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

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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 and partial ESP documents (Shotwell et al., 2019 Appendix 1A, pp. 105-151, Shotwell et al., 2020 Appendix 1A, pp. 104-135) which are available within the Gulf of Alaska (GOA) walleye pollock (pollock) stock assessment and fishery evaluation or SAFE reports for further information regarding the ecosystem and socioeconomic linkages for this stock.

Management Considerations

Summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for GOA pollock:

- Cooler below average temperatures at surface and depth, below average marine heatwave events and increased mean southwestern wind direction suggest favorable egg and larval habitat conditions, but sustained April gap winds near Kodiak may have altered advective patterns.
- Mixed lower trophic indicators (lowest chlorophyll *a* concentration of time series, later spring bloom peak, lower small copepod abundance, higher large copepod abundance, and average planktivore success) suggest adequate larval prey resources.
- Low spring larval abundance and low summer catches of young-of-year (YOY) pollock in the Shelikof survey together with low CPUE of YOY pollock in the nearshore Kodiak survey suggest a weak 2023 year class.
- Percent euphausiids in the diet of juvenile pollock on the bottom trawl survey increased slightly to just above average and condition of fall pollock in the fishery in 2022 and winter pollock in the acoustic survey in 2023 increased but were still below average.
- Center of gravity shifted to the second most southwest position in the time series in 2023 while area occupied increase to the highest value of the times series suggesting a more spread out population in more suitable habitat for GOA pollock.
- Biomass estimates of Pacific ocean perch and sablefish continue to be large with a stable but low biomass estimate of arrowtooth flounder as competitors and predators of GOA pollock.
- Fishery CPUE in the winter spring increased and remained above average in 2023 implying pollock were concentrated, so catch rates were higher and roe may be in better condition.
- Ex-vessel price increased to just above average in 2022 and roe-per-unit-catch in the fishery increased to just slightly below the long-term average in 2023.

Modeling Considerations

Summary results from the intermediate and advanced stage monitoring analyses for GOA pollock:

- Highest ranked predictor variables of GOA pollock recruitment based on the importance methods in the intermediate stage indicator analysis were the spring sea surface temperature in western, central GOA, and the fall pollock condition of adults in the fishery (inclusion probability > 0.5).
- Updated estimates from the 2023 CEATTLE model run indicate that 1) age-1 natural mortality for pollock has steadily decreased since 2005 and remains low likely due to recent declines in arrowtooth flounder, 2) total biomass consumed by modelled predators has decreased and near time-series low, and 3) ration for adult (age 4+) pollock in 2023 remains low but has increased since 2019.

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 1A.1) and economic performance (Table 1A.1). Please refer to the last full ESP document (Shotwell et al., 2019) 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 GOA pollock 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 GOA pollock socioeconomic categories, only fishery performance and 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., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Figure 1A.2a and Figure 1A.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) chlorophyll *a* concentration and 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, 2) methods for calculating the time series for spring small copepods and summer large copepods from the EcoFOCI survey were updated to better standardize across gear types and resulted in starting the time series at 1994, 3) time-series calculations for the larval catch-per-unit-effort (CPUE) estimates from the Eco FOCI survey were updated to use a model-based approach (sdmTMB; Anderson et al. 2022) instead of the previous area-weighted mean, in part to better account for variable survey coverage in recent years due to ship-time constraints, and 4) regional quotient indicators for pollock harvesting and processing revenue in the GOA 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 1A.2a.a-d)

a.) **Annual marine heatwave** cumulative index over the central GOA (contact: S. Barbeaux). Proposed sign of the relationship to recruitment is negative.

b.) **Spring** (April-May) **daily sea surface temperatures** (SST) for the western and central (combined) GOA 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.

c.) **Summer bottom temperatures** from the AFSC bottom trawl survey (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative.

d.) Mean **springtime** (April-May) **surface wind direction** from National Data Buoy Center for site B-AMAA2 located in the NE Kodiak Archipelago (contact: L. Rogers). Proposed sign of the relationship to recruitment is negative.

Lower Trophic Indicators (Figure 1A.2a.e-o)

e.) Derived **chlorophyll *a* concentrations** during spring seasonal peak (May) in the western and central GOA regions calculated from ESA GlobColour blended satellite product (contact: M. Callahan). Proposed sign of the relationship to recruitment is positive.

f.) **Peak timing of the spring bloom** averaged across individual ADF&G statistical areas in the western and central GOA region calculated from ESA GlobColour blended satellite product (contact: M. Callahan). Proposed sign of the relationship to recruitment is positive.

g.) **Spring small copepods** for larvae GOA pollock from the EcoFOCI spring survey (contact: L. Rogers). Proposed sign of the relationship to recruitment is positive.

h.) **Summer large copepods** for young-of-the-year (YOY) from the EcoFOCI summer survey (contact: L. Rogers). Proposed sign of the relationship to recruitment is positive.

i.) **Summer euphausiid abundance** from the AFSC acoustic survey for the Kodiak core survey area (contact: P. Ressler). Proposed sign of the relationship to recruitment is positive.

j.) Parakeet **auklet** (planktivores) **reproductive success at Chowiet** Island (contact: S. Zador). Proposed sign of the relationship to recruitment is positive.

k.) **Spring pollock larvae catch-per-unit-of-effort** (CPUE) from the EcoFOCI spring survey (contact: L. Rogers). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

l.) **Summer young-of-the-year** (YOY) **pollock catch-per-unit-of-effort** (CPUE) from the EcoFOCI summer survey (contact: L. Rogers). Proposed sign of the relationship to recruitment is positive.

m.) **Summer pollock condition for young-of-the-year** (YOY) from EcoFOCI summer survey (contact: L. Rogers). Proposed sign of the relationship to recruitment is positive.

n.) **Summer pollock catch-per-unit-of-effort** (CPUE) of **young-of-the-year** (YOY) from the AFSC beach seine survey in the Kodiak region (contact: B. Laurel and M. Litzow). Proposed sign of the relationship to recruitment is positive.

o.) **Pollock relative biomass of young-of-the-year** (YOY) from screening burrows of tufted puffins at Aiktak Island (contact: S. Zador). Proposed sign of the relationship to recruitment is positive.

Upper Trophic Indicators (Figure 1A.2a.p-y)

p.) **Summer pollock predation mortality for age-1** from RACE and IPHC surveys (contact: C. Barnes). Proposed sign of the relationship to recruitment is negative.

q.) Proportion-by-weight of **euphausiids in the diets** of juvenile GOA pollock from summer bottom-trawl surveys (contact: K. Aydin). Proposed sign of the relationship to recruitment is positive.

r.) **Fall pollock condition** for **adults** from the pollock fishery sampled by observers (contact: C. Monnahan). Proposed sign of the relationship to recruitment is positive and the time series is lagged by minus one year for the intermediate stage indicator analysis.

s.) **Winter pollock condition** for **adults** from the late winter AFSC acoustic survey of pre-spawning pollock in the GOA (contact: C. Monnahan). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

t.) **Summer pollock center of gravity northeastings** estimated by a spatio-temporal model using the package VAST on bottom trawl survey data (contact: Z. Oyafuso). Proposed sign of the relationship to recruitment is negative.
u.) **Summer pollock area occupied** estimated by a spatio-temporal model using the package VAST on bottom trawl survey data (contact: Z. Oyafuso). Proposed sign of the relationship to recruitment is positive.
v.) **Arrowtooth flounder total biomass** from the most recent stock assessment model (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.
w.) **Pacific ocean perch total biomass** from the most recent stock assessment model (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.
x.) **Sablefish total biomass** from the most recent stock assessment model (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.
y.) **Steller sea lion non-pup estimates** for the GOA portion of the western Distinct Population Segment (contact: K. Sweeney). Proposed sign of the relationship to recruitment is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.

Socioeconomic Indicators:

Fishery Performance Indicators (Figure 1A.2b.a-b)

a.) **Winter-spring pollock catch-per-unit-of-effort** (CPUE) from fishery observer data (contact: C. Monnahan)
b.) **Summer-fall pollock catch-per-unit-of-effort** (CPUE) from fishery observer data (contact: C. Monnahan).

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

c.) Annual real **ex-vessel price per pound** of GOA pollock from fish ticket information (contact: J. Lee).
d.) Annual **pollock roe per-unit-catch** during January to March (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 1A.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 1A.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 1A.2a,b) and evaluate each year's status in the historical indicator time series graphic (Figures 1A.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 GOA pollock stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the 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 1A.2).
- If the value is above/below the mean but below/above 1 standard deviation of the mean (solid green line in Figure 1A.2) we us the terms "above average" or "below average".
- Any value within 1 standard deviation of the mean is considered "neutral" in Table 1A.2.
- If the value is above/below 1 standard deviation of the mean (solid green line in Figure 1A.2) we us the term "high" or "low".

Overall both the physical and lower trophic indicators scored average for 2023, while the upper trophic indicators increased to above average, the fishery performance indicators were average, and the economic indicator was average (Figure 1A.3). Compared to last year's results, this is the same value for the physical and lower trophic indicators, an improvement from below average for the upper trophic indicators, and the same for the fishery performance and economic indicators. We note caution when comparing scores between odd to even years as there are many lower and upper trophic indicators missing in even years due to the off-cycle year surveys in the GOA. Also, there have been other cancellations due to COVID-19 and continuing issues with staffing of NOAA white ships since 2020 that have resulted in delayed or canceled surveys, reductions in survey sampling coverage and resolution, increased uncertainty in survey results, and increased costs/reduced efficiency for surveys. This has limited production and delivery timing of several indicators. Some fishery performance and economic indicators are 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).

For physical indicators (Table 1A.2a, Figure 1A.2a.a-d), there has been increased sea surface and bottom warming in the GOA ecosystem and the presence of a series of major marine heatwaves since 2014 (Figure 1A.2a.a-c). However, from 2020 through 2023 there were reduced temperatures both at the surface and bottom and reduced annual marine heatwave events from the previous warm stanza. Cooler temperatures tend to be associated with zooplankton communities that are dominated by larger, more lipid

rich species and lowers the susceptibility for starvation, which suggests improved conditions for egg and larval stages. The direction of the mean surface wind had shifted back toward the southwest (down Shelikof Strait) and is below average for the time series in 2023 similar to 2020 (Figure 1A.2a.d). In contrast, the surface wind trajectories for 2015 and 2016 were northwestward and westward, respectively, while the trajectory for 2013 was strongly southward. A more detailed look at 2023 reveals winds blowing offshore through April, consistent with an extended period of gap winds, followed by more typical easterly or northeasterly winds through May. When surface wind trajectories for the spring period (April-May) are toward the southwest, estimates of age-1 pollock abundance tend to increase presumably because there is more retention in favorable habitat off Kodiak Island and the Shelikof sea valley and potentially favorable conditions for survival (Wilson and Laman, 2021).

For lower trophic indicators (Table 1A.2a, Figure 1A.2a.e-o), estimates of chlorophyll *a* concentration decreased to the lowest estimate in the time series in 2023 with a concurrent late (high) peak timing of the spring bloom, which may have implications for prey availability and larval mismatch with prey (Figure 1A.2a.e-f). Spring small copepods have had elevated abundances during recent sampling, particularly during the marine heatwave of 2014-2016 and in 2019, and abundances in 2023 are lower than those observed recently (Figure 1A.2a.g). Small copepods have multiple generations per year, faster turnover rates, and metabolic rates that scale with temperature. Thus, cooler temperatures reduced the rate at which the small copepod population increased. Recent warm years had high abundances of small copepods in spring and numbers in 2023 were lower than those peaks. Late summer, large copepod abundance declined from the early 2000s until the marine heatwave of 2014-2016. In 2023, large copepod numbers were similar to recent years and slightly higher than in the marine heat wave years (Figure 1A.2a.h). Large copepod abundances are influenced by timing of the annual cohort of the dominant large species: *C. marshallae*, *N. cristatus*, and *Neocalanus* spp. The dominant large species in summer is *C. marshallae* as both other large species have likely entered diapause. Long-term variability in mesozooplankton in this region is thought to be driven by Pacific Decadal Oscillation (PDO) and El Nino-Southern Oscillation (ENSO) cycles. Zooplankton are an important prey base for larval and juvenile fishes in spring and summer. While small copepod numbers were reduced relative to recent spring values, numbers remained high indicating that there is likely a significant number of nauplii and smaller copepods available as prey for larval fishes. Both large copepod numbers and euphausiid abundances were average during the late summer relative to long-term trends. Both are principal diet items for juvenile fish and these numbers appear to indicate adequate forage (Figure 1A.2a.g-h). There were no updates for euphausiids (Figure 1A.2a.i) due to an issue with recurring radiated noise on the survey but a data processing solution is being implemented and there may be updates in the future. Reproductive success of planktivorous parakeet auklet seabirds on Chowiet Island increased to average suggesting sufficient zooplankton prey resources (Figure 1A.2a.j).

Spring pollock larval abundance remained low in 2023, similar to observations in 2021, and lower than 2019 (Figure 1A.2a.k). The EcoFOCI survey was truncated due to vessel staffing, resulting in only partial coverage of the core survey area. Hence, 2023 estimates have greater uncertainty (Rogers and Axler, 2023). Years of high abundance for the late winter to early spring shelf spawners (i.e., Pacific cod, pollock, and northern rock sole) were associated with cooler winters and enhanced alongshore winds during spring. With temperature conditions in 2023 being consistent with an “average” to "cool" climate year, we expected to observe increased abundances of pollock. The prolonged period of offshore gap winds in the area of Kodiak in April may have altered the flow of the Alaska Coastal Current and advection patterns for larvae, but we were unable to investigate whether distributions were unusual with our abbreviated survey. Ichthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. In both 2015 and 2019, low abundances of pollock and Pacific cod larvae were the first indicators of failed year-classes for those species. In 2023, abundance of pollock and Pacific cod larvae were again low, suggesting another poor year class, although abundances may have been higher outside the surveyed region. Catches of age-0 pollock were third

lowest on record, with the majority of fish found on the bank to the southwest of the Shelikof Sea Valley (Figure 1A.2a.l). No age-0 pollock were caught at over 1/3 of the stations. The spatial distribution was similar to 2019 in the areas sampled. The abundance of age-0 pollock in late summer reflects the number of surviving larvae from spawning in the spring and survival processes through the summer. This late-summer survey also provides an assessment of the abundance, size, and condition of young-of-year (YOY) pollock before entering their first winter, giving an early indicator of potential year-class strength. Low catches of young-of-year pollock, together with previously observed low larval abundance, suggest a weak 2023 year class (Rogers and Porter, 2023). There were no updates for summer pollock YOY condition (Figure 1A.2a.m). CPUE of YOY pollock in the summer nearshore surveys in Kodiak also decreased to below average in 2023 (Figure 1A.2a.n) consistent with the larvae and YOY CPUE in the Shelikof survey. There were no updates for the pollock relative biomass in Aiktak (Figure 1A.2a.o). The low abundance of gadid larvae, combined with low to average abundance of the other indicator species, suggests poor to average forage for piscivorous predators, including seabirds, who rely on larval and juvenile fish. YOY pollock are key forage fish species in the Gulf of Alaska, providing prey for seabirds, fishes, and mammals.

For upper trophic indicators (Table 1A.2a, Figure 1A.2a.p-y), there were no updates for the predation estimates on age-1 pollock (Figure 1A.2a.p). Percent of euphausiids in the diet for juveniles was slightly above average in 2023, similar to 2021 (Figure 1A.2a.q). Condition of adult pollock in the fall fishery of 2022 increased from 2021 but is still below average and subsequent condition of winter adult pollock from the acoustic survey also increased from low in 2022 to just below average in 2023, continuing the good correlation between the two indicators (Figure 1A.2a.r-s) and suggesting that prey resources have improved since last year. Center of gravity of the GOA pollock population continued decreasing in 2023 to the second most southwest position in the time series and area occupied increased to the highest value in the time series suggesting a more spread out population in more suitable habitat for GOA pollock (Figure 1A.2a.t-u). Potential competitors to GOA pollock are the recent multiple large year classes of juvenile sablefish and an increasing population of Pacific Ocean perch (POP). Major predators of pollock include arrowtooth flounder and Steller sea lions (SSL). The arrowtooth flounder and Pacific ocean perch stock assessment models were not updated in 2022 as it was an off-cycle year (Figure 1A.2a.v-w). Estimates from the 2023 bottom trawl survey for arrowtooth flounder were 5% greater than in 2021 (but below average) and for Pacific ocean perch were 8% greater than in 2021 (above average). Sablefish biomass estimates remain above average from the most recent stock assessment model and is the highest in the time series (Figure 1A.2a.x). Relative population numbers from the 2023 longline survey for sablefish were 4% greater than in 2022. There were no updates for predicted adult counts of SSL (Figure 1A.2a.y).

For fishery performance indicators (Table 1A.2b, Figure 1A.2b.a-b), the CPUE in the winter spring increased slightly in 2023 and remained above average and the summer fall CPUE also increased slightly in 2022 and remained below average. Higher fishery performance CPUE in the 1st trimester implies that the pollock were very concentrated, likely in pre-spawning aggregations, so catch rates remain above average and roe may be in better condition. CPUE for the 1st and 3rd trimesters compared to model estimates of exploitable biomass track the estimated exploitable biomass from the assessment model reasonably well.

For economic indicators (Table 1A.1a, Figure 1A.2b.c-d), ex-vessel price increased and is now slightly above average (Figure 1A.2b.c). 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 pollock products. As such, the impact of COVID-19 on prices appears relatively muted with only marginal changes in first-wholesale and export prices. Cost pressure from COVID-19 mitigation efforts likely had upstream impacts on ex-vessel prices, which

decreased significantly but appear to be on the rise in 2022. Roe per unit catch in 2023 increased from 2022 and is just slightly below average (Figure 1A.2b.d).

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used for the intermediate stage statistical test to quantify the association between hypothesized predictors and GOA pollock 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., 2019). 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 1991 through the 2019 year-class but is missing a few years (1999, 2001-2003, 2011) due to two indicators with some gaps (winter pollock condition and pollock relative biomass). We provide the relationship between the observed and predicted estimates (Figure 1A.4, top panel, left side) and the fit over time (Figure 1A.4, top panel, right side) for reference. We then provide the mean relationship between each predictor variable and log GOA pollock recruitment over time (Figure 1A.4, bottom panel, 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 1A.4, bottom panel, right side). A higher probability indicates that the variable is a better candidate predictor of GOA pollock recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process are continue to be the spring sea surface temperature in the western central GOA, and the fall pollock condition of adults in the fishery (Figure 1A.4). The sign of the relationship between the fall pollock condition indicator and recruitment is negative and contrary to what we originally proposed for this indicator. This may mean that the indicator is representing some other indirect effect of condition in the winter fishery and pollock recruitment and should be explored further prior to use within the stock assessment model.

Advanced Stage: Research Model Test

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

Another modeling effort to create a gap free estimate of predation mortality is through a multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate- Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics; Holsman et al., 2016) that has recently been developed for understanding trends in total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the GOA (Adams et al., 2022; Adams et al., 2023). Total mortality rates are based on estimates of residual mortality estimates (M1), time- and age-varying predation mortality (M2), and time- and age-varying fishing mortality (F). CEATTLE has been modified for the GOA and implemented in Template Model Builder (Kristensen et al., 2015) to allow for the fitting of multiple sources of data, time-varying selectivity, time-varying catchability, and random effects. The model is based, in part, on the parameterization and data used for the most recent stock assessment model of each species (Barbeaux et al., 2023, Monnahan et al., 2023, and Shotwell et al., 2021b). The model is fit to data from five fisheries and seven surveys, including both age and length composition assumed to come from a multinomial distribution. Model estimates of M2 are empirically driven by temperature- and bioenergetics-based consumption information and diet data from the GOA to inform predator-prey suitability. The model was fit to data from 1977 to present (Figure 1A.5, reproduced from Adams et al., 2023). Age-1 natural mortality for pollock has steadily decreased since 2005 and remains low and below the long-term mean and the value used for the single species assessment in 2023 (Figure 1A.5, top panel). Predation mortality for this model is primarily driven by arrowtooth flounder and total biomass of arrowtooth has declined in recent years (Shotwell et al., 2021b). Estimates of total biomass consumed of pollock as prey across all ages decreased in 2023 and is currently near the all-time low for the time series (Figure 1A.5, middle panel). Annual predation demand (ration) has been steadily decreasing for pollock since 2016, and remains low in 2023 (Figure 1A.5, bottom panel).

Potentially in the future, estimates of age-specific predation mortality or other high importance indicators from the Intermediate Stage analysis could be used directly within the operational stock assessment model to help explain the variability in natural mortality, growth, or recruitment events for GOA pollock.

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., 2019, 2020) and past report cards (Shotwell et al., 2021, 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 many indicators.
- Investigation of NOAA National Center for Environmental Prediction (NCEP) model-based estimates of surface wind might to extend the wind-recruitment comparison as the buoy data and the NCEP winds are correlated, but further study is needed.
- Refinements or updates to current indicators (e.g., chlorophyll *a*) that were only partially specialized for GOA pollock such as more specific phytoplankton indicators tuned to the spatial and temporal distribution of GOA pollock larvae as well as phytoplankton community structure information (e.g., hyperspectral information for size fractionation).
- Development of large-scale indicators from multiple data to understand prey trends at the spatial scale relevant to management (e.g., regional to area-wide estimates of zooplankton biomass, offshore to nearshore monitoring of pollock larvae) and align the spatial and temporal extent of

available zooplankton or other productivity indicators to the specific needs of the GOA pollock stock in the future.

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

Socioeconomic Priorities

- Reorganization of indicators by scale, structure, and dependence per December 2022 SSC request that may result in a transition of indicators currently reported and a potential shift in focus
- Re-evaluation of fishery 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 GOA pollock 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 1A.1a Pollock in the Gulf of Alaska ex-vessel market data. Total and retained catch (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), the Central Gulf's share of value, and number of trawl vessels; average and most recent five years.

	2013-2017 Average	**2018**	**2019**	**2020**	**2021**	**2022**
Total catch K mt	153.96	158.1	120.2	107.5	101.2	132.7
Retained catch K mt	152.33	155.88	118.89	106.63	99.5	131.46
Ex-vessel value M $	$37.1	$42.25	$36.12	$27.8	$27.32	$48.99
Ex-vessel price lb $	$0.11	$0.12	$0.14	$0.12	$0.12	$0.17
Central Gulf share of catch	76.74%	75.97%	73.99%	75.31%	76.62%	75.33%
Vessels #	68.6	71	62	61	59	55

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

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

	2013-2017 Average	**2018**	**2019**	**2020**	**2021**	**2022**
All Products volume K mt	61.44	69.06	51.09	39.95	31.64	41.47
All Products value M $	$101.42	$104.92	$85.87	$70.47	$68.63	$119.77
All Products price lb $	$0.75	$0.69	$0.76	$0.8	$0.98	$1.31
Head & Gut volume K mt	29.3	39.83	28.41	22.62	14.02	20.1
Head & Gut value share	33.76%	34.5%	37.95%	36.82%	21.02%	25.16%
Head & Gut price lb $	$0.53	$0.41	$0.52	$0.52	$0.47	$0.68
Fillets volume K mt	10.62	13.08	8.8	7.84	8.65	11.77
Fillets value share	28.75%	32.01%	31.34%	34.05%	42.92%	45.59%
Fillets price lb $	$1.24	$1.16	$1.39	$1.39	$1.54	$2.1
Surimi volume K mt	11.92	9.77	6.95	5.43	5.93	6.48
Surimi value share	23.34%	19.76%	19.28%	18.15%	24.4%	18.6%
Surimi price lb $	$0.9	$0.96	$1.08	$1.07	$1.28	$1.56
Roe volume K mt	2.09	2.39	1.89	1.55	1.03	1.34
Roe value share	8.64%	9.21%	6.87%	5.34%	6.19%	7.26%
Roe price lb $	$1.9	$1.83	$1.42	$1.1	$1.88	$2.94

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

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

	2013-2017 Average	**2018**	**2019**	**2020**	**2021**	**2022**
Global Pollock Catch K mt	3366.12	3395.71	3494.66	3544.26	3483.96	-
U.S. Share of Global Catch	44%	45%	44%	42%	42%	-
Russian Share of global catch	49%	49%	50%	52%	50%	-
GOA share of global	4.57%	4.66%	3.44%	3.03%	2.9%	-
Export volume K mt	382.15	415.21	380.06	323.49	311.58	273.36
Export value M US$	$1017.21	$1129.14	$1119.9	$941.88	$899.3	$884.04
Export price lb US$	$1.21	$1.23	$1.34	$1.32	$1.31	$1.47
Import value M US$	$119.03	$78.05	$123.17	$99.84	$96.07	$140.93
Net Exports	$898.17	$1051.09	$996.73	$842.04	$803.23	$743.11
Japan volume share	21.45%	21.87%	22.85%	19.33%	21.02%	21.23%
Japan value share	21.55%	25.6%	23.88%	20.17%	21.1%	20.09%
China volume share	13.77%	13.64%	10.14%	9.68%	6.77%	11.65%
China value share	11.35%	9.88%	6.69%	6.45%	5.3%	7.49%
Europe* volume share	35.95%	32.93%	35.15%	36.98%	32.68%	31.48%
Europe* value share	36.31%	33.35%	36.86%	39.42%	36.3%	35.37%
Meat Volume Share	50.48%	49.91%	47.07%	45.77%	41.11%	42.69%
Meat Value share	48.33%	44.64%	44.34%	44.02%	40.79%	42.56%
Surimi Volume Share	44.83%	44.76%	45.82%	46.96%	53.8%	52.18%
Surimi Value share	39.04%	42.36%	42.58%	42.22%	49.39%	49.01%
Roe Volume Share	4.69%	5.33%	7.11%	7.27%	5.09%	5.13%
Roe Value share	12.62%	13%	13.09%	13.77%	9.82%	8.43%

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

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

Table 1A.2a. Beginning stage ecosystem indicator analysis for GOA pollock, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term 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.

Category	Indicator	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
Physical	Annual Heatwave GOA Model	**high**	neutral	neutral	neutral	neutral
	Spring Temperature Surface WCGOA Satellite	**high**	neutral	neutral	neutral	neutral
	Summer Temperature Bottom GOA Survey	**high**	NA	neutral	NA	neutral
	Spring Wind Direction Kodiak Buoy	neutral	neutral	neutral	neutral	neutral
Lower Trophic	Spring Chlorophylla Biomass WCGOA Satellite	**low**	neutral	neutral	neutral	**low**
	Spring Chlorophylla Peak WCGOA Satellite	*high*	neutral	neutral	neutral	*high*
	Spring Small Copepod Abundance Shelikof Survey	*high*	NA	neutral	NA	neutral
	Summer Large Copepod Abundance Shelikof Survey	neutral	NA	NA	NA	neutral
	Summer Euphausiid Abundance Kodiak Survey	neutral	NA	NA	NA	NA
	Annual Auklet Reproductive Success Chowiet Survey	neutral	NA	neutral	neutral	neutral
	Spring Pollock CPUE Larvae Shelikof Survey	neutral	NA	neutral	NA	neutral
	Summer Pollock CPUE YOY Shelikof Survey	neutral	NA	NA	NA	neutral
	Summer Pollock Condition YOY Shelikof Survey	**low**	NA	NA	NA	NA
	Summer Pollock CPUE YOY Nearshore Kodiak Survey	neutral	neutral	neutral	neutral	neutral

Category	Indicator	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
	Annual Pollock Relative Biomass Aiktak Survey	neutral	NA	NA	NA	NA
Upper Trophic	Summer Pollock MT Consumed Age1 GOA Model	neutral	NA	neutral	NA	NA
	Summer Pollock Euphausiid Diet Juvenile GOA Survey	*high*	NA	neutral	NA	neutral
	Fall Pollock Condition Adult GOA Fishery	neutral	neutral	neutral	neutral	NA
	Winter Pollock Condition Adult GOA Survey	neutral	neutral	neutral	**low**	neutral
	Summer Pollock Center Gravity Northeast WCGOA Model	neutral	NA	neutral	NA	*low*
	Summer Pollock Area Occupied WCGOA Model	neutral	NA	neutral	NA	*high*
	Annual Arrowtooth Biomass GOA Model	neutral	*low*	*low*	NA	NA
	Annual Pacific Ocean Perch Biomass GOA Model	**high**	**high**	**high**	NA	NA
	Annual Sablefish Biomass GOA Model	neutral	**high**	**high**	**high**	NA
	Annual Steller Sea Lion Adult GOA Survey	neutral	neutral	neutral	NA	NA

Table 1A.2b: Beginning stage socioeconomic indicator analysis for GOA pollock, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term mean). A gray fill and text = "NA" will appear if there were no data for that year.

Category	**Indicator**	**2019 Status**	**2020 Status**	**2021 Status**	**2022 Status**	**2023 Status**
Fishery Performance	Winter Spring Pollock CPUE Adult GOA Fishery	high	neutral	high	neutral	neutral
	Summer Fall Pollock CPUE Adult GOA Fishery	neutral	neutral	neutral	neutral	NA
Economic	Annual Pollock Real Ex-vessel Price Fishery	neutral	neutral	neutral	neutral	NA
	Winter Spring Pollock Roe Per Unit Catch Fishery	neutral	neutral	low	neutral	neutral

Figures

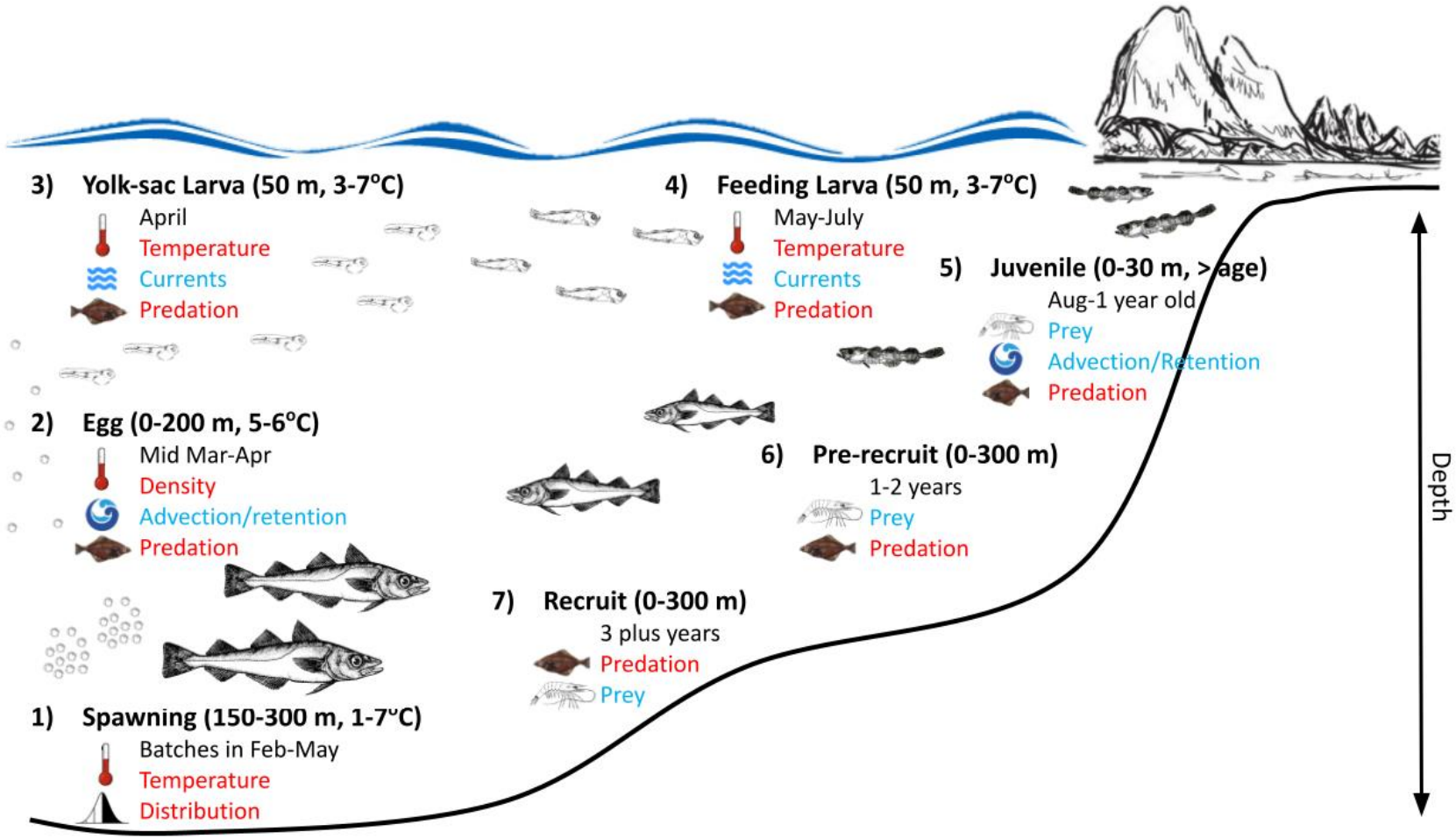

Figure 1A.1: Life history conceptual model for GOA pollock summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text indicates increases in the process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

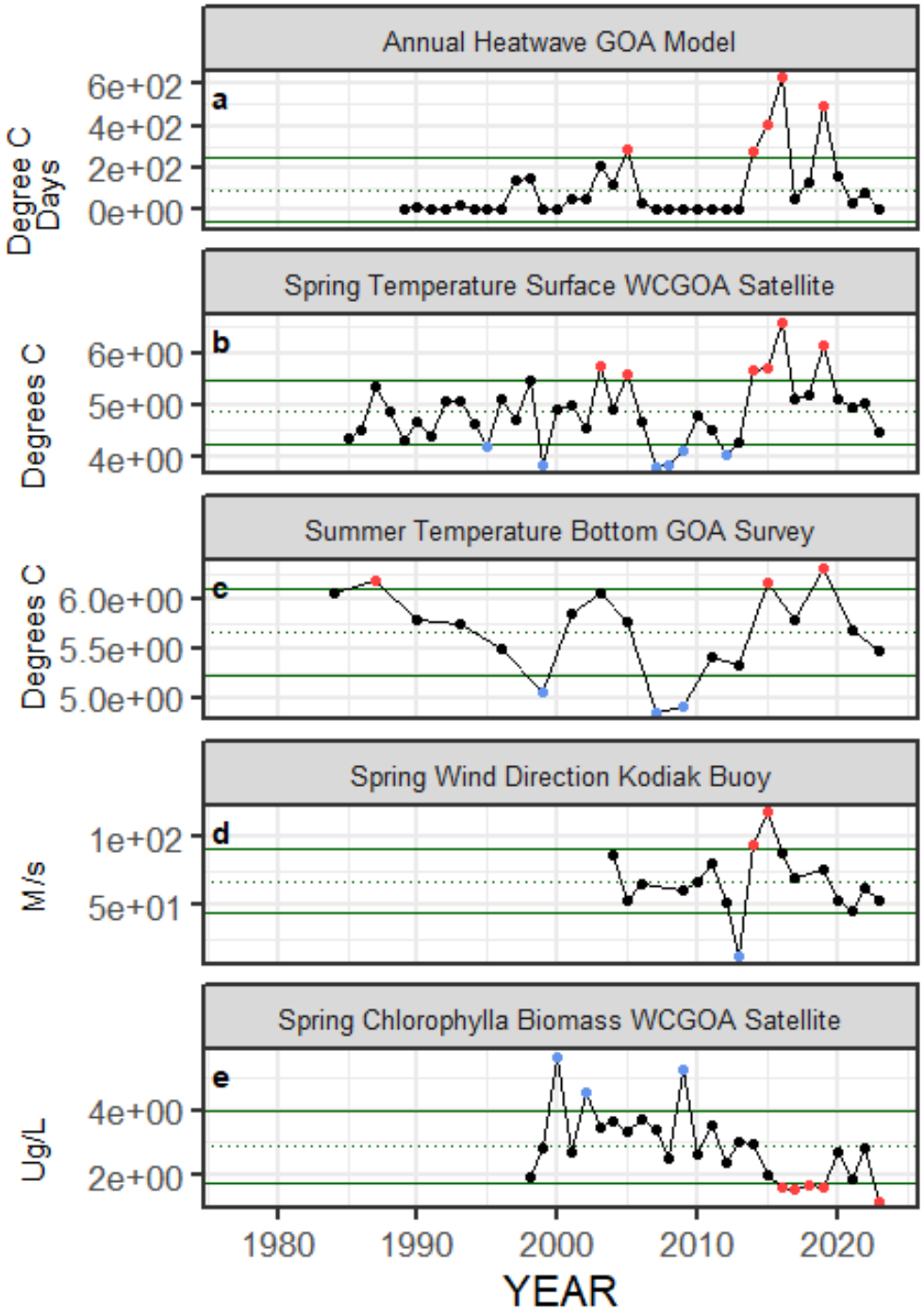

Figure 1A.2a. Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored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

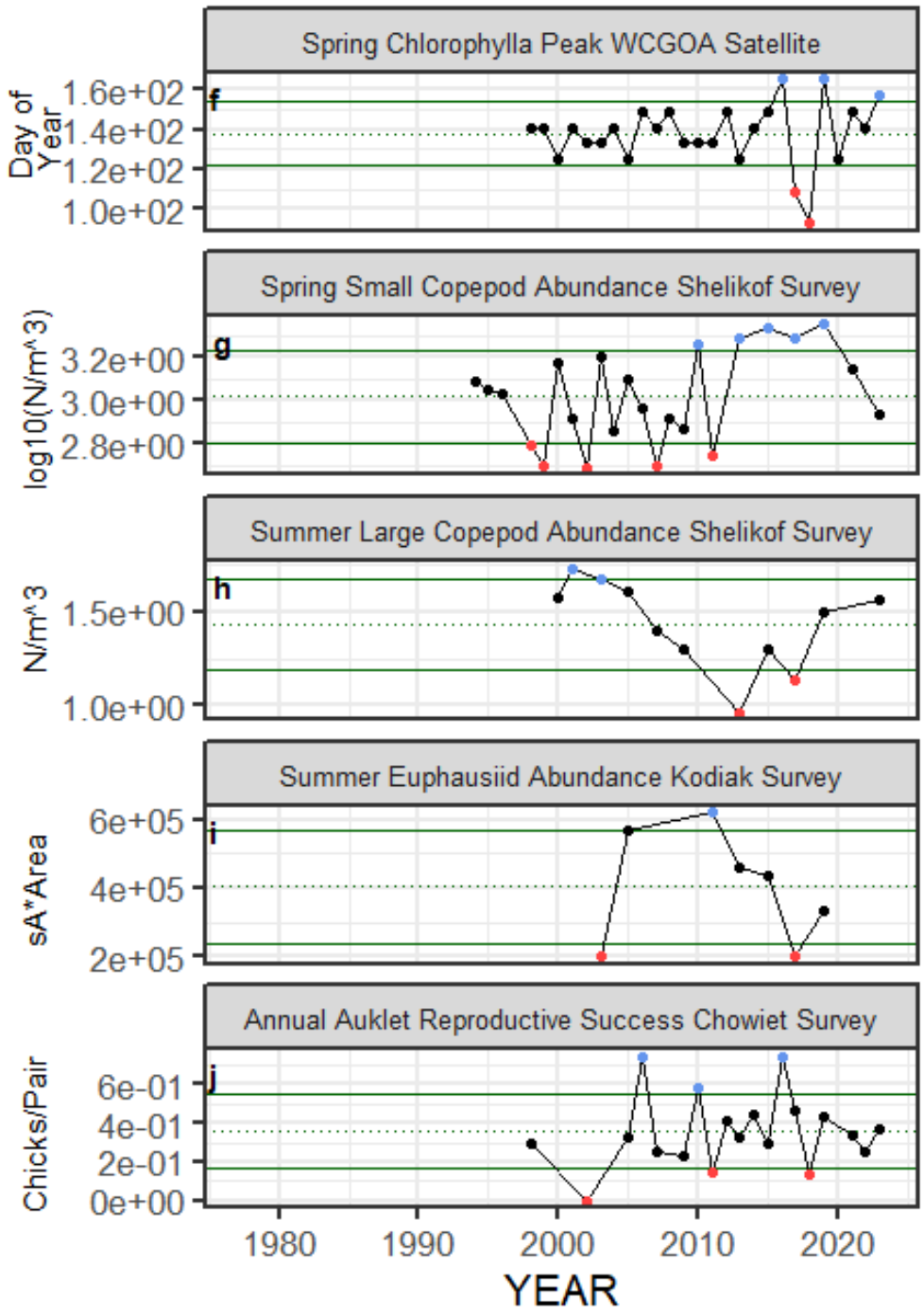

Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are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

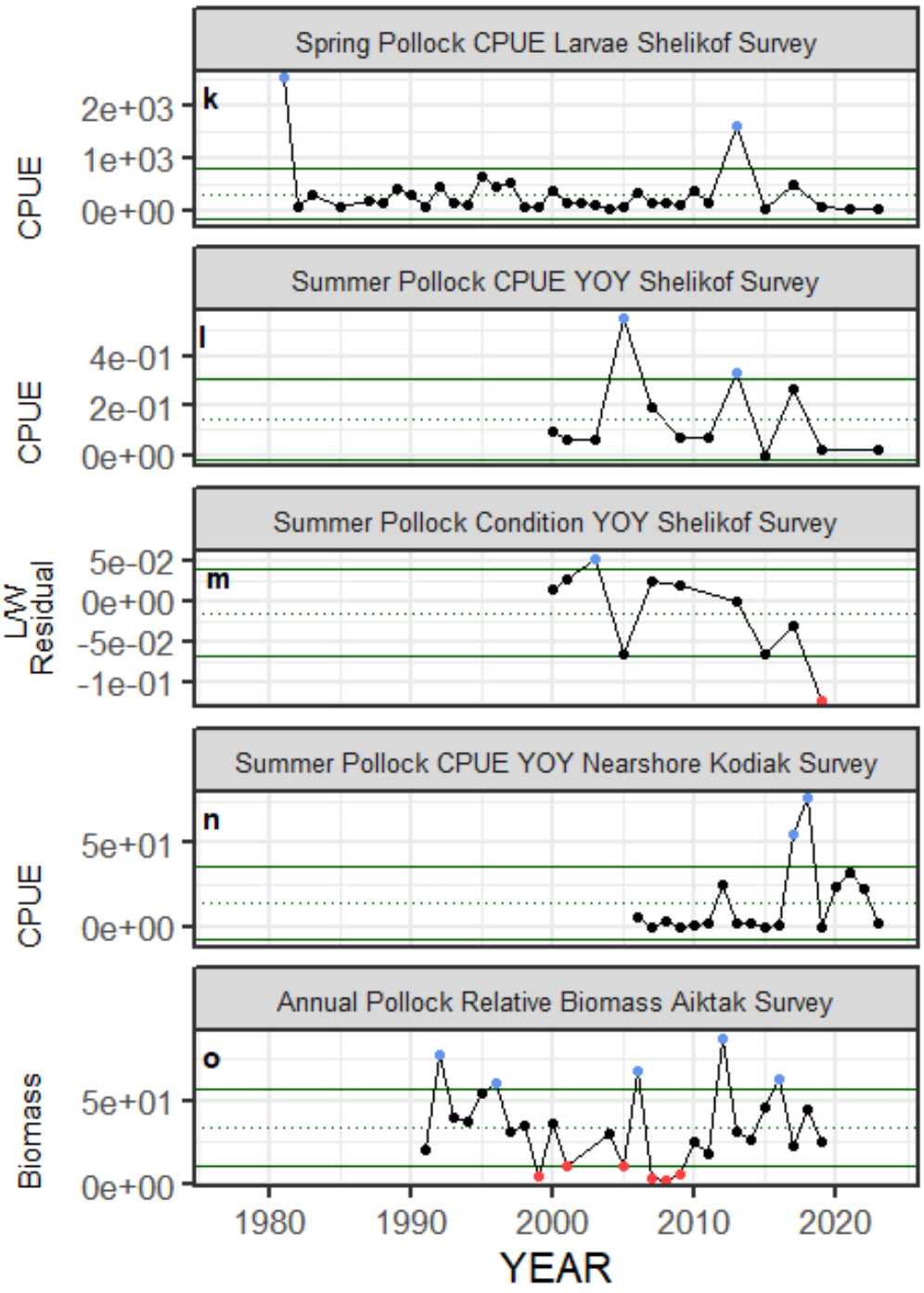

Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are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

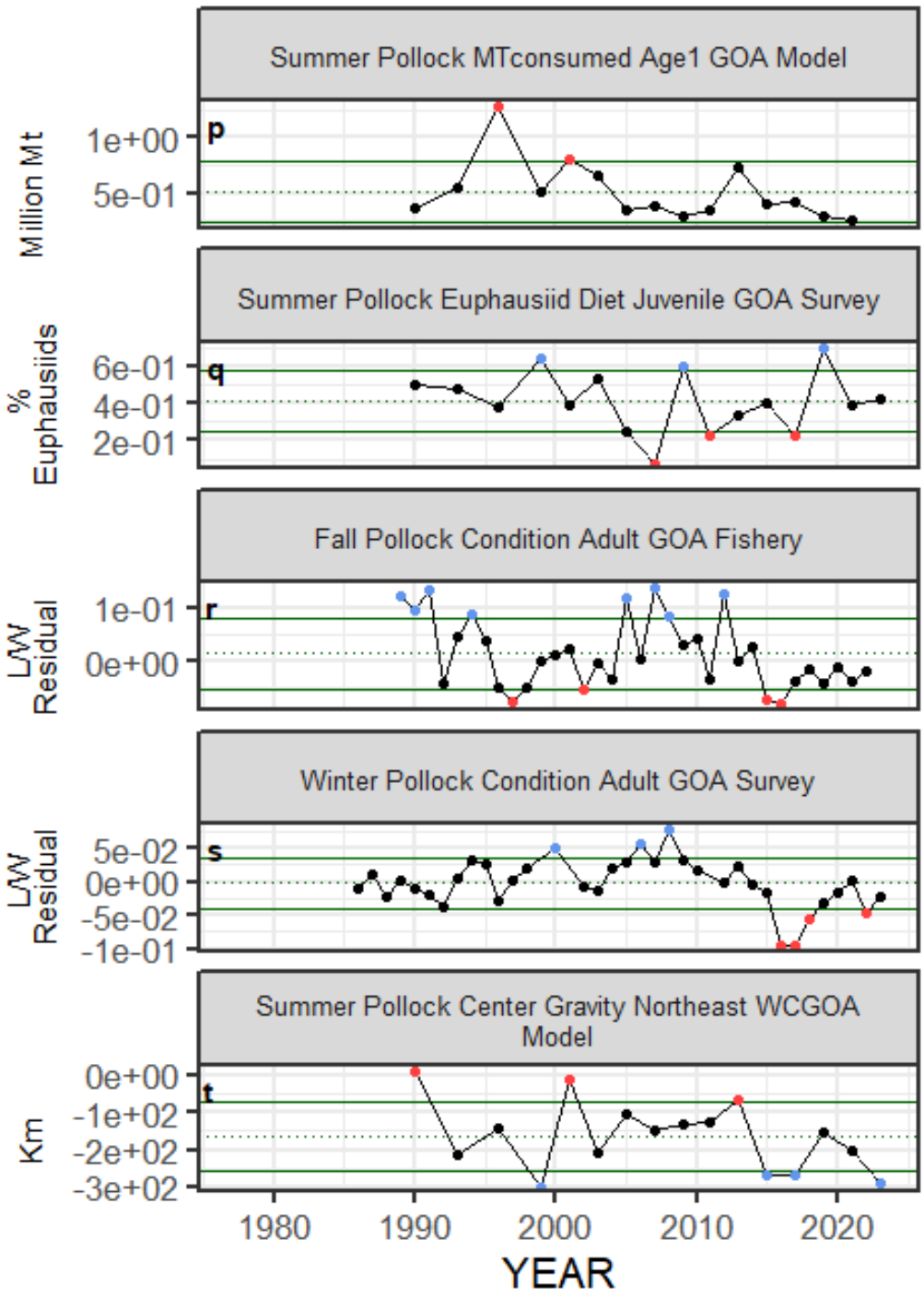

Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are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

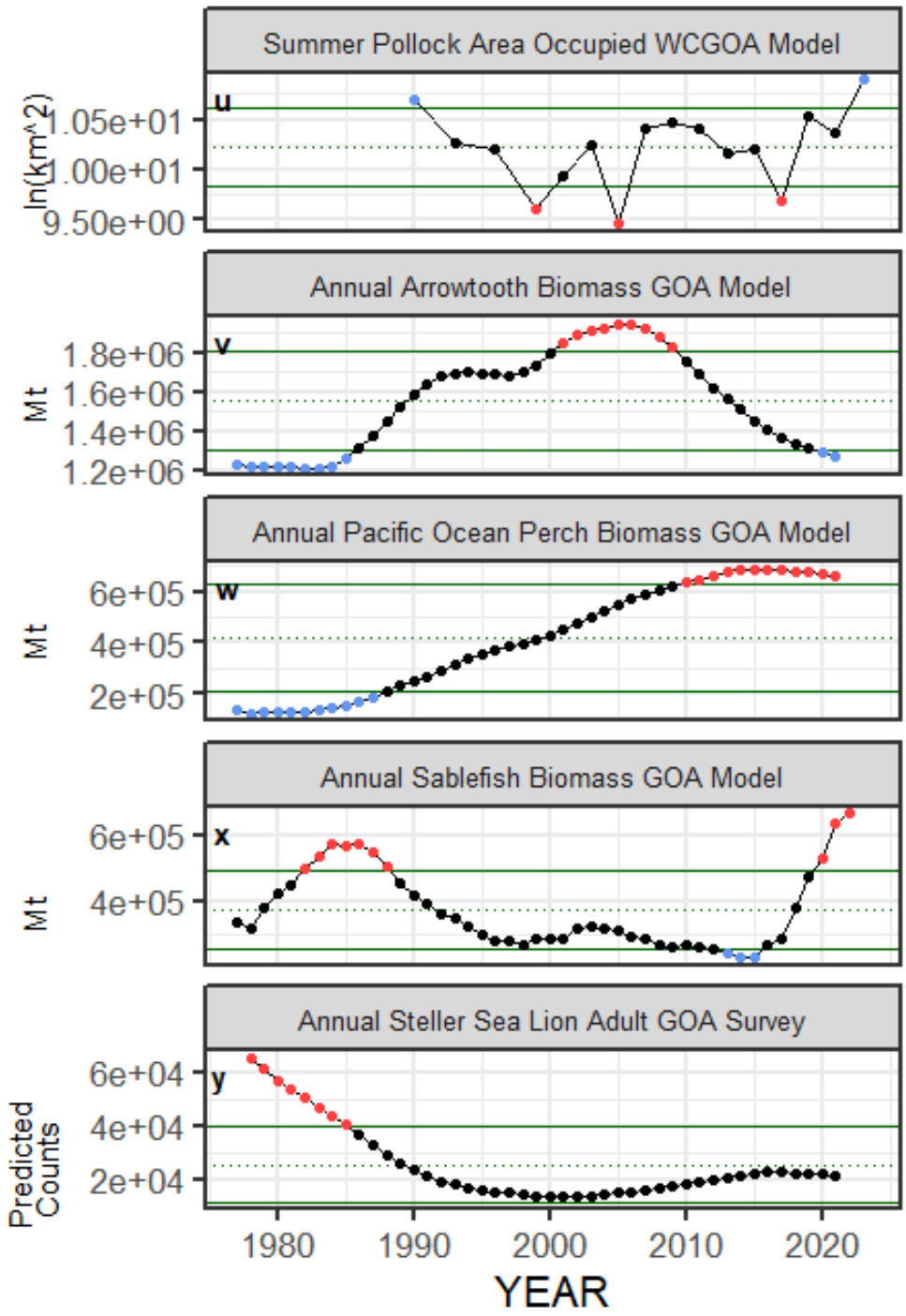

Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are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

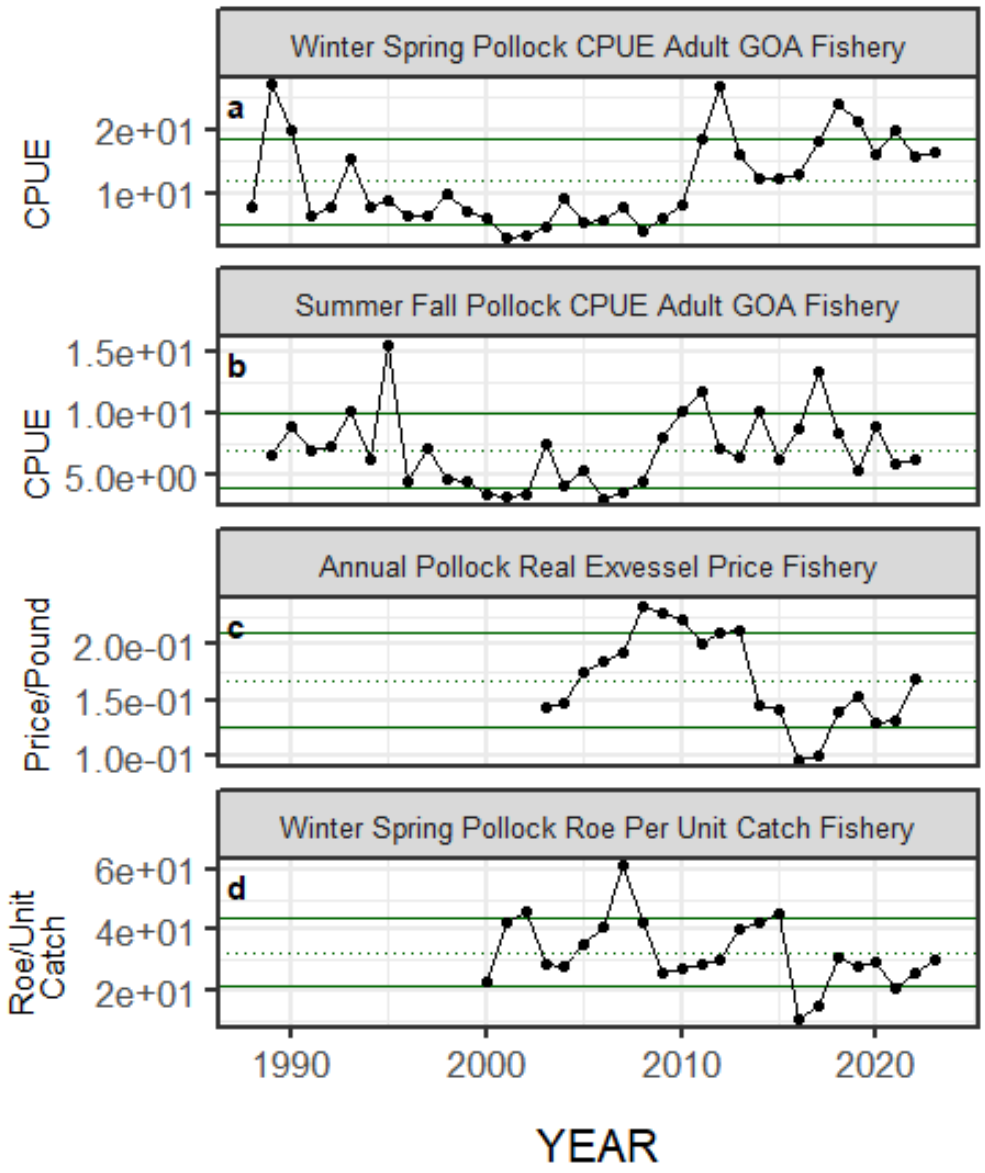

Figure 1A.2b. Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

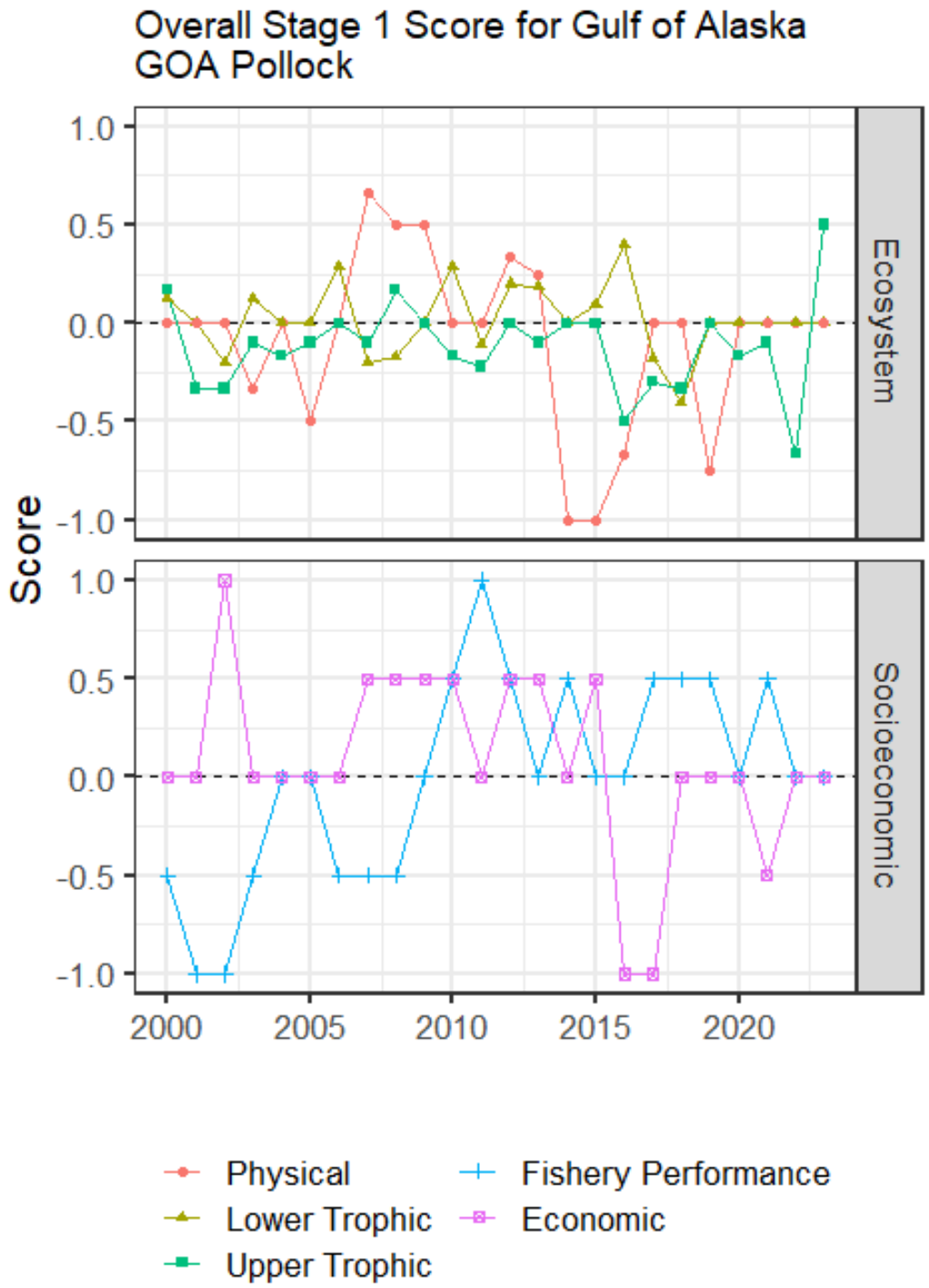

Figure 1A.3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.

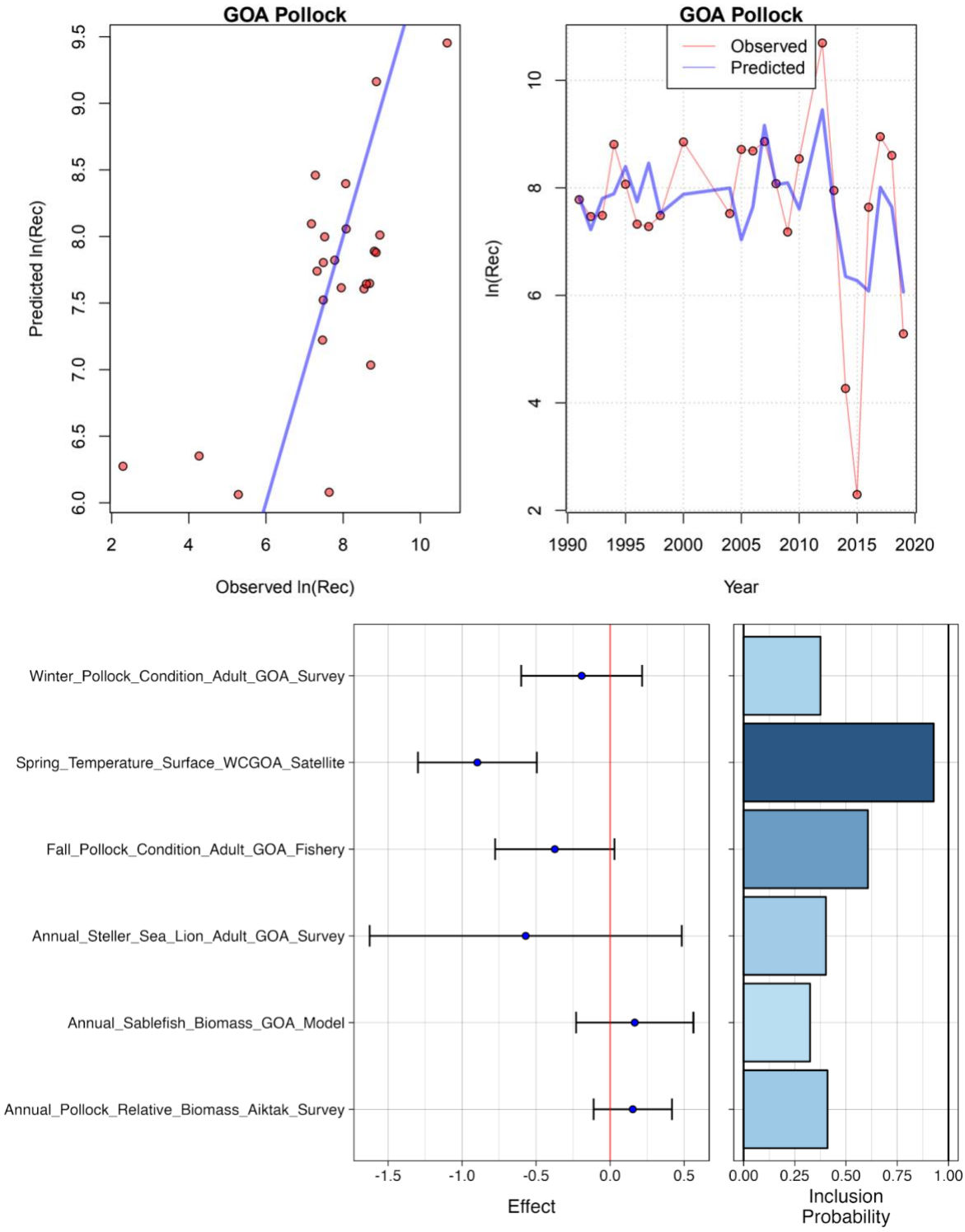

Figure 1A.4: Bayesian adaptive sampling output showing (top graph) observed and predicted model fit and (bottom graph) the mean relationship and uncertainty (95% confidence intervals) with log GOA pollock recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.

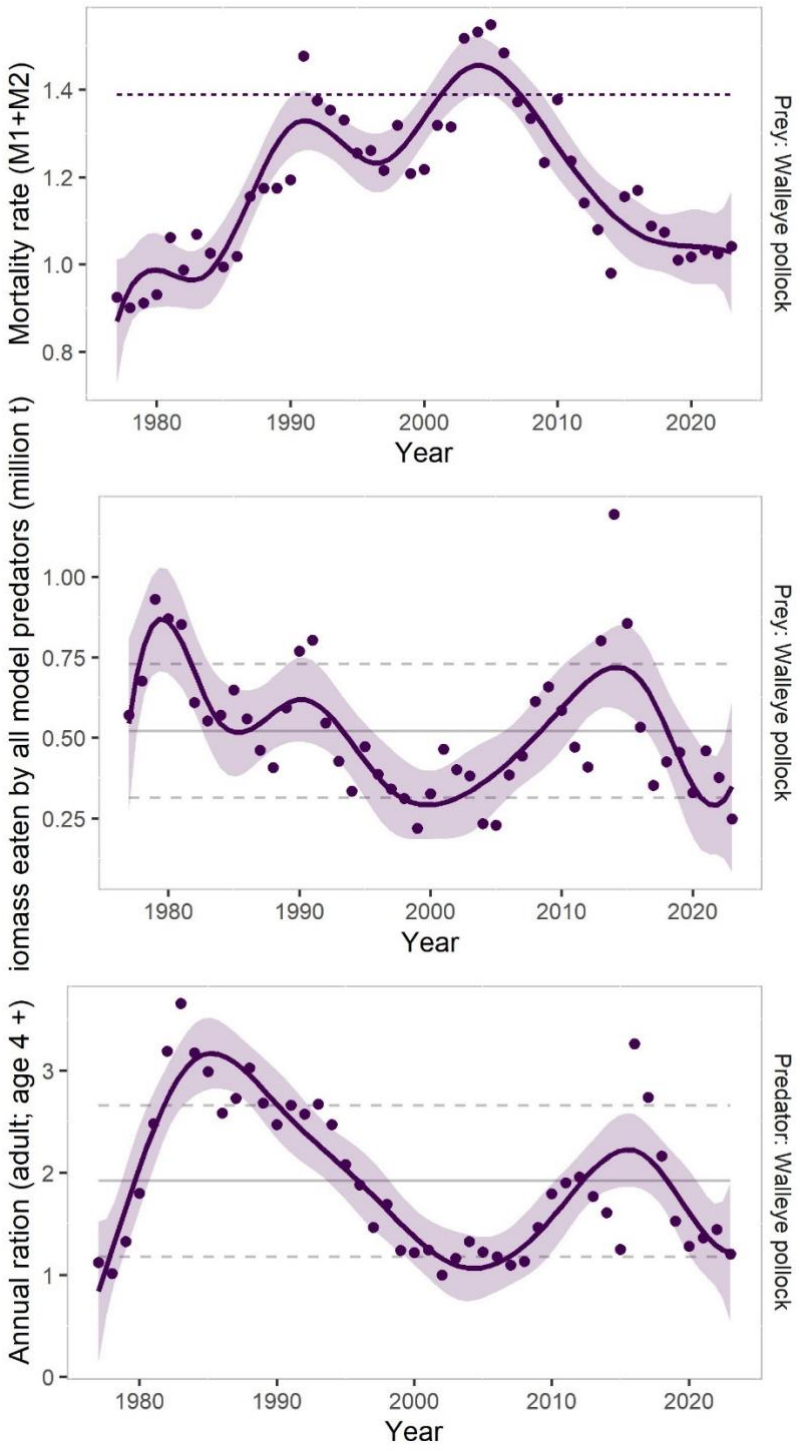

Figure 1A.5: Results from the most recent CEATTLE model run (points) for Gulf of Alaska pollock with loess polynomial smoother (solid line), top panel is annual variation in age-1 natural mortality (M1 + M2) and dashed line is the estimate from the single species model, middle panel is biomass (million mt) of pollock consumed as prey across all ages annually by all predators in the model, and bottom panel is annual ration (100,000 tons consumed per year) for age 4 plus pollock. Gray lines for the middle and bottom panel are the time series mean (solid) and 1 standard deviation from the mean (dashed).