Appendix D. Ecosystem and Socioeconomic Profile of the Bristol Bay red king crab stock - Update

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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 and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., 2023). This update report provides supporting information for the Bristol Bay red king crab (BBRKC) ESP report card (Fedewa et al., 2026) and details the methodology and results from statistical analyses used to monitor current year status and trends of ecosystem and socioeconomic indicators. The BBRKC stock was evaluated at the intermediate indicator analysis stage using the Bayesian Adaptive Sampling (BAS) importance method. Highlights of the indicator assessment are summarized below as 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:

- There were no ecosystem indicators that directly influenced BBRKC recruitment

Contextual Indicators:

- Bristol Bay average bottom temperature in summer 2026 was the 4th coldest in the 47-year survey time series, resulting in a delay in the female molt-mate cycle. Of the females that had successfully molted and mated at the time of survey sampling, < 1% had empty clutches.
- Area occupied by mature males and females in Bristol Bay was above average in summer 2026. The ratio of red king crab in the Northern District to Bristol Bay has continued to decline since 2021, the fall 2025 fishery catch distance from shore was near average, and 82% of the BBRKC stock was located in year-round closure areas in summer 2026. Collectively, these spatial indicators suggest that the population continues to occupy core habitats in Bristol Bay despite below average summer bottom temperatures that have historically aggregated crab closer to the Alaska Peninsula.
- Spring bottom water pH increased from 2025 to 2026 to a near-average value. However, this time series has shown a declining trend for the past three decades and negative effects on juvenile red king crab growth, shell hardening, and survival are expected if pH levels reach 7.8.

Fishery-Informed Indicators:

- Total effort in the 2025/26 BBRKC fishery, as measured by number of active vessels (37) and total potlifts (13.2 thousand), increased relative to the previous year fishery, but both indicators remain below the post-rationalization average.
- The 2025/26 BBRKC fishery catch per unit effort (CPUE) was 29 and was a slight decrease from the previous season CPUE, but above the 30-year average of legal crab per potlift.
- While the center of distribution of fishing activity in the 2025/26 fishery is one of the westernmost centers of distribution seen in the timeseries, this spatial footprint encompasses historic fishing grounds and likely doesn't reflect a shift in fleet behavior.
- Results from the Alaska Bering Sea Crabbers (ABSC) Skipper Survey are consistent with high fishery CPUE and good fishing. Most captains (81%) reported a >10% increase in perceived abundance of legal males relative to the previous open season. 57% of skippers reported no significant change in fishing behavior, with the remaining skippers noting either longer or shorter soaks and increased communication with the fleet during the season.
- Incidental catch of BBRKC during 2025 non-directed fisheries remains near-average

Total Allowable Catch (TAC) Considerations:

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

- Predictive, contextual and fishery-informed ABC considerations above can be used to inform TAC considerations within the purview of the State TAC setting process. Ecosystem indicators in the monitoring category may also be relevant to TAC considerations but are not interpreted here (Figure D.2a and Table D.1)
- Economic indicators for the 2025/26 fishery are not yet available but will be updated prior to the October NPFMC meeting.

Introduction/Background

An ESP was recommended for Bristol Bay red king crab (BBRKC) in 2019 and the ESP full report was created in 2020 (Fedewa et al., 2020). In years following full reports, an ESP update report may be created in conjunction with the full or updated SAFE report schedule. The ESP update provides descriptions of all indicators developed for the ESP and results from a statistical indicator analysis completed with current year indicator data. Any necessary changes to the indicator suite such as newly available indicators, modifications due to data changes, or removals can also be catalogued. The intent of an ESP update report is to provide results of new data since the last ESP full report. It is not a full re-evaluation of the indicator selection or analysis choices. If a full re-evaluation is recommended, a subsequent ESP full report can be scheduled depending on regional prioritization.

A simplified report card infographic is also created in conjunction with the ESP full or update report to highlight the most important takeaways of the ESP. The ESP report card is a rapid communication presented with the SAFE report while the ESP full or update report contains supporting information for the report card and is appended to the SAFE report. For access to the ESP full report or subsequent update reports please visit the Alaska ESP webpage at https://akesp.psmfc.org.

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock with a conceptual model detailing ecosystem processes by life history stage (Figure D.1). Please refer to the last full ESP document (Fedewa et al., 2020) for more details.

Indicator Assessment

Selected indicators for BBRKC are organized into categories: three for ecosystem indicators (larval, juvenile, and adult) and three for socioeconomic indicators (fishery-informed, economic, and community). For detailed information regarding these ecosystem and socioeconomic indicators and the proposed mechanistic linkages for BBRKC, please refer to the previous ESP documents (Fedewa et al., 2020). Time series of these indicators are provided in Figure D.2a (ecosystem indicators) and Figure D.2b (socioeconomic indicators).

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.1 for any value within 1 standard deviation of the mean.

- "High" or "Low": Used in Table D.1 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).

Indicator Suite

Below we list 1) a short description of each indicator, including the data source and contributor, 2) the indicator lag assigned for ecosystem indicator analysis as determined by the proposed mechanistic relationship between the stock and indicator (ecosystem indicators only), 3) potential factors driving indicator trends, and 4) potential implications of directional shifts in indicator trends on the stock.

Ecosystem Indicators:

<u>Larval Indicators (Figure D.2a .a-d)</u>

a. <u>Arctic Oscillation Index:</u> January - March Arctic Oscillation index from the NOAA National Climate Data Center. Proposed sign of the relationship is negative. Contact: Erin Fedewa
    - Lag assigned for ecosystem indicator analysis: 6 years
    - Factors influencing trends: The Arctic Oscillation is a measure of the relative strength of low pressure over the Arctic and is defined by surface atmospheric weather patterns.
    - Implications: Poor BBRKC recruitment has been associated with positive values of the Arctic Oscillation (Szuwalski et al., 2021).
b. <u>Summer Wind Stress:</u> Summer wind stress (m/s) in Bristol Bay from NOAA/NCDC blended winds and Metop-A ASCAT satellite (NOAA/NESDIS, CoastWatch). Proposed sign of the relationship is negative. Contact: Dale Robinson
    - Lag assigned for ecosystem indicator analysis: 6 years
    - Factors influencing trends: Wind stress is affected by wind speed, the shape of wind waves and atmospheric stratification.
    - Implications: Higher wind stress suggests less suitable conditions for larval first-feeding success (Paul et al., 1989).
c. <u>Chlorophyll *a* Concentration:</u> April – June average chlorophyll *a* concentration in the Bristol Bay Red King Crab management district, calculated with the ESA OC-CCI blended satellite product. Proposed sign of the relationship is positive. Contact: Matt Callahan
    - Lag assigned for ecosystem indicator analysis: 6 years
    - Factors influencing trends: Spring chlorophyll 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: Low chlorophyll-a concentrations indicate less diatoms in the water column, which are a critical prey source for larval RKC (Paul et al., 1989).
d. <u>Bristol Bay Sockeye Inshore Run Size:</u> Annual inshore run size of Bristol Bay sockeye salmon (in millions of fish), calculated as the sum of catches in five terminal fishing districts, plus the escapement of sockeye to nine major river systems. The current year run size estimate is preliminary and subject to change until fish ticket numbers are finalized. Proposed sign of the relationship is negative. Contact: Curry Cunningham
    - Lag assigned for ecosystem indicator analysis: 6 years
    - Factors influencing trends: High sockeye salmon abundance in the Bering Sea has been linked to increased prey abundance and sea surface temperatures (Yasumiishi et al., 2024).
    - Implications: The recent high production stanza for sockeye salmon and record high run sizes suggest the potential for increased predation on larval red king crab in Bristol Bay.

Juvenile Indicators (Figure D.2a. e-g)

e. Spring pH: Spring (February – April 15) pH index of Bristol Bay bottom waters, estimated from the MOM6-NEP10k model hindcast. Proposed sign of the relationship is positive. Contact: Darren Pilcher
    - Lag assigned for ecosystem indicator analysis: 4 years
    - Factors influencing trends: The pH values on the inner and middle shelf of the Bering Sea are driven by freshwater runoff from river systems and bacterial respiration of sinking organic matter generated by phytoplankton productivity. In addition, shifts in seasonal sea-ice extent, water column stratification, and shear-induced vertical mixing directly drive year-to-year shifts in bottom water pH and carbonate chemistry (Pilcher et al., 2026).
    - Although drivers of interannual pH variability are poorly understood, declining pH values over the full time series are due to positive trends in the partial pressure of carbon dioxide in surface waters (Pilcher et al., 2019).
    - Implications: Juvenile red king crab condition, growth, shell hardness and survival are negatively impacted by exposure to pH values below 7.8 (Long et al. 2013; Swiney et al., 2017), and ocean acidification may be a significant factor in the recruitment failure of BBRKC (Litzow et al., 2025).

f. Bottom Temperature: Estimated average summer bottom temperature in Bristol Bay from the EBS bottom trawl survey. Bottom temperatures are standardized to June 14th of each year to account for differences in survey sampling dates among years. Proposed sign of the relationship is negative. Contact: Erin Fedewa
    - Lag assigned for ecosystem indicator analysis: 2 years
    - Factors influencing trends: Bottom temperatures in the Bering Sea are driven by winter sea ice extent and winds, and summer cold pool formation.
    - Implications: While red king crab have a wide thermal tolerance (Long and Daly 2017), colder temperatures drive shifts in ovigerous female distributions and delay embryonic development and hatching (Loher and Armstrong 2005).

g. Pacific Cod Predator Density: Summer Pacific cod density (kg/km²) estimated from EBS bottom trawl survey stations included in the BBRKC management district. Proposed sign of the relationship is negative. Contact: Erin Fedewa
    - Lag assigned for ecosystem indicator analysis: 1 year
    - Factors influencing trends: Pacific cod are a major predator of red king crab, and predation likely increases in the spring when crab are soft and molting.
    - Implications: High Pacific cod density suggests increased predation pressure on BBRKC.

Adult Indicators (Figure D.2a. h-n)

h. Benthic Prey Density: Summer benthic invertebrate mean density (kg/km²), estimated from EBS bottom trawl survey stations included in BBRKC management district. Invertebrates are subset to include species observed in red king crab diet studies, and include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes. Proposed sign of the relationship is positive. Contact: Erin Fedewa
    - Lag assigned for ecosystem indicator analysis: 1 year
    - 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: High benthic invertebrate density suggests increased prey availability for BBRKC. However, the bottom trawl survey does not sample key prey items such as polychaetes and bivalves well, thus this indicator is a fairly coarse proxy for prey quantity.

i. BBRKC Mature Male Area Occupied: The minimum area containing 95% of the cumulative mature male red king crab CPUE in the BBRKC management district during the EBS summer bottom trawl survey. Proposed sign of the relationship is positive. Contact: Erin Fedewa
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: Red king crab spatial distributional shifts have been associated with changes in bottom temperatures (Loher and Armstrong, 2005; Zacher et al., 2018).
   - Implications: The range expansion of mature male red king crab during the past decade has been associated with a northward shift in centroids of abundance. Range expansion may suggest that mature males are tracking thermal habitat preferences in response to recent warming in the Bering Sea.

j. BBRKC Mature Female Area Occupied: The minimum area containing 95% of the cumulative mature female red king crab CPUE in the BBRKC management district during the EBS summer bottom trawl survey. Proposed sign of the relationship is positive. Contact: Erin Fedewa
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: Northerly shifts in stock distribution are generally associated with both warmer temperatures and high Pacific Decadal Oscillation values during the summer, and mature female RKC appear to avoid waters < 2°C (Loher and Armstrong, 2005; Zheng and Kruse, 2006).
   - Implications: Spatial distribution shifts may result in more mature females inhabiting the Nearshore Bristol Bay Trawl Closure Area, although continued range contraction may raise concern for increased competition for resources.

k. Fishery Catch Distance from Shore: The mean distance legal male red king crab were caught from shore during the fishery, calculated using fishery observer data. During 2021 and 2022 fishery closures, mean distance from shore was estimated with satellite-tagged legal male red king crab, and calculated as the mean distance from shore for all tags east of 165°W. This boundary approximates the actual fishing grounds rather than the spatial allocation of tagging efforts. No directional relationship with the stock. Contact: Leah Zacher
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: Red king crab during the fall fishery tend to aggregate in the center of Bristol Bay and the Red King Crab Savings Area in warm years, and disperse along the Alaska Peninsula in cold years (Zacher et al., 2018).
   - Implications: A spatial shift in fishing effort may be indicative of population-level distribution shifts from summer to fall. Distance from shore has implications for crab-fishing gear interactions, bycatch of crab, and unobserved mortality, most notably if BBRKC are found outside of protected areas.

l. Female BBRKC Reproductive Failure: The proportion of newshell mature female BBRKC with no eggs, empty egg cases, or dead eggs. Because cold temperatures delay the female molt/mate cycle, oldshell barren females are excluded under the assumption that they will likely molt and mate in the coming months after survey sampling is complete. Proposed sign of the relationship is negative. Contact: Erin Fedewa
   - Lag assigned for ecosystem indicator analysis: 7 years
   - Factors influencing trends: Female reproductive potential is a function of female size, clutch size, and sperm reserves (Gardner et al., 2024). An increased frequency of

clutch failure may indicate sperm limitation, inability to locate a mate, or energetic limitations imposed on extrusion and fertilization.
   - Implications: An increase in the proportion of mature females with empty clutches suggests a reduction in reproductive potential of the stock. A > 30% proportion of mature females with empty clutches in the late 1970's coincided with a stock collapse, suggesting that clutch failures should be continually monitored for under depressed population levels.

m. Northern District to Bristol Bay RKC Ratio: Calculated as the ratio of total red king crab abundance in the Northern District to total red king crab abundance in the Bristol Bay Management District. Proposed sign of the relationship is negative. Contact: Erin Fedewa
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: The Northern District to Bristol Bay District ratio may be driven by shifts in larval advection patterns, or exchange between the two districts due to seasonal migrations or directional movement. Preliminary results from tagging studies suggest that males tagged just above the management boundary move south into Bristol Bay in the fall, but don't rejoin the core Bristol Bay stock (L. Zacher, personal communication). Mature females tagged further north did not re-enter Bristol Bay during the study.
   - Implications: A large increase in the abundance ratio between the two districts may coincide with northward range expansion of the Bristol Bay stock and movement outside of management boundaries during the summer survey period. Because red king crab in the Northern Unstratified District are not included in the BBRKC stock assessment, this indicator tracks a critical management concern.

n. Proportion of BBRKC in Closure Areas: The proportion (%) of total BBRKC interpolated abundance during the summer EBS bottom trawl survey occurring within year-round closure areas. Closure areas include the Red King Crab Savings Area, the Red King Crab Savings Subarea in subsequent calendar years following a BBRKC directed fishery closure, and the Nearshore Bristol Bay Trawl Closure Area (with the exception of the Togiak/Nearshore Bristol Bay Trawl Area). NMFS Reporting Area 516 was excluded as a closure area since the area is only closed seasonally. Proposed sign of the relationship is positive. Contact: Erin Fedewa
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: Proportion of the population found in closure areas is influenced by interannual variability in stock distribution and spatial extent (likely temperature-mediated), although high catch stations can disproportionately impact the estimate in years when survey catch is patchy.
   - Implications: An increase in the proportion of BBRKC in closure areas suggests the potential for reduced bycatch of crab in groundfish fisheries, and a potential reduction in interactions with fishing gear during the summer period. However, seasonal migrations and shifts in groundfish fishing intensity throughout the year highlight the limited utility of this indicator for drawing inference on bycatch and unobserved mortality.

Socioeconomic Indicators:

Fishery Informed Indicators (Figure D.2b. a-g)

a. Number of Active Vessels: Annual number of active vessels in the BBRKC fishery to represent the level of fishing effort assigned to the fishery. Contacts: Ethan Nichols
   - Factors influencing trends: BSAI crab fishing vessels are highly specialized for the fishery and have a limited portfolio of non-crab fishing targets. Variation in the size of

the BBRKC fleet is driven by the TAC in BBRKC, EBS snow crab, and increasingly, Tanner crab, with crab harvest quota leasing facilitating adjustment of the fleet to achieve efficient deployment of harvesting capacity, although anecdotal evidence suggests some vessels may temporarily operate at a loss in order to retain crew and access to quota lease contracts.
- Implications: Variation in the size and composition of the active fleet may have implications for overall fleet behavior.

b. <u>Fishery CPUE:</u> Annual catch-per-unit-effort (CPUE) reported in fishery year, expressed as mean number of crabs per potlift, in the BBRKC fishery to represent relative efficiency of fishing effort. The cost recovery fishery is not included. Incidental catch and potlifts are included but contribute a nearly negligible portion of catch and effort. Contact: Tyler Jackson
- Factors influencing trends: Annual fishery CPUE can vary based on a suite of factors including total fishery potlifts, BBRKC abundance, pot gear soak time, pot gear configuration, bait, weather/tides, 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.

c. <u>Fishery Total Potlifts:</u> Total (directed and incidental) potlifts in the BBRKC directed fishery, representing the level of fishing effort expended by the active fleet. The cost recovery fishery is not included. Contact: Tyler Jackson
- Factors influencing trends: Annual fishery total potlifts can vary based on a suite of factors including number of active vessels, TAC size, CPUE, weather/tides, distance to fishing grounds, and fleet dynamics.
- Implications: Changes in total potlifts represent the level of fishing effort expended by the active fleet

d. <u>Annual Incidental Catch:</u> Annual estimates of incidental catch biomass estimates of BBRKC (tons) in federally managed EBS groundfish fisheries. Contact: Ethan Nichols
- Factors influencing trends: Incidental catch of BBRKC in groundfish fisheries occurs primarily in non-pelagic flatfish trawl fisheries and is influenced by the magnitude, temporal and spatial distribution of groundfish fisheries, depth fished (particularly for mature and immature female BBRKC), gear and other aspects of flatfish harvesting effort, as well as the size distribution, abundance, spatial, and temporal distribution of the BBRKC stock (Ryznar and Litzow, 2024).
- Implications: Rapid changes of incidental catch may imply shifting distribution of the BBRKC population into non-preferred habitat, which could increase competition and predation. Additionally, an increase in incidental catch could be viewed as an early indicator of large year classes of BBRKC or confirmatory of previously estimated year classes.

e. <u>Alaska Bering Sea Crabbers (ABSC) Skipper Survey Perceived Abundance:</u> Responses from a single question in the ABSC Skipper Survey, disseminated to all skippers following the completion of the most recent fishery. Skippers were asked to rank perceived abundance of legal males during the 2025/26 fishery relative to the last BBRKC season. Open-ended “other” response choice was not included. Contact: Cory Lescher
- Factors influencing trends: Perceived abundance can vary based on a suite of factors including fishing location, soak time and skipper skill and experience

- Implications: Changes in perceived abundance often help to explain skipper adaptation strategies, and can be used as a relative measure of stock status

f. Alaska Bering Sea Crabbers (ABSC) Skipper Survey Changes in Fishing Practices: Responses from a single question in the ABSC Skipper Survey, disseminated to all skippers following the completion of the most recent fishery. Skippers were asked to select the most significant change they made in fishing practices during the 2025/26 fishery relative to the last BBRKC season. Open-ended "other" response choice was not included. Contact: Cory Lescher
    - Factors influencing trends: Changes in fisher behavior can be driven by factors such as increased bycatch, low CPUE, shifts in stock abundance and/or distribution, operating cost, and experience and knowledge
    - Implications: Changes in fishing practices can be used to interpret trends in fishery performance metrics and the health of the stock

g. Alaska Bering Sea Crabbers (ABSC) Skipper Survey Principal Driver of Changes: Responses from a single question in the ABSC Skipper Survey, disseminated to all skippers following the completion of the most recent fishery. Skippers were asked to select their main reason for any change in fishing practices during the 2025/26 fishery relative to the last BBRKC season. Open-ended "other" response choice was not included. Contact: Cory Lescher
    - Factors influencing trends: Motivation for changes in fisher behavior can be driven by bycatch and fishery regulations, TAC allocation and CPUE
    - Implications: Understanding the motivation for changes in fishing practices can assist fishery managers in developing more effective management strategies

Economic Indicators (Figure D.2b. h-j)

Economic data relevant to the most recent fishery are not yet available but will be included in this document prior to the October NPFMC meeting.

h. Ex-vessel Value: Annual ex-vessel value of the BBRKC fishery landings represents gross economic returns to the harvest sector, as a principal driver of fishery behavior. Contact: Brian Garber-Yonts.
    - Factors influencing trends: TBD
    - Implications: TBD

i. Ex-vessel Price: Annual red king crab ex-vessel price per pound represents per-unit economic returns to the harvest sector, as a principal driver of fishery behavior. Contact: Brian Garber-Yonts.
    - Factors influencing trends: TBD
    - Implications: TBD

j. Ex-vessel Revenue Share: Annual red king crab ex-vessel revenue share, expressed as vessel-average proportion of annual gross landings revenue earned from the BBRKC fishery. Contact: Brian Garber-Yonts.
    - Factors influencing trends: TBD
    - Implications: TBD

Indicator Analysis

Ecosystem and socioeconomic indicators are monitored through distinct workflows, depending on the management decisions they are intended to inform. 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 ecosystem 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) to estimate predictive performance of indicators. The advanced stage may be used for testing a research ecosystem linked stock assessment model where output can be compared with the current operational stock assessment model.

We evaluated the socioeconomic indicators using only the beginning stage statistical tests and did not assign a proposed relationship between the indicator and stock, 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).

Ecosystem Indicator Analysis

The BBRKC stock is data-rich with an associated size-structured stock assessment model (Generalized Model for Assessing Crustacean Stocks or GMACS); therefore, the ecosystem indicators were evaluated using intermediate indicator analysis 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 as an intermediate stage indicator analysis to quantify the strength and direction of association between ecosystem indicators and BBRKC recruitment. 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). BBRKC recruitment, our population process of interest, was calculated using the EBS bottom trawl survey abundance of male "pre-recruit" red king crab (≥ 95mm carapace length and ≤ 120mm carapace length) under the assumption that this size class represents individuals that are one molt away from recruiting to the fishery, and approximately 6 - 7.9 years post-settlement (Loher et al., 2001).

Prior to running BAS, the full suite of 14 ecosystem indicators was winnowed to indicators that directly relate to recruitment. We eliminated the following indicators, as they are not hypothesized to drive BBRKC recruitment and instead, provide contextual information about the stock or a relevant management concern: 1) proportion of mature males in closure areas, 2) fishery catch distance from shore, 3) mature female area occupied, 4) mature male area occupied, and 5) Northern District to Bristol Bay red king crab ratio. 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 relative to other ecosystem indicators once lags were applied (n = 23 years, 2004-2026), it was dropped from the final BAS model to allow for the longest model run possible.

Ecosystem indicator lags were assigned to the remaining indicator suite 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. Preliminary sensitivity analyses indicate that BAS results are robust to +/- 1-year lags, although the inability to accurately age crab results in difficulties assigning lags with high confidence. Pre-recruit male BBRKC were assumed to be 6 - 7 years old, therefore larval indicators were assigned a lag of 6 years. Female BBRKC crab reproductive failure was lagged an additional year beyond the 6-year larval lag, assuming a 12-month embryo development period. Bottom temperature and pH are assumed to affect growth and survival of juvenile stages, and were assigned lags of 2 and 4 years, respectively. One-year lags were assigned to benthic prey density and Pacific cod predator density assuming impacts to survival the year following poor feeding conditions and high predation pressure.

Prior to BAS modeling, we assessed correlations among indicators ($r \geq 0.6$) because collinearity can reduce the interpretability of posterior inclusion probabilities. No indicators were excluded, resulting in eight predictors: pH, bottom temperature, female reproductive failure, Pacific cod density, Arctic Oscillation, sockeye salmon run size, benthic prey density, and wind stress (Figure D.4), spanning 30 years (1997–2026). Missing observations, particularly those associated with the cancelled 2020 EBS bottom trawl survey, resulted in the exclusion of 2020–2022.

The final model selected using BAS included only wind stress (Figure D.5). While wind and pH had the highest posterior inclusion probabilities in the final model (0.60 and 0.52, respectively; Figure D.6b), neither indicator showed strong posterior support, and the 95% credible intervals of model-averaged effects overlapped zero (Figure D.6a). Model predicted fit (Figure D.6c) and average predicted fit across the recruitment time series (Figure D.6d) were also very poor. Thus, although wind and pH received the greatest relative support among indicators, there is limited evidence that either indicator has a clear directional effect on recruitment. Because the BAS analysis presented here identified no indicators that demonstrated predictive capacity, we categorized the full suite of ecosystem indicators as either contextual (mature male area occupied, mature female area occupied, fishery catch distance from shore, female reproductive failure, proportion of mature males in closure areas, Northern District to Bristol Bay red king crab ratio, and pH) or monitoring (wind stress, benthic prey density, Pacific cod predator density, bottom temperature, Arctic Oscillation index, sockeye salmon inshore run size, and chlorophyll-*a* concentration) based on the criteria listed above.

Following the indicator analysis, we summarize recent indicator trends in a five-year status table (Table D.1a), with indicators categorized as predictive, contextual, or monitoring. Indicator status is classified as high, low, or neutral based on whether values are more than one standard deviation above, below, or within the long-term mean. For predictive and contextual indicators, potential concerns for stock status are identified based on the direction of the indicator–stock relationship. Relationships for predictive indicators are based on importance analyses, whereas contextual and monitoring relationships are based on the conceptual model and hypothesized mechanisms (Figure D.1). Status is shown using a "traffic light" system: blue indicates a high indicator value associated with favorable stock conditions, red indicates a high value associated with unfavorable conditions, and neutral values are uncolored. No relationship is assigned when the direction of an indicator–stock relationship is unclear. In addition, the Executive Summary at the beginning of this document provides a concise overview of predictive and contextual indicator trends, and an interpretation of results from the intermediate stage indicator analysis that can be used to inform ABC and TAC decisions.

Socioeconomic Indicator Analysis

We present 10 socioeconomic indicators that depict a historical time series of key socioeconomic information for the BBRKC fishery: 4 fishery-informed indicators derived from NMFS/ADFG in-season management monitoring systems, 3 selected from the Alaska Bering Sea Crabbers (ABSC) Bristol Bay Red King Crab Skipper Survey, and 3 economic indicators drawn from mandatory economic reporting systems (to be updated prior to the October Council meeting). Indicators derived from agency monitoring and reporting systems use time series of historical data through the most recent (2025/26) BBRKC fishery, which occurred during the final months of 2025, and are used to assess current status of the fishery relative to long-term trends.

Indicators from the ABSC Skipper Survey represent a synthesis of responses to the 2025/26 survey, which elicited single period comparisons between the most recent fishery and the fishery the year prior. Inclusion of these indicators is primarily intended as a provisional mechanism for incorporating fishery-dependent data on fleet behavior and catch observations into ABC buffer considerations. The initial selection of three questions from the survey as indicators focuses on skippers' perception of the abundance of legal males and perceived changes and drivers of fishing behavior. These are drawn from a total of 9 recurring questions, which also encompass questions regarding the abundance and explanatory factors for encounters with sublegal males and females, and shell condition of legal males.

The Executive Summary at the beginning of this document provides a summary and interpretation of fishery-informed indicator trends that can be used to inform ABC decisions.

Conclusion

The BBRKC ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., 2023). The conceptual model provides a reference for the comprehensive literature review and associated tables of the ESP full report (Fedewa et al., 2020). Fourteen ecosystem and eleven socioeconomic indicators were identified to monitor for BBRKC. Because BBRKC is a data-rich stock, ecosystem indicators were evaluated using intermediate indicator analysis stage methods. We provide several overarching takeaways from the indicator assessment results, which can be used for evaluating concerns in the main stock assessment or management decisions related to acceptable biological catch (ABC) and total allowable catch (TAC) considerations. Indicators that can inform ABC and risk tables include predictive, contextual, or fishery-informed indicators. Indicators that can inform TAC include all ABC indicators as well as economic and community indicators.

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Tables

Table D.1a: First stage ecosystem indicator analysis for BBRKC, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of the long-term mean). Fill color of the cell is based on the proposed sign of the overall 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	2022 Status	2023 Status	2024 Status	2025 Status	2026 Status
Contextual	BBRKC Mature Male Area Occupied	neutral	neutral	*high*	neutral	*high*
	BBRKC Mature Female Area Occupied	neutral	neutral	neutral	neutral	*high*
	Fishery Catch Distance from Shore	neutral	neutral	neutral	neutral	NA
	Female BBRKC Reproductive Failure	neutral	neutral	neutral	**high**	neutral
	Proportion of BBRKC in Closure Areas	neutral	neutral	*high*	neutral	neutral
	Northern District:Bristol Bay RKC Ratio	**high**	**high**	**high**	neutral	neutral
	Spring pH	**low**	**low**	**low**	**low**	neutral
Monitoring	Benthic Prey Density	*high*	neutral	neutral	neutral	*high*
	Bottom Temperature	neutral	neutral	neutral	neutral	*low*
	Pacific Cod Predator Density	neutral	neutral	neutral	neutral	neutral
	Arctic Oscillation Index	neutral	neutral	neutral	neutral	neutral
	Summer Wind Stress	neutral	neutral	neutral	**high**	neutral
	Chlorophyll a Concentration	neutral	*high*	neutral	*high*	*high*
	Bristol Bay Sockeye Inshore Run Size	**high**	**high**	neutral	**high**	neutral

Table D.1b: First stage socioeconomic indicator analysis for BBRKC, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of the long-term 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 BBRKC fishery is prosecuted Oct-Dec, such that the calendar year corresponds to the first period of the crab season-year; the most recent BBRKC fishery occurred during the 2025/26 crab season. ABSC Skipper Survey indicator status is reported for the most recent crab season only.

Indicator category	**Indicator**	**2021 Status**	**2022 Status**	**2023 Status**	**2024 Status**	**2025 Status**
Fishery Informed	Number of Active Vessels	NA	NA	low	low	low
	Fishery CPUE	NA	NA	neutral	high	high
	Fishery Total Potlifts	NA	NA	low	low	low
	Annual Incidental Catch	neutral	neutral	neutral	neutral	neutral
	ABSC Skipper Survey: Perceived Abundance	NA	NA	NA	NA	high
	ABSC Skipper Survey: Changes in Fishing Practices	NA	NA	NA	NA	neutral
	ABSC Skipper Survey: Principal Driver of Changes	NA	NA	NA	NA	neutral
Economic	Ex-vessel Value	NA	NA	low	low	NA
	Ex-vessel Price	NA	NA	high	high	NA
	Ex-vessel Revenue Share	NA	NA	high	high	NA

Figures

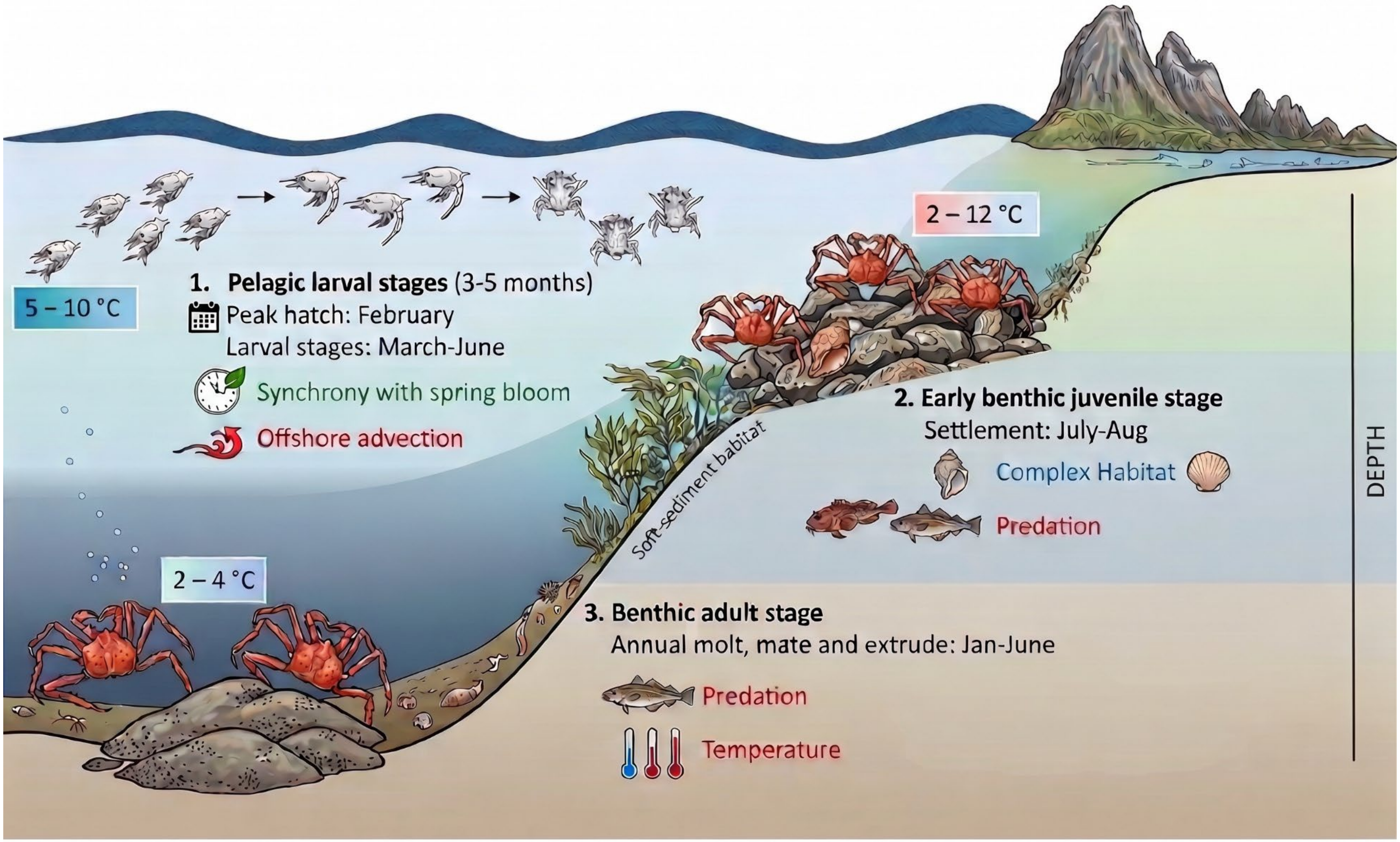

Figure D.1: Life history conceptual model for BBRKC summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text means that increases in the process positively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

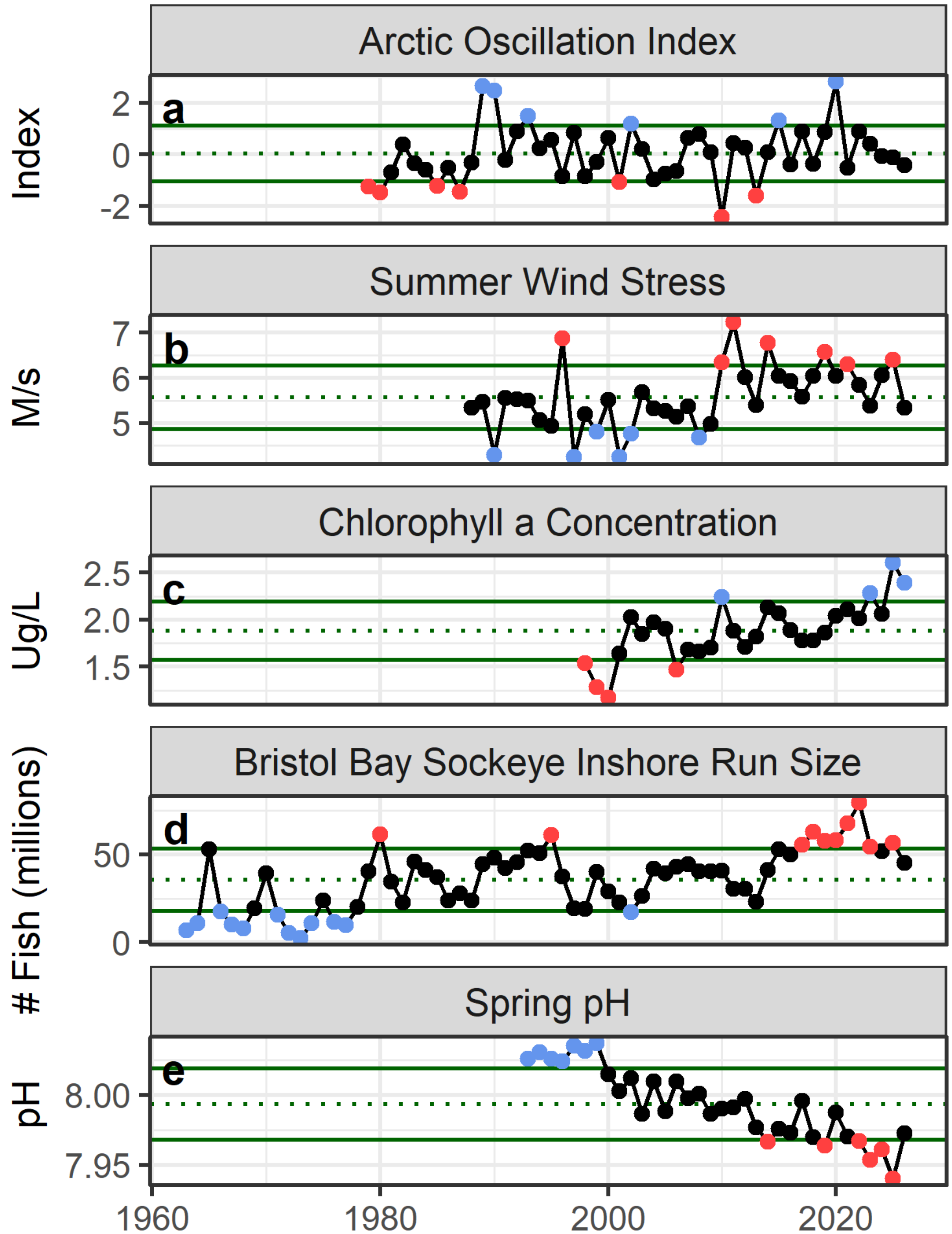

Figure D.2a: Selected ecosystem indicators for BBRKC with time series ranging from 1963 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

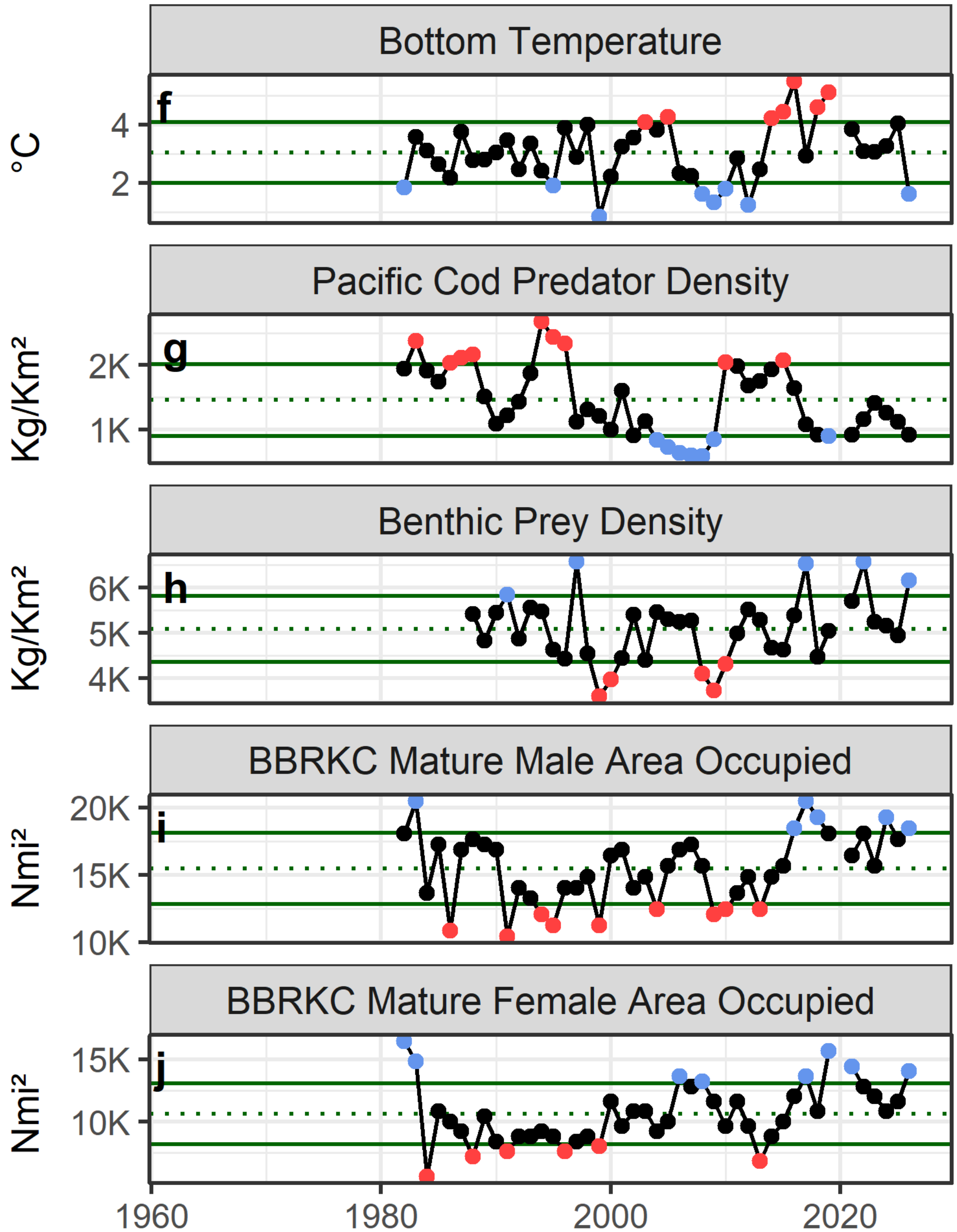

Figure D.2a (cont.): Selected ecosystem indicators for BBRKC with time series ranging from 1963 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

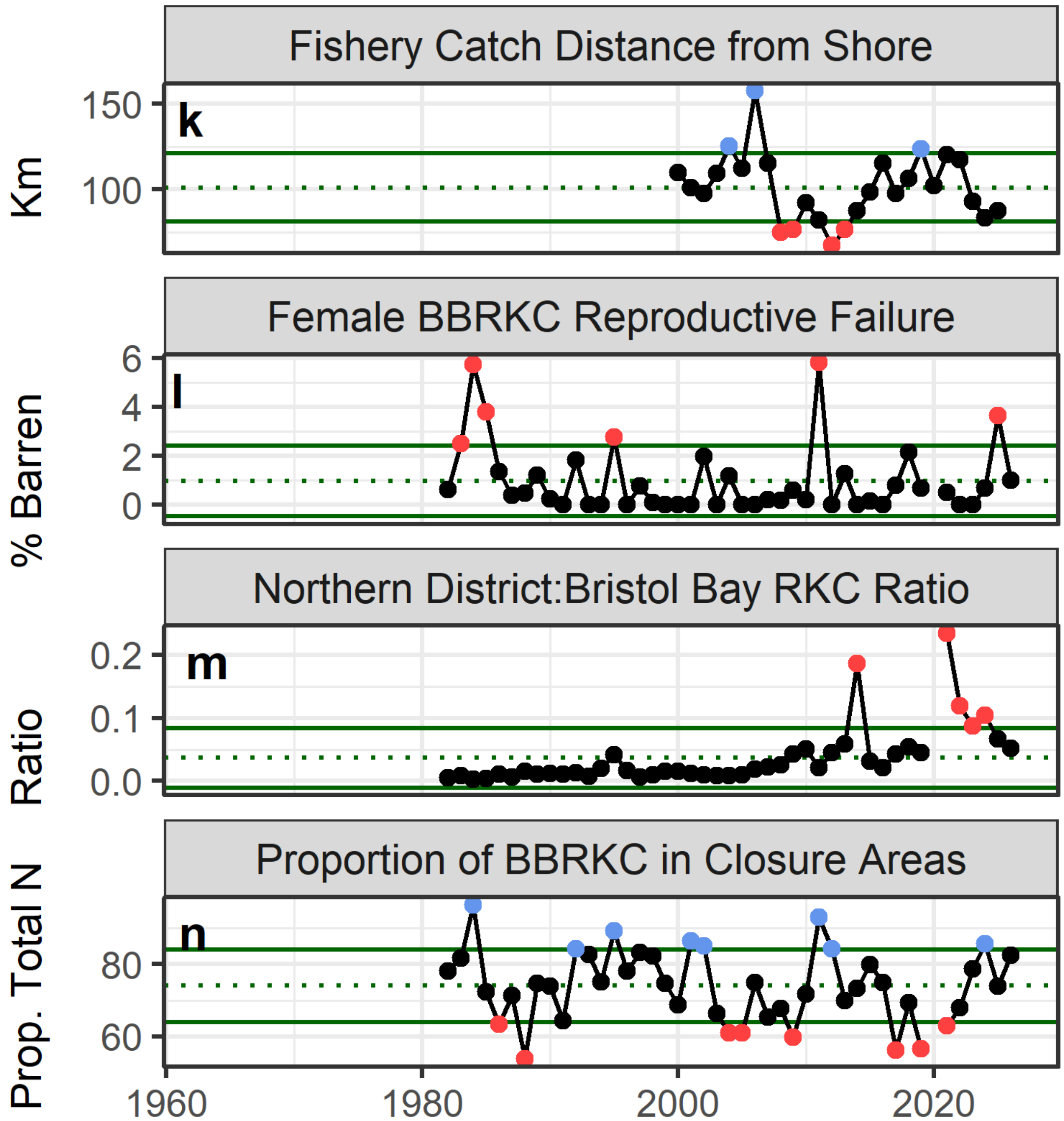

Figure D.2a (cont.): Selected ecosystem indicators for BBRKC with time series ranging from 1963 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

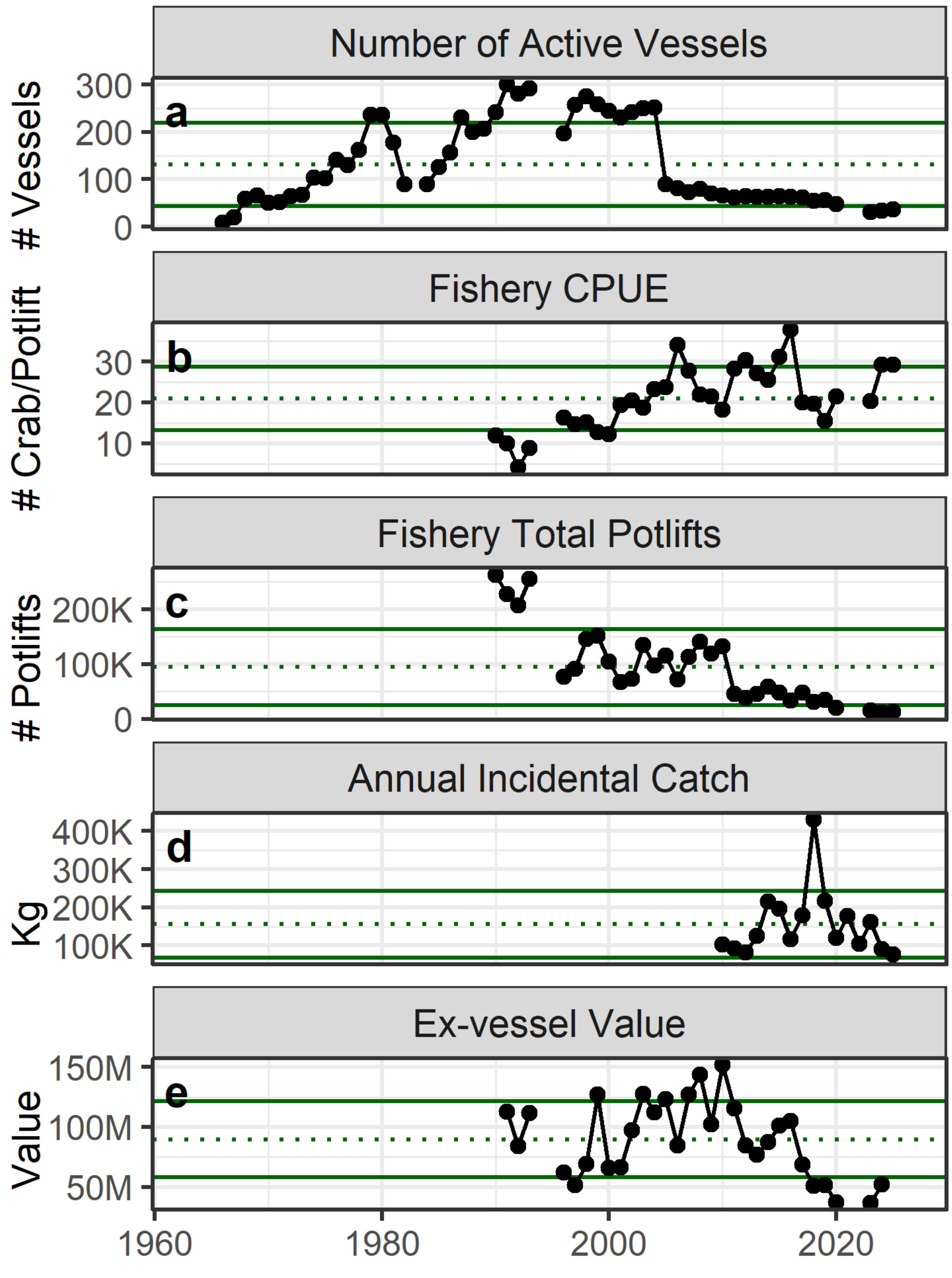

Figure D.2b: Selected socioeconomic indicators for BBRKC with time series ranging from 1966 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

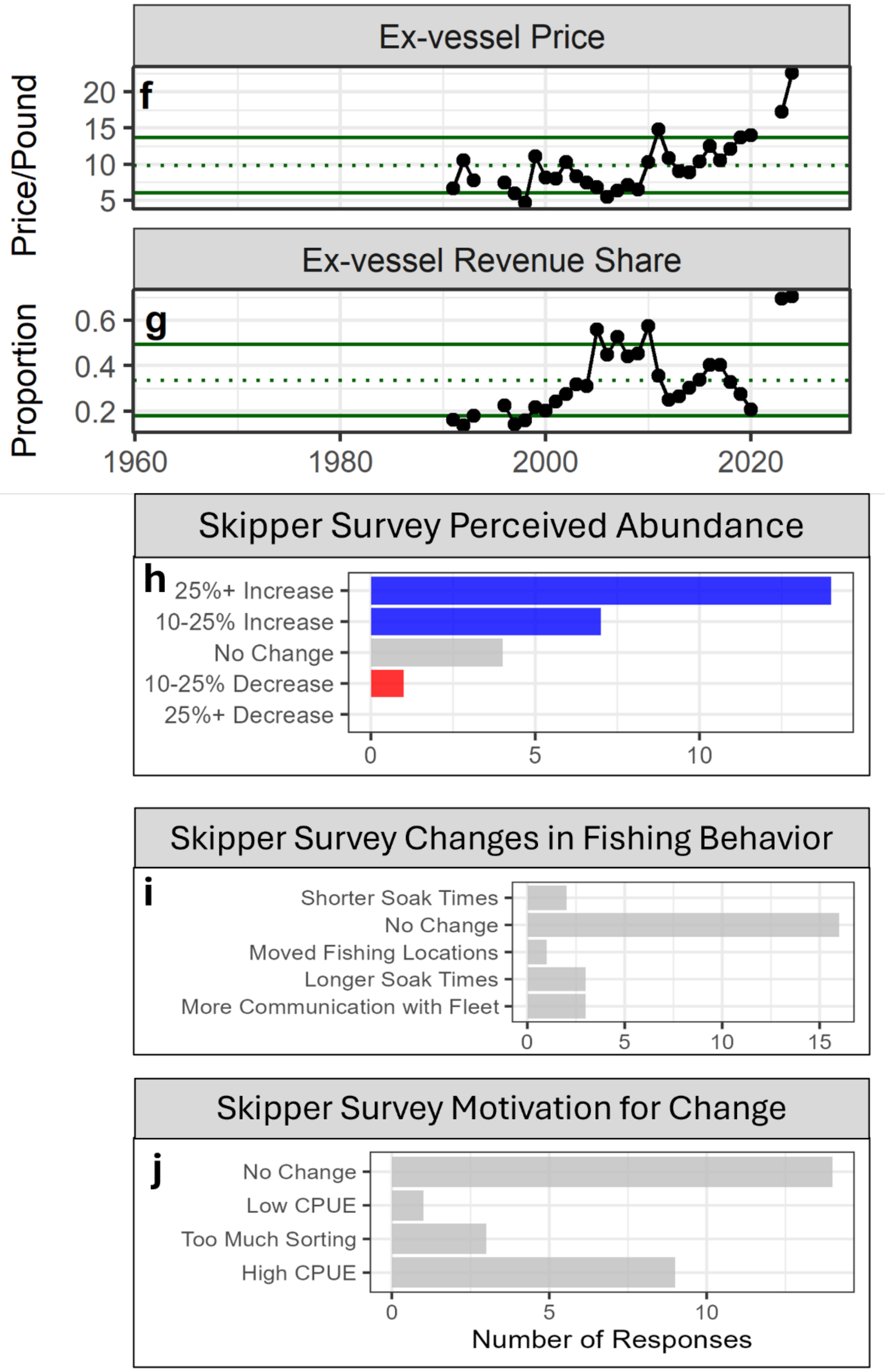

Figure D.2b (cont.): Selected socioeconomic indicators for BBRKC with time series ranging from 1966 – present. Alaska Bering Sea Crabbers Skipper Survey plots (D.2h-D.2j) include current year responses relative to the previous fishing season. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

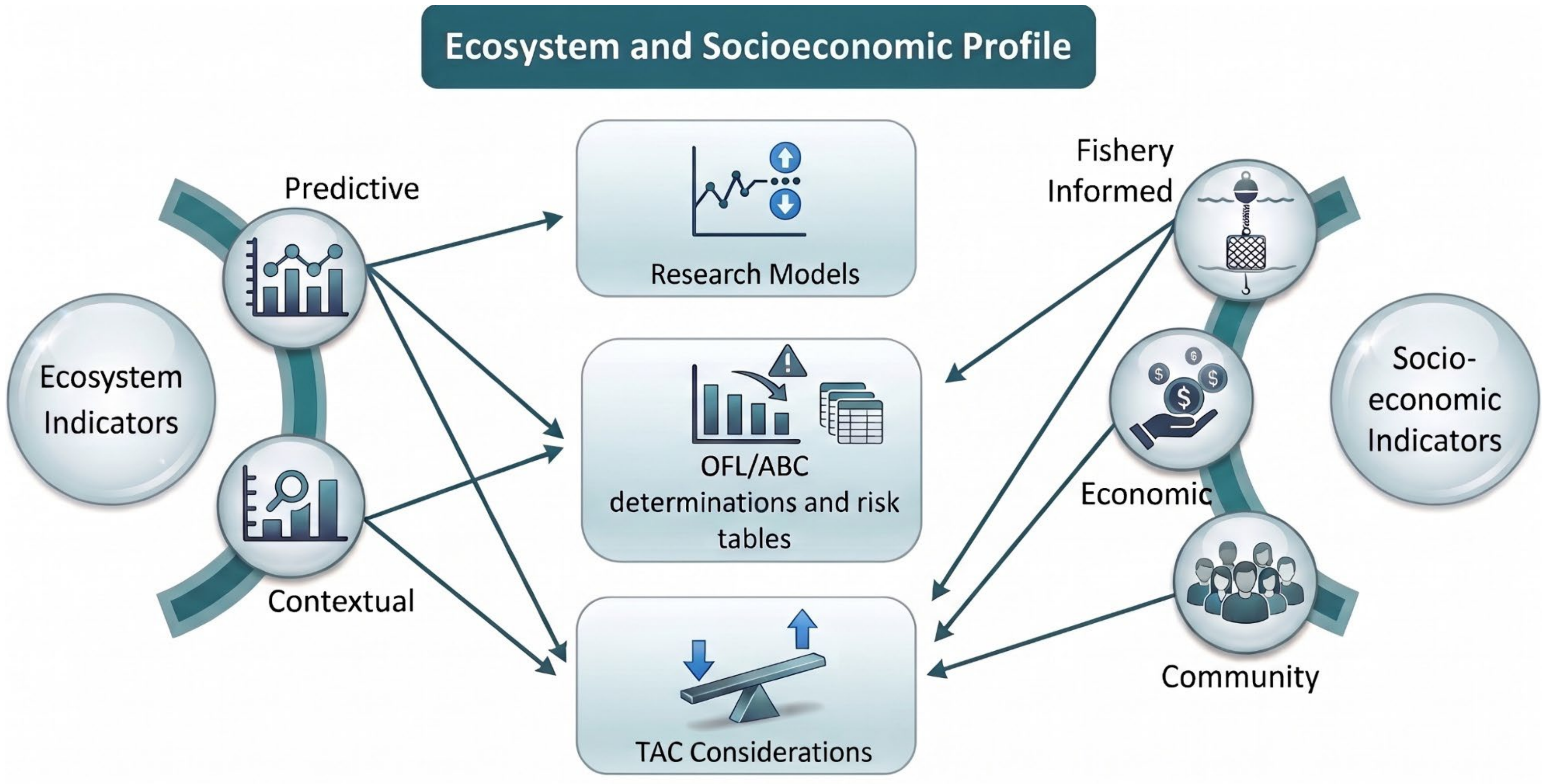

Figure D.3: Schematic of decision pathways for ecosystem and socioeconomic indicators

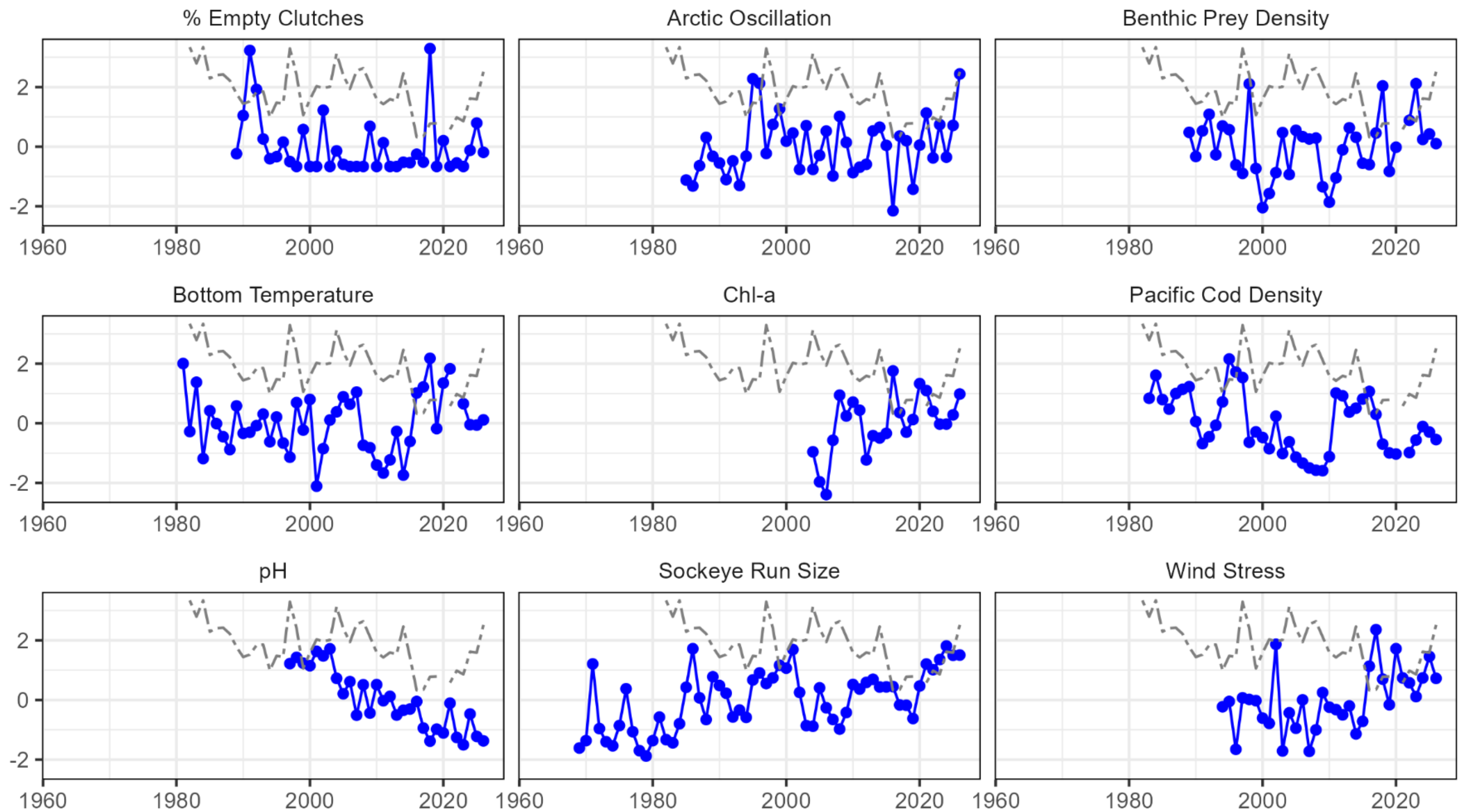

Figure D.4: Standardized ecosystem indicators (blue lines) considered for evaluation with Bayesian Adaptive Sampling. The grey line on each facet is the response variable, log-transformed BBRKC recruitment (survey abundance of 95 - 120mm males).

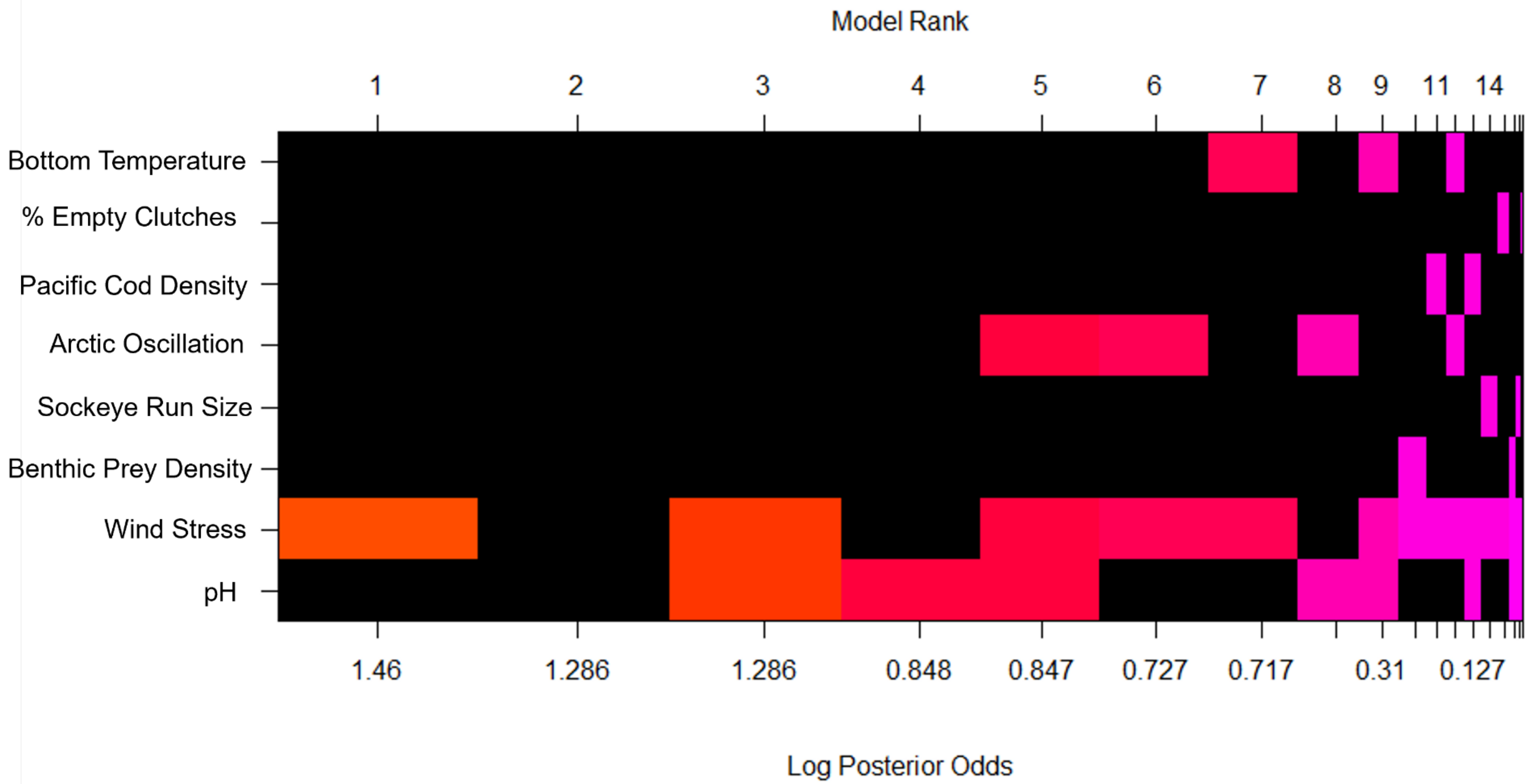

Figure D.5: Visualization of model space of the top models tested with Bayesian Adaptive Sampling. Models are sorted by their posterior probability from best at the left to worst at the right with the rank on the top x-axis, and each column represents one of the tested models.

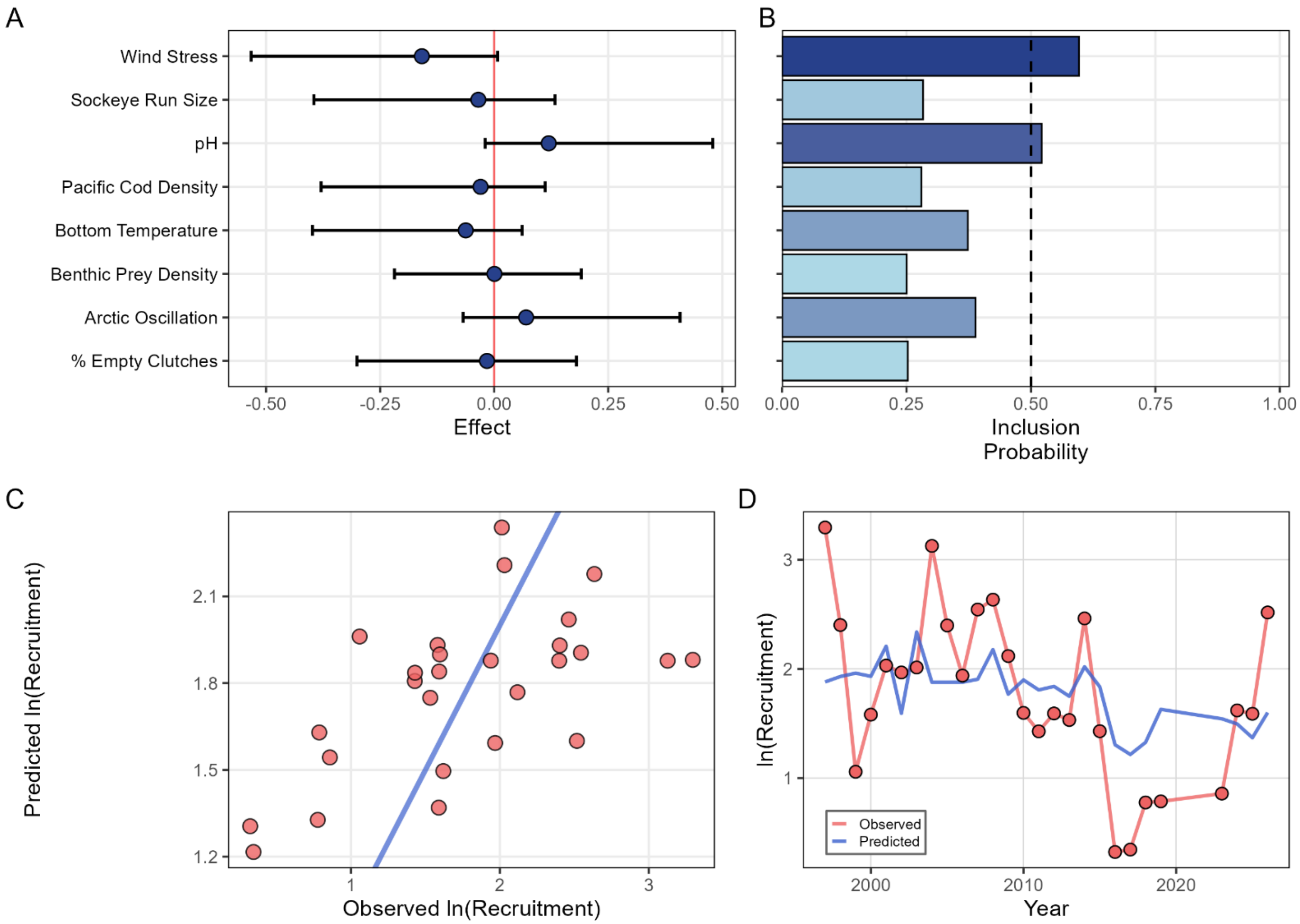

Figure D.6: Bayesian adaptive sampling (BAS) results showing model-averaged estimates of the relationship between ecosystem indicators and log-transformed BBRKC recruitment (survey abundance of 95–120 mm males). a) Estimated standardized effect sizes and associated posterior uncertainty (±1 SD), and b) the marginal inclusion probabilities for each ecosystem indicator, c) model predicted fit (1:1 line), and d) average fit across the abbreviated recruitment time series (1997-2026).