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

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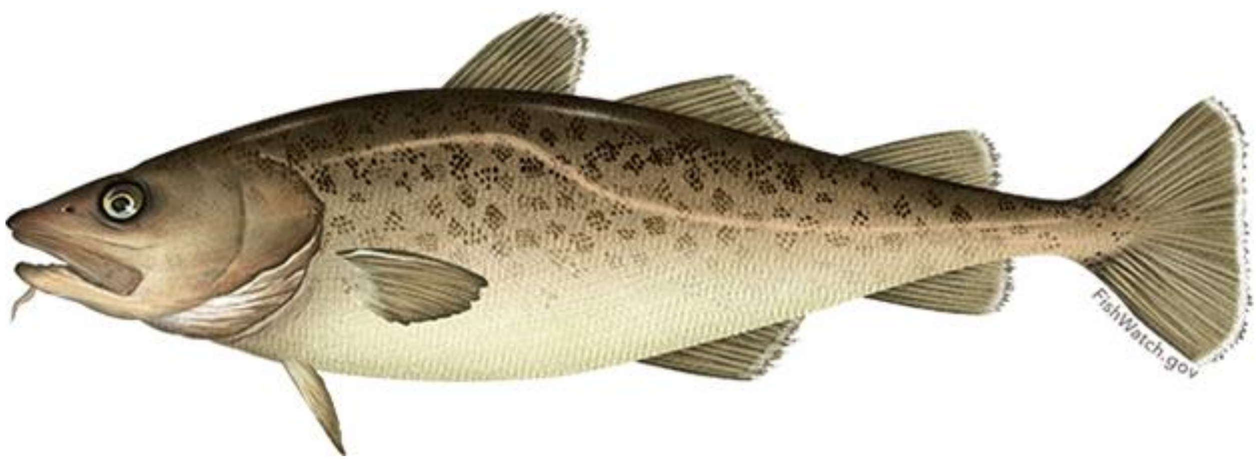

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Current Year Update

The ecosystem and socioeconomic profile, or ESP, is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., *Accepted*). 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.

Please refer to the last full ESP document (Shotwell et al., 2021, Appendix 2.2, pp. 347-411), which is available within the eastern Bering Sea (EBS) Pacific cod stock assessment and fishery evaluation, or SAFE report, for further information regarding the ecosystem and socioeconomic linkages for this stock.

Management Considerations

The following are the summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for EBS Pacific cod:

- The North Pacific Index increased to above the long-term mean signifying a weak Aleutian Low, high sea level pressure, warming sea surface temperatures, higher precipitation, increased downwelling, and generally calmer conditions.
- Winter sea-ice extent during the advance season decreased to below the time series mean and is similar in extent to 2020, while ice extent during the retreat season remains just below average increasing steadily since 2020.
- Spring and summer surface temperature decreased to average conditions and bottom temperature continues to decrease from 2022 and is now similar to 2006 and 2011 values.
- Spring bloom peak timing was at the average for the time series, but bloom timing varies spatially and match would be dependent on spawning and movement of the Pacific cod population.
- Condition for juvenile Pacific cod remained above average, while adult condition decreased to below average but still within the long term mean.
- Center of gravity estimates suggest the Pacific cod population has moved southeast from 2022, with above average area occupied, similar to the 2011 survey.
- Arrowtooth flounder biomass has steadily increased over the time series and remains above the long term mean from the most recent stock assessment model in 2022, with an 11% decrease in the 2023 EBS shelf bottom trawl survey.
- Ex-vessel value increased to within one standard deviation of the time series mean, although still below average, and price and revenue-per-unit-effort increased to average in 2022.

Modeling Considerations

The following are the summary results from the intermediate and advanced stage 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).
- Updated estimates of time-varying natural mortality and ration from the 2023 CEATTLE model run indicate that 1) age-1 natural mortality for Pacific cod has decreased and remains below the long-term mean and the single species estimate, 2) total biomass consumed by modelled predators has increased and is above the long-term mean, and 3) ration for adult (age 4+) Pacific cod has decreased but is still above the long-term mean.

Assessment

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock in conceptual models 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., 2021) for more details.

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). Please refer to this report for information on community engagement in the EBS Pacific cod fishery.

Indicator Suite

The list of ESP indicators is organized by categories, three for ecosystem indicators (physical, lower trophic, and upper trophic) and three for socioeconomic indicators (fishery performance, economic, and community). For EBS Pacific cod socioeconomic categories, only economic indicators are available at this time. A short description and contact name for the indicator contributor are provided. For ecosystem indicators, we also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant, and specify the lag applied if the indicator was tested in the intermediate stage indicator analysis (see section below for more details). Please refer to the full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions and proposed mechanistic linkages for this stock (Shotwell et al., 2021). Time series of the ecosystem and socioeconomic indicators are provided in Figure 2.2.2a and Figure 2.2.2b, respectively.

ESP indicators are evaluated during a full ESP. Report card years maintain those indicators but minor modifications may be needed annually to ensure product delivery. Modifications to ecosystem indicators in 2023 include: 1) methods for calculating the climatology for sea ice extent indicators were previously computed for the entire record and are now computed for the 1981-2010 period following standard practice for this dataset, 2) peak timing of the spring bloom derived from MODIS satellite measurements have been replaced with a European Space Agency (ESA) GlobColour blended satellite product because the satellites that hold the MODIS instruments will soon be retired due to changes in orbits, 3) morphometric condition indicators are estimated using the stratum biomass weighted length-weight residual method from previous years instead of the VAST-based condition index due to feedback from the Plan Teams, staff limitations, and no clear path to transition condition indicators for other surveys, and 4) regional quotient indicators for Pacific cod harvesting and processing revenue in the BSAI communities are no longer reported in the ESP as this community level information is provided in the ACEPO report (Wise et al., 2022). These modifications will preclude direct comparison to indicator timeseries in previous ESP documents.

Ecosystem Indicators:

Physical Indicators (Figure 2.2.2a.a-e)

a.) **North Pacific Index** (NPI) calculated as the area-weighted sea level pressure (SLP) from November to March over the region 30°N-65°N, 160°E-140°W (contact: E. Siddon). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

b.) Anomalies of average daily **sea-ice extent** relative to 1978-2010 mean computed over **ice-advance** season of December through February (contact: M. Wang). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

c.) Anomalies of average daily **sea-ice extent** relative to 1978-2010 mean computed over **ice-retreat** season of March through May (contact: M. Wang). Proposed sign of the relationship to recruitment is positive.

d.) **Spring to summer** (April-June) **daily sea surface temperatures** (SST) for the EBS shelf from the NOAA Coral Reef Watch Program (contact: M. Callahan). Proposed sign of the relationship to recruitment is negative and the time series is not lagged for the intermediate stage indicator analysis.

e.) **Summer** (July-September) **bottom temperatures** over the EBS shelf from the Bering 10K ROMS-NPZ model (contact K. Kearney, reference Kearney et al., 2021). Proposed sign of the relationship to recruitment is negative and the time series is not lagged for the intermediate stage indicator analysis.

Lower Trophic Indicators (Figure 2.2.2a.f-g)

f.) **Peak timing of the spring bloom** averaged across individual ADF&G statistical areas in the EBS calculated from ESA GlobColour blended satellite product (contact: J. Nielsen). Proposed sign of the relationship to recruitment is positive.

g.) **Summer euphausiid abundance** for the EBS shelf from the AFSC acoustic survey (contact: P. Ressler). Proposed sign of the relationship to recruitment is positive.

Upper Trophic Indicators (Figure 2.2.2a.h-m)

h.) **Summer condition for juvenile** (<460 mm) **Pacific cod** from the AFSC EBS shelf bottom trawl survey (contact: S. Rohan, reference Prohaska and Rohan, 2023). Proposed sign of the relationship to recruitment is positive.

i.) **Summer condition for adult** (>=460 mm) **Pacific cod** from the AFSC EBS shelf bottom trawl survey (contact: S. Rohan, reference Prohaska and Rohan, 2023). Proposed sign of the relationship to recruitment is positive.

j.) **Summer Pacific cod center of gravity eastings** estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data (contact: M. Hall). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

k.) **Summer Pacific cod center of gravity northings** estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data (contact: M. Hall). Proposed sign of the relationship to recruitment is negative and the time series is not lagged for the intermediate stage indicator analysis.

l.) **Summer Pacific cod area occupied** estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data (contact: M. Hall). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

m.) **Arrowtooth flounder total biomass** from the most recent stock assessment model in the EBS (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative and the time series is lagged two years for the intermediate stage indicator analysis.

Socioeconomic Indicators:

Economic Indicators (Figure 2.2.2b.a-c)

a.) Annual estimated **real ex-vessel value** of EBS Pacific cod (contact: J. Lee).

b.) Annual **real ex-vessel price per pound** of EBS Pacific cod from fish ticket information (contact: J. Lee).

c.) Annual estimated **real revenue per unit effort** measured in weeks fished of EBS Pacific cod (contact: J. Lee).

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, growth, catchability). These regression techniques provide a simple predictive performance for the variable 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

We use a simple scoring calculation for this beginning stage traffic light evaluation on the indicators listed in the Indicator Suite section. Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long-term mean. A sign based on the anticipated relationship between the ecosystem indicator and the stock (generally shown in Figure 2.2.1 and specifically by indicator in the Indicator Suite, Ecosystem Indicators section) is also assigned to the indicator where possible. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a "+1" score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a "-1" score. All values less than or equal to one standard deviation from the long-term mean are average and receive a "0" score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 2.2.3). We note, per December 2023 SSC suggestion, that the socioeconomic indicators can provide a combination of performance and context and the overall scores by category should only include indicators that reflect performance. In this way higher scores should reflect “good” conditions and would not be influenced by indicators that are included for context (e.g., composition of product form, or market share). We also provide five year indicator status tables with a color (ecosystem indicators only) for the relationship with the stock (Tables 2.2.2a,b) and evaluate each year’s status in the historical indicator time series graphic (Figures 2.2.2a,b) for each ecosystem and socioeconomic indicator.

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the EBS Pacific cod stock regarding recruitment, movement, stock productivity, and stock health. We start with the physical indicators and proceed through increasing trophic levels, then evaluate the socioeconomic indicators as listed above. Here we concentrate on updates since the last ESP report card (Shotwell et al., 2022). We use the following nomenclature when describing these indicators:

- If the value in the time series is at the long-term mean of the time series (or the mean), we use the term “average” (dotted green line in Figure 2.2.2).
- If the value is above/below the mean but below/above 1 standard deviation of the mean (solid green line in Figure 2.2.2) we us the terms “above average” or “below average”.
- Any value within 1 standard deviation of the mean is considered “neutral” in Table 2.2.2.
- If the value is above/below 1 standard deviation of the mean (solid green line in Figure 2.2.2) we us the term “high” or “low”.

Overall, the physical and upper trophic level indicators scored above average, while the lower trophic indicators were average for 2023 (Figure 2.2.3). Compared to last year's results, this is the same value for lower trophic indicators, and an improvement from average for the physical indicators and below average for the upper trophic indicators. We note caution when comparing scores between odd to even years as there is one lower trophic indicator (summer euphausiid abundance) missing in odd years due to an off-cycle year survey. 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. Economic indicators are all lagged by at least one year due to timing of the availability of the current year information and the production of this report. Economic indicators scored average for 2022 (data received in 2023), which is an increase from below average in 2021.

For physical indicators (Table 2.2.2a, Figure 2.2.2a.a-e), the winter to spring North Pacific Index (NPI) increased to a high value in 2023 (Figure 2.2.2a.a). 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). 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 (Figure 2.2.2a.b). Similarly, the extent of sea ice during the ice retreat season (Mar-May) 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 (Figure 2.2.2a.c). Spring to summer surface temperatures decreased again from 2022 and are average since the warm stanza that has dominated since 2014 (Figure 2.2.2a.d). The simulated 2023 bottom temperature conditions were below average (Figure 2.2.2a.e).

For lower trophic indicators (Table 2.2.2a, Figure 2.2.2a.f-g), the timing of the spring bloom was average (Figure 2.2.2a.f). The bloom timing varies spatially, with blooms occurring earlier in the inner domain to later in the outer domain (Nielsen et al., 2021). A match or mismatch with larvae of the EBS Pacific cod stock would likely depend on where the primary spawning was occurring from year to year and thus seems dependent on movement. There was no summer EBS acoustic-trawl survey this year, so there are no updates for the euphausiid abundance index (Figure 2.2.2a.g) (P. Ressler *pers. commun.*).

For upper trophic indicators (Table 2.2.2a, Figure 2.2.2a.h-m), condition of juvenile Pacific cod in the EBS in 2023 was slightly above average, similar to 2022, which continues the trend of neutral morphometric condition since 2017. Condition of juveniles increased from 1999 to 2004, decreased from 2005 to 2009, then fluctuated around neutral from 2010 to 2023, aside from a positive year in 2016 (Figure 2.2.2a.h). The condition of adult Pacific cod in the EBS in 2023 was below average, which also continues the trend of neutral morphometric condition since 2018. Condition of adults increased from 1999 to 2003, decreased from 2003 to 2006, then fluctuated around neutral from 2007 to 2023, aside from negative years in 2012, 2015, and 2017 (Figure 2.2.2a.h-i). Many factors may contribute to the variation in morphometric condition such as environmental conditions that affect prey quality, temperature-dependent metabolic rates, survey timing, stomach fullness of individual fish, migration patterns, and 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 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 2022-2023. Temperature can negatively affect growth rates if prey resources are insufficient to make up for increased metabolic demand (Prohaska and Rohan, 2023). Center of gravity estimates for EBS Pacific cod have shifted from 2022, with the population center moving more east (high) and south (below average) (Figure 2.2.2a.j-k). Area occupied has increased to above average (Figure 2.2.2a.l) meaning the population is more spread out than in 2022. Arrowtooth flounder biomass (Figure 2.2.2a.m) remains high from the most recent stock assessment model in 2022 (Shotwell et al., 2022) and 2023 EBS shelf bottom trawl survey estimates are 11% lower than in 2022.

For economic indicators (Table 2.2.1b, Table 2.2.2b, Figure 2.2.2b.a-c), ex-vessel value increased from a time-series low in 2021 to below average in 2022, but is still among the lowest levels observed since 2013 (Figure 2.2.2b.a). Price per pound in 2022 reversed a recent declining trend since 2019, increasing to slightly greater than average (Figure 2.2.2b.b). Beginning in 2016, reductions in global supply put upward pressure on prices, resulting in significant year over year price increases in 2017 and 2018. In 2019 prices leveled off as markets adjusted. In 2020 COVID-19 closures resulted in increased demand for retail products and frozen products, and decreased foodservice and fresh products. Retail and foodservice are both significant components of the market for cod products. As such, the impact of COVID-19 on prices appeared relatively muted, with only marginal changes in first-wholesale and export prices. Cost pressure from COVID-19 mitigation efforts likely had impacts on net revenues as well as upstream impacts on ex-vessel prices, which decreased significantly in 2020 and 2021. Mirroring recent trends in, and modest increases in ex-vessel price and retained catch in 2022, revenue per unit effort also increased from below average to average in 2022 (Figure 2.2.2b.c).

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used for the intermediate stage statistical test to quantify the association between hypothesized predictors and EBS Pacific cod recruitment and to assess the strength of support for each hypothesis. In this stage, the full set of indicators is first evaluated for normality and transformed as needed or removed if the indicator cannot be transformed for this analysis. The remaining set of indicators is winnowed to the predictors that could directly relate to recruitment and highly correlated covariates (>0.6) are removed. We explore recruitment here as it was initially identified for this importance test within the full ESP (Shotwell et al., 2021). Other time-varying stock assessment parameters of interest could be evaluated should they become priorities for exploring ecosystem linkages in the future. Covariates with the strongest links to recruitment are retained and then z-scored. We further restrict potential covariates to those that can provide the longest model run (e.g., indicators from biennial surveys or gappy time series would be removed) and through the most recent estimate of recruitment that is well estimated (not just average recruitment) in the current operational stock assessment model. This results in a model run from 1985 through the 2019 year-class. We provide the relationship between the observed and predicted estimates (Figure 2.2.4, top panel, left side) and the fit over time (Figure 2.2.4, top panel, right side) for reference. We then provide the mean relationship between each predictor variable and log EBS Pacific cod recruitment over time (Figure 2.2.4b, left side), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 2.2.4b, right side). 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 this process is the summer bottom temperature from the ROMS-NPZ model (inclusion probability = 0.65) (Figure 2.2.4).

Advanced Stage: Research Model Test

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. 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 2023) has been developed for understanding trends in total mortality for Pacific cod, walleye pollock, and arrowtooth flounder from the EBS (Holsman et al., 2023). 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., 2023, Barbeaux et al., 2023, and Shotwell et al., 2022). 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 present (Figure 2.2.5, reproduced from Holsman et al., 2023). Age-1 natural mortality for Pacific cod has steadily decreased since 2018, and remains below the long-term mean and the value used for the single species assessment (Figure 2.2.5, top panel). Predation mortality for this model is primarily driven by arrowtooth flounder and total biomass of arrowtooth has been steadily increasing to a time-series high in recent years (Shotwell et al., 2022). Estimates of total biomass consumed of Pacific cod as prey across all ages increased in recent years and is currently above the long term mean (Figure 2.2.5, middle panel). Annual predation demand (ration) has been fluctuating in a decadal pattern over the time series and appears to be changing direction in 2023 from a steady increase since 2012, but remains above average (Figure 2.2.5, bottom panel). The warm temperatures in this system continue to lead to high metabolic (and energetic) demand of predators; however, declines in total predator biomass, particularly in Pacific cod, contribute to a decline in total consumption and therefore reduced predation rates and mortality.

The EBS CEATTLE model can provide gap-free estimates of predation mortality that could be tested in the operational stock assessment model. Additionally, the time series of bioenergetics-based consumption input to the CEATTLE model could be compared to condition indicators from the surveys for context on recent condition trends. 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 run in single- and multi-species modes further allow for evaluation of the relative role of cannibalism in density dependent recruitment processes. 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.

Data Gaps and Future Research Priorities

While the metric and indicator assessments provide a relevant set of proxy indicators for evaluation at this time, there are certainly areas for improvement. The list below summarizes the data gaps and future research priorities for this ESP by ecosystem and socioeconomic category. Please reference the full ESP (Shotwell et al., 2021) and past report cards (Shotwell et al., 2022) for more details.

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 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.
- 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.
- Investigation of the EBS CEATTLE model to create a gap-free index of age-1 through age-3 predation mortality, bioenergetics (e.g., annual ration, consumption), and near-term forecasts of weight-at-age (from the temperature linked growth model in the EBS CEATTLE model).
- 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 size grade (e.g., proportion landed, price per pound)
    - Revenue per unit effort by area or gear 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.

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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.

	2013-2017 Average	**2018**	**2019**	**2020**	**2021**	**2022**
Total catch K mt	251.1	220.3	198	169.9	135.8	160.7
Retained catch K mt	247	218.01	195.93	167.39	132.08	158.45
Vessels #	163.6	193	196	189	146	150
CP H&L share of BSAI catch	50.48%	46.27 %	45.21 %	43.95 %	44.63 %	44.43 %
CP trawl share of BSAI catch	14.79%	13.91 %	13.04 %	13.18 %	13.73 %	12.91 %
Shoreside retained catch K mt	78.57	82.48	77.53	68.34	52.69	64.85
Shoreside catcher vessels #	115	144	149	151	115	120
CV pot gear share of BSAI catch	14.13%	19.38 %	21.98 %	21.4%	23.11 %	25.06 %
CV trawl share of BSAI catch	17.35%	18.03 %	16.98 %	18.86 %	16.63 %	15.77 %
Shoreside ex-vessel value M $	$42.93	$65	$62.26	$53.43	$39.35	$60.76
Shoreside ex-vessel price lb $	$0.27	$0.4	$0.42	$0.39	$0.37	$0.47
Shoreside fixed gear ex-vessel price premium	$0.05	$0.07	$0.11	$0.1	$0.04	$0.19

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.

	2013-2017 Average	**2018**	**2019**	**2020**	**2021**	**2022**
All Products volume K mt	122.32	107.41	94.97	77.62	62.86	76.22
All Products value M $	$368.81	$458.84	$346.52	$265.88	$236.67	$378.96
All Products price lb $	$1.37	$1.94	$1.66	$1.55	$1.71	$2.26
Fillets volume K mt	8.71	10.36	8.02	7.51	5.61	10.13
Fillets value share	16.15%	20.53%	19.98%	23.24%	22.43%	27.02%
Fillets price lb $	$3.1	$4.12	$3.91	$3.73	$4.29	$4.59
Head & Gut volume K mt	98.04	79.04	70.25	55.04	45.96	47.35
Head & Gut value share	76.38%	70.73%	71.53%	65.98%	68.53%	62.92%
Head & Gut price lb $	$1.3	$1.86	$1.6	$1.45	$1.6	$2.28
At-sea value share	70.64%	63.54%	66.96%	63.83%	65.49%	65.09%
At-sea price premium ($/lb)	-$0.176	-$0.51	-$0.36	-$0.48	-$0.34	-$0.38

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 for head and gut (H&G), fillets, China, Japan, and Europe; average and most recent 5 years.

	2013-2017 Average	**2018**	**2019**	**2020**	**2021**	**2022**
Global cod catch K mt	1797.73	1635.95	1564	1489.05	1527.47	-
U.S. P. cod share of global catch	20.9%	18.2%	17.2%	15.1%	13.4%	-
Europe Share of global catch*	75.7%	78.3%	78.5%	80.4%	82.3%	-
Pacific cod share of U.S. catch	99.7%	99.9%	99.8%	99.7%	99.5%	-
U.S. cod consumption K mt (est.)	111.97	113.62	106.28	103.36	107.36	134.2
Share of U.S. cod not exported	29.9%	35.5%	36.8%	45%	53.3%	61.3%
Export volume K mt	104.09	73.14	65.1	44.48	32.52	33.25
Export value M US$	$312.94	$253.37	$217.88	$139.4	$101.68	$104.91
Export price lb US$	$1.36	$1.57	$1.52	$1.42	$1.42	$1.43
Frozen (H&G) volume share	92.18%	90.95%	92.31%	92.32%	89.44%	87.78%
Frozen (H&G) value share	90.84%	90.42%	90.71%	89.83%	84.21%	85.86%
Fillets volume share	3.25%	4.97%	4.68%	5.86%	8.73%	10.88%
Fillets value share	4.57%	5.69%	5.84%	7.38%	12.93%	12.11%
China volume share	52.93%	47.55%	41.52%	39.52%	31.36%	47.7%
China value share	50.44%	46.46%	40.21%	37.35%	28.38%	48.04%
Japan volume share	14.55%	15.06%	11.86%	13.04%	10.99%	4.64%
Japan value share	15.4%	16.67%	12.97%	13.89%	11.78%	4.29%
Europe volume share*	19.06%	15.95%	21.6%	20.13%	11.53%	17.16%
Europe value share*	20.19%	17.67%	23.12%	20.69%	10.95%	17.39%

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

Table 2.2.2a. Beginning stage ecosystem indicator analysis for EBS Pacific cod, including indicator title and the indicator status of 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	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
Physical	Winter Spring North Pacific Index Model	neutral	*high*	neutral	neutral	*high*
	Winter Sea Ice Advance BS Satellite	**low**	neutral	neutral	neutral	neutral
	Spring Sea Ice Retreat BS Satellite	**low**	neutral	neutral	neutral	neutral
	Spring Summer Temperature Surface SEBS Satellite	**high**	**high**	neutral	neutral	neutral
	Summer Temperature Bottom SEBS Model	**high**	neutral	neutral	neutral	neutral
Lower Trophic	Spring Chlorophyll a Peak SEBS Satellite	**low**	neutral	neutral	neutral	neutral
	Summer Euphausiid Abundance EBS Survey	NA	NA	NA	neutral	NA
Upper Trophic	Summer Pacific Cod Condition Juvenile EBS Survey	neutral	NA	neutral	neutral	neutral
	Summer Pacific Cod Condition Adult EBS Survey	neutral	NA	neutral	neutral	neutral
	Summer Pacific Cod Center Gravity East EBS Model	*high*	neutral	neutral	neutral	*high*
	Summer Pacific Cod Center Gravity North EBS Model	**high**	neutral	**high**	neutral	neutral
	Summer Pacific Cod Area Occupied EBS Model	neutral	NA	neutral	neutral	neutral
	Annual Arrowtooth Biomass EBS Model	neutral	**high**	**high**	**high**	NA

Table 2.2.2b. Beginning stage socioeconomic indicator analysis for EBS Pacific cod, including indicator title and the indicator status of 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 time series mean). A gray fill and text = “NA” will appear if there were no data for that year.

Indicator category	Indicator	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
Economic	Annual Pacific Cod Real Exvessel Value EBS Fishery	neutral	neutral	low	neutral	NA
	Annual Pacific Cod Real Exvessel Price EBS Fishery	neutral	neutral	neutral	neutral	NA
	Annual Pacific Cod Real Revenue Per Unit Effort EBS Fishery	high	neutral	neutral	neutral	NA

Figures

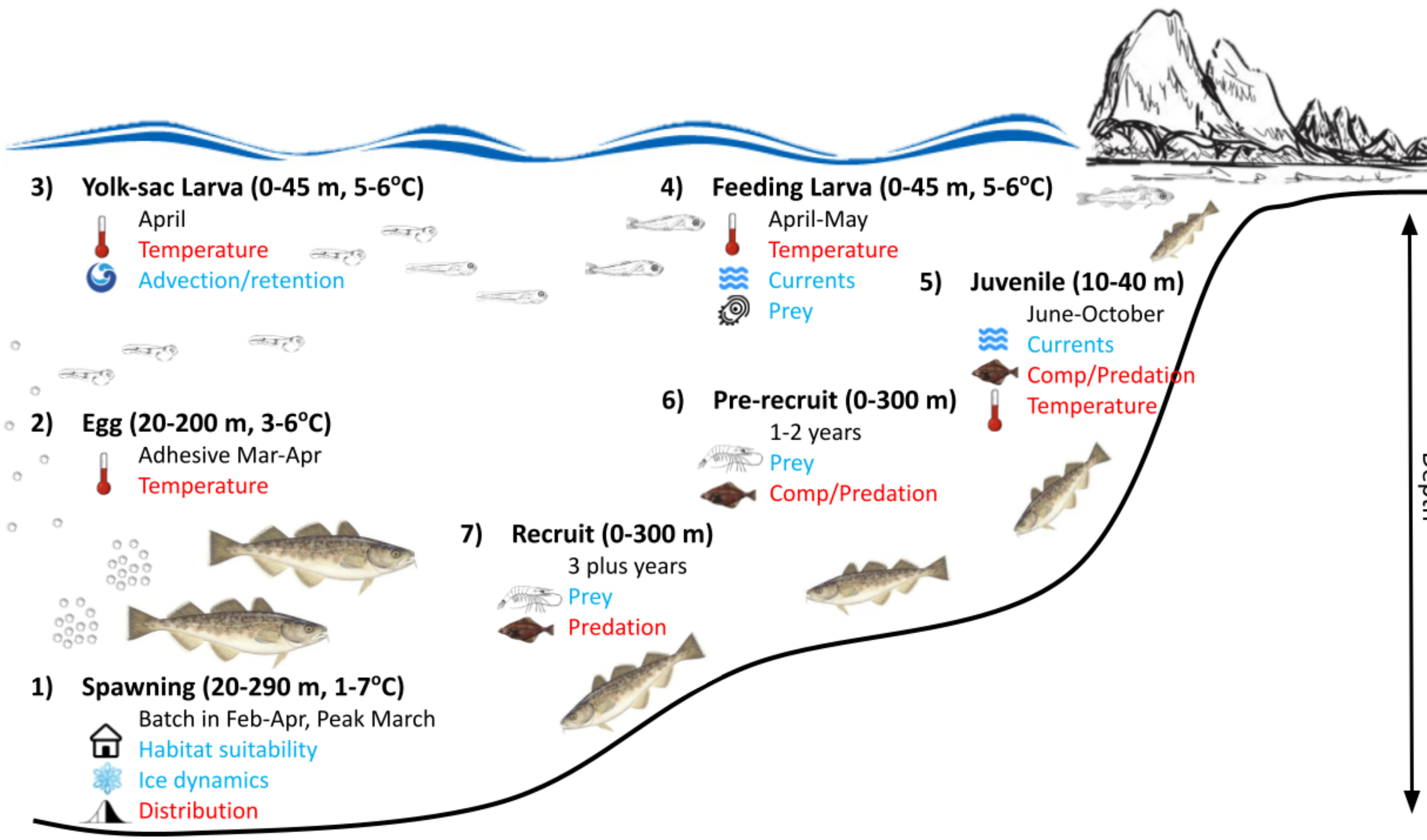

Figure 2.2.1: Life history conceptual model for EBS Pacific cod summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in the process negatively affect survival, while blue text means increases in the process positively affect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

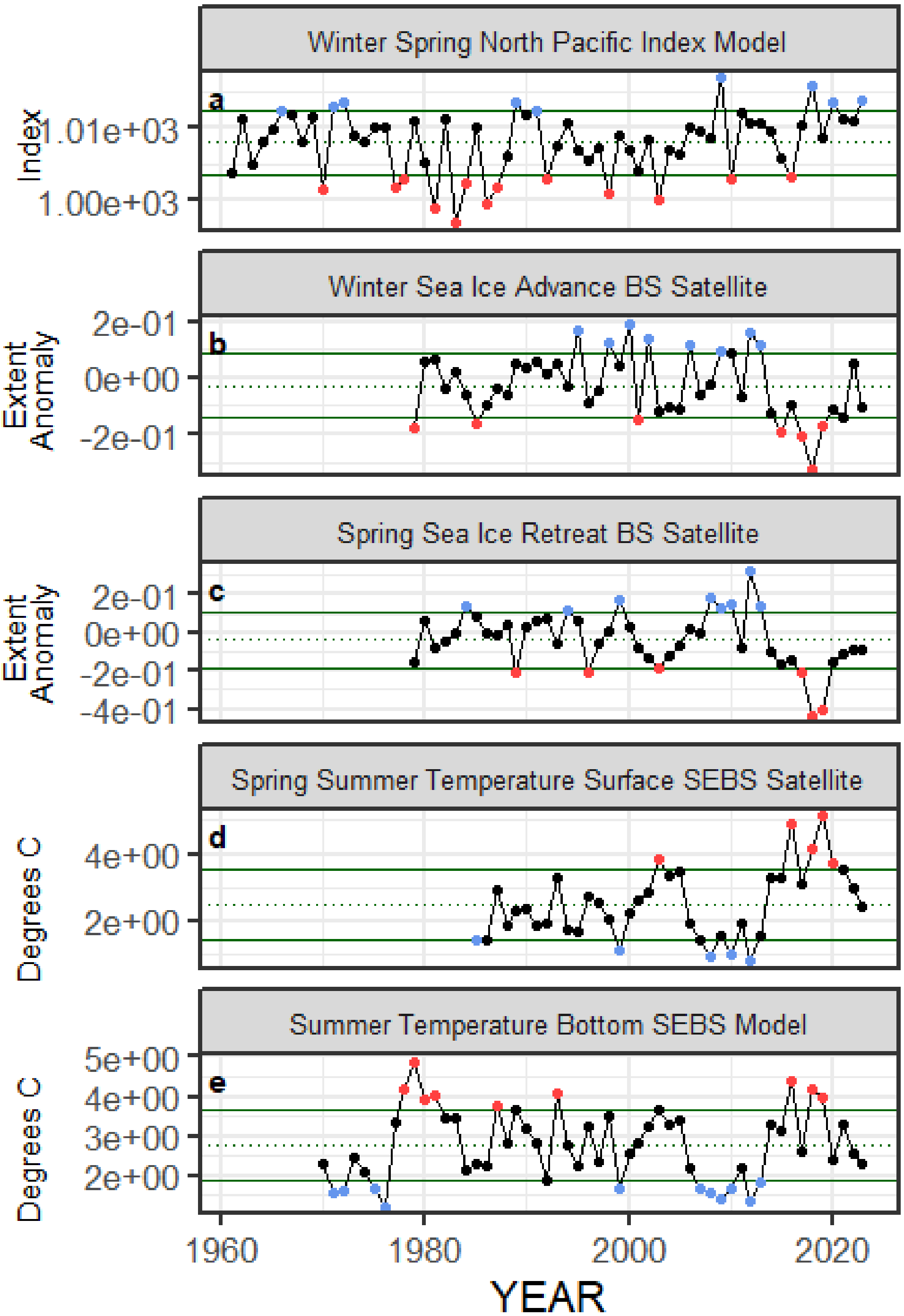

Figure 2.2.2a. Selected ecosystem indicators for EBS Pacific cod with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are 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.

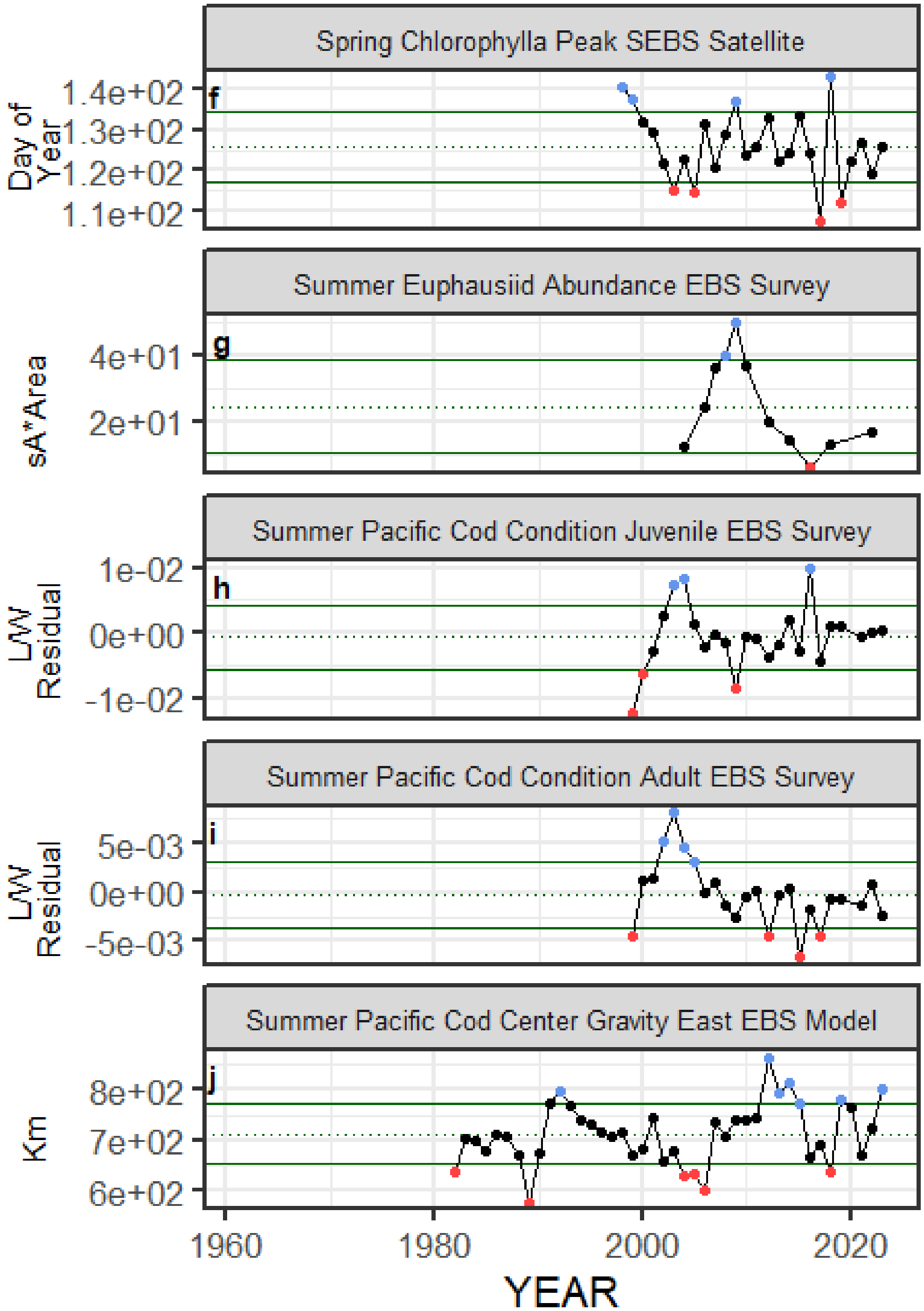

Figure 2.2.2a (cont.). Selected ecosystem indicators for EBS Pacific cod with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series 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.

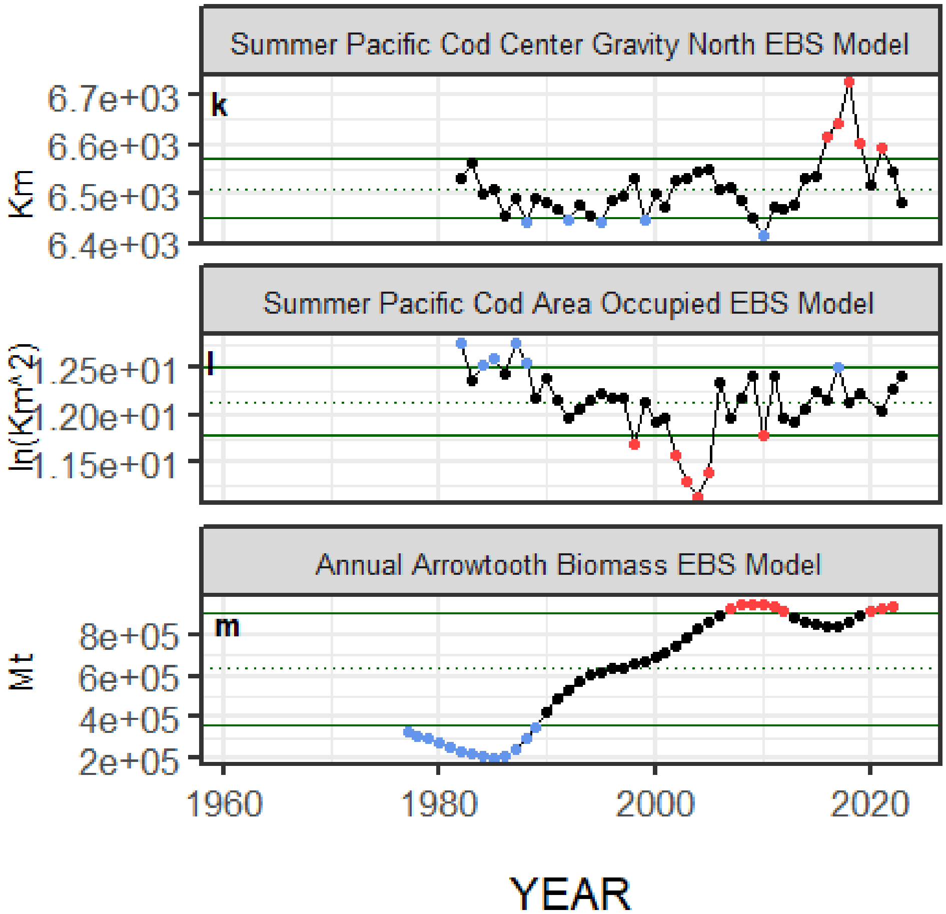

Figure 2.2.2a (cont.). Selected ecosystem indicators for EBS Pacific cod with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series 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.

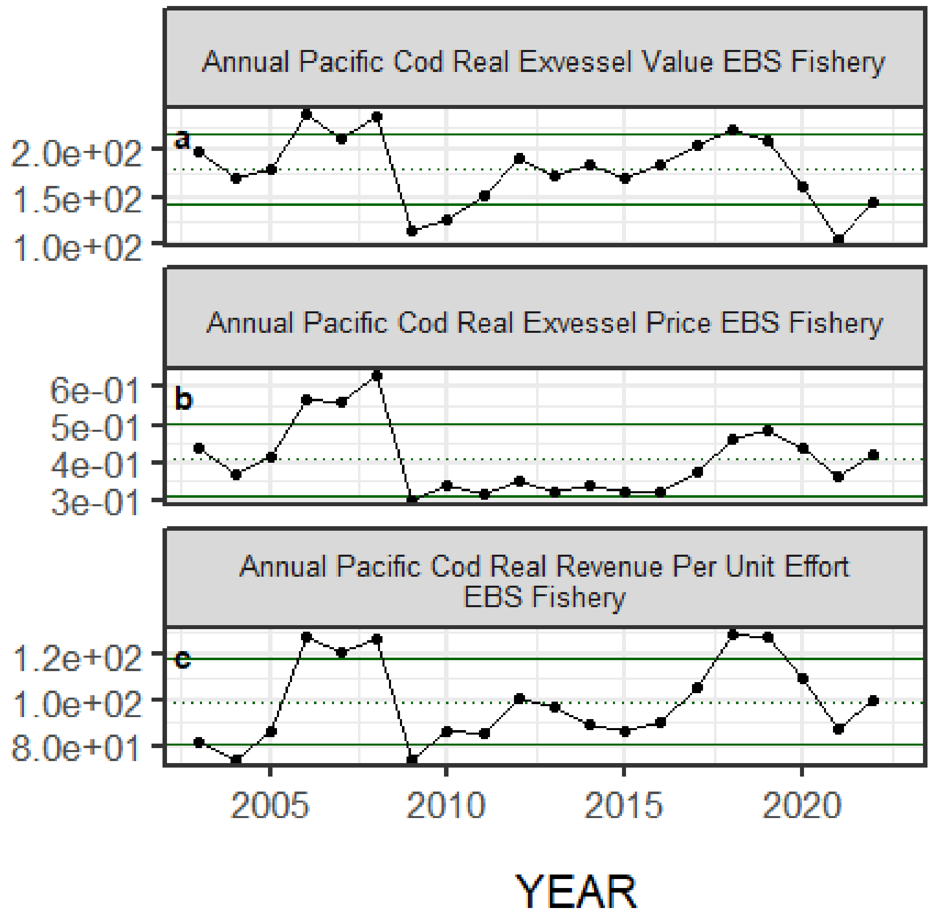

Figure 2.2.2b. Selected socioeconomic indicators for EBS Pacific cod with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

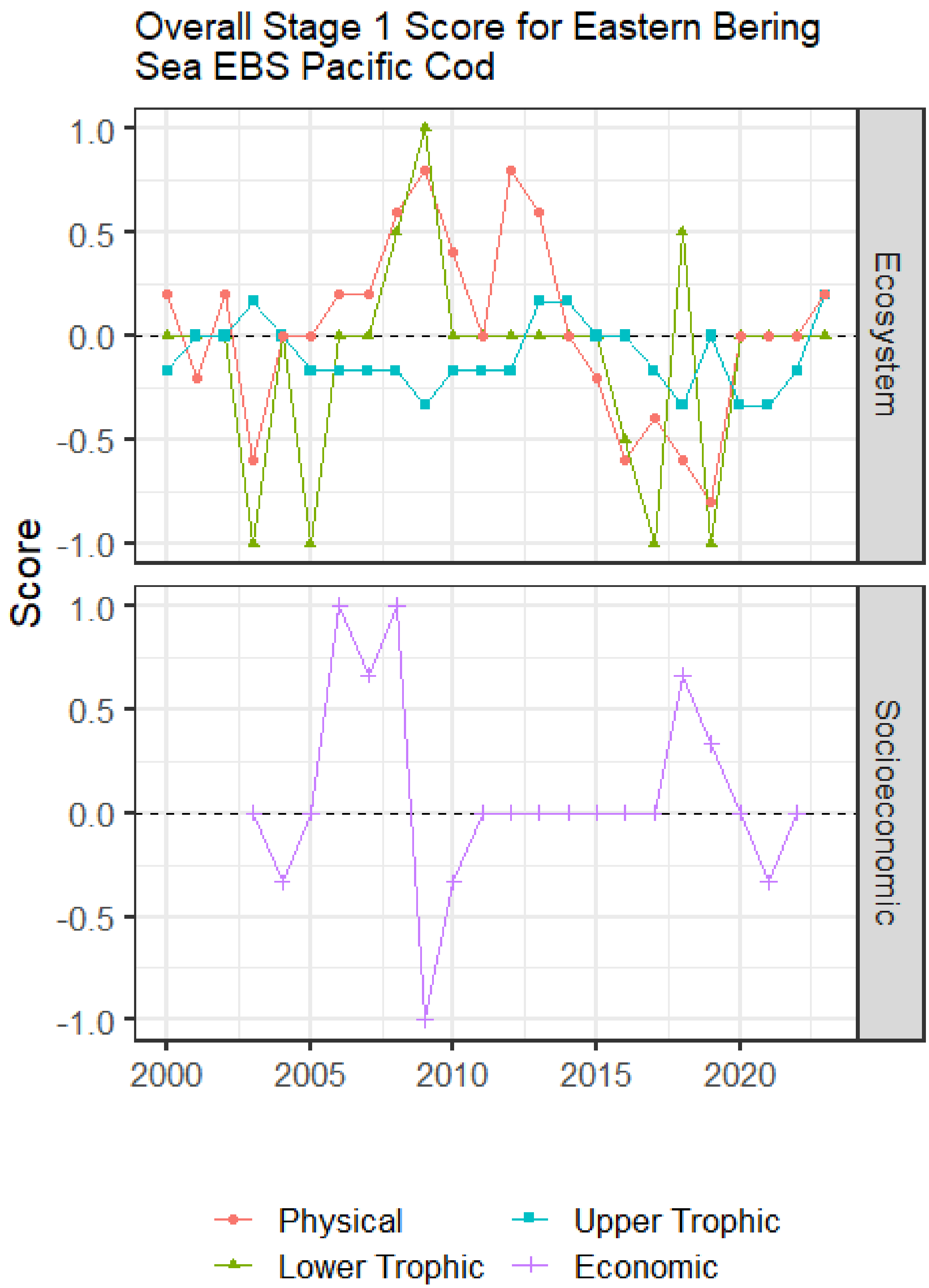

Figure 2.2.3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.

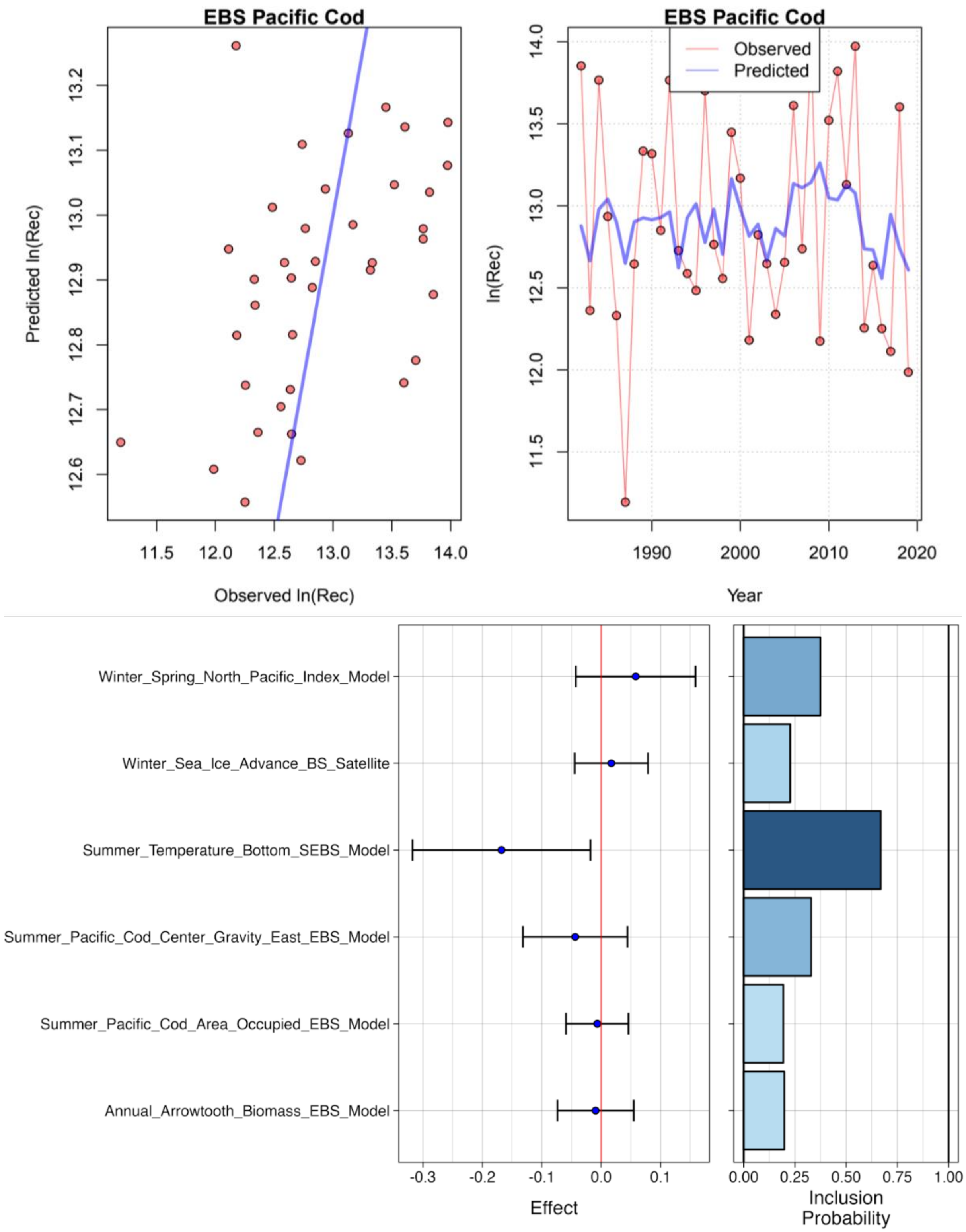

Figure 2.2.4: Bayesian adaptive sampling output showing (top graph) observed and predicted model fit and (bottom graph) the mean relationship and uncertainty (95% confidence intervals) with log EBS Pacific cod recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.

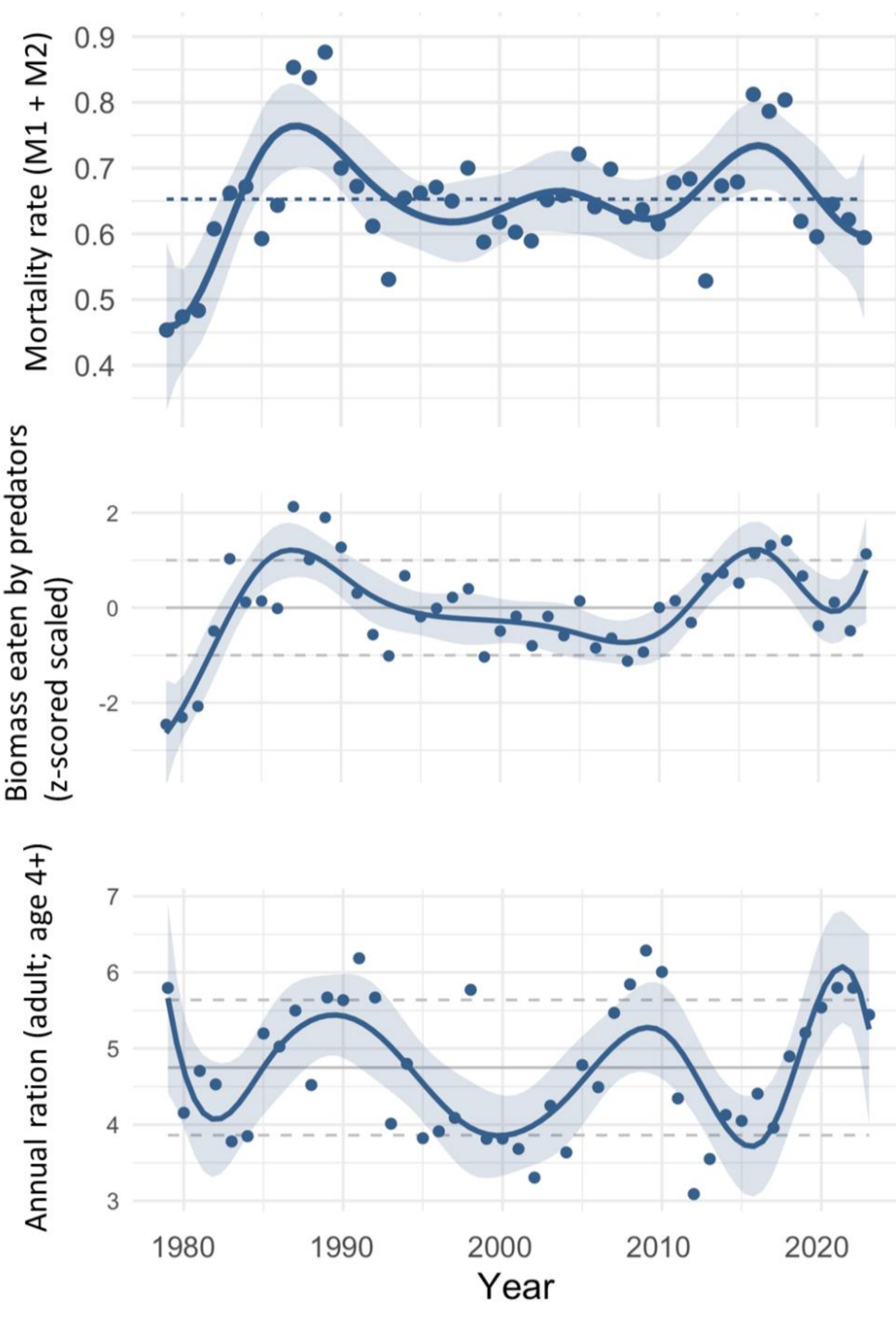

Figure 2.2.5: Results from the most recent CEATTLE model run (points) for eastern Bering Sea Pacific cod with loess polynomial smoother (solid line), top panel is annual variation in age-1 natural mortality (M1 + M2) and dashed line is the estimate from the single species model, middle panel is biomass (million mt) of Pacific cod consumed as prey across all ages by all predators annually in the model, and bottom panel is annual ration (100,000 tons consumed per year) for age 4 plus Pacific cod. Gray lines for the middle and bottom panels are the time series mean (solid) and 1 standard deviation from the mean (dashed).