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

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September 2025

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This report may be cited as: Hennessey, S.M., and B. Garber-Yonts. 2025. Appendix D. Ecosystem and Socioeconomic Profile of the Tanner crab stock in the Eastern Bering Sea. *In*: Stockhausen, W.T. 2025. Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK. Available from: https://www.npfmc.org/library/safe-reports/.

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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.

Acceptable Biological Catch (ABC) Considerations:

The following are summary results from the indicator analysis that can inform ABC decisions:

Predictive Indicators:

- Juvenile Tanner crab temperature occupied, integrating ecological effects of bottom temperature, cold pool extent, and species interactions, increased to slightly above average, at 3.5°C. This suggests the potential for average growth and survival in the following year.
- Benthic predator density in core Tanner crab habitats reached all-time lows during the 2018-2021 marine heatwave. However, predator density has been increasing annually since 2021, which has the potential for increased predator-prey interactions and reduced survival of juvenile cohorts.
- Strengthening summer along-shelf wind since 2022 may facilitate transport of Tanner crab larvae to more suitable settlement habitats, predicting increasing larval survival over this period. This may also contribute to subsequent increased recruitment to the fishery over the next 3-5 years.

Contextual Indicators:

- Visual prevalence of bitter crab disease (BCD) doubled from the previous year to 2.7%, the 2nd highest value to date. This coincided with a large abundance of small (< 70mm) Tanner crabs observed by the NOAA bottom trawl survey in 2025, which suggests the potential for higher disease mortality. However, it is unclear if BCD has large and lasting effects on the stock.
- A northwest stock distribution shift and range expansion since 2021 coincided with depressed snow crab abundance. This spatial distribution shift suggests increased utilization of northern outer shelf habitats and the potential for increased competition with snow crab, although mature males underwent a range contraction in 2025.
- Male size at terminal molt estimates increased dramatically in 2025 from slightly below the time series mean to 109.4mm, the highest value since 1997. Female size at maturity increased from

below average to near average sizes and mature female Tanner crab reproductive failure remains low at 2.9%, suggesting high reproductive potential of the stock.

Fishery-Informed Indicators:

- Fishing effort in the 2024/25 fishery, as measured by number of active vessels (20), was below the post-rationalization average of 27, but consistent with the level of 19-21 vessels during the previous four seasons. Total potlifts increased in both the east and west components of the fishery compared to the previous season. However, the eastern component's 21 thousand potlifts remained below the post-2005 average of 33 thousand, while the western component's 49 thousand potlifts were substantially greater than the historical average of 28 thousand.
- TAC utilization in both the eastern and western Tanner fisheries was at near-100% in the 2024/25 fishery, consistent with limited availability of other targets for crab vessels and continued robust market demand for Tanner crab.
- CPUE of retained crab in the 2024/25 eastern fishery declined from the previous season to 43.6, but was only slightly below the post-2005 average of 46.6; CPUE in the western fishery increased substantially from the previous season, to 57, well above the post-2005 average of 39.8.
- The center of distribution of fishing activity in the 2024/25 fishery generally remained well within the historical range in both the east and west components, although at 167°W, the western component of the fishery was centered near the eastern bound of the historical range, consistent with the previous three seasons.

Total Allowable Catch (TAC) Considerations:

The following are the summary results from the indicator analysis that can inform TAC decisions:

- All ABC considerations above can be used to inform TAC considerations within the purview of the ADF&G TAC setting process. While ecosystem indicators in the monitoring category may also be relevant to TAC considerations, we do not synthesize them here (but see Figure D.2a for current-year trends).
- Economic and community indicators reflect the increased importance of the EBS Tanner crab fishery to industry and community stakeholders, as the fleet consolidates to maintain efficiency in response to limited availability of historical mainstay EBS snow and Bristol Bay red king crab fisheries, while the crab industry continues to face continued financial stresses as a result of stock conditions and market volatility.

Responses to SSC and Plan Team Comments on ESPs in General

"*The CPT discussed a new approach to categorize ESP indicators into predictive and contextual indicators. ... The SSC provisionally supports this approach, but would like the opportunity to review an example ESP where this approach is applied before fully endorsing it.*" (SSC, June 2025)

We intend for the full Tanner ESP to serve as an example of this approach, and look forward to SSC and CPT feedback.

"*The CPT requested more information on how indicators were initially identified and the relationships of ecosystem indicators with crab response variables. While the primary focus here is ecosystem indicators, the SSC notes that information on how fishery performance and socioeconomic indicators were chosen should also be included.*" (SSC, June 2025)

Fishery performance/fishery-informed indicators were identified by the CPT based on previous iterations of ESPs for other crab stocks, which have been informed by considerations identified by ADFG in the TAC-setting process for the respective crab stocks/fisheries, focusing on metrics of the level, location, and efficiency of fishing effort. Similarly, economic and community indicators were specified on the basis of what has been previously reported in crab ESPs, including the return of community indicators, which had been largely suspended from ESPs pending general guidance from the SSC and Council regarding priorities for ESP/socioeconomic indicators to inform TAC setting; a novel economic indicator was added to the Tanner crab ESP - lease cost as percent of ex-vessel gross value (Lease Cost Share), which captures a particularly dynamic effect of the consolidation of the active fleet in response to low TACs across Bering Sea crab fisheries. We address the request for more information on ecosystem indicator identification and relationships with recruitment in the section below.

Responses to SSC and Plan Team Comments Specific to this ESP

"The CPT asked for information that was used in the initial identification of indicators, including providing relationships of the ecosystem indicators with crab response variables. The CPT suggested that including the response variable(s) in the time series plots for comparison would be useful." (CPT, May 2025)

The conceptual diagram (Figure D.1) was used for ecosystem indicator development, identifying vulnerabilities based on life history stage from the literature and expert knowledge, and the "Factors influencing trends" and "Implications" bullet points underneath each ecosystem indicator in the Indicator Suite section identify the rationale for the proposed relationship/mechanism. We have added a new figure (Figure D.5) displaying the lagged and standardized ecosystem indicators tested in the final Bayesian Adaptive Sampling Model overlaid with our Tanner crab recruitment response variable.

"The CPT discussed whether to use survey data or model output estimates for recruitment as a response variable in indicator selection and in the Bayesian Adaptive Sampling (BAS) analysis, especially given the eventual aim to include the indicators in assessments. It could be helpful to review data inputs to other ESPs to consider response variables." (CPT, May 2025)

Thank you for this suggestion. While we did not have time to explore this yet, we intend to further test and refine our response variables in future iterations of this process.

"The CPT commented that crab distribution may be influenced by where the fleet is fishing and is not simply a reflection of population movement. In addition, the distribution could be a product of larval release location. Therefore the indicator based on the centroid of adult male distribution is not a simple indicator of population status." (CPT, May 2025)

We agree that Tanner crab distributions can be influenced by many factors and the centroid of adult male distribution is not an indicator of population status. We have clarified the intent of this indicator in the text, as the centroid of adult male distribution was constructed to provide context on the distribution of the stock itself.

"The CPT discussed that alternative female reproductive potential metrics might be considered and that it would be helpful to consider what question is being answered in the metric chosen. The current metric of the proportion of females that have a full clutch (measured on the survey as ¾ to full) reflects high reproductive potential. The CPT suggested that a metric that reflects low potential may be more informative of poor environmental conditions and a useful metric when there is future population concern." (CPT, May 2025)

We have created a metric of reproductive failure and are using this new indicator in the place of reproductive potential. While clutch fullness can also indicate the potential status of mate availability, with females using sperm reserves having decreased clutch fullness, and reproductive failure is generally low in EBS Tanner crab, we also identified a change in clutch index protocol in the NMFS survey that impacted our fullness metric prior to 1998. This, in conjunction with the CPT's recommendation, informed our use of reproductive failure to both better capture potentially poor environmental conditions influencing reproductive output and to maximize time series length for indicator importance analyses.

"The CPT asked for more information on the lags used for each metric in the BAS analysis, as they were not available in the presentation. The author indicated that larval indicators were lagged 4 years, indicators for juveniles were lagged 2 years and some others 1 year. The CPT discussed that these lags need additional consideration (e.g., the lag for the larval indicators was considered to be too short) and explanation in the final ESP." (CPT, May 2025)

We have reassessed and modified the lags and have provided more rationale for each lag in the Indicator Monitoring Analysis section. We will also provide more detailed information in the presentation to CPT in September.

"The CPT asked that the results of the BAS analysis include the posterior probability distributions for the model predictions for inclusion on the model fit plot as well as an interpretation of the results in terms of the percent influence each indicator has (e.g., what does a 0.4 for chlorophyll-a concentration mean in terms of changes in recruitment?). Both types of information should be readily available from the results of the BAS analysis. The model fit plot would be enhanced by adding the sampling-based confidence intervals to the data." (CPT, May 2025)

We are currently working to add the sampling-based confidence intervals to the data on the model fit plot, as well as interpretation of the results in terms of the percent influence of each indicator, and will incorporate this into subsequent iterations of this document, but have been unable to complete this as of yet.

"The CPT commented that the time series of indicators used in the BAS analysis are short and that the analysis could be better informed by a longer time series. As the start of the time series is limited by availability of data, the CPT suggested that data for some indicators go back further in time and might be included in an analysis with fewer indicators. The CPT also suggested there might be ROMS output that could be used to extend, in particular, the chlorophyll-a time series further back in time." (CPT, May 2025)

We have revised our analysis to only include indicators that allow for maximum time series length, removing chlorophyll-a concentration from consideration. Including ROMS output is not tractable at this time as the Bering10K model has been reported to have limited skill in reproducing observed spatial and temporal patterns of primary production (Kearny et al., 2020). We note that the time series length constraint of the BAS analysis continues to be a challenge and we are working on exploring other analysis frameworks, such as Dynamic Structural Equation Modeling (DSEM), that may be better suited to the nature of the data we have available.

"The CPT commented that for the economic indicators, it would be interesting to look at the centroid of the fishery in relation to the centroid of the stock from the survey." (CPT, May 2025)

This is likely feasible, but incorporation of additional locational indicators for the fishery awaits CPT consideration of the ESP's initial set of fishery-informed indicators before introducing additional candidates.

"The CPT suggested that a challenge in using socio-economic indicators is that they are based on past data, and it would be useful to have a discussion at the CPT, SSC and Council levels on what is the best information that we have the capacity to provide that is likely to be the most useful to stakeholders." (CPT, May 2025)

Strongly agreed; given the inherently retrospective empirical data collection processes regarding- and limitations on accurately forecasting - socioeconomic factors, particularly those specific to individual stocks/fisheries, authors await guidance from the SSC and Council regarding priority socioeconomic information to inform recurring annual management decisions (e.g. ABC/OFL and TAC-setting) and, ideally, more specific criteria for selection of socioeconomic indicators in the respective categories. This guidance would be most useful if it would address the limited role the Council and NMFS play in TAC setting for crab stocks.

"*A draft ESP was also presented and the CPT provided a number of recommendations to the stock assessment author. The SSC concurs with the CPT recommendations and looks forward to the final ESP in October 2025. The SSC also discussed the utility of long-term indicators in the context of changing environmental conditions and recommends adding an indicator on the effects of temperature on size of maturity. While long-term indicators provide historical context, they may not provide adequate context for future conditions. The SSC suggests continued evaluation of indicators and their overall utility.*" (SSC, June 2025)

This is valuable feedback and is something we will continue to consider and incorporate as we develop indicators and methodologies to evaluate indicator importance. Our current understanding of how temperature affects size at maturity is still incomplete, but analyses are in progress to explore this question. While providing context for future conditions is important, we first have to evaluate stock-indicator relationships and assess predictive capacity before we can use any of these relationships to forecast. Additionally, we need to undergo adequate skill testing on these forecasts for them to be useful. However, we will continue to iterate and evaluate our indicators to work towards this goal.

Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, a gap remains between conducting ecosystem research and integrating it with 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. The high ecosystem role, recruitment variability, commercial importance and constituent demand of the stock created a high score for stock assessment prioritization (Methot, 2015). The vulnerability scores were moderate based on habitat assessment prioritization (McConnaughey et al., 2017), and high sensitivity with moderate exposure based on future climate vulnerability (Spencer et al., 2019). The new data classification scores for EBS Tanner crab suggest a data-moderate stock with high quality data for catch and abundance, and moderate quality data for size/age composition, life history categories, and ecosystem linkages (Lynch et al., 2018). These initiative scores and data classification levels suggest a moderate to high priority for conducting an ESP for EBS Tanner crab. Additionally, 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 D.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 D.2a). Larval stage indicator development utilized blended satellite data products from NOAA, NASA, and ESA. Data for late-juvenile through adult EBS Tanner crab stage indicators 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 D.1, Table D.1) and economic performance (Table D.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 D.2), and use this information to create a summary conceptual model of this information (Figure D.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. Wind-driven advection of Tanner crab larvae may also transport them to favorable settlement habitat (Rosenkranz et al., 2001). 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 decreasing sea ice, 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

As described below, the set of socioeconomic indicators proposed in this ESP are categorized as Fishery Performance, Economic Performance, and Community indicators. Fishery Performance indicators are intended to represent processes most directly involved in prosecution of the EBS Tanner crab fishery, and thus have the potential to differentially affect the condition of the stock depending on how they influence the timing, spatial distribution, selectivity, and other aspects of fishing pressure. Economic Performance indicators are intended to capture observable dimensions of key economic drivers of fishery performance and fleet behavior, and along with Community indicators, capture some of the most proximate economic effects within the harvest and processing sectors of the fishery.

Notwithstanding these categorical distinctions of indicators, the social and economic processes that affect, and are affected by, the condition of the stock are complex and interrelated at different time scales. While the complex of reciprocal linkages between condition of the EBS Tanner crab stock and fishery and economic performance-related processes may be hypothesized in principle, no conceptual model currently exists that is adequate to support practical predictive application of socioeconomic indicators comparable to that of ecosystem indicators for informing the Tanner crab assessment. Data collection and monitoring of most socioeconomic processes in the EBS Tanner crab fishery are conducted during or after the fishing season, and typically result in a data lag of up to two years behind the current assessment. Consequently, the current status of socioeconomic processes conditioned by the conduct and output of the fishery cannot be captured in indicators that provide advance predictive information for use in informing the current stock assessment and harvest specification processes. As such, in the context of the ESP, available time series of socioeconomic indicators are largely limited to providing a general frame of reference regarding socioeconomic factors associated with historic fishery management, to inform interpretation of historic patterns observed in other data series captured in the assessment and, potentially, stimulating research on linkages between socioeconomic processes and stock condition.

Socioeconomic processes associated with fisheries are strongly influenced by the institutional structures of fishery management, which develop over time and include both measures undertaken in the course of in-season management, as well as comprehensive changes in management and industry structures that induce complex, multidimensional change affecting numerous social and economic processes. Implementation of the Crab Rationalization (CR) Program, including the shift from Guideline Harvest Level (GHL) to TAC management (effectively controlling harvest overages) beginning in 2005 is an example of the latter, and arguably represents a regime shift in management and economic structure of the fishery (a full summary of the management history of the EBS Tanner crab fishery is beyond the scope of the ESP; see NPFMC, 2017 and Nichols et al., 2021). Among other changes, the CR program resulted in rapid consolidation of the BSAI crab fleet, from a high of 272 vessels in 1994 to 78 during the first year of the CR program.

The allocation of tradable crab harvest quota shares, with leasing of annual harvest quota, had a profound impact on the fishing fleet. This system facilitated fleet consolidation and improved operational and economic efficiency, changing the timing of the fishery from short derby seasons to more extended seasons, and inducing extensive and ongoing changes in harvest sector ownership, employment, and income. Crab processing sector provisions of the CR program include allocation of transferable processing quota shares (PQS), leasing of annual processing quota and custom-processing arrangements that enable PQS holders that do not operate a processing plant to purchase IFQ crab landings and direct them to a processing plant for custom processing, and community protection measures, including regional designation on harvest quota, requiring associated catch to be landed to ports within a specified region.

While these and other elements of CR program design facilitated similar operational and economic efficiencies in the harvest sector, with more limited consolidation of processing capacity to somewhat fewer plants in fewer locations, they have also limited some economic adjustments that would likely have occurred in their absence. Unalaska/Dutch Harbor has historically and to-date received the largest share of EBS Tanner crab landings, with Akutan, Kodiak, and King Cove representing the other principal landing ports since 2005, and Kodiak receiving the second largest share of landings over the most recent five years. See the Council's 17-Year Program Review for the CR Program for detailed description and analysis of program structure and management (NPFMC, 2024).

These and other institutional changes continue to influence the geographic and inter-sectoral distribution of benefits produced by the EBS Tanner crab fishery, both through direct ownership and labor income in the crab harvest and processing sectors, and indirect social and economic effects on fishery- dependent communities throughout Alaska and the greater Pacific Northwest region. The full range of available metrics reflecting fishery, economic, and social processes cannot be captured within the scope of the ESP framework. A more comprehensive suite of metrics and indicators intended to inform Bering Sea crab fishery management, including annual harvest specifications as well as consideration of management measures addressing distributional issues or mitigation of social and economic effects of stock declines, low TAC levels and fishery closures, are provided in the annual Crab Economic SAFE and ACEPO reports.

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 may 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 D.2a (ecosystem indicators) and Figure D.2b (socioeconomic indicators). Ecosystem indicators are also listed in a status table for quick reference over the past five years in Table D.3a.

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 D.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 D.2).
- “Neutral”: Used in Table D.3 for any value within 1 standard deviation of the mean.
- “High” or “Low”: Used in Table D.3 if the value was more than 1 standard deviation above or below the mean (above or below the solid green lines in Figure D.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 D.2a.a-b)</u>

a. 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 five years for intermediate stage indicator analysis.
    - Contact: S. Hennessey

- Status and trends: Summer surface temperature increased slightly from 2024 to 2025, and remained below the 43-year time series average.
- Factors influencing trends: Warmer summer surface temperatures coincide with a weakening in the Aleutian Low pressure system and decreased sea ice extent (Rodionov and Overland, 2005).
- Implications: Higher surface temperatures can favor the production of key larval prey and may also lead to increased larval growth (Armstrong et al., 1981; Zheng and Kruse, 2000).

b. May-June Along-Shelf Wind: Average monthly May – June along-shelfbreak component of interpolated 4x daily NCEP/NCAR reanalysis 10m winds (2° x 2° resolution; m/s). Proposed sign of the relationship is positive, and the time series is lagged five years for intermediate stage indicator analysis.
   - Contact: T. Hennon
   - Status and trends: Southeasterly along-shelf winds have been increasing since 2020, but decreased from high conditions in 2023 to slightly above average in 2024; (2025 results pending).
   - Factors influencing trends: Wind strength and direction in the eastern Bering Sea is largely influenced by the strength and position of the Aleutian Low pressure system, with a stronger Aleutian Low associated with stronger winds (Stabeno et al., 2001).
   - Implications: Increased along-shelf winds favor offshore transport of larval crabs, carrying them to more suitable settlement habitat and potentially increasing overlap with prey resources (Rosenkranz et al., 2001).

<u>2. Juvenile Indicators (Figure D.2a.c-h)</u>

c. Chlorophyll-*a* Concentration: Mean April – June 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.
   - Contact: M. Callahan and J. Nielsen
   - Status and trends: Chlorophyll-*a* concentration increased to a time series high in 2025 following a slight decrease in 2024.
   - 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 increased by almost 0.7°C from 2024 to 2025, with the 2025 estimate falling slightly above the 43-year average.

- Factors influencing trends: Temperatures occupied by juvenile Tanner crab are influenced by bottom temperatures in the Bering Sea and cold pool extent, due to warmer-water habitat preferences of juveniles (Rosenkranz et al., 2001, Ryer et al., 2016), as well as density-dependent processes.
- Implications: Occupied temperatures below 2°C may be indicative of reduced habitat availability and slower growth for juvenile Tanner crabs, as juvenile growth is inhibited at these low temperatures (Ryer et al., 2016). This may also coincide with increased overlap and competitive interactions with snow crab.

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 – 2025). Proposed sign of the relationship is negative as these fish species are major predators of juvenile Tanner crab, and the time series is lagged three years for intermediate stage indicator analysis.
    - Contact: S. Hennessey
    - Status and trends: The density of key benthic predators continued to increase slightly in 2025, but remains below average.
    - Factors influencing trends: Declines in the spatial extent of the cold pool coincides with both increased benthic predator density and spatial overlap between predators and juvenile Tanner crab, which may lead to increased predation pressure (Lang et al., 2003; Livingston, 1989).
    - Implications: Increases in benthic predator densities may lead to elevated predation pressure on Tanner crab juveniles, especially if this increase is coupled with greater Tanner crab recruitment. However, this may not have a strong negative impact on the stock if juvenile Tanner crab are in sufficient densities or there is low overlap with benthic predators.

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 three 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 remained slightly above the 40-year average; (2025 results pending).
    - 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 (Livingston, 1989).
    - Implications: Increases in Pacific cod consumption of Tanner crab often coincide with years of strong Tanner crab recruitment, which may lead to an increase in top-down predation pressure. However, greater consumption on small Tanner crab does 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 three years for intermediate stage indicator analysis.

- Contact: S. Hennessey
- Status and trends: Visually-diagnosed BCD prevalence doubled from 2024 to 2025, to 2.7%, which is the 2nd highest value of the 36-year time series. 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: High visual BCD prevalence often coincides with large recruitment events of small (20-40mm) Tanner crab. This may contribute to reduced survival to larger juvenile size classes. However, it is unclear if BCD has large and lasting effects on the stock.

h. Summer Benthic Invertebrate Density: Summer benthic invertebrate density (kg/km²), estimated from EBS bottom trawl survey stations included in the 50th percentile of mean Tanner crab CPUE across years (1988 – 2025). 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 remained high in 2025.
    - 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 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. However, the bottom trawl survey does not sample key prey items such as polychaetes and bivalves well, and this indicator is therefore a relatively coarse proxy for prey quantity for Tanner crab.

<u>3. Adult Indicators (Figure D.2a.i-m)</u>

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 2025 from slightly below the time series mean to above average. This follows the 2nd lowest value in the time series in 2023, and is the highest value on record since 1997.
    - 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 declined to near average, following all-time high values in 2023 and 2024.
    - Factors influencing trends: The spatial extent of Tanner crab in the EBS can 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: Range expansion of mature male Tanner crab often coincides with increased abundances of large males. However, there may also be implications for density-dependent prey limitations or competition with snow crab (Murphy, 2020).

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 2025 mature male center of abundance was the farthest west observed in the 43-year time series to date, decreasing from the previous three years and continuing an overall westward shift over time.
    - Factors influencing trends: Center of mature male abundance track bottom temperatures and interactions with other species such as snow crab (Murphy, 2020), and may also be impacted by the spatial distribution of the fishing fleet.
    - 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 increased from well below the 43-year average to a near-average size of 82mm carapace width.
    - 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 decreases in size may not have a strong negative impact on the stock.

m. Female Tanner Crab Reproductive Failure: The proportion of hardshell mature female Tanner crab with no eggs, empty egg cases, or dead eggs. Proposed sign of the relationship is negative.
    - Contact: S. Hennessey

- Status and trends: The proportion of mature female Tanner crab with reproductive failure remained slightly below average, with 2.9% of hardshell females having empty or dead clutches.
- Factors influencing trends: Female reproductive failure is driven by the inability to find a mate, and/or utilize stored sperm reserves to fertilize egg clutches (Webb, 2008; Webb et al., 2016; Murphy et al., 2017). An increased frequency of clutch failure may indicate sperm limitation, or energetic limitations imposed on extrusion and fertilization. Barren clutches can also be attributed to senescence, suggesting that a mature female population composed of old-shell females (primarily shell condition 5) may drive year to year trends in the proportion of empty clutches.
- Implications: A low proportion of mature females with empty clutches indicates higher reproductive potential, and suggests that the majority of females were able to find mates or utilize stored sperm during the mating season.

Socioeconomic Indicators:

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

ab. 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 east and west of 166°W EBS Tanner crab management areas.

- Contact: B. Garber-Yonts and J. Lee
- Status and trends: The number of vessels active in the fishery during 2024 declined to 18 in the eastern component and 12 in the western component, substantially declined from the previous calendar year's 21 and 18 vessels, respectively, and among the lowest levels of participation during a period when both eastern and western components of the fishery were open.
- Factors influencing trends: Tanner crab fisheries have historically been harvested as a secondary target by a varying segment of the fleets participating mainly in the EBS snow crab and Bristol Bay red king crab fisheries. With closures and/or low TACs in the primary fisheries, Tanner crab represents an important income source for active vessels, however, efficiency-driven contraction of the respective fleets in response to the limited TACs in snow crab and Bristol Bay red king crab during the most recent open seasons carries over to a proportionally smaller segment targeting Tanner crab.
- Implications: Variation in the size and composition of the active fleet may have implications for overall fleet behavior, including intervessel coordination and search efficiency.

cd. 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 east and west of 166°W EBS Tanner crab management areas.

- Contact: B. Daly
- Status and trends: CPUE of retained crab in the 2024/25 eastern fishery declined from the previous season to 43.6, but was only slightly below the post-2005 average of 46.6; CPUE in the western fishery increased substantially from the previous season, to 57, well above the post-2005 average of 39.8
- Factors influencing trends: Annual fishery CPUE can vary based on a suite of factors including total fishery potlifts, EBS Tanner crab abundance, pot gear soak time, pot gear configuration, bait. weather/tides/sea ice, and fleet dynamics.

- Implications: Changes in CPUE can be used to interpret shifts in relative stock abundance and/or distribution, inform management decisions, and explain timing and distribution of fishing effort.

ef. 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 east and west of 166°W EBS Tanner crab management areas.
- Contact: B. Daly
- Status and trends: Total potlifts increased from the previous season in both the east and west components of the fishery; the 21 thousand potlifts in the eastern component was substantially less than the post-2005 average of 33 thousand, while the 29 thousand potlifts in the western component was greater than the historical average of 28 thousand.
- Factors influencing trends: The increased potlifts reflects the substantially increased TACs in both components of the fishery from the most recent previous seasons combined with the concurrent contraction in the active fleet, noting the different trends in CPUE in the respective components cited above.
- Implications: TBD

gh. Centroid of Fishery - Latitude: Center of gravity, expressed in latitude, as an index of spatial distribution for the Tanner crab fishery to monitor spatial shifts in fishery behavior. This indicator is split by the east and west of 166°W EBS Tanner crab management areas.
- Contact: B. Daly
- Status and trends: The latitudinal center of gravity for the eastern component has remained relatively south from 2021 - 2024, while the western component has been steadily moving north from well below average to near average latitude.
- Factors influencing trends: TBD
- Implications: TBD

ij. Centroid of Fishery - Longitude: 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 east and west of 166°W EBS Tanner crab management areas.
- Contact: B. Daly
- Status and trends: The longitudinal center of the fishery has remained west for the eastern component, while the western component has shifted notably east since 2020.
- Factors influencing trends: TBD
- Implications: TBD

kl. Annual Incidental Catch: Annual incidental catch of Tanner crab in EBS groundfish fisheries. This indicator is split by the east and west of 166°W EBS Tanner crab management areas.
- Contact: B. Garber-Yonts and J. Lee
- Status and trends: Incidental catch in both sections of Tanner crab during 2024 groundfish fisheries was substantially below the long-term average, continuing the trend of consistently low bycatch in the eastern section following the sharp decline in 2019, and slightly exceeding the more recent average in the western section since 2014 of 72.6 thousand metric tons.
- Factors influencing trends: TBD
- Implications: TBD

mn. 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 east and west of 166°W EBS Tanner crab management areas.

- Contact: B. Daly
- Status and trends: TAC utilization in both components of the fishery has reached 100% consistently since 2015 (with the exception of 2020 in the western component).
- Factors influencing trends: Continued full utilization reflects consistent market demand relative to early years of the rationalization program, though ex-vessel pricing for Tanner crab product has declined in the last two years from covid-era peaks; full utilization is further supported recently with greater dependence on the fishery given limited availability of other targets.
- Implications: Full utilization of Tanner crab TACs can be expected to continue provided EBS snow and/or Bristol Bay red king crab fisheries are opened concurrently.

2. Economic Indicators (Figure D.2b.o-r)

o. 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: B. Garber-Yonts and J. Lee
   - Status and trends: Ex-vessel value of the combined Tanner crab catch increased by 29% from the 2023 calendar year, to $10.6 million.
   - Factors influencing trends: Increased gross revenue for 2024 largely reflects increased TAC and production during the year, though ex-vessel price increased modestly.
   - Implications: Although below the long-term mean, the fishery generated significant income for the crab harvest sector.

p. 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: B. Garber-Yonts and J. Lee
   - Status and trends: Ex-vessel price increased modestly from 2023, to $3.75 per pound, after declining sharply from $6.86 in 2022.
   - Factors influencing trends: Strong domestic consumer demand during late-2020 through 2022 appeared to stall, with high inventories in 2023 driving market prices down, but both appeared to stabilize in 2024.
   - Implications: The US embargo of seafood imports from Russia and uncertainty over tariffs on imports from other countries have the potential to improve competitiveness of Tanner crab in the domestic market in 2025/26 and put upward pressure on ex-vessel price.

q. 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: B. Garber-Yonts and J. Lee
   - Status and trends: Ex-vessel revenue share increased modestly from 22% in 2023 to 24% in 2024.
   - Factors influencing trends: The share of total ex–vessel earning remained historically high in 2024, despite the sharp decline in ex-vessel price from the covid-era peak; with low availability of other crab and non-crab targets, Tanner landings remain a significant income source for the consolidated active fleet.
   - Implications: The relatively high level of ex-vessel revenue share during the most recent years indicates increased dependence on the Tanner crab fishery. Whereas variation in ex-vessel price and revenue have implications for income for crab quota holders as well as active vessels, implications of the level of, and interannual variation in, revenue share are primarily limited to the active fleet, its owners and crew members.

r. Lease cost share: Lease cost as percent of ex-vessel gross value.
- Contact: B. Garber-Yonts and J. Lee
- Status and trends: Lease royalties paid by active crab vessels comprised 31% of total ex-vessel value in 2023; (2024 results pending)
- Factors influencing trends: Tanner TACs and the active fleet remained largely stable between 2022 and 2023; with further consolidation of the fleet during 2024, expectations are for substantial increase in the volume of leasing, potentially putting downward pressure on lease rates (share of ex-vessel revenue per pound paid to QS holder).
- Implications: The effect of quota share consolidation on the reduced active crab fleet on participating vessels and crews may be partly mitigated by lower lease rates; noting that idled vessels and crew members do not generally have a mechanism for making income from the fishery in the absence of QS holdings and resulting IFQ royalty payments.

3. Community Indicators (Figure D.2b.s-u)

s. Number of Active Processors: Annual number of active plants processing EBS Tanner crab.
- Contact: B. Garber-Yonts and J. Lee
- Status and trends: The number of active processors taking landings of Tanner crab declined sharply in 2023, to 2 plants from 6 in 2021-2022; (2024 results pending).
- Factors influencing trends: Contraction of crab processing capacity has been a long term trend, but has reached unprecedented levels in 2023. In addition to adjustment of processing capacity to accommodate lower crab TACs, the Alaska processing industry has undergone considerable turbulence recently due to extensive market and financial dynamics beyond the scope of the ESP.
- Implications: Potential critical threshold for processing capacity.

t. Processing Labor Hours: Annual number of hours spent processing EBS Tanner crab.
- Contact: B. Garber-Yonts and J. Lee
- Status and trends: Indicator value for 2023 cannot be reported due to confidentiality; (2024 results pending).
- Factors influencing trends: TBD
- Implications: TBD

u. Local Quotient Landed: Percentage of the TAC that is landed in Unalaska/Dutch Harbor from the EBS Tanner crab fishery.
- Contact: B. Garber-Yonts and J. Lee
- Status and trends: The local quotient for Tanner crab processing revenue in the principal port receiving landings increased to 4% in 2024, up from 3% in 2022-2023, and 1% over the previous 5 years.
- Factors influencing trends: Local quotient has increased in recent years, reflecting modestly increasing first wholesale price in 2024, and substantially increasing volume, compared to trends in groundfish and other fisheries processed at this port.
- Implications: Tanner crab landings remain a small portion of the aggregate volume and value of processed seafood produced from Dutch Harbor/Unalaska plants.

Indicator Monitoring Analysis

Ecosystem and socioeconomic indicators are monitored through distinct workflows, depending on the management decisions they are intended to inform (Figure D.3). Ecosystem indicators generally inform the acceptable biological catch (ABC) and can either be incorporated directly into the model through predictive or causal inference or indirectly through contextual avenues such as risk tables (Dorn and Zador, 2020). Socioeconomic indicators related to the performance or behavior of the fishery can also impact the ABC both directly by informing time-varying fishery selectivity and indirectly through context in the risk table. Other socioeconomic indicators such as those related to the economics of the fishery or the communities that are supported by the fishery impact decisions further downstream of the stock assessment process and generally are used in decisions related to total allowable catch (TAC). Additionally, all indicators selected for monitoring in the ESP may inform TAC deliberations.

We evaluated the ecosystem indicators through a series of stages using statistical tests that increase in complexity depending on the data availability of the stock (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 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.

The three stages can be considered as gates for how to monitor the indicator suite and are generally related to the data availability for the stock assessment. Data-limited stocks would only have enough information for the beginning stage and simple scoring analysis. Age- or length-structured assessment models with moderate to rich data availability would be able to move past the beginning stage or gate and evaluate the indicators using importance methods but outside the assessment model. The most data rich stocks with an integrated ecosystem-linked modeling platform could move past the intermediate stage or gate and evaluate indicators using the advanced methodology (e.g., 'rceattle' with dynamic structural equation modeling or DSEM, Champagnat et al., *in review*).

At this time, we evaluated the socioeconomic indicators using only the beginning stage statistical tests and do not assign a proposed relationship as the role of socioeconomic indicators in the stock assessment process is currently being evaluated by the North Pacific Fishery Management Council (NPFMC or Council, December 2023, 2024 memorandum). Once recommendations are provided after the evaluation, we will update the analysis options for socioeconomic indicators. We also note, per Scientific and Statistical Committee (SSC) guidance, that the socioeconomic indicators can provide a combination of performance and context and any 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).

Ecosystem Indicator Analysis

The EBS Tanner crab stock is data rich with an associated Tier 3 assessment model; therefore the ecosystem indicators were evaluated using intermediate stage methods. Results from this intermediate stage analysis are used to categorize ecosystem indicators as a) predictive indicators that demonstrate a robust quantitative relationship with the population process of interest, b) contextual indicators that provide anticipatory information to inform a management concern or highlight a potential red flag related directly to the status or health of the stock, but lack predictive skill, or c) monitoring indicators that do not demonstrate quantitative links to population processes, nor provide information that is immediately relevant to the stock and/or fishery managers. The intent of this indicator categorization is to succinctly communicate potential red flags for the stock based on current-year indicator trends and stock-indicator relationships, while providing a mechanism to down-weight indicators that don't quantitatively inform population processes. Monitoring indicators are reported in this document and will continue to be evaluated annually, but we limit our interpretation and synthesis to predictive and contextual indicators only in an effort to communicate only the most relevant ecosystem considerations for setting biological reference points for the current year.

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and EBS Tanner crab recruitment, 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). 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 prior to 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*).

Prior to running BAS, the full suite of 13 ecosystem indicators was winnowed to the predictors that directly relate to recruitment. We eliminated mature male area occupied, mature male center of abundance, male size at maturity, female size at maturity, and female reproductive failure, as they are not hypothesized to drive Tanner crab recruitment and instead, provide contextual information about the stock or a relevant management concern. We further restricted potential covariates to those that provided the longest model run, and through the most recent estimate of recruitment when possible. Given the short time series length for chlorophyll-*a* concentration (n = 27 years), this indicator was dropped from the final BAS model.

Ecosystem indicator lags were assigned based on hypothesized mechanistic linkages between the proposed life history stage and the indicator, as well as targeted size ranges that the indicators are hypothesized to have the greatest impact on. Prerecruit male Tanner crab were assumed to be five years old, therefore larval indicators were assigned a lag of five years. Indicators such as juvenile disease prevalence, benthic predator density, and Pacific cod consumption disproportionately impact small Tanner crab size classes, and were therefore assigned a lag of three years. Benthic invertebrate density was assigned a lag of two years, as prey resources and prerecruit energetic condition is likely to be an integrated effect that also depends on more recent conditions to inform survival of prerecruits. Juvenile temperature occupied was assumed to be the most immediate effect with an assigned lag of one year, with the prior year's conditions informing our response variable.

We also eliminated highly correlated indicators ($r \geq 0.6$) prior to running the model, with the understanding that high correlations among predictors may "dilute" inclusion probabilities and render them less useful as a posterior summary of variable importance. None of the remaining indicators were eliminated based on this criterion. Because missing data are dropped from BAS model runs, 14 years were dropped due to incomplete observations, and resulted in a model run from 1992 - 2024. NAs due to the cancellation of the 2020 EBS bottom trawl survey were especially problematic, and resulted in 2020 - 2023, and 2025 being dropped from the analysis after lagging indicators.

The final BAS model used a final suite of seven predictors: summer surface temperature, along-shelf wind, juvenile Tanner crab temperature occupied, disease prevalence, benthic predator density, Pacific cod consumption, and benthic prey density (Figure D.4). We provide the mean relationship between each predictor variable and the estimates of EBS Tanner crab recruitment over time (Figure D.4, top left), with error bars describing the uncertainty (95% credible intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure D.4, top right). Model predicted fit (1:1 line, Figure D.4, bottom left) and average fit across the recruitment time series subset (1992 - 2024, Figure D.4, bottom right) show that these predictors explained a moderate amount of variation in EBS Tanner crab recruitment (R^2 = 0.49). However, we note that the wide credible intervals suggest a large degree of uncertainty in the estimated effects. Additional model diagnostic plots are provided in Figures D.5 and D.6.

The top BAS model had three indicators with an inclusion probability > 0.5 and directional effects that were distinguishable from zero (Figure D.4). These indicators were benthic predator density (effect = -0.43), juvenile occupancy temperature (effect = -0.24), and along-shelf wind (effect = 0.17), and were classified as predictive indicators. However, the direction of the occupied temperature effect was counter to the proposed overall relationship with recruitment. This may be due to the fact that juvenile occupied temperature is also reflective of bottom temperature and cold pool extent, which relate to sea ice dynamics in the system. Colder years lead to ice-associated blooms, which have been linked to increased flux of phytoplankton to the benthos that provides key lipids that lead to increased energetic condition in Tanner crabs (Copeman et al., 2021, 2025), which may explain the negative correlation between occupied temperature and prerecruit abundance. The remaining indicators were sorted into contextual (juvenile Tanner crab disease prevalence, mature male area occupied, mature male center of abundance, male size at maturity, female size at maturity, and female reproductive failure) and monitoring (summer surface temperature, chlorophyll-*a* concentration, Pacific cod consumption, and benthic prey density) categories based on the criteria listed above.

We also summarize recent indicator trends and management considerations by providing a five year status table of the indicators organized into predictive, contextual, or monitoring categories (Table D.3a). Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long term mean. Potential concerns for the health or status of the stock are identified using predictive relationships (predictive ecosystem indicators) or proposed mechanistic relationships (contextual ecosystem indicators) with the stock, and are communicated as a sign and associated color relative to the indicator value and directional indicator-stock relationship. The sign of the relationship for predictive indicators is based on the importance method results, while the sign for contextual or monitoring indicators is based on the conceptual model (Figure D.1). The color of the status cell (also referred to as the "traffic light") is related to the sign of the indicator and the status. 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 table cell is colored blue. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that table cell is colored red. All values less than or equal to one standard deviation from the long-term mean are average and there is no assigned color. Also, if the sign of the relationship between an ecosystem indicator and the stock is unclear, no relationship is assigned.

Along-shelfbreak winds have been generally increasing over the past five years, favoring offshore transport of larvae towards potentially more suitable settlement habitat (Rosenkranz et al., 2001), which may contribute to slightly elevated Tanner crab recruitment to the fishery in ~5 years due to above average larval survival. However, current-year data are not yet available for this indicator. Summer surface temperature, conversely, has decreased in recent years, although it exhibited a slight increase in 2025 but remains near the long term mean. Warmer surface temperatures coincide with a weakening in the Aleutian Low pressure system and decreased sea ice extent (Rodionov and Overland, 2005), and have been correlated with favorable production of key larval prey (Zheng and Kruse, 2000), which may lead to increased larval growth (Armstrong et al., 1981, 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 increased to a time series high in 2025, characteristic of a large, productive spring bloom and the potential for increased benthic production. Benthic invertebrate densities have remained generally high since a peak in 2017, remaining high after a slight decline in 2023. Temperature occupied by juvenile Tanner crab has also increased slightly from 2024 to

2025, with the 2025 estimate falling above the 43-year mean. 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 been increasing since 2021 reaching levels slightly above average. Juvenile Tanner crab disease prevalence doubled from the previous year to the 2nd highest value to date. However, it is unclear if bitter crab disease has large and lasting effects on the stock, and increased prevalence often coincides with high recruitment of small Tanner crab.

Mature male Tanner crab spatial extent declined to near average after an all-time high in 2024, and centroids of abundance are the farthest northwest in the time series. Male Tanner crab size at terminal molt increased dramatically in 2025, from slightly below the time series mean to the highest value since 1997. Female Tanner crab size at maturity also increased, shifting from below average to near average sizes, and mature female Tanner crab reproductive failure remains below average, which may support elevated stock reproductive output.

Socioeconomic Indicator Analysis

We present seven socioeconomic indicators and seven 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 2024 (noting that data is in process for some economic and community indicators and 2024 values are pending as of initial distribution of the ESP). 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.

As noted above, the set of fishery-informed indicators indicate marginally reduced effort overall in the fishery during the 2024 fishing year as measured by number of active vessels, which was below the post-rationalization average of 27, but consistent with the level of 19-21 vessels during the previous four seasons, although active participation in the western fishery declined more sharply. Reflecting increased TACs and consolidated fleets, total potlifts increased from the previous season in both the east and west components of the fishery, particularly in the western component, and fishing activity remained within the historical fishing grounds, generally, though continuing the eastward shift in effort in the western component of the fishery from recent years, with CPUE in the western fishery increasing substantially from the previous season to well above the post-2005 average. Economic and community indicators generally reflect the efficient adjustment of harvesting and processing capacity in response to overall reduced availability of crab targets, and highlight the sustained importance of the EBS Tanner crab fisheries as market demand remains relatively strong despite the sharp decline in demand post-covid and lingering effect of high inventories. It is important to note, however, that available indicators are limited to systematic data collection that records active harvest and processing observations, but does not capture socioeconomic effects of the contraction on owners and operators of idled crab vessels and crewmembers, reduced processing employment, and tax revenues in crab processing communities.

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). The indicator synthesis provides a comprehensive literature review with accompanying ecological synthesis and mechanism tables to support indicator selection. Thirteen ecosystem and 14 socioeconomic indicators were identified to monitor for EBS Tanner crab. There were sufficient data and a complex stock assessment model available for this stock and, therefore, the ecosystem indicators were evaluated using intermediate stage methods.

The importance method explored to date was Bayesian Adaptive Sampling. This method identified three indicators with high inclusion probability (> 0.5) and a directional effect distinguishable from zero for explaining variability in EBS Tanner crab recruitment. The socioeconomic indicators were evaluated using beginning stage simple scoring analysis.

We provide several overarching takeaways from the indicator synthesis and assessment results. This information can be used for evaluating concerns in the main stock assessment or other management decisions and we organize the results by acceptable biological catch (ABC) and total allowable catch (TAC) considerations. Indicators that can inform ABC include predictive, contextual, or fishery-informed indicators. Indicators that can inform TAC include all ABC indicators as well as economic and community indicators. Predictive indicators (inclusion probabilities > 0.5 and effect distinguishable from zero) suggest that juvenile Tanner crab may experience relatively average growth and survival with slightly above average temperature occupied. These predictive indicator results have potential to be used within the stock assessment model in an ecosystem linked assessment. Contextual indicators suggest that the stock may have high reproductive output, but there may be increased overlap with snow crab due to the increased utilization of the northern outer shelf by mature male Tanner crab, as well as potentially elevated juvenile mortality due to high disease prevalence. Fishery-informed indicators suggest generally stable stock conditions relative to the most recent seasons and the post-2005 historical record. No considerations observed in the most recent fishery suggest greater than normal risk of overfishing. Predictive, contextual, and fishery-informed indicators can be used for risk tables. Specifically, the majority of stock-specific ecosystem indicators related to natural mortality, growth, and recruitment suggest no additional concerns, and ecosystem concerns are minor with uncertain impacts on the stock. The Tanner crab fishery has become more important to industry and community stakeholders, as shown by the economic and community indicators. This is a direct result of the fleet consolidating to maintain efficiency in response to limited availability of historical mainstay EBS snow crab and Bristol Bay red king crab fisheries, and shift is happening while the crab industry continues to face financial stress as a result of stock conditions and market volatility.

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 developing indicators for juvenile Tanner crab cohort progression, stock spatial patchiness, Tanner crab/snow crab overlap, and the effects of temperature on male and female size at maturity, as well as refining the wind indicator and potentially including an indicator for sea ice retreat timing instead of chlorophyll-a concentration to better capture the relationship between benthic/pelagic flux and juvenile condition.
- The indicator importance analysis should also be improved upon, including the further evaluation of lags and potential integrated effects of indicators over several years. The exploration of different modeling frameworks such as Dynamic Structural Equation Models to better understand causal relationships between indicators and recruitment is also a priority.

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.
- Systematic socioeconomic data collection is largely limited to active vessel and processing participants in BSAI crab fisheries. While the ESP can only capture a limited number of socioeconomic indicators, it is important to note that many of the most important, and in many cases, severe economic stresses facing the crab industry and associated communities are beyond the scope of systematic monitoring and data collection systems.
- ESP authors continue to await guidance from the SSC and Council regarding priority socioeconomic information to inform recurring annual management decisions (e.g. ABC/OFL and TAC-setting) and, ideally, more specific criteria for selection of socioeconomic indicators in the respective categories. This guidance would be most useful if it would address the limited role the Council and NMFS play in TAC setting for crab stocks.

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).

Acknowledgements

We would like to thank all the contributors for their timely response to requests and questions regarding their data, report summaries, and manuscripts. We thank the staff of the Shellfish Assessment Program, Groundfish Assessment Program, Marine Lipid Laboratory, and the Food Habits Laboratory for the rapid turnaround of survey data and field-collected samples to facilitate timely uptake and incorporation into this document. We also thank the Crab Plan Team and SSC for their helpful insight on the development of this report and future reports. We would also like to thank the AFSC personnel and divisions, the Alaska Department of Fish and Game, and the Southwest Fisheries Science Center CoastWatch Program for their data contributions. We thank the Alaska Fisheries Information Network and neXus Data Solutions teams for their extensive help with data management and processing for this report. Finally, we thank Dr. Abigail Tyrell for assistance in coding and automating ESP report cards.

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Tables

Table D.1: List of data sources used in the ESP evaluation. Please see the main EBS Tanner crab SAFE document, the Ecosystem Status 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
NOAA Physical Science Laboratory database	Interpolated 4x daily NCEP/NCAR reanalysis 10m winds (2° x 2° resolution; m/s)	1948-present	Global
ESA Ocean Colour CCI	4 km blended chlorophyll-a concentration data aggregated to 8-day composites of satellite ocean color	1998-present	Global
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 D.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, 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 D.2b: 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 D.3a: 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	2021 Status	2022 Status	2023 Status	2024 Status	2025 Status
Predictive	Juvenile Tanner Crab Temperature of Occupancy	*high*	neutral	neutral	neutral	neutral
	Summer Benthic Predator Density	*low*	neutral	*low*	neutral	neutral
	May-June Along-Shelf Wind	neutral	neutral	*high*	neutral	NA
Contextual	Summer Juvenile Tanner Crab Disease Prevalence	neutral	**high**	neutral	neutral	**high**
	Male Tanner Crab Size at Terminal Molt	neutral	neutral	**low**	neutral	*high*
	Male Tanner Crab Area Occupied	neutral	neutral	*high*	*high*	neutral
	Male Tanner Crab Center of Abundance	neutral	neutral	***west***	***west***	***west***
	Female Tanner Crab Size at Maturity	neutral	neutral	neutral	**low**	neutral
	Female Tanner Crab Reproductive Failure	neutral	neutral	neutral	neutral	neutral
Monitoring	Summer Surface Temperature	neutral	neutral	neutral	neutral	neutral
	Chlorophyll-a Concentration	neutral	*high*	*high*	neutral	*high*
	Summer Pacific Cod Consumption	neutral	neutral	neutral	neutral	NA
	Summer Benthic Invertebrate Density	*high*	*high*	neutral	*high*	*high*

Table D.3b: First stage socioeconomic 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). A gray fill and text = "NA" will appear if there were no data for that year. A red color indicates a fishery closure and the text = "closed" will appear. Note that the year heading references calendar year; the EBS Tanner crab fishery is prosecuted Oct-May, such that the calendar year corresponds to the first period of the crab season-year; the most recent EBS Tanner crab fishery occurred during the 2024/25 crab season.

Indicator category	Indicator	2020 Status	2021 Status	2022 Status	2023 Status	2024 Status
Fishery Informed	Number of Active Vessels - East of 166°W	closed	closed	neutral	neutral	neutral
	Number of Active Vessels - West of 166°W	neutral	neutral	neutral	neutral	neutral
	Fishery CPUE - East of 166°W	closed	closed	neutral	high	neutral
	Fishery CPUE - West of 166°W	low	neutral	neutral	neutral	high
	Fishery Total Potlifts - East of 166°W	closed	closed	neutral	neutral	neutral
	Fishery Total Potlifts - West of 166°W	neutral	neutral	neutral	neutral	neutral
	Centroid of Fishery, Latitude - East of 166°W	closed	closed	neutral	neutral	neutral
	Centroid of Fishery, Latitude - West of 166°W	neutral	low	low	neutral	neutral
	Centroid of Fishery, Longitude - East of 166°W	closed	closed	low	neutral	neutral
	Centroid of Fishery, Longitude - West of 166°W	neutral	high	high	high	neutral
	Annual Incidental Catch - East of 166°W	neutral	neutral	neutral	low	low
	Annual Incidental Catch - West of 166°W	neutral	neutral	neutral	neutral	neutral
	TAC Utilization - East of 166°W	closed	closed	high	high	high
	TAC Utilization - West of 166°W	neutral	high	high	high	high

Indicator category	Indicator	2020 Status	2021 Status	2022 Status	2023 Status	2024 Status
Economic	Ex-vessel Value	neutral	neutral	neutral	neutral	neutral
	Ex-vessel Price	neutral	high	high	neutral	neutral
	Ex-vessel Revenue Share	low	neutral	high	high	high
Community	Leasing	high	neutral	neutral	high	NA
	Number of Active Processors	neutral	neutral	neutral	low	NA
	Processing Labor Hours	neutral	neutral	neutral	neutral	NA
	Local Quotient Landed	neutral	neutral	neutral	neutral	neutral

Figures

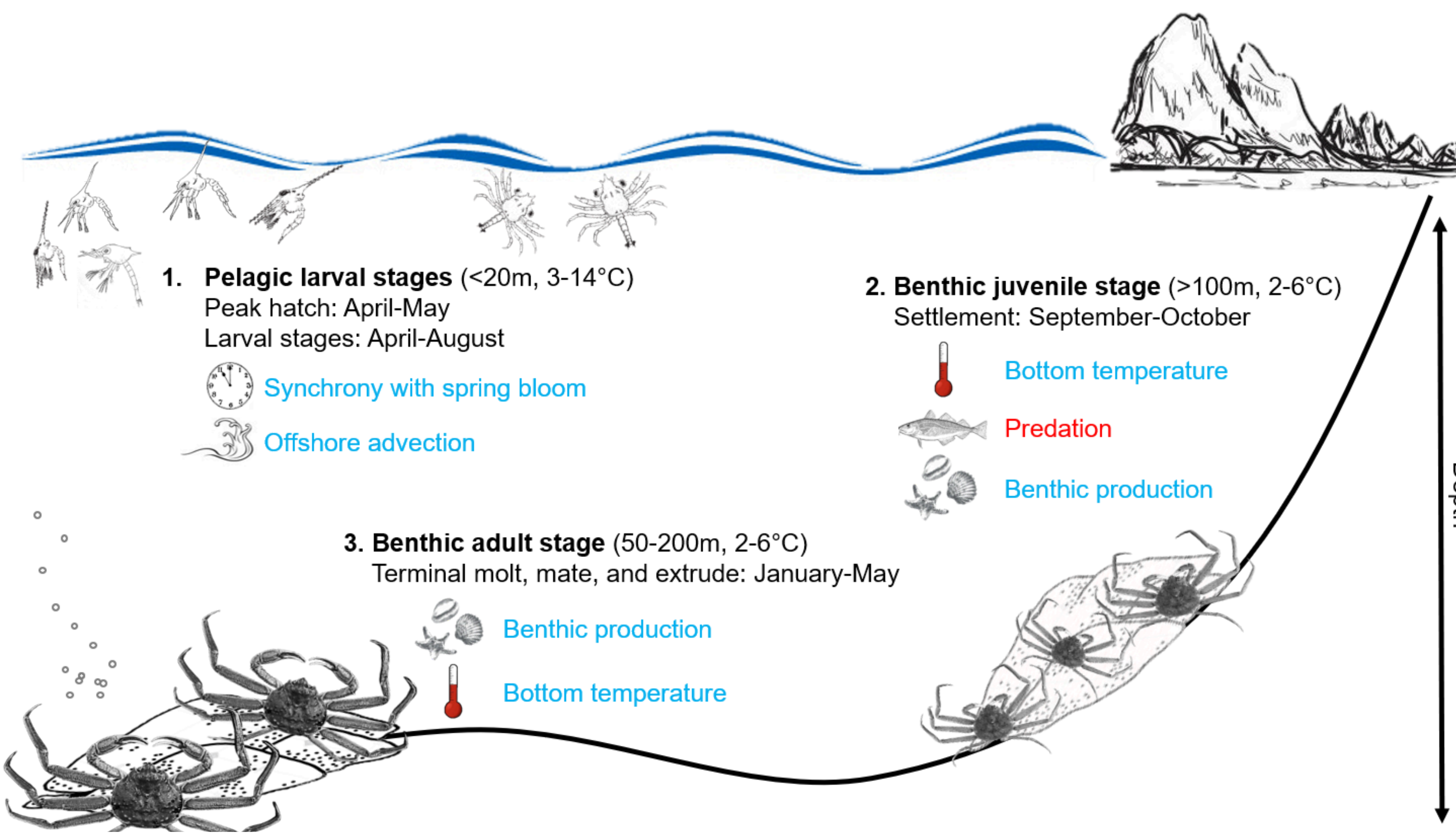

Figure D.1: Life history conceptual model for EBS Tanner crab summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text means that increases in the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

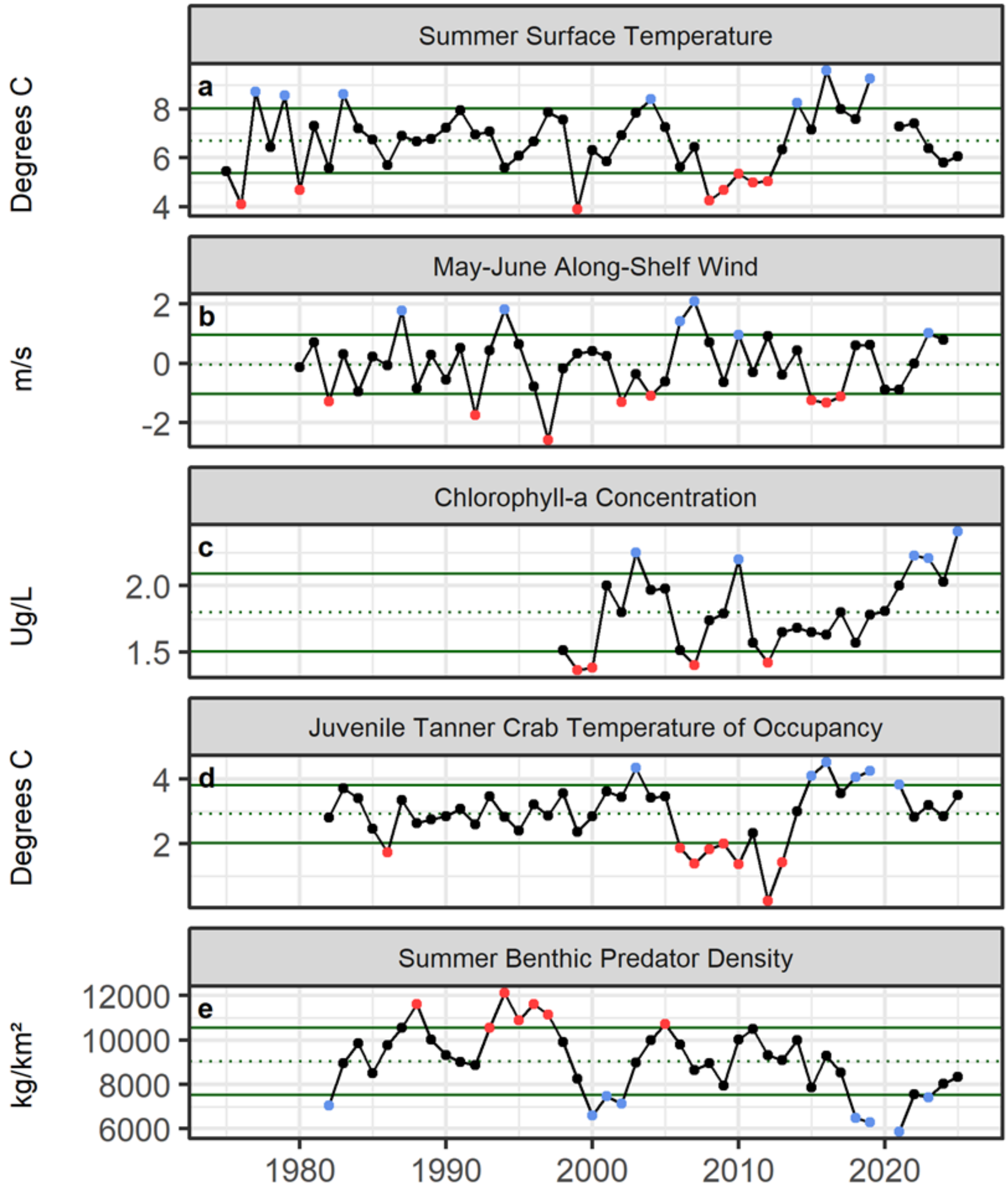

Figure D.2a: Selected ecosystem indicators for EBS Tanner crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

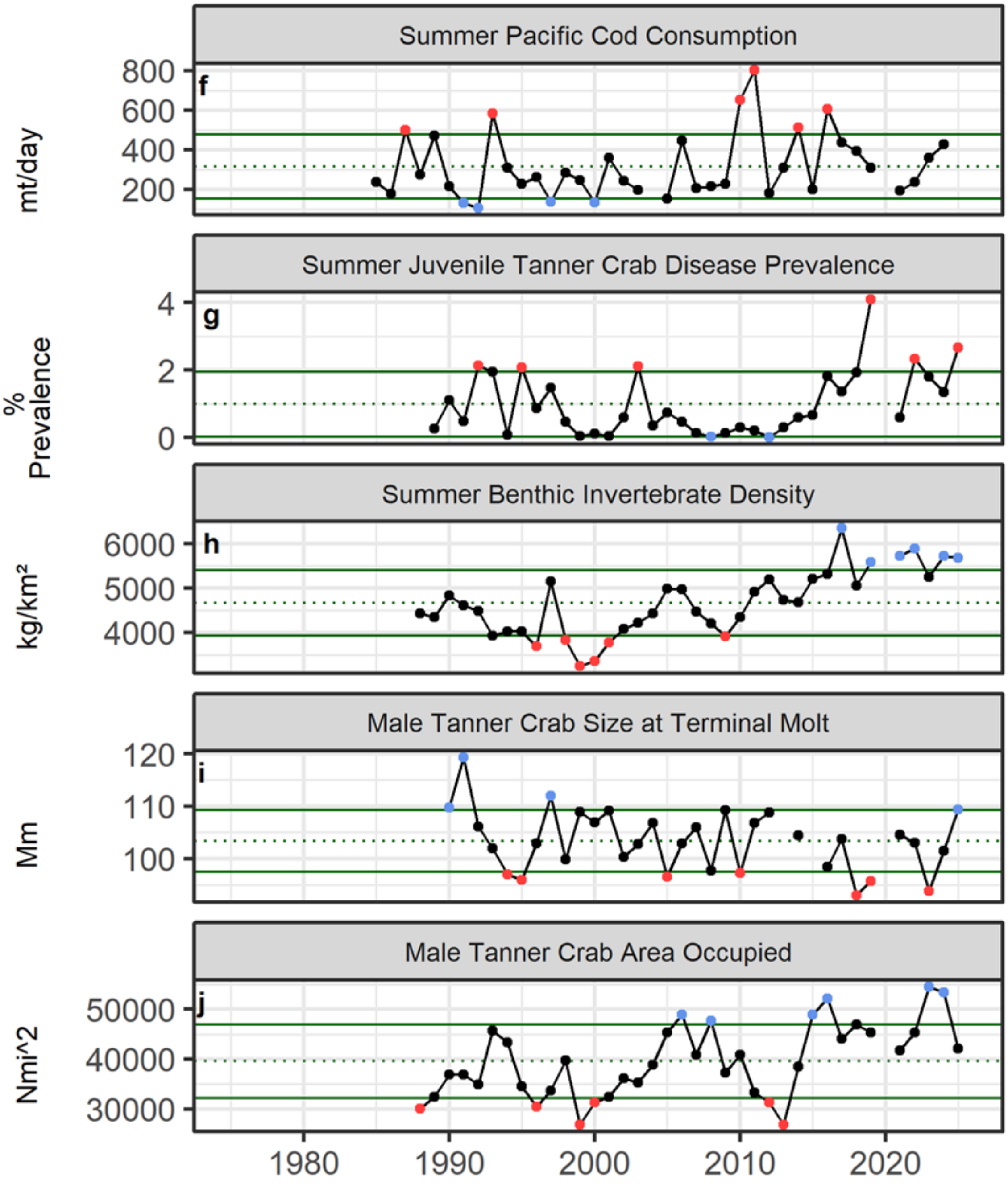

Figure D.2a (cont.): Selected ecosystem indicators for EBS Tanner crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

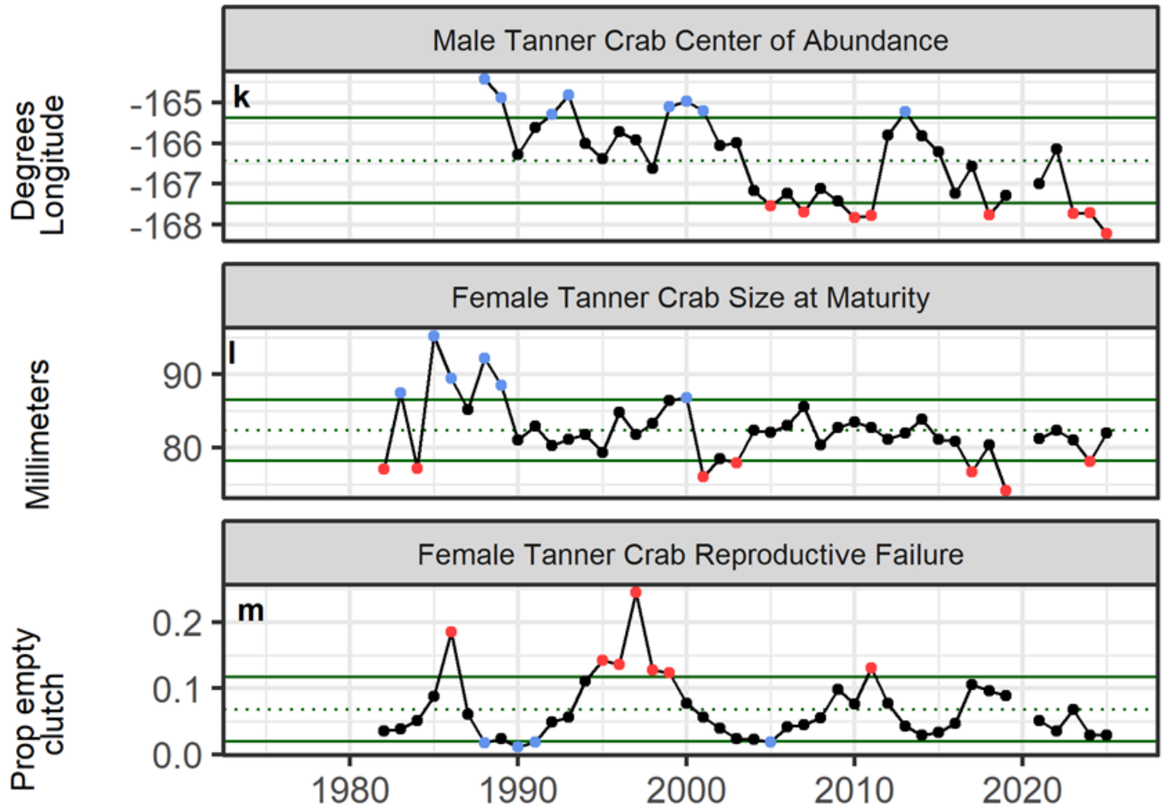

Figure D.2a (cont.): Selected ecosystem indicators for EBS Tanner crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

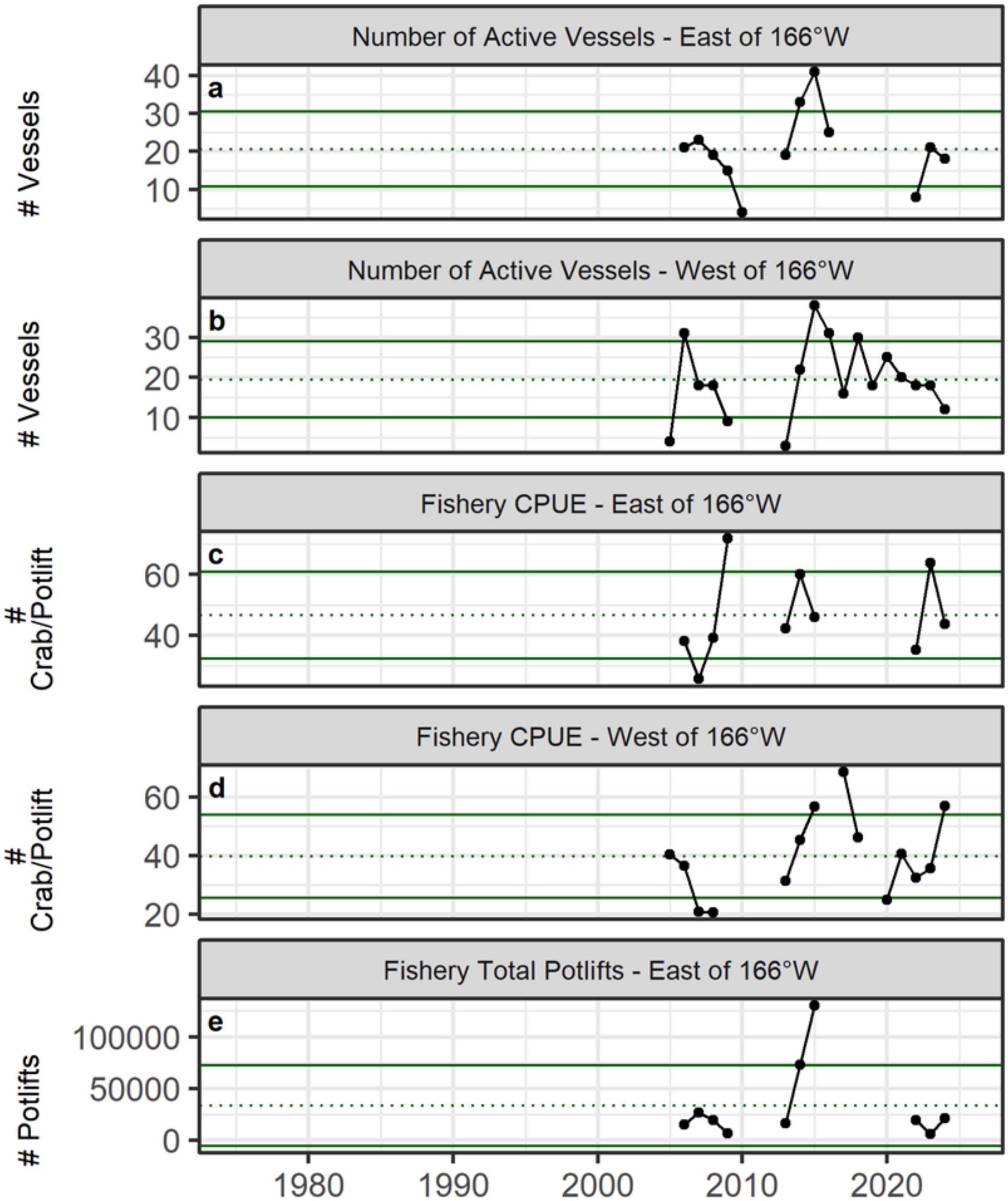

Figure D.2b: Selected socioeconomic indicators for EBS Tanner crab with time series ranging from 1990 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

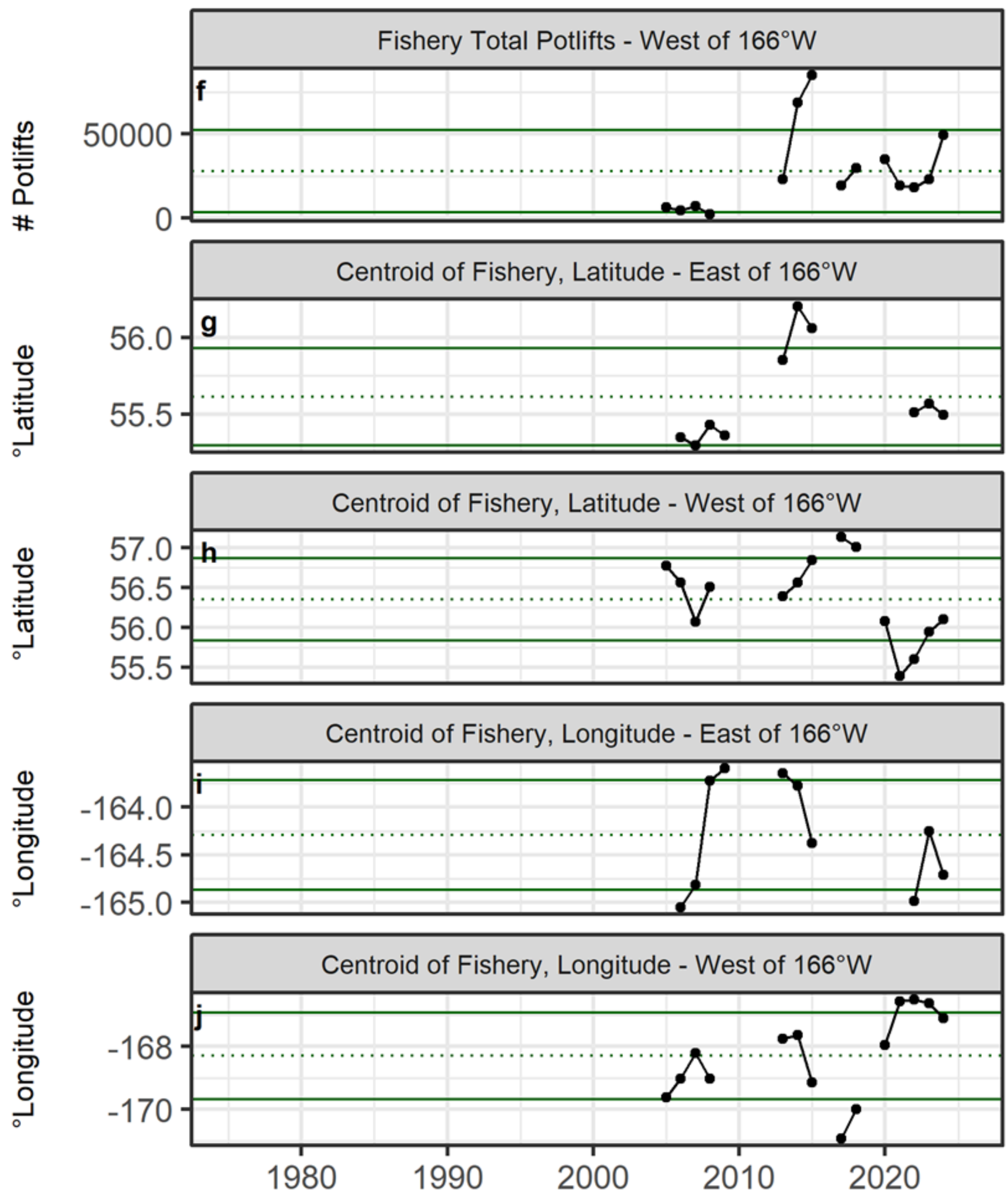

Figure D.2b (cont.): Selected socioeconomic indicators for EBS Tanner crab with time series ranging from 1990 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

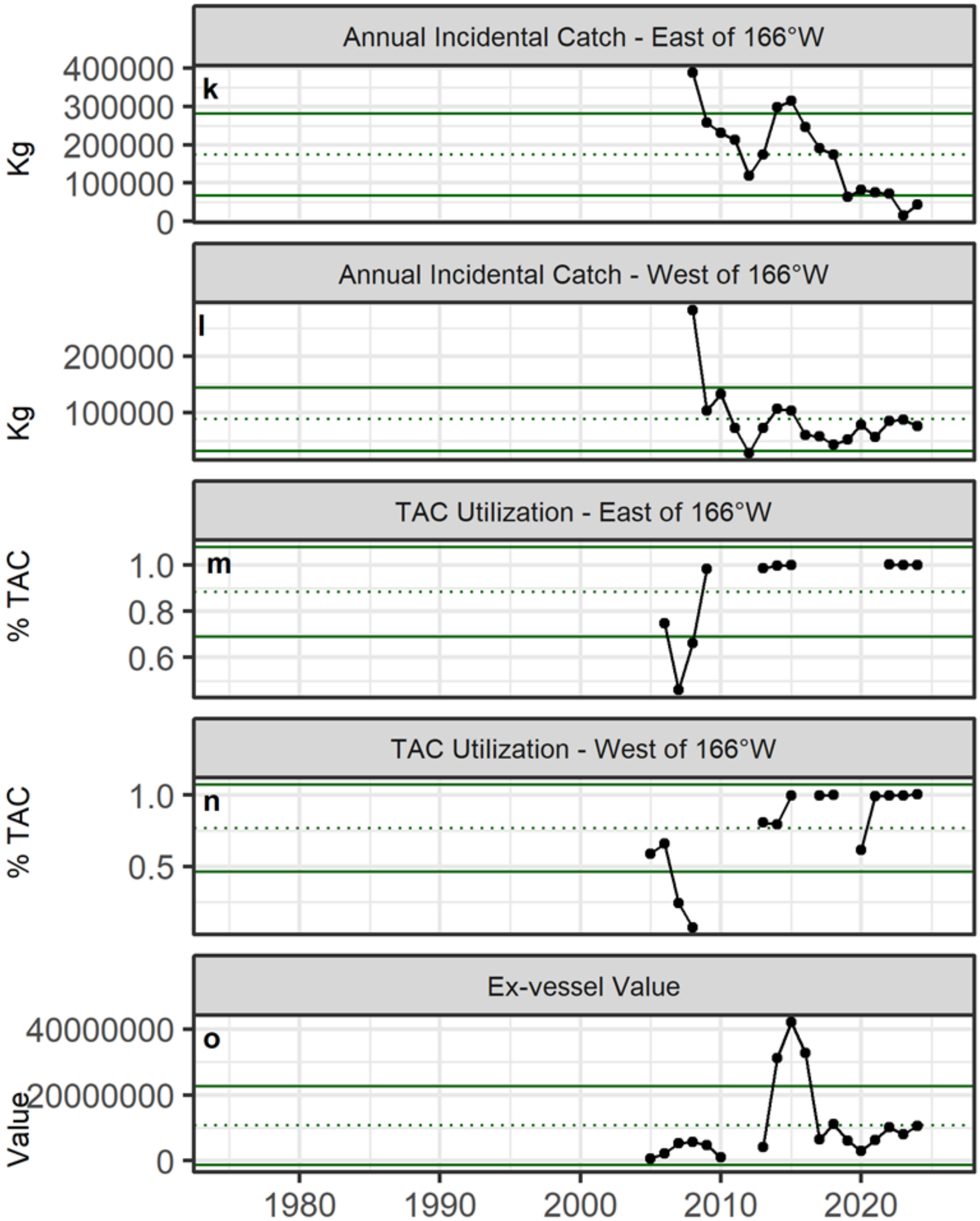

Figure D.2b (cont.): Selected socioeconomic indicators for EBS Tanner crab with time series ranging from 1990 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

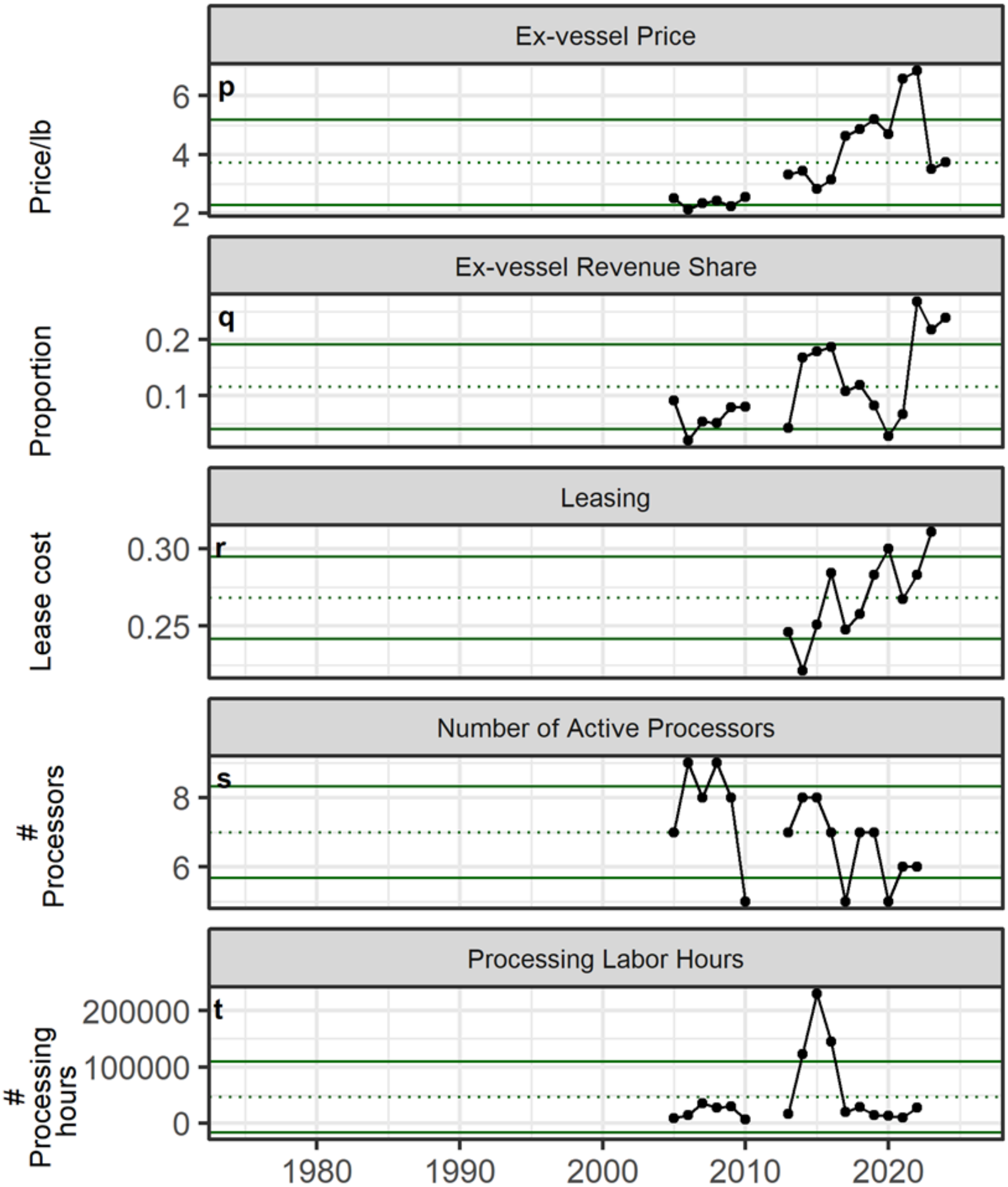

Figure D.2b (cont.): Selected socioeconomic indicators for EBS Tanner crab with time series ranging from 1990 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

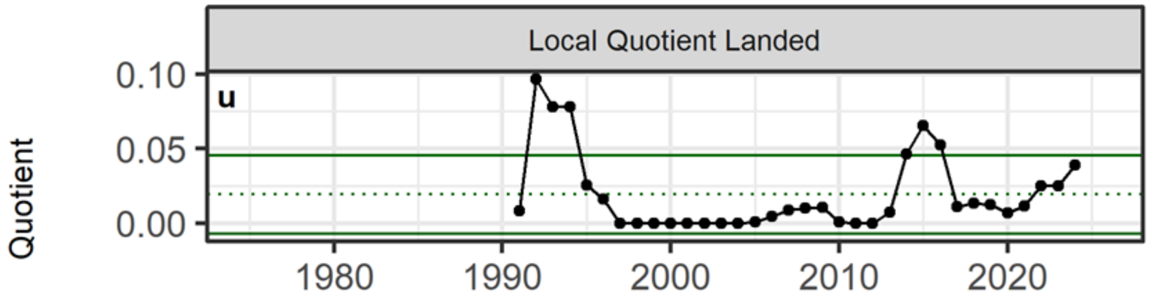

Figure D.2b (cont.): Selected socioeconomic indicators for EBS Tanner crab with time series ranging from 1990 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

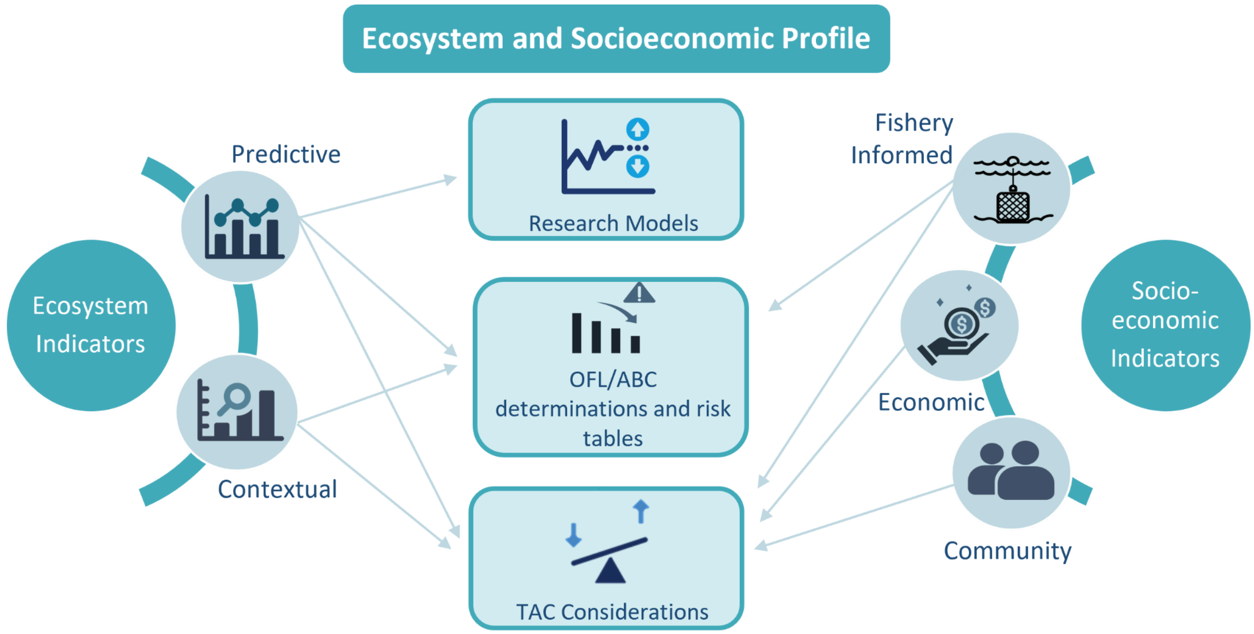

Figure D.3: Schematic of decision pathways for ecosystem and socioeconomic indicators

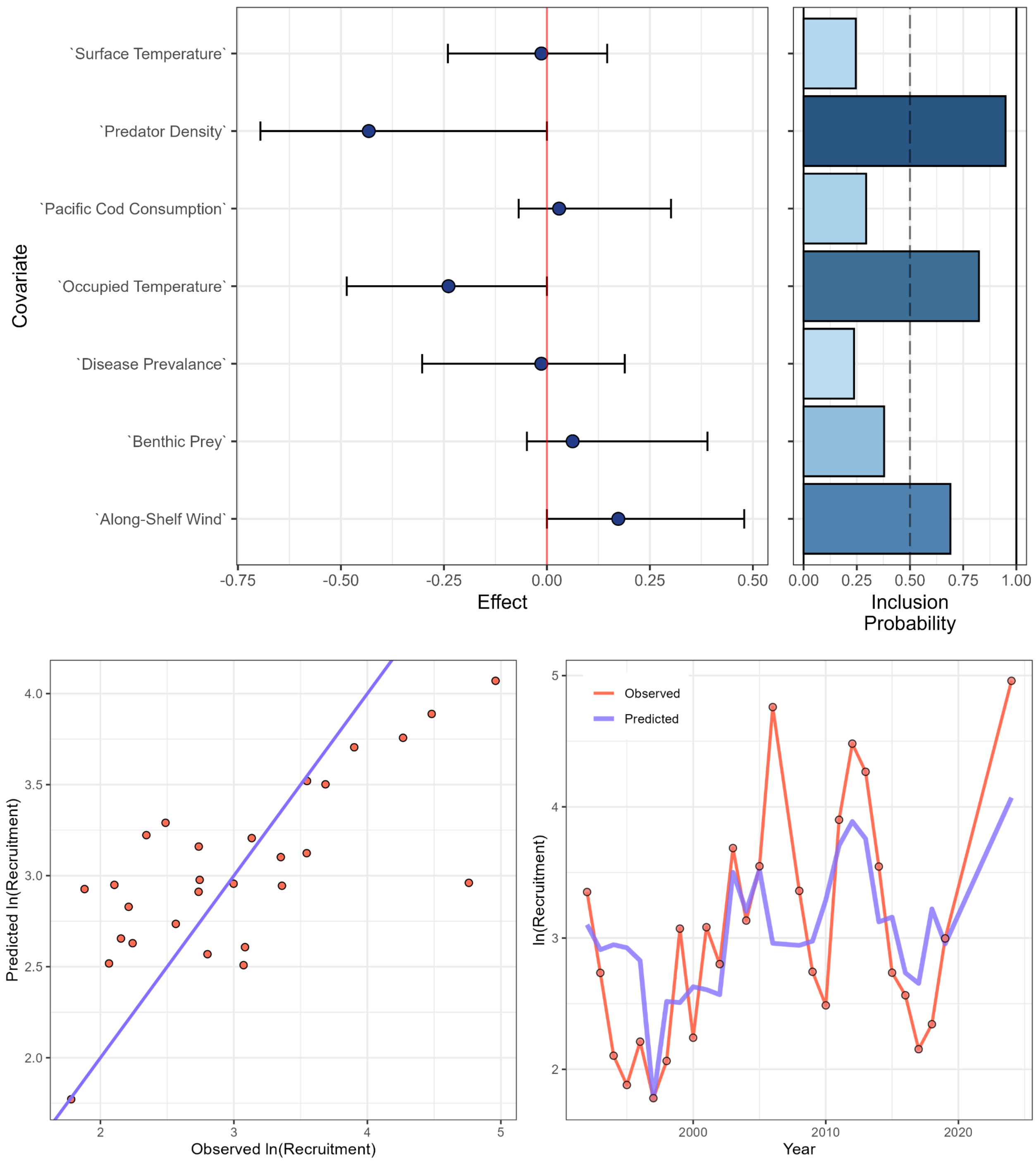

Figure D.4: Bayesian adaptive sampling output showing the mean relationship and uncertainty (95% CI) with log-transformed estimated EBS Tanner crab recruitment from the SEBS bottom trawl survey: the estimated effect (top left) and the marginal inclusion probabilities (top right) for each predictor variable 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 (1992-2024, bottom right).

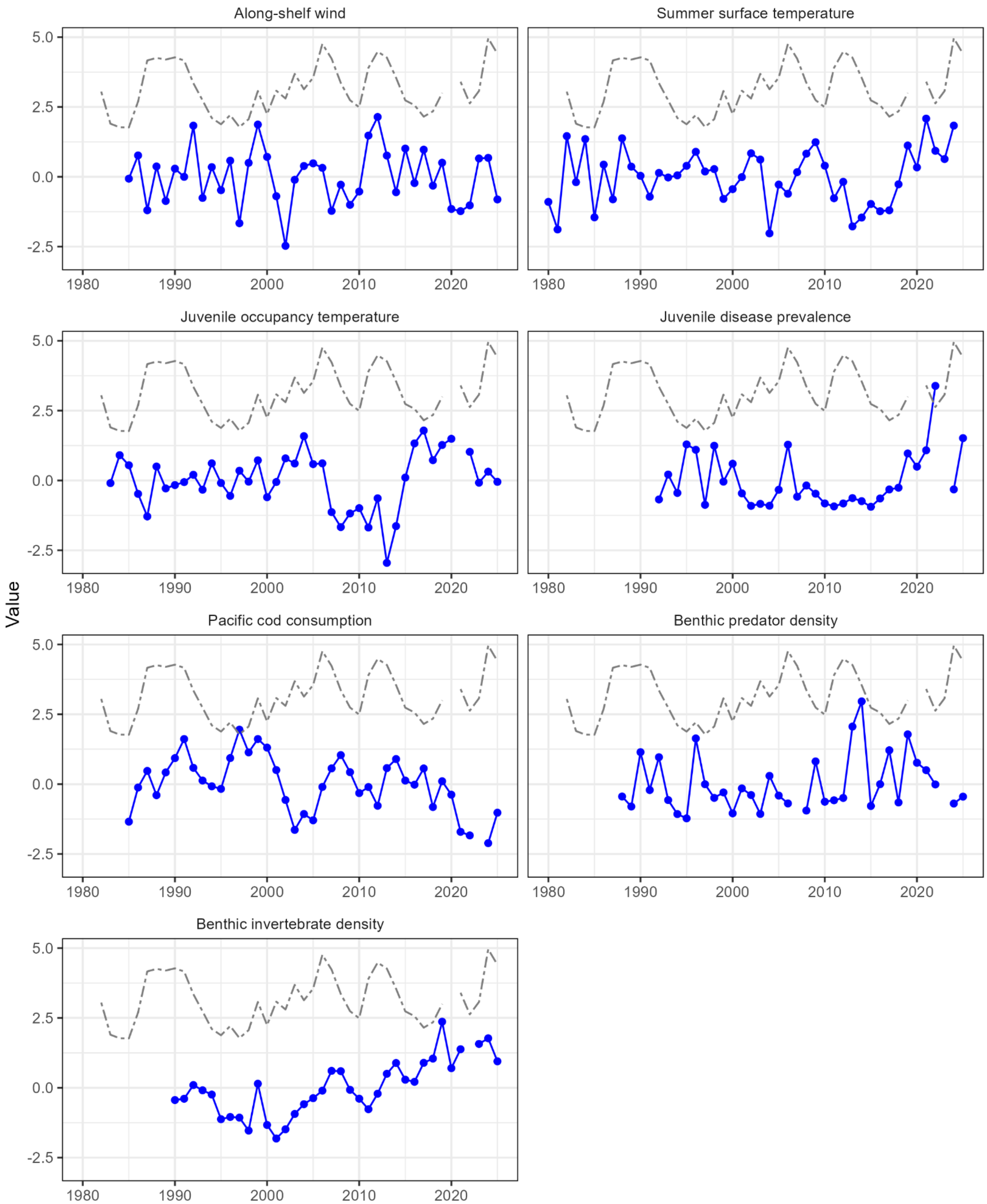

Figure D.5: Standardized ecosystem indicators (blue lines) tested in the final Bayesian Adaptive Sampling Model. The grey line on each facet is the response variable, Tanner crab recruitment (survey abundance of 70-85 mm males), on the log-scale.

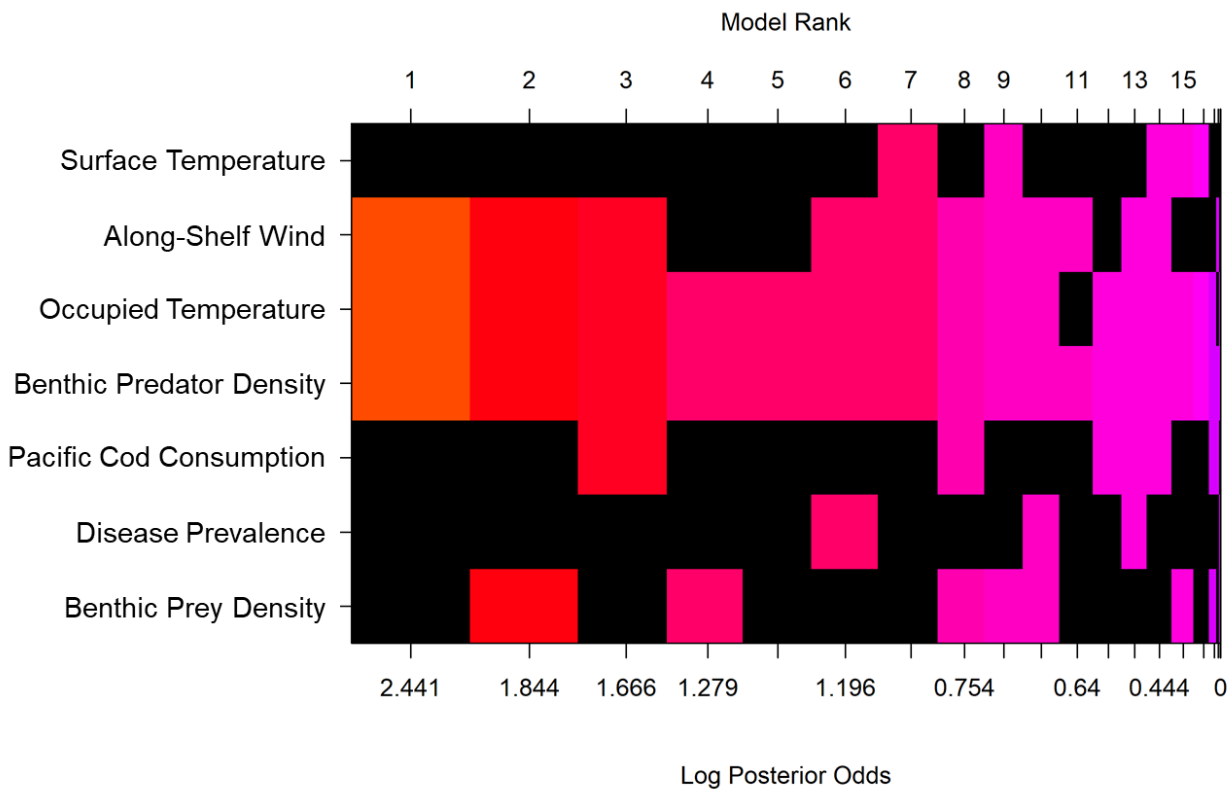

Figure D.6: Visualization of model space of top models tested with Bayesian Adaptive Sampling. Models are sorted by their posterior probability from best at the left to worst at the right with the rank on the top x-axis and log posterior odds on the bottom x-axis, and each column represents one of the top 17 models.