10. Assessment of the Pacific Ocean Perch Stock in the Gulf of Alaska

Peter-John F. Hulson, and Maia S. Kapur

November 2023

# Executive Summary

Pacific ocean perch in the Gulf of Alaska are assessed on a biennial stock assessment schedule to coincide with the availability of new survey data. Consequently, we present a full stock assessment using a statistical age-structured model. Survey and fishery data are used to estimate population trends and projected future population estimates are used to recommend catch limits.

## Summary of Changes in Assessment Inputs

*Changes in the input data*: We updated the catch for 2020 and used preliminary catch estimates for 2021-2023 (see Specified catch estimation section), along with 2021 bottom trawl survey biomass, and 2020 fishery age composition.

*Changes in the assessment methodology*: The assessment methodology is the same as the 2020 assessment.

## Summary of Results

For the 2022 fishery, we recommend the maximum allowable ABC of 38,268 t. This ABC is a 6% increase from the 2021 ABC of 36,177 t. The increase is attributed to the model continuing to react to five consecutive survey biomass estimates larger than 1 million tons as well as an increase in survey biomass in 2021 compared to 2019. This also resulted in an 11% higher ABC than the 2022 ABC projected last year. The corresponding reference values for Pacific ocean perch are summarized in the following table, with the recommended ABC and OFL values in bold. The stock is not being subject to overfishing, is not currently overfished, nor is it approaching a condition of being overfished.

|  | As estimated or *specified last* year for: | | As estimated or *recommended this* year for: | |
| --- | --- | --- | --- | --- |
| **Quantity/Status** | 2022 | 2023 | 2023\* | 2024\* |
| M (natural mortality) | 0.059 | 0.059 | 0.059 | 0.059 |
| Tier | 3a | 3a | 3a | 3a |
| Projected total (age 2+) biomass (t) | 102,715 | 99,957 | 100,371 | 96,045 |
| Projected female spawning biomass (t) | 42,791 | 40,462 | 40,474 | 37,408 |
| B100% | 84,832 | 84,832 | 84,832 | 84,832 |
| B40% | 33,933 | 33,933 | 33,933 | 33,933 |
| B35% | 29,691 | 29,691 | 29,691 | 29,691 |
| FOFL | 0.073 | 0.073 | 0.073 | 0.073 |
| *max*FABC | 0.061 | 0.061 | 0.061 | 0.061 |
| FABC | 0.061 | 0.061 | 0.061 | 0.061 |
| OFL (t) | 6,396 | 6,088 | 6,143 | 5,874 |
| *max*ABC (t) | 5,358 | 5,100 | 5,147 | 4,921 |
| ABC (t) | 5,358 | 5,100 | 5,147 | 4,921 |
|  | As determined *last* year for: | | As determined *this* year for: | |
| **Status** | 2021 | 2022 | 2022 | 2023 |
| Overfishing | No | n/a | No | n/a |
| Overfished | n/a | No | n/a | No |
| Approaching overfished | n/a | No | n/a | No |
| \*Projections are based on an estimated catch of 2,842 t for 2022 and estimates of 3,489 t and 2,884 t used in place of maximum permissible ABC for 2023 and 2024. | | | | |

Text table of area apportionments (if any) for the recommended one- and two-year ahead ABCs and OFLs, with a brief description of the apportionment methodology.

## Area Allocation of Harvest

The following table shows the recommended ABC apportionment for 2022 and 2023. The apportionment percentages are the same as in the last full assessment. Please refer to the 2020 full stock assessment report (Fenske *et al.* 2020) for information regarding the apportionment rationale for GOA dusky rockfish.

|  | | Western | Central | Eastern | Total |
| --- | --- | --- | --- | --- | --- |
| Area Apportionment | | 5% | 84.4% | 10.6% | 100% |
| 2022 | ABC (t) | 269 | 4,534 | 569 | 5,372 |
| 2022 | OFL (t) |  |  |  | 8,614 |
| 2023 | ABC (t) | 259 | 4,373 | 549 | 5,181 |
| 2023 | OFL (t) |  |  |  | 8,146 |

Amendment 41 prohibited trawling in the Eastern area east of 140° W longitude. The ratio of biomass still obtainable in the W. Yakutat area (between 147° W and 140° W) is 0.75. This results in the following apportionment to the W. Yakutat area:

|  |  | W. Yakutat | E. Yakutat/Southeast |
| --- | --- | --- | --- |
| 2022 | ABC (t) | 427 | 142 |
| 2023 | ABC (t) | 412 | 137 |

If so are so kind as to provide tables for the plan team, place them here

## Summaries for Plan Team

| Stock | Year | Biomass1 | OFL | ABC | TAC | Catch |
| --- | --- | --- | --- | --- | --- | --- |
| Dusky Rockfish | 2020 | 54,626 | 4,492 | 3,676 | 3,676 | 2,198 |
| 2021 | 97,702 | 8,655 | 5,389 | 5,389 | 2,9022 |
| 2022 | 97,767 | 8,614 | 5,372 |  |  |
| 2023 | 95,682 | 8,146 | 5,181 |  |  |
| 1Total biomass (age 4+) estimates from age-structured model. | | | | | | |
| 2Current as of October 22, 2023 . Source: NMFS Alaska Regional Office Catch Accounting System via the AKFIN database (http://www.akfin.org). | | | | | | |

|  |  | 2021 | | | | 2022 | | 2023 | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Stock | Area | OFL | ABC | TAC | Catch2 | ABC | OFL | ABC | OFL |
| Dusky Rockfish | W |  | 270 | 270 | 144 |  | 269 |  | 259 |
| C |  | 4,548 | 4,548 | 2,727 |  | 4,534 |  | 4,373 |
| WYAK |  | 468 | 468 | 30 |  | 427 |  | 412 |
| EYAK/SEO |  | 103 | 103 | 1 |  | 142 |  | 137 |
| Total | 8,655 | 5,389 | 5,389 | 2,902 | 8,614 | 5,372 | 8,146 | 5,181 |
| 2Current as of October 22, 2023 . Source: NMFS Alaska Regional Office Catch Accounting System via the AKFIN database (http://www.akfin.org). | | | | | | | | | |

## Responses to SSC and Plan Team Comments on Assessments in General

“The SSC requests that all authors fill out the risk table in 2019…” (SSC December 2018)

A risk table has been included in this assessment.

## Responses to SSC and Plan Team Comments Specific to this Assessment

“For this cycle, the SSC also agrees with the author’s justification for the adjustment of the likelihood weight of the survey index to utilize this new time series more appropriately.”

The likelihood weighting has remained consistent with the weights found in the last full assessment.

# Introduction

## Biology and Distribution

Pacific ocean perch (*Sebastes alutus*, POP) have a wide distribution in the North Pacific from southern California around the Pacific rim to northern Honshu Is., Japan, including the Bering Sea. The species appears to be most abundant in northern British Columbia, the Gulf of Alaska (GOA), and the Aleutian Islands (Allen and Smith 1988). Adults are found primarily offshore on the outer continental shelf and the upper continental slope in depths of 150-420 m. Seasonal differences in depth distribution have been noted by many investigators. In the summer, adults inhabit shallower depths, especially those between 150 and 300 m. In the fall, the fish apparently migrate farther offshore to depths of ~300-420 m. They reside in these deeper depths until about May, when they return to their shallower summer distribution (Love et al. 2002). This seasonal pattern is probably related to summer feeding and winter spawning. Although small numbers of POP are dispersed throughout their preferred depth range on the continental shelf and slope, most of the population occurs in patchy, localized aggregations (Hanselman et al. 2001). POP are generally considered to be semi-demersal but there can at times be a significant pelagic component to their distribution. POP often move off-bottom during the day to feed, apparently following diel euphausiid migrations (Brodeur 2001). Commercial fishing data in the GOA since 1995 show that pelagic trawls fished off-bottom have accounted for as much as 31% of the annual harvest of this species. There is much uncertainty about the life history of POP, although generally more is known than for other rockfish species (Kendall and Lenarz 1986). The species appears to be viviparous (the eggs develop internally and receive at least some nourishment from the mother), with internal fertilization and the release of live young. Insemination occurs in the fall, and sperm are retained within the female until fertilization takes place ~2 months later. The eggs hatch internally, and parturition (release of larvae) occurs in April-May. Information on early life history is very sparse, especially for the first year of life. POP larvae are thought to be pelagic and drift with the current, and oceanic conditions may sometimes cause advection to suboptimal areas (Ainley et al. 1993) resulting in high recruitment variability. However, larval studies of rockfish have been hindered by difficulties in species identification since many larval rockfish species share the same morphological characteristics (Kendall 2000). Genetic techniques using allozymes (Seeb and Kendall 1991) and mitochondrial DNA (Li 2004) are capable of identifying larvae and juveniles to species, but are expensive and time-consuming. Post-larval and early young-of-the-year POP have been positively identified in offshore, surface waters of the GOA (Gharrett et al. 2002), which suggests this may be the preferred habitat of this life stage. Transformation to a demersal existence may take place within the first year (Carlson and Haight 1976). Small juveniles probably reside inshore in very rocky, high relief areas, and by age 3 begin to migrate to deeper offshore waters of the continental shelf (Carlson and Straty 1981). As they grow, they continue to migrate deeper, eventually reaching the continental slope where they attain adulthood. Adult and juvenile populations are believed to be spatially separated (Carlson and Straty 1981; Rooper et al. 2007). POP are mostly planktivorous (Carlson and Haight 1976; Yang 1993; Yang and Nelson 2000; Yang 2003; Yang et al. 2006). In a sample of 600 juvenile perch stomachs, Carlson and Haight (1976) found that juveniles fed on an equal mix of calanoid copepods and euphausiids. Larger juveniles and adults fed primarily on euphausiids, and to a lesser degree, copepods, amphipods and mysids (Yang and Nelson 2000). In the Aleutian Islands, myctophids have increasingly comprised a substantial portion of the POP diet, which also compete for euphausiid prey (Yang 2003). POP and walleye pollock (Gadus chalcogrammus) probably compete for the same euphausiid prey as euphausiids make up about 50% of the pollock diet (Yang and Nelson 2000). Consequently, the large removals of POP by foreign fishermen in the GOA in the 1960s may have allowed walleye pollock stocks to greatly expand in abundance. Predators of adult POP are likely sablefish, Pacific halibut, and sperm whales (Major and Shippen 1970). Juveniles are consumed by seabirds (Ainley et al. 1993), other rockfish (Hobson et al. 2001), salmon, lingcod, and other large demersal fish. POP is a slow growing species, with a low rate of natural mortality, a relatively old age at 50% maturity (8.4 - 10.5 years for females in the GOA), and a very old maximum age of 98 years in Alaska (84 years maximum age in the GOA) (Hanselman et al. 2003a). Age at 50% recruitment to the commercial fishery has been estimated to be between 7 and 8 years in the GOA. Despite their viviparous nature, they are relatively fecund with number of eggs/female in Alaska ranging from 10,000-300,000, depending upon size of the fish (Leaman 1991). Rockfish in general were found to be about half as fecund as warm water snappers with similar body shapes (Haldorson and Love 1991). The evolutionary strategy of spreading reproductive output over many years is a way of ensuring some reproductive success through long periods of poor larval survival (Leaman and Beamish 1984). Fishing generally selectively removes the older and faster-growing portion of the population. If there is a distinct evolutionary advantage of retaining the oldest fish in the population, either because of higher fecundity or because of different spawning times, age-compression could be deleterious to a population with highly episodic recruitment like rockfish (Longhurst 2002). Research on black rockfish (Sebastes melanops) has shown that larval survival may be dramatically higher from older female spawners (Berkeley et al. 2004, Bobko and Berkeley 2004). The black rockfish population has shown a distinct downward trend in age-structure in recent fishery samples off the West Coast of North America, raising concerns about whether these are general results for most rockfish. de Bruin et al. (2004) examined POP (S. alutus) and rougheye rockfish (S. aleutianus) for senescence in reproductive activity of older fish and found that oogenesis continues at advanced ages. Leaman (1991) showed that older individuals have slightly higher egg dry weight than their middle-aged counterparts. Such relationships have not yet been determined to exist for POP or other rockfish in Alaska. Stock assessments for Alaska groundfish have assumed that the reproductive success of mature fish is independent of age. Spencer et al. (2007) showed that the effects of enhanced larval survival from older mothers decreased estimated Fmsy (the fishing rate that produces maximum sustainable yield) by 3% to 9%, and larger decreases in stock productivity were associated at higher fishing mortality rates that produced reduced age compositions. Preliminary work at Oregon State University examined POP of adult size by extruding larvae from harvested fish near Kodiak, and found no relationship between spawner age and larval quality (Heppell et al. 2009). However, older spawners tended to undergo parturition earlier in the spawning season than younger fish. A more recent study suggest that larval quality is both a function of spawner age and parturition timing.

## Stock Structure

A few studies have been conducted on the stock structure of POP. Based on allozyme variation, Seeb and Gunderson (1988) concluded that POP are genetically quite similar throughout their range, and genetic exchange may be the result of dispersion at early life stages. In contrast, analysis using mitochondrial DNA techniques indicates that genetically distinct populations of POP exist (Palof 2008). Palof et al. (2011) report that there is low, but significant genetic divergence (FST = 0.0123) and there is a significant isolation by distance pattern. They also suggest that there is a population break near the Yakutat area from conducting a principle component analysis. Withler et al. (2001) found distinct genetic populations on a small scale in British Columbia. Kamin et al. (2013) examined genetic stock structure of young of the year POP. The geographic genetic pattern they found was nearly identical to that observed in the adults by Palof et al. (2011). In a study on localized depletion of Alaskan rockfish, Hanselman et al. (2007) showed that POP are sometimes highly depleted in areas 5,000-10,000 km2 in size, but a similar amount of fish return in the following year. This result suggests that there is enough movement on an annual basis to prevent serial depletion and deleterious effects on stock structure. In 2012, the POP assessment presented the completed stock structure template that summarized the body of knowledge on stock structure and spatial management (Hanselman et al. 2012a).

# Fishery

## Description of the Directed Fishery

A POP trawl fishery by the U.S.S.R. and Japan began in the GOA in the early 1960s. This fishery developed rapidly, with massive efforts by the Soviet and Japan¬ese fleets. Catches peaked in 1965, when a total of nearly 350,000 metric tons (t) was caught. This apparent overfishing resulted in a precipitous decline in catches in the late 1960s. Catches continued to decline in the 1970s, and by 1978 catches were only 8,000 t (Figure 9-1). Foreign fishing dominated the fishery from 1977 to 1984, and catches generally declined during this period. Most of the catch was taken by Japan (Carlson et al. 1986). Catches reached a minimum in 1985, after foreign trawling in the GOA was prohibited.

The domestic fishery first became important in 1985 and expanded each year until 1991 (Figure 9-1). Much of the expansion of the domestic fishery was apparently related to increasing annual quotas; quotas increased from 3,702 t in 1986 to 20,000 t in 1989. In the years 1991-95, overall catches of slope rockfish diminished as a result of the more restrictive management policies enacted during this period. The restrictions included: (1) establishment of the management subgroups, which limited harvest of the more desired species; (2) reduction of total allowable catch (TAC) to promote rebuilding of POP stocks; and (3) conservative in-season management practices in which fisheries were sometimes closed even though substantial unharvested TAC remained. These closures were necessary because, given the large fishing power of the rockfish trawl fleet, there was substantial risk of exceeding the TAC if the fishery were to remain open. Since 1996, catches of POP have increased again, as good recruitment and increasing biomass for this species have resulted in larger TAC’s. In recent years, the TAC’s for POP have usually been fully taken (or nearly so) in each management area except Southeast Outside. (The prohibition of trawling in Southeast Outside during these years has resulted in almost no catch of POP in this area). In 2013, approximately 21% of the TAC was taken in the Western GOA. NMFS did not open directed fishing for POP in this area because the catch potential from the expected effort (15 catcher/processors) for a one day fishery (shortest allowed) exceeded the available TAC. The 2014 fishery in this area didn’t occur until October but nearly all of the TAC was harvested.

### Catch Patterns

Detailed catch information for POP in the years since 1977 is listed in Table 9-1. The reader is cautioned that actual catches of POP in the commercial fishery are only shown for 1988-2019; for previous years, the catches listed are for the POP complex (a former management grouping consisting of POP and four other rockfish species), POP alone, or all Sebastes rock¬fish, depending upon the year (see Table 9-1). POP make up the majority of catches from this complex. The acceptable biological catches and quotas in Table 9-1 are Gulf-wide values, but in actual practice the NPFMC has divided these into separate, annual apportionments for each of the three regulatory areas of the GOA. Historically, bottom trawls have accounted for nearly all the commercial harvest of POP. In recent years, however, the portion of the POP catch taken by pelagic trawls has increased. The percentage of the POP Gulf-wide catch taken in pelagic trawls increased from an average of 7% during 1990-2005 to an average of 24% and up to 31% after 2006. Before 1996, most of the POP trawl catch (>90%) was taken by large factory-trawlers that processed the fish at sea. A significant change occurred in 1996, however, when smaller shore-based trawlers began taking a sizeable portion of the catch in the Central area for delivery to processing plants in Kodiak. These vessels averaged about 50% of the catch in the Central Gulf area since 1998. By 2008, catcher vessels were taking 60% of the catch in the Central Gulf area and 35% in the West Yakutat area. Factory trawlers continue to take nearly all the catch in the Western Gulf area.

In 2007, the Central GOA Rockfish Program was implemented to enhance resource conservation and improve economic efficiency for harvesters and processors who participate in the Central GOA rockfish fishery. This rationalization program establishes cooperatives among trawl vessels and processors which receive exclusive harvest privileges for rockfish management groups. The primary rockfish management groups are northern rockfish, POP, and pelagic shelf rockfish.

### Bycatch and Discards

Gulf-wide discard rates (% discarded, current as of October 24, 2021) for POP in the commercial fishery are listed as follows: Year 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 % Discard 11.3 8.6 7.3 15.1 8.2 5.7 7.8 3.7 4.1 6.8 4.1

Year 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021  
% Discard 6.6 4.8 7.6 9.5 3.8 6.8 14.8 4.7 7.4 4.5 2.2

Total FMP groundfish catch estimates in the GOA rockfish targeted fisheries are shown in Table 9-3. For the GOA rockfish fishery, the largest non-rockfish bycatch groups are arrowtooth flounder, Atka mackerel, walleye pollock, Pacific cod, and sablefish. Catch of POP in other GOA fisheries is mainly in arrowtooth flounder, walleye pollock-midwater, and rex sole targeted fishing (Table 9-4). Non-FMP species catch in the rockfish target fisheries is dominated by giant grenadier and miscellaneous fish (Table 9-5). The increase in POP discards in 2017 can likely be attributed to an extremely high bycatch of POP in the arrowtooth flounder directed fishery (Table 9-4). Hulson et al. (2014) compared bycatch for the combined rockfish fisheries in the Central GOA from before and during the Rockfish Program to determine the impacts of the Rockfish Program and found the bycatch of the majority of FMP groundfish species in the Central GOA was reduced following implementation of the Rockfish Program. Prohibited species catch in the GOA rockfish fishery is generally low (Table 9-6). Catch of prohibited and non-target species generally decreased with implementation of the Central GOA Rockfish Program (Hulson et al. 2014).

## Management Measures

In 1991, the NPFMC divided the slope assemblage in the GOA into three management subgroups: POP, shortraker/rougheye rockfish, and all other species of slope rockfish. In 1993, a fourth management subgroup, northern rockfish, was also created. In 2004, shortraker rockfish and rougheye rockfish were divided into separate subgroups. These subgroups were established to protect POP, shortraker rockfish, rougheye rockfish, and northern rockfish (the four most sought-after commercial species in the assemblage) from possible overfishing. Each subgroup is now assigned an individual ABC (acceptable biological catch) and TAC (total allowable catch), whereas prior to 1991, an ABC and TAC was assigned to the entire assemblage. Each subgroup ABC and TAC is apportioned to the three management areas of the GOA (Western, Central, and Eastern) based on distribution of survey biomass. Amendment 32, which took effect in 1994, established a rebuilding plan for POP. The amendment stated that “stocks will be considered to be rebuilt when the total biomass of mature females is equal to or greater than BMSY” (Federal Register: April 15, 1994). Prior to Amendment 32, overfishing levels had been defined GOA-wide. Under Amendment 32, “the overfishing level would be distributed among the eastern, central, and western areas in the same proportions as POP biomass occurs in those areas. This measure would avoid localized depletion of POP and would rebuild POP at equal rates in all regulatory areas of the GOA.” This measure established management area OFLs for POP. Amendment 41, which took effect in 2000, prohibited trawling in the Eastern area east of 140 degrees W. longitude. Since most slope rockfish, especially POP, are caught exclusively with trawl gear, this amendment could have concentrated fishing effort for slope rockfish in the Eastern area in the relatively small area between 140 degrees and 147 degrees W. longitude that remained open to trawling. To ensure that such a geographic over-concentration of harvest would not occur, since 1999 the NPFMC divided the Eastern area into two smaller management areas: West Yakutat (area between 147 and 140 degrees W. longitude) and East Yakutat/Southeast Outside (area east of 140 degrees W. longitude). Separate ABC’s and TAC’s are now assigned to each of these smaller areas for POP, while separate OFLs have remained for the Western, Central, and Eastern GOA management areas. In November, 2006, NMFS issued a final rule to implement Amendment 68 of the GOA groundfish Fishery Management Plan for 2007 through 2011. This action implemented the Central GOA Rockfish Program (formerly the Rockfish Pilot Program or RPP). The intention of this program is to enhance resource conservation and improve economic efficiency for harvesters and processors in the rockfish fishery. This should spread out the fishery in time and space, allowing for better prices for product and reducing the pressure of what was an approximately two week fishery in July. The authors will pay close attention to the benefits and consequences of this action. Since the original establishment of separate OFLs by management areas for POP in the rebuilding plan (Amendment 32) in 1994, the spawning stock biomass has tripled. The rebuilding plan required that female spawning biomass be greater than Bmsy and the stock is now 53% higher than Bmsy (using B40% as a proxy for Bmsy). Management has prosecuted harvest accurately within major management areas using ABC apportionments. While evidence of stock structure exists in the GOA, it does appear to be along an isolation by distance cline, not sympatric groups (Palof et al. 2011; Kamin et al. 2013). Palof et al. (2011) also suggest that the Eastern GOA might be distinct genetically, but this area is already its own management unit, and has additional protection with the no trawl zone. Hanselman et al. (2007) showed that POP are reasonably resilient to serial localized depletions (areas replenish on an annual basis). The NPFMC stock structure template was completed for GOA POP in 2012 (Hanselman et al. 2012a). Recommendations from this exercise were to continue to allocate ABCs by management area or smaller. However, the original rationale for area-specific OFLs from the rebuilding plan no longer exists because the overall population is above target levels and is less vulnerable to occasional overages. Therefore, in terms of rebuilding the stock, management area OFLs are no longer a necessity for the GOA POP stock. Management measures since the break out of POP from slope rockfish are summarized in Table 9-2.

# Data

The following table summarizes the data used for this assessment (bold font denotes new data to this year’s assessment):

| **Source** | **Data** | **Years** |
| --- | --- | --- |
| NMFS Groundfish survey | Survey biomass | 1984-1999 (triennial), 2001-2019 (biennial) |
| Age composition | 1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019 |
| U.S. trawl fishery | Catch | 1961-2020 |
| Age composition | 1998-2002, 2004-2006, 2008, 2010, 2012, 2014, 2016, 2018 |
| Length composition | 1991-1997, 2003, 2007, 2009, 2011, 2013, 2015, 2017, 2019 |

## Fishery

### Catch

Catches ranged from 2,500 t to 350,000 t since 1961. The detailed catch information for POP is listed in Table 9-1 and annual summaries shown graphically in Figure 9-1 (these annual values are used in the assessment model). Additional research and non-commercial catches (excluded from the directed fishery analysis) have been generally less than 100 t annually and are presented (as required) in Appendix 9-A.

### Age and Size Composition

Observers aboard fishing vessels and at onshore processing facilities have provided data on size and age composition of the commercial catch of POP. Ages were determined from the break-and-burn method (Chilton and Beamish 1982). Table 9-7 summarizes the fishery length compositions from the most recent 10 years, Table 9-8 summarizes age compositions for the fishery, and Figures 9-2 and 9-3 show the distributions graphically for fishery age and length composition data fit by the assessment. The age compositions for the fishery prior to 2004 show strong 1986 and 1987 year classes. After 2004 the fishery age composition data show the presence of several relatively strong year classes including the 1993, 1994, and 1998 year classes. Each of these year classes, with the exception of the 1993 and 1994 year classes, have also been identified in the trawl survey age composition data. Fishery length composition is available from the early 1960s to present (Figure 9-3 and Table 9-7). Due to the availability of age data from both the fishery and trawl survey we do not fit the recent fishery length composition, but rather use the historical fishery length composition data shown in Figure 9-3. We note that the fishery length samples are used to determine the fishery age composition through the use of an age-length key, which weights the age samples from the fishery by the length samples. Fishery length composition data prior to the mid-1970s indicates that the mean length of POP was smaller than after the mid-1970s. We hypothesize that rather than year classes moving into the population in these years (and thus reducing the mean length) that there were differences in growth, thus, we use a different size age transition matrix in these years (as described in the Parameters Estimated Outside the Assessment Model section below). In general, because of the selectivity of the fishery at older ages, there is no strong recruitment signal in the fishery length composition data.

## Survey

### Biomass Estimates from Trawl Surveys

Bottom trawl surveys were conducted on a triennial basis in the GOA in 1984, 1987, 1990, 1993, 1996, and a biennial survey schedule has been used since the 1999 survey. The surveys provide much information on POP, including an abundance index, age composition, and growth characteristics. The surveys are theoretically an estimate of absolute biomass, but we treat them as a relative index in the stock assessment. The surveys covered typically cover all of the NMFS areas of the GOA out to a depth of 500 m. In some years the surveys extended to 1,000 m and in the 2001 the survey covered only the central and western GOA (budget limitations affected the ability to cover the Eastern GOA). Regional and Gulf-wide biomass estimates (with corresponding coefficients of variation in total biomass) for POP are shown in Table 9-9. Gulf-wide biomass estimates for with 95% confidence intervals are shown in Figure 9-4. Biomass estimates of POP were relatively low in 1990, increased markedly in both 1993 and 1996, and remained around the 1996 value in 1999 and 2001 (Table 9-9 and Figure 9-4). These surveys were characterized with relatively larger uncertainty with coefficients of variation (CV) greater than 20% (reaching a maximum in 1999 of 53%). Large catches of an aggregated species like POP in just a few individual hauls can greatly influence biomass estimates and are a source of much variability. Biomass estimates of POP decreased in 2003, then increased in 2005 and remained relatively stable until 2011, indicating that the biomass in 2003 may have been anomalously small. In 2013 biomass estimates increased markedly and have remained above one million tons since. The largest biomass estimate of the time series occurred in 2017. Since the 2003 survey biomass estimates of POP have been associated with relatively small uncertainty, with CVs below 20% in all but one year (2017, with a CV of 22%). This reduced uncertainty is because POP continue to be more uniformly distributed than in the past, as indicated by increasing proportion of tows that catch POP in the survey as well as declining uncertainty in the trawl survey catch per unit effort (CPUE, Figure 9-5). The 2021 survey biomass estimate is the second largest on record and is 22% larger than the 2019 biomass estimate. Regionally, both the Central and Western GOA increased while the estimate for the Eastern GOA declined from 2019 (Table 9-9). The general distribution of CPUE in the 2021 survey were comparable to 2017 and 2019 in the Central and Eastern GOA (Figure 9-5). The most notable difference in POP CPUE distribution in 2021 compared to 2019 and 2017 is in the far western part of the Western GOA.

### Age and Size Composition

Ages were determined from the break-and-burn method (Chilton and Beamish 1982). The survey age compositions from 1990-2017 surveys showed that although the fish ranged in age up to 84 years, most of the population was relatively young; mean survey age has increased from 9.2 years in 1990 to 15.6 years in 2017 (Table 9-10). The first four surveys identified relatively strong year classes in the mid-1980s (1984-1988) and also showed a period of very weak year classes during the 1970s to mid-19080s (Figure 9-6). The weak year classes through this period of time may have delayed recovery of POP populations after they were depleted by the foreign fishery. Since the 1999 survey the age compositions have indicated several stronger than average year classes. Starting with the 2003 and through the 2009 survey the age composition data indicated relatively strong year classes in 1998, 2000, and 2002. Since the 2009 survey the age composition data has distinguished relatively strong year classes in 2006, 2008, and 2010. The 2017 survey age composition indicates that the 2007 year class could also be relatively strong and the plus age group of 25 and older has increased to 0.15 (from an average of 0.04 prior to 2011). The 2019 survey age composition indicates the possible emergence of a strong 2016 year class. These relatively strong year classes since 1998 may be contributing to the increase in survey biomass observed since 2013. Gulf-wide population size compositions for POP are shown in Figure 9-7. These size composition data identify several year classes that have moved through the population since 2001. The 2001 and 2009 survey length compositions indicated relatively strong year classes in 1998 and 2006 (which were ~17-21 cm in these surveys). The 2006 year class was again relatively strong in the 2011 data (which would have been ~24-28 cm) and both the 1998 and 2006 year classes were corroborated with the survey age composition data. The 2019 survey length compositions indicated a mode at ~17-21 cm (age-3), which would be the 2016 year class. The most recent length composition data from the 2021 survey detects this mode but it is not as strong as that seen in 2019. Survey size data are used in constructing the age-length transition matrix, but not used as data to be fitted in the stock assessment model.

### Summer Acoustic-Trawl Survey

Acoustic-trawl (AT) surveys designed to evaluate walleye pollock abundance in the Gulf of Alaska have been conducted by the Alaska Fisheries Science Center (AFSC) in summer months (June – August) on odd years from 2013 to 2021 aboard the NOAA ship Oscar Dyson (Jones et al. 2014, Jones et al. 2017, Jones et al. 2019). POP are routinely encountered during these surveys and abundance estimates for POP are available for the surveyed area. The surveys cover the Gulf of Alaska continental shelf and shelfbreak from depths of 50 to 1000 m, including associated bays and troughs, and extend from the continental shelf south of the Islands of Four Mountains in the Aleutian Islands eastward to Yakutat Bay. The surveys consist of widely-spaced (25 nmi) parallel transects along the shelf, and more closely spaced transects (1-15 nmi) in troughs, bays, and Shelikof Strait. Mid-water and bottom trawls are used to identify species and size of acoustic targets. Surveys prior to 2019 used a single length distribution of POP caught in combined hauls to scale the acoustic data to abundance and biomass. Starting in 2019, the length distribution from the haul nearest to the acoustic signal was used for scaling. A generalized physoclist target strength (TS) to length (L) relationship (TS = 20Log10(L)-67.5; Foote 1987) was used to scale acoustic signal to length. More specific computational details of the AT methods for abundance estimation can be found in Jones et al. 2019. The summer Gulf AT survey data is not currently used in the assessment model, but biomass estimates are available since the 2013 survey. We will continue to report these estimates in the POP SAFE as current research is exploring the potential for including this information into the assessment model. The following table includes the biomass estimates provided by the AT survey:

| Year | 2013 | 2015 | 2017 | 2019 | 2021 |
| --- | --- | --- | --- | --- | --- |
| Biomass( | mt) 262, | 889 438, | 545 172, | 388 144, | 045 277,941 |

Figure 9-8 shows the distribution of POP within the AT survey for the most recent three surveys. Compared to 2019, the biomass of POP was more spread out across the transects, with a large estimate south of Kodiak Island (Figure 9-8).

# Analytical approach

## General Model Structure

Prior to 2001, the stock assessment was based on an age-structured model using an early FORTRAN version of the stock synthesis framework (Methot 1990). Since then it was modified and written in to AD Model Builder software (see Fournier et al. 2012 for recent reference) as described in Courtney et al. (2007). The population dynamics, with parameter descriptions and notation are shown in Table 9-11. The formulae to estimate the observed data by the POP assessment are shown in Table 9-12. Finally, the likelihood and penalty functions used to optimize the POP assessment are shown in Table 9-13. Since its initial adaptation in 2001, the models’ attributes have been explored and changes have been made to the template to adapt to POP and other species. The following changes have been adopted within the POP assessment since the initial model in 2001:

* 2003: Size to age matrix added for the 1960s and 1970s to adjust for density-dependent growth, natural mortality and bottom trawl survey catchability estimated within model
* 2009: Fishery selectivity estimated for three time periods describing the transition from a foreign to domestic fishery, MCMC projections used with a pre-specified proportion of ABC for annual catch
* 2014: Maturity at age estimated conditionally with addition of new maturity data
* 2015: Extended ageing error matrix adopted to improve fit to plus age group and adjacent age classes
* 2017: Length bins for fishery length composition data set at 1cm, removed 1984 and 1987 trawl survey data, time block added to fishery selectivity starting in 2007 to coincide with the Central GOA rockfish program
* 2020: Fishery age composition data constructed with age-length key, prior for bottom trawl catchability set at 1.15 (Jones et al. 2021), and prior for natural mortality set at 0.0614 (Hamel 2015)

## Description of Alternative Models

Given recent developments and the results of the CIE review, we only present one model configuration which matches the one accepted in 2020 (but with updated data).

## Parameters Estimated Outside the Assessment Model

Growth of POP is estimated using length-stratified methods to estimate mean length and weight at age from the bottom trawl survey that are then modeled with the von Bertlanffy growth curve (Hulson et al. 2015). Two size to age transition models are employed in the POP assessment, the first for data from the 1960s and 1970s, the second for data after the 1980s. The additional size to age transition matrix is used to represent a lower density-dependent growth rate in the 1960s and 1970s (Hanselman et al. 2003a).

The von Bertlanffy parameters used for the 1960s and 1970s size to age transition matrix are:

= 41.6 cm, = 0.15 = -1.08

The von Bertlanffy parameters used for the post 1980s size to age transition matrix are:

= 41.1 cm = 0.18 = -0.49

The size to age conversion matrices are constructed by adding normal error with a standard deviation equal to the bottom trawl survey data for the probability of different ages for each size class. This is estimated with a linear relationship between the standard deviation in length with age. The linear parameters used for the 1960s and 1970s size to age transition matrix are (a-intercept, b-slope):

a = 0.42 b = 1.38 The linear parameters used for the post 1980s size to age transition matrix are (a-intercept, b-slope):

a = -0.02 b = 2.18

Weight-at-age was estimated with weight at age data from the same data set as the length at age. The estimated growth parameters are shown below. A correction of (-)/2 was used for the weight of the pooled ages (Schnute et al. 2001).

= 901 g = 0.20 = -0.37 = 3.04 The above growth parameters are updated for each assessment with the addition of new age, length, and weight data from the trawl survey. The average percent change in spawning biomass estimated from the current assessment with previous growth parameters compared to using the updated growth information above was less than 0.5%.

Aging error matrices were constructed by assuming that the break-and-burn ages were unbiased but had a given amount of normal error around each age based on percent agreement tests conducted at the AFSC Age and Growth lab. In 2015 an extended ageing error matrix was implemented into the POP assessment in order to improve the fit to the plus age group and adjacent age classes (Hulson et al. 2015). For a data plus age group of 25, the resulting model plus age group was 29 so that 99.9% of the fish greater than age 29 were within the 25 plus age group of the data.

## Parameters Estimated Inside the Assessment Model

Natural mortality (), catchability () and recruitment deviations () are estimated with the use of prior distributions as penalties. The prior mean for is based on maximum age from Hamel (2015). Natural mortality is a notoriously difficult parameter to estimate within the model so we assign a relatively precise prior CV of 10%. Catchability is a parameter that is somewhat unknown for rockfish, so while we assign it a prior mean of 1 (assuming all fish in the area swept are captured and there is no herding of fish from outside the area swept, and that there is no effect of untrawlable grounds), we assign it a less precise CV of 45%. This allows the parameter more freedom than that allowed to natural mortality. Recruitment deviation is the amount of variability that the model allows for recruitment estimates. Rockfish are thought to have highly variable recruitment, so we assign a high prior mean to this parameter of 1.7 with a CV of 20%.

Fishery selectivity is estimated within four time periods that coincide with the transition from a foreign to domestic fishery. These time periods are: - 1961-1976: This period represented the massive catches and overexploitation by the foreign fisheries which slowed considerably by 1976. We do not have age data from this period to examine, but we can assume the near pristine age-structure was much older than now, and that at the high rate of exploitation, all vulnerable age-classes were being harvested. For these reasons we chose to only consider asymptotic (logistic) selectivity. - 1977-1995: This period represents the change-over from the foreign fleet to a domestic fleet, but was still dominated by large factory trawlers, which generally would tow deeper and further from port. - 1996-2006: During this period we have noted the emergence of smaller catcher-boats, semi-pelagic trawling and fishing cooperatives. The length of the fishing season has also been recently greatly expanded. - 2007-Present: This period coincides with the start of the Rockfish Program in the Central Gulf, a fishing cooperative that has influenced the behavior and composition (catcher versus factory trawlers) of the fishery.

Fishery selectivity across these time periods transitions from an asymptotic selectivity from 1961-1976 into dome-shaped fishery selectivity after 1977. We fitted a logistic curve for the first block, an averaged logistic-gamma in the 2nd block, and a gamma function for the 3rd and 4th blocks. Bottom trawl survey selectivity is estimated to be asymptotic with the logistic curve.

Maturity-at-age is modeled with the logistic function conditionally within the assessment following the method presented in Hulson et al. (2011). Parameter estimates for maturity-at-age are obtained by fitting two datasets collected on female POP maturity from Lunsford (1999) and Conrath and Knoth (2013). Parameters for the logistic function describing maturity-at-age are estimated conditionally in the model so that uncertainty in model results (e.g., ABC) can be linked to uncertainty in maturity parameter estimates.

Other parameters estimated conditionally include, but are not limited to: mean recruitment, fishing mortality, and spawners per recruit levels. The numbers of estimated parameters for the recommended model are shown below. Other derived parameters are described in Box 1.

Parameter name Symbol Number Natural mortality M 1 Catchability q 1 Log-mean-recruitment μ\_r 1 Recruitment variability σ\_r 1 Spawners-per-recruit levels F\_(35%),F\_(40%),F\_(100%) 3 Recruitment deviations ε\_y^r 87 Average fishing mortality μ\_f 1 Fishing mortality deviations ε\_y^f 61 Fishery selectivity coefficients s\_a^f 6 Survey selectivity coefficients s\_a^t 2 Maturity-at-age coefficients m ̂\_a 2 Total 166

## Model Uncertainty

Evaluation of model uncertainty is obtained through a Markov Chain Monte Carlo (MCMC) algorithm (Gelman et al. 1995). The chain length of the MCMC was 10,000,000 and was thinned to one iteration out of every 2,000. We omit the first 1,000,000 iterations to allow for a burn-in period. We use these MCMC methods to provide further evaluation of uncertainty in the results below including 95% credible intervals for some parameters (computed as the 5th and 95th percentiles of the MCMC samples).

# Results

## Model Evaluation

The model used in this assessment is the same as the model accepted in 2020 with updated data and parameter priors. When we present alternative model configurations, our usual criteria for choosing a superior model are: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, catchabilities, and selectivities, (3) a good visual fit to length and age compositions, and (4) parsimony. Because the current assessment model is the same as 2020 we will evaluate the 2021 assessment based on differences in results compared to the 2020 assessment. Model 20.1 with data updated through 2021 generally results in reasonable fits to the data, estimates biologically plausible parameters, and produces consistent patterns in abundance compared to previous assessments. The assessment model continues to underestimate the trawl biomass since the 2013 survey, although, the retrospective pattern indicates that the model fit is continuing to improve to the trawl survey with additional assessments.

## Time Series Results

Key results have been summarized in Tables 9-14 to 9-18. Model predictions generally fit the data well (Figures 9-1, 9-2, 9-3, 9-4, and 9-6) and most parameter estimates and likelihood functions have remained similar to the last several years using this model (Table 9-14).

### Definitions

Spawning biomass is the biomass estimate of mature females. Total biomass is the biomass estimate of all POP age two and greater. Recruitment is measured as the number of age two POP. Fishing mortality is the mortality at the age the fishery has fully selected the fish.

### Biomass and exploitation trends

Estimated total biomass gradually increased from a low near 85,000 t in 1980 to over 596,000 t at the peak in 2015 (Figure 9-9). MCMC credible intervals indicate that the historic low is reasonably certain while recent increases are not quite as certain. Spawning biomass shows a similar trend (Figure 9-9). These estimates show a rapid increase since 1992, which coincides with an increase in uncertainty. The recent estimates of spawning biomass are nearly at historical levels prior to the 1970s. Age of 50% selection is 5 for the survey and between 7 and 9 years for the fishery (Figure 9-10). Fish are fully selected by both fishery and survey between 10 and 15. Current fishery selectivity is dome-shaped and with the addition of the recent time block after 2007 matches well with the ages caught by the fishery. Catchability is slightly larger (1.82) than that estimated in 2020 (1.8). The high catchability for POP is supported by several empirical studies using line transect densities counted from a submersible compared to trawl survey densities (Krieger 1993 [=2.1], Krieger and Sigler 1996 [=1.3], Jones et al. 2021 [=1.15]). Compared to the last full assessment, spawning biomass and age-6+ total biomass has increased in response to fitting the large trawl survey biomass estimates since 2013 (Table 9-15, Figure 9-9).

Fully-selected fishing mortality shows that fishing mortality has decreased dramatically from historic rates and has leveled out in the last decade (Figure 9-11). Goodman et al. (2002) suggested that stock assessment authors use a “management path” graph as a way to evaluate management and assessment performance over time. We chose to plot a phase plane plot of fishing mortality to (%) and the estimated spawning biomass relative to unfished spawning biomass (%). Harvest control rules based on % and % and the tier 3b adjustment are provided for reference. The management path for POP has been above the F35% adjusted limit for most of the historical time series (Figure 9-12). In addition, since 2004, POP SSB has been above % and fishing mortality has been below F40% since 1983.

### Recruitment

Recruitment (as measured by age 2 fish) for POP is highly variable and large recruitments comprise much of the biomass for future years (Figure 9-13). Recruitment has increased since the early 1970s, starting with the 1986 year class. Since the 1990s there have been several larger than average year classes, with the largest resulting in 2006. The largest differences in estimated recruitment between the current assessment and the 2020 assessment resulted at the end of the time series (Table 9-15 and Figures 9-13 and 9-14), which should not be unexpected given the influence of additional age composition data on recent recruitment estimates. The survey age data and the large 2013-2019 survey biomass suggests that the 2006-2009, 2010, 2012, and 2016 year classes may be above average (Figure 9-14). However, these recent recruitments are still highly uncertain as indicated by the MCMC credible intervals in Figure 9-13. POP do not seem to exhibit much of a stock-recruitment relationship because large recruitments have occurred during periods of high and low biomass (Figure 9-13).

### Uncertainty results

From the MCMC chains described in Uncertainty approach, we summarize the posterior densities of key parameters for the recommended model using histograms (Figure 9-15) and credible intervals (Table 9-16 and 9-17). We also use these posterior distributions to show uncertainty around time series estimates of survey biomass (Figure 9-4), total and spawning biomass (Figure 9-9), fully selected fishing mortality (Figure 9-11) and recruitment (Figure 9-13).

Table 9-16 shows the maximum likelihood estimate (MLE) of key parameters with their corresponding standard deviation derived from the Hessian matrix. Also shown are the MCMC, mean, median, standard deviation and the corresponding Bayesian 95% credible intervals (BCI). The Hessian and MCMC standard deviations are similar for q, M, and F40%, but the MCMC standard deviations are larger for the estimates of female spawning biomass and ABC. These larger standard deviations indicate that these parameters are more uncertain than indicated by the Hessian approximation. The distributions of these parameters with the exception of natural mortality are slightly skewed with higher means than medians for current spawning biomass and ABC, indicating possibilities of higher biomass estimates (Figure 9-15). Uncertainty estimates in the time series of spawning biomass also result in a skewed distribution towards higher values, particularly at the end of the time series and into the 15 year projected times series (Figure 9-16).

### Retrospective analysis

A within-model retrospective analysis of the recommended model was conducted for the last 10 years of the time-series by dropping data one year at a time. The revised Mohn’s “rho” statistic (Hanselman et al. 2013) in female spawning biomass was -0.16 (slightly larger than the 2020 value of -0.15), indicating that the model increases the estimate of female spawning biomass in recent years as data is added to the assessment. The retrospective female spawning biomass and the relative difference in female spawning biomass from the model in the terminal year are shown in Figure 9-17 (with 95% credible intervals from MCMC). In general the relative difference in female spawning biomass early in the time series is low, in recent years the increases in spawning biomass have been up to 30% compared to the terminal year. This result is not unexpected as given the large trawl survey biomass estimates since 2013; the model is responding to this data by increasing the estimates of biomass in each subsequent year.

## Harvest recommendations

### Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the “overfishing level” (OFL), the fishing mortality rate used to set OFL (FOFL), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (FABC) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, POP in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: %, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; %,,equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and %, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing.

Estimation of the % reference point requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the average of age-2 recruitments between 1979 and 2019 (i.e., the 1977 – 2017 year classes). Because of uncertainty in very recent recruitment estimates, we lag 2 years behind model estimates in our projection. Other useful biomass reference points which can be calculated using this assumption are % and %, defined analogously to %. The 2022 estimates of these reference points are:

|% | 331,917| |% | 132,767| |% | 116,171| |% | 0.10| |% | 0.12|

### Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2022 is estimated at 216,635 t. This is above the B40% value of 132,767 t. Under Amendment 56, Tier 3, the maximum permissible fishing mortality for ABC is F40% and fishing mortality for OFL is F35%. Applying these fishing mortality rates for 2022, yields the following ABC and OFL:

**TABLE HERE**

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2022 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2023 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2022. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawnfrom an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch after 2022 is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2019, are as follow (“” refers to the maximum permissible value of under Amendment 56):

* Scenario 1: In all future years, *F* is set equal to . (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
* Scenario 2: In 2022 and 2023, *F* is set equal to a constant fraction of , where this fraction is equal to the ratio of the realized catches in 2019-2021 to the ABC recommended in the assessment for each of those years. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In many fisheries the ABC is routinely not fully utilized, so assuming an average ratio catch to ABC will yield more realistic projections.)
* Scenario 3: In all future years, *F* is set equal to 50% of . (Rationale: This scenario provides a likely lower bound on FABC that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
* Scenario 4: In all future years, *F* is set equal to the 2013-2017 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of than .)
* Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA’s requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as ):

* Scenario 6: In all future years, *F* is set equal to . (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2018 or 2) above ½ of its MSY level in 2018 and above its MSY level in 2028 under this scenario, then the stock is not overfished.)
* Scenario 7: In 2022 and 2023, *F* is set equal to max , and in all subsequent years F is set equal to FOFL. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2020 or 2) above 1/2 of its MSY level in 2020 and expected to be above its MSY level in 2030 under this scenario, then the stock is not approaching an overfished condition.)

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios (Table 10.16). The difference for this assessment for projections is in Scenario 2 (Author’s *F*); we use pre-specified catches to increase accuracy of short-term projections in fisheries where the catch is usually less than the ABC. This was suggested to help management with setting preliminary ABCs and OFLs for two-year ahead specifications.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2022, it does not provide the best estimate of OFL for 2023, because the mean 2022 catch under Scenario 6 is predicated on the 2022 catch being equal to the 2022 OFL, whereas the actual 2022 catch will likely be less than the 2022 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

## Risk Table and ABC recommendation

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The following template is used to complete the risk table:

|  | ***Assessment-related considerations*** | ***Population dynamics considerations*** | ***Environmental/ecosystem considerations*** | ***Fishery Performance*** |
| --- | --- | --- | --- | --- |
| Level 1: Normal | Typical to moderately increased uncertainty/minor unresolved issues in assessment. | Stock trends are typical for the stock; recent recruitment is within normal range. | No apparent environmental/ecosystem concerns | No apparent fishery/resource-use performance and/or behavior concerns |
| Level 2: Substantially increased concerns | Substantially increased assessment uncertainty/ unresolved issues. | Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical. | Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators. | Some indicators showing adverse signals but the pattern is not consistent across all indicators |
| Level 3: Major Concern | Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias. | Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns. | Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock) | Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types |
| Level 4: Extreme concern | Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable. | Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns. | Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components | Extreme anomalies in multiple performance indicators that are highly likely to impact the stock |

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. “Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. “Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. “Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. “Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.”

#### Assessment considerations

#### Population dynamics considerations

#### Environmental/Ecosystem considerations

#### Fishery performance

#### Summary and ABC recommendation

| *Assessment-related considerations* | *Population dynamics considerations* | *Environmental/ecosystem considerations* | *Fishery Performance* |
| --- | --- | --- | --- |
| Level 1: No increased concerns | Level 1: No increased concerns | Level 1: No increased concerns | Level 1: No increased concerns |

### Area Allocation of Harvests

### Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

*Is the stock being subjected to overfishing?* The official catch estimate for the most recent complete year (2021) is *correct this later* r catch %>% filter(Year==year-1) %>% pull(Catch) %>% format(., big.mark = “,”)` t. This is less than the 2021 OFL of 5,402 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

*Is the stock currently overfished?* This depends on the stock’s estimated spawning biomass in 2022:

* 1. If spawning biomass for 2022 is estimated to be below ½ , the stock is below its MSST.
  2. If spawning biomass for 2022 is estimated to be above the stock is above its MSST.
  3. If spawning biomass for 2022 is estimated to be above ½ but below , the stock’s status relative to MSST is determined by referring to harvest Scenario #6 (Table 10.16). If the mean spawning biomass for 2028 is below , the stock is below its MSST. Otherwise, the stock is above its MSST.

*Is the stock approaching an overfished condition?* This is determined by referring to harvest Scenario #7:

* 1. If the mean spawning biomass for 2024 is below 1/2 , the stock is approaching an overfished condition.
  2. If the mean spawning biomass for 2024 is above , the stock is not approaching an overfished condition.
  3. If the mean spawning biomass for 2024 is above 1/2 but below , the determination depends on the mean spawning biomass for 2034 If the mean spawning biomass for 2034 is below , the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition. Based on the above criteria and Table 10.16, the stock is not overfished and is not approaching an overfished condition.

The fishing mortality that would have produced a catch for last year equal to last year’s OFL is 0.0641.

# Ecosystem Considerations

## Ecosystem Effects on the Stock

1. Predator population trends (historically, in the present, and in the foreseeable future). These trends could affect stock mortality rates over time.
2. Changes in habitat quality (historically, in the present, and in the foreseeable future). Changes in the physical environment such as temperature, currents, or ice distribution could affect stock migration and distribution patterns, recruitment success, or direct effects of temperature on growth.

## Fishery Effects on the Ecosystem

1. Fishery-specific contribution to bycatch of prohibited species, forage (including herring and juvenile pollock), HAPC biota (in particular, species common to the target fishery), marine mammals, birds, and other sensitive non-target species (including top predators such as sharks, expressed as a percentage of the total bycatch of that species.
2. Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components.
3. Fishery-specific effects on amount of large-size target fish.
4. Fishery-specific contribution to discards and offal production.
5. Fishery-specific effects on age at maturity and fecundity of the target species.
6. Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance).

# Data Gaps and Research Priorities

## Life history and habitat utilization

## Assessment Data

# References

Fenske, K.H., Hulson, P.-J.F., Williams, B. and O’Leary, C.A. (2020) Assessment of the Dusky Rockfish stock in the Gulf of Alaska. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

# Tables

Table 10.1. Summary of key management measures and the time series of catch, ABC, and TAC for northern rockfish in the Gulf of Alaska

| year | catch |
| --- | --- |
| 1999 | 1 |
| 2000 | 2 |

Table 10.2. Commercial catch (t) and management action for northern rockfish in the Gulf of Alaska, 1961-present. The \*Description of the catch time series\* Section describes procedures use to estimate catch during 1961-1993. Ctach estimates for 1993-2019 are from NMFS Observer Program and Alaska Regional Office updated through October XX, 2020.

| year | catch |
| --- | --- |
| 1,999 | 1 |
| 2,000 | 2 |

# Figures



Figure 10.1. pressure

# Appendix 10a. Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, a dataset has been generated to help estimate total catch and removals from NMFS stocks in Alaska. This dataset estimates total removals that occur during non-directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For Gulf of Alaska (GOA) northern rockfish, these estimates can be compared to the research removals reported in previous assessments (Heifetz et al. 2009; Table 10 A-1). Northern rockfish research removals are minimal relative to the fishery catch and compared to the research removals of other species. The majority of research removals are taken by the Alaska Fisheries Science Center’s (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of northern rockfish in the GOA. Other research activities that harvest northern rockfish include longline surveys by the International Pacific Halibut Commission and the AFSC and the State of Alaska’s trawl surveys. Recreational harvest of northern rockfish rarely occurs. Total removals from activities other than a directed fishery have been near 10 t for 2010 – 2017. The 2017 other removals is <1% of the 2018 recommended ABC of 4,529 t and represents a very low risk to the northern rockfish stock. Research harvests from trawl in recent years are higher in odd years due to the biennial cycle of the AFSC bottom trawl survey in the GOA and have been less than 10 t except in 2013 when 18 t were removed. These removals do not pose a significant risk to the northern rockfish stock in the GOA.

## References

Heifetz, J., D. Hanselman, J. N. Ianelli, S. K. Shotwell, and C. Tribuzio. 2009. Gulf of Alaska northern rockfish. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2010. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 817-874.

# Appendix 10b: VAST model-based abundance

## Background

Model-based abundance indices have a long history of development in fisheries (Maunder and Punt 2004). We here use a delta-model that uses two linear predictors (and associated link functions) to model the probability of encounter and the expected distribution of catches (in biomass or numbers, depending upon the specific stock) given an encounter (Lo *et al*. 1992; Stefánsson 1996).  
Previous research has used spatial strata (either based on strata used in spatially stratified design, or post-stratification) to approximate spatial variation (Helser *et al*. 2004), although recent research suggests that accounting for spatial heterogeneity within a single stratum using spatially correlated residuals and habitat covariates can improve precision for the wrestling index (Shelton *et al*. 2014).  
Model-based indices have been used by the Pacific Fisheries Management Council to account for intra-class correlations among hauls from a single contract vessel since approximately 2004 (Helser *et al*. 2004).  
Specific methods evolved over time to account for strata with few samples (Thorson and Ward 2013), and eventually to improve precision based on spatial correlations (Thorson *et al*. 2015) using what became the Vector Autoregressive Spatio-temporal (VAST) model (Thorson and Barnett 2017).

The performance of VAST has been evaluated previously using a variety of designs.  
Research has showed improved performance estimating relative abundance compared with spatially-stratified index standardization models (Grüss and Thorson 2019; Thorson *et al*. 2015), while other simulation studies have shown unbiased estimates of abundance trends (Johnson *et al*. 2019).  
Brodie *et al*. (2020) showed improved performance in estimating index scale given simulated data relative to generalized additive and machine learning models.  
Using real-world case studies, Cao *et al*. (2017) showed how random variation in the placement of tows relative to high-quality habitat could be “controlled for” using a spatio-temporal framework, and OLeary *et al*. (2020) showed how combining surveys from the eastern and northern Bering Sea within a spatio-temporal framework could assimilate spatially unbalanced sampling in those regions. Other characteristics of model performance have also been simulation-tested although these results are not discussed further here.

## Settings used in 2020

The software versions of dependent programs used to generate VAST estimates were:

R (>=3.5.3), INLA (18.07.12), TMB (1.7.15), TMBhelper (1.2.0), VAST (3.3.0), FishStatsUtils (2.5.0), sumfish (3.1.22)

We used a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution for the distribution of positive catch rates. We extrapolated catch density using 3705 m (2 nmi) X 3705 m (2 nmi) extrapolation-grid cells; this results in 36,690 extrapolation-grid cells for the eastern Bering Sea, 15,079 in the northern Bering Sea and 26,510 for the Gulf of Alaska (some Gulf of Alaska analyses eliminated the deepest stratum with depths >700 m because of sparse observations, resulting in a 22,604-cell extrapolation grid). We used bilinear interpolation to interpolate densities from 500 “knots” to these extrapolation-grid cells (i.e, using fine\_scale=TRUE feature); knots were distributed spatially in proportion to the distribution of extrapolation-grid cells (i.e., having an approximately even distribution across space) using knot\_method = 'grid'. No temporal smoothing was used (i.e. variation was estimated using independent and identically distributed methods). We estimated “geometric anisotropy” (the tendency for correlations to decline faster in some cardinal directions than others), and included a spatial and spatio-temporal term for both linear predictors.  
Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen 2016).

### Diagnostics

For each model, we confirm that the Hessian matrix is positive definite and the gradient of the marginal likelihood with respect to each fixed effect is near zero (absolute value < 0.0001).  
We then conduct a visual inspection of the quantile-quantile plot for positive catch rates to confirm that it is approximately along the one-to-one line, and also check the frequency of encounters for data binned based on their predicted encounter probability (which again should be along the one-to-one line).  
Finally, we plot Pearson residuals spatially, to confirm that there is no residual pattern in positive and negative residuals.

## References

Brodie, S.J., Thorson, J.T., Carroll, G., et al. (2020) Trade-offs in covariate selection for species distribution models: A methodological comparison. Ecography 43, 11–24.

Cao, J., Thorson, J., Richards, A. and Chen, Y. (2017) Geostatistical index standardization improves the performance of stock assessment model: An application to northern shrimp in the Gulf of Maine. Canadian Journal of Fisheries and Aquatic Sciences.

Grüss, A. and Thorson, J.T. (2019) Developing spatio-temporal models using multiple data types for evaluating population trends and habitat usage. ICES Journal of Marine Science 76, 1748–1761.

Helser, T.E., Punt, A.E. and Methot, R.D. (2004) A generalized linear mixed model analysis of a multi-vessel fishery resource survey. Fisheries Research 70, 251–264.

Johnson, K.F., Thorson, J.T. and Punt, A.E. (2019) Investigating the value of including depth during spatiotemporal index standardization. Fisheries Research 216, 126–137.

Lo, N.C.-h., Jacobson, L.D. and Squire, J.L. (1992) Indices of relative abundance from fish spotter data based on delta-lognornial models. Canadian Journal of Fisheries and Aquatic Sciences 49, 2515–2526.

Maunder, M.N. and Punt, A.E. (2004) Standardizing catch and effort data: A review of recent approaches. Fisheries research 70, 141–159.

O’Leary, C.A., Thorson, J.T., Ianelli, J.N. and Kotwicki, S. Adapting to climate-driven distribution shifts using model-based indices and age composition from multiple surveys in the walleye pollock (gadus chalcogrammus) stock assessment. Fisheries Oceanography.

Shelton, A.O., Thorson, J.T., Ward, E.J. and Feist, B.E. (2014) Spatial semiparametric models improve estimates of species abundance and distribution. Canadian Journal of Fisheries and Aquatic Sciences 71, 1655–1666.

Stefánsson, G. (1996) Analysis of groundfish survey abundance data: Combining the GLM and delta approaches. ICES journal of Marine Science 53, 577–588.

Thorson, J.T. (2018) Three problems with the conventional delta-model for biomass sampling data, and a computationally efficient alternative. Canadian Journal of Fisheries and Aquatic Sciences 75, 1369–1382.

Thorson, J.T. and Barnett, L.A. (2017) Comparing estimates of abundance trends and distribution shifts using single-and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science 74, 1311–1321.

Thorson, J.T. and Kristensen, K. (2016) Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research 175, 66–74.

Thorson, J.T., Shelton, A.O., Ward, E.J. and Skaug, H.J. (2015) Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science 72, 1297–1310.

Thorson, J.T. and Ward, E.J. (2013) Accounting for space–time interactions in index standardization models. Fisheries Research 147, 426–433.