Appendix 2.2 Ecosystem and Socioeconomic Profile of the Pacific cod stock in the Eastern Bering Sea - Report Card

S. Kalei Shotwell and Russel Dame (Editors)

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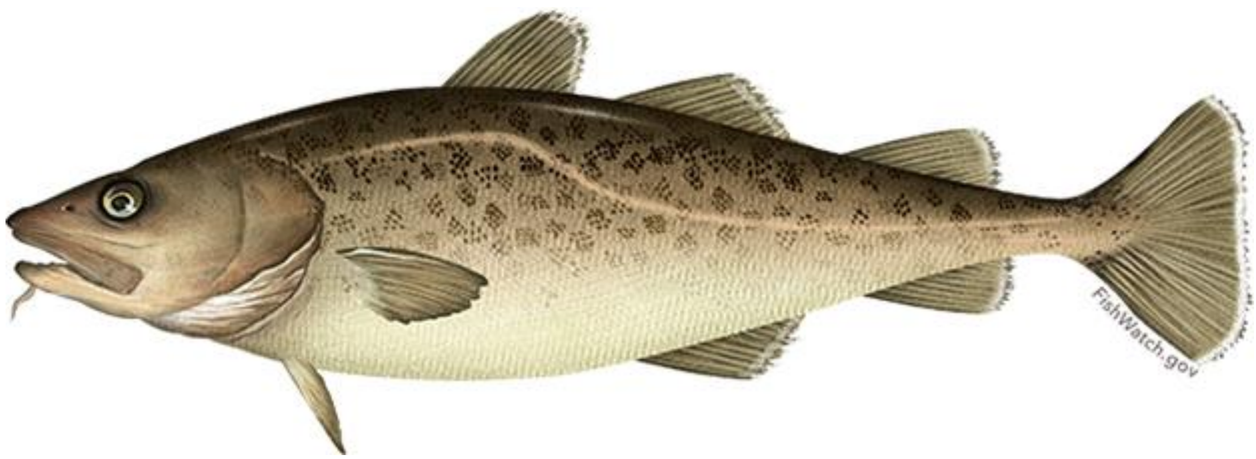

With Contributions from:

ESP Team: Steve J. Barbeaux, Tom Hurst, Ben Laurel, Krista Oke, Lauren Rogers, and Elizabeth Siddon

ESP Data: Anna Ableman, Grant Adams, Kerim Aydin, Lewis Barnett, Matt Callahan, Brian Garber-Yonts, Kirstin Holsman, Kelly Kearney, Jean Lee, Mike Levine, Beth Matta, Sandi Neidetcher, Jens Nielsen, Patrick Ressler, Heather Renner, Sean Rohan, Kalei Shotwell, Elizabeth Siddon, Katie Sweeney, Muyin Wang

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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., 2021a). 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., 2021a, Shotwell et al., 2023b). These documents are available as an appendix within the eastern Bering Sea (EBS) Pacific cod 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 EBS Pacific cod:

Acceptable Biological Catch (ABC) Information:

- The North Pacific Index returned to near average signifying moderate atmospheric conditions of a normal Aleutian Low, neither stormy or calm.
- Spring surface temperature continues to decrease to cool conditions and is now slightly below average but there was a sharp decline to low for the euphausiid abundance from the summer acoustic surveys.
- Evidence of time-varying total mortality for age-1 Pacific cod within the Climate- Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) multispecies model. Age-1 total natural mortality is currently below the long term mean.
- Bottom temperatures from the ROMS hindcast are highly correlated with surface temperatures but appear to cool faster than the surface throughout the recent cooling trend since 2020 and is now slightly below average.
- Condition for juvenile Pacific cod decreased to below average and could signify poor feeding conditions potentially influenced by the expanding area occupied since 2021.
- Winter sea-ice extent during the advance season increased slightly but remains below average and is similar in extent to 2020, while ice extent during the spring retreat season has increased steadily since 2020 and is now near average, which may have implications on spawn timing.
- Annual predation demand (ration) has been trending upward for the past decade, implying higher energetic needs throughout the warm years which may partially explain the near average to below average adult condition since 2007.
- Center of gravity estimates suggest the Pacific cod population has moved southwest from 2023, with above average area occupied, similar to the 2011 survey.
- Declines in total predator biomass contribute to net decrease in total biomass eaten of Pacific cod from 2019-2024 relative to the previous decade and indicates continued favorable top-down conditions for juvenile groundfish survival in 2024 through predator release

Total Allowable Catch (TAC) Information:

- Ex-vessel value decreased in 2023, remaining below the historical average and slightly below one-standard deviation of the historical range.
- The average ex-vessel price per pound declined slightly in 2023, but remained above the historical mean for five of the past six years and within one-standard deviation of the historical range.

- Revenue-per-unit-effort was stable in 2023, remaining above the historical average and within one standard deviation of the historical range.

Modeling Considerations

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

- The highest ranked predictor variable of EBS Pacific cod recruitment based on the importance methods in the intermediate stage indicator analysis was the summer bottom temperature from the ROMS-NPZ model (inclusion probability > 0.5).

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 2.2.1) and economic performance (Table 2.2.1). Please refer to the last full ESP document (Shotwell et al., 2021a) for more details.

Indicator Suite

The following list of indicators for EBS Pacific cod is organized into 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 2.2.2).
- “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 2.2.2).
- “Neutral”: Used in Table 2.2.2 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 2.2.2).

This update focuses on new developments since the last ESP (Shotwell et al., 2023b). For detailed information regarding these ecosystem and socioeconomic indicators and the proposed mechanistic linkages for EBS Pacific cod, please refer to the previous ESP documents (Shotwell et al., 2021-2023b). Time series of these indicators are provided in Figure 2.2.2a (ecosystem indicators) and Figure 2.2.2b (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:

- Age-1 EBS Pacific cod time-varying natural mortality (M1+M2) estimated by the CEATTLE multispecies model.
- Annual ration of age 1+ EBS Pacific cod from the most recent CEATTLE multispecies model (Holsman et al., 2024a) as an estimate of bioenergetic requirements.
- Biomass of EBS Pacific cod consumed (or eaten as prey) by all predators in the CEATTLE multispecies model (Holsman et al., 2024a) as an estimate of predation from primary predators.

Modified indicators include:

- Updates to the length cutoff between adults and juveniles in the condition indicators to match the cutoff between subadults and adults (from 46 cm to 58 cm) that was used for the 2022 EFH 5-year review (accepted by the Council in 2023).
- Truncated the time series of the condition indicators to 1990-2023 to match the groundfish assessment program's standardized survey time series.

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.
- Arrowtooth flounder total biomass was removed because it was replaced with information from the CEATTLE multispecies model regarding the biomass of EBS Pacific cod consumed as prey by all predators within the multispecies model (arrowtooth flounder, walleye pollock (pollock), Pacific cod, and Pacific halibut) (Holsman et al., 2024a).

Ecosystem Indicators:

1. Larval to YOY Indicators (Figure 2.2.2a.a-c)

a. Winter Spring North Pacific Index Model: The winter to spring North Pacific Index (NPI) is calculated as the area-weighted sea level pressure (SLP) from November to March over the region 30°N-65°N, 160°E-140°W. 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: Elizabeth Siddon
    - Status and trends: The winter to spring NPI steadily decreased from 2011 to 2016 and then increased to very near the time series peak in 2018, was near average in 2019, and remained in an above-average to high status through 2023. In 2024, the NPI returned to average similar to 2019.
    - Factors influencing trends: The NPI effectively represents the state of the Aleutian Low with higher values signifying high sea level pressure, warming sea surface temperatures, higher precipitation, and increased downwelling (Weingartner, 2005).
    - Implications: The strength of the Bering Slope Current is correlated with the NPI, such that weaker flows correlate with higher recruitment success of Pacific cod (Thompson, 2018).

b. Spring Summer Temperature Surface SEBS Satellite: Spring to summer (April-June) daily sea surface temperatures (SST) on a 5 km grid averaged over the southeastern Bering sea (10 m to shelf break (200 m) south of 60 degrees N) (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). Available from 1985 to present. Code available at: https://github.com/jordanwatson/ESP_Indicators. 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 the highest in the time series or well above average from 2014-2022, but appear to be on a declining trend since 2021 and have recently decreased to below average in 2024.
- Factors influencing trends: Sea surface temperatures in the Bering sea are strongly influenced by sea ice and stratification, particularly over the middle shelf where surface and bottom temperature dynamics can be decoupled much of the year (Ladd and Stabeno, 2012).
- Implications: The cooler surface temperatures imply a shorter food web and potentially larger, more lipid-rich zooplankton species which may improve feeding conditions for larval Pacific cod.

c. Summer Euphausiid Abundance EBS Survey: Summer euphausiid (‘krill’, principally *Thysanoessa* spp.) abundance is represented as the mean numerical density (no. m-3) of euphausiids across the surveyed area, computed from acoustic backscatter at 120 kHz classified as euphausiids and associated trawling. The index is for the EBS shelf survey area (Ressler, 2022). Proposed sign of the relationship to recruitment is positive.

- Contact: Patrick Ressler
- Status and trends: Summertime euphausiid density increased in the eastern Bering sea from 2004-2009, then subsequently declined 2010 through 2016, when the lowest value in the time series was reported. Euphausiid density increased in summers 2018 through 2022, but declined again in 2024 to the second-lowest value in the time series.
- Factors influencing trends: Factors controlling annual changes in euphausiid abundance in the north Pacific are not well understood; possible candidates include bottom-up forcing by temperature and food supply, and top-down control through predation (Hunt et al. 2016). When factors including temperature, pollock abundance, primary production, and spatial location have been considered in eastern Bering sea multiple regression models, temperature has been the best predictor, with increases in euphausiid abundance associated with cold temperatures in the eastern Bering Sea (Ressler et al., 2014).
- Implications: Age-0 Pacific cod prey quality and quantity, and therefore energetic condition, impacts survival and recruitment success of Pacific cod (Farley et al., 2015). Age-0 cod feed predominantly on copepods and euphausiids, and growth conditions in summer-fall are related to temperature and foraging conditions with warm years resulting in larger body sizes but lower energy content (i.e., lower lipid content) (Strasburger et al., 2014; Farley et al., 2016). Bioenergetic model estimates of growth potential suggest that temperatures above the thermal optimal for growth combined with lower energetic content of the diet may lead to reduced late-summer growth during warm years in the southeastern Bering Sea (Hurst et al., 2018). A low index of euphausiid abundance implies reduced prey resources for age-0 Pacific cod.

<u>2. Juvenile Indicators (Figure 2.2.2a.d-f)</u>

d. Pacific Cod Predation Mortality Age-1 EBS Model: Estimate of Pacific cod 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 been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the EBS (Holsman et al., 2024a). Proposed sign of the relationship to recruitment is negative.

- Contact: Kirstin Holsman

- Status and trends: Age-1 natural mortality for EBS Pacific cod has steadily increased from 2000 to 2018. Since 2018, natural mortality has been below average, and remains below the long-term mean in 2024.
- 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 at age-1 for Pacific cod in the model was primarily driven by arrowtooth flounder and arrowtooth flounder biomass has been steadily increasing since the 1990s and has remained at high levels since 2007 (Shotwell et al., 2023c).
- Implications: There is evidence of time-varying predation mortality on age-1 Pacific cod because estimates from the CEATTLE multispecies model have historically varied above and below the time-invariant single species stock assessment value.

e. Summer Temperature Bottom SEBS Model: The ROMS Bering10K hindcast simulation (see data source for details) SEBS bottom temperature index is defined as the bottom temperature vertically averaged over the bottom 5m of the water column, spatially averaged over grid cells whose rho-coordinates fall within groundfish strata 10-62 (area-weighted), extracted from weekly-averaged output on July 1 of each simulated year. 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: Kelly Kearney
   - Status and trends: The Bering Sea shelf appears to be highly mixed as surface shelf temperatures are highly correlated with summer bottom temperatures. However, bottom temperatures appear to cool faster than the surface temperatures throughout the recent cooling trend since 2020. The simulated 2024 bottom temperature conditions increased from 2023 and were slightly below average.
   - Factors influencing trends: After springtime stratification, bottom temperatures showed delayed warming making them cooler than average for the spring and summer in recent years.
   - Implications: Hatch timing/success is highly temperature-dependent (Laurel et al., 2008), with optimal hatch occurring in waters ranging between 4-6°C (Bian et al., 2016; Laurel and Rogers, 2020) over a broad range of salinities (Alderdice and Forrester, 1971).

f. Summer Pacific Cod Condition Juvenile EBS Survey: Summer stratum-biomass weighted morphometric condition of juvenile (<58 cm) Pacific cod. The length cutoff between adult and juvenile Pacific cod was revised this year to match the cutoff between subadult (included under the definition of juveniles for this indicator) and adult Pacific cod used to define Essential Fish Habitat (EFH) for the 2022 EFH five-year review. Morphometric condition was estimated using residuals of a length-weight regression fit to individual length-weight measurements collected during AFSC/RACE eastern Bering Sea bottom trawl surveys from 1999 to present. Proposed sign of the relationship to recruitment is positive.
   - Contact: Sean Rohan
   - Status and trends: The condition of juvenile Pacific cod in the EBS in 2024 was below average but within 1 standard deviation of the time series mean, which continues the trend of neutral morphometric condition observed since 2017. The condition of juveniles increased from 1999 to 2004 and fluctuated around neutral from 2005 to 2024, aside from a negative year in 2009 and positive year in 2016.
   - Factors influencing trends: Many factors contribute to variation in morphometric condition so it is unclear which specific factors contributed to neutral condition of juvenile Pacific cod in the EBS in 2024. Factors that may contribute to variation in morphometric condition include environmental conditions that affect prey quality and temperature-dependent metabolic rates, survey timing, stomach fullness of individual

fish, fish migration patterns, and the distribution of samples within survey strata. Temperature is an important factor that can influence the morphometric condition of Pacific cod by influencing metabolic rates, prey availability, and prey quality. Historically in the eastern Bering Sea (EBS), "cold" years (with a small cold pool) were associated with negative morphometric condition (e.g., 1999, 2012) and warm years (e.g., 2002-2005) were associated with positive morphometric condition. However, during exceptionally warm years from 2018-2021, the morphometric condition of Pacific cod was neutral for adult and juvenile Pacific cod and this trend continued into the average temperature years in 2022-2024. Temperature can negatively affect growth rates if prey resources are insufficient to make up for increased metabolic demand. Additional information about the groundfish morphometric condition indicator and factors that can influence estimates of morphometric condition are described in the EBS Groundfish Morphometric Condition contribution in the 2024 Eastern Bering Sea Ecosystem Status Report (Prohaska et al., 2024).

- Implications: In the Gulf of Alaska, elevated temperatures during the 2014-2016 marine heatwave were associated with lower growth rates of Pacific cod and lower morphometric condition in 2015 (adults and juveniles combined), likely because of a decrease in prey resources and increase in metabolic demand (Barbeaux et al., 2020). Below average condition suggests that juvenile Pacific cod in the EBS are not able to find sufficient prey resources.

<u>3. Adult Indicators (Figure 2.2.2a.g-n)</u>

g. Winter Sea Ice Advance BS Satellite NSIDC: Anomalies of average daily sea-ice extent relative to 1981-2010 mean computed over ice-advance season of December through February. 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: Muyin Wang
   - Status and trends: The extent of the sea ice during the ice advance season (Dec-Feb) decreased dramatically in 2014 and continued to decline to a time-series low in 2018, then increased somewhat in 2019-2021, was above average in 2022, and is now below average in 2023 similar to 2020.
   - Factors influencing trends: Winter sea ice in the Bering Sea is driven by atmospheric CO_2, ocean heat transport and winds.
   - Implications: In the Bering Sea, the intensity and timing of the spring bloom depend on the timing of sea ice retreat. The low and high of ice extent in either the advance or retreat season seem to coincide with the last two large recruitments of EBS Pacific cod, suggesting that sea ice extent likely does not relate directly to recruitment for this stock, but rather to movement during spawning and, potentially, to subsequent match/mismatch with the spring bloom.

h. Spring Sea Ice Retreat BS Satellite: Anomalies of average daily sea-ice extent relative to 1981-2010 mean computed over ice-retreat season of March through May. Proposed sign of the relationship to recruitment is positive.
   - Contact: Muyin Wang
   - Status and trends: The extent of sea ice during the ice retreat season steadily decreased from a time-series high in 2012 to the time-series low in 2018, remained low in 2019, but increased in 2020 and has been steadily increasing to just below average in 2022 and 2023.
   - Factors influencing trends: Winter sea ice in the Bering Sea is driven by atmospheric CO_2, ocean heat transport and winds.

- Implications: In the Bering Sea, the intensity and timing of the spring bloom depend on the timing of sea ice retreat. The low and high of ice extent in either the advance or retreat season seem to coincide with the last two large recruitments of EBS Pacific cod, suggesting that sea ice extent likely does not relate directly to recruitment for this stock, but rather to movement during spawning and, potentially, to subsequent match/mismatch with the spring bloom.

i. Summer Pacific Cod Condition Adult EBS Survey: Summer stratum-biomass weighted morphometric condition of adult (>=58 cm) Pacific cod. The length cutoff between subadult (included under the definition of juveniles for this indicator) and adult Pacific cod was revised this year to match the cutoff between adults and subadults used to define Essential Fish Habitat (EFH) for the 2022 EFH five-year review. Morphometric condition was estimated using residuals of a length-weight regression fit to individual length-weight measurements collected during AFSC/RACE eastern Bering Sea bottom trawl surveys from 1999 to present. Proposed sign of the relationship to recruitment is positive.
   - Contact: Sean Rohan
   - Status and trends: The condition of adult Pacific cod in the EBS in 2024 was within 1 standard deviation of the mean, which continues the trend of neutral morphometric condition observed since 2018. The condition of adult Pacific cod increased from 1999 to 2003, decreased from 2003 to 2006, then fluctuated around neutral from 2007 to 2024, aside from negative years in 2012, 2015, and 2017.
   - Factors influencing trends: Many factors contribute to variation in morphometric condition so it is unclear which specific factors contributed to neutral condition of juvenile Pacific cod in the EBS in 2024. Factors that may contribute to variation in morphometric condition include environmental conditions that affect prey quality and temperature-dependent metabolic rates, survey timing, stomach fullness of individual fish, fish migration patterns, and the distribution of samples within survey strata. Temperature is an important factor that can influence the morphometric condition of Pacific cod by influencing metabolic rates, prey availability, and prey quality. Historically in the eastern Bering Sea (EBS), "cold" years (with a small cold pool) were associated with negative morphometric condition (e.g., 1999, 2012) and warm years (e.g., 2002-2005) were associated with positive morphometric condition. However, during exceptionally warm years from 2018-2021, the morphometric condition of Pacific cod was neutral for adult and juvenile Pacific cod and this trend continued into the average temperature years in 2022-2024. Temperature can negatively affect growth rates if prey resources are insufficient to make up for increased metabolic demand. Additional information about the groundfish morphometric condition indicator and factors that can influence estimates of morphometric condition are described in the EBS Groundfish Morphometric Condition contribution in the 2024 Eastern Bering Sea Ecosystem Status Report (Prohaska et al., 2024).
   - Implications: In the Gulf of Alaska, elevated temperatures during the 2014-2016 marine heatwave were associated with lower growth rates of Pacific cod and lower morphometric condition in 2015 (adults and juveniles combined), likely because of a decrease in prey resources and increase in metabolic demand (Barbeaux et al., 2020). Below average condition suggests that adult Pacific cod in the EBS are not able to find sufficient prey resources.

j. Annual Ration Pacific Cod EBS Model: Estimate of ration (kg per individual per year) for Pacific cod (age-4 plus) from the Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) that has been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the EBS (Holsman et al., 2016). Proposed sign of the relationship to recruitment is negative.

- Contact: Kirstin Holsman
- Status and trends: Annual predation demand (ration) has been fluctuating in a decadal pattern over the time series, with a sharp decreasing trend from 2010 to 2012 and then steadily increasing to an above average state to 2018 where it has stayed through 2024.
- Factors influencing trends: Recent above average rations may be driven by anomalously warm water temperatures in the Bering Sea during heatwave years. However, cooler temperatures in 2023 and 2024 may shift the annual ration to a lower state.
- Implications: While warm temperatures continue to lead to high metabolic (and energetic) demand of predators, declines in total predator biomass, in particular Pacific cod, are contributing to a net decrease in total consumption (relative to 2016) and therefore reduced consumption and mortality in 2021–2024. This pattern indicates continued favorable top-down conditions for juvenile groundfish survival in 2024 through predator release due to declining biomass of Pacific cod.

k. Summer Pacific Cod Center Gravity East EBS Model: Spatio-temporal delta-generalized linear mixed model using standard settings for an "index standardization" model (Thorson 2019) for estimating numerical abundance, implemented using the package VAST (Thorson and Barnett 2017) in the R statistical environment (R Core Team 2017). This configuration includes spatial and spatio-temporal variation in two linear predictors of a Poisson-link delta model (Thorson 2018), using a gamma distribution for residual variation in positive catch rates. We specified a model with 750 "knots" and conducted bilinear interpolation from the location of knots to the location of extrapolation grid cells. Knots were distributed proportional to the spatial distribution of extrapolation grid cells within this spatial domain. We calculated center of gravity as the abundance weighted average of the location of extrapolation grid cells (Thorson et al. 2016a) available as northings and eastings. We used epsilon bias correction to correct for retransformation bias (Thorson and Kristensen, 2016). Units are km. 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: Lewis Barnett
- Status and trends: Center of gravity (COG) eastings indicate that the core of the population density has moved steadily more west from 1992 to 2006 before returning eastward through 2012. It then shifted westward to 2018 and has since fluctuated widely among years with a slight trend overall to the east.
- Factors influencing trends: The eastward extent of the core of the population density is primary influenced by sea bottom temperatures during the summer survey season, which in turn is driven largely by the volume of sea ice the prior spring.
- Implications: The eastings COG is negatively correlated with the extent of sea ice during the ice retreat season (Mar-May) and reflects a combination of movement and productivity changes that have resulted in more of the Pacific cod population being in the NBS in recent (warm) years compared to 2010 and prior. The increasing density of predatory fish in the NBS increases the potential for greater natural mortality rates for their prey in this region, namely pollock and snow crab. It is possible that access to this new habitat has increased the amount of prey available to Pacific cod.

l. Summer Pacific Cod Center Gravity North EBS Model: Spatio-temporal delta-generalized linear mixed model using standard settings for an “index standardization” model (Thorson 2019) for estimating numerical abundance, implemented using the package VAST (Thorson and Barnett 2017) in the R statistical environment (R Core Team 2017). This configuration includes spatial and spatio-temporal variation in two linear predictors of a Poisson-link delta model (Thorson 2018), using a gamma distribution for residual variation in positive catch rates. We specified a model with 750 “knots” and conducted bilinear interpolation from the location of knots to the location of extrapolation grid cells. Knots were distributed proportional to the spatial distribution of extrapolation grid cells within this spatial domain. We calculated center of gravity as the abundance weighted average of the location of extrapolation grid cells (Thorson et al. 2016a) available as northings and eastings. We used epsilon bias correction to correct for retransformation bias (Thorson and Kristensen, 2016). Units are km. 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: Lewis Barnett
- Status and trends: Center of gravity (COG) northings indicate that the core of the population density has moved south from 2005 to 2010 before a more dramatic northward shift from 2010 to 2018, and has since steadily shifted south since to return to near the time series mean.
- Factors influencing trends: The northward extent of the core of the population density is primary influenced by sea bottom temperatures during the summer survey season, which in turn is driven largely by the volume of sea ice the prior spring.
- Implications: The northings COG is highly negatively correlated with the extent of sea ice during the ice retreat season (Mar-May) and reflects a combination of movement and productivity changes that have resulted in more of the Pacific cod population being in the NBS in recent (warm) years compared to 2010 and prior. The increasing density of predatory fish in the NBS increases the potential for greater natural mortality rates for their prey in this region, namely pollock and snow crab. It is possible that access to this new habitat has increased the amount of prey available to Pacific cod.

m. Summer Pacific Cod Area Occupied EBS Model: Spatio-temporal delta-generalized linear mixed model using standard settings for an "index standardization" model (Thorson 2019) for estimating numerical abundance, implemented using the package VAST (Thorson and Barnett 2017) in the R statistical environment (R Core Team 2017). This configuration includes spatial and spatio-temporal variation in two linear predictors of a Poisson-link delta model (Thorson 2018), using a gamma distribution for residual variation in positive catch rates. We specified a model with 750 "knots" and conducted bilinear interpolation from the location of knots to the location of extrapolation grid cells. Knots were distributed proportional to the spatial distribution of extrapolation grid cells within this spatial domain. We calculated effective area occupied as the area needed to encompass the population if it was distributed homogenously at its mean population density (Thorson et al. 2016a). We used epsilon bias correction to correct for retransformation bias (Thorson and Kristensen, 2016). Units are in square kilometers. 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: Lewis Barnett
  - Status and trends: Effective area occupied has generally contracted from the beginning of the time series to approximately 2005, when the area occupied rapidly increases into 2006. Since that time it has shown high interannual variability around this elevated mean value and increased to high in 2024 for the first time since 2017.
  - Factors influencing trends: The effective area occupied is primary influenced by sea bottom temperatures during the summer survey season, which in turn is driven largely by the volume of sea ice the prior spring.
  - Implications: The effective area occupied is negatively correlated with the extent of sea ice during the ice retreat season (Mar-May) and reflects a combination of movement and productivity changes that have resulted in expansion of the Pacific cod population into the NBS in the middle to late 2010s. The increasing density of predatory fish in the NBS increases the potential for greater natural mortality rates for their prey in this region, namely pollock and snow crab. It is possible that access to this new habitat has increased the amount of resources available to Pacific cod.

n. Annual Biomass Consumed Pacific Cod EBS Model: Estimate of Pacific cod biomass consumed (or eaten as prey, in million tons) from the Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics (CEATTLE) that has been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the EBS (Holsman et al., 2016). Proposed sign of the relationship to recruitment is negative.
   - Contact: Kirstin Holsman
   - Status and trends: Estimates of total biomass consumed of Pacific cod as prey across all ages steadily has varied within the past decade and has decreased from being above average in 2023 to below average in 2024.
   - Factors influencing trends: Population trends of predators included in the CEATTLE model (arrowtooth flounder, pollock, Pacific cod, Pacific halibut) impact total biomass consumed of Pacific cod as prey.
   - Implications: While warm temperatures continue to lead to high metabolic (and energetic) demand of predators, declines in total predator biomass, in particular Pacific cod, are contributing to a net decrease in total consumption (relative to 2016) and therefore reduced predation rates and mortality in 2021–2024. This pattern indicates continued favorable top-down conditions for juvenile groundfish survival in 2024 through predator release due to declining biomass of Pacific cod.

Socioeconomic Indicators:

<u>1. Fishery Informed Indicators</u>

Information on fishery catch-per-unit-effort and other fishery-informed indicators is included within the main SAFE document (Barbeaux et al., 2024) and is not repeated here.

<u>2. Economic Indicators (Figure 2.2.2b.a-c)</u>

a. Annual Pacific Cod Real Ex-vessel Value EBS Fishery: Annual estimated real ex-vessel value measured in millions of dollars and inflation adjusted to 2023 USD.
   - Contact: Russel Dame
   - Status and trends: Since 2018, ex-vessel value has declined year-over-year, reaching a historical low of $110 million in 2021, the lowest value of the time series. In 2022, the ex-vessel value increased to $168 million before decreasing to $146 million in 2023. The 2023 ex-vessel value remained below the historical average and one standard deviation of the historical range.
   - Factors influencing trends: Total catch decreased by 7% in 2023, coupled with reductions in the average ex-vessel price per-pound, resulted in a decline in the ex-vessel value. The average ex-vessel price per-pound, however, has remained above the historical average for six of the last seven years, suggesting that the decline in value is primarily associated with the significant declines in catch since 2016.
   - Implications: Reductions in the value of the fishery may cause vessels to substitute to other species that can be caught with similar gear types and have higher expected profits. Vessels that remain in the fishery will have the lowest marginal cost, relative to all other vessels, or highest revenue per unit effort, which may increase the average revenue per vessel despite potential decreases in the overall fishery.

b. Annual Pacific Cod Real Ex-vessel Price EBS Fishery: Average real ex-vessel price per pound of EBS Pacific cod measured in millions of dollars and inflation adjusted to 2023 USD.
   - Contact: Russel Dame
   - Status and trends: The average ex-vessel price per-pound has decreased by 8% in 2023 to $0.44 per pound. This remains slightly above the historical average and within one-standard deviation of the historical range.

- Factors influencing trends: Reductions in the 2023 average ex-vessel price per-pound may be associated with the decrease in the average ex-vessel price per-pound for the head & gut product type. The two primary product types for Pacific cod are head and gut (H&G; ~65%) and fillets (~25%). The average price per-pound of fillets remained relatively unchanged while the average price per-pound for H&G declined by 19% in 2023.
- Implications: The decline in the average price per-pound of H&G Pacific cod may result in processors choosing to process more fillets than H&G. Compared to the 2014 to 2018 average, the volume of fillets has remained unchanged while the volume of H&G has decreased by 50%.

c. Annual Pacific Cod Real Revenue Per Unit Effort EBS Fishery: Annual estimated real revenue per unit effort measured in weeks fished and inflation adjusted to 2023 USD.
  - Contact: Russel Dame
  - Status and trends: The revenue per-unit effort remained stable in 2023, remaining above the historical average for three of the past four years, and within one-standard deviation of the historical range.
  - Factors influencing trends: With reductions in the value of the fishery in 2023, the number of weeks fished (measure of effort) must have declined to keep revenue per-unit effort stable.
  - Implications: TBD

<u>3. Community Indicators</u>

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., 2022). 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 EBS Pacific cod 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.

Beginning Stage: Traffic Light Test

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 2.2.3). We also provide a five-year indicator status table with a color for the relationship with the stock (Table 2.2.2).

Overall, the ecosystem indicators score in 2024 decreased from the previous year to average (Figure 2.2.3, black line). By category, the larval indicators decreased from above average to below average, juvenile indicators remained average and adult indicators remained above average (Figure 2.2.3, green, blue, and purple lines). We note caution when comparing scores between odd to even years as there is one indicator missing in odd years due to the off-cycle year survey in the EBS. 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.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and EBS Pacific cod 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 EBS Pacific cod recruitment over time (Figure 2.2.4, 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 2.2.4, top right). We also provide model predicted fit (1:1 line, Figure 2.2.4, bottom left) and average fit across the recruitment time series subset (1985-2019, Figure 2.2.4, bottom right). A higher probability indicates that the variable is a better candidate predictor of EBS Pacific cod recruitment.

The highest ranked predictor variable (inclusion probability > 0.5) based on the most recent BAS analysis (Shotwell et al., 2023b) was the summer bottom temperature from the ROMS-NPZ model (inclusion probability = 0.65) (Figure 2.2.4). The direction of this effect was consistent with the proposed overall relationship with recruitment. These indicators are marked with an asterisk (*) in Table 2.1.2 and may assist with evaluation of the indicator suite within the risk table.

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 address potential nonstationarity and missing observations of the current indicators suite. This may allow for identifying more robust indicators for potential use in the operational stock assessment model. We plan to explore additional importance techniques in future ESP report cards.

Advanced Stage: Research Model Test

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

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; Holsman et al., 2024a) has been developed for understanding trends in total mortality for Pacific cod, walleye pollock, and arrowtooth flounder from the EBS (Holsman et al., 2024). Total mortality estimates are based on residual mortality estimates (M1), time- ang age-varying predation mortality (M2), and time- and age-varying fishing mortality (F). The model is based, in part, on the parameterization and data used for the most recent stock assessment model of each species (Ianelli et al., 2024, Barbeaux et al., 2024, Shotwell et al., 2024). The model is fit to annual index and age and length composition data (assumed to come from a multinomial distribution). Model estimates of M2 are calculated from annually varying temperature- and age-based bioenergetics model estimates of annual metabolic and prey consumption demand growth, as well as species distribution model-based estimates of predator and prey overlap (optional) and empirically calculated diet composition (from annual summer NEBS+ SEBS surveys of predator stomach content), which informs predator-prey suitability. The most recent model was fit to data from 1979 to 2024 and has a very similar trend between the single- and multi-species mode (Holsman et al., 2024a). The age-1 mortality index could provide a gap free estimate of predation mortality; however, fitting age-specific annually varying mortality within the model could be challenging given the lack of data on younger fish (age 0-3) and will require further development. Comparisons of the model run in single- and multi-species modes further allow for evaluation of the relative role of cannibalism in density dependent recruitment processes.

In the future, highly ranked predictor variables could be evaluated in the advanced stage statistical test, which is a modeling application that analyzes predictor performance and estimates risk within the operational stock assessment model. The summer bottom temperature index could be used directly to help explain the variability in recruitment deviations and predict pending recruitment events for EBS Pacific cod. Also, the sea ice extent during the ice retreat period, or simply the center of gravity northings from the VAST model, could be used as covariates if future spatial models were developed for this stock. Comparisons of the model with and without climate effects on recruitment can also help disentangle climate effects on growth from that of climate effects on recruitment and mortality.

Socioeconomic Monitoring

Total catch decreased by 6% from 2022 levels to 152 thousand mt in 2023. A slight increase from the historical low in 2021, but remained below one-standard deviation of the historical mean for the fourth consecutive year. The average ex-vessel price per pound has declined slightly in 2023 but remains above the historical mean. The reduction in catch coupled with the reduction in the average ex-vessel price per pound caused a reduction in the ex-vessel revenue in 2023 (Table 2.2.1a). Similarly, with declines in total catch, the first-wholesale volume of BSAI Pacific cod declined in 2023 to 70 thousand mt from the 2014 to 2018 average of 119 thousand mt (Table 2.2.1b). Reductions in supply did have a positive impact on the average first-wholesale price per pound, increasing from an average of $1.52 from 2014 to 2018 to $2.01 in 2023. The reductions in first-wholesale volume outweighed the increase in price as the first wholesale value decreased to $312 million in 2023, a 20% decline from the 2014 to 2018 average of $400 million. Pacific cod is primarily processed into head & gut and fillets. The volume of Pacific cod processed to H&G has declined with retained catch, but the volume processed into fillets has remained relatively stable. Additionally, the average first-wholesale price per pound of fillets has increased more quickly than H&G products, causing the value share of H&G products to decline year-over-year while the value share of fillets increase.

Similar trends are being seen in the global production of Pacific cod (Table 2.2.1c). Global production of Pacific cod has declined to approximately 1.5 million mt in 2022 from the 2014 to 2018 average of approximately 1.8 million mt (-7%). In 2023, export volume and value of Alaskan Pacific cod has declined from the 2014 to 2018 average of 98 thousand mt and $302 million to 45 thousand mt and $159 million. A majority of Alaskan Pacific cod exports go to Asian markets, primarily China and Japan, representing two-thirds of volume and value historically. Recent trends in Asian exports, however, suggest that less than one-half of Pacific cod export volume and value now go toward Asian markets. This may be associated with the increased trade tariffs in 2023 in China against U.S. seafood and recent reports that state Russian export volumes of seafood to China increased by 36.1% from 2022 levels and is on track to increase further in 2024. Although exports to China and Japan are declining, exports to European countries have increased compared to the 2014 to 2018 average. Additionally, the share of cod being consumed domestically has increased year-over-year between 2019 and 2022, when demand for frozen products increased during the COVID-19 pandemic.

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., 2021-2023b).

Ecosystem Priorities

- Development of high-resolution remote sensing (e.g., regional surface temperature, transport estimates, primary production estimates) or climate model indicators (e.g., bottom temperature, nutrient-phytoplankton-zooplankton variables) to assist with the current multi-year data gap for several indicators.
- Refinements or updates to current indicators (e.g., chlorophyll *a*) that were only partially specialized for EBS Pacific cod such as more specific phytoplankton indicators tuned to the spatial and temporal distribution of EBS Pacific cod 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 Pacific cod larvae).
- Investigating environmental regulation of first year of life processes in Pacific cod to understand the interrelationship between processes occurring during pre-settlement (spawning/larvae), settlement (summer growth), and post-settlement (first overwintering) phases. Specific information on temperature ranges for optimal growth would allow development of thresholds that could be included in the indicator analysis.
- Development of a spawning habitat index for EBS Pacific cod, analogous to that for the Gulf of Alaska, to characterize spatial and temporal changes in spawning habitat in the EBS and its importance for larval phenology, advection, and survival.
- 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 Pacific cod during their first autumn and winter, when predation mortality is thought to be significant.
- Evaluation of condition and energy density of juvenile and adult Pacific cod samples at the outer edge of the population from NBS bottom trawl or longline surveys to understand the impacts of shifting spatial statistics such as center of gravity and area occupied.

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 performance 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., revenue share, price per pound)
    - Revenue per unit effort by area, gear, or 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 EBS Pacific cod ESP will include these data gaps and research priorities that could be developed for the next full ESP assessment (please contact Kalei Shotwell at kalei.shotwell@noaa.gov for more details).

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Tables

Table 2.2.1a. Bering Sea & Aleutian Islands Pacific cod catch and ex-vessel data. Total and retained catch (thousand metric tons), number of vessel, catcher/processor (CP) hook-and-line (H&L) share of catch, CP trawl share of catch, shoreside retained catch (thousand metric tons), shoreside number of vessel, shoreside pot gear share of catch, shoreside trawl share of catch, shoreside ex-vessel value and price (million US$), and fixed gear to trawl price premium (US$ per pound); average and most recent 5 years.

	2014-2018 Average	**2019**	**2020**	**2021**	**2022**	**2023**
Total catch (K mt)	245.1	198.0	169.9	135.8	160.7	151.5
Retained catch (K mt)	241.85	195.93	167.39	132.08	158.45	149.59
Vessels (#)	167.2	196	189	146	150	140
CP H&L share of BSAI catch (%)	49.81%	45.21%	43.95%	44.63%	44.43%	43.77%
CP trawl share of BSAI catch (%)	14.01%	13.04%	13.18%	13.73%	12.91%	13.63%
Shoreside retained catch (K mt)	80.79	77.53	68.34	52.69	64.85	61.25
Shoreside catcher vessels (#)	119.6	150	151	115	120	109
CV pot gear share of BSAI catch (%)	15.7%	21.98%	21.4%	23.11%	25.06%	24.47%
CV trawl share of BSAI catch (%)	17.39%	16.98%	18.86%	16.63%	15.77%	16.44%
Shoreside ex-vessel value (M $)	$48.51	$62.26	$53.61	$39.35	$60.88	$54.29
Shoreside ex-vessel price ($/lb)	$0.30	$0.42	$0.39	$0.37	$0.47	$0.45
Shoreside fixed gear ex-vessel price premium ($/lb)	$0.05	$0.11	$0.07	$0.04	$0.03	-$0.02

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 2.2.1b. Bering Sea & Aleutian Islands Pacific cod first-wholesale market data. First-wholesale production (thousand metric tons), value (million US$), price (US$ per pound); fillet and head and gut volume (thousand metric tons), value share (%), and price (US$ per pound); At-sea share of value (%) and at-sea shoreside price difference (US$ per pound); average and most recent 5 years.

	2014-2018 Average	2019	2020	2021	2022	2023
All Products volume (K mt)	119.47	94.97	77.62	62.86	76.22	70.43
All Products value (M $)	$399.86	$346.52	$265.88	$236.67	$379.02	$312.02
All Products price ($/lb)	$1.52	$1.66	$1.55	$1.71	$2.26	$2.01
Fillets volume (K mt)	9.02	8.02	7.51	5.61	10.13	9.01
Fillets value share (%)	16.86%	19.98%	23.24%	22.43%	27.01%	28.89%
Fillets price ($/lb)	$3.39	$3.91	$3.73	$4.29	$4.59	$4.54
Head & Gut volume (K mt)	94.30	70.25	55.04	45.96	47.35	47.01
Head & Gut value share (%)	75.38%	71.53%	65.98%	68.53%	62.93%	61.77%
Head & Gut price ($/lb)	$1.45	$1.60	$1.45	$1.60	$2.29	$1.86
At-sea value share (%)	69.30%	66.96%	63.83%	65.49%	65.09%	64.21%
At-sea price premium ($/lb)	-$0.22	-$0.36	-$0.48	-$0.34	-$0.38	-$1.12

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 2.2.1c. Cod U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production (%), and Europe's share of global production (%); U.S. export volume (thousand metric tons), value (million US$), and price (US$ per pound); U.S. cod consumption (estimated), and share of domestic production remaining in the U.S. (estimated %); and the share of U.S. export volume (%) and value share (%) for head and gut (H&G), fillets, China, Japan, and Europe; average and most recent 5 years.

	2014-2018 Average	**2019**	**2020**	**2021**	**2022**	**2023**
Global cod catch (K mt)	1761.27	1574.03	1498.08	1530.62	1457.14	-
U.S. cod share of global catch (%)	20.7%	17.4%	15.0%	13.4%	16.4%	-
Europe Share of global catch* (%)	76.0%	78.3%	80.5%	82.3%	79.3%	-
Pacific cod share of U.S. catch (%)	99.7%	99.8%	99.7%	99.5%	99.5%	-
U.S. cod consumption K mt (est.) (K mt)	113.76	106.28	103.33	107.37	134.43	95.23
Share of U.S. cod not exported (%)	30.9%	36.8%	45.0%	53.3%	61.4%	42.2%
Export volume (K mt)	98.36	65.10	44.48	32.51	33.23	45.07
Export value M ($)	$302.01	$217.88	$139.40	$101.67	$104.72	$158.73
Export price ($/lb)	$1.39	$1.52	$1.42	$1.42	$1.43	$1.60
Frozen H&G volume share (%)	92.32%	92.31%	92.32%	89.45%	87.86%	91.4%
Frozen H&G value share (%)	91.09%	90.71%	89.83%	84.22%	86.02%	89.73%
Fillets volume share (%)	3.45%	4.68%	5.86%	8.72%	10.89%	7.39%
Fillets value share (%)	4.63%	5.84%	7.38%	12.92%	12.14%	8.72%
China volume share (%)	52.63%	41.52%	39.52%	31.36%	47.75%	42.55%
China value share (%)	50.19%	40.21%	37.35%	28.39%	48.14%	39.73%
Japan volume share (%)	14.96%	11.86%	13.04%	10.98%	4.65%	5.83%
Japan value share (%)	16.06%	12.97%	13.89%	11.77%	4.31%	5.66%
Europe volume share* (%)	17.92%	21.60%	20.13%	11.54%	17.17%	22.62%
Europe value share* (%)	19.06%	23.12%	20.69%	10.95%	17.42%	23.93%

*Europe refers to: Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom

Notes: Pacific cod in this table is for all U.S. unless noted, `cod' in this table refers to Atlantic and Pacific cod. Russia, Norway, and Iceland account for the majority of Europe's cod catch which is largely focused in the Barents Sea.
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-

	2014-2018 Average	2019	2020	2021	2022	2023

fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

Table 2.2.2. Beginning stage ecosystem indicator analysis for EBS Pacific cod, including indicator title and the indicator status for the last five available years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of the time series mean). Fill color of the cell is based on the sign of the anticipated 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	Winter Spring North Pacific Index Model	*high*	neutral	neutral	*high*	neutral
	Spring Summer Temperature Surface SEBS Satellite	**high**	neutral	neutral	neutral	neutral
	Summer Euphausiid Abundance EBS Survey	neutral	NA	neutral	NA	**low**
Juvenile	Pacific Cod Predation Mortality Age1 EBS Model	neutral	neutral	neutral	neutral	neutral
	* Summer Temperature Bottom SEBS Model	neutral	neutral	neutral	neutral	neutral
	Summer Pacific Cod Condition Juvenile EBS Survey	NA	neutral	neutral	neutral	neutral
Adult	Winter Sea Ice Advance BS Satellite NSIDC	neutral	neutral	neutral	neutral	neutral
	Spring Sea Ice Retreat BS Satellite	neutral	neutral	neutral	neutral	neutral
	Summer Pacific Cod Condition Adult EBS Survey	NA	neutral	neutral	neutral	neutral
	Annual Ration Pacific Cod EBS Model	neutral	**high**	neutral	neutral	neutral
	Summer Pacific Cod Center Gravity East EBS Model	neutral	neutral	neutral	*high*	neutral
	Summer Pacific Cod Center Gravity North EBS Model	neutral	**high**	neutral	neutral	neutral
	Summer Pacific Cod Area Occupied EBS Model	NA	neutral	neutral	neutral	*high*
	Annual Biomass Consumed Pacific Cod EBS Model	neutral	neutral	neutral	neutral	neutral

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

Figures

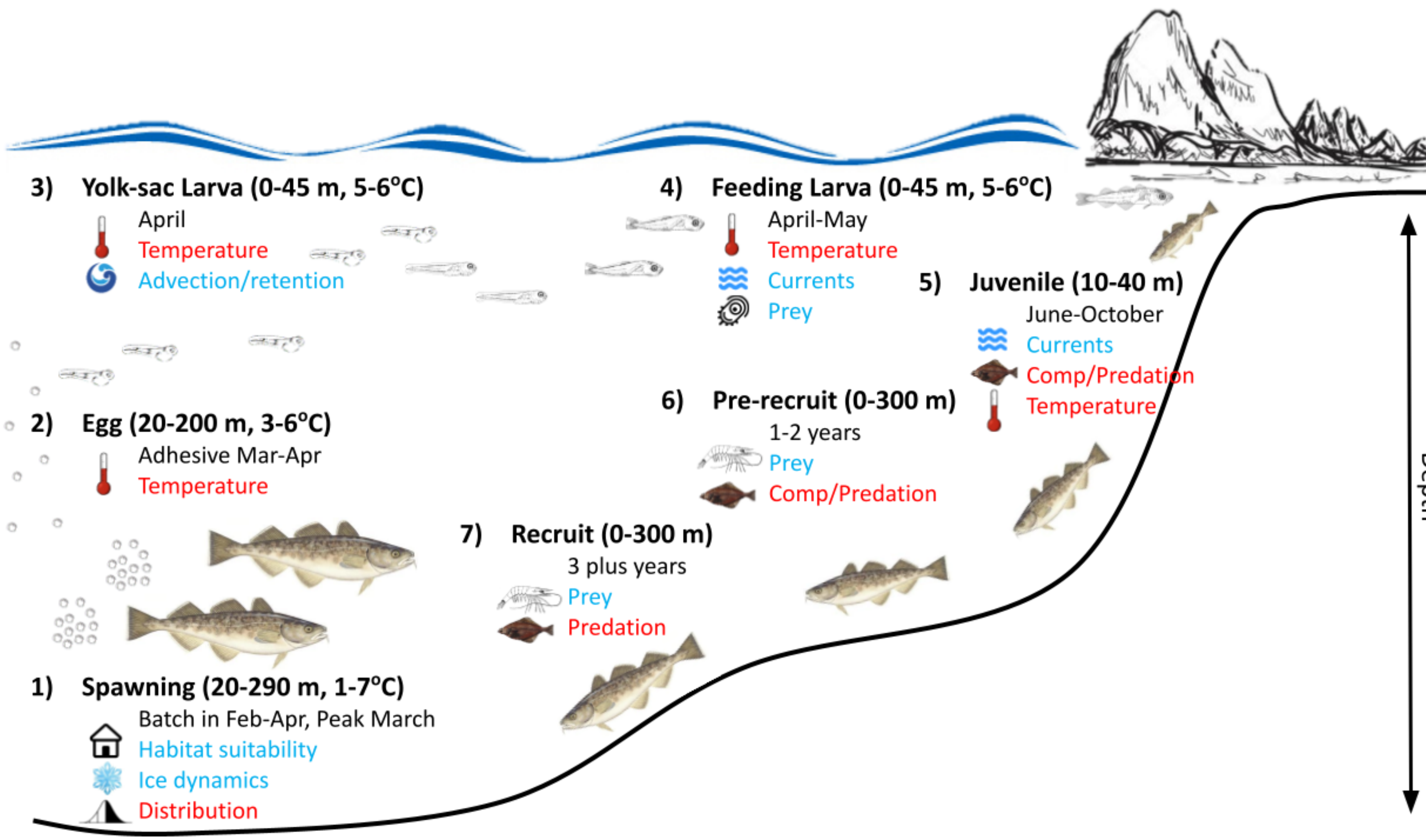

Figure 2.2.1: Life history conceptual model for EBS Pacific cod summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in the process negatively affect survival, while blue text means increases in the process positively affect survival.

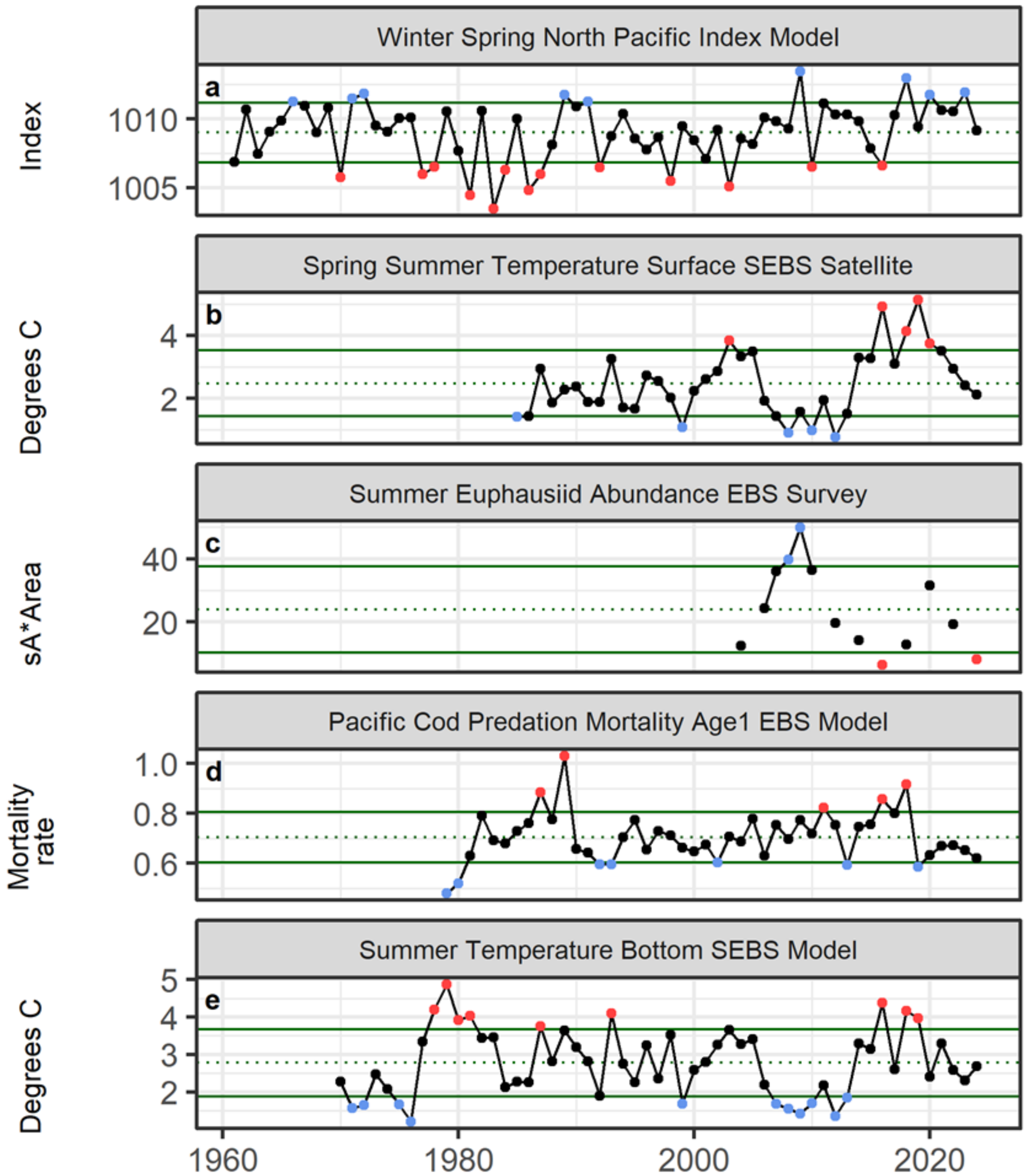

Figure 2.2.2a. Selected ecosystem indicators for EBS Pacific cod with time series ranging from 1961 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are 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.

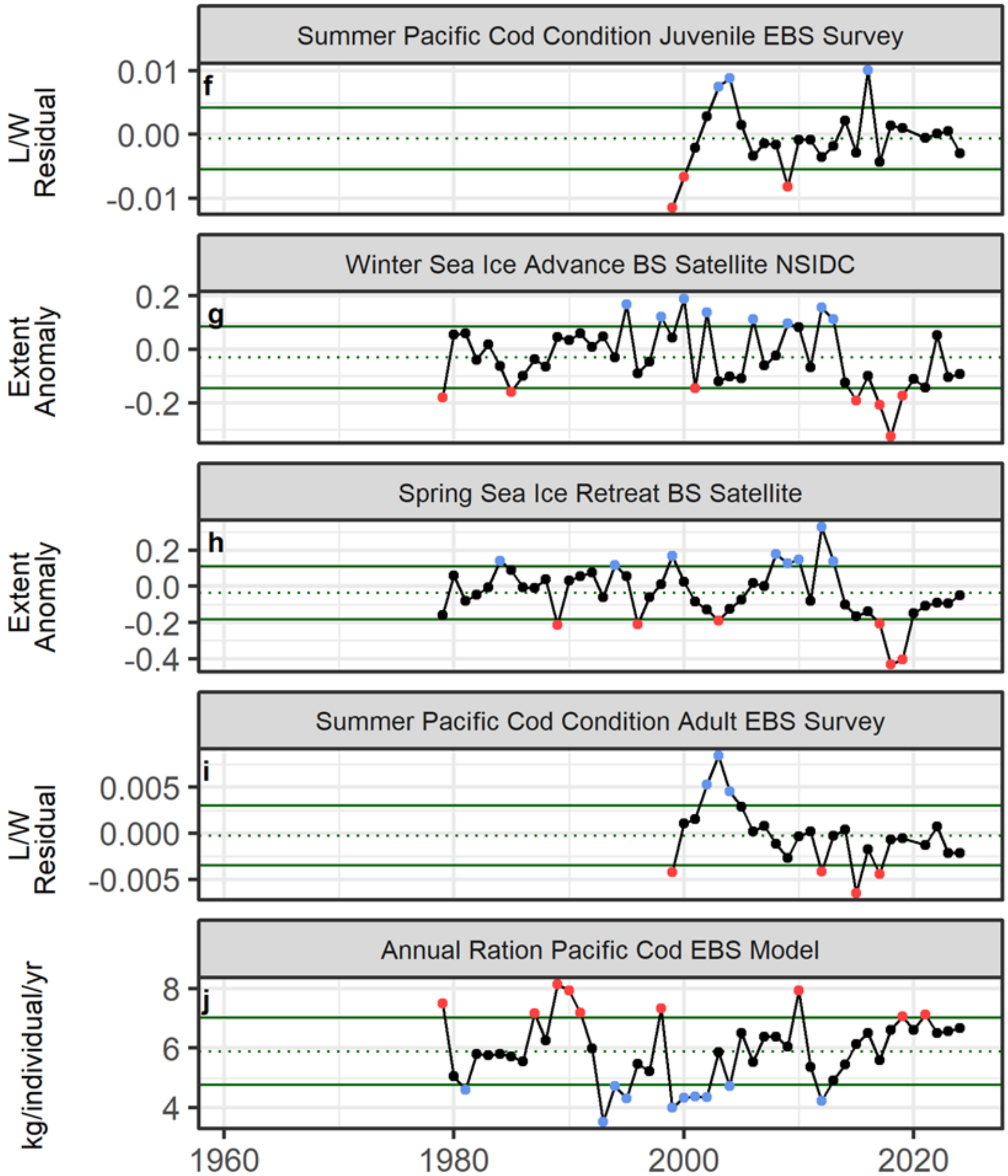

Figure 2.2.2a (cont.). Selected ecosystem indicators for EBS Pacific cod with time series ranging from 1961 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series 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.

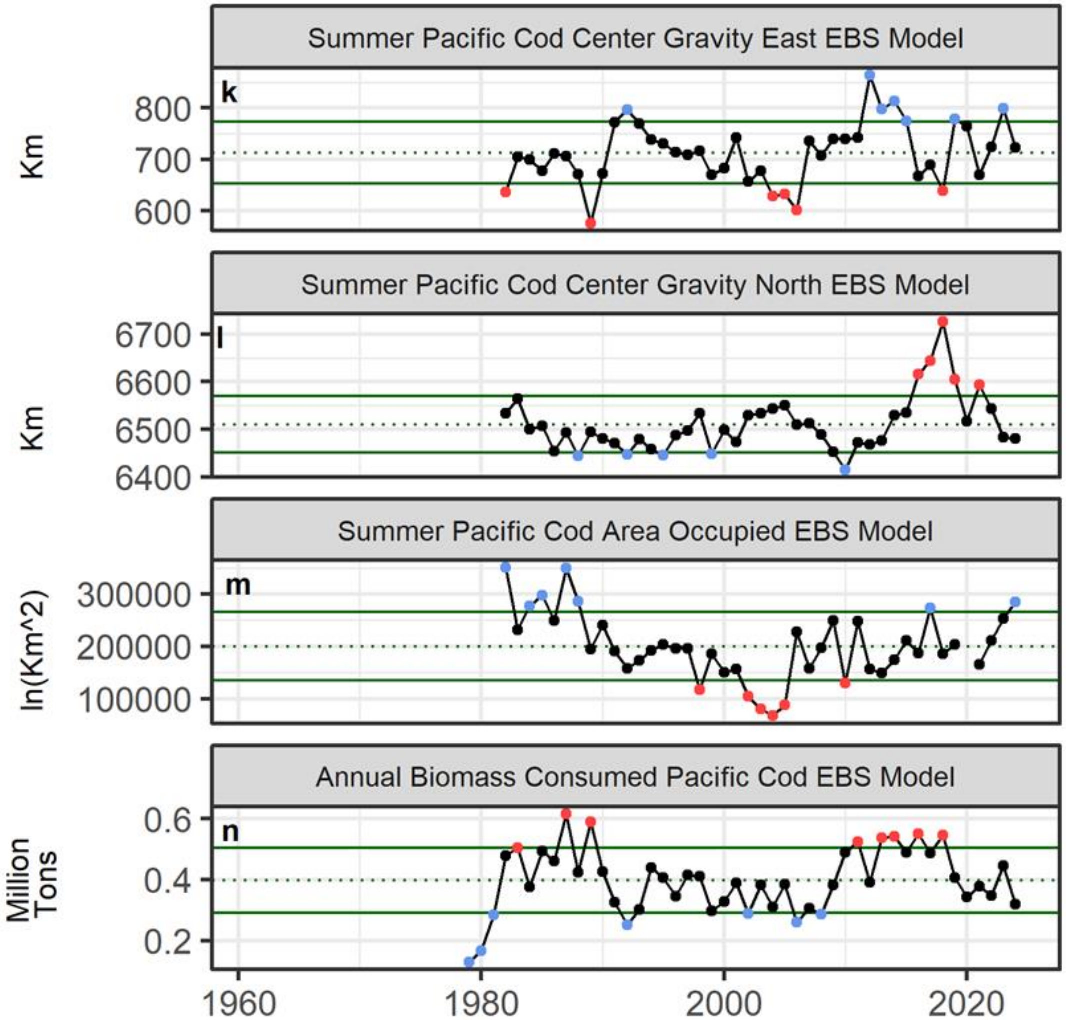

Figure 2.2.2a (cont.). Selected ecosystem indicators for EBS Pacific cod with time series ranging from 1961 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series 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.

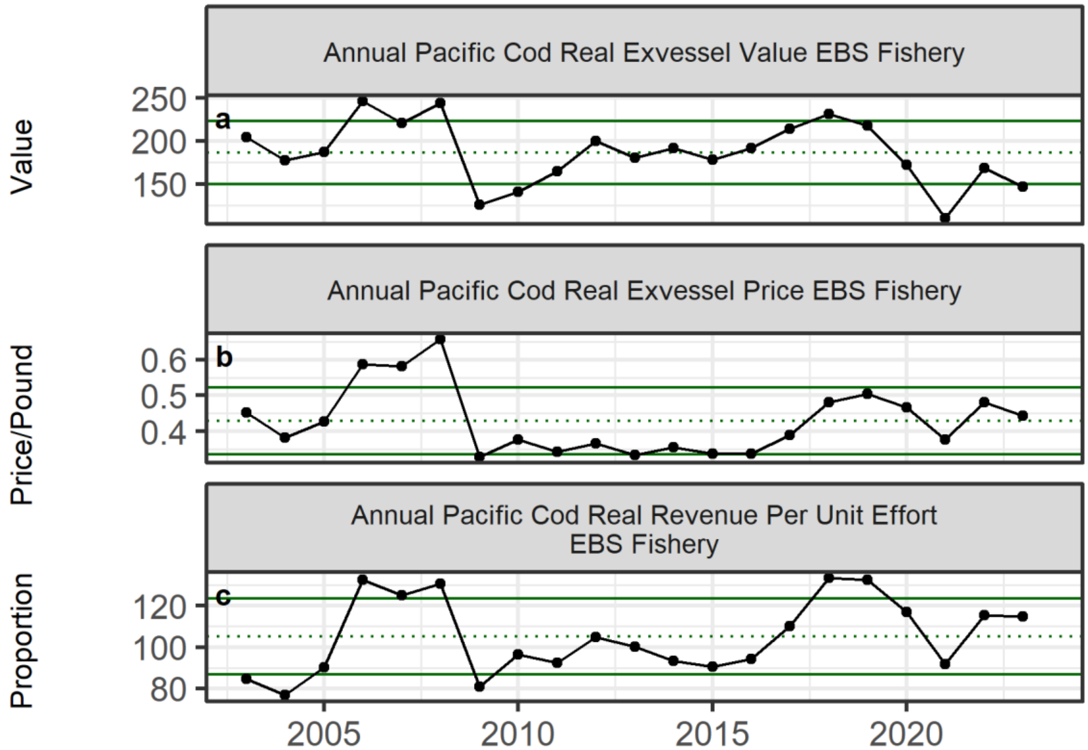

Figure 2.2.2b. Selected socioeconomic indicators for EBS Pacific cod with time series ranging from 2003 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

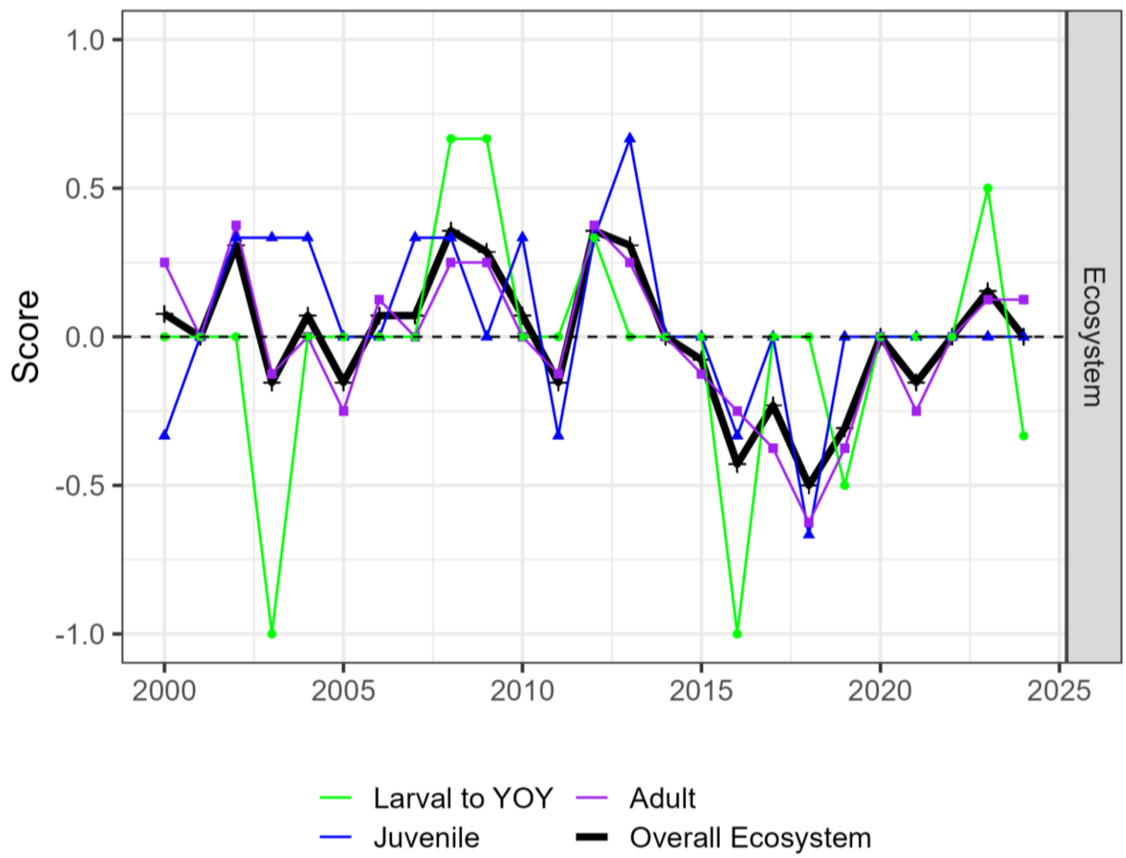

Figure 2.2.3: Simple summary traffic light score by overall ecosystem and category (larval to young-of-the-year (YOY), juvenile, and adult) for ecosystem indicators from 2000 to present.

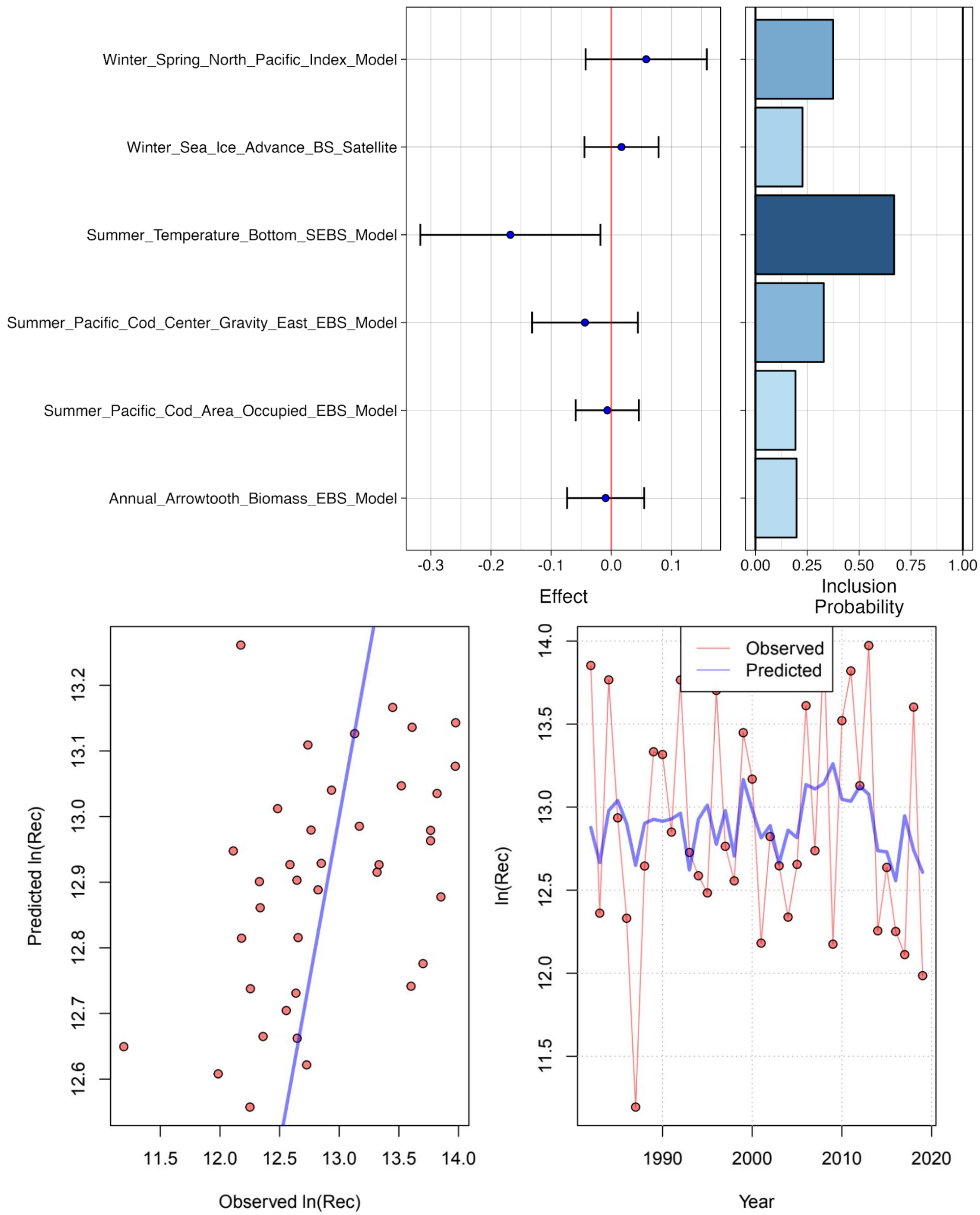

Figure 2.2.4: Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed estimated EBS Pacific cod recruitment from the operational stock assessment model: the estimated effect (top left) and the marginal inclusion probabilities (top right) for each 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 (1994-2019, bottom right).