Appendix B. Ecosystem and Socioeconomic Profile of the Snow Crab stock in the Eastern Bering Sea - Report Card

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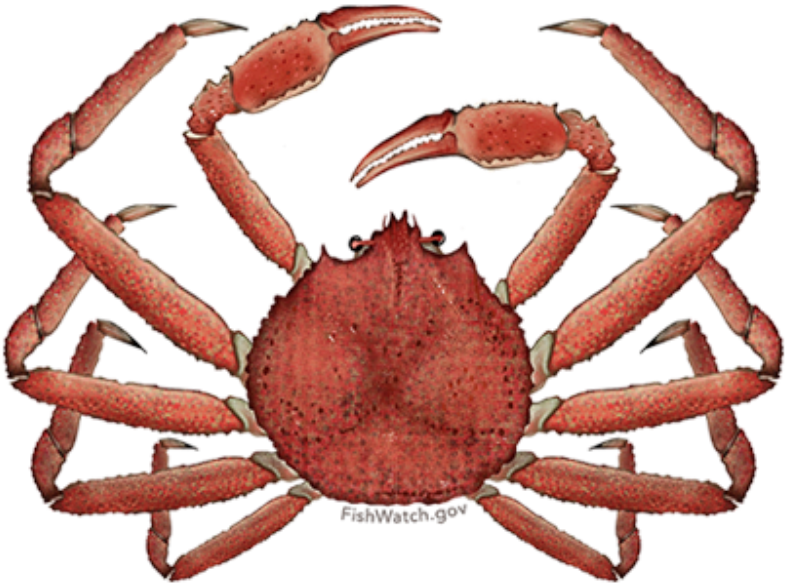

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Current Year Update

The Ecosystem and Socioeconomic Profile or ESP is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., 2023). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

Please refer to the last full ESP and most recent report card documents (Fedewa et al., 2022, Fedewa et al., 2023) which are available as an appendix within the eastern Bering Sea (EBS) snow crab stock assessment and fishery evaluation or SAFE report for further information regarding the ecosystem and socioeconomic linkages for this stock.

Management Considerations

The following are the summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for snow crab:

- Low chlorophyll *a* concentrations and a less pronounced spring bloom suggest poor larval feeding conditions and food supply to the benthos, but juvenile snow crab energetic condition remains high relative to the dramatic decline in condition during the snow crab population collapse.
- Southward shifts in the centroids of mature male abundance, juvenile snow crab occupied temperatures < 1°C, and reduced Pacific cod predation are consistent with the return of cold water habitat critical for stock rebuilding and recruitment
- A high proportion (90%) of mature females with full clutches suggests increased reproductive capacity despite depressed large male abundance and a heavily female-biased operational sex ratio
- The Bering Sea snow crab fishery was closed for the 2022/23 and 2023/24 seasons, such that no data was generated to extend most of the socioeconomic indicator time series reported in previous ESPs for the stock. Although not adequately captured within the limited range of socioeconomic indicators reported in the ESP to date, the unprecedented and ongoing economic and social pressures on the crab industry and stakeholder communities associated with the decline of BSAI crab fisheries, represent critical management considerations and require improved data and analyses to inform management.

Modeling Considerations

The following are the summary results from the most recent intermediate and advanced stage monitoring analyses for snow crab (Fedewa et al., 2023):

- The highest ranked predictor variables in the intermediate stage monitoring analysis were 1) juvenile snow crab temperature of occupancy and 2) Pacific cod consumption, although effect sizes were relatively small and marginal inclusion probabilities were < 0.5 for all predictors.
- The advanced stage monitoring analysis provides updates on developing research ecosystem linked models that are not yet included as a model alternative in the main stock assessment. We have not received updates on new research ecosystem linked models for snow crab at this time.

Assessment

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock in conceptual models detailing 1) ecosystem processes by snow crab life history stage (Figure 1). Please refer to the last full ESP document (Fedewa et al., 2022) for more details.

Indicator Suite

The following list of indicators for snow crab is organized by categories: three for ecosystem indicators (larval, juvenile, and adult) and three for socioeconomic indicators (fishery performance, economic, and community). The indicator name and short description are provided in the heading. We also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant. Following the indicator heading is a series of bullets that include information on the contact for the indicator, status and trends for the current year, factors influencing those trends, and implications for fishery management. This format follows the Ecosystem Status Reports. We use the following nomenclature when describing these indicators:

- If the value in the time series is at the long-term mean of the time series (or the mean), we use the term "average" (dotted green line in Figure 2).
- If the value is above/below the mean but below/above 1 standard deviation of the mean (solid green line in Figure 2) we use the terms "above average" or "below average".
- Any value within 1 standard deviation of the mean is considered "neutral" in Table 1.
- If the value is above/below 1 standard deviation of the mean (solid green line in Figure 2) we use the term "high" or "low".

We concentrate on updates since the last ESP report card (Fedewa et al., 2023). Please refer to the last full ESP document for detailed information regarding these ecosystem and socioeconomic indicator descriptions and proposed mechanistic linkages for this stock (Fedewa et al., 2022). Time series of the ecosystem and socioeconomic indicators are provided in Figure 2a and Figure 2b, respectively.

New ecosystem indicators for 2024 include 1) mature female reproductive capacity, measured as proportion of the mature female population with full clutches, and 2) an operational sex ratio, estimated as the ratio between large males and mature female abundances.

Ecosystem Indicators:

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

a. Chlorophyll *a* Concentration: April – June average chlorophyll *a* concentration on the north-middle shelf of the eastern Bering Sea (BSIERP regions 9 and 5), calculated with the ESA GlobColour blended satellite product (4km resolution, 8-day composite data). Proposed sign of the relationship is positive and the time series is lagged five years for intermediate stage indicator analysis.

- Contact: Erin Fedewa
- Status and trends: Chlorophyll *a* concentration increased in 2024 following the time series low in 2023, although still remains well below the 27-year mean.
- Factors influencing trends: Spring chlorophyll *a* concentration is directly influenced by the timing and magnitude of the spring bloom, and strongly impacts the amount of energy that is transferred through trophic pathways in the Bering Sea.

- Implications: Low chlorophyll *a* 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).

b. Arctic Oscillation Index: January - March Arctic Oscillation index from the NOAA National Climate Data Center. Proposed sign of the relationship is negative and the time series is lagged five years for intermediate stage indicator analysis.
    - Contact: Erin Fedewa
    - Status and trends: The Arctic Oscillation was in a neutral state in winter 2024.
    - 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), suggesting that stock productivity won't be directionally influenced by a neutral Arctic Oscillation.

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

c. Summer Cold Pool Spatial Extent: Calculated as the total area (nmi^2) of all EBS bottom trawl survey stations with bottom temperatures < 2°C. Proposed sign of the relationship is positive and the time series is lagged four years for intermediate stage indicator analysis.
    - Contact: Erin Fedewa
    - Status and trends: The spatial extent of the cold pool in the eastern Bering Sea declined from 2023 to 2024, and is slightly below the 36-year time series mean.
    - Factors influencing trends: The spatial extent of the cold pool is determined by winter sea ice extent and winds. The cold pool drives the spatial distribution of snow crab and key groundfish predators like Pacific cod.
    - Implications: An intermediate cool pool that extended south to the Pribilof Islands in summer 2024 indicates suitable cold-water habitat for snow crab recruitment and stock rebuilding.

d. Juvenile Snow Crab Temperature of Occupancy: Mean bottom temperature weighted by immature snow crab CPUE during the EBS summer bottom trawl survey. Proposed sign of the relationship is negative and the time series is lagged one year for intermediate stage indicator analysis.
    - Contact: Erin Fedewa
    - Status and trends: Temperatures occupied by juvenile snow crab increased by 0.8°C from 2023 to 2024, and the 2024 estimate remains slightly above the 36-year mean.
    - Factors influencing trends: Temperatures occupied by juvenile snow crab are directly influenced by bottom temperatures in the Bering Sea and cold-water habitat preferences of stenothermic juveniles. Occupied temperatures that exceed 2°C may be indicative of an upper temperature threshold.
    - Implications: Occupied temperatures below 1°C indicate that cold-water habitat critical for evading groundfish predators was widely available for juvenile snow crab in 2024.

e. Winter Sea Ice Advance BS Satellite NSIDC: January-February average winter sea ice extent (km^2) in the Bering Sea from the NOAA National Snow and Ice Data Center (NSIDC). Proposed sign of the relationship is positive and the time series is lagged three years for intermediate stage indicator analysis.
    - Contact: Erin Fedewa

- Status and trends: Winter sea ice extent declined from 2023 to 2024, and remains slightly below the 46-year average.
- Factors influencing trends: Winter sea ice in the Bering Sea is driven by atmospheric CO2, ocean heat transport and winds.
- Implications: Low levels of sea ice are associated with dampened snow crab productivity (Litzow et al., 2024; Mullowney et al., 2023), so increases in sea ice extent following the snow crab collapse suggest positive conditions for food supply to the benthos, benthic production, and snow crab rebuilding.

f. Summer 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 and the time series is lagged three years for intermediate stage indicator analysis.
    - Contact: Erin Fedewa
    - Status and trends: Visually-diagnosed BCD prevalence remained relatively stable in 2024 at 0.24%, and prevalence has remained below the 35-year average since the snow crab population collapse in 2021. However, visual detection methods substantially underestimate disease prevalence, and infections detected with sensitive PCR assays at disease monitoring sites indicate that prevalence levels in the EBS have reached 50% in recent years, and prevalence levels in the NBS prior to the collapse exceeded 80% (Fedewa et al., in review).
    - Factors influencing trends: BCD tends to occur at stations with high population density of small, new shell crab, and 2 - 4°C bottom temperatures (Balstad et al., 2024).
    - Implications: Record-high visual BCD prevalence in 2016 coinciding with a large recruitment event of small (20-30mm) snow crab likely drove high mortality rates prior to the collapse. Disease monitoring will be critical as the snow crab population continues to rebuild because an increased proportion of small snow crab in the system could lend to higher BCD prevalence in the near future.

g. Summer 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 and the time series is lagged one year for intermediate stage indicator analysis.
    - Contact: Erin Fedewa
    - Status and trends: Energetic condition of juvenile snow crab decreased from 2023 to 2024, and is the lowest estimate since the start of the population collapse in 2019.
    - Factors influencing trends: Energetic condition of juvenile snow crab mid- and post-collapse was driven by bottom temperatures and population density (Fedewa et al., in prep). Declines in lipid storage in juvenile snow crab have been linked to warmer temperatures and reduced food quality in the Bering Sea (Copeman et al., 2021).
    - Implications: Very poor energetic condition of juvenile snow crab during the start of the population collapse in 2019 suggests that mortalities were driven, in part, by energetic limitations. Increased energetic condition post-collapse suggests favorable conditions for high survival and strong recruitment.

h. Summer Pacific Cod Consumption: The daily summer consumption of snow crab (mt/day) by Pacific cod in the eastern Bering Sea, estimated from Pacific cod diet compositions, EBS trawl survey CPUE, and temperature adjusted length-specific maximum consumption rates. Pacific cod consumption estimates include unidentified *Chionocetes* sp. as well as identified *C. opilio* from

stomach contents. Proposed sign of the relationship is negative and the time series is lagged three years for intermediate stage indicator analysis.

- Contact: Kerim Aydin
- Status and trends: Daily consumption of juvenile snow crab by Pacific cod declined from 2022 to 2023, and is well below the 39-year mean. 2024 consumption estimates will be available in October 2024.
- Factors influencing trends: Declines in the spatial extent of the cold pool coincide with northerly shifts in Pacific cod centroids of abundance, resulting in increased spatial overlap between Pacific cod and juvenile snow crab. Annual consumption estimates are also driven by juvenile snow crab population size, and as generalists, Pacific cod tend to predate heavily on snow crab when the abundance of small juveniles is high.
- Implications: Peaks in Pacific cod consumption of snow crab in 2016 coincided with a very large snow crab recruitment event. Recent declines in consumption despite new recruitment following the population collapse in 2021 suggest reduced top-down predation pressure and a positive outlook for stock rebuilding.

3. Adult Indicators (Figure 2a.i-n)

i. Summer Benthic Invertebrate 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 and the time series is lagged one year for intermediate stage indicator analysis.

- Contact: Erin Fedewa
- Status and trends: Following a substantial decline in benthic invertebrate density from 2022 to 2023, densities increased in 2024 and were slightly above the 37-year mean.
- Factors influencing trends: Environmental factors such as bottom temperature, primary production and ice cover likely affect spatiotemporal variation in epibenthic invertebrates, but the dynamics remain poorly understood (Yeung and McConnaughey, 2006).
- Implications: Increases in benthic invertebrate density in 2024 suggest the potential for increased prey availability for juvenile and adult snow crab. Higher densities may also be indicative of larger scale increases in benthic production.

j. Male Snow Crab Size at Terminal Molt: 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: Jon Richar
- Status and trends: The size at which 50% of the male snow crab population underwent terminal molt increased slightly in 2024, and has increased by over 15 mm following a dramatic reduction in 2021. Although annual size at terminal molt is highly variable, this indicator has been trending down for the past three decades.
- Factors influencing trends: Temporal shifts in size at terminal molt in male snow crab are likely driven by recruitment variability, density dependent growth, and ocean temperatures (Murphy 2021; Mullowney and Baker, 2021).
- Implications: Directional downward shifts in size at terminal molt lead to a higher abundance of small mature males that are protected from the fishery, resulting in higher exploitation rates on large, industry preferred males. In addition, the potential

for sperm limitation in populations depleted of large male snow crab may decrease reproductive potential of the stock (Baker et al., 2022).

k. 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
    - Status and trends: The spatial extent of mature male snow crab has continued to decline since 2022, and the 2024 estimate is well below the 36-year mean.
    - 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: Continued declines in the spatial extent of mature male snow crab are consistent with depressed abundances of large males since the snow crab collapse in 2021. Range contraction has implications for density-dependent prey limitations (Szuwalski et al., 2023). However, areas occupied by immature snow crab and mature females have expanded alongside increases in abundance, suggesting a positive outlook for stock rebuilding.

l. 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
    - Status and trends: The mature male centroid of abundance has continued to shift south since the most northerly centroid on record was observed in 2021. The 2024 centroid of abundance remains above the 36-year mean.
    - Factors influencing trends: Historically, centroids of abundance have tracked bottom temperatures, and were further south with low bottom temperatures (Orensanz et al., 2005). Centroids of abundance are expected to shift north under warming as snow crab track preferred cold-water habitat.
    - Implications: Southward shifts in the centroids of mature male abundance are consistent with the return of cold water bottom temperatures and a cold pool in the EBS.

m. Female Snow Crab Reproductive Potential: The proportion of primiparous, mature female snow crab with full clutches. Full clutches are designated as code “5” and code “6” from the EBS bottom trawl survey clutch fullness indices. 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
    - Status and trends: In 2024, nearly 90% of primiparous females had full to ¾ full clutches, and the proportion was slightly above the 36-year mean.
    - Factors influencing trends: Female reproductive potential is a function of fecundity, egg production, clutch size, and sperm reserves (Webb et al., 2016; Murphy et al., 2017). Clutch size is influenced by the quantity and quality of sperm reserves, and declining trends in the proportion of mature females with full clutches may indicate sperm limitation.
    - Implications: Following a decline in the proportion of females with full clutches in 2021, a greater proportion of full clutches in 2024 suggests increased reproductive capacity despite depressed large male abundance.

n. Snow Crab Operational Sex Ratio: The ratio of large male (> 95 mm) to mature female snow crab abundance in the EBS.
    - Contact: Erin Fedewa
    - Status and trends: The operational sex ratio declined in 2024 to a 0.06 to 0.94 ratio of large males to mature females. The operational sex ratio has remained below the 36-year mean since 2009 and the population has remained heavily female-biased in recent years.
    - 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: (all monetary values are inflation-adjusted to $2022 value)

<u>1. Fishery Performance Indicators (Figure 2b.a-e)</u>

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.
    - Contact: Brian Garber-Yonts
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed
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
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed
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
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed
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
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed
e. Annual Incidental Catch: Annual incidental catch of snow crab in EBS groundfish fisheries
    - Contact: Brian Garber-Yonts
    - Status and trends: Incidental catch of snow crab in BSAI groundfish in 2023 increased from the previous two years, but was near the lower bound of the historical range and below the average of the previous five years.

- Factors influencing trends: TBD
- Implications: TBD

2. Economic Indicators (Figure 2b.f-i)

f. TAC Utilization: Percentage of annual EBS snow crab total allowable catch that was harvested by active vessels
    - Contact: Brian Garber-Yonts
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed

g. 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
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed

h. 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
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed

i. 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
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed

3. Community Indicators

j. Alaska Bering Sea Crabbers (ABSC) Skipper Survey, distributed to captains following the most recent snow crab season. Although not yet an established time series, the questionnaire is designed to extract both qualitative and quantitative information on perceived abundance, fisher behavior and gear performance.
    - Contact: Cory Lescher
    - Status and trends: Fishery closed
    - Factors influencing trends: Fishery closed
    - Implications: Fishery closed

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, growth, catchability). These regression techniques provide a simple predictive performance for the variable of

interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for providing visibility on current research ecosystem models and may be used for testing a research ecosystem linked stock assessment model where output can be compared with the current operational stock assessment model to understand information on retrospective patterns, prediction performance, and comparisons to model outputs.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light evaluation on the indicators listed in the Indicator Suite section. Please refer to the last full ESP document (Fedewa et al., 2022) for more details on the simple scoring calculation. The scores are summed by the ecosystem or socioeconomic indicator categories and divided by the total number of indicators available in that category for a given year. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 3). We also provide five year indicator status tables with a color (ecosystem indicators only) for the relationship with the stock (Tables 1a,b). Socioeconomic indicators representing the target fishery are reported by calendar year through 2022, the last year that the fishery was open. Incidental catch is reported for the most recent full calendar year.

Overall, the ecosystem indicators scored slightly below average for 2024, but this trend was driven by a single indicator, mature male area occupied (Figure 3). The majority of 2024 indicators were neutral, emphasizing the return of cold-water conditions and ecosystem stabilization following the 2018-2019 marine heatwave. By category from 2023 to 2024, the larval indicators increased from below average to average, the juvenile indicators remained average, and the adult indicators decreased from above average to below average (Figure 3). Only the incidental catch indicator in the (currently ongoing) EBS groundfish fisheries was updated for the socioeconomic indicators due to the continued snow crab fishery closure. Additionally, ABSC Skipper Survey results reported in the 2022 ESP could not be conducted. However, we note that these missing data should emphasize the economic hardships being faced by the snow crab harvesters and processors during these closure periods in lieu of more meaningful community indicators that have not yet been developed.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and snow crab recruitment (survey abundance of immature male snow crab, 50 – 65mm), and to assess the strength of support for each hypothesis (Fedewa et al., 2023). We provide the mean relationship between each predictor variable and snow crab recruitment over time (Figure 4a), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 4b). Results from this analysis may assist with evaluation of the updated indicator suite for use in the risk table. A higher probability (> 0.5) indicates that the variable is a better candidate predictor of snow crab recruitment.

The highest ranked predictor variables based on the most recent BAS analysis were 1) juvenile snow crab temperature of occupancy, and 2) Pacific cod consumption. Inclusion probabilities < 0.5 indicate that the selected suite of indicators explained little variation in snow crab recruitment. Intermediate stage indicator importance tests in future ESP report cards will explore additional statistical techniques to address potential nonstationarity and missing observations.

Advanced Stage: Research Model Test

Research models have been explored to assess potential mechanisms for increased mortality (e.g. bitter crab syndrome, cod predation, cannibalism) in 2018-2019 (Szuwalski et al., 2023), but there are no current models in development to report.

Data Gaps and Future Research Priorities

Future research should support the development of indicators that quantify snow crab physiological and biological responses to rapidly changing ecosystem conditions in the Bering Sea. Recent, dramatic population declines emphasize the importance of understanding proximate causes and mechanisms for mortality including predator-prey interactions, disease dynamics, shifts in benthic prey production, and responses to thermal stress. Proposed laboratory studies, for example, should focus on defining thermal limits across snow crab life history stages and quantifying temperature-dependent growth, respiration and consumption rates. Many previous studies are limited to mature snow crab and have been assessed only on the eastern Canadian snow crab stock (e.g. Foyle et al. 1989), potentially limiting the applicability of published results to the eastern Bering Sea snow crab stock. Early life history data gaps also result in difficulties identifying potential recruitment bottlenecks and mechanistic linkages during larval and early benthic stages.

The limited scope and timeliness of socioeconomic indicators reported in the ESP provide limited information regarding the economic stresses on the harvest and processing sectors of the Bering Sea crab fisheries and associated communities resulting from the recent declines in the two principal Bering Sea crab fisheries. These stresses, if persistent, have the potential to induce substantial structural changes in crab harvest and processing industries, as well as management changes intended to mitigate adverse social and economic effects, ultimately inducing systematic operational changes in the behavior of snow crab fishing vessels. Developing community indicators to highlight these economic hardships during fishery closures is also of critical importance in light of multiple crab fishery closures. Research in spatial aspects of the EBS snow crab fishery with direct relation to the stock assessment may provide the basis for further development of relevant and informative socioeconomic indicators for use in the ESP. As well, improving the timeliness of socioeconomic indicators should be explored, including use of models for nowcast/forecast of time series, and or alternate or proxy measures that track key socioeconomic indicators.

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Tables

Table 1a. First stage ecosystem indicator analysis for snow crab, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of time series mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = "NA" will appear if there were no data for that year.

Indicator category	Indicator	2020 Status	2021 Status	2022 Status	2023 Status	2024 Status
Larval	Chlorophyll *a* Concentration	neutral	neutral	neutral	**low**	neutral
	Arctic Oscillation Index	**high**	neutral	neutral	neutral	neutral
Juvenile	Summer Cold Pool Extent	NA	**low**	neutral	neutral	neutral
	Juvenile Snow Crab Temperature of Occupancy	NA	**high**	neutral	neutral	neutral
	Winter Sea Ice Extent	neutral	neutral	neutral	neutral	neutral
	Juvenile Snow Crab Disease Prevalence	NA	neutral	neutral	neutral	neutral
	Juvenile Snow Crab Energetic Condition	NA	neutral	neutral	neutral	neutral
	Summer Pacific Cod Consumption	NA	neutral	neutral	neutral	NA
Adult	Summer Benthic Invertebrate Density	NA	neutral	neutral	neutral	neutral
	Male Snow Crab Size at Terminal Molt	NA	**low**	neutral	neutral	neutral
	Summer Male Snow Crab Area Occupied	NA	neutral	neutral	neutral	**low**
	Summer Male Snow Crab Center of Abundance	NA	*high*	*high*	*high*	neutral
	Female Snow Crab Reproductive Potential	NA	neutral	**low**	neutral	neutral
	Snow Crab Operational Sex Ratio	NA	neutral	neutral	neutral	neutral

Table 1b. First stage socioeconomic indicator analysis for snow crab, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of time series mean). A gray fill and text = "NA" will appear if there were no data for that year. A red color indicates a fishery closure and the text = "Closed" will appear.

Indicator category	Indicator	2020 Status	2021 Status	2022 Status	2023 Status	2024 Status
Fishery Performance	Number of Active Vessels in Snow Crab Fishery	neutral	neutral	low	**Closed**	**Closed**
	Annual CPUE of Snow Crab Fishery	neutral	neutral	neutral	**Closed**	**Closed**
	Total Potlifts in Snow Crab Fishery	neutral	neutral	neutral	**Closed**	**Closed**
	Snow Crab Fishery Centroid	neutral	high	high	**Closed**	**Closed**
	Annual Snow Crab Incidental Catch	neutral	neutral	neutral	neutral	NA
Economic	TAC Utilization of Snow Crab Fishery	neutral	neutral	neutral	**Closed**	**Closed**
	Ex-vessel Value	neutral	neutral	low	**Closed**	**Closed**
	Ex-vessel Price	high	high	high	**Closed**	**Closed**
	Ex-vessel Revenue Share	high	high	neutral	**Closed**	**Closed**

Figures

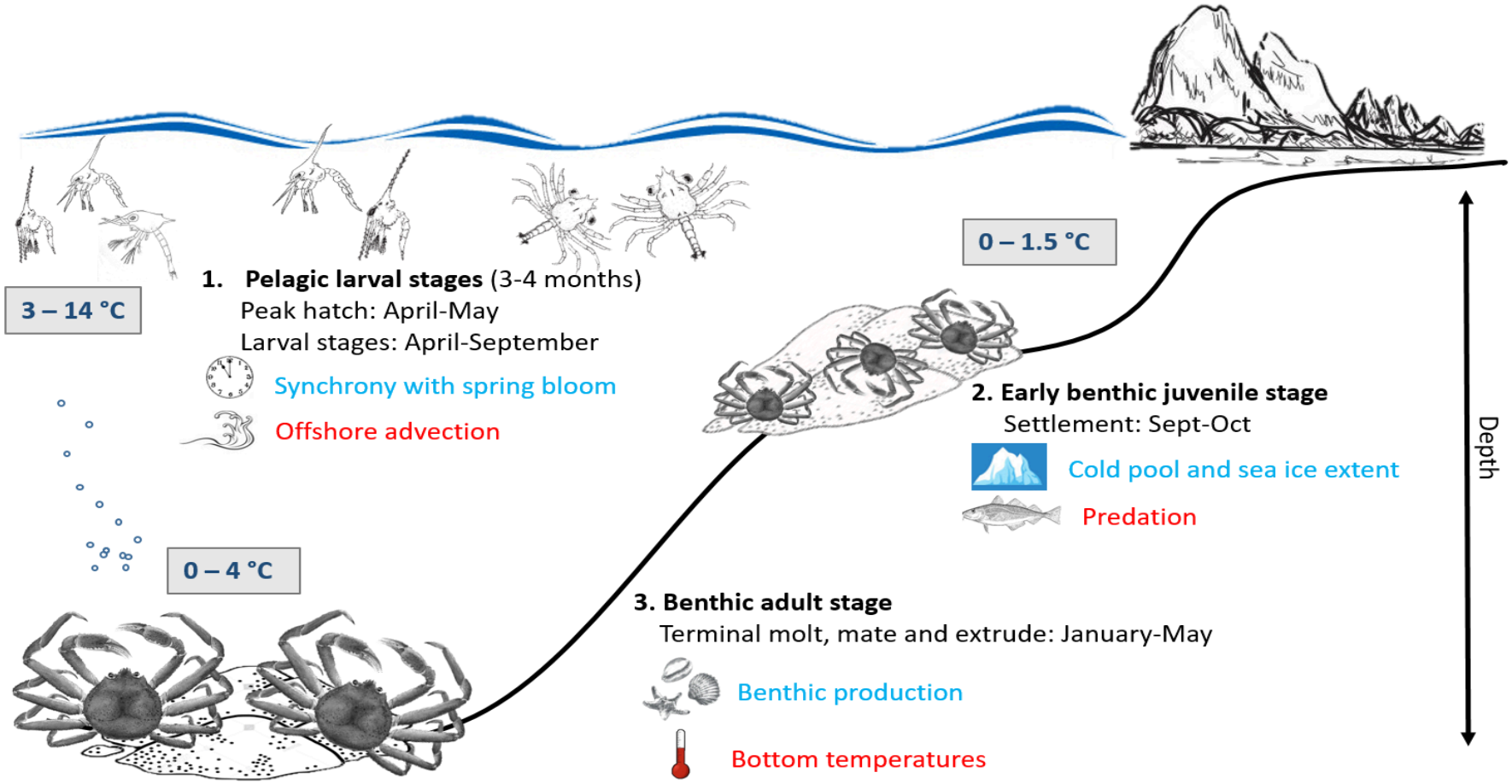

Figure 1: Life history conceptual model for snow crab summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

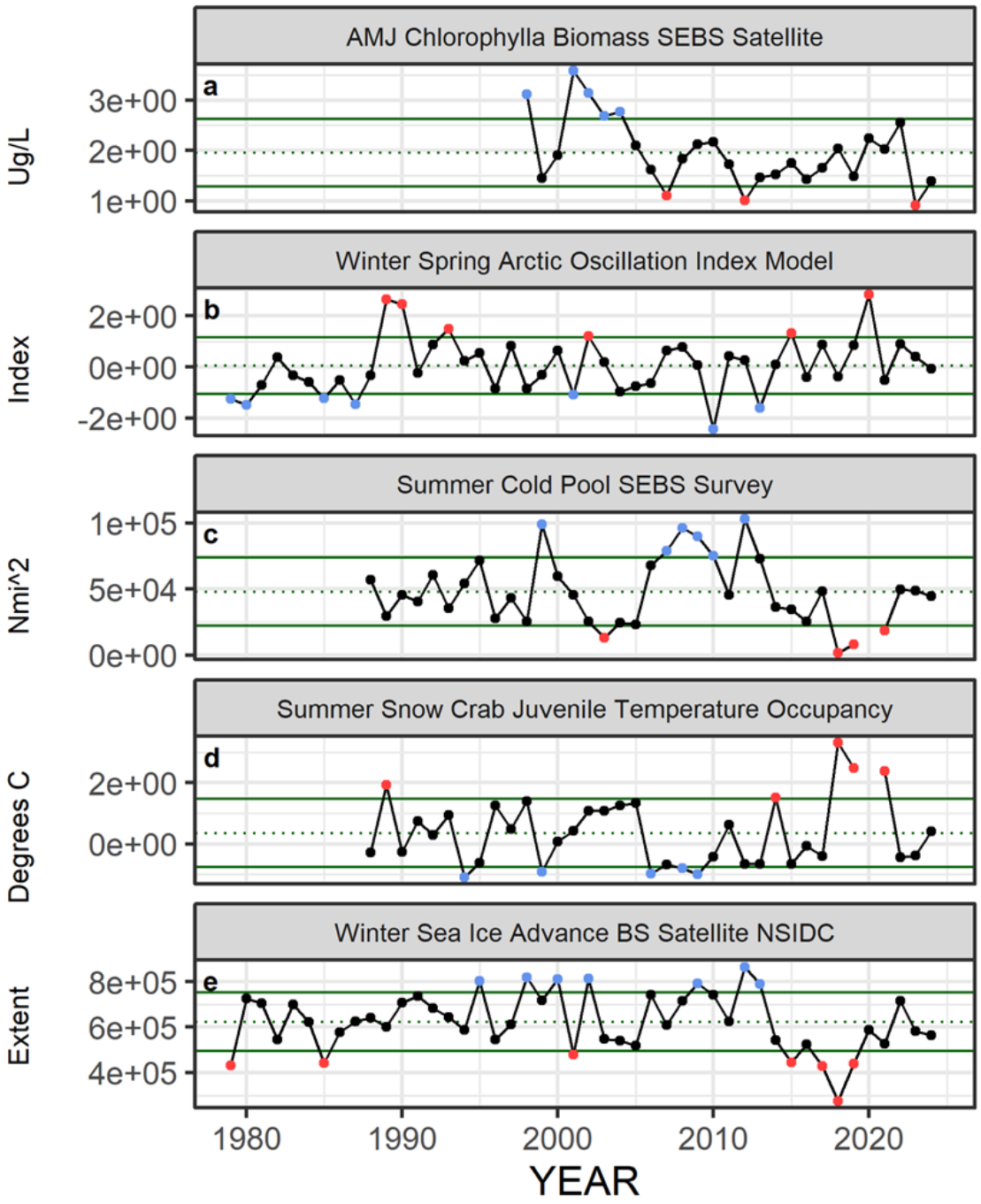

Figure 2a. Selected ecosystem indicators for snow crab with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral. If "NA" then a gap will appear in the time series.

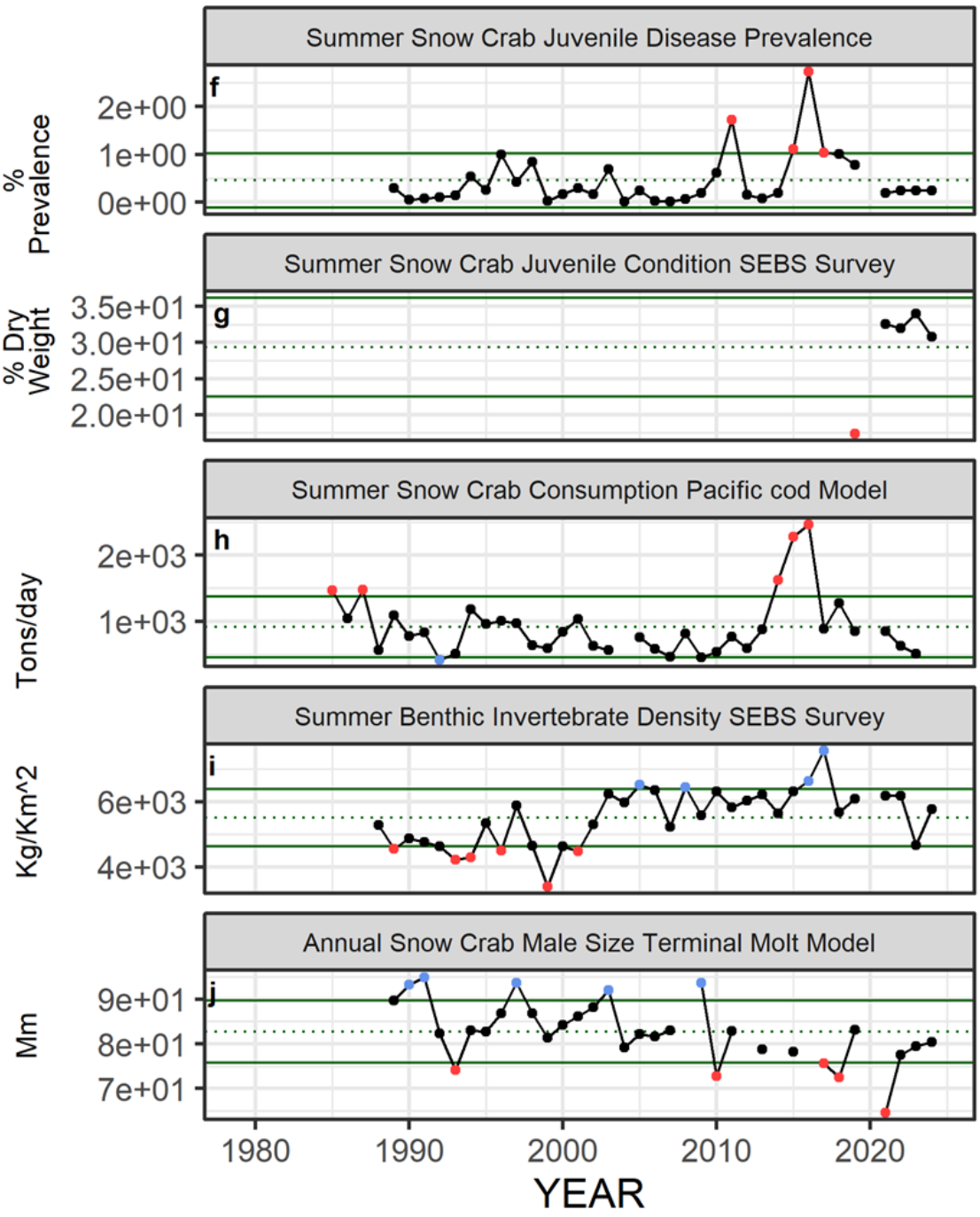

Figure 2a (cont.). Selected ecosystem indicators for snow crab with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral. If "NA" then a gap will appear in the time series.

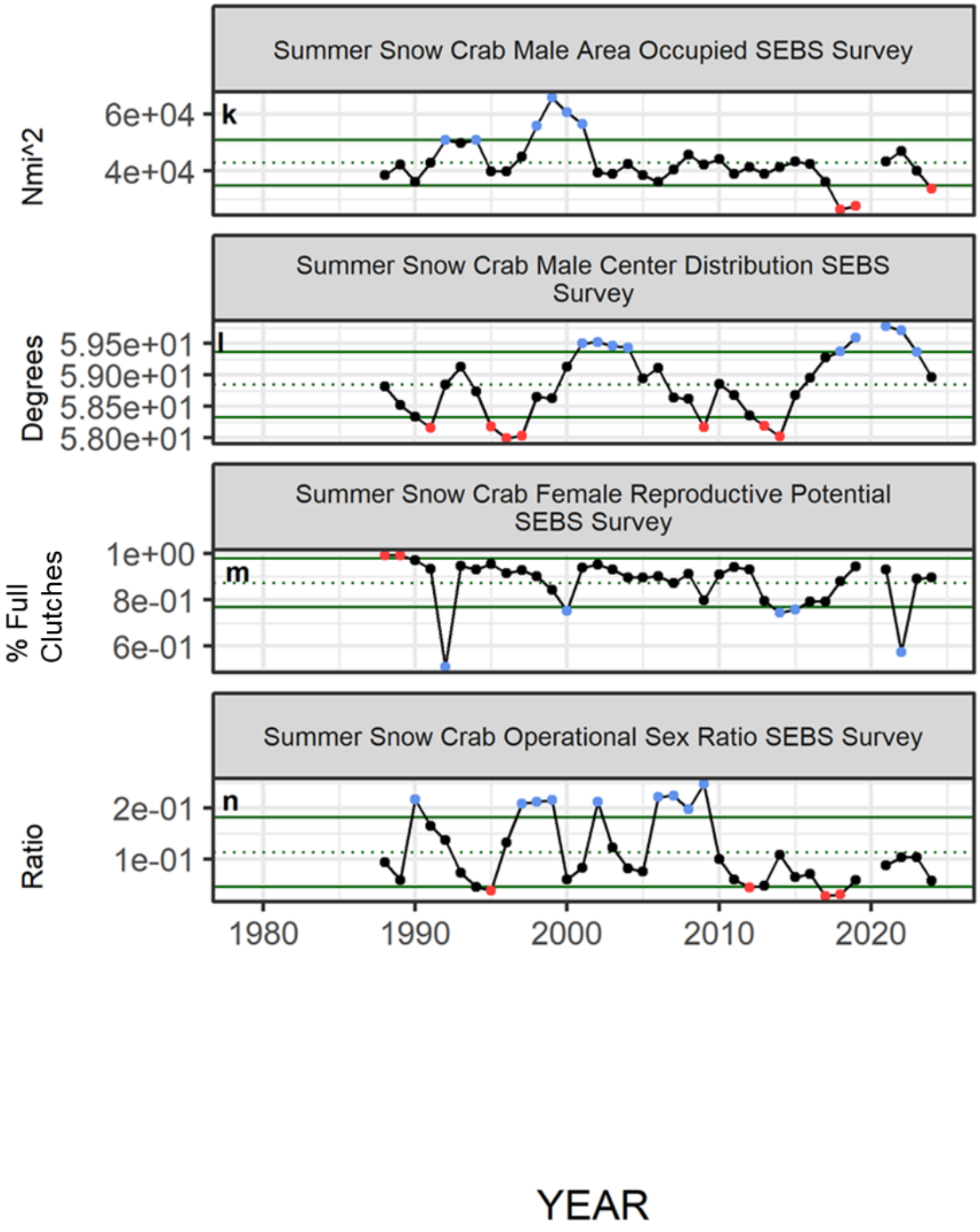

Figure 2a (cont.). Selected ecosystem indicators for snow crab with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral. If "NA" then a gap will appear in the time series.

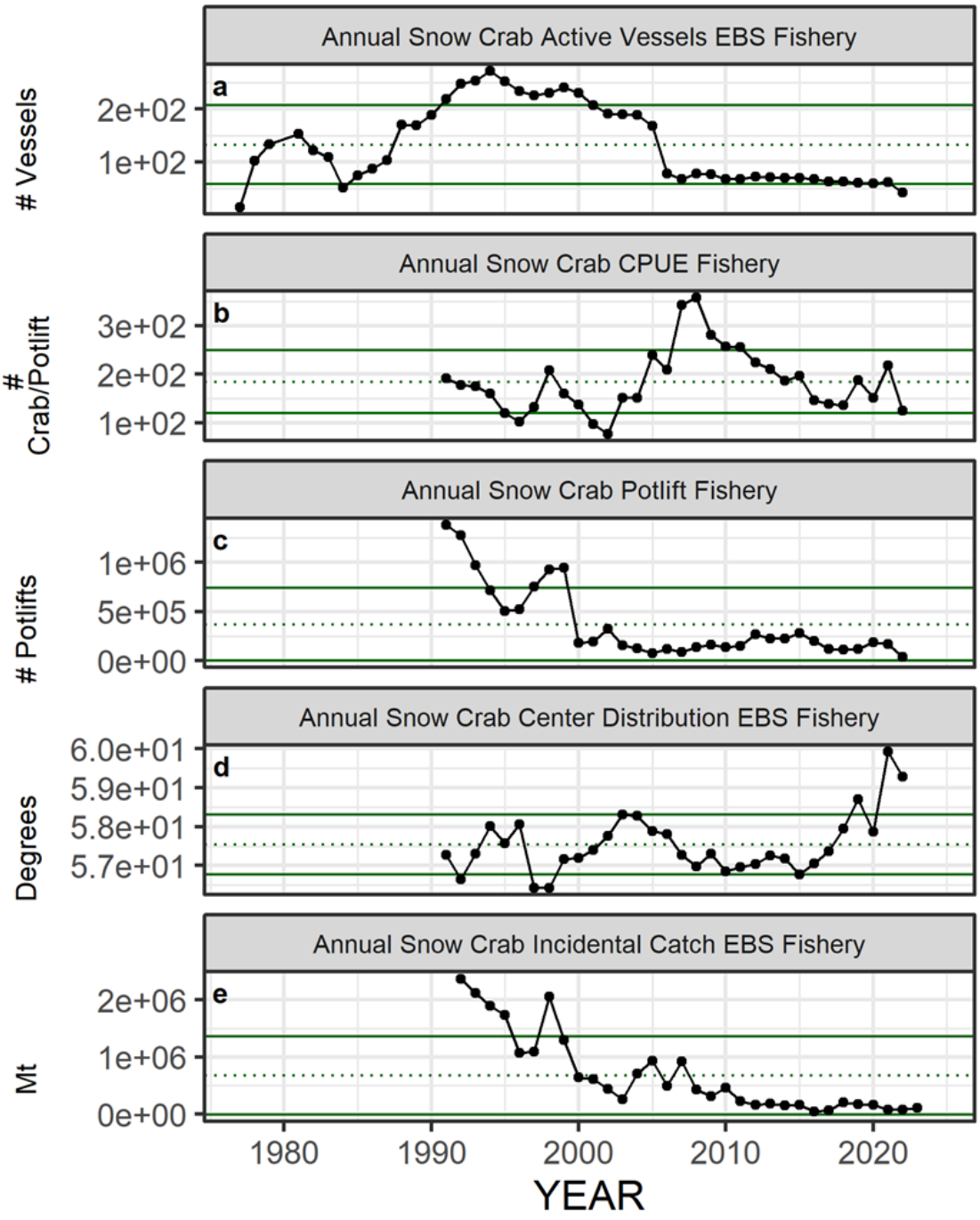

Figure 2b. Selected socioeconomic indicators for snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. If "NA" then a gap will appear in the time series.

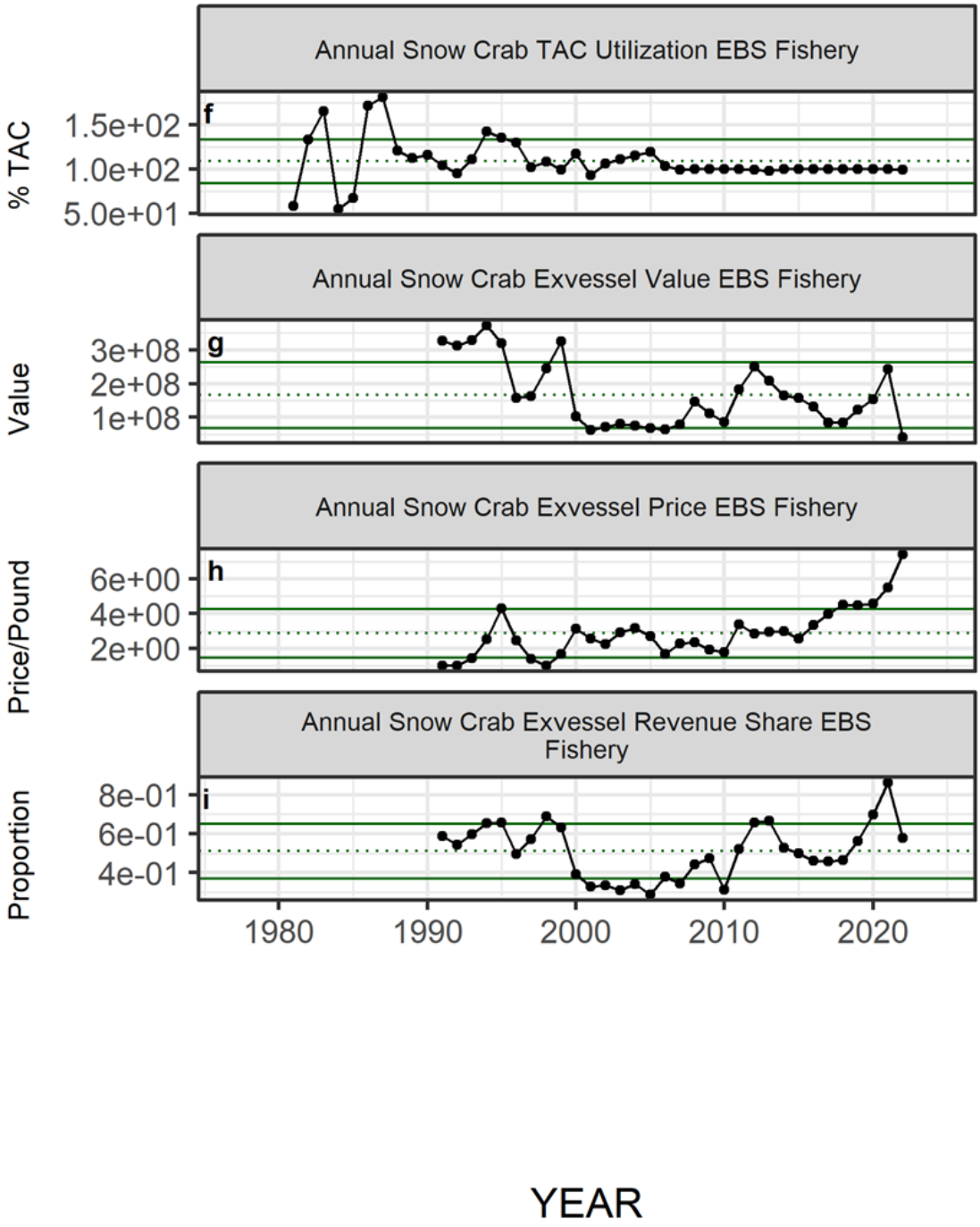

Figure 2b (cont.). Selected socioeconomic indicators for snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. If "NA" then a gap will appear in the time series.

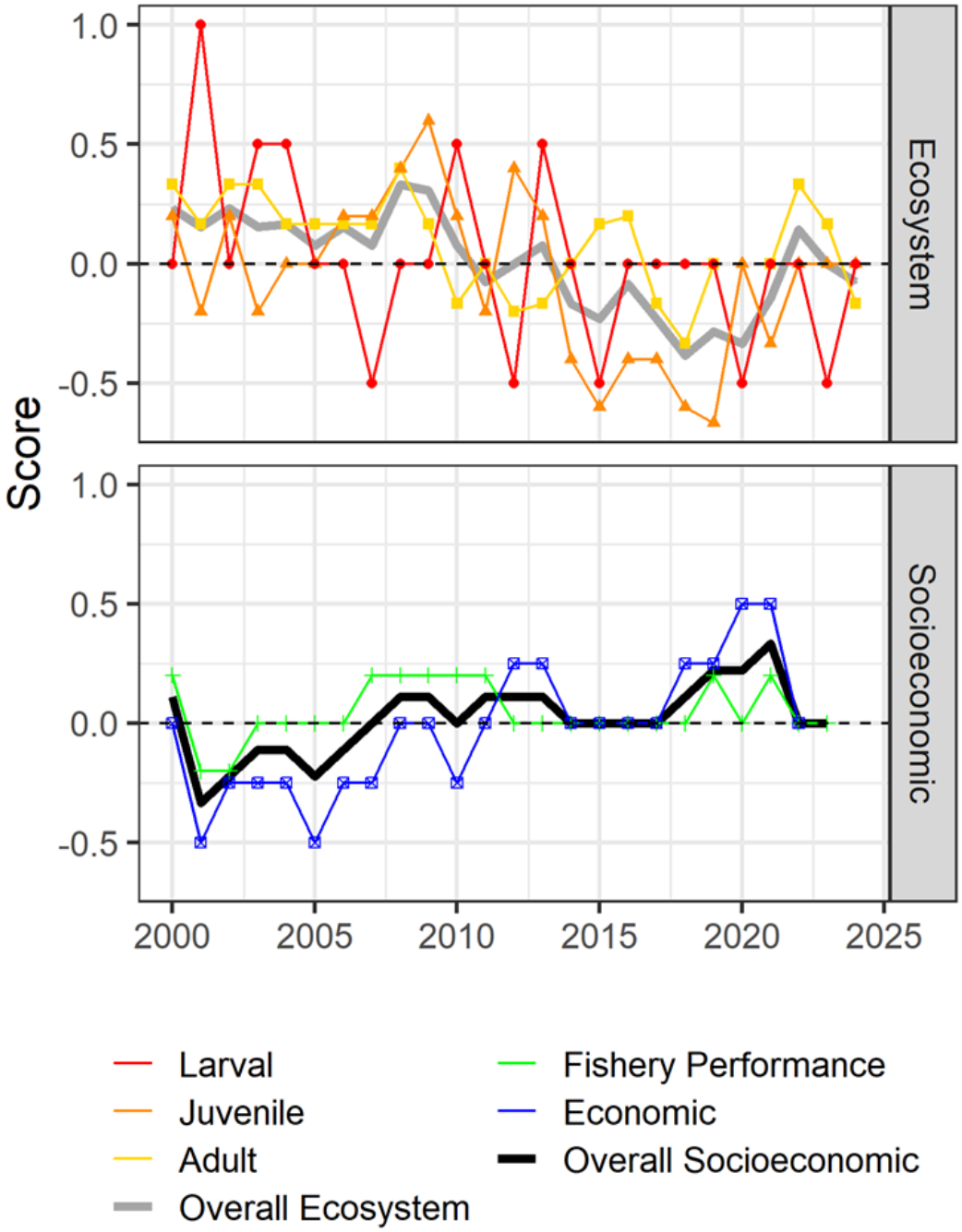

Figure 3: Simple summary traffic light score by category and overall for ecosystem and socioeconomic indicators from 2000 to present.

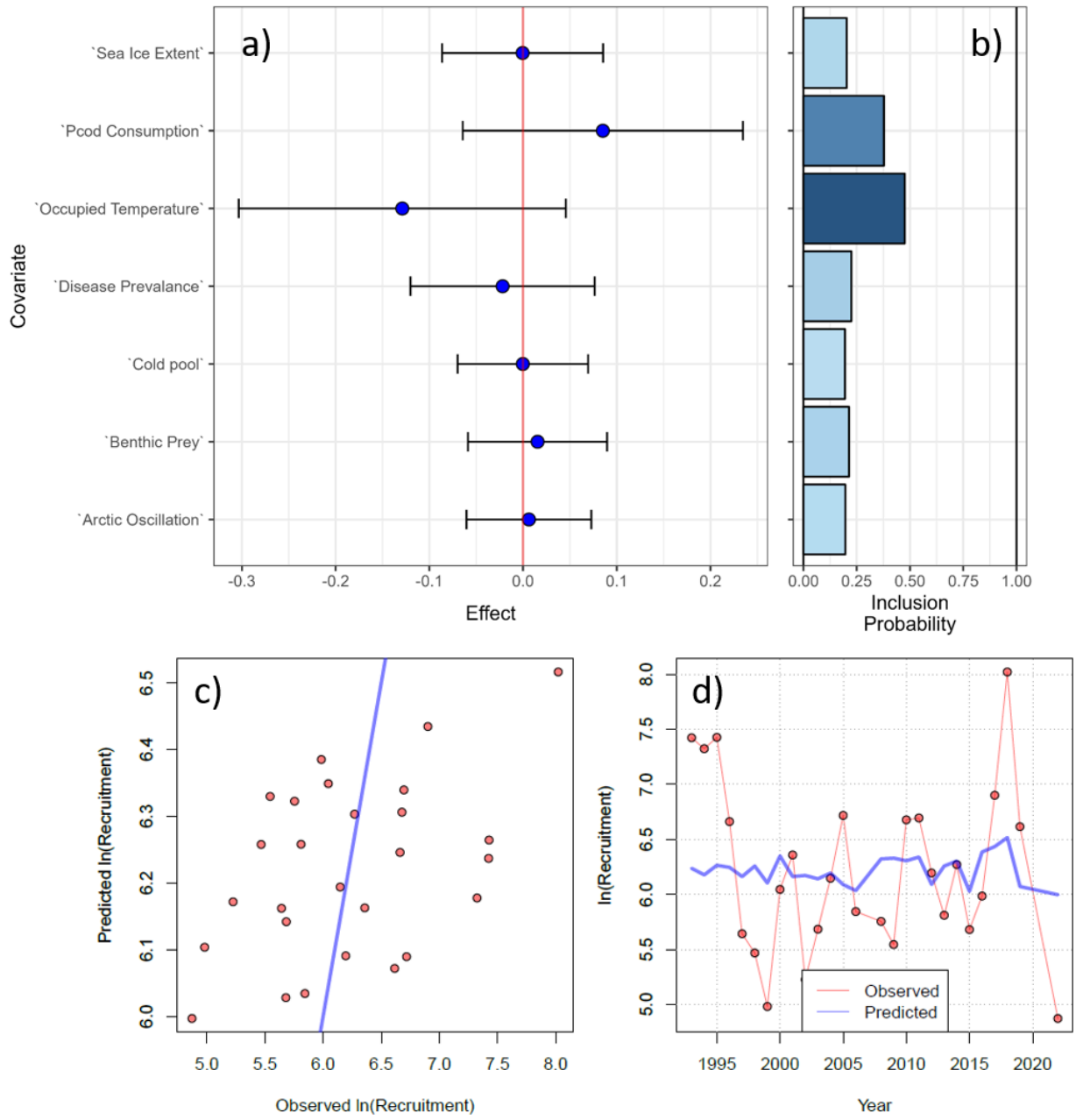

Figure 4. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed EBS male snow crab recruitment (50-65mm male snow crab survey abundance): a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the recruitment time series (1993 – 2021).