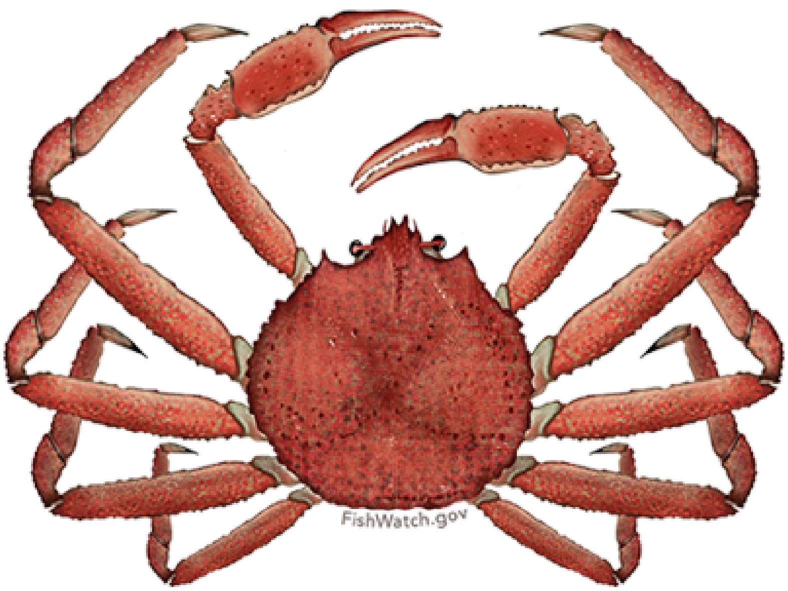
Appendix A. Ecosystem and Socioeconomic Profile of the eastern Bering Sea snow crab stock - Update

Erin Fedewa, Kalei Shotwell, and Brian Garber-Yonts (Editors)

September 2025



With Contributions from:

ESP Data: Kerim Aydin, Matt Callahan, Louise Copeman, Ben Daly, Jean Lee, and Jens Nielsen

This report may be cited as: Fedewa, E., Shotwell, K., and Garber-Yonts, B. 2025. Appendix A. Ecosystem and Socioeconomic Profile of the eastern Bering Sea snow crab stock - Update. *In*: Szuwalski 2025. An Assessment for eastern Bering Sea snow crab. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/about-the-council/plan-teams/bsai-crab-planning-team/.

Table of Contents

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 eastern Bering Sea (EBS) snow crab ESP report card (Fedewa et al., 2025), and details the methodology and results from statistical analyses used to monitor current year status and trends of ecosystem and socioeconomic indicators. The EBS snow crab 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 quantitatively predicted EBS snow crab recruitment

Contextual Indicators:

- Mean bottom water temperature in the EBS increased by 0.5°C and winter/spring sea ice extent declined by 18% from 2024 to 2025. Despite warm conditions, juvenile snow crab occupying temperatures < 1°C indicate that thermal thresholds were not likely exceeded in 2025 and cold-water habitat was available.
- Juvenile snow crab energetic condition fell below laboratory-derived starvation thresholds during the population collapse, although a rebound in energetic condition post-collapse (2021-2025) indicates conditions suitable for high survival and stock recovery.
- Bitter crab disease and Pacific cod predation indicators that represent proximate mechanisms for mortality have remained below average for the past five years.
- A contraction in the area occupied by mature males since 2022 has coincided with a steady decline in the spatial extent of the cold pool and a southward shift in the mature male snow crab center of abundance. A reduced spatial footprint was an apparent red flag during the recent snow crab population collapse, suggesting that the spatial extent of the stock should be closely monitored if it continues trending downward.
- The size at which 50% of the male snow crab population molted to maturity has been trending down for the past three decades, and decreased from 2024 to 2025. Mature female mean size at maturity increased substantially from 2024 to 2025, consistent with a cohort of large, immature females that were observed by the NOAA bottom trawl survey in 2024. These notable trends in growth and maturity alongside increased mature female abundance in 2025 contributed to a strongly female-skewed operational sex ratio, although < 1% of mature females with empty clutches suggests high reproductive potential despite depressed abundances of large male snow crab.

Fishery-Informed Indicators:

- Total effort in the fishery, as measured by number of active vessels (25) and total potlifts (15.7 thousand), was at a historical low during the 2024/25 fishery.

- CPUE of retained crab in the 2024/25 fishery increased to 219, well above the long term average, from a relatively extreme low of 124 during the last open season (2021/22), and the highest level since 2011/12.
- Crab vessel captain observations on fishing conditions in the 2024/25 fishery, as reported in the Alaska Bering Sea Crabbers Skipper Survey, are consistent with high fishery CPUE. The majority (67%) of captains reported a greater than 10% increase in abundance of industry-preferred males relative to the previous open season, with 38% of respondents reporting a 25% or greater increase. The most commonly reported change in fishing practice from 2021/22 was setting pots at greater depth (48% of respondents) and the principal driver of change in fishing practices (43% of responses) was proportion of undesirable (dirty, low meat fill, bitter crab, etc) crab, compared to 10% of respondents indicating low CPUE as the principal driver.
- The center of distribution of fishing activity in the 2024/25 fishery remained near the extreme northern bound of the historical range, at 59.67 degrees North latitude, marginally north of the center of distribution during the 2021/22 season, and only slightly south of the 59.92 degree historical extreme observed during the 2020/21 season.
- Incidental catch of EBS snow crab to date in 2025 groundfish fisheries is at a historical low of 27.4 thousand metric tons.

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 also 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.
- Economic and community indicators for the 2024/25 fishery are not yet available. The fishery was closed for the 2023/24 fishery.

Introduction/Background

An ESP was recommended for EBS snow crab in 2021 and the ESP full report was created in 2022 (Fedewa et al., 2022). The ESP full report is provided as an appendix to the operational stock assessment and fishery evaluation or SAFE report for the EBS snow crab stock and is reviewed and evaluated at the same time as the operational stock assessment. The elements of an ESP full report include a justification supporting the ESP recommendation, description of data streams used in the ESP, comprehensive literature review, synthesis of ecosystem and socioeconomic processes, description of the selected indicator suite, statistical analysis of the indicators according to the data availability of the stock, summary conclusions, and a final section detailing data gaps and research priorities.

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 includes mainly static elements in a short background to recap the ESP full report, reference the conceptual model, provide descriptions of the selected indicators used in the indicator analysis, and update the statistical analysis with new 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 A.1). Please refer to the last full ESP document (Fedewa et al., 2022) for more details.

Indicator Assessment

Selected indicators for EBS snow crab 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 EBS snow crab, please refer to the previous ESP documents (Fedewa et al., 2022). Time series of these indicators are provided in Figure A.2a (ecosystem indicators) and Figure A.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 A.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 A.2).
- "Neutral": Used in Table A.1 for any value within 1 standard deviation of the mean.
- "High" or "Low": Used in Table A.1 if the value was more than 1 standard deviation above or below the mean (above or below the solid green lines in Figure A.2).

The ESP full report evaluates the indicator suite as a whole when the ESP is first created (Fedewa et al., 2022). The ESP update report maintains all these indicators but may require some modifications each year to ensure delivery of the best scientific information available. Changes this year are documented below.

New indicators in the 2025 suite include:

- Female Snow Crab Size at Maturity

Modified indicators in the 2025 suite include:

- Winter/Spring Sea Ice Extent: Transitioned from NSIDC winter sea ice extent in the Bering Sea to a spatially resolved sea ice concentration product from the ERA5 reanalysis dataset.
- Female Snow Crab Reproductive Failure: This modified indicator replaces the Female Snow Crab Reproductive Potential indicator, and measures the proportion of mature females with empty clutches rather than the proportion with full clutches.
- Spatial Extent of Bottom Waters < 0°C: Previously reported as the Summer Cold Pool Spatial Extent, recent research suggests that < 0°C is a more meaningful thermal threshold for juvenile snow crab rather than constraining the area to < 2°C only, as typically defined (Fedewa et al., in revision). For this ESP, we refer to the spatial extent of bottom waters < 0°C as the "cold pool" for ease of understanding and consistency.
- Chlorophyll *a* Concentration: Transitioned from the ESA GlobColour blended satellite product to the ESA OC-CCI blended satellite product.
- Pacific Cod Consumption: Pacific cod consumption estimates previously classified all unidentified *Chionocetes* sp. prey items as *C. opilio.* New methods classify *Chionocetes* sp. as

either *C. opilio* or *C. bairdi* based on the proportion of each crab species in a given stratum at a given Pacific cod length bin.

Note: These modifications preclude direct comparison with previous ESP indicator time series.

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) factors driving indicator trends, and 4) potential implications of indicator trends for EBS snow crab.

Ecosystem Indicators:

Larval Indicators (Figure A.2a. a-b)

a. Arctic Oscillation Index: 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: 7 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 snow crab recruitment has been associated with positive values of the Arctic Oscillation (Szuwalski et al., 2021).

b. Chlorophyll *a* Concentration: Mean April – June average chlorophyll *a* concentration on the north-middle shelf of the EBS (BSIERP regions 9 and 5), calculated with the ESA OC-CCI blended satellite product. Proposed sign of the relationship is positive. Contact: Matt Callahan and Jens Nielsen.
    - Lag assigned for ecosystem indicator analysis: 7 years
    - 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: Low chlorophyll concentrations and subsequently less diatoms in the water column may drive increased larval mortality due to less favorable feeding conditions (Incze et al., 1987). A reduction in diatoms would also suggest less production reaching the seafloor, which may negatively impact juvenile snow crab lipid storage and energetic condition (Copeman et al., 2021).

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

c. Spatial Extent of Bottom Waters < 0°C: The total area (nmi²) of all EBS bottom trawl survey stations with bottom temperatures < 0°C. Proposed sign of the relationship is positive. Contact: Erin Fedewa.
    - Lag assigned for ecosystem indicator analysis: 1 year
    - Factors influencing trends: The spatial extent of bottom waters less than 0°C is determined by winter sea ice extent and winds.
    - Implications: The EBS snow crab population collapse was attributed, in part, to the absence of bottom waters < 0°C during the 2018-2019 marine heatwave (Szuwalski et al., 2023; Litzow et al., 2024), suggesting that declines in cold-water habitat availability negatively impact snow crab recruitment and productivity.

d. Juvenile Snow Crab Temperature of Occupancy: Mean bottom temperature weighted by immature snow crab CPUE during the EBS summer bottom trawl survey, representing the realized thermal niche of juvenile snow crab. Proposed sign of the relationship is negative. Contact: Erin Fedewa.

- Lag assigned for ecosystem indicator analysis: 1 year
- Factors influencing trends: Temperatures occupied by juvenile snow crab are directly influenced by bottom temperatures in the Bering Sea and thermal preferences of stenothermic juveniles. Realized thermal niches are also influenced by species interactions.
- Implications: Occupied temperatures < 0°C are critical for supporting high snow crab density and elevated energetic reserves (Fedewa et al. in revision). Occupied temperatures > 2°C have been suggested as an upper temperature threshold for juvenile snow crab (Murphy 2020). Marine heatwaves and the resulting loss of climate refugia are expected to increase temperatures occupied by juvenile snow crab beyond thermal preferences.

e. Winter/Spring Sea Ice Extent: January-April average winter sea ice concentration in the Bering Sea from the ERA5 reanalysis dataset. Concentration values represent the percentage of the EBS covered by sea ice in winter/spring, with values below 15% considered ice-free. Proposed sign of the relationship is positive. Contact: Erin Fedewa.
   - Lag assigned for ecosystem indicator analysis: 3 years
   - Factors influencing trends: Winter sea ice in the Bering Sea is driven by atmospheric CO_2, ocean heat transport and winds.
   - Implications: Low levels of sea ice have been associated with dampened productivity of snow crab (Mullowney et al., 2023).

f. Juvenile Snow Crab Disease Prevalence: Prevalence (%) of immature snow crab showing visual symptoms of Bitter Crab Disease (BCD) during the summer EBS bottom trawl survey, calculated as the abundance of visually positive immature crab divided by total immature abundance. Proposed sign of the relationship is negative. Contact: Erin Fedewa.
   - Lag assigned for ecosystem indicator analysis: 3 years
   - Factors influencing trends: Bitter crab disease tends to occur at stations with high population density of small, new shell crab, and 2 - 4°C bottom temperatures (Balstad et al., 2024). However, visual detection methods substantially underestimate disease prevalence, and infections detected with sensitive PCR assays at disease monitoring sites indicate that prevalence levels are much higher than reported here (Fedewa et al., 2025).
   - Implications: Because bitter crab disease is assumed fatal and primarily affects small crab, increases in visual disease prevalence are expected to negatively impact survival and recruitment success. Disease monitoring is critical when large cohorts enter the population because an increased proportion of small snow crab in the system could lead to higher disease prevalence and mortality.

g. Juvenile Snow Crab Energetic Condition: Summer snow crab juvenile energetic condition is estimated from water content in the hepatopancreas (% dry weight) sampled from snow crab on the EBS bottom trawl survey. Proposed sign of the relationship is positive. Contacts: Erin Fedewa and Louise Copeman.
   - Lag assigned for ecosystem indicator analysis: 1 year
   - Factors influencing trends: Dramatic declines in energetic condition during the 2018-2019 snow crab population collapse were driven by warming during a marine heatwave and high snow crab population density (Fedewa et al., in revision). Declines in lipid storage in juvenile snow crab have also been linked to warmer temperatures and reduced food quality in the Bering Sea (Copeman et al., 2021).

- Implications: Increased energetic condition suggests favorable conditions for high survival and recruitment, whereas energetic condition that falls below a laboratory-derived threshold of 22.6% has been attributed to starvation-induced mortality (Copeman et al., in prep).

h. Pacific Cod Consumption: The daily summer consumption of snow crab (mt/day) by Pacific cod in the EBS, estimated from Pacific cod diet compositions, EBS trawl survey CPUE, and temperature adjusted length-specific maximum consumption rates. Pacific cod consumption estimates include unidentified *Chionocetes* sp. as well as identified *C. opilio* from stomach contents. Unidentified crab were extrapolated to *C. opilio* based on identified *C. bairdi* and *C. opilio* proportions by cod size and stratum. Proposed sign of the relationship is negative. Contact: Kerim Aydin.
    - Lag assigned for ecosystem indicator analysis: 4 years
    - Factors influencing trends: Consumption rates are driven by Pacific cod abundance, juvenile snow crab abundance, the spatial extent of the cold pool, and the spatial overlap between Pacific cod and snow crab (Reum et al. in revision).
    - Implications: High consumption rates indicate increased top-down predation pressure, and the potential for reduced recruitment of juvenile snow crab.

Adult Indicators (Figure A.2a. i-o)

i. Benthic Prey Density: Summer benthic invertebrate density (kg/km²), estimated from EBS bottom trawl survey stations included in the 50th percentile of mean snow crab CPUE. Invertebrates are subset to include species observed in snow 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 may suggest increased prey availability for juvenile and adult snow crab. 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.

j. Male Snow Crab Size at Maturity: Carapace width (mm) at 50% probability of having undergone terminal molt for male snow crab, as determined from maturity ogives developed from EBS bottom trawl survey data for newshell males only. Proposed sign of the relationship is positive. Contact: Erin Fedewa.
    - Not included in ecosystem indicator analysis
    - Factors influencing trends: Temporal shifts in size at terminal molt in male snow crab are likely driven by recruitment variability, density dependent growth, and ocean temperatures (Murphy 2021; Mullowney and Baker, 2021). Larger size at maturity has also been linked to higher abundances of large males, suggesting that increased competition for mates may delay the terminal molt to later instar stages.
    - 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 snow crab may decrease reproductive potential of the stock (Baker et al., 2022).

k. Female Snow Crab Size at Maturity: Mean carapace width (mm) of newshell mature female snow crab, weighted by newshell mature female density. Proposed sign of the relationship is positive. Contact: Erin Fedewa.
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: Temporal shifts in size at terminal molt in snow crab are likely driven by recruitment variability, density dependent growth, and ocean temperatures (Orensanz et al. 2007; Murphy 2021).
   - Implications: Because fecundity increases with female size, directional downward shifts in size at maturity could decrease reproductive potential.

l. Mature Male Snow Crab Area Occupied: The minimum area containing 95% of the cumulative mature male snow crab CPUE 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: The spatial extent of snow crab in the EBS contracts in response to warmer bottom temperatures and a smaller cold pool extent (Fedewa et al., 2021). Spatial extent is also influenced by snow crab abundance due to density dependent range contraction (Murphy et al., 2010).
   - Implications: Declines in the spatial extent of mature male snow crab can result in density-dependent prey limitation and starvation-induced mortality, which are exacerbated in warm temperatures due to increased metabolic demand (Szuwalski et al., 2023). Dramatic declines in the spatial extent of mature males preceded the 2019-2021 population collapse, emphasizing the importance of this indicator as a potential red flag.

m. Mature Male Snow Crab Center of Abundance: CPUE-weighted average latitude of the mature male snow crab stock 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: Historically, centroids of abundance have tracked bottom temperatures, and were further south with colder temperatures (Orensanz et al., 2005).
   - Implications: Centroids of abundance are expected to shift north under warming as snow crab track preferred cold-water habitat. This may have implications for availability to the snow crab fishery and NOAA bottom trawl survey.

n. Female Snow Crab Reproductive Failure: The proportion of hardshell mature female snow crab with no eggs, empty egg cases, or dead eggs. Hardshell crab are designated as code “2” to “5” from the EBS bottom trawl survey shell condition indices. Proposed sign of the relationship is negative. Contact: Erin Fedewa.
   - Lag assigned for ecosystem indicator analysis: 8 years
   - 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 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 high reproductive potential, and suggests that the majority of females were able to find mates or utilize stored sperm during the mating season.

o. Snow Crab Operational Sex Ratio: The ratio of large male (> 95 mm CW) to mature female snow crab abundance in the EBS. The proposed sign of the relationship is positive under the assumption that the sex ratio will always be < 0.5 because only large males are used in the calculation. Contact: Erin Fedewa.
   - Not included in ecosystem indicator analysis
   - Factors influencing trends: The operational sex ratio is directly influenced by the relative abundances of large males and mature females. Non-synchronous shifts in abundance between the two sexes, or a male population dominated by small mature males are two mechanisms for a skewed operational sex ratio.
   - Implications: A female-biased operational sex ratio suggests the possibility for sperm limitation (Baker et al., 2022), however, a high proportion of full clutches in mature females indicates that female sperm reserves are likely sufficient for egg production.

Socioeconomic Indicators:

Fishery Informed Indicators (Figure A.2b. a-h)

a. Number of Active Vessels: Annual number of active vessels in the snow crab fishery to represent the level of fishing effort assigned to the fishery. Contacts: Jean Lee and Brian Garber-Yonts.
   - 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 EBS snow crab fleet is driven by the TACs in the EBS snow crab, BBRKC and, increasingly, Tanner crab fisheries, with crab harvest quota leasing facilitating adjustment of the fleet to achieve efficient deployment of harvesting capacity.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, including intervessel coordination and search efficiency.

b. Fishery CPUE: Annual catch-per-unit-effort (CPUE), expressed as mean number of crabs per potlift, in the snow crab fishery to represent relative efficiency of fishing effort. Contact: Ben Daly.
   - Factors influencing trends: Annual fishery CPUE can vary based on a suite of factors including total fishery potlifts, EBS snow 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.

c. Fishery Total Potlifts: Annual total potlifts in the snow crab fishery to represent the level of fishing effort expended by the active fleet. Contact: Ben Daly.
   - 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: TBD

d. Centroid of Fishery: Center of gravity, expressed in latitude, as an index of spatial distribution for the snow crab fishery to monitor spatial shifts in fishery behavior. Contact: Ben Daly.
   - Factors influencing trends: TBD
   - Implications: TBD

e. Annual Incidental Catch: Annual incidental catch of snow crab in EBS groundfish fisheries. Contact: Brian Garber-Yonts and Jean Lee.
   - Factors influencing trends: TBD
   - Implications: TBD

f. Alaska Bering Sea Crabbers (ABSC) Skipper Survey Perceived Abundance: 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 industry preferred male snow crab during the 2024/2025 fishery relative to the last snow crab 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.

g. 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 2024/2025 fishery relative to the last snow crab 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.

h. 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 2024/2025 fishery relative to the last snow crab 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 A.2b. i-k)

i. Ex-vessel Value: Annual snow crab ex-vessel value of the snow crab fishery landings represents gross economic returns to the harvest sector, as a principal driver of fishery behavior. Contact: Brian Garber-Yonts and Jean Lee.
   - Factors influencing trends: Data for the 2024/25 fishery is not yet available. The fishery was closed for the 2023/24 season.
   - Implications: TBD

j. Ex-vessel Price: Annual snow 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 and Jean Lee.
   - Factors influencing trends: Data for the 2024/25 fishery is not yet available. The fishery was closed for the 2023/24 season.
   - Implications: TBD

k. Ex-vessel Revenue Share: Annual snow crab ex-vessel revenue share, expressed as vessel-average proportion of annual gross landings revenue earned from the EBS snow crab fishery. Contact: Brian Garber-Yonts and Jean Lee.
   - Factors influencing trends: Data for the 2024/25 fishery is not yet available. The fishery was closed for the 2023/24 season.
   - Implications: TBD

Indicator Analysis

Ecosystem and socioeconomic indicators are monitored through distinct workflows, depending on the management decisions they are intended to inform (Figure A.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 estimate 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 external to the assessment model. The most data rich stocks with an integrated ecosystem-linked modeling platform could move past the intermediate stage or gate to evaluate indicators using the advanced methodology (e.g., integrated age-structured stock assessment model with dynamic structural equation modeling or DSEM, Champagnat et al., *in review*).

We evaluated the socioeconomic indicators using only the beginning stage statistical tests and did not assign a proposed relationship between the indicator and the 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). 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 for the stock 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 snow crab stock is data-rich with an associated size-structured 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 to quantify the strength and direction of association between ecosystem indicators and EBS snow crab recruitment. BAS explores model space, or the full range of candidate combinations of predictor variables, to estimate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model-averaged predictions for snow crab recruitment (Clyde et al., 2011). Snow crab recruitment was calculated using the EBS bottom trawl survey abundance of newshell male "pre-recruit" snow crab (≥ 65mm carapace width and ≤ 80mm carapace width) under the assumption that this size class represents Instar X (~ 6.7 - 7.7 years post-settlement), and individuals that are 1 -2 molts away from terminally molting and recruiting to the fishery (Sainte-Marie et al., 1995).

Prior to running BAS, the full suite of 15 ecosystem indicators was winnowed to the predictors that directly relate to recruitment. We eliminated the following indicators, as they are not hypothesized to drive snow crab recruitment and instead, provide contextual information about the stock or a relevant management concern: 1) operational sex ratio, 2) male size at maturity, 3) female size at maturity, 4) mature male area occupied, and 5) mature male center of abundance. 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 juvenile snow crab energetic condition (n = 6 years, 2019/2021-2025) relative to other ecosystem indicators, this indicator was dropped from the final BAS model. With lags applied, chlorophyll-*a* concentration (n = 21 years, 2005-2025) and female reproductive failure (n = 30 years, 1996-2025) limited the 1989 model run start date and were therefore also eliminated. The Pacific cod consumption time series included data up to 2024 only, as a current-year update is not yet available due to the lag time in stomach processing following the completion of the EBS bottom trawl survey.

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 fairly robust to +/- 1 year lags, although the inability to accurately age crab results in difficulties assigning lags with high confidence. Pre-recruit male snow crab were assumed to be 6 - 7 years old, therefore larval indicators were assigned a lag of six years. Juvenile snow crab disease prevalence, Pacific cod consumption and sea ice extent disproportionately impact small juvenile snow crab, and were therefore assigned representative lags of 3 - 4 years. Benthic invertebrate density, spatial extent of bottom waters < 0°C and juvenile snow crab temperature occupied were assigned a lag of one year, as prey resources and thermal conditions are likely to be an integrated effect that depends more on recent conditions to inform survival of pre-recruits.

Prior to running the model, we also eliminated highly correlated indicators ($r \geq 0.6$) with the understanding that high correlations among predictors may "dilute" inclusion probabilities and render them less useful as a posterior summary of variable importance. The spatial extent of bottom waters < 0°C time series was highly correlated with juvenile snow crab temperature occupied ($r = -0.78$), and Pacific cod consumption was highly correlated with disease prevalence ($r = 0.6$). We chose to drop the spatial extent of bottom waters < 0°C from the final model while retaining juvenile snow crab temperature occupied, given that temperatures occupied are a more direct measure for thermal conditions experienced by highly stenothermic juvenile snow crab. Likewise, we eliminated disease prevalence from the final suite of predictors with the knowledge that our measure of visual prevalence greatly underestimates true disease prevalence, and there is likely more confidence in a direct estimate of consumption. This resulted in a final suite of 5 predictors: juvenile snow crab temperature occupied, sea ice extent, Pacific cod consumption, benthic prey density and Arctic Oscillation (Figure A.4). Because missing data are dropped from BAS model runs, 18 years were dropped due to incomplete observations, and resulted in a model run from 1989 - 2025. NAs due to the cancellation of the 2020 EBS bottom trawl survey were especially problematic, and resulted in 2020, 2021 and 2024 being dropped from the analysis after lagging indicators.

The final model selected using BAS was the intercept-only model (Figure A.5), indicating that the ecosystem indicators tested had no predictive skill for estimating snow crab recruitment over the years evaluated. We provide the mean relationship between each predictor variable and the estimates of EBS snow crab recruitment over time (Figure A.6a) and the marginal inclusion probabilities for each predictor variable (Figure A.6b) to illustrate that credible intervals for all effect sizes overlapped zero, and marginal inclusion probabilities were < 0.5. Model predicted fit (Figure A.6c) and average predicted fit across the recruitment time series subset (1989 - 2025; Figure A.6d) were also very poor. Because the BAS analysis presented here identified no indicators that demonstrated predictive capacity, we categorized the full suite of ecosystem indicators as either contextual (juvenile snow crab temperature occupied, sea ice extent, disease prevalence, juvenile snow crab energetic condition, Pacific cod consumption, male snow crab size at maturity, male snow crab area occupied, male snow crab center of abundance, female snow crab reproductive failure and snow crab operational sex ratio) or monitoring (Arctic oscillation index, chlorophyll-a concentration, spatial extent of bottom waters < 0°C, benthic prey density and female snow crab size at maturity) based on the criteria listed above.

We also summarize recent indicator trends and provide management considerations by providing a five year status table of the indicators organized into predictive, contextual, or monitoring categories (Table A.1). 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 and hypothesized relationship with the stock (Figure A.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.

Overall, results from the traffic light table (Table A.1a) indicate that mature male range contraction and a strongly female-biased operational sex ratio are at anomalous values in 2025, and may represent potential red flags for the stock. Conversely, high female size at maturity and a low proportion of females with empty clutches relative to the long-term mean indicate positive signals for reproductive capacity of the stock. All remaining contextual indicators with 2025 updates remained within one standard deviation of their long-term mean. The Executive Summary at the beginning of this document provides a summary of 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 12 socioeconomic indicators that depict a historical time series of key socioeconomic information for the EBS snow crab fishery - 5 fishery-informed indicators derived from NMFS/ADFG in-season management monitoring systems, 3 selected from the Alaska Bering Sea Crabbers (ABSC) Snow Crab Skipper Survey - 2025, and 3 economic indicators drawn from mandatory economic reporting systems (ADFG’s Commercial Operators Annual Reports). All socioeconomic indicators are produced from observations captured during or after completion of the 2024/25 fishery. Indicators derived from agency monitoring and reporting systems use time series of historical data through the most recent (2024/25) fishery, which occurred during the initial months of 2024, 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 survey, which elicited single period comparisons between the 2024/25 fishery and the most recent previous fishery. Inclusion of these indicators is primarily aimed at informing ABC determinations, and is intended as a provisional mechanism for incorporating an alternative source of fishery-dependent data on fleet behavior and observations of abundance, age, sex, and other conditions of the catch, for consideration of authors and reviewers of the assessment. It is expected that recommendations from the CPT and SSC regarding the general suitability of the ABSC survey as a source of indicators for inclusion in the ESP, and the initial selection of three representative questions as indicators focuses on skipper’s perception of the abundance of industry-preferred 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. Additional indicators, including syntheses of survey time series (n = 3 as of 2024) may be developed for future ESPs pending CPT and SSC evaluation of the initial selection of indicators and of the ABSC survey as a candidate data source for the ESP generally.

The most recent fishery represented levels of fishing effort (number of active vessels and total potlifts) below 1-sd of the long term average (Table A.1b, c). The fleet consolidated from 42 in the 2021/22 fishery, to 25 in the 2024/25 fishery, compared to an average of 69 vessels in the post-rationalization period prior to 2021/22. Quota royalty income likely mitigates some financial impact of non-entry for vessel owners that have substantial crab quota share holdings, however, idling of a significant segment of the fleet has distributional effects, including for crew members and associated communities, and over time may have structural implications for the crab harvest sector. A commensurate decline in total potlifts occurred between 2021/22 and 2024/25. In contrast, efficiency of effort increased for the 2024/25 fishery, as indicated by a moderately increased CPUE (within the 1-sd range above the long-term average), and high (relative to the previous season) crab skipper perception of abundance of industry-preferred males. ABSC survey results indicated that the most common response regarding changes in fishing behavior relative to the previous season was shifting to greater depths, and the most common driver of changed fishing strategy was catch of crab with poor shell condition. The center of distribution of the fishery continued the recent shift of the fishery toward the northwestern bounds of the fishing grounds. Incidental catch in groundfish fisheries declined slightly, remaining near the lower bound of the 1-sd range about the long-term mean.

Data needed to produce economic indicators for the 2024/25 fishery are not yet available, and the fishery was closed for the 2023/24 season.

For this EBS snow crab ESP update, a more limited set of socioeconomic indicators is reported than for previous iterations, and compared to the full ESP produced for the 2025/25 Tanner crab assessment. Given resource limitations, a more inclusive set of socioeconomic indicators in crab ESPs (both full ESPs and update versions) awaits general guidance from the SSC and Council regarding priorities for ESP/socioeconomic indicators to inform TAC setting.

Conclusion

The EBS snow crab 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., 2022). Fifteen ecosystem and twelve socioeconomic indicators were identified to monitor and analyze for EBS snow crab. Because EBS snow crab is a data-rich stock with an annual fishery-independent survey to assess population status, ecosystem indicators were evaluated using intermediate indicator analysis stage methods. We provide several overarching takeaways from the indicator 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 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.

Because no predictive indicators were identified in the indicator analysis, ecosystem indicators are interpreted as providing contextual information only for EBS snow crab. Contextual indicators suggest potential red flags with directional downward shifts in male maturity and spatial extent, a strongly female-skewed sex ratio, and declines in the spatial extent of cold bottom water and winter/spring sea ice. However, energetic condition of juvenile snow crab remains high in 2025, predation and disease pressure have remained low, and temperatures occupied by juveniles suggest that cold-water habitat was available despite warming. Overall, ecosystem indicators show warm conditions and reduced ice extent in the EBS, but warming is not yet approaching critical thresholds for highly stenothermic juvenile snow crab. Ecosystem concerns are minor with uncertain impacts on the stock. Fishery-informed indicators suggest that, despite historically low levels of fishing effort during the 2024/25 season, efficiency of effort increased substantially from the most recent (2021/22) fishery, and was high relative to the most recent several open seasons. No economic indicators are reported for the 2024/25 season due to the normal lag in production of economic data. Overall, socioeconomic indicators generally support improved stock condition relative to the most recent (2021/22) fishery. Despite continued extreme northerly shift in the center of distribution of fishing activity, no considerations observed in the most recent fishery suggest greater than normal risk, independent of other considerations captured in the assessment and risk table.

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 extend our gratitude to Molly Zaleski for reviewing a draft of this document, and thank Ethan Nichols and Ben Daly for assisting in the interpretation of fishery-informed indicators. 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, and S. Hennessey for the development of the crabpack R package for wrangling Shellfish Assessment Program survey data. 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.

Literature Cited

Baker, K. D., Mullowney, D. R. J., and Sainte-Marie, B. 2022. Large males matter: Low sperm reserves in female snow crab (*Chionoecetes opilio*) off Newfoundland, Canada. Fisheries Research, 253:13.

Balstad, L. J., Fedewa, E. J., and Szuwalski, C. S. 2024. Drivers of bitter crab disease occurrence in eastern Bering Sea snow crab (*Chionoecetes opilio*). ICES Journal of Marine Science.

Clyde, M. A., J. Ghosh, and M. L. Littman. 2011. Bayesian Adaptive Sampling for Variable Selection and Model Averaging. Journal of Computational and Graphical Statistics 20:80-101.

Copeman, L. A., Ryer, C. H., Eisner, L. B., Nielsen, J. M., Spencer, M. L., Iseri, P. J., and Ottmar, M. L. 2021. Decreased lipid storage in juvenile Bering Sea crabs (*Chionoecetes* spp.) in a warm (2014) compared to a cold (2012) year on the southeastern Bering Sea. Polar Biology, 44: 1883-1901.

Dorn, M. W. and S. G. Zador. 2020. A risk table to address concerns external to stock assessments when developing fisheries harvest recommendations. Ecosys. Health and Sustainability. 6(1):1-11.

Fedewa, E. J., Jackson, T. M., Richar, J. I., Gardner, J. L., and Litzow, M. A. 2020. Recent shifts in northern Bering Sea snow crab (*Chionoecetes opilio*) size structure and the potential role of climate-mediated range contraction. Deep Sea Research Part II: Topical Studies in Oceanography: 104878.

Fedewa, E., B. Garber-Yonts, and K. Shotwell. 2022. Appendix G. Ecosystem and Socioeconomic Profile of the eastern Bering Sea snow crab stock. *In*: Szuwalski 2022. An Assessment for eastern Bering Sea snow crab. North Pacific Fishery Management Council, Anchorage, AK. Available from https://akesp.psmfc.org.

Fedewa E.F., Jensen P.C., Small H.J., Litzow M.A., Malick M.J., Zacher L.S., Long W.C., Kotwicki S. 2025. Bitter crab disease dynamics in eastern Bering Sea Tanner and snow crab: an underestimated and emergent stressor. Fisheries Research, 283: 107307.

Fedewa, E., Shotwell, K., and Garber-Yonts, B. 2025. Appendix A. Ecosystem and Socioeconomic Profile of the eastern Bering Sea snow crab stock - Report Card. *In*: Szuwalski 2025. An Assessment for eastern Bering Sea snow crab. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/about-the-council/plan-teams/bsai-crab-planning-team/.

Fedewa, E.F., Copeman, L.A., Litzow, M.A. In revision. Energetic limitations and mass mortality of Bering Sea snow crab: Interacting effects of warming and density on collapse and recovery.

Incze, L. S., Armstrong, D. A., and Smith, S. L. 1987. Abundance of larval Tanner crabs (*Chionoecetes* spp.) in relation to adult females and regional oceanography of the southeastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences, 44: 1143-1156.

Incze, L. S., Armstrong, D. A., and Wencker, D. L. 1982. Rates of development and growth of larvae of *Chionoecetes bairdi* and *C. opilio* in the southeastern Bering Sea. *In* Proceedings of the International Symposium on the Genus *Chionoecetes*, 3rd edn, pp. 191-218. Ed. by A. J. Paul, F. Gaffney, D. Haapa, J. Reeves, R. Baglin, and S. K. Davis. Alaska Sea Grant College Program, University of Alaska Fairbanks, Anchorage, AK.

Litzow, M. A., Fedewa, E. J., Malick, M. J., Connors, B. M., Eisner, L., Kimmel, D. G., Kristiansen, T., Nielsen, J.M., Ryznar, E.R. 2024. Human-induced borealization leads to the collapse of Bering Sea snow crab. Nature Climate Change.

Mullowney, D. R. J., and Baker, K. D. 2021. Size-at-maturity shift in a male-only fishery: factors affecting molt-type outcomes in Newfoundland and Labrador snow crab (*Chionoecetes opilio*). ICES Journal of Marine Science, 78: 516-533.

Mullowney DRJ, Baker KD, Szuwalski CS, Boudreau SA, Cyr F, et al. 2023. Sub-Arctic no more: Short- and long-term global-scale prospects for snow crab (*Chionoecetes opilio*) under global warming. PLOS Climate 2(10).

Murphy, J. T., Hallowed, A. B., and Anderson, J. J. 2010. Snow crab spatial distributions: Examination of density-dependent and independent processes. In Biology and Management of Exploited Crab Populations under Climate Change, 25th edn, pp. 49-79. Ed. by G. H. Kruse, G. L. Eckert, R. J. Foy, R. N. Lipcius, B. Sainte-Marie, D. L. Stram, and D. Woodby. Alaska Sea Grant College Program, University of Alaska Fairbanks, Anchorage, AK.

Murphy, J. T., Rugolo, L. J., and Turnock, B. J. 2017. Integrating demographic and environmental variables to calculate an egg production index for the Eastern Bering Sea snow crab (*Chionoecetes opilio*). Fisheries Research, 193: 143-157.

Murphy, J. T. 2021. Temporal and spatial variability in size-at-maturity for the eastern Bering Sea snow and Tanner crab (*Chionoecetes opilio* and *C. bairdi*). Fisheries Research, 234: 105761.

Orensanz, J., Ernst, B., Armstrong, D., Stabeno, P., and Livingston, P. 2005. Contraction of the geographic range of distribution of snow crab (*Chionoecetes opilio*) in the Eastern Bering Sea: An environmental ratchet? Reports of California Cooperative Oceanic Fisheries Investigations, 45: 65-79.

Orensanz, J.M., Ernst, B., Armstrong, D.A. 2007. Variation of Female Size and Stage at Maturity in Snow Crab (*Chionoecetes Opilio*) (Brachyura: Majidae) from the Eastern Bering Sea. Journal of Crustacean Biology 27: 576–591.

Reum, J.C., Thorson, J.T., Fedewa, E.F. In revision. Joint spatiotemporal models for the estimation of prey consumption and predator-prey overlap: Dynamics of Pacific cod predation on snow and Tanner crab in the eastern Bering Sea.

Sainte-Marie, B., Raymond, S., and Brêthes, J. 1995. Growth and maturation of the benthic stages of male snow crab, *Chionoecetes opilio* (Brachyura: Majidae). *Canadian Journal of Fisheries and Aquatic Sciences*. 52(5): 903-924.

Shotwell, S.K., K., Blackhart, C. Cunningham, E. Fedewa, D., Hanselman, K., Aydin, M., Doyle, B., Fissel, P., Lynch, O., Ormseth, P., Spencer, S., Zador. 2023. Introducing the Ecosystem and Socioeconomic Profile, a proving ground for next generation stock assessments. Coastal Management. 51:5-6, 319-352.

Szuwalski, C., Cheng, W., Foy, R., Hermann, A. J., Hollowed, A., Holsman, K., Lee, J., et al. 2021. Climate change and the future productivity and distribution of crab in the Bering Sea. ICES Journal of Marine Science, 78: 502-515.

Szuwalski, C. S., Aydin, K., Fedewa, E. J., Garber-Yonts, B., and Litzow, M. A. 2023. The collapse of eastern Bering Sea snow crab. Science, 382: 306-310.

Webb, J. B., Slater, L. M., Eckert, G. L., and Kruse, G. H. 2016. The contribution of fecundity and embryo quality to reproductive potential of eastern Bering Sea snow crab (*Chionoecetes opilio*). Canadian Journal of Fisheries and Aquatic Sciences, 73: 1800-1814.

Yeung C, McConnaughey RA. 2006. Community structure of eastern Bering Sea epibenthic invertebrates from summer bottom-trawl surveys 1982 to 2002. Mar Ecol Prog Ser 318:47-63.

Tables

Table A.1a: First stage ecosystem indicator analysis for EBS snow crab, 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	2021 Status	2022 Status	2023 Status	2024 Status	2025 Status
Contextual	Juvenile Snow Crab Temperature of Occupancy	**high**	neutral	neutral	neutral	neutral
	Winter/Spring Sea Ice Extent	neutral	neutral	neutral	neutral	neutral
	Juvenile Snow Crab Disease Prevalence	neutral	neutral	neutral	neutral	neutral
	Juvenile Snow Crab Energetic Condition	neutral	neutral	neutral	neutral	neutral
	Pacific Cod Consumption	neutral	neutral	neutral	neutral	NA
	Male Snow Crab Size at Maturity	**low**	neutral	neutral	neutral	neutral
	Mature Male Snow Crab Area Occupied	neutral	neutral	neutral	**low**	**low**
	Mature Male Snow Crab Center of Abundance	*high*	*high*	*high*	neutral	neutral
	Female Snow Crab Reproductive Failure	neutral	**high**	*low*	neutral	*low*
	Snow Crab Operational Sex Ratio	neutral	neutral	neutral	neutral	**low**
Monitoring	Chlorophyll *a* Concentration	*high*	*high*	neutral	neutral	*high*
	Arctic Oscillation Index	neutral	neutral	neutral	neutral	neutral
	Spatial Extent of Bottom Waters < 0°C	**low**	neutral	neutral	neutral	neutral
	Benthic Prey Density	*high*	*high*	neutral	*high*	*high*
	Female Snow Crab Size at Maturity	neutral	neutral	neutral	neutral	*high*

Table A.1b: First stage socioeconomic indicator analysis for EBS snow crab, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term mean). A gray fill and text = "NA" will appear if there were no data for that year. A red color indicates a fishery closure and the text = "Closed" will appear. Note that the year heading references calendar year; the EBS snow crab fishery is prosecuted Jan-May, such that the calendar year corresponds to the second period of the crab season-year; the most recent snow crab fishery occurred during the 2024/25 crab season.

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

Figures

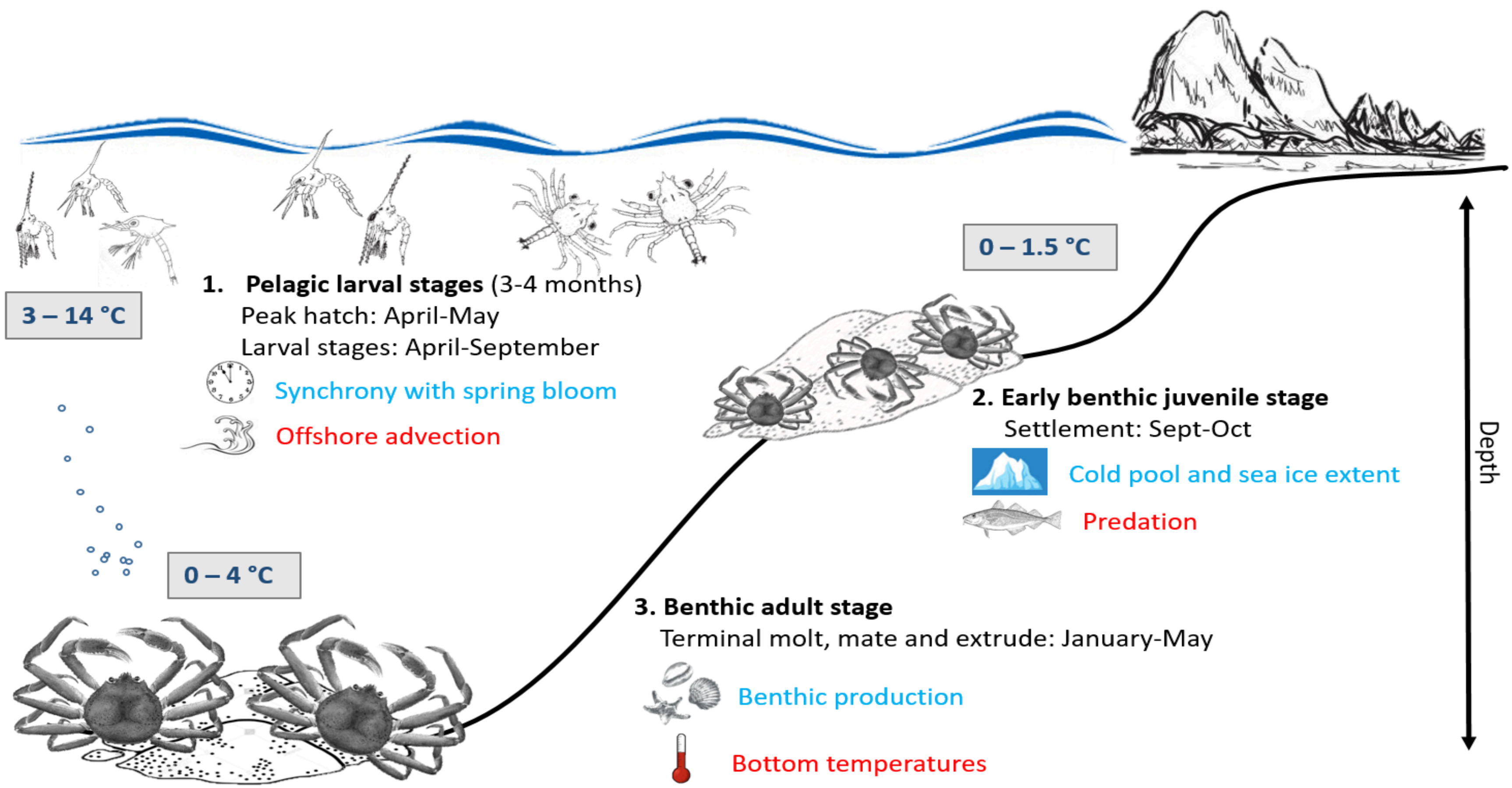


Figure A.1: Life history conceptual model for EBS snow crab summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text means that increases in the process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

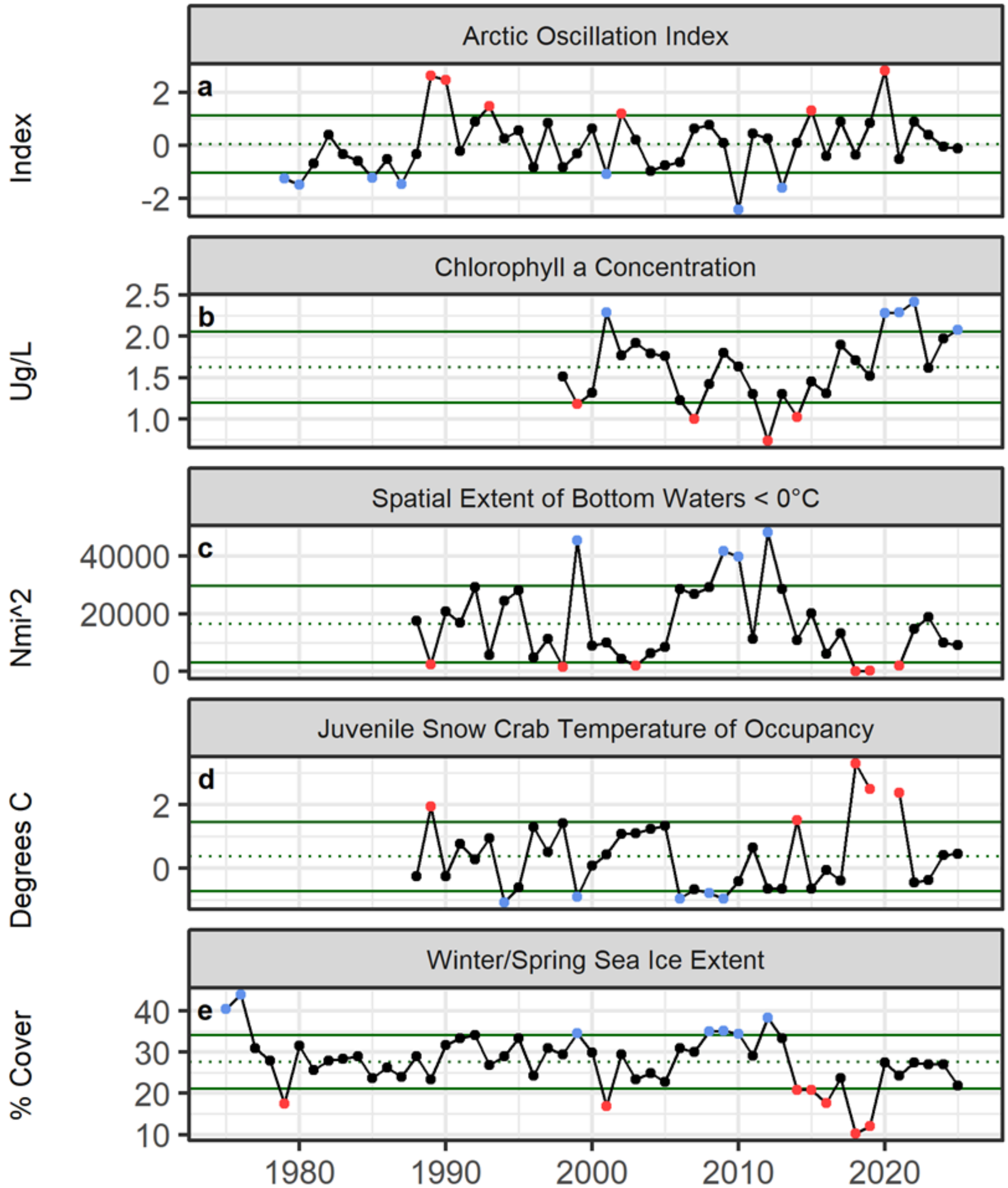


Figure A.2a: Selected ecosystem indicators for EBS snow crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

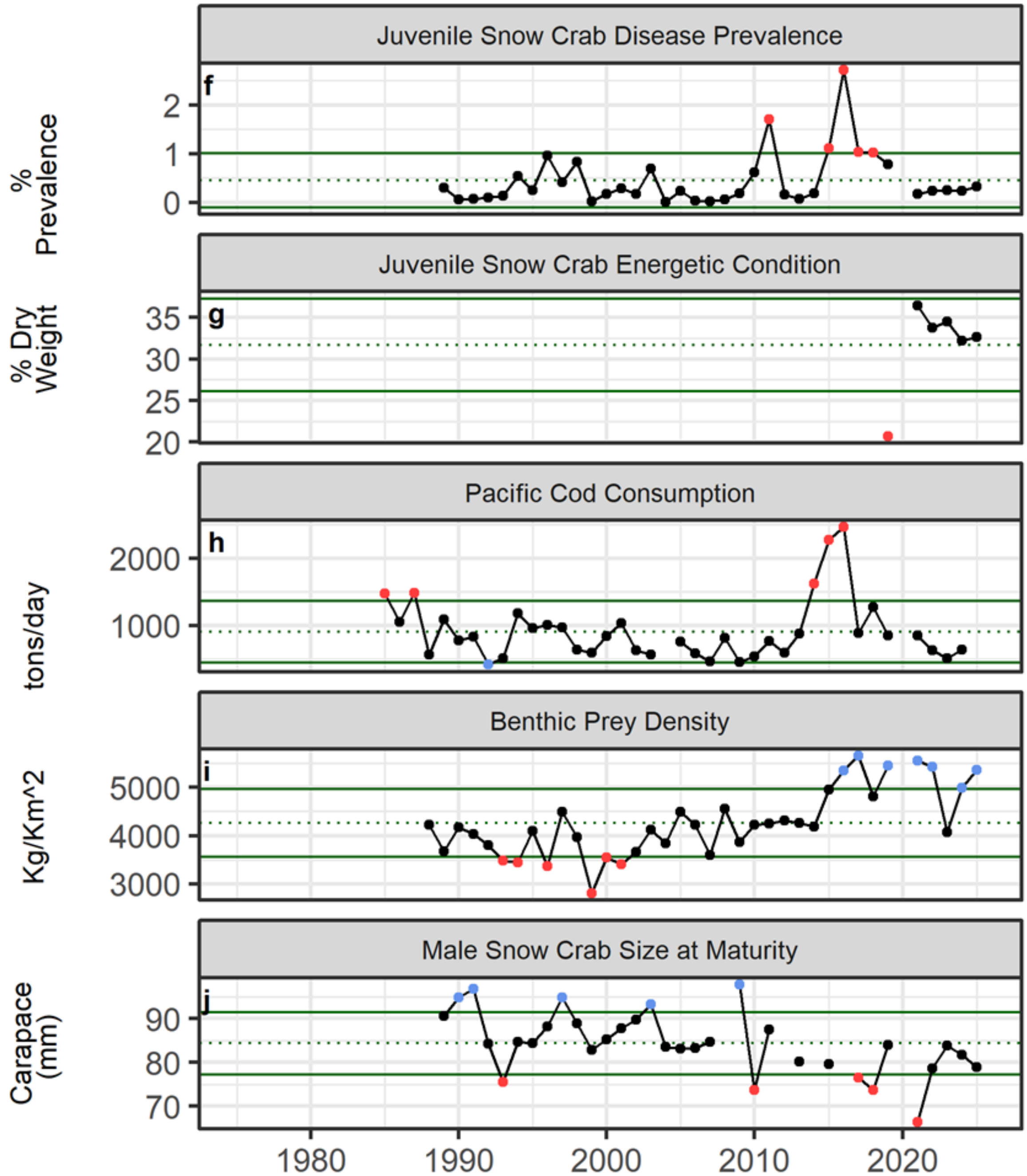


Figure A.2a (cont.): Selected ecosystem indicators for EBS snow crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

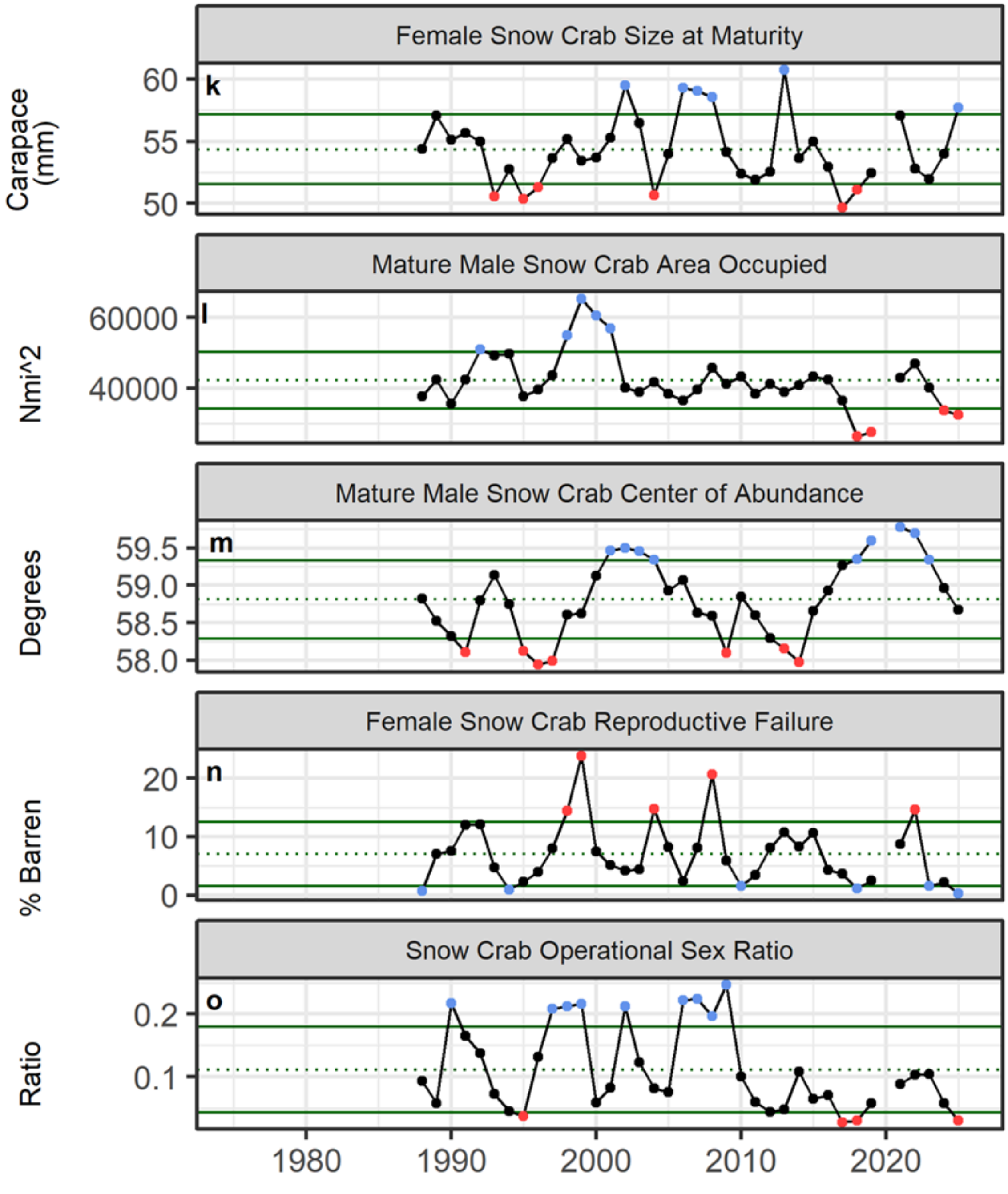


Figure A.2a (cont.): Selected ecosystem indicators for EBS snow crab with time series ranging from 1975 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

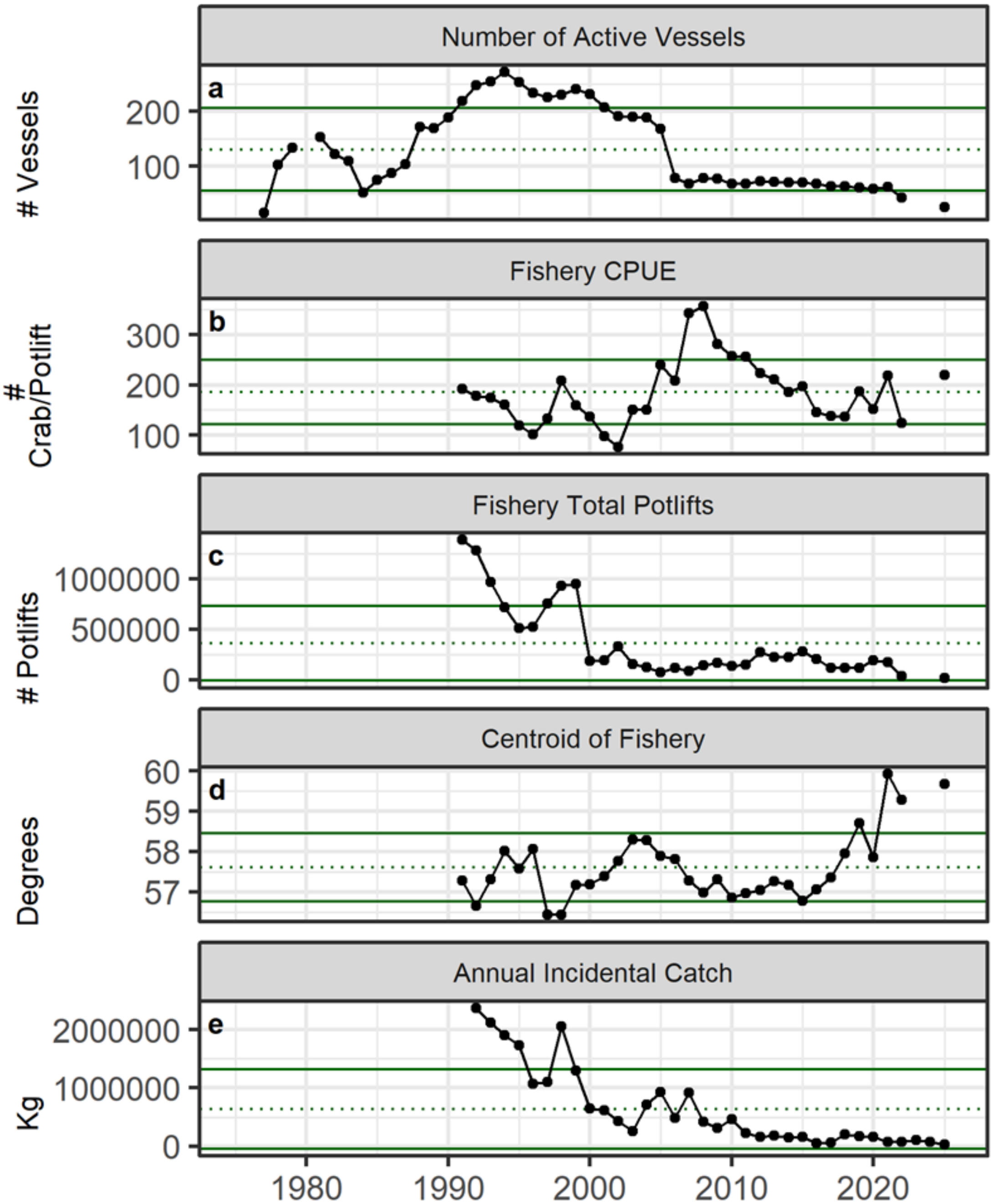


Figure A.2b: Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

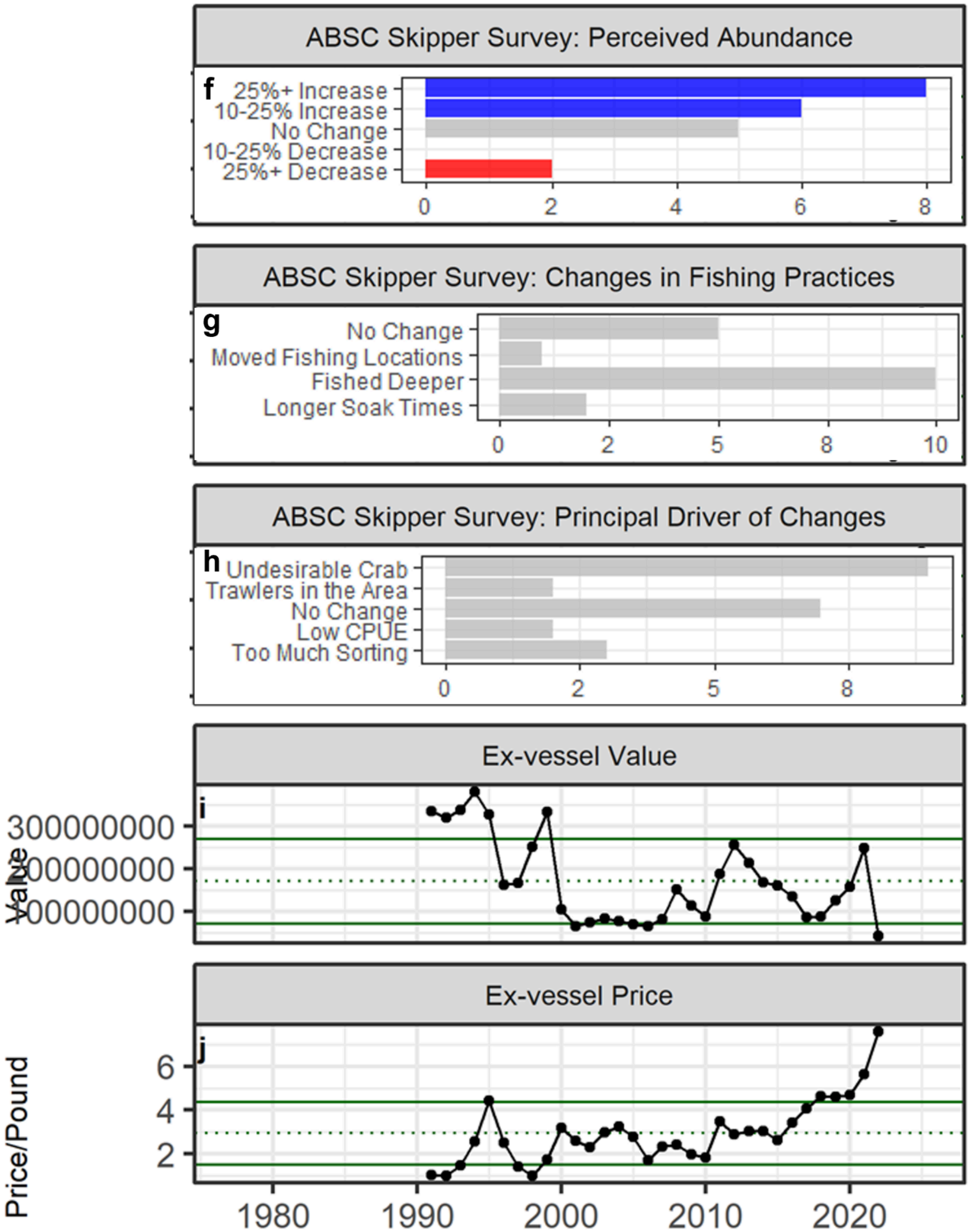


Figure A.2b (cont.): Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

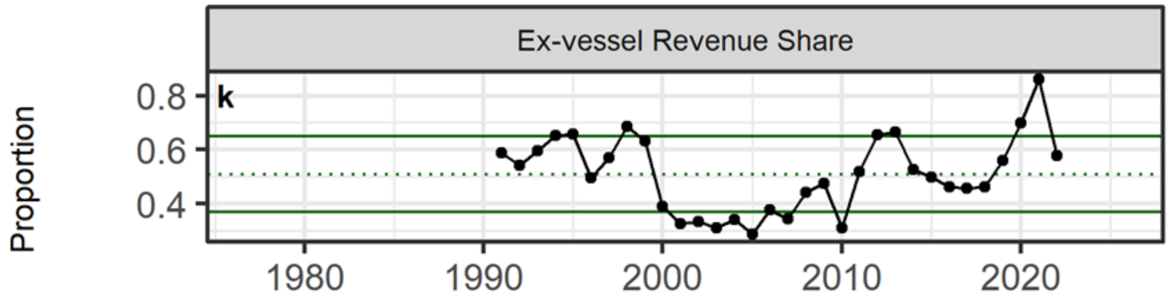


Figure A.2b (cont.): Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

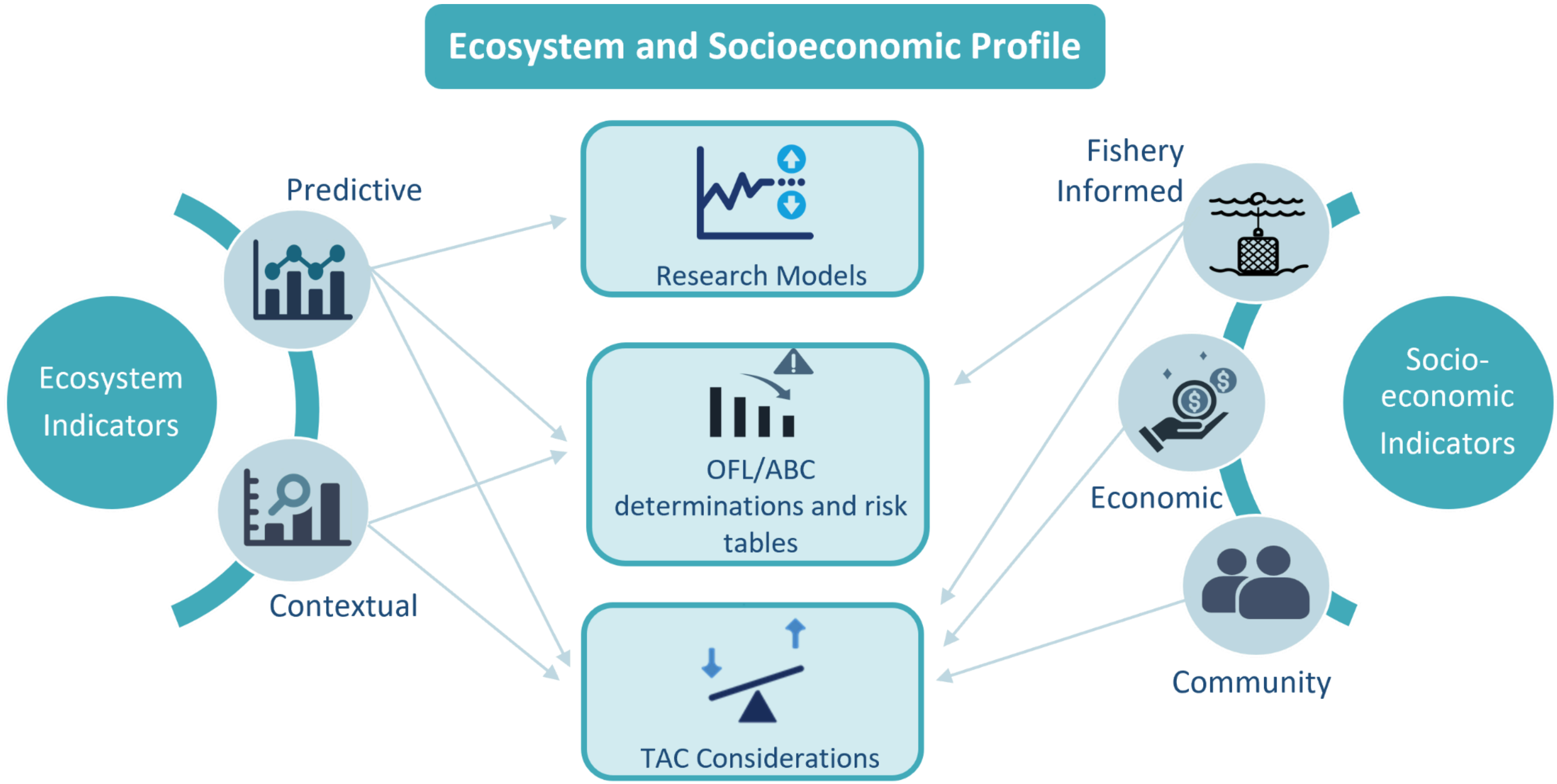


Figure A.3: Schematic of decision pathways for ecosystem and socioeconomic indicators.

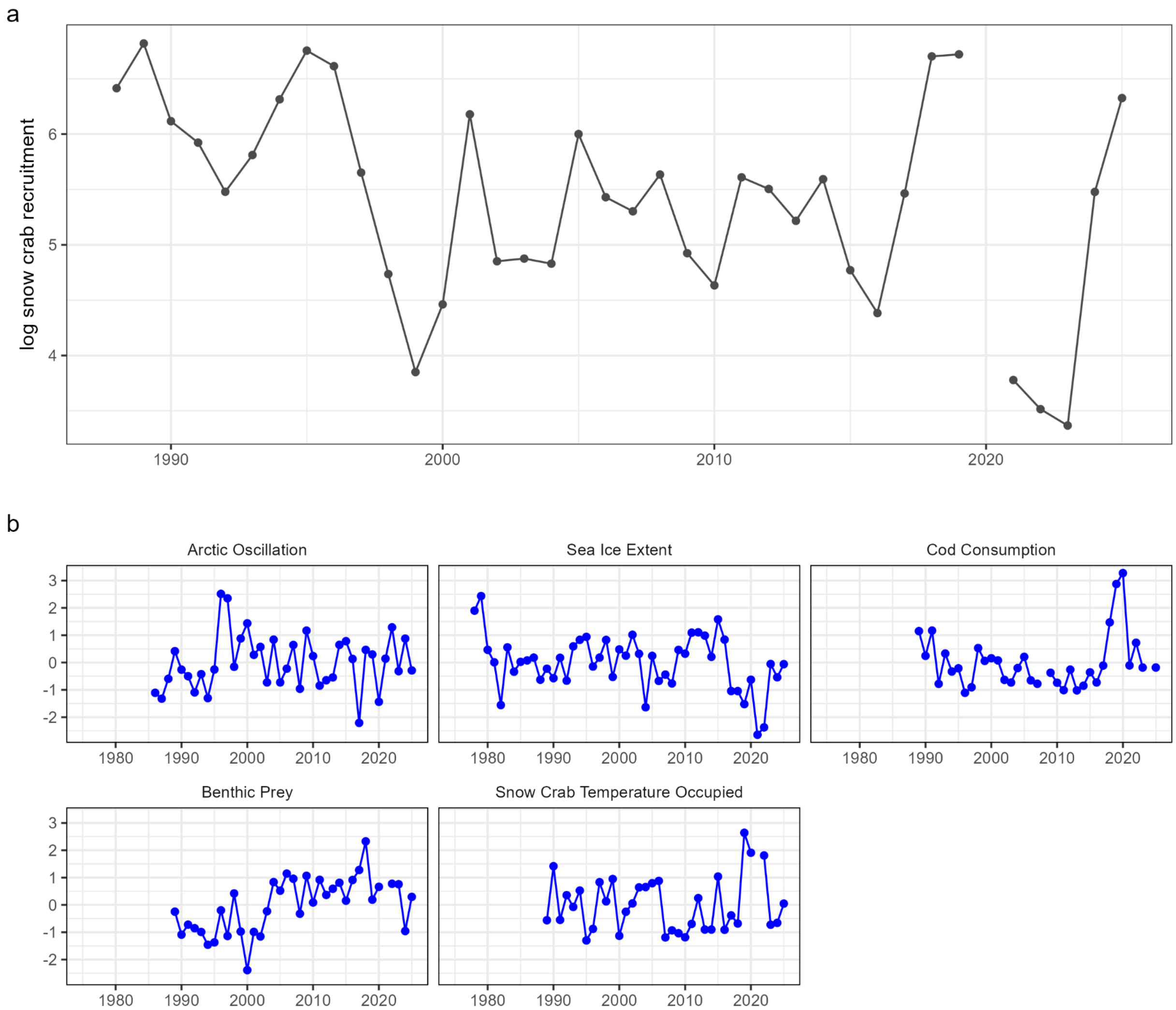


Figure A.4: Bayesian Adaptive Sampling response and predictor variables. a) Response variable, log-transformed snow crab recruitment (survey abundance of 65-80 mm males), and b) standardized ecosystem indicators tested in the final Bayesian Adaptive Sampling Model.

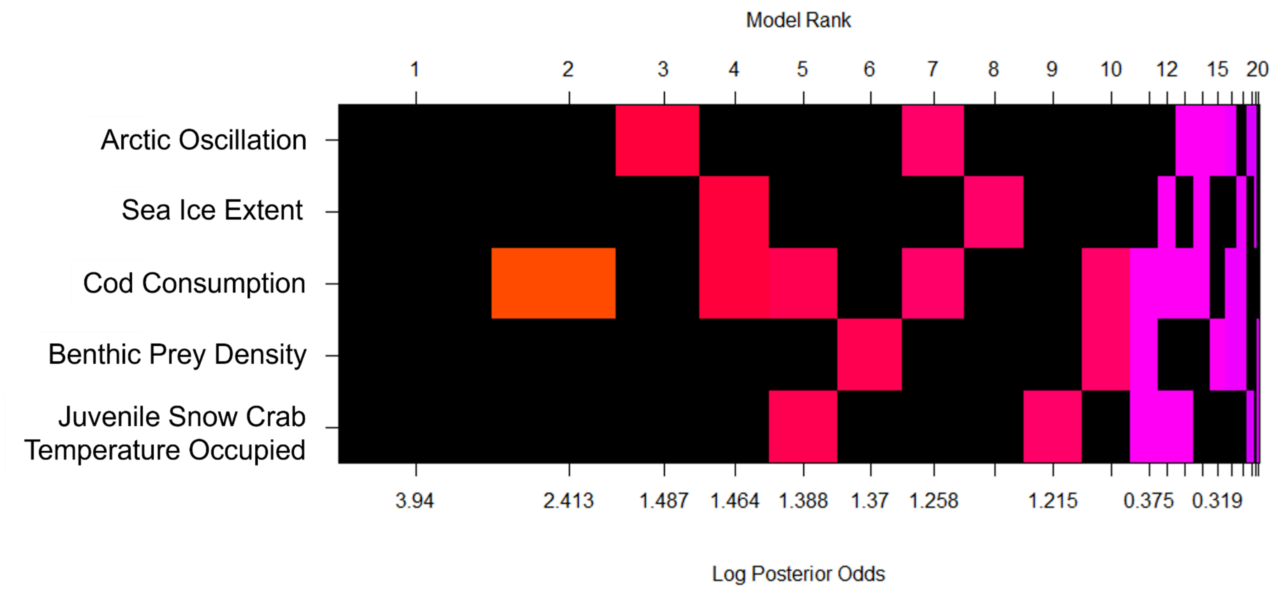


Figure A.5: Visualization of model space of the top models tested with Bayesian Adaptive Sampling. Models are sorted by their posterior probability from best at the left to worst at the right with the rank on the top x-axis, and each column represents one of the tested models.

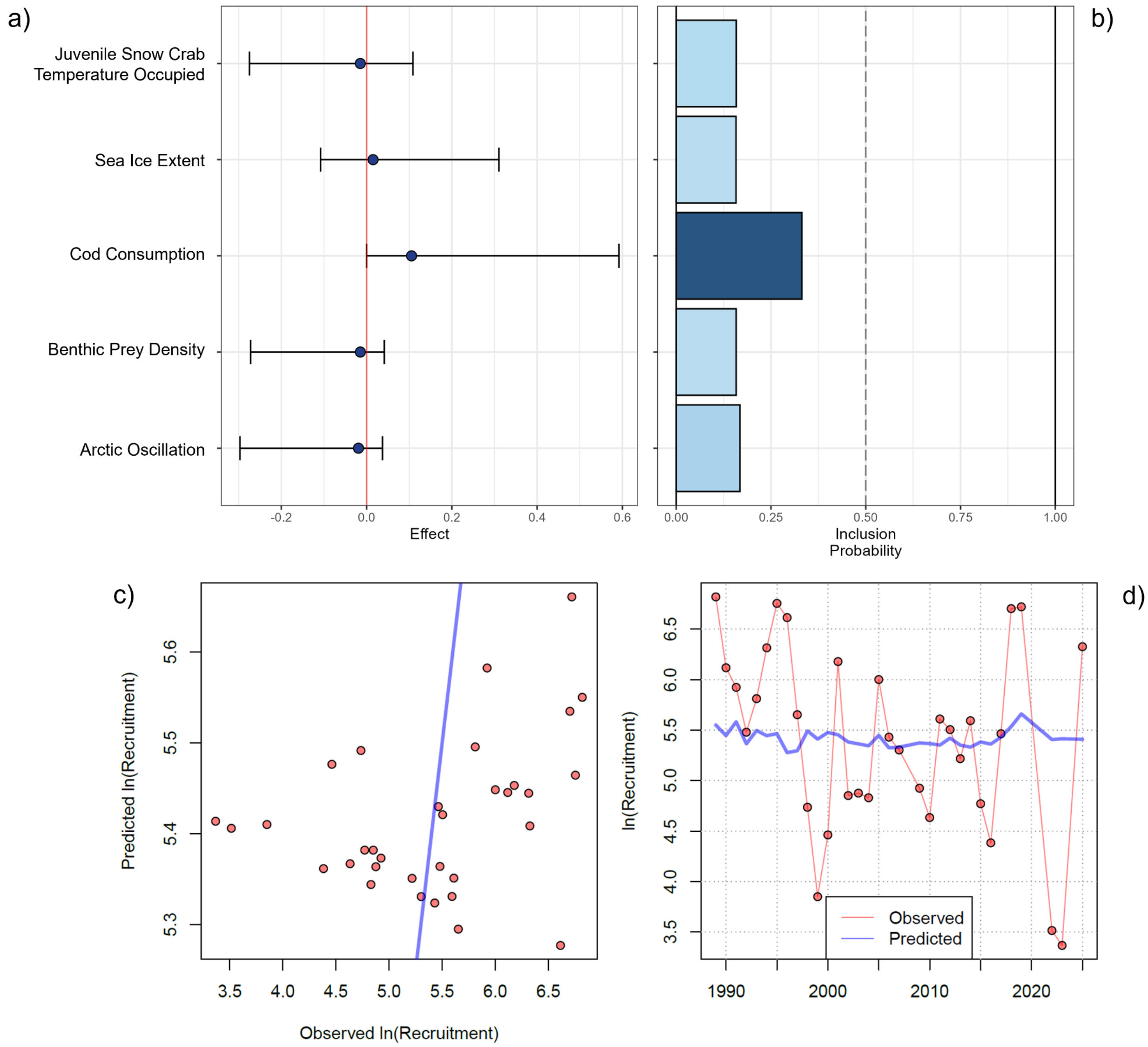


Figure F.6: Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed EBS recruitment (survey abundance of 65 - 90 mm males). a) The estimated effect and b) the marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes c) model predicted fit (1:1 line) and d) average fit across the abbreviated recruitment time series (1989 - 2025).