Appendix 1A. Ecosystem and Socioeconomic Profile of the Walleye Pollock stock in the Gulf of Alaska - Report Card

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Executive Summary

The ecosystem and socioeconomic profile (ESP), is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators. It also communicates linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., 2023a). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

The ESP report card provides data updates to the most recent year available of the indicator suite created in the initial full ESP (Shotwell et al., 2019). For more information regarding the ecosystem and socioeconomic linkages for this stock, please refer to the last full ESP and most recent report card documents (Shotwell et al., 2019, Shotwell et al. 2023b). These documents are available as an appendix within the Gulf of Alaska (GOS) walleye pollock (pollock) stock assessment and fishery evaluation (SAFE) reports.

Management Considerations

The following are summary considerations from recent updates to the ecosystem and socioeconomic indicators evaluated for GOA pollock:

Acceptable Biological Catch (ABC) Information:

- No marine heatwave events, average sea surface temperatures, and mean wind direction toward the west suggest neutral to favorable egg and larval habitat conditions.
- Few larval prey indicators due to biennial survey sampling but high planktivore seabird reproductive success suggests adequate prey for larvae.
- High catch-per-unit-effort (CPUE) of young-of-the-year (YOY) pollock in the nearshore Kodiak survey and average relative biomass of pollock YOY in seabird diets suggest an average to above average 2024 year-class.
- Time-varying total mortality for age-1 pollock estimated within the Climate- Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) multispecies model is currently above the value used in the operational stock assessment model.
- Condition of fall pollock in the fishery in 2023 decreased and remains below average, but winter pollock condition in the acoustic survey in 2024 increased to near average.
- Predation demand of pollock for prey based on the CEATTLE model has been steadily decreasing since 2016 reflecting the ageing of the large 2013 cohort.
- Biomass consumed of GOA pollock as prey by all predators in the CEATTLE model remains low, reflecting the lower recent biomass of predators in the CEATTLE model and no recent large recruitment events of pollock.
- Biomass estimates of GOA Pacific ocean perch and Alaska sablefish, competitors and predators of GOA pollock, continue to be large.

Total Allowable Catch (TAC) Information:

- Fishery CPUE in the winter-spring decreased significantly in 2024, falling below the historical average but within one-standard deviation of the historical CPUE range implying pollock were less concentrated, so catch rates were lower and roe may be in slightly worse condition.
- Roe-per-unit-catch in the fishery decreased in 2024, remaining below the historical average but within one-standard deviation of the historical range.
- The average annual ex-vessel price per pound declined from 2022 levels falling below one-standard deviation for the first time since 2017 and remained below the historical average for the ninth year in the last decade.

Modeling Considerations

The following are the summary results from the most recent intermediate (Shotwell et al., 2023b) and advanced stage ecosystem monitoring analyses for GOA pollock:

- The highest ranked predictor variables of GOA pollock recruitment based on the importance methods in the intermediate stage indicator analysis were the spring sea surface temperature in western and central GOA management areas, and the fall pollock condition of adults in the fishery (inclusion probability > 0.5).
- A new research model was developed in 2024 that formally incorporates the ESP indicators into the 2023 GOA pollock stock assessment model using an embedded dynamic structural equation modeling (DSEM) framework. Initial results include significant reductions in recruitment variation and improved short-term projections of recruitment.

Assessment

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock with a conceptual model detailing ecosystem processes by life history stage (Figure 1A.1) and economic performance (Table 1A.1). Please refer to the last full ESP document (Shotwell et al., 2019) for more details.

Indicator Suite

The following list of indicators for GOA pollock is organized by categories: three for ecosystem indicators (larval to YOY, juvenile, and adult) and three for socioeconomic indicators (fishery informed, economic, and community). The indicator name and short description are provided in each heading. For ecosystem indicators, we include the proposed sign of the overall relationship between the indicator and a stock assessment parameter of interest (e.g., recruitment, natural mortality, growth), where relevant, and specify the lag applied if the indicator was tested in the ecosystem intermediate stage indicator analysis (see section below for more details). Each indicator heading is followed by bullet points that provide information on the contact and citation for the indicator data, the status and trends for the current year, factors influencing those trends, and implications for fishery management. The following nomenclature was used to describe these indicators:

- "Average": Used if the value in the time series is near the long-term mean (dotted green line in figure 1A.2).
- "Above average" or "Below average": Used if the value is above or below the mean but was within 1 standard deviation of the mean (in between solid green lines in Figure 1A.2).
- "Neutral": Used in Table 1A.2 for any value within 1 standard deviation of the mean.
- "High" or "Low": Used if the value was more than 1 standard deviation above or below the mean (above or below the solid green lines in Figure 1A.2).

This update focuses on new developments since the last ESP (Shotwell et al., 2023b). For detailed information regarding ecosystem and socioeconomic indicators and the proposed mechanistic linkages for GOA pollock, please refer to the previous ESP documents (Shotwell et al., 2019-2023b). Time series of these indicators are provided in Figure 1A.2a (ecosystem indicators) and Figure 1A.2b (socioeconomic indicators).

The full ESP process evaluates the indicator suite as a whole when the ESP is first created (Shotwell et al., 2023a). Report card documents maintain all these indicators but may require some modifications each year to ensure delivery of the best scientific information available.

New indicators in the 2024 suite include:

- Annual ration of age 1+ pollock from the most recent CEATTLE multispecies model as an estimate of bioenergetic requirements.
- Biomass of pollock consumed (or eaten as prey) by all predators in the CEATTLE multispecies model as an estimate of predation from primary predators.

Modified indicators include:

- Mean wind direction was updated to include the north/south (N/S) component for easier interpretation.
- Age-1 pollock predation mortality estimated from bottom trawl and setline surveys has been replaced by the CEATTLE multispecies model estimate of age-1 pollock natural mortality (M1+M2).
- Biomass estimates for GOA Pacific ocean perch and Alaska sablefish now include the current year by using the projection estimate from the most recently accepted operational stock assessment model.

Note: These modifications will preclude direct comparison with previous ESP indicator time series.

Removed indicators:

- Chlorophyll *a* derived indicators (concentration and peak timing of the spring bloom) were temporarily removed due to a product discrepancy that requires further evaluation.
- Summer euphausiid abundance indicator was removed, as no updates have been available since 2019 and future updates are unknown.
- Arrowtooth flounder total biomass was removed because it was replaced with information from the CEATTLE multispecies model regarding the biomass of pollock consumed as prey by all predators within the multispecies model (arrowtooth flounder, pollock, Pacific cod, and Pacific halibut) (Adams et al., 2022).

Ecosystem Indicators:

1. Larval to YOY Indicators (Figure 1A.2a.a-k)

a. Annual Heatwave CGOA Model: Annual marine heatwave index is calculated from daily sea surface temperatures for 1981 through present from the NOAA High-resolution Blended Analysis Data for the central GOA. Data source is the NOAA Optimum Interpolation Sea Surface Temperature (OISST) v2.1 from the NOAA Centers for Environmental Information (NCEI). Daily mean sea surface temperature data were processed to obtain the marine heatwave cumulative intensity (MHWCI) (Hobday et al., 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the January 1983 through December 2012 time series. Spatial resolution is 5 km satellite sea surface temperatures aggregated over a polygon defined by longitude -145 to -160 and depth <300m followed by annual summation of a cumulative heatwave index in degree Celsius days in the GOA. Proposed sign of the relationship to recruitment is negative.
    - Contact: Steve Barbeaux
    - Status and trends: Marine heatwave events are historically absent but have increased in the current decade at the central GOA spatial scale. Large events have occurred in 2005, 2014-2016, and 2019, but have decreased in recent years. There were no heatwave events so far in 2024.
    - Factors influencing trends: Generally, cool conditions are related to winter balances between heat loss, coastal runoff, and stratification, while warm conditions are associated with El Nino events (1998, 2003, and 2016) and marine heatwaves (Janout et al., 2010).

Additionally, detection of marine heatwaves will depend on the suite of baseline years that are included for the marine heatwave calculation.

- Implications: Absence of marine heatwaves implies cooler conditions which may aid growth and survival during the early life history stages of GOA pollock, although multiple mechanisms occur in concert during large heatwave events to result in a cascade of poor conditions that impact pollock recruitment (Rogers et al., 2021).

b. Spring Temperature Surface WCGOA Satellite: Spring (April-May) daily sea surface temperatures (SST) on a 5 km grid averaged over the western and central GOA (combined over the 10m-200m shelf for NMFS areas 610, 620, 630) (Watson, 2020) from the NOAA Coral Reef Watch Program which provides the Global 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018), from 1985 to present. Code available at: https://github.com/jordanwatson/ESP_Indicators. This seasonal and spatial distribution coincides with peak larval abundance of GOA pollock and where the bulk of the GOA pollock population is located. Proposed sign of the relationship to recruitment is negative and the time series is not lagged for the intermediate stage ecosystem monitoring analysis (see details below).
    - Contact: Matt Callahan
    - Status and trends: Spring sea surface temperatures were high or above average from 2014-2022 and have recently decreased to below average in 2023 and average in 2024.
    - Factors influencing trends: Many weather, climate and oceanographic factors influence sea surface temperatures (Holbrook et al., 2019). Generally, cool conditions in the GOA are related to winter balances between heat loss, coastal runoff, and stratification, while warm conditions are associated with El Nino events and marine heatwaves (Janout et al., 2010).
    - Implications: The cooler surface temperatures imply potentially more lipid-rich zooplankton species which may improve feeding conditions for larval pollock.

c. Spring Wind NS Direction: Mean springtime (April-May) north/south surface wind strength from the National Data Buoy Center (www.NDBC.NOAA.gov) for site B-AMAA2 located in the NE Kodiak Archipelago (Wilson and Laman, 2020). In previous years, the mean direction was reported. We updated this to the N/S component of the winds to aid in interpretation of the time series values. Mean wind direction and the N/S component of the winds are highly correlated (r=0.94). Positive values indicate mean winds blowing from the south. Data are available from 2004-2006, 2009-2017 and 2019-2024. The proposed sign of the relationship to recruitment is negative.
    - Contact: Lauren Rogers
    - Status and trends: The mean wind direction at NDBC-site AMAA2 was toward the west during spring 2024, with very little N/S displacement (hence a value near zero). In contrast, most years have a southerly wind direction (negative values), except for 2014-2016, when the N/S component was more northerly or neutral.
    - Factors influencing trends: In the Gulf, winds are dominated by cyclonic storm systems that exhibit pronounced seasonality (Stabeno et al., 2004). During spring, cyclonic winds begin to moderate and anticyclonic winds can drive intermittent upwelling. The AMAA2 site was chosen to indicate winds at a point where they are likely to affect the bifurcation of coastal flow. Northeasterly wind (blowing towards the southwest) has been associated with retention of pollock larvae (Stabeno et al., 1996) and juveniles (Wilson and Laman, 2021) in favorable habitats in the Kodiak Island/Shelikof sea valley vicinity.
    - Implications: When the AMAA2 wind trajectories for this period (Apr-May) are toward the southwest (down Shelikof Strait), estimates of age-1 pollock abundance tend to increase presumably because downwelling-favorable northeasterly winds enhance retention of larvae and juveniles in areas that favor survival (Wilson and Laman, 2021).

d. Spring Small Copepod Abundance Shelikof Survey: Spring small copepods (<2 mm) were summarized as log-10 transformed mean catch per m^3 for the core sampling area in Shelikof Strait and Sea Valley of the EcoFOCI spring surveys. The current survey year (if available) is often represented by a rapid zooplankton assessment to provide a preliminary estimate of zooplankton abundance and community structure (Kimmel et al., 2019). Ongoing work will determine the robustness of the rapid zooplankton assessment through comparison with quantitative data with high taxonomic resolution. Small copepods are prey for larval and early juvenile pollock. In 2023, time series were revised to standardize by gear type. This indicator is only updated on odd years due to the biennial sampling schedule of the EcoFOCI spring surveys. The proposed sign of the relationship to recruitment is positive.

- Contact: Lauren Rogers
- Status and trends: Small copepods have had elevated abundances during recent sampling, particularly during the marine heatwave of 2014-2016 and in 2019, and abundances in 2023 were lower than those observed recently.
- Factors influencing trends: Small copepod abundances were reduced in spring and this makes sense with respect to life history characteristics of small copepods, e.g. multiple generations per year, faster turnover times, and metabolic rates that scale with temperature. Thus, cooler temperatures reduced the rate at which small copepod population increased. Recent warm years had high abundances of small copepods in spring and numbers in 2023 were lower than those peaks.
- Implications: Zooplankton are an important prey base for larval and juvenile fishes in spring and summer. While small copepod numbers were reduced relative to recent spring values, numbers remained high indicating that there is likely a significant number of nauplii and smaller copepods available as prey for larval fishes.

e. Summer Large Copepod Abundance Shelikof Survey: Summer large copepods (> 2mm) were summarized as log-10 transformed mean catch per m^3 for the core sampling area in Shelikof Strait and Sea Valley of the EcoFOCI late-summer surveys (August - September). The most recent survey year is represented by a rapid zooplankton assessment to provide a preliminary estimate of zooplankton abundance and community structure (Kimmel et al., 2019). Ongoing work will determine the robustness of the rapid zooplankton assessment through comparison with quantitative data with high taxonomic resolution. Large copepods are important prey for young-of-the-year (YOY) pollock and other groundfishes in summer. In 2023 time series were revised to standardize by gear type. This indicator is only updated on odd years due to the biennial sampling schedule of the EcoFOCI late-summer surveys. Additionally, there was no survey in 2021. The proposed sign of the relationship to recruitment is positive.

- Contact: Lauren Rogers
- Status and trends: Late summer, large copepod abundance declined from the early 2000s until the marine heatwave of 2014-2016. In 2023, large copepod numbers were similar to recent years and slightly higher than the marine heat wave years.
- Factors influencing trends: Large copepod abundances are influenced by timing of the annual cohort of the dominant large species: *C. marshallae*, *N. cristatus*, and *Neocalanus* spp. The dominant large species in summer is *C. marshallae* as both other large species have likely entered diapause. Long-term variability in mesozooplankton in this region is thought to be driven by Pacific Decadal Oscillation (PDO) and El Nino-Southern Oscillation (ENSO) cycles.
- Implications: Zooplankton are an important prey base for juvenile fishes in summer. Large copepod numbers were average during the late summer relative to long-term trends. Both are principal diet items for juvenile fish and these numbers appear to indicate adequate forage.

f. Annual Auklet Reproductive Success Chowiet Survey: Parakeet auklet reproductive success is measured at Chowiet Island during variable years since 1998. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that had eggs laid. This species is a diving plankton feeder, like pollock, and reproductive success may be indicative of the prey field in a central area to the GOA pollock population. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service (Higgins et al., 2018). Proposed sign of the relationship to recruitment is positive.
    - Contact: Stephani Zador
    - Status and trends: reproductive success is highly variable across the time series and increased from average to high in 2024.
    - Factors influencing trends: Availability of sufficient zooplankton production around the seabird colony.
    - Implications: Marine seabirds are sensitive indicators of change in the productivity of marine ecosystems and their reproductive success can signal processes affecting the availability of prey for fish feeding in the same areas (Warzybok et al., 2018). Higher breeding success of zooplankton-feeding seabirds such as parakeet auklets implies good zooplankton resources as prey for YOY pollock.

g. Spring Pollock CPUE Larvae Shelikof Survey: Spring pollock larvae catch-per-unit-of-effort (CPUE) were summarized as mean abundance for the core sampling area in the EcoFOCI spring surveys. The primary sampling gear used is a 60-cm bongo sampler fitted with 505-Âµm mesh nets. Oblique tows are carried out mostly from 100 m depth to the surface or from 10 m off bottom in shallower water (Matarese et al., 2003). Historical sampling has been concentrated in the vicinity of Shelikof Strait and Sea Valley during mid-May through early June. From this area and time, a subset of data has been developed into time series of ichthyoplankton abundance. On-board counts give rapid estimates of relative abundance (Rapid Larval Assessment), which are presented in the year of collection, and subject to revision following detailed laboratory processing of samples. In 2023, time-series calculations were updated to use a model-based approach (sdmTMB; Anderson et al. 2022) instead of the previous area-weighted mean, in part to better account for variable survey coverage in recent years due to ship-time constraints. In 2023, the EcoFOCI survey was truncated due to vessel staffing, resulting in only partial coverage of the core survey area. Hence, 2023 estimates have greater uncertainty (see Rogers and Axler 2023 ESR Contribution). This indicator is only updated on odd years due to the biennial sampling schedule of the EcoFOCI spring surveys. Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage ecosystem monitoring analysis (see details below).
    - Contact: Lauren Rogers
    - Status and trends: Walleye pollock larval abundance remained below average in 2023, similar to observations in 2021, and lower than 2019.
    - Factors influencing trends: Years of high abundance for the late winter to early spring shelf spawners (i.e., Pacific cod, walleye pollock, and northern rock sole) were associated with cooler winters and enhanced alongshore winds during spring. With temperature conditions in 2023 being consistent with an "average" to “cool” climate year, we expected to observe increased abundances of walleye pollock. A prolonged period of offshore gap winds in the area of Kodiak in April may have altered the flow of the Alaska Coastal Current and advection patterns for larvae, but we were unable to investigate whether distributions were unusual with our abbreviated survey.
    - Implications: Ichthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. In both 2015 and 2019, low abundances of walleye pollock and Pacific cod larvae were the first indicators of failed year-classes for those species. In 2023, abundance of walleye pollock and Pacific

cod larvae were again low, suggesting another poor year class, although abundances may have been higher outside the surveyed region. The low abundance of gadid larvae, combined with low to average abundance of the other indicator species, suggests poor to average forage for piscivorous predators, including seabirds, who rely on larval and juvenile fish.

h. Summer Pollock CPUE YOY Shelikof Survey: Summer pollock young-of-year (YOY, aka age-0) catch-per-unit-of-effort (CPUE) were summarized as the area-weighted mean abundance for the core sampling area between Kodiak and the Shumagin Islands of the EcoFOCI summer surveys. Age-0 pollock were collected using a Stauffer trawl (aka anchovy trawl) equipped with a small-mesh (2x3-mm) codend liner towed obliquely to a maximum headrope depth of 200 m. This indicator is only updated on odd years due to the biennial sampling schedule of the EcoFOCI late-summer surveys. Additionally, there was no survey in 2021. The proposed sign of the relationship with recruitment is positive.
    - Contact: Lauren Rogers
    - Status and trends: Catches of age-0 pollock were below average and the third lowest on record, with the majority of fish found on the bank to the southwest of the Shelikof Sea Valley. No age-0 pollock were caught at over 1/3 of the stations. The spatial distribution was similar to 2019 in the areas sampled.
    - Factors influencing trends: The abundance of age-0 pollock in late summer reflects the number of surviving larvae from spawning in the spring and survival processes through the summer. Downwelling-favorable springtime winds are likely important for retaining larvae and juveniles in favorable nursery habitats near Kodiak and Shelikof, which contributes to recruitment (Wilson and Laman 2021).
    - Implications: Young-of-year pollock are key forage fish species in the Gulf of Alaska, providing prey for seabirds, fishes, and mammals. This late-summer survey also provides an assessment of the abundance, size, and condition of young-of-year pollock before entering their first winter, giving an early indicator of potential year-class strength. Low catches of young-of-year pollock, together with previously observed low larval abundance, suggest a weak 2023 year class.

i. Summer Pollock Condition YOY Shelikof Survey: Summer body condition of YOY (age-0) pollock was calculated based on samples taken in the EcoFOCI late-summer midwater trawl survey. A small-mesh mid-water trawl was used to sample the upper 200 m or from 5 m off bottom. A random sample of age-0 individuals was frozen at sea and later processed in the laboratory for body length and weight. A body condition index was calculated as the residuals from a regression of ln(body weight) on ln(length) using data from all surveys combined and included day of year to account for variation in time of sampling. An annual index was calculated for the core area in the western GOA between Kodiak and the Shumagin Islands by weighting individual condition values by station-specific CPUE. Fish with positive residuals are considered "fatter" with greater energetic reserves to survive life stage transitions such as first overwinter survival (Rogers et al., 2021). This indicator is only updated on odd years due to the biennial sampling schedule of the EcoFOCI late-summer surveys. Additionally, there was no survey in 2021. The proposed sign of the relationship with recruitment is positive.
    - Contact: Lauren Rogers
    - Status and trends: Average body condition of age-0 pollock in 2023 was similar to 2019, which was the lowest observed in the time series. Condition was also low in the two previous years sampled (2015 and 2017) as well as 2005. Higher than average body condition was observed in 2001, 2003, 2007 and 2009. No data are available for 2021 due to cancellation of the late-summer EcoFOCI survey.
    - Factors influencing trends: Body condition of age-0 pollock is likely influenced by temperature, which increases metabolic demands, and prey quality and quantity, which

determine their ability to meet those demands. In 2015, during the North Pacific marine heatwave, temperatures were warm and prey quality and quantity were reduced, resulting in poor body condition (Rogers et al. 2021). In 2019, warm conditions returned to the GOA, including at depth, which likely contributed to low condition at end of summer for age-0 pollock.

- Implications: Juvenile pollock rapidly increase their energy storage in late summer, presumably to increase their survival chances during winter, when prey are scarce (Siddon et al. 2013). In the Bering Sea, low energy storage prior to the first winter has been associated with poor year-class strength for juvenile pollock. Whether this relationship holds for the Gulf of Alaska is yet to be seen, but poor body condition in 2015, 2017, 2019, and 2023 reflects suboptimal ecosystem conditions for pollock growth both during and after the recent marine heatwaves, which may have had adverse effects on overwinter survival.

j. Summer Pollock CPUE YOY Nearshore Kodiak Survey: Summer walleye pollock CPUE of YOY was estimated using the AFSC beach seine survey available from 2006-present. Beach seine sampling of age-0 pollock was conducted at two Kodiak Island bays during 2006-2021 and an expanded survey was conducted during 2018-2021 at 13 additional bays on Kodiak Island, the Alaska Peninsula, and the Shumagin Islands (n = 3 - 9 fixed stations per bay, 95 total stations). Sampling occurs during July and August (days of year 184-240), within two hours of a minus tide at the long-term Kodiak sites, and within three hours of a low tide at the expanded survey sites. At all sites, a 36 m long, negatively buoyant beach seine is deployed from a boat and pulled to shore by two people standing a fixed distance apart on shore. Wings on the seine (13 mm mesh) are 1 m deep at the ends and 2.25 m in the middle with a 5 mm delta mesh cod end bag. The seine wings are attached to 25 m ropes for deployment and retrieval from shore. The seine is set parallel to and ~ 25 m, making the effective sampling area ~ 900 m 2 of bottom habitat. Data represent a model-based index of annual catch per unit effort (CPUE) for age-0 pollock to resolve inter-annual differences in sampling across different bays and different days of the year. Specifically, a Bayesian zero-inflated negative binomial (ZINB) model was used invoking year as a categorical variable, day of year as a continuous variable, and site nested within bay as a group-level (random) effect. The day of year effect was modeled with thin plate regression splines to account for non-linear changes in abundance through the season and the number of basis functions was limited to 3 to avoid over-fitting data. This model was fit using Stan 2.21.0, R 4.0.2 and the brms package (Carpenter et al. 2017, Buerkner 2017, R Core Team 2021). Proposed sign of the relationship to recruitment is positive.

- Contact: Ben Laurel
- Status and trends: Age-0 walleye pollock numbers are annually variable in the nearshore but showed steep declines during marine heatwave periods (2014-26; 2019). Walleye pollock numbers have been notably higher since 2016 in non-heatwave years.
- Factors influencing trends: Factors influencing nearshore abundance of age-0 juvenile pollock have not been fully evaluated but seine CPUE estimates have been shown to be relatively good indicators of future recruitment (Litzow et al. 2022). The steep declines in age-0 abundance during marine heatwaves suggests there is poor survival of egg and larval stages in the spring.
- Implications: Age-0 pollock numbers in the nearshore likely represent a small portion of the overall offshore population but serve as indicators of future recruitment.

k. Annual Pollock Relative Biomass Aiktak Survey: Pollock relative biomass of YOY is measured from screening burrows of tufted puffins at Aiktak Island annually since 1991. This species is a diving fish-feeder and estimates of pollock relative biomass from feeding samples may be indicative of pollock densities near the western edge of the pollock population. Data are collected by the Alaska Maritime National Wildlife Refuge, U.S. Fish and Wildlife Service (Youngren et al., 2019). Proposed sign of the relationship to recruitment is positive.

- Contact: Stephani Zador
- Status and trends: Relative biomass of YOY pollock is highly variable across the time series and increased from low to average in 2024.
- Factors influencing trends: Changes in the availability of small, schooling fish up to approximately 90 m below the surface may impact the ability of diving seabirds to sample YOY pollock. Shifts in distribution of the seabird population may also impact measures of relative biomass measured at the colony.
- Implications: Fish-eating diving seabirds such as tufted puffins sample local populations of forage fish and may represent trends in those fish populations. Aiktak Island is near the western edge of the GOA pollock population and increased relative biomass of pollock from bill loads may indicate an increase in YOY population distribution.

2. Juvenile Indicators (Figure 1A.2a.l-m)

l. Pollock Predation Mortality Age-1 GOA Model: Estimate of walleye pollock age-1 natural mortality (model estimated sex-specific, time- and age-invariant residual mortality, M1, plus model estimates of time- and age-varying predation mortality, M2) from the Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) that has recently been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the GOA (Adams et al., 2022). Proposed sign of the relationship to recruitment is negative.
    - Contact: Grant Adams
    - Status and trends: Age-1 natural mortality for pollock peaked in 2003, steadily decreased to a low in 2014 and has since fluctuated below the long-term mean. The 2024 value of 1.45 yr^{-1} is an increase from 2023 and above the age-1 single species stock assessment value of 1.39 yr^{-1}, but is still below the long-term average of 1.5 yr^{-1}.
    - Factors influencing trends: Temporal patterns in total natural mortality reflect annually varying changes in predation mortality by pollock, Pacific cod, and arrowtooth flounder that primarily impact age-1 fish (but also impact older age classes). Predation mortality in the multispecies model at age-1 was primarily driven by arrowtooth flounder. Arrowtooth flounder biomass has been low since 2017 but has increased slightly in the following years (Shotwell et al., 2023c).
    - Implications: There is evidence of time-varying predation mortality on age-1 pollock due to the species modeled in CEATTLE that has historically varied above and below the time-invariant single species stock assessment value.

m. Summer Pollock Euphausiid Diet Juvenile GOA Survey: Summer pollock proportion-by-weight of euphausiids in the diets of juvenile (10-25 cm, likely age-1) GOA pollock from summer bottom-trawl surveys, 1990 to present, various years. This indicator is only updated on odd years due to the biennial sampling schedule of the summer bottom trawl survey in the GOA. Proposed sign of the relationship to recruitment is positive.
    - Contact: Kerim Aydin
    - Status and trends: Percent of euphausiids in the diet for juveniles was slightly above average in 2023, similar to 2021.
    - Factors influencing trends: The marine heatwave was a major perturbation to pelagic primary and secondary production throughout the GOA altering phenology, community composition, and abundance at lower trophic levels (Batten et al., 2018; Suryan et al., 2021). Euphausiid distribution is patchy and population dynamics remain difficult to explain in the absence of more accurate temporal and spatial sampling (Kimmel et al., 2023), but are likely influenced by biomass fluctuations of competitors for zooplankton

prey such as pink salmon and other groundfish species such as Pacific ocean perch and juvenile sablefish.

- Implications: Consumption of euphausiids has been associated with improved growth and body condition in the western GOA (Wilson et al., 2013). Above average percent euphausiids in juvenile pollock diets imply sufficient prey resources and may lead to good overall condition.

3. Adult Indicators (Figure 1A.2a.n-w)

n. Summer Temperature Bottom GOA Survey: Summer bottom temperatures were obtained by averaging the haul-specific bottom temperature (degrees Celsius) collected on the AFSC bottom trawl survey over all hauls from 1984 to present. Data are available triennial since 1984 and biennial since 2000. Proposed sign of the relationship to recruitment is negative.
   - Contact: Kalei Shotwell
   - Status and trends: Lower bottom temperatures from 2021 through 2023 following the high and above average temperatures during the marine heatwave.
   - Factors influencing trends: Subsurface waters below mixed layers can absorb and store heat. These changes do not occur at the same timescales as changes in surface water temperatures, often showing delayed responses by a year or more. These temperature changes are also very small compared to surface waters. The warmer subsurface waters become, the less cooling capacity they have to absorb heat from surface waters (Siwicke, 2022).
   - Implications: Cooler bottom temperatures suggest improved conditions for spawning and egg deposition.

o. Fall Pollock Condition Adult GOA Fishery: Fall pollock condition for adults was estimated from length-weight data from the fishery sampled by observers (1989-2018). A log length-weight regression was fitted and then the residuals from the regression were averaged by year. Data only for the months of August, September, and October were used to measure condition at the end of the production year. The length-weight regression included a slope term for month, and this term increased slightly in value from August to October, indicating that condition improved during these months. Proposed sign of the relationship to recruitment is positive and the time series is lagged by minus one year for the intermediate stage ecosystem monitoring analysis (see details below).
   - Contact: Cole Monnahan
   - Status and trends: Condition of adult pollock in the fall fishery of 2023 decreased from 2022 and is still below average.
   - Factors influencing trends: Factors that could affect residual fish body condition could include temperature, timing of the fishery, stomach fullness, movement in or out of normal fishing grounds, or variable somatic growth (O'Leary and Rohan, 2023).
   - Implications: It is unclear why condition of pollock in the fall fishery has decreased and uncoupled from condition of pollock in the winter acoustic survey but may imply reduced prey resources during the fall or a spatial shift in the fishery.

p. Winter Pollock Condition Adult GOA Survey: Winter pollock condition for adults was estimated from length-weight data from the late winter acoustic surveys of pre-spawning pollock in the GOA. Most of the sampling occurred in Shelikof Strait, but data from outside Shelikof Strait were not excluded. A log length-weight regression was fitted and then the residuals from the regression were averaged by year. Fish in spawning or post-spawning condition were excluded, and the analysis was limited to fish greater or equal to 35 cm to exclude the age-1 and age-2 pollock. Estimates were produced for 1986 to present, excluding 1999, 2001, and 2011. Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage ecosystem monitoring analysis (see details below).

- Contact: Cole Monnahan
- Status and trends: Condition of winter adult pollock from the acoustic survey increased from below average in 2023 to just near average in 2024, which is a break from the correlation between the fall condition from the fishery.
- Factors influencing trends: Factors that could affect residual fish body condition could include temperature, timing of the fishery, stomach fullness, movement in or out of normal fishing grounds, or variable somatic growth (O'Leary and Rohan, 2023).
- Implications: Cooling environmental conditions may imply improved prey resources such as euphausiids and increase condition of pollock prior to spawning. Roe quality may also be impacted by winter condition and may be reflected in the roe-per-unit-catch.

q. Annual Ration Pollock GOA Model: Estimate of annual predation demand (ration) of walleye pollock (age-1+) from the CEATTLE that has recently been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the GOA (Adams et al., 2022). Proposed sign of the relationship to recruitment is negative.
    - Contact: Grant Adams
    - Status and trends: Ration has been steadily decreasing for pollock since 2016, and remains below average in 2024.
    - Factors influencing trends: Decreasing population trends since the large 2013 recruitment event for GOA pollock in recent years result in decreasing demand for prey.
    - Implications: Rates of cannibalism would decrease as the GOA pollock population decreases, although the amount of cannibalism is fairly low in the GOA.

r. Summer Pollock Center Gravity Northeast WCGOA Model: The rotated center of gravity calculation was configured to improve the interpretation of shifts in center of gravity, such that the axes along which this metric was summarized are approximately parallel and perpendicular to the continental shelf within the core distribution of walleye pollock. This metric characterizes the rotated axis and is reported in km. Catch and effort data from the GOA groundfish bottom trawl survey were used to calculate this metric. This indicator is only updated on odd years due to the biennial sampling schedule of the summer bottom trawl survey in the GOA. Proposed sign of the relationship to recruitment is negative.
    - Contact: Zack Oyafuso
    - Status and trends: The center of gravity for WCGOA walleye pollock shifted towards the southwest compared to 2021.
    - Factors influencing trends: The southwestern shift in the center of gravity is current with both an expansion of effective area occupied and a large increase in the design-based estimate of total GOA walleye pollock biomass.
    - Implications: Changes in the distributional characteristics of marine populations may impact the spatial distributions of fishing activities and trophic interactions.

s. Summer Pollock Area Occupied WCGOA Model: The effective area occupied is the area required to contain a population given its average density. The spatial domain is the WCGOA. This metric is reported in log-km^2. Catch and effort data from the GOA groundfish bottom trawl survey were used to calculate this metric. This indicator is only updated on odd years due to the biennial sampling schedule of the summer bottom trawl survey in the GOA. Proposed sign of the relationship to recruitment is positive.
    - Contact: Zack Oyafuso
    - Status and trends: The estimated effective area occupied for WCGOA walleye pollock markedly increased from 2021 and is currently the highest estimate in 1990-2023 period.
    - Factors influencing trends: The large expansion of effective area occupied is concurrent with a large increase in the design-based estimate of total GOA walleye pollock biomass.
    - Implications: The expansion of effective area occupied in 2023 implies a wider spatial distribution covered by walleye pollock in the GOA relative to the 1990-2023 time series.

Changes in the distributional characteristics of marine populations may impact the spatial distributions of fishing activities and trophic interactions.

t. Annual Biomass Consumed Pollock GOA Model: Estimate of walleye pollock biomass consumed (or eaten as prey, in tons) by all predators from the Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) that has recently been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the GOA (Adams et al., 2022). Proposed sign of the relationship to recruitment is negative.
    - Contact: Grant Adams
    - Status and trends: Estimates of total biomass of pollock consumed as prey across all ages increased in 2024 but is currently low and well below the long-term mean.
    - Factors influencing trends: Population trends of predators included in the CEATTLE model (arrowtooth flounder, pollock, Pacific cod, Pacific halibut) and recruitment of pollock impact total biomass consumed of pollock as prey.
    - Implications: As predator populations decline in the GOA and recruitment remains low so does the predation pressure on GOA pollock.

u. Annual Pacific Ocean Perch Biomass GOA Model: Pacific ocean perch total biomass from the most recent stock assessment model. Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage ecosystem monitoring analysis (see details below).
    - Contact: Kalei Shotwell
    - Status and trends: Estimates from the 2023 bottom trawl survey for Pacific ocean perch were 8% greater than in 2021. Total biomass estimates have been steadily increasing over the time series to a peak in 2016 and have only slightly declined in recent years. The most recent projection for 2024 is slightly decreased from 2023 but still above average.
    - Factors influencing trends: Pacific ocean perch population trends have been increasing for the past decade.
    - Implications: Pacific ocean perch may be a significant competitor of GOA pollock and biomass has been increasing in the GOA.

v. Annual Sablefish Biomass GOA Model: Sablefish total biomass (age-2+) from the most recent stock assessment model. Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage ecosystem monitoring analysis (see details below).
    - Contact: Kalei Shotwell
    - Status and trends: Sablefish biomass estimates remain above average from the most recent stock assessment model and the most recent projection for 2024 is at the highest in the time series.
    - Factors influencing trends: Sablefish population trends have been increasing for the past decade due to several recent large recruitment events since the onset of the 2014-2016 marine heatwave.
    - Implications: Juvenile sablefish may be a significant competitor of pollock for euphausiid prey. Adult sablefish are generalists and may become a significant predator of GOA pollock as the population grows and density-dependent factors (Cheng et al., 2024) potentially push sablefish out of their preferred slope habitat.

w. Annual Steller Sea Lion Adult GOA Survey: Steller sea lion non-pup estimates for the GOA portion of the western Distinct Population Segment. Surveys for Steller sea lions usually occur on odd years but the surveys did not occur in the GOA in 2023. Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage ecosystem monitoring analysis (see details below).
    - Contact: Katie Sweeney

- Status and trends: Significant declines occurred in the 1990s through early 2000s but the population has been increasing over the past decade.
- Factors influencing trends: Some anomalous changes have occurred in population trends since 2017, following the heatwave event of 2014-2016 but the impact on the Steller sea lion population is likely delayed as they are a long-lived species.
- Implications: Steller sea lions show some dependence on pollock for their diet and predation pressure on GOA pollock will increase as the sea lion populations have increased over the past decade.

Socioeconomic Indicators:

<u>1. Fishery Informed Indicators (Figure 1A.2b.a-c)</u>

a. Winter Spring Pollock CPUE Adult GOA Fishery: Winter-spring pollock CPUE (catch of pollock in tons/hour) was estimated from fishery observer data. Data were filtered to exclude catches less than 80% pollock, and gears other than pelagic gear. Only tows with a performance code of "no problem" were used. The geometric mean CPUE was calculated by taking the log of the CPUE and then exponentiating. Mean CPUE was calculated for the first trimester (Jan-April).
    - Contact: Cole Monnahan
    - Status and trends: The winter-spring pollock CPUE declined in 2024 to below the historical average for the first time since 2010 but remains within one-standard deviation of the historical range.
    - Factors influencing trends: TBD
    - Implications: Lower CPUE in the 1st trimester implies that the pollock were not as concentrated in pre-spawning aggregations, so catch rates were lower and may impact roe quality.

b. Summer Fall Pollock CPUE Adult GOA Fishery: Summer-fall pollock CPUE (catch of pollock in tons/hour) was estimated from fishery observer data. Data were filtered to exclude catches less than 80% pollock, and gears other than pelagic gear. Only tows with a performance code of “no problem” were used. The geometric mean CPUE was calculated by taking the log of the CPUE and then exponentiating. Mean CPUE was calculated for the third trimester (Aug-Dec, mostly Aug.-Oct.).
    - Contact: Cole Monnahan
    - Status and trends: The summer-fall pollock CPUE increased from 2022 levels to slightly above the historical average and remains within one-standard deviation of the historical range.
    - Factors influencing trends: TBD
    - Implications: TBD

c. Winter Spring Pollock Roe Per Unit Catch Fishery: Annual pollock roe per-unit-catch during January to March was calculated from 2000-2024. Production of roe per-unit catch during January to March, the peak roe production months, is potentially indicative of the fecundity of the stock. As a high priced pollock product, processors and harvesters have an incentive to maximize the production of roe subject to harvest controls. A number of other factors besides fecundity can potentially influence the relative share of roe to retained catch including roe prices and the timing of harvest. This metric is constructed as 1000*(roe production)/(retained catch) (Fissel et al., 2019).
    - Contact: Russel Dame
    - Status and trends: Roe production declined slightly from 2023 levels but remained within one-standard deviation of the historical range.
    - Factors influencing trends: The decline in the winter-spring pollock CPUE suggests that pollock may be less concentrated which may have a negative effect on roe quality. The

average first-wholesale price of roe, however, remains above the 2014 to 2018 average for the third consecutive year (2021-2023) with volume remaining stable, suggesting that wholesalers are able to sell roe despite potential reductions in quality.

- Implications: As roe per-unit catch and the first-wholesale volume of roe remain below pre-2013 levels, the price of roe may continue to increase higher than the historical average, assuming no significant changes in demand. High prices may incentivize vessels to target fish with high levels of roe despite potential reductions in quality.

2. Economic Indicators (Figure 1A.2b.d)

d. Annual Pollock Real Ex-vessel Price: Annual real ex-vessel price per pound was calculated from 2003-2023. Ex-vessel prices are the revenue per pound of retained pollock delivered to processors. Increases in the ex-vessel price per pound may incentivize vessels to increase their harvest through increased effort or capital improvements. Many other factors can influence the returns and the incentive to change harvest including changes to costs and activities in other fisheries in which harvesters may participate (similar gear type, capital characteristics, region, etc.). The ex-vessel price metric has been inflation adjusted to 2023 USD to account for general trends in prices over time.

- Contact: Russel Dame
- Status and trends: The average ex-vessel price per-pound of GOA pollock decreased from $0.17 to $0.13 in 2023, falling below one-standard deviation of the historical average for the first time since 2017. The 2023 average ex-vessel price per pound is approximately 40% less than the 2005 to 2013 average of $0.22 per pound.
- Factors influencing trends: Recent declines in ex-vessel price may be associated with the increase in Russian seafood exports entering the global market with recent reports stating that Russian exports of seafood to China are up 36.1% from 2022 levels and are continuing to rise. Additionally, the decline in the average ex-vessel price compared to pre-2014 levels may also be associated with the significant increase in total catch since 2014 with relatively stable levels of demand. Total catch increased from an average of 73 thousand mt between 2005 and 2013 to 142 thousand mt between 2014 and 2023.
- Implications: As prices remain low compared to pre-2014 levels, vessels targeting GOA pollock may choose to target a substitute species that can be targeted with the same gear and receive a higher profit margin. This may be supported by the reduction in active vessels each year since 2014.

3. Community Indicators

An analysis of commercial processing and harvesting data may be conducted to examine sustained participation for those communities substantially engaged in a commercial fishery. The Annual Community Engagement and Participation Overview (ACEPO) report evaluates engagement at the community level and focuses on providing an overview of harvesting and processing sectors of identified highly engaged communities for groundfish and crab fisheries in Alaska (Wise et al., 2024). An example of community indicators has been included in the Alaska sablefish ESP report (Shotwell and Dame, 2024) and we plan to include a similar set of indicators in the next report card for GOA pollock following review and recommendations for the Alaska sablefish ESP report.

Indicator Monitoring Analysis

Ecosystem and socioeconomic indicators are monitored through distinct workflows, depending on the management decisions they are intended to inform. These workflows are defined for each indicator suite in the following sections.

Ecosystem Monitoring

Ecosystem indicators undergo up to three stages of statistical analysis (beginning, intermediate, and advanced) to monitor their impact on stock health (Shotwell et al., 2023a). The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the indicator value from each year relative to the mean of the whole time series and includes the proposed sign of the overall relationship between the indicator and the stock health. The intermediate stage uses importance methods related to a stock assessment parameter of interest (e.g., recruitment, growth, catchability). These regression techniques provide a simple predictive performance for the parameter of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for providing visibility on current research ecosystem models and may be used for testing a research ecosystem linked stock assessment model where output can be compared with the current operational stock assessment model to understand information on retrospective patterns, prediction performance, and comparisons to model outputs.

<u>Beginning Stage: Traffic Light Test</u>

The scores are summed by the ecosystem indicator categories and divided by the total number of indicators available in that category for a given year (see Shotwell et al., 2023b for method details). The ecosystem scores over time provide a history of stock productivity and comparison of indicator performance (Figure 1A.3). We also provide a five-year indicator status table with a color for the relationship with the stock (Table 1A.2).

Overall, the ecosystem indicators score in 2024 increased from the previous year to above average (Figure 1A.3, black line). By category, the larval indicators increased from below average to above average, juvenile indicators remained average, and adult indicators decreased from above average to average (Figure 1A.3, green, blue, and purple lines). We note caution when comparing scores between odd to even years as there are many indicators missing in even years due to the off-cycle year surveys in the GOA. Also, there have been other cancellations due to COVID-19 and continuing issues with staffing of NOAA white ships since 2020 that have resulted in delayed or canceled surveys, reductions in survey sampling coverage and resolution, increased uncertainty in survey results, and increased costs/reduced efficiency for surveys. This has limited production and delivery timing of several indicators.

<u>Intermediate Stage: Importance Test</u>

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and GOA pollock recruitment estimated in the operational stock assessment, and to assess the strength of support for each hypothesis (see Shotwell et al., 2023b for methods details). We provide the mean relationship between each predictor variable and the estimates of GOA pollock recruitment over time (Figure 1A.4, top left), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 1A.4, top right). We also provide model predicted fit (1:1 line, Figure 1A.4, bottom left) and average fit across the recruitment time series subset (1991-2019, with a few missing years, Figure 1A.4, bottom right). A higher probability indicates that the variable is a better candidate predictor of GOA pollock recruitment.

The highest ranked predictor variables (inclusion probability > 0.5) based on this process are the spring sea surface temperature in the western central GOA (inclusion probability > 0.9), and the fall pollock condition of adults in the fishery (inclusion probability > 0.6) (Figure 1A.4). These indicators are marked with an asterisk (*) in Table 1A.2. The sign of the relationship between the fall pollock condition indicator and recruitment was negative and contrary to what we originally proposed for this indicator. This may mean that the indicator is representing some other indirect effect of condition in the winter fishery and pollock recruitment and should be explored further, potentially within the context of a causal model (see details below), prior to use within the stock assessment model.

Many indicators were removed from the BAS analysis due to limitations around missing data, collinearity, and short time series. Incorporating additional importance methods in this intermediate stage indicator analysis may be useful for evaluating the full suite of indicators and may allow for identifying more robust indicators for potential use in the operational stock assessment model.

Advanced Stage: Research Model Test

Several research ecosystem models have been developed or are being developed for GOA pollock. We provide a short description of those current or proposed models along with citations where relevant.

Considerable variation has occurred in the GOA pollock biomass over the past four decades and during that time the demersal fish community has transitioned from a pollock dominated community to one that is dominated by upper-trophic level predators (Anderson and Piatt 1999, Mueter and Norcross 2002). An indicator of predation mortality for age-1 pollock has been included in the GOA pollock ESP as an upper trophic level indicator (Figure 1A.2a.p). To evaluate population-level impacts of predation on GOA pollock, a research model was developed that included indices of pollock predation and modeled the predation component of natural mortality as time-varying (Dorn and Barnes, 2022). There was evidence of intense and highly variable predation on GOA pollock and arrowtooth flounder was, by far, the dominant pollock predator. When predation was included in the model, Dorn and Barnes (2022) found that natural mortality ranged from 37% higher to 17% lower than the long-term mean. Resulting estimates of exploitable pollock biomass differed by as much as 14% between models with and without time-varying predation mortality; however deviations of this magnitude are probably not large enough to cause inadvertent overfishing. This method allows for an evaluation of the impacts of time-varying predation on GOA pollock, provides for a relatively simple way to incorporate ecological information into single species stock assessments, and can be used to identify inconsistencies in biomass estimates for future consideration (Dorn and Barnes, 2022).

Another modeling effort to create a gap free estimate of predation mortality is through a multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate- Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics; Holsman et al., 2016) that has recently been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the GOA (Adams et al., 2022; Adams et al., 2023). Total mortality rates are based on estimates of residual mortality estimates (M1), time- and age-varying predation mortality (M2), and time- and age-varying fishing mortality (F). CEATTLE has been modified for the GOA and implemented in Template Model Builder (Kristensen et al., 2015) to allow for the fitting of multiple sources of data, time-varying selectivity, time-varying catchability, and random effects. The model is based, in part, on the parameterization and data used for the most recent stock assessment model of each species (Barbeaux et al., 2024, Monnahan et al., 2024, and Adams and Shotwell, 2024). The model is fit to data from five fisheries and seven surveys, including both age and length composition assumed to come from a multinomial distribution. Model estimates of M2 are empirically driven by temperature- and bioenergetics-based consumption information and diet data from the GOA to inform predator-prey suitability. The model was fit to data from 1977 to present and has a similar trend as the single species model with some slight differences in magnitude historically (Figure 1A.5, Adams et al., 2024).

A new research model was developed in 2024 that allows for ESP indicators to be formally incorporated into the model in a quantitative way. Dynamic structural equation models (DSEM; Thorson et al. 2024) are a computationally efficient statistical framework for modeling time-series data that can handle simultaneous or lagged effects, causal links, and smooth over missing data. This framework has promise as a novel way to model climate and environmental drivers in stock assessments. Dr. Juliette Champagnat led the development of a GOA pollock research model by embedding DSEM into the 2023 GOA pollock assessment and used it to test whether ESP indicators could improve understanding of recruitment variability. A series of causal maps were developed with the help of subject matter experts and linked to log recruitment deviations inside the stock assessment model. Initial results for this DSEM-linked assessment approach are very promising. Namely, the ESP data reduced variation in recruitment by 70% (sigmaR from 1.0 to 0.5), had statistically significant improvements (reductions in AIC by about 20 points) and improved short-term projections of recruitment. This research model will continue into 2025, with plans to expand it to other stocks and processes like growth and mortality.

Socioeconomic Monitoring

Total catch increased to 133 thousand mt in 2022 from a historical low of 101 thousand mt in 2021. Total catch remained stable in 2023, increasing by approximately 2% to 135 thousand mt. Although catch increased from 2021 to 2023, the average price per pound remained stable at $0.13 per pound resulting in an increase of total value to $37.5 million from $27 million in 2021. Compared to the 2014 to 2018 average, total ex-vessel value remained stable despite declines in total catch (Table 1A.1a). In the first-wholesale market, total volume decreased with reductions in total catch. Total first-wholesale value, however, increased to $115 million in 2023 from the 2014 to 2018 average due to an increase in the first-wholesale price from $0.70 to $1.08 per pound. Pollock is processed into a variety of product forms, such as fillets, head & gut, surimi, and roe. For each of these product types, the average price per pound decreased from the historical highs in 2022 to 2023 but remained above the 2014 to 2018 average with fillets and roe increasing by over 50% (Table 1A.1b).

The global catch of pollock increased in 2019 and 2020 before decreasing in subsequent years. Compared to the 2014 to 2018 average, 2022 levels of global catch remain relatively stable. Between 2019 and 2022, the share of global catch attributed to the U.S. declined from 44% to 37% while the Russian share increased from 49% to 57% (Table 1A.1c). Recent reports state that in 2023 Russian export volumes of seafood to China increased by 36.1% from 2022 levels and is on track to increase further in 2024 suggesting that the Russian share of global pollock catch may increase further. Total U.S. exports of pollock, however, have also increased to 326 thousand mt in 2023 from 2022 levels with a small decline (-5%) in export price to $1.40. This resulted in an increase in export value to approximately $1 million (Table 1A.1c).

Data Gaps and Future Research Priorities

While current indicator assessments offer a valuable set of proxy indicators, there are notable areas for improvement. The list below summarizes the data gaps and future research priorities for this ESP by ecosystem and socioeconomic category. For more details, please refer to previous ESP documents (Shotwell et al., 2019-2023b).

Ecosystem Priorities

- Development of high-resolution remote sensing (e.g., transport estimates, primary production estimates) or regional ocean model indicators (e.g., bottom temperature, stratification, nutrient dynamics, prey fields) to assist with the current multi-year data gap for many indicators.
- Investigation of NOAA National Center for Environmental Prediction (NCEP) model-based estimates of surface wind might extend the wind-recruitment comparison as the buoy data and the NCEP winds are correlated, but further study is needed.
- Refinements or updates to current indicators (e.g., chlorophyll *a*) that were only partially specialized for GOA pollock such as more specific phytoplankton indicators tuned to the spatial and temporal distribution of GOA pollock larvae as well as phytoplankton community structure information (e.g., hyperspectral information for size fractionation).
- Development of large-scale indicators from multiple data sources to understand prey trends at the spatial scale relevant to management (e.g., regional to area-wide estimates of zooplankton biomass, offshore to nearshore monitoring of pollock larvae) and align the spatial and temporal

extent of available zooplankton or other productivity indicators to the specific needs of the GOA pollock stock in the future.
- Evaluation of demographic differences in the YOY population within and among larval and juvenile surveys conducted in the Central and Western GOA.
- Investigation into size shifts in the YOY population and associated processes such as earlier spawning, faster larval/juvenile growth, and/or higher larval/juvenile mortality.
- Evaluation of climate-driven changes in size and age and how that may impact survival trajectories of YOY cohorts and their potential to recruit to the fishery.
- Investigating environmental regulation of first year of life processes for pollock to understand the interrelationship between processes occurring during pre-settlement (spawning/larvae), settlement (summer growth) and post-settlement (first overwintering) phases.
- Exploration of spatial distribution of egg and larvae stages, transport processes, and connectivity between spawning and juvenile nursery areas using the ROMS-NPZ coupled with an IBM.
- Increased sampling of predator diets in fall and winter to understand predation on YOY pollock during their first autumn and winter, when predation mortality is thought to be significant.
- Investigation of the GOA CEATTLE model to create a gap-free index of age-1 predation mortality, bioenergetics (e.g., annual ration, consumption), and near-term forecasts of weight-at-age (from the temperature linked growth model in the GOA CEATTLE model).
- Evaluation of condition and energy density of juvenile and adult pollock samples at the outer edge of the population from the GulfWatch Alaska program or longline surveys to understand the impacts of shifting spatial statistics such as center of gravity and area occupied.
- Evaluation of biological references points under projected climate scenarios using GOA Ecopath and the Atlantis ecosystem model as part of the GOA Regional Action Plan.

Socioeconomic Priorities

- Reorganization of indicators by scale, structure, and dependence per December 2022 SSC request that may result in a transition of indicators currently reported and a potential shift in focus.
- Re-evaluation of fishery derived indicators to potentially include:
    - CPUE measures (e.g., proportion of the catch by gear, level of effort by gear)
    - Fleet characteristics (e.g., number of active vessels, number of processors)
    - Spatial distribution measures (e.g., center of gravity, area occupied)
- Re-evaluation of economic indicators to potentially include:
    - Percentage of total allowable catch (TAC) harvested by active vessels
    - Measures by product type (e.g., surimi-, roe-, and fillet-specific proportion landed, price per pound)
    - Revenue per unit effort by area, gear, and product type
- Evaluation of additional sources of socioeconomic information to determine what indicators could be provided in the ESP that are not redundant with indicators already provided in the Economic SAFE and the ACEPO report.
- Consideration of the timing of indicators that are delayed by 1 to several years depending on the data source from the annual stock assessment cycle and when updates can be available.
- Consideration on how to include local knowledge, traditional knowledge, and subsistence information to understand recent fluctuations in stock health, shifts in stock distributions, or changes in size or condition of species in the fishery per SSC recommendation.

As indicators are improved or updated, they may replace those in the current set of ecosystem or socioeconomic indicators to allow for refinement of the indicator analyses and potential evaluation of performance and risk. Incorporating additional importance methods in the intermediate stage indicator analysis may also be useful for evaluating the full suite of indicators and may allow for identifying robust indicators for potential use in the operational stock assessment model. The annual request for information (RFI) for the groundfish and crab ESPs will include these data gaps and research priorities that could be developed for the next ESP assessment (please contact Kalei Shotwell at kalei.shotwell@noaa.gov for more details).

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Tables

Table 1A.1a Pollock in the Gulf of Alaska ex-vessel market data. Total and retained catch (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), the Central Gulf's share of value, and number of trawl vessels; average and most recent five years.

	2014-2018 Average	2019	2020	2021	2022	2023
Total catch (K mt)	166.3	120.2	107.5	101.2	132.7	135.1
Retained catch (K mt)	164.71	118.89	106.63	99.50	131.46	133.69
Ex-vessel value (M $)	$38.25	$36.12	$27.80	$27.32	$48.99	$37.52
Ex-vessel price ($/lb)	$0.11	$0.14	$0.12	$0.12	$0.17	$0.13
Central Gulf share of catch (%)	75.53%	73.99%	75.31%	76.62%	75.33%	74.16%
Vessels (#)	68.6	62	61	58	55	52

Source:Source: NMFS Alaska Region Blend and Catch-accounting System estimates; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 1A.1b. Pollock in the Gulf of Alaska first-wholesale market data. First-wholesale production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut, fillet, surimi, and roe production volume (thousand metric tons), price (US$ per pound), and value share; average and most recent five years.

	2014-2018 Average	2019	2020	2021	2022	2023
All Products volume (K mt)	67.34	51.09	39.95	31.64	41.47	48.24
All Products value (M $)	$103.78	$85.87	$70.47	$68.63	$119.77	$114.91
All Products price ($/lb)	$0.70	$0.76	$0.80	$0.98	$1.31	$1.08
Head & Gut volume (K mt)	33.01	28.41	22.62	14.02	20.10	20.29
Head & Gut value share (%)	32.93%	37.95%	36.82%	21.02%	25.16%	20.36%
Head & Gut price ($/lb)	$0.47	$0.52	$0.52	$0.47	$0.68	$0.52
Fillets volume (K mt)	12.08	8.80	7.84	8.65	11.77	13.19
Fillets value share (%)	30.61%	31.34%	34.05%	42.92%	45.59%	45.31%
Fillets price ($/lb)	$1.19	$1.39	$1.39	$1.54	$2.10	$1.79
Surimi volume (K mt)	12.15	6.95	5.43	5.93	6.48	9.59
Surimi value share (%)	22.89%	19.28%	18.15%	24.40%	18.60%	19.09%
Surimi price ($/lb)	$0.89	$1.08	$1.07	$1.28	$1.56	$1.04
Roe volume (K mt)	2.13	1.89	1.55	1.03	1.34	1.96
Roe value share (%)	7.67%	6.87%	5.34%	6.19%	7.26%	9.78%
Roe price ($/lb)	$1.70	$1.42	$1.10	$1.88	$2.94	$2.60

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 1A.1c. Pollock U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, Russian share of global production, U.S. export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound), the share of U.S. export volume and value with Japan, China and Germany, the share of U.S. export volume and value of meats (including H&G and fillets), surimi and roe, average and most recent five years.

	2014-2018 Average	2019	2020	2021	2022	2023
Global Pollock Catch (K mt)	3395.72	3494.66	3544.26	3484.19	3358.62	-
U.S. Share of Global Catch (%)	44%	44%	42%	42%	37%	-
Russian Share of Global Catch (%)	49%	50%	52%	50%	57%	-
GOA share of global (%)	4.90%	3.44%	3.03%	2.90%	3.95%	-
Export volume (K mt)	393.10	380.06	323.49	311.38	274.06	326.26
Export value (M US$)	$1049.41	$1119.9	$941.88	$898.85	$885.64	$1004.41
Export price ($/lb)	$1.21	$1.34	$1.32	$1.31	$1.47	$1.40
Import value (M US$)	$103.47	$123.17	$99.68	$96.24	$141.25	$105.46
Net Exports (M US$)	$945.94	$996.73	$842.2	$802.61	$744.40	$898.95
Japan volume share (%)	22.14%	22.85%	19.33%	21.01%	21.2%	25.04%
Japan value share (%)	23.23%	23.88%	20.17%	21.08%	20.07%	22.90%
China volume share (%)	13.58%	10.14%	9.68%	6.77%	11.62%	7.67%
China value share (%)	10.95%	6.69%	6.45%	5.30%	7.48%	5.18%
Europe* volume share (%)	35.07%	35.15%	36.98%	32.70%	31.38%	32.10%
Europe* value share (%)	35.19%	36.86%	39.42%	36.31%	35.30%	37.86%
Meat volume share (%)	50.23%	47.07%	45.77%	41.13%	42.68%	40.55%
Meat value share (%)	47.08%	44.34%	44.02%	40.80%	42.53%	43.42%
Surimi volume share (%)	44.85%	45.82%	46.96%	53.77%	52.20%	54.25%
Surimi value share (%)	40.06%	42.58%	42.22%	49.37%	49.06%	47.08%
Roe volume share (%)	4.92%	7.11%	7.27%	5.10%	5.12%	5.20%
Roe value share (%)	12.85%	13.09%	13.77%	9.83%	8.41%	9.50%

Notes: Exports are from the US and are not specific to the GOA region. Aggregate exports may not fully account for all pollock exports as products such as meal, minced fish and other ancillary product may be coded as generic fish type for export purposes.

Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

Table 1A.2. Beginning stage ecosystem indicator analysis for GOA pollock, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of the long-term mean). Fill color of the cell is based on the proposed sign of the overall relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = "NA" will appear if there were no data for that year.

Indicator category	Indicator	2020 Status	2021 Status	2022 Status	2023 Status	2024 Status
Larval to YOY	Annual Heatwave CGOA Model	neutral	neutral	neutral	neutral	neutral
	* Spring Temperature Surface WCGOA Satellite	neutral	neutral	neutral	neutral	neutral
	Spring Wind NS Direction	neutral	*low*	neutral	neutral	neutral
	Spring Small Copepod Abundance Shelikof Survey	NA	neutral	NA	neutral	NA
	Summer Large Copepod Abundance Shelikof Survey	NA	NA	NA	neutral	NA
	Annual Auklet Reproductive Success Chowiet Survey	NA	neutral	neutral	neutral	*high*
	Spring Pollock CPUE Larvae Shelikof Survey	NA	neutral	NA	neutral	NA
	Summer Pollock CPUE YOY Shelikof Survey	NA	NA	NA	neutral	NA
	Summer Pollock Condition YOY Shelikof Survey	NA	NA	NA	**low**	NA
	Summer Pollock CPUE YOY Nearshore Kodiak Survey	neutral	neutral	neutral	neutral	*high*
	Annual Pollock Relative Biomass Aiktak Survey	NA	neutral	neutral	**low**	neutral
Juvenile	Pollock Predation Mortality Age1 GOA Model	neutral	neutral	neutral	neutral	neutral
	Summer Pollock Euphausiid Diet Juvenile GOA Survey	NA	neutral	NA	neutral	NA
Adult	Summer Temperature Bottom GOA Survey	NA	neutral	NA	neutral	NA
	* Fall Pollock Condition Adult GOA Fishery	neutral	neutral	neutral	neutral	NA
	Winter Pollock Condition Adult GOA Survey	neutral	neutral	**low**	neutral	neutral
	Annual Ration Pollock GOA Model	neutral	neutral	neutral	neutral	neutral

Indicator category	**Indicator**	**2020 Status**	**2021 Status**	**2022 Status**	**2023 Status**	**2024 Status**
	Summer Pollock Center Gravity Northeast WCGOA Model	NA	neutral	NA	*low*	NA
	Summer Pollock Area Occupied WCGOA Model	NA	neutral	NA	*high*	NA
	Annual Biomass Consumed Pollock GOA Model	neutral	neutral	neutral	*low*	*low*
	Annual Pacific Ocean Perch Biomass GOA Model	**high**	**high**	**high**	neutral	neutral
	Annual Sablefish Biomass GOA Model	neutral	**high**	**high**	**high**	**high**
	Annual Steller Sea Lion Adult GOA Survey	**high**	**high**	NA	NA	NA

* Indicator has inclusion probability > 0.5 in the intermediate stage importance test.

Figures

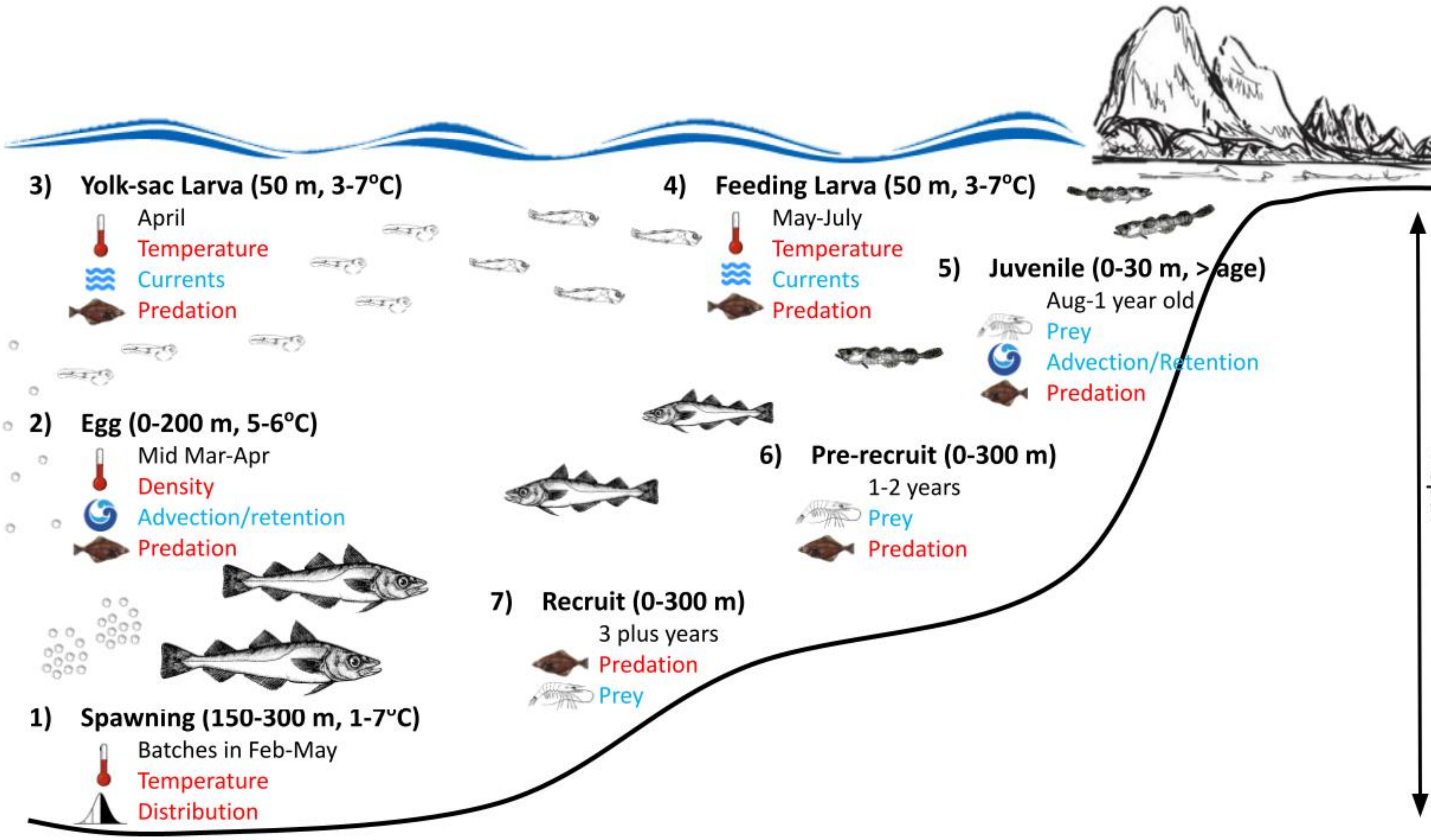


Figure 1A.1: Life history conceptual model for GOA pollock summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text indicates increases in the process positively affect survival.

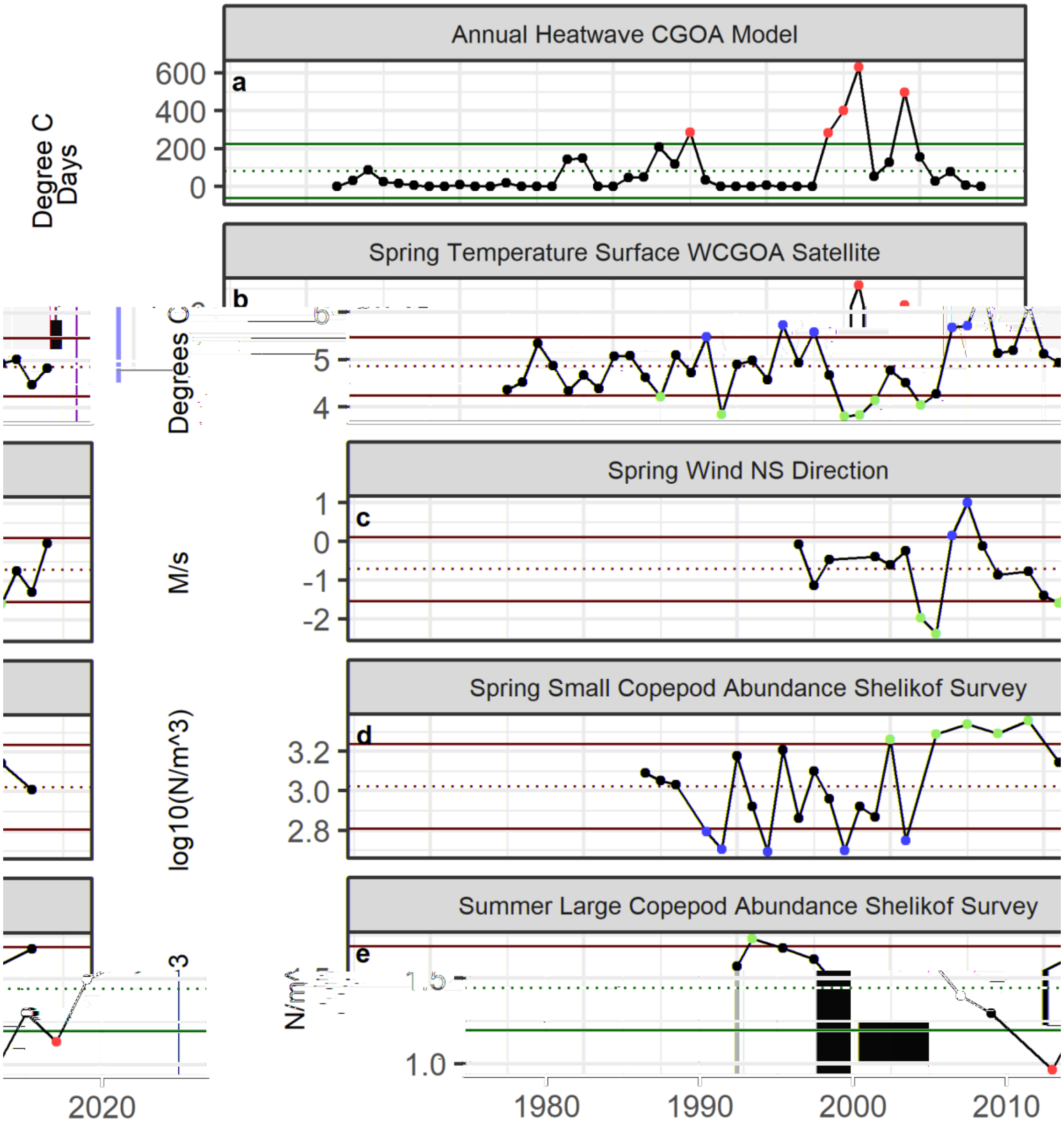


Figure 1A.2a. Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

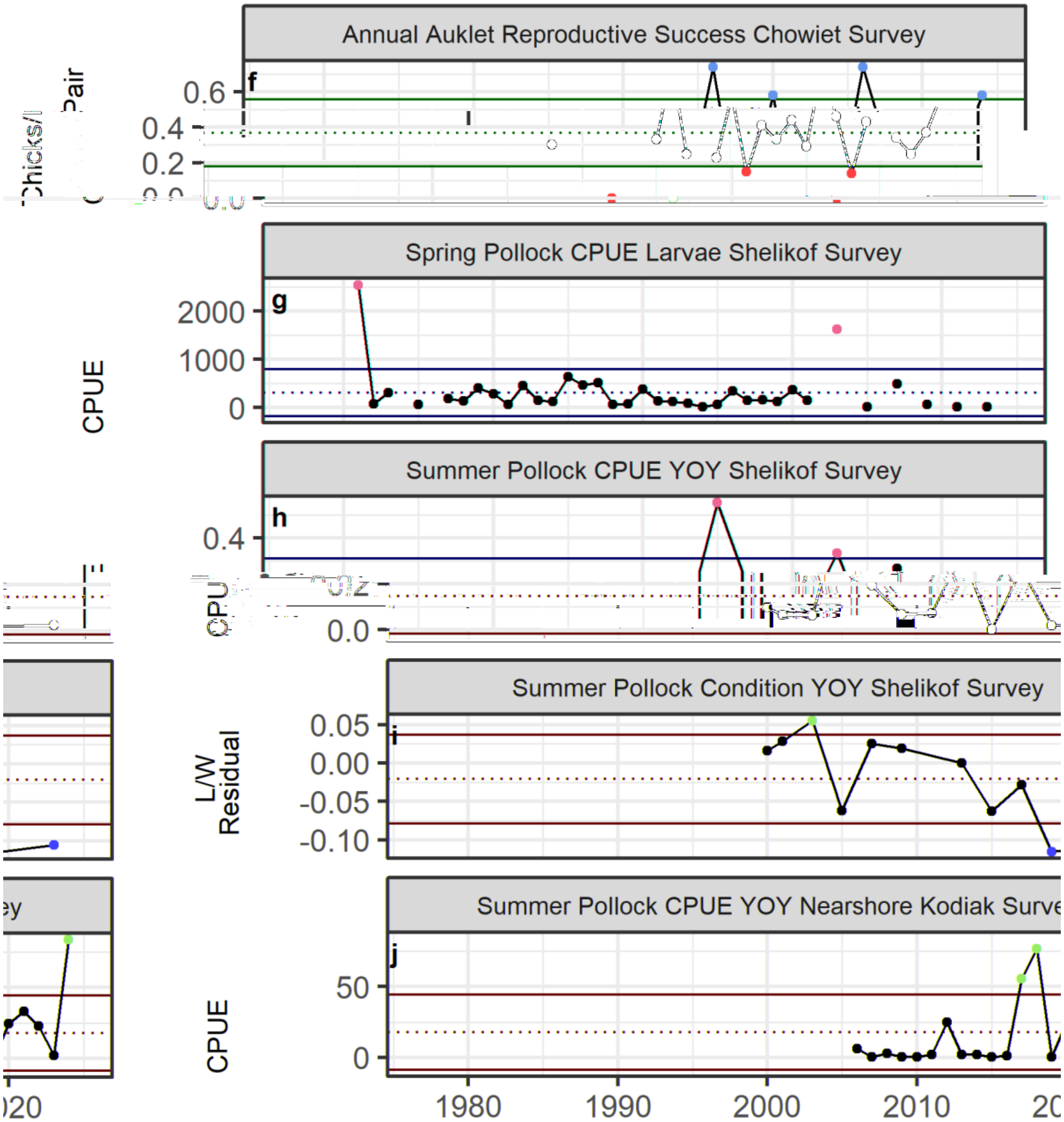
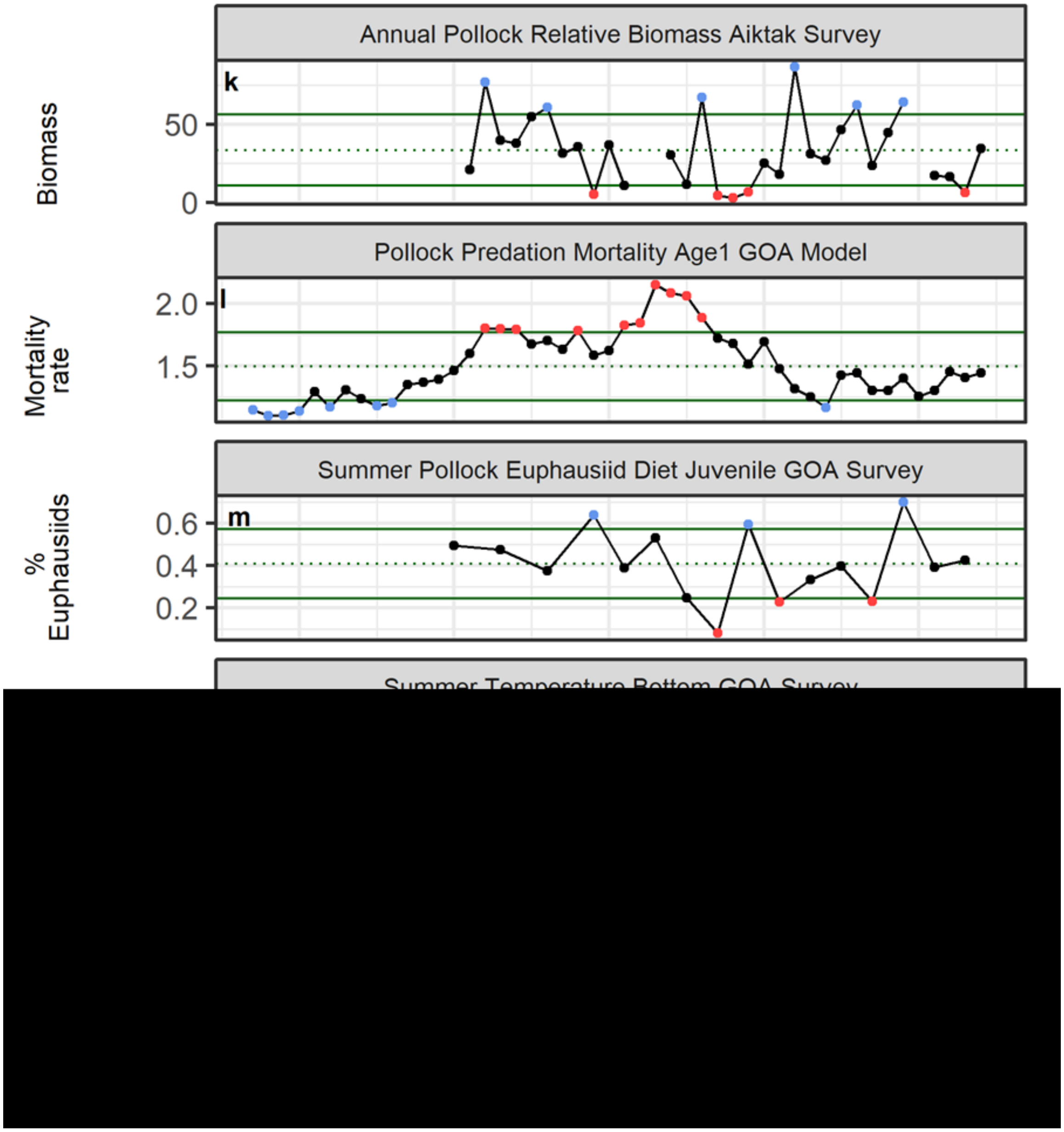


Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.



[redacted]

Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

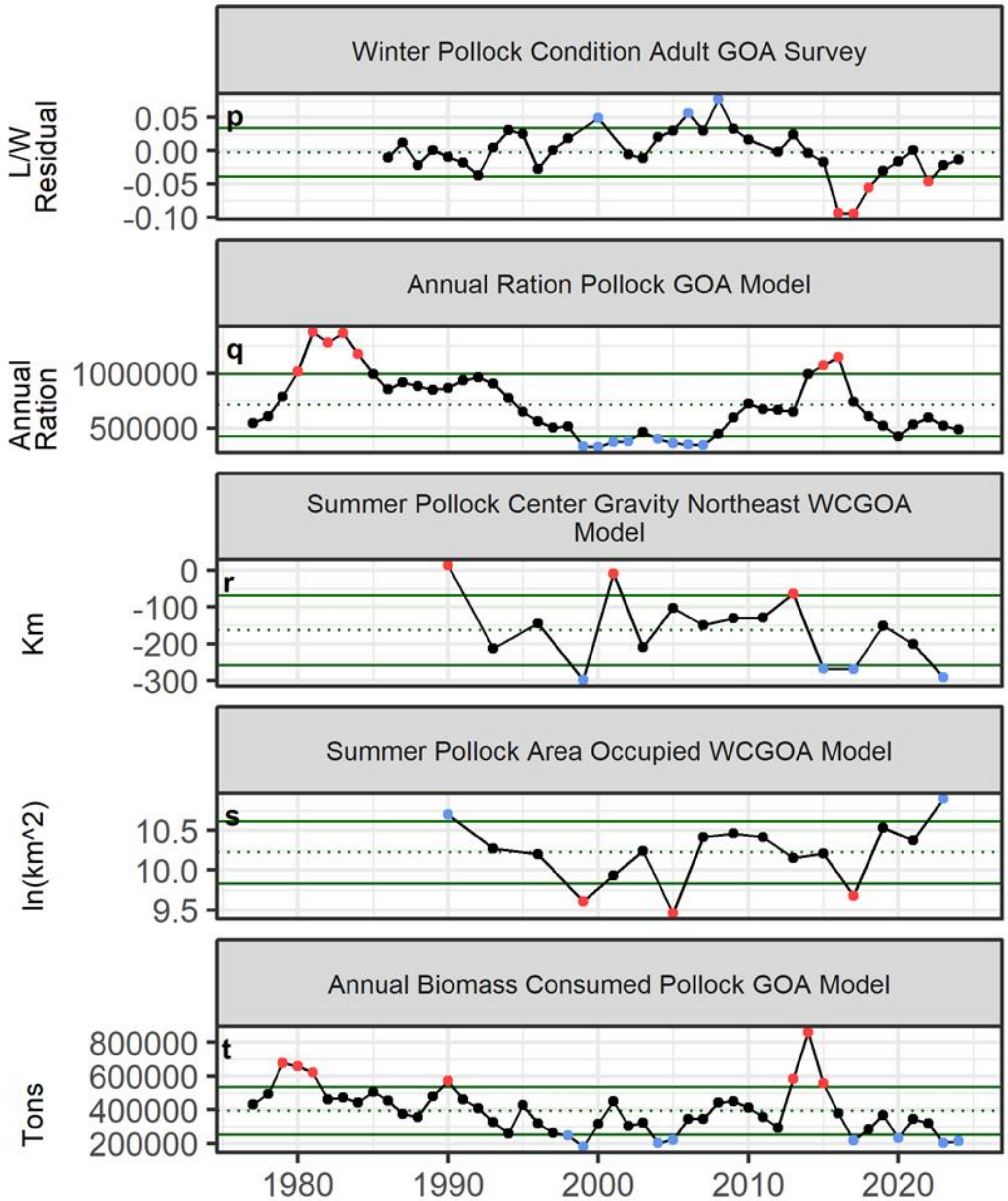


Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

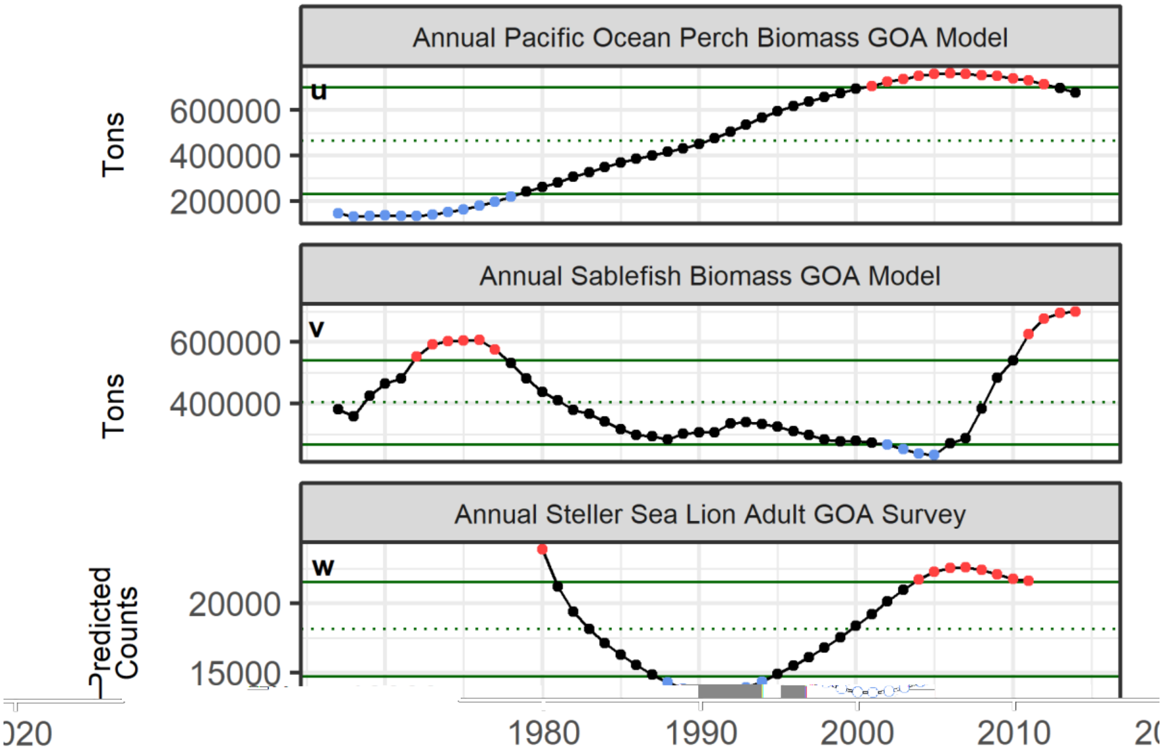


Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

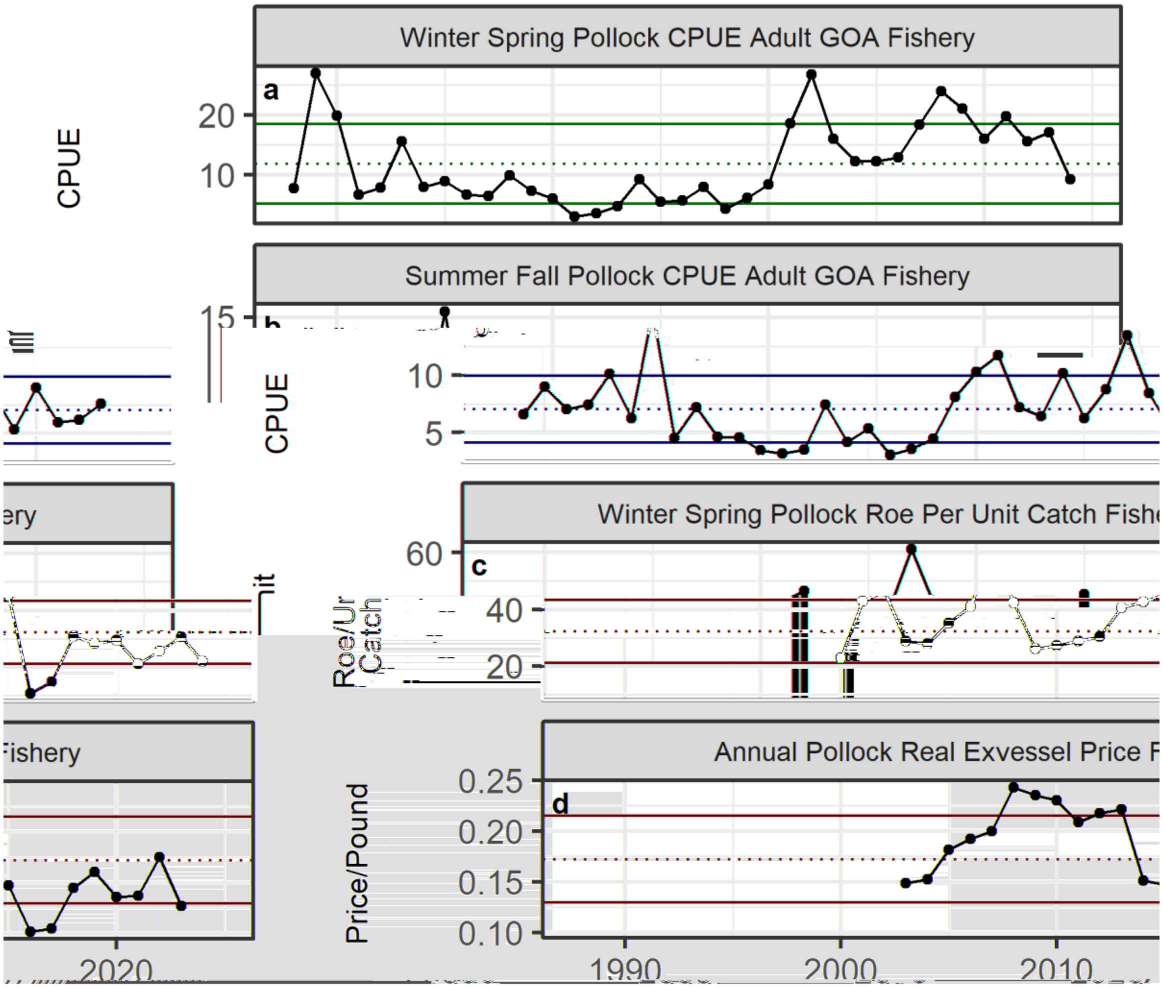


Figure 1A.2b. Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

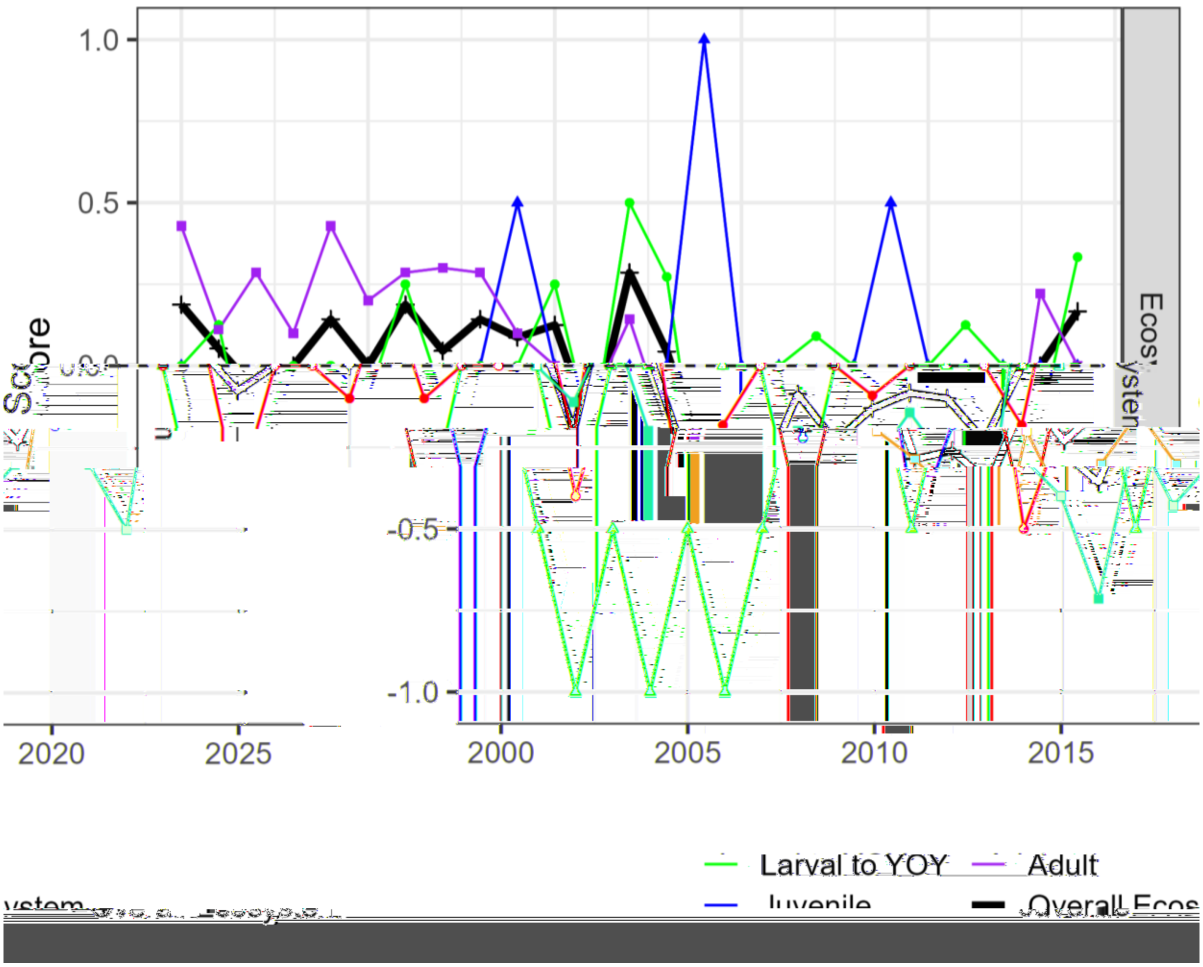


Figure 1A.3: Simple summary traffic light score by overall ecosystem and category (larval to young-of-the-year (YOY), juvenile, and adult) for ecosystem indicators from 2000 to present.

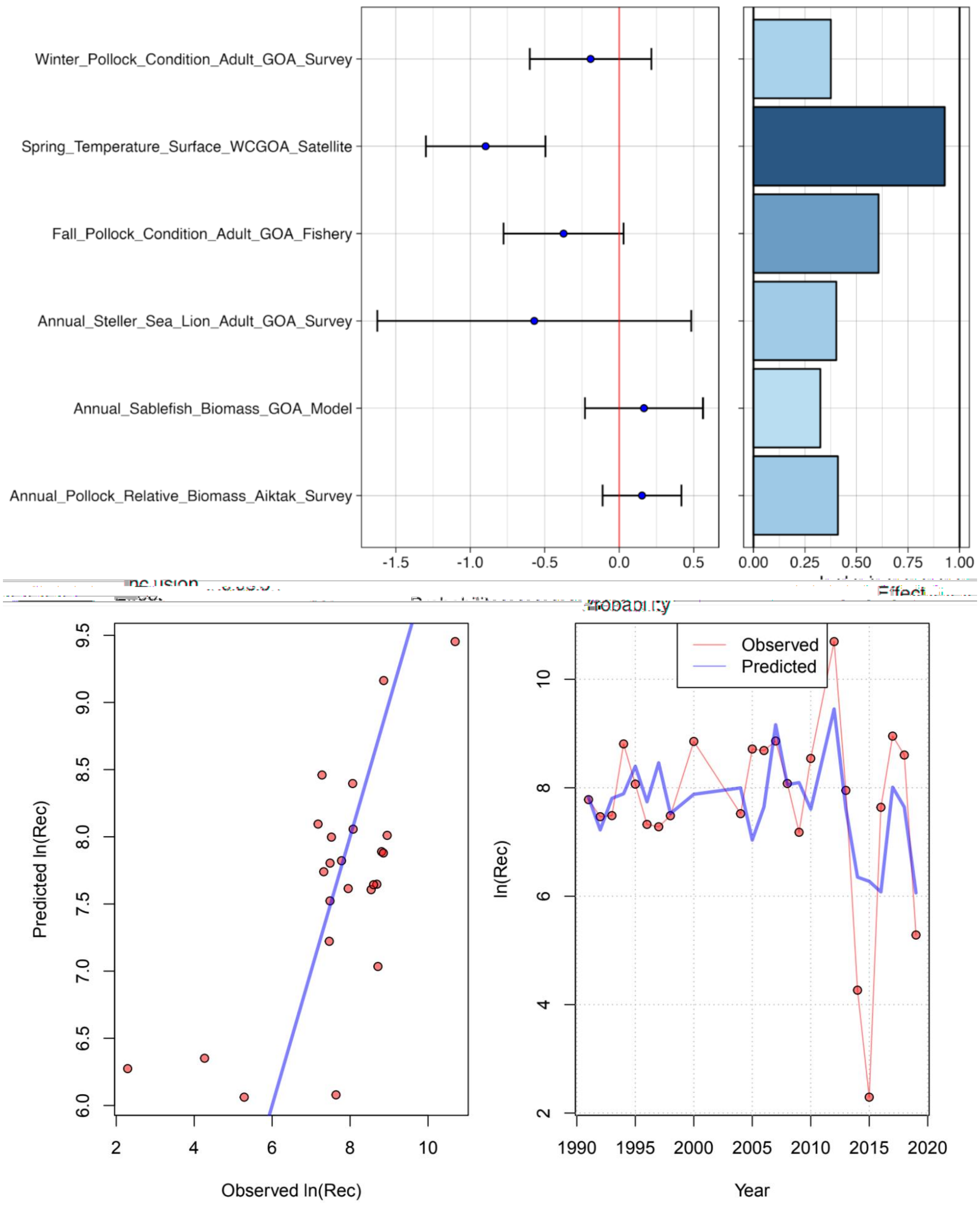


Figure 1A.4: Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed estimated GOA pollock recruitment from the operational stock assessment model: the estimated effect (top left) and the marginal inclusion probabilities (top right) for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model predicted fit (1:1 line, bottom left) and average fit across the abbreviated recruitment time series (1991-2019, with a few missing years, bottom right).

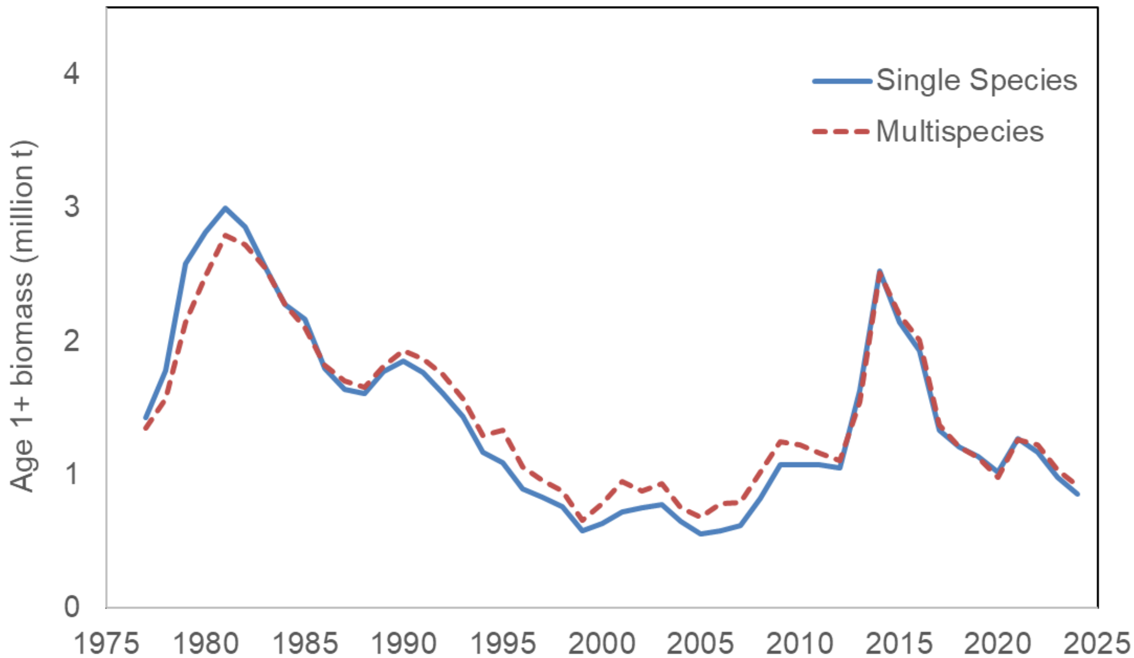


Figure 1A.5: Age 1+ biomass for Gulf of Alaska pollock from the most recent single species stock assessment model (blue solid line) compared to the Climate- Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) multispecies model (red dashed line).