growth) during their 3rd year.	Hart, 1973
	After settlement to the seamount, it is suggested that little growth occurs (based on length-frequency distributions).	Uchiyama & Sampaga, 1989; Sasaki, 1986; Wetherall & Yong, 1986
Growth rate thorough time	The combination of the migration theory and the occurrence in Hawaii of large-bodied fish suggests steady pelagic growth. Body growth, body height and weight are however suggested to	Kiyota *et al*., 2016

	decrease in demersal fishes after their growth years.	
	Demersal fishes at the SE-NHR had a single peak in body length with no monthly peaks.	Iguchi, 1973; Takahasi & Sasaki, 1977
	Linear growth of body length was found to stop after settlement. At this point, a relative decrease in body depth due to the use of fat reserves was proposed. A rapid change in fat type from “fat” to “intermediate”.	Humphreys *et al.*, 1989
	The growth curve used for epipelagic armorhead supported the study hypothesis of a 2.5 year long epielagic period, where growth was rapid for the first year, followed by slower growth after the first year. The study found a sufficient fit to the von Bertalanffy function and thus suggested an asymptotic length achieved during the epipelagic stage and slower growth at 2 years of age. Continual growth in larger fish was not suggested, and a different growth curve may apply to individuals over 400 mm SL in different environmental conditions (however such specimens were not obtained in this study).	Murakami *et al*., 2016

Sexual maturity	The age and timing of sexual maturity remain undetermined. Challenges in determination of the exact age of maturity were noted. Sexual maturity is estimated to be at around 2 years, however the potential that sexual maturity is reached before reaching the seamounts is discussed (no evidence to date to confirm this). FI transformation of newly-recruited fish supports energy requirement for reproduction.	Kiyota *et al.*, 2016 Uchiyama & Sampaga, 1990 Humphreys *et a*l., 1989
Diet	Feeding and predation is discussed from previous studies of stomach content. Results show that NPA are dependent on deep scattering layer (DSL) and plankton food items (instead of local benthic prey). Feeding rates were found to be low in 1972 trawling surveys. It is uncertain whether this was due to fast digestion by the fish or inadequate feeding. Feeding considered to be occurring on seamount rises and slopes due to diurnal variation.	Kiyota *et al*., 2016 Kitani & Iguchi, 1974
Genetic differentiation	Genetic differentiation between North Pacific populations of NPA has not been reported.	Kiyota *et al*., 2016 Martin *et al*., 1992

	A lack of differentiation was found from mtDNA analyses of demersal individuals from Hancock and Koko seamount and eastern North Pacific pelagic specimens. Additionally, no significant differentiation was found for morphological types. No difference in frequencies of composite mtDNA haplotypes and no area-specific restriction fragment length polymorphism profiles were found between sampling sites from the SE-NHR, Hachijo Island and the eastern North Pacifc. Pelagic armorhead were concluded to be one metamorphic species in the North Pacific Ocean based on morphometric, meristic and electrophoretic evidence. Thus, NPA is considered to form a meta-population in the SE-NHR.	Yanagimoto *et al*., 2008 Humphreys *et al*., 1989 Borets, 1979; Martin *et al*., 1992; Yanagimoto *et al*., 2008
Maximum age	Maximum age remains unresolved; lifespan is considered by some to be 7 years, while others believe it to be 11 years. Armorhead is not considered to be long-lived.	"Information describing…" (2008)
Natural Mortality (M)	Commercial fishing data from the Soviet Union (1968-1975) was analyzed and cohorts of 8 and 9 year old fish were traced to estimate the	Borets, 1975; 1976

	instantaneous natural mortality coefficient (0.25/yr). Annual changes to relative abundances of two cohorts in 1985 and 1986 were used to estimate natural mortality (0.54/yr). Females had a natural mortality of 0.045/month, which was higher than that of males, which had 0.037/month in the 1986 cohort. Bias in Borets (1975) was discussed. Natural mortality was not estimated in years leading up to 2016.	 Somerton & Kikkawa, 1992 Kiyota *et al*., 2016.
Weight-length relationship	LogBW =αlogSL + β was used to estimate L-W relationship. No difference between sexes was found using the Standard Length-Body weight allometric models.	Murakami *et al*., 2016

Data gaps and next steps

The primary data gaps for the NPFC Convention Area stock of North Pacific Armorhead that could be useful for a stock assessment are:

- Time series of spatially explicit catch and effort dating to the initiation of the fishery in 1967
    - If possible, a standardized index that accounted for differential targeting among Splendid Alfonsino and North Pacific Armorhead
- Age, length and weight data from the fisheries catch for each seamount if possible
- Age, length, and weight data from surveys if possible (by year and area, if possible).
- A time series of survey abundance for either individual seamounts or combined seamounts
    - If possible, a standardized biomass estimate for the entire population
- A time series of recruitment (or proxy) for NPA
- A model or map that indicates the distribution of juvenile and adult NPA by size
- Evaluation of data quality and suitability for use in assessing and managing NPA.

The proposed next steps for assessment/management of North Pacific Armorhead stocks might be:

1. The formation of a small working group that could determine the location/availability of data holdings from each Member
2. Discussion of data sharing agreements
3. Discussion of data quality for catch, effort, survey(s), biological data. Develop a list of data, including biological parameters that could inform stock assessment or management (i.e. values or reasonable ranges for age at 50% maturity, fecundity, growth rates, M, etc).
4. Engaging an external expert in data limited assessment that could direct the BFME on potential directions that could be taken based on data availability and quality.

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