Appendix E. Draft Ecosystem and Socioeconomic Profile of the Tanner crab stock in the Eastern Bering Sea

Shannon Hennessey (Editor)

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With Contributions from:

ESP Team: Erin Fedewa, Brian Garber-Yonts, Mike Litzow, Kalei Shotwell, and Buck Stockhausen

ESP Data: Kerim Aydin, Matt Callahan, Ben Daly, Jean Lee, Jens Nielsen, and Jon Richar

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Executive Summary

The ecosystem and socioeconomic profile (ESP), is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators. It also communicates linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., 2023). 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.

National initiatives and North Pacific Fishery Management Council (NPFMC) Plan Team and Scientific and Statistical Committee (SSC) recommendations suggest a high priority for conducting an ESP for the EBS Tanner crab stock. In addition, annual guidelines for the Alaska Fisheries Science Center (AFSC) support research that improves our understanding of environmental forcing of ecosystem processes with a focus on variables that can provide direct input into or improve stock assessment and management. The EBS Tanner crab ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for EBS Tanner crab, and may be considered a proving ground for potential use in the main stock assessment.

We use information from a variety of data streams available for the EBS Tanner crab stock and present results of applying the ESP process through an indicator synthesis and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic processes for EBS Tanner crab by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the indicator synthesis and assessment are summarized below as management and modeling considerations that can be used for evaluating concerns in the main stock assessment or other management decisions.

Management Considerations

The following are summary considerations from the ecosystem and socioeconomic indicators evaluated for EBS Tanner crab:

Acceptable Biological Catch (ABC) Information:

- Chlorophyll-*a* concentration remains high in the mid-outer shelf of the EBS, coinciding with a decline in the winter Aleutian Low - Beaufort Sea Anticyclone and surface temperature after peaks in 2017-2020. This suggests a more pronounced spring bloom and an increase in large cell plankton like diatoms, which are a critical food source for crab larvae and key benthic production for juveniles.
- Juvenile Tanner crab temperature occupied, encompassing bottom temperature, cold pool extent, as well as ecological interactions, remains average relative to the 42-year mean (2.9°C) following the 2018-2019 heat wave.
- Visual prevalence of bitter crab disease increased dramatically in 2019, and has declined in 2024 following a peak again in 2022.
- Benthic predator density in core Tanner crab habitats reached all-time lows during the 2018-2021 marine heatwave, but density has increased annually since 2021. This, coupled with increasing Pacific cod consumption on juvenile Tanner crab, suggests increased predator-prey interactions and reduced survival of juvenile cohorts.
- Benthic invertebrate densities have remained above average since a peak in 2017, which suggests higher prey availability for Tanner crab juveniles and adults.
- Despite lower abundance of mature male Tanner crab from 2021- 2023, mature male spatial extent is at an all-time high and centroids of abundance have shifted northwest since 2023. Increased utilization of northern outer shelf habitats may increase competitive interactions with snow crab.

- Male size at terminal molt estimates were characterized as the smallest mean sizes in the time series, but 2024 rebounded to just below average. This recent trend is similarly reflected in the mature female Tanner crab reproductive potential, with a record low proportion of females with full clutches in 2023. Annual female size at maturity has also decreased, which suggests a decline in stock reproductive output.

Total Allowable Catch (TAC) Information:

- There are no socioeconomic indicator highlights for consideration at this time

Modeling Considerations

The following are the summary results from the most recent intermediate and advanced stage ecosystem monitoring analyses for EBS Tanner crab:

- The highest ranked predictor for the recruitment regression model was chlorophyll-*a* concentration. There were four other indicators with inclusion probabilities > 0.5: juvenile Tanner crab temperature occupied, the Aleutian Low - Beaufort Sea Anticyclone, Pacific cod consumption, and small Tanner crab disease prevalence. However, the latter two indicators had nonsignificant effects on recruitment.
- Overall, the intermediate stage monitoring analyses explained a large amount of variation in Tanner crab recruitment using survey design-based estimates ($R^2 = 0.90$). Future efforts should explore the exclusion of indicators with short time series as well as other modeling frameworks.

Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating it with the stock assessment. A consistent approach has been lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. This new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process (Shotwell et al. 2023). The ESP uses data collected from a variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Sigler et al., 2017; Lynch et al., 2018) and recommended by the NPFMC groundfish and crab Plan Teams and the Scientific and Statistical Committee (SSC).

This ESP for EBS Tanner crab (*Chionoecetes bairdi*) follows the template for ESPs (Shotwell et al. 2023) and replaces the previous ecosystem considerations section in the main EBS Tanner crab stock assessment and fishery evaluation (SAFE) report. Information from the original ecosystem considerations section may be found in Stockhausen, 2024.

The ESP process consists of the following four steps:

1. Evaluate national initiative and stock assessment classification scores (Lynch et al., 2018) along with regional research priorities to assess the priority and goals for conducting an ESP.
2. Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.
3. Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.
4. Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

Justification

An ESP was recommended for EBS Tanner crab by the Crab Plan Team (CPT) in January 2024 (CPT Jan 2024) and was reconfirmed in May 2024 (CPT May 2024). The national initiative scores and AFSC research priorities also support conducting an ESP for the EBS Tanner crab stock, and AFSC research priorities support studies that improve our understanding of environmental forcing of ecosystem processes with focus on variables that provide direct input into stock assessment and management.

Data

Data used to generate ecosystem metrics and indicators for the EBS Tanner crab ESP were collected from a variety of laboratory studies, remote sensing databases, fisheries surveys, regional reports, and fishery observer data collections (Table E.1). Results from laboratory studies were specifically used to inform metrics and indicators relating to thermal tolerances, phenology, and energetics across EBS Tanner crab life history stages (Table E.2a). Larval indicator development utilized blended satellite data products from NOAA, NASA, and ESA. Data for late-juvenile through adult EBS Tanner crab stages were derived from the annual NOAA eastern Bering Sea bottom trawl survey and fishery observer data collected during the EBS Tanner crab fishery. Data from the NOAA Resource Ecology and Ecosystem Modeling (REEM) food habits database were used to determine Pacific cod consumption rates.

Data used to generate socioeconomic metrics and indicators will be derived from fishery-dependent sources, including commercial landings data for EBS Tanner crab collected in ADFG fish tickets and the BSAI Crab Economic Data Report (EDR) database (both sourced from AKFIN), and effort statistics reported in the most recent ADFG Annual Management Report for BSAI shellfish fisheries estimated from ADF&G Crab Observer program data (Leon et al. 2017).

Indicator Synthesis

In this synthesis section, we provide information on relevant ecosystem and/or socioeconomic processes through a thorough life history evaluation of the EBS Tanner crab stock. We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock with a conceptual model detailing ecosystem processes by life history stage (Figure E.1, Table E.1) and economic performance (Table E.2).

Ecosystem Processes

Data evaluated over life stages (e.g., embryo, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. Here, we summarize important ecosystem processes or potential bottlenecks across Tanner crab life history stages from the literature, process studies, and laboratory rearing experiments (Table E.2), and use this information to create a summary conceptual model of this information (Figure E.1). Details on why these processes were highlighted, as well as the potential relationship between ecosystem processes and stock productivity, are described below.

After molting to maturity, female Tanner crab mate and extrude new egg clutches in late winter or spring, which remain attached to pleopods on the female's abdomen for 12-16 months prior to hatching (Donaldson and Adams 1989). Fecundity is positively correlated with female size, and primiparous females have a lower fecundity than multiparous females (Swiney 2008, Zheng 2008). While the optimal temperature range for embryo development has not been established, laboratory studies often keep broodstock at 5-6°C to hatch larvae (Stevens 2003, Ryer et al. 2016). Peak hatching of Tanner crab larvae occurs in late April to early May (Armstrong et al. 1981) and tidal current patterns and phytoplankton chemicals may act as cues for larval release (Starr et al. 1994, Stevens 2003). Larval duration for the two zoeal stages (Incze et al. 1982) and the megalops stage (Jewett and Haight 1977) is approximately 30 days each. A longer larval stage associated with cooler temperatures may leave larvae more vulnerable to pelagic predators for a prolonged period. Furthermore, historical larval year-class failures have coincided with low zooplankton abundance over the middle shelf and low water column stability, suggesting that increased larval mortality is related to less favorable feeding conditions (Incze et al. 1987) and mismatches between larval release and the spring bloom (Somerton 1982). Laboratory studies also suggest that relatively high prey densities are required for successful feeding in Tanner crab zoeae (Paul et al. 1979). Major predators of larval Tanner crab include yellowfin sole (Armstrong et al. 1981), and other predators such as walleye pollock, jellyfish, and juvenile salmon have been found to prey on larvae of congeners (Kruse et al. 2007).

Tanner crab larvae settle from late August to the end of October (Incze et al. 1982). Early benthic instars are found on the outer shelf at depths >100 m in soft sediments such as mud and sand, where temperatures are generally >2°C (Ryer et al. 2016). Seasonal stratification and resulting high productivity of the surface waters over the middle shelf result in organically rich sand and mud substrates (Smith and McConnaughey 1999, McConnaughey and Smith 2000), which can provide a key lipid-rich food source for juvenile Tanner crab, leading to increased energetic condition (Copeman et al. 2018). Laboratory studies have shown that these energetic stores are prerequisites for molting, growth, and survival in crab early life history stages (Beder 2015), which indicates that variability in energetic reserves could represent a potential recruitment bottleneck in Tanner crab. However, increased warming and declines in sea ice are expected to decrease benthic juvenile Tanner crab prey resources supplied to the benthos through decreased benthic-pelagic flux (Copeman et al. 2021). Both settlement intensity and early benthic survival are likely critical determinants of year-class strength in Tanner crab, and successful advection to areas of suitable benthic substrate and temperature are thought to be critical criteria for juvenile survival (Ryer et al. 2016). Density dependence may also play a regulatory role due to high rates of cannibalism and potential prey resource limitation in juvenile nurseries (Chuchukalo et al. 2011, Ryer et al. 2016). Previous studies have shown that Pacific cod, flatfishes, sculpin, skates, are major predators of juvenile Tanner crab (Livingston 1989, Lang et al. 2003, 2005). Juvenile Tanner crab are especially vulnerable to predation and cannibalism during and immediately following molting.

Spatial patterns in juvenile and adult Tanner crab distributions are largely determined by thermal requirements and depth. Mature female Tanner crab have been found in shallow- and deep-water mating aggregations, but brooding of eggs occurs at depth (150-200m; Tyler and Kruse 1997, Stevens 2003). Immature Tanner crab concentrate in deeper waters of the EBS middle and outer shelf, avoiding thermal habitats <2°C, while large males often occupy slightly shallower habitats than the rest of the population (Murphy 2020). With increases in sea ice retreat, juvenile Tanner crab habitat may shift to the northwest as temperatures become more favorable and the extent of the cold pool shrinks (Ryer et al. 2016). Shifts in centers of abundance of mature female Tanner crab relative to prevailing currents may affect larval supply to nursery areas (Zheng and Kruse 2006), as currents over the middle shelf generally move larvae northward (Richar et al. 2015). While 2°C may represent a critical lower temperature threshold for juvenile Tanner crab, negative effects on metabolic processes are not apparent until temperatures exceed 12°C (Ryer et al. 2016), therefore projected warming in the EBS will likely lead to increases in suitable Tanner crab habitat. However, snow crab may constrain the northern extent of the Tanner crab range, as overlap between juvenile Tanner crab and adult snow crab can lead to increased predation on Tanner crab (Murphy 2020).

Socioeconomic Processes

A review of socioeconomic processes relevant to EBS Tanner crab is not available for this ESP draft.

Indicator Assessment

In this assessment section, we provide a time-series suite of indicators that represents the critical processes identified by the previous indicator synthesis section. These indicators must be useful for stock assessment in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of stages using statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al. 2023).

Indicator Suite

The following list of indicators for EBS Tanner crab is organized into categories: three for ecosystem indicators (larval, juvenile, and adult) and three for socioeconomic indicators (fishery informed, economic, and community). The indicator name and short description are provided in each heading. For ecosystem indicators, we include the proposed sign of the overall relationship between the indicator and a stock assessment parameter of interest (e.g., recruitment, natural mortality, growth), where relevant, and specify the lag applied if the indicator was tested in the ecosystem intermediate stage indicator analysis (see section below for more details). Each indicator heading is followed by bullet points that provide information on the contact and citation for the indicator data, the status and trends for the current year, factors influencing those trends, and implications for fishery management. Time series of these indicators are provided in Figure E.2a (ecosystem indicators) and Figure E.2b (socioeconomic indicators). Ecosystem indicators are also listed in a status table for quick reference over the past five years in Table E.3.

The following nomenclature was used to describe these indicators within the list:

- “Average”: Used if the value in the time series is near the long-term mean (dotted green line in Figure E.2).
- “Above average” or “Below average”: Used if the value is above or below the mean but was within 1 standard deviation of the mean (in between solid green lines in Figure E.2).
- “Neutral”: Used in Table E.3 for any value within 1 standard deviation of the mean.
- “High” or “Low”: Used in Table E.3 if the value was more than 1 standard deviation above or below the mean (above or below the solid green lines in Figure E.2).

In some cases, we include value-added products to more fully explore some of the indicators in the suite and allow for a more in-depth interpretation of the indicator. At this time, we do not have any value-added indicators for EBS Tanner crab but may in the future.

Ecosystem Indicators:

<u>1. Larval Indicators (Figure E.2a.a-b)</u>

a. Aleutian Low - Beaufort Sea Anticyclone: Mean December – March Aleutian Low - Beaufort Sea Anticyclone (ALBSA) index from the NOAA Physical Sciences Laboratory. Proposed sign of the relationship is negative, and the time series is lagged four years for intermediate stage indicator analysis.
    - Contact: S. Hennessey
    - Status and trends: The ALBSA was in a neutral state in 2024.
    - Factors influencing trends: A high ALBSA index has been related to earlier melt spring timing, and which can impact the spring bloom and key diatom availability that are critical prey for larval Tanner crab (Zheng and Kruse 2000, 2006).
    - Implications: Declines in the ALBSA in recent years may indicate a switch to more favorable feeding conditions for larval Tanner crab, having a positive effect on growth and survival.

b. Summer Surface Temperature: Mean surface temperature during the EBS summer bottom trawl survey. Proposed sign of the relationship is positive, and the time series is lagged four years for intermediate stage indicator analysis.
    - Contact: S. Hennessey
    - Status and trends: Summer surface temperature decreased from 2023 to 2024, and remained below the 42-year time series average.
    - Factors influencing trends: The recent average summer surface temperatures coincide with a weakening in the ALBSA and average winter sea ice advance.
    - Implications: While higher surface temperatures can favor the production of key larval prey and may also lead to increased larval growth (Armstrong et al. 1981), average but declining temperatures indicate the potential for unfavorable larval conditions if this trend continues.

2. Juvenile Indicators (Figure E.2a.c-h)

c. Chlorophyll-*a* Concentration: Mean April – July Ocean Colour CCI chlorophyll-*a* concentration (µg/L) in the outer-middle shelf of the eastern Bering Sea (BSIERP Regions 3-6, 8), calculated with the ESA OC-CCI blended satellite product (4km resolution, 8-day composite data). Proposed sign of the relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.
   - Contact: M. Callahan and J. Nielsen
   - Status and trends: Chlorophyll-*a* concentration decreased in 2024 following the time series high in 2023, but remains high at well above the 26-year mean.
   - Factors influencing trends: Spring chlorophyll-*a* concentration is directly influenced by the timing and magnitude of the spring bloom, and strongly impacts the amount of energy that is transferred through trophic pathways in the Bering Sea.
   - Implications: High chlorophyll-*a* concentrations and subsequently more diatoms in the water column may result in increased production reaching the seafloor, positively impacting juvenile Tanner crab food resources as lipid-rich diets due to diatom-rich organic matter on the seafloor have been linked to increased juvenile growth (Copeman et al. 2018). Increased diatoms may also lead to reduced larval mortality due to favorable feeding conditions (Incze et al. 1987).

d. Juvenile Tanner Crab Temperature of Occupancy: Mean bottom temperature weighted by immature Tanner crab CPUE during the EBS summer bottom trawl survey. Proposed sign of the relationship is positive, and the time series is lagged one year for intermediate stage indicator analysis.
   - Contact: S. Hennessey
   - Status and trends: Temperatures occupied by juvenile Tanner crab decreased by 0.3°C from 2023 to 2024, with the 2024 estimate falling just below the 42-year average.
   - Factors influencing trends: Temperatures occupied by juvenile Tanner crab are directly influenced by bottom temperatures in the Bering Sea and cold pool extent, due to warmer-water habitat preferences of juveniles. Occupied temperatures below 2°C may be indicative of reduced habitat availability, as juvenile growth is inhibited at these low temperatures (Ryer et al. 2016).
   - Implications: Occupied temperature near the long-term mean indicates average thermal habitat conditions, and no concern for juvenile Tanner crab growth and survival.

e. Summer Benthic Predator Density: Summer Pacific cod, rock sole, yellowfin sole, and flathead sole density (kg/km^2) estimated from the EBS bottom trawl survey stations included in the 50th percentile of mean Tanner crab CPUE across years (1982 – 2024). Proposed sign of the relationship is negative as these fish species are major predators of juvenile Tanner crab, and the time series is lagged one year for intermediate stage indicator analysis.
   - Contact: S. Hennessey
   - Status and trends: The density of key benthic predators increased slightly in 2024, but remains below average.
   - Factors influencing trends: Declines in the spatial extent of the cold pool coincides with increased benthic predator density, which may lead to increased predation pressure on juvenile Tanner crab.
   - Implications: Increases in benthic predators following low densities in 2018-2021, coupled with increased recruitment of small Tanner crab, may lead to increased predation pressure on Tanner crab juveniles. However, these increases do not appear to be having a strong negative impact on the stock.

f. Summer Pacific Cod Consumption: The daily summer consumption of Tanner crab (mt/day) by Pacific cod in the eastern Bering Sea, estimated from Pacific cod diet compositions, EBS trawl survey CPUE, and temperature adjusted length-specific maximum consumption rates. Pacific cod consumption estimates include unidentified *Chionoecetes* sp. as well as identified *C. bairdi* from stomach contents. Unidentified crab were assigned to *C. bairdi* based on identified *C. bairdi* and *C. opilio* proportions by cod size and stratum. Proposed sign of the relationship is negative, and the time series is lagged two years for intermediate stage indicator analysis.
   - Contact: K. Aydin
   - Status and trends: Daily consumption of juvenile Tanner crab by Pacific cod exhibited a moderate increase from 2023 to 2024, and remains slightly above the 40-year average.
   - Factors influencing trends: Declines in the spatial extent of the cold pool coincide with northerly shifts in Pacific cod centroids of abundance, resulting in decreased spatial overlap between Pacific cod and juvenile Tanner crab. This may result in lower predation pressure on small Tanner crab. Annual consumption estimates are also driven by juvenile Tanner crab population size, and as generalists, Pacific cod tend to predate heavily on Tanner crab when the abundance of small juveniles is high.
   - Implications: Recent increases in Pacific cod consumption of Tanner crab since 2021 coincided with several years of strong Tanner crab recruitment. These increases in consumption suggest an increase in top-down predation pressure, but do not appear to have a strong negative impact on the stock.

g. Summer Juvenile Tanner Crab Disease Prevalence: Prevalence (%) of small Tanner crab (< 70mm) showing visual symptoms of Bitter Crab Disease (BCD) during the summer EBS bottom trawl survey, calculated as the abundance of visually positive small Tanner crab divided by total small Tanner crab abundance. Proposed sign of the relationship is negative, and the time series is lagged two years for intermediate stage indicator analysis.
   - Contact: S. Hennessey
   - Status and trends: Visually-diagnosed BCD prevalence decreased in 2024 to 1.3%, but remains slightly above the 35-year average. However, visual detection methods substantially underestimate disease prevalence, and infections detected with sensitive PCR assays at disease monitoring sites indicate that prevalence levels in the EBS have reached 50% in recent years (Fedewa et al. 2025).
   - Factors influencing trends: BCD tends to occur in areas with high population density of small, new shell crab, and 4-6°C bottom temperatures (Fedewa et al. 2025).
   - Implications: Record-high visual BCD prevalence in 2019 coinciding with a large recruitment event of small (20-40mm) Tanner crab may have contributed to reduced survival to larger juvenile size classes in 2021. However, it is unclear if BCD has large and lasting effects on the stock, as recruitment has been high in the past several years despite slightly elevated BCD prevalence.

h. Summer Benthic Invertebrate Density: Summer benthic invertebrate density (kg/km^2), estimated from EBS bottom trawl survey stations included in the 50th percentile of mean Tanner crab CPUE across years (1982 – 2024). Invertebrates include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp, and polychaetes. Proposed sign of the relationship is positive, and the time series is lagged two years for intermediate stage indicator analysis.
   - Contact: S. Hennessey
   - Status and trends: Following a decline in benthic invertebrate density from 2022 to 2023, densities increased in 2024 and were slightly above the 42-year mean.
   - Factors influencing trends: Environmental factors such as bottom temperature, primary production, and ice cover likely affect spatiotemporal variation in epibenthic

invertebrates, but the dynamics remain poorly understood (Yeung and McConnaughey 2006).
- Implications: Increases in benthic invertebrate density in 2024 suggest the potential for increased prey availability for juvenile and adult Tanner crab. Higher densities may also be indicative of larger scale increases in benthic production.

3. Adult Indicators (Figure E.2a.i-m)

i. Male Tanner Crab Size at Terminal Molt: Carapace width (mm) at 50% probability of having undergone terminal molt for male Tanner crab, as determined from maturity ogives developed from EBS bottom trawl survey data for new hardshell males only. Proposed sign of the relationship is positive.
   - Contact: J. Richar
   - Status and trends: The size at which there is a 50% probability of a male Tanner crab undergoing terminal molt increased dramatically in 2024 to slightly below the time series mean, following the 2nd lowest value in the time series in 2023. Although annual size at terminal molt is highly variable, this indicator has been trending down for the past three decades.
   - Factors influencing trends: Temporal shifts in size at terminal molt in male Tanner crab are likely driven by recruitment variability, density dependent growth, and ocean temperatures (Murphy 2021).
   - Implications: Directional downward shifts in size at terminal molt lead to a higher abundance of small mature males that are protected from the fishery, resulting in higher exploitation rates on large, industry preferred males. In addition, the potential for sperm limitation in populations depleted of large male Tanner crab may decrease reproductive potential of the stock (Webb 2008).

j. Male Tanner Crab Area Occupied: The minimum area containing 95% of the cumulative mature male Tanner crab CPUE during the EBS summer bottom trawl survey. Male maturity was determined using the annual carapace width (mm) size at which 50% of the population was mature. Proposed sign of the relationship is positive.
   - Contact: S. Hennessey
   - Status and trends: The spatial extent of mature male Tanner crab has remained at an all-time high since 2023, and is well above the 42-year mean.
   - Factors influencing trends: The spatial extent of Tanner crab in the EBS may expand in response to warmer bottom temperatures and a smaller cold pool extent. Spatial extent may also be influenced by decreased overlap with snow crab due to their population collapse in 2018-2019.
   - Implications: Continued increases in the spatial extent of mature male Tanner crab coincide with increased abundances of large males since. Range expansion may have implications for density-dependent prey limitations or competition with snow crab (Murphy 2020). However, areas occupied by immature Tanner crab and mature females have expanded alongside increases in abundance, suggesting a positive outlook for the stock.

k. Male Tanner Crab Center of Abundance: CPUE-weighted average longitude of the mature male Tanner crab stock during the EBS summer bottom trawl survey. Male maturity was determined using the annual carapace width (mm) size at which 50% of the population was mature.
   - Contact: S. Hennessey
   - Status and trends: The mature male centroid of abundance has shifted slightly west over time, and the 2024 centroid of abundance remains west of the 42-year mean.

- Factors influencing trends: Centroids of abundance track bottom temperatures and interactions with other species such as snow crab (Murphy 2020).
- Implications: The longitudinal center of distribution of the Tanner crab stock can signal how far east or west the stock is centered in relation to the 166°W management boundary.

l. Female Tanner Crab Size at Maturity: Mean carapace width (mm) of mature female Tanner crab from EBS bottom trawl survey data, for new hardshell females only. Proposed sign of the relationship is positive.
    - Contact: S. Hennessey
    - Status and trends: The mean size of mature female Tanner crab declined to well below the 42-year average, consistent with an overall declining trend since 2015.
    - Factors influencing trends: Temporal shifts in size at terminal molt in female Tanner crab are likely driven by recruitment variability, density dependent growth, and ocean temperatures (Murphy 2021).
    - Implications: Decreased size of female Tanner crab maturity is linked to decreased fecundity, and may lead to reduced reproductive output (Zheng 2008). However, there has been strong recruitment in the years following a record low female size at maturity in 2019, suggesting that these recent decreases in size may not be having a strong negative impact on the stock.

m. Female Tanner Crab Reproductive Potential: The proportion of primiparous, mature female Tanner crab with full clutches. Full clutches are designated as code "5" and "6" from the EBS bottom trawl survey clutch fullness indices. Proposed sign of the relationship is positive.
    - Contact: S. Hennessey
    - Status and trends: The proportion of mature female Tanner crab increased dramatically in 2024 to above the time series mean, with 80% of primiparous females having full to ¾ full clutches. This rebound follows an all-time low in 2023, and is consistent with an increased variability in reproductive potential in recent years.
    - Factors influencing trends: Female reproductive potential is a function of fecundity, egg production, clutch size, and sperm reserves (Swiney 2008). Clutch size is influenced by the quantity and quality of sperm reserves, and declining trends in the proportion of mature females with full clutches may indicate sperm limitation.
    - Implications: Following a large decline in the proportion of females with full clutches from 2021 to 2023, a greater proportion of full clutches in 2024 suggests increased reproductive capacity.

Socioeconomic Indicators:

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

a. Number of Active Vessels: Annual number of active vessels in the Tanner crab fishery, representing the level of fishing effort assigned to the fishery. This indicator is split by the Eastern Bering Sea and Western Bering Sea Tanner crab management areas.
    - Contact: J. Lee

b. Fishery CPUE: Annual catch-per-unit-effort (CPUE) of retained catch, expressed as mean number of crabs per potlift, in the Tanner crab fishery, representing relative efficiency of fishing effort. This indicator is split by the Eastern Bering Sea and Western Bering Sea Tanner crab management areas.
    - Contact: B. Daly

c. Fishery Total Potlifts: Annual total potlifts in the Tanner crab fishery, representing the level of fishing effort expended by the active fleet. This indicator is split by the Eastern Bering Sea and Western Bering Sea Tanner crab management areas.
   - Contact: B. Daly

d. Centroid of Fishery: Center of gravity, expressed in longitude, as an index of spatial distribution for the Tanner crab fishery to monitor spatial shifts in fishery behavior. This indicator is split by the Eastern Bering Sea and Western Bering Sea Tanner crab management areas.
   - Contact: B. Daly

e. Annual Incidental Catch: Annual incidental catch of Tanner crab in EBS groundfish fisheries. This indicator is split by the Eastern Bering Sea and Western Bering Sea Tanner crab management areas.
   - Contact: J. Lee

f. TAC Utilization: Percentage of the annual EBS Tanner crab total allowable catch (TAC) (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing. This indicator is split by the Eastern Bering Sea and Western Bering Sea Tanner crab management areas.
   - Contact: J. Lee

<u>2. Economic Indicators (Figure E.2b.g-j)</u>

g. Ex-vessel Value: Annual Tanner crab ex-vessel value of the Tanner crab fishery landings, representing gross economic returns to the harvest sector, as a principal driver of fishery behavior.
   - Contact: J. Lee

h. Ex-vessel Price: Annual Tanner crab ex-vessel price per pound, representing per-unit gross economic returns to the harvest sector, as a principal driver of fishery behavior.
   - Contact: J. Lee

i. Ex-vessel Revenue Share: Annual Tanner crab ex-vessel revenue share, expressed as vessel-average proportion of annual gross landings revenue earned from the EBS Tanner crab fishery.
   - Contact: J. Lee

j. Leasing: Lease cost as percent of ex-vessel gross value.
   - Contact: J. Lee

<u>3. Community Indicators (Figure E.2b.k-m)</u>

k. Number of Active Processors: Annual number of active buyers of EBS Tanner crab.
   - Contact: J. Lee

l. Processing Labor Hours: Annual number of hours spent processing EBS Tanner crab.
   - Contact: J. Lee

m. Local Quotient Landed: Percentage of the TAC that is landed in Dutch Harbor from the EBS Tanner crab fishery.
   - Contact: J. Lee

Indicator Monitoring Analysis

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

Ecosystem Monitoring

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

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

A simple scoring calculation is used for the beginning stage evaluation. 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 indicator and the stock (Figure E.3) 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 (larval, juvenile, and adult) indicators and divided by the total number of indicators available in that category for a given year. We provide the category scores for the past twenty years as the majority of indicators were available throughout this time period (Figure E.2a). The ecosystem scores over time provide a history of stock productivity and comparison of indicator performance.

Overall, the ecosystem indicators score in 2025 increased from the previous year, remaining above average (Figure E.3, black line). By category, the larval indicators remained average, the juvenile indicators remained above average, and the adult indicators increased from below average to average (Figure E.3, green, blue, and purple lines).

Following the 2017-2019 highest winter Aleutian Low - Beaufort Sea Anticyclone (ALBSA) values since the late 1980s, the ALBSA has steadily decreased to near the long term mean in 2024. This index is correlated with earlier melt timings (Cox et al. 2019), and a strong Aleutian Low coincides with periods of weak Tanner crab recruitment as it can inhibit growth of key larval diatom prey (Zheng and Kruse 2000). This declining trend is also reflected in SEBS summer surface temperature, which has decreased in recent years although remains near the long term mean. Warmer surface temperatures have been correlated with favorable production of key larval prey, which may lead to increased larval growth (Rosenkranz et al. 2001). Therefore, a continued decrease in surface temperature may result in less favorable larval conditions.

Key production indicators for juveniles and adults include chlorophyll-*a* concentrations and benthic invertebrate densities. Chlorophyll-*a* concentrations decreased in 2024 following the time series high in 2023, but remained high, characteristic of a large, productive spring bloom and increased benthic production. Benthic invertebrate densities have remained generally high since a peak in 2017, increasing from a slight decline in 2024. Temperature occupied by juvenile Tanner crab has also decreased slightly from 2023 to 2024, with the 2024 estimate falling just below the 42-year average. This indicator is highly correlated with both bottom temperature and cold pool extent, so reflects both of these processes as well as other ecological interactions such as predation pressure and competition. Benthic predator densities have increased in recent years coinciding with declines in the spatial extent of the cold pool, but densities remain below average. Likewise, Pacific cod consumption on Tanner crab juveniles has increased since 2021 reaching levels slightly above average. Juvenile Tanner crab disease prevalence exhibited a large peak in 2019, but has since declined to near-average levels.

Mature male Tanner crab spatial extent is at an all-time high, despite lower abundances from 2021-2023, and the centroid of abundance has shifted to the northwest since 2023. Male Tanner crab size at maturity has remained low in recent years, but has rebounded slightly to just below average in 2024. Likewise, mature female Tanner crab reproductive potential has exhibited similar trends, with a record low proportion of females with full clutches in 2023 that returned to average in 2024. This indicator also appears to be becoming more variable over time. Annual female size at maturity has also had a declining trend, and decreased from 2022-2024. This suggests a potential overall decline in stock reproductive output.

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

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and EBS Tanner crab recruitment estimated in the operational stock assessment, and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al. 2011). Prior to running BAS, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment, indicators are lagged to reflect hypothesized relationships with recruitment, and highly correlated covariates are removed

This resulted in a model run from 2000 through 2021 for EBS Tanner crab. We provide the mean relationship between each predictor variable and the estimates of EBS Tanner crab recruitment over time (Figure E.4, top left), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure E.4, top right). We also provide model predicted fit (1:1 line, Figure E.4, bottom left) and average fit across the recruitment time series subset (2000 - 2021, Figure E.4, bottom right). A higher probability indicates that the variable is a better candidate predictor of EBS Tanner crab recruitment. Design-based recruitment estimates were calculated as area-swept abundance of 70-85mm male Tanner crab. This size class was selected to target males at a size just before terminal molt and recruitment to the fishery, based on size-age relationships estimated in Donaldson et. al (1981) and pseudocohort modal analysis using BSFRF survey data (M. Heller-Shipley, *personal communication*).

The highest ranked predictor variables (inclusion probability > 0.5) based on this process are chlorophyll-*a* concentration, small Tanner crab temperature occupied, ALBSA, Pacific cod consumption, and small Tanner crab disease prevalence (Figure E.4). The three indicators with the highest inclusion probabilities also had effects that significantly differed from zero, which were chlorophyll-*a* concentration (effect = 0.55), small Tanner crab temperature occupied (effect = -0.37), and ALBSA (effect = -0.35). However, the direction of the occupied temperature effect was counter to the proposed overall relationship with recruitment. This was also the case with Pacific cod consumption, which had a suggestively positive relationship with recruitment. While it is possible that there may be an interaction between small Tanner crab temperature occupied and Pacific cod consumption that leads to a reversal of the predicted covariate effects on recruitment, there was very little correlation between the two covariate time series therefore the underlying mechanism for this result remains unclear.

Other candidate BAS models were also evaluated, including removing the chlorophyll-*a* concentration indicator due to its short time series length. This resulted in a decrease in model fit ($R^2 = 0.55$), and a shift in the suite of indicators with inclusion probabilities of > 0.5. Additionally, no indicator had an effect that significantly differed from zero, although the general direction of predicted effects remained largely consistent. BAS models with increased larval and early juvenile indicator lags were also assessed, but did not lead to improved fits to recruitment estimates. Therefore, only results from the initial BAS model are presented.

<u>Advanced Stage: Research Model Test</u>

At this time, we do not have any ecosystem research models to report for EBS Tanner crab.

Socioeconomic Monitoring

We present four socioeconomic indicators and six fishery informed indicators that depict a historical time-series of key socioeconomic information for the EBS Tanner crab fishery. Each indicator uses historical data through January 2024. A one-year lag is presented to account for post-season adjustments of vessel revenues (and submission deadlines of COAR Buying reports, our primary economic data source) and to capture the end-of-year retained catch information. Select socioeconomic indicators have an associated indicator that provides additional detail and context at a more granular level than state- or fishery-wide. Similar to the ten socioeconomic and fishery informed indicators, each associated indicator uses a historical time-series to analyze information at a region, gear, or size specific level. Select associated indicators, where stated, use in-season data through October 2024 to provide the most current information available.

An analysis of socioeconomic indicators will be included in the final Tanner crab ESP document in September, 2025.

Conclusion

The EBS Tanner crab ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., 2023). Given the indicator synthesis and assessment we provide the following summary management and modeling considerations that can be used for evaluating concerns in the main stock assessment or other management decisions:

Management Considerations

The following are summary considerations from the ecosystem and socioeconomic indicators evaluated for EBS Tanner crab:

Acceptable Biological Catch (ABC) Information:

- Chlorophyll-*a* concentration remains high in the mid-outer shelf of the EBS, coinciding with a decline in the winter Aleutian Low - Beaufort Sea Anticyclone and surface temperature after peaks in 2017-2020. This suggests a more pronounced spring bloom and an increase in large cell plankton like diatoms, which are a critical food source for crab larvae and key benthic production for juveniles.
- Juvenile Tanner crab temperature occupied, encompassing bottom temperature, cold pool extent, as well as ecological interactions, remains average relative to the 42-year mean (2.9°C) following the 2018-2019 heat wave.

- Visual prevalence of bitter crab disease increased dramatically in 2019, and has declined in 2024 following a peak again in 2022.
- Benthic predator density in core Tanner crab habitats reached all-time lows during the 2018-2021 marine heat wave but density has increased annually since 2021. This, coupled with increasing Pacific cod consumption on juvenile Tanner crab, suggests increased predator-prey interactions and reduced survival of juvenile cohorts.
- Benthic invertebrate densities have remained above average since a peak in 2017, which suggests higher prey availability for Tanner crab juveniles and adults.
- Despite lower abundance of mature male Tanner crab from 2021- 2023, mature male spatial extent is at an all-time high and centroids of abundance have shifted northwest since 2023. Increased utilization of northern outer shelf habitats may increase competitive interactions with snow crab.
- Male size at terminal molt has remained low in recent years, but has rebounded slightly to just below average in 2024. This recent trend is similarly reflected in the mature female Tanner crab reproductive potential, with a record low proportion of females with full clutches in 2023. Annual female size at maturity has also decreased, which suggests a decline in stock reproductive output.

Total Allowable Catch (TAC) Information:

- Socioeconomic indicator trends and implications will be presented in September 2025.

Modeling Considerations

The following are the summary results from the most recent intermediate and advanced stage ecosystem monitoring analyses for EBS Tanner crab:

- The highest ranked predictor for the recruitment regression model was chlorophyll-*a* concentration. There were four other indicators with inclusion probabilities > 0.5: juvenile Tanner crab temperature occupied, ALBSA, Pacific cod consumption, and small Tanner crab disease prevalence. However, the latter two indicators had nonsignificant effects on recruitment.
- Overall, the intermediate stage monitoring analyses explained a large amount of variation in Tanner crab recruitment using survey design-based estimates ($R^2 = 0.90$). Future efforts should explore the exclusion of indicators with short time series as well as other modeling frameworks.

Data Gaps and Future Research Priorities

While current indicator assessments offer a valuable set of proxy indicators, there are notable areas for improvement. The list below summarizes the data gaps and future research priorities for this ESP by ecosystem and socioeconomic category.

Ecosystem Priorities

- Future research should support the development of indicators that quantify Tanner crab physiological and biological responses to rapidly changing ecosystem conditions in the Bering Sea. Additional research should be done on intermolt durations and sizes across stages for EBS Tanner crab specifically.
- Refinements or updates to existing indicators may also be warranted. This includes exploring the use of the North Pacific Index instead of the ALBSA and incorporating a NE wind larval Tanner crab indicator, as well as developing indicators for juvenile Tanner crab cohort progression, stock spatial patchiness, and Tanner crab/snow crab overlap.

Socioeconomic Priorities

- The development of an Alaska Bering Sea Crabbers (ABSC) Skipper Survey for EBS Tanner crab would provide valuable qualitative and quantitative information on perceived abundance, fisher behavior, and gear performance.

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

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Tables

Table E.1: List of data sources used in the ESP evaluation. Please see the main EBS Tanner crab SAFE document, the Ecosystem Considerations Report (Siddon 2024) and the Economic Status Report (Garber-Yonts et al. 2024) for more details.

Title	Description	Years	Extent
AFSC Bottom Trawl Survey	Bottom trawl survey of crab and groundfish in June through August, eastern Bering Sea using Poly Nor'Eastern trawl on stratified random sample grid, catch per unit of effort in metric tons	1982-present	Bering Sea annual
REEM Diet Database	Food habits data and associated analyses collected by the Resource Ecology and Ecosystem Modeling (REEM) Program, AFSC on multiple platforms	1990-present	Bering Sea annual
ESA Ocean Colour CCI	4 km blended chlorophyll-a concentration data aggregated to 8-day composites of satellite ocean color	1998-present	Global
NOAA Physical Science Laboratory	Daily Aleutian Low - Beaufort Sea Anticyclone 850mb height data from NCEP R1 4 pts., constructed by the National Oceanic and Atmospheric Administration (NOAA) Physical Science Laboratory	1950-present	North Pacific / Pacific Arctic
ADF&G Crab Observer program data	Tanner crab catch and effort data (number of active vessels, total pots lifted, and CPUE), sourced from Alaska Department of Fish and Game (ADF&G) Annual Fishery Management Report	1980-2019	Alaska
ADF&G fish ticket database	Volume, value, and port of landing for Alaska crab and groundfish commercial landings; data processed and provided by Alaska Fisheries Information Network	1992-2019	Alaska

Table E.2a: Ecological information by life history stage for EBS Tanner crab.

Stage	Habitat & Distribution	Phenology	Age, Length, Growth	Energetics	Diet	Predators / Competitors
Egg	Clutch of embryos brooded under the female's abdomen until hatching	397 days for multiparous females to 489 days for primiparous females at 6°C(1)	Egg diameter: 0.57-0.63mm(2)	NA	Yolk	Amphipods and nemertean worms feed on egg clutches
Larvae	Pelagic; concentrated in the upper 20m over the middle and outer shelf(3)	Peak hatching in late April - early May(4)	Mean carapace length (stage II zoea): 1.04mm(5)	NA	Diatoms, small copepods(6)	Juvenile pollock, Pacific salmon, and jellyfishes
Juvenile	Benthic; found in silt, fine sand, and mud habitat (100-200m depth)(7)	Settlement peaks in late September(8), later benthic stages molt annually in the spring(9)	12-18 benthic instar stages until final molt to maturity(9)	Growth indices highest at 6°C(10)	Crustaceans, polychaetes, molluscs, sediment/ detritus(11,12)	Pacific cod, flatfish, sculpins, skates, crab(13,14)
Adult	Benthic; mud and sand bottoms (50-200m depth)(4)	5-6+ years, form mating aggregations in spring to mate(15)	Average size at terminal molt: females 83mm CW, males 112mm CW(9)	Occupy temperatures between -2-8°C	Polychaetes, echinoderms, crustaceans, molluscs(16)	Pacific cod, skates, halibut, sculpin(17)

Note: Subscripts in table correspond to the following citations in sequential order 1. Swiney et al. 2008, 2. Krause et al. 2001, 3. Incze et al. 1987, 4. Armstrong et al. 1981, 5. Haynes 1981, 6. Incze and Paul 1983, 7. Zhou and Shirley 1997, 8. Incze et al. 1982, 9. Donaldson et al. 1981, 10. Ryer et al. 2016, 11. Tarverdieva 1976, 12. Copeman et al. 2018, 13. Jewett, 1982, 14. Rosenkranz et al. 2001, 15. Stone 1999, 16. Jewett and Feder 1983, 17. Mito 1974.

Table E2.b: Key processes affecting survival by life history stage for EBS Tanner crab.

Stage	Processes Affecting Survival	Relationship to EBS Tanner crab
Egg	1. Temperature	Temperature directly impacts gonadal development and egg incubation duration$_{(1)}$
Larvae	1. Synchrony with spring bloom 2. Offshore advection	Larval growth and survival is dependent on high concentrations of diatoms and microzooplankton$_{(2)}$. Advection offshore to areas with suitable bottom temperatures and substrate likely increases larval survival$_{(1,3)}$
Juvenile	1. Temperature 2. Predation 3. Benthic production (prey)	Bottom temperatures <2°C can inhibit juvenile Tanner crab growth and survival$_{(4)}$. Predation by Pacific cod and flatfishes is a dominant source of juvenile Tanner crab mortality$_{(1)}$, and food availability may influence patterns in growth, energetic condition, and survival of Tanner crab.
Adult	1. Benthic production (prey, competition) 2. Temperature	Food availability may influence patterns in growth, energetic condition, and survival of Tanner crab. Shifts in the spatial extent of Tanner crab are driven by bottom temperatures and cold pool dynamics in the EBS$_{(5)}$

Note: Subscripts in table correspond to the following citations in sequential order 1. Rosenzranz et al. 2001, 2. Incze and Paul 1983, 3. Rosenkranz et al. 1998, 4. Ryer et al. 2016, 5. Murphy 2020.

Table E.3: First stage ecosystem indicator analysis for EBS Tanner crab, 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). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = “NA” will appear if there were no data for that year.

Indicator category	Indicator	2020 Status	2021 Status	2022 Status	2023 Status	2024 Status
Larval	* Winter Spring Aleutian Low - Beaufort Sea Anticyclone - Model	**high**	neutral	neutral	neutral	neutral
	Summer Surface Temperature - SEBS Survey	NA	neutral	neutral	neutral	neutral
Juvenile	* Chlorophyll-*a* Concentration SEBS - Satellite	neutral	neutral	*high*	*high*	*high*
	* Juvenile Tanner Crab Temperature of Occupancy - SEBS Survey	NA	*high*	neutral	neutral	neutral
	Summer Benthic Predator Density - SEBS Survey	NA	*low*	neutral	*low*	neutral
	* Summer Pacific Cod Consumption	NA	neutral	neutral	neutral	neutral
	* Summer Juvenile Tanner Crab Disease Prevalence - SEBS Survey	NA	neutral	**high**	neutral	neutral
	Summer Benthic Invertebrate Density - SEBS Survey	NA	*high*	*high*	neutral	*high*
Adult	Male Tanner Crab Size at Terminal Molt - Model	NA	neutral	neutral	**low**	neutral
	Summer Male Tanner Crab Area Occupied - SEBS Survey	NA	neutral	*high*	*high*	*high*
	Summer Male Tanner Crab Center of Distribution - SEBS Survey	NA	neutral	neutral	neutral	neutral
	Female Tanner Crab Size at Maturity - SEBS Survey	NA	neutral	neutral	neutral	**low**
	Female Tanner Crab Reproductive Potential - SEBS Survey	NA	neutral	neutral	**low**	neutral

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

Figures

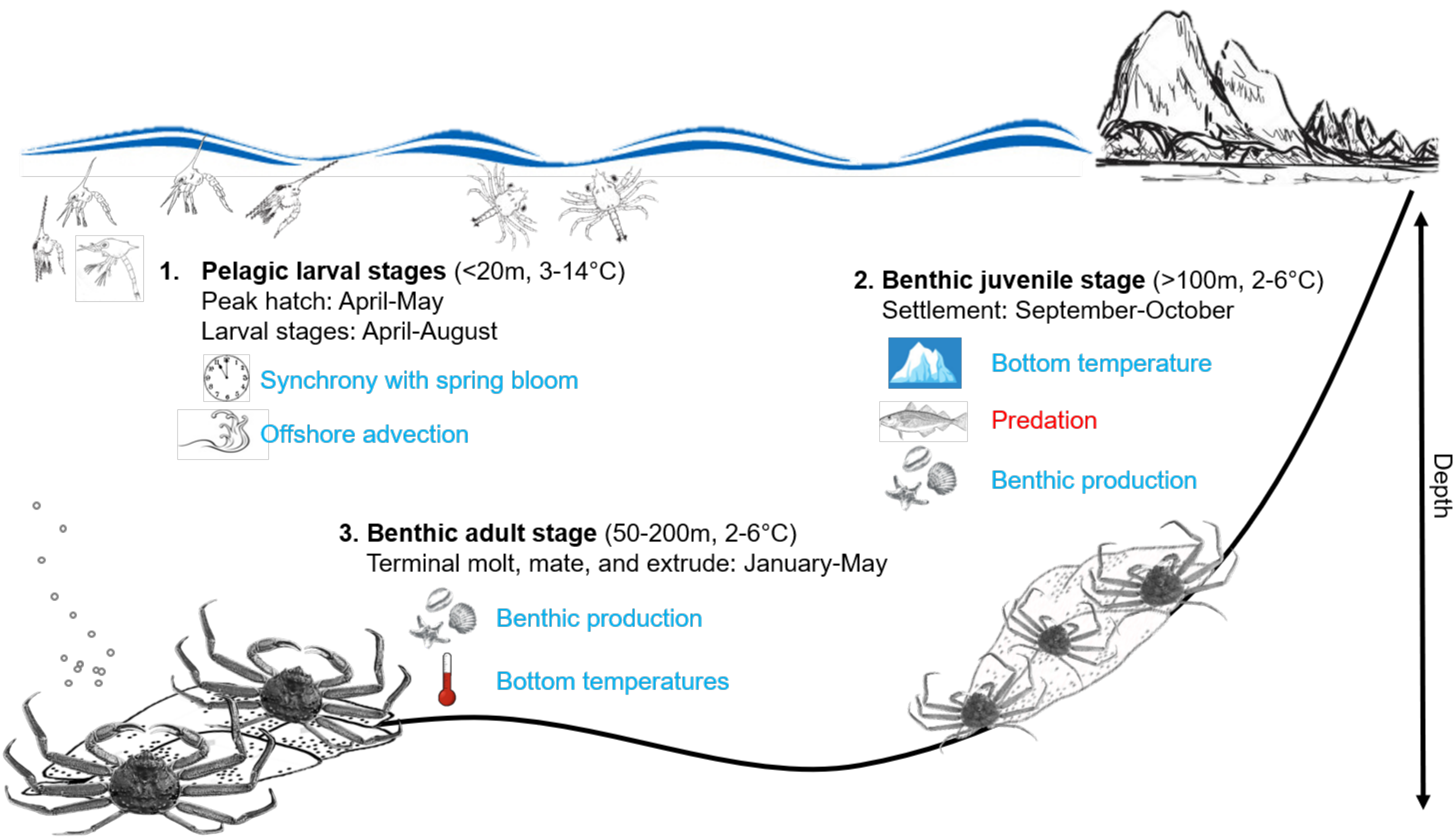

Figure E.1: Life history conceptual model for EBS Tanner crab summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text means that increases in the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

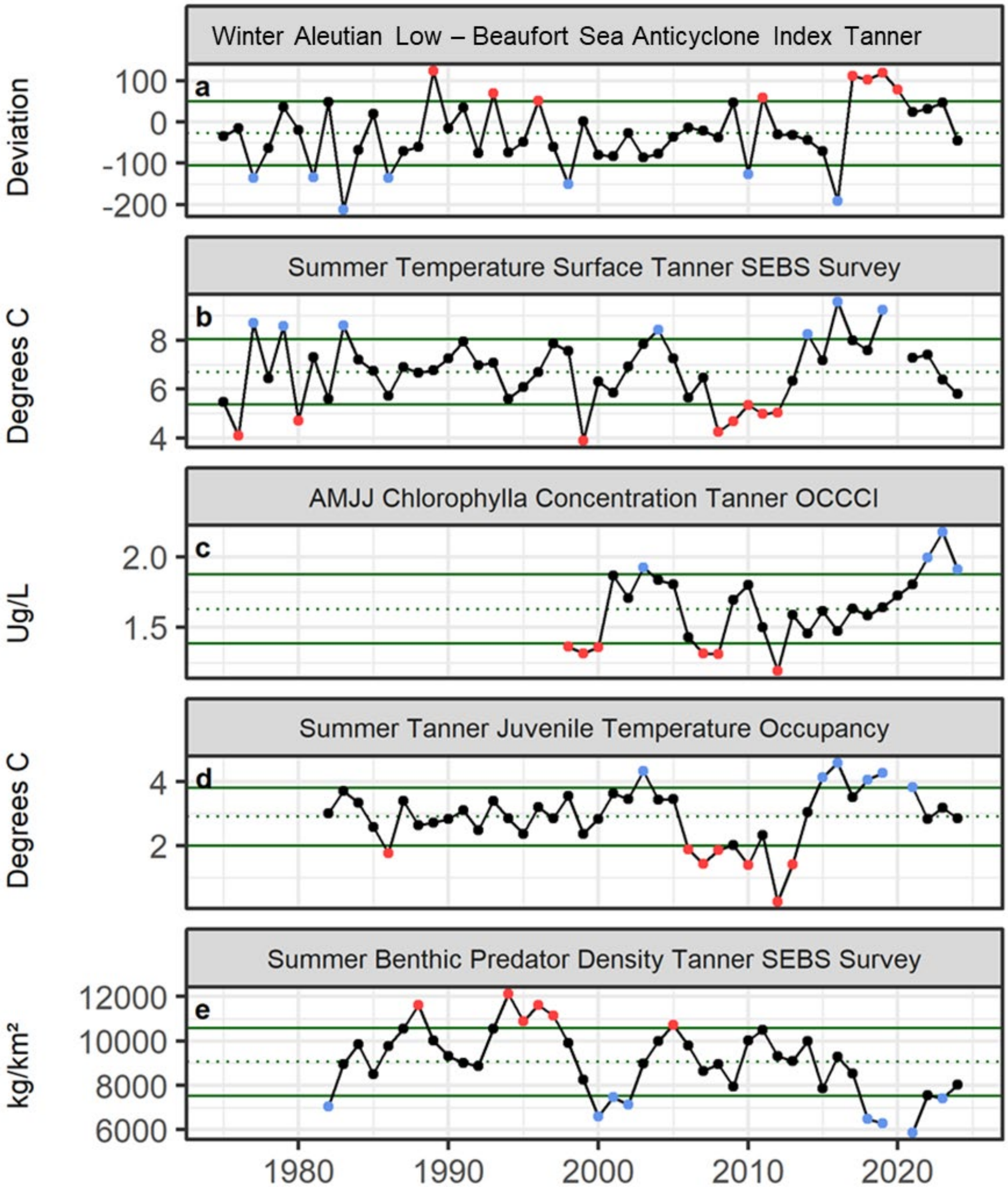

Figure E.2a: Selected ecosystem indicators for EBS Tanner crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored 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.

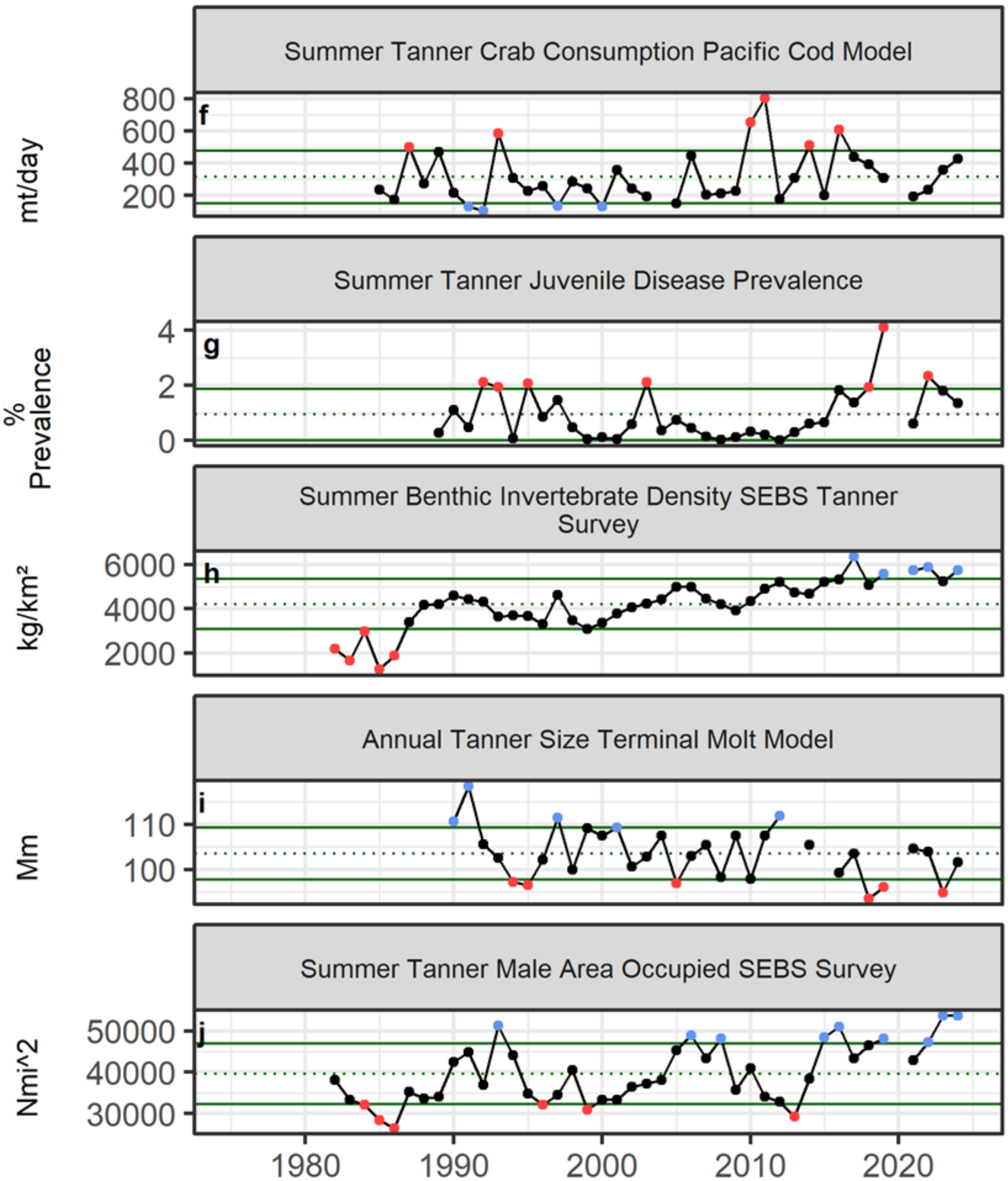

Figure E.2a (cont.): Selected ecosystem indicators for EBS Tanner crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series 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.

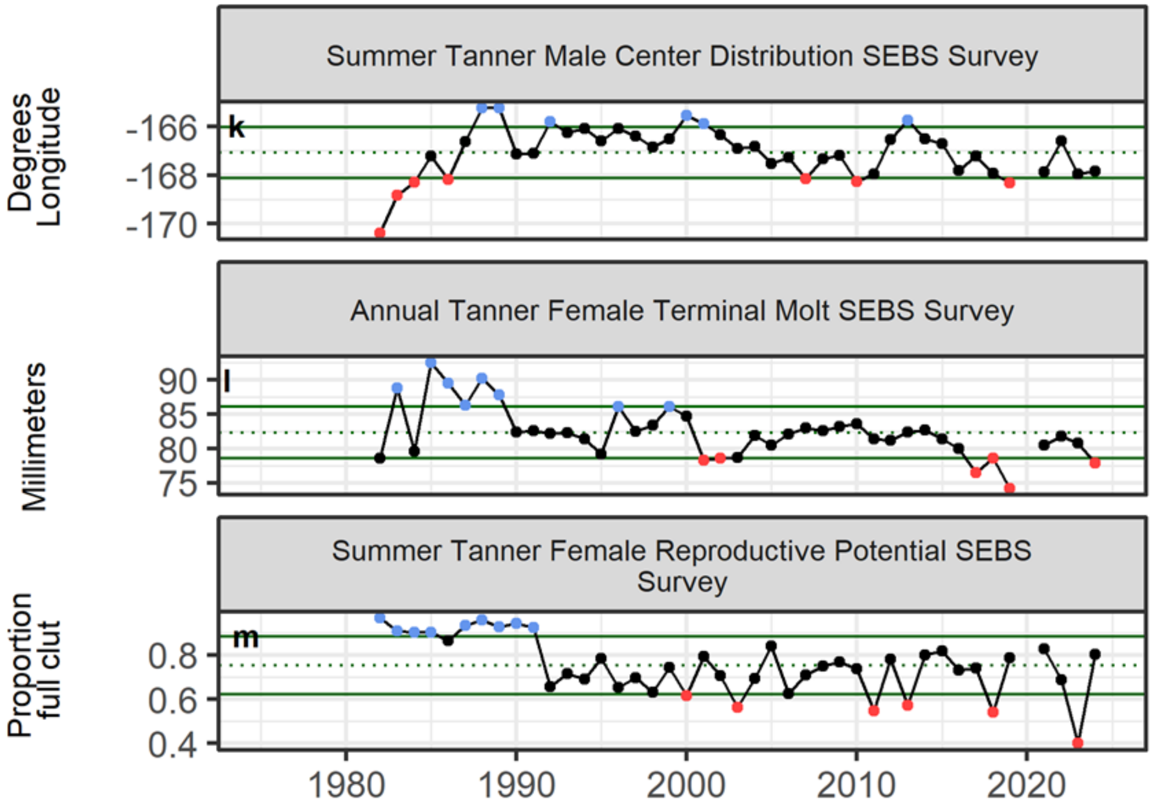

Figure E.2a (cont.): Selected ecosystem indicators for EBS Tanner crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series 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.

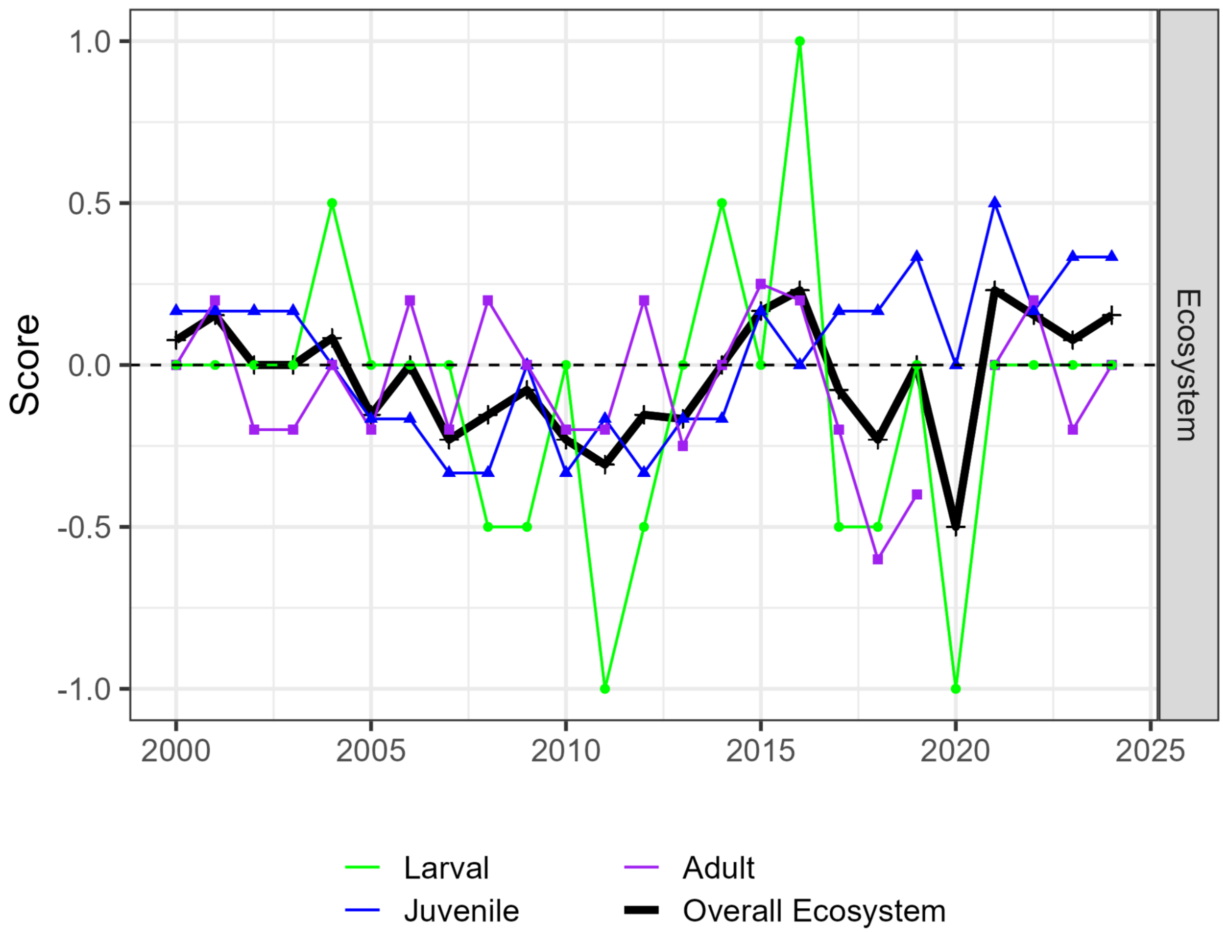

Figure E.3: Simple summary traffic light score by overall ecosystem and category (larval, juvenile, and adult) for ecosystem indicators from 2000 to present.

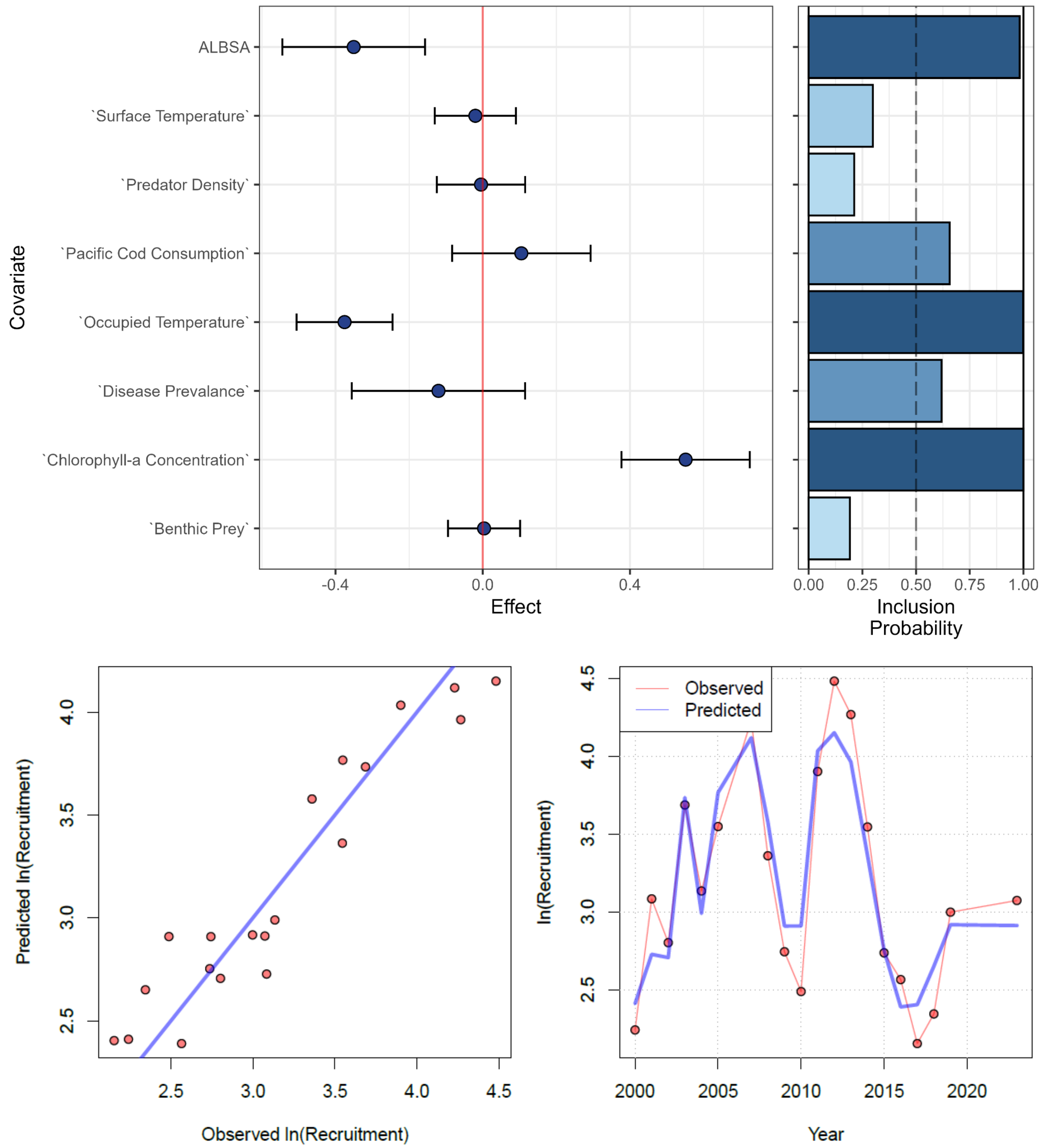

Figure E.4: Bayesian adaptive sampling output showing the mean relationship and uncertainty (95% CI) with log-transformed estimated EBS Tanner crab recruitment from the SEBS bottom trawl survey: the estimated effect (top left) and the marginal inclusion probabilities (top right) for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model predicted fit (1:1 line, bottom left) and average fit across the abbreviated recruitment time series (2000-2021, bottom right).