Appendix xx. Ecosystem and Socioeconomic Profile of the snow crab stock in the Eastern Bering Sea

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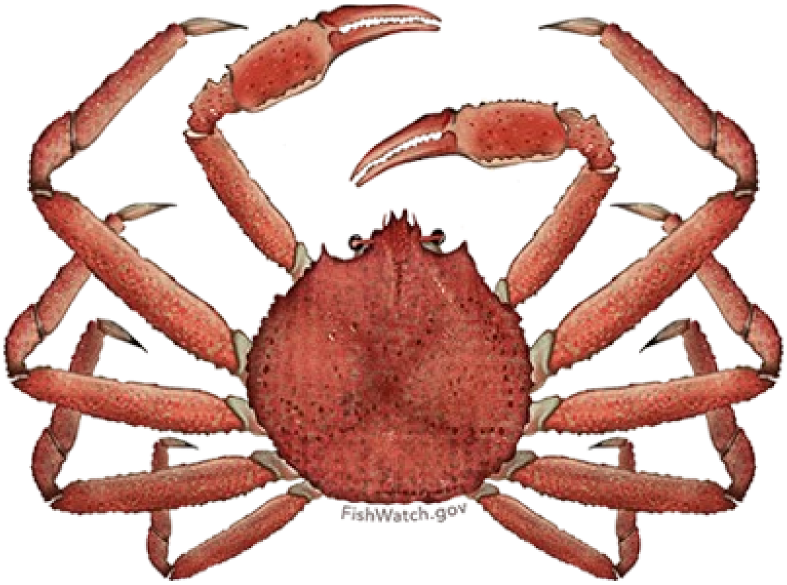

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Executive Summary

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

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

Management Considerations

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

- While the Arctic Oscillation index remains in a positive phase in 2022 following the highest Arctic Oscillation index in history, near-normal cold pool extent and sea ice concentration indicate a return to average environmental conditions in the Bering Sea.
- Temperatures occupied by juvenile snow crab decreased by nearly 3°C from 2021 to 2022, suggesting optimal cold-water habitat availability for predator refuge.
- Following a dramatic increase in the prevalence of bitter crab syndrome and Pacific cod predation in 2016, disease prevalence remains near-average in 2022. Pacific cod consumption on snow crab has remained near-average in 2019 and 2021.
- The average center of abundance of mature male snow crab from 2021-2022 was the most northerly in the 34-year time series, indicative of a large-scale distribution shift from historic mid-shelf habitats.
- Vessel participation in the EBS snow crab fishery declined to 42 in 2022, the lowest level since 1977 and approximately 68% of the average fleet size over the previous five years. Although driven by the historically low TAC level set for the 2021-2022 fishery, the contraction of the active fleet was limited relative to the 80% reduction in TAC.
- Fishery performance indicators, including low CPUE during 2022 and the extreme northerly shift of the center of distribution of fishing activity observed in 2021 and 2022, combined with results of a survey of snow crab vessel captains, were indicative of adverse fishing conditions during 2022.
- Economic performance indicators reported for 2021 (the most recent year available) increased, reflecting historically high ex-vessel value of snow crab landings, however, recent market trends combined with adverse fishery performance indicators reported for 2022 are evidence of severe economic stresses in the fishery and dependent stakeholders during the current period.

Modeling Considerations

The following are the summary considerations from the intermediate and advanced stage monitoring analyses for EBS snow crab:

- The highest ranked predictor for the recruitment regression model was the cold pool extent, although effect sizes were relatively small (<0.2) and marginal inclusion probabilities were < 0.5 for all predictors.
- Overall, intermediate stage monitoring analyses explained little variation in snow crab recruitment using both survey design-based and assessment model output estimates for recruitment. Future efforts should refine model covariates and lags pre-assigned to indicators.

Responses to SSC and Plan Team Comments

"The stage 2 indicator analysis uses a Bayesian approach and scales effect and inclusion probability for indicators where there are longer time series. Some indicators have different lags, and the CPT requested that these be explained in the final ESP document. The CPT also noted that the IBM and benthic cohort model results are not yet ready for inclusion as ESP indicators" (CPT, May 2022)

Lags assigned to indicators for use in statistical analyses are now detailed in indicator description text of the current document. Based on CPT recommendation, the ecosystem indicator suite does not include indicators developed from the snow crab IBM model.

"With regards to the Ecosystem and Socio-economic Profile (ESP) for snow crab, the SSC highlights previous requests to ESP analysts and Plan Teams to consider carefully the addition of social and community indicators in appropriate documents to meet requirements of National Standard 2. This is especially important for this stock in the context of upcoming rebuilding analyses and will be critical to track changes during rebuilding to account for the needs of affected communities and to ensure a fair and equitable distribution of rebuilding benefits and costs. The SSC highlights in particular the cascading effects of the snow crab collapse on communities that strongly depend on the resource, such as St. Paul." (SSC, June 2022)

Community indicators are currently available in the Annual Community and Participation Overview (ACEPO) report (Wise et al., 2021), which presents social and economic information for communities that are substantially engaged in and/or dependent on the commercial groundfish and crab fisheries in Alaska, as well as in the annual Crab Economic SAFE. Moving forward, we plan to concentrate development of socioeconomic indicators in the ESP that are most directly associated with the condition or health of the stock and the conduct of the fishery, and therefore have the most direct bearing on the scope of stock assessment development and harvest specification decision processes that are the focus of ESP documents. Effort has also been made to incorporate fishery-derived community indicators in this document that were developed from Alaska Bering Sea Crabber's Skipper Surveys distributed to the snow crab fleet following the 2020-2021 and 2021-2022 directed fisheries. We see the Skipper Survey as a means to extract local stakeholder knowledge through industry collaborations to potentially inform better decision making and improve socioeconomic outcomes for the snow crab fleet.

Introduction

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

This ESP for EBS snow crab (*Chionoecetes opilio*) follows the template for ESPs (Shotwell et al., *In Review*) and replaces the previous ecosystem considerations section in the main EBS snow crab stock assessment and fishery evaluation (SAFE) report. Information from the original ecosystem considerations section may be found in Szuwalski (2021).

The ESP process consists of the following four steps:

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

Justification

National initiatives and NPFMC recommendations support conducting an ESP for the EBS snow crab stock. The high commercial importance and constituent demand of the stock and cold water habitat dependence throughout the life cycle created a high score for both stock assessment and habitat assessment prioritization (Methot, 2015; McConnaughey et al., 2017). The vulnerability scores were low to moderate based on productivity, susceptibility (Patrick et al., 2010), and high sensitivity with low exposure based on future climate exposure (Spencer et al., 2019). The new data classification scores for EBS snow crab suggest a data-moderate stock with high quality data for catch and abundance, and moderate quality data for size/age composition, life history categories, and ecosystem linkages (Lynch et al., 2018). These initiative scores and data classification levels suggest a moderate to high priority for conducting an ESP for EBS snow crab. Additionally, AFSC research priorities support studies that improve our understanding of environmental and climate forcing of ecosystem processes with focus on variables that provide direct input into stock assessment and management. Finally the Crab Plan Team and SSC have requested an ESP be conducted for EBS snow crab as time allows to consider what indicators directly affect the EBS snow crab stock, and to better understand potential drivers of the 2021 snow crab stock collapse.

Data

Initially, information on EBS snow crab was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 2016. These include (but are not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment categorization. Data derived from this effort served as the initial starting point for developing the ESP metrics for stocks in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) groundfish fishery management plans (FMP) and the BSAI king and tanner crab FMP. Please see Shotwell et al., *In Review*, for more details.

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

Data used to generate socioeconomic metrics and indicators were derived from fishery-dependent sources, including commercial landings data for EBS snow crab collected in ADFG fish tickets and the BSAI Crab Economic Data Report (EDR) database (both sourced from AKFIN), and effort statistics reported in the most recent ADFG Annual Management Report for BSAI shellfish fisheries estimated from ADF&G Crab Observer program data (Leon et al. 2017). Community indicators were developed from Alaska Bering Sea Crabber's Skipper Surveys distributed to the snow crab fleet following the 2020-2021 and 2021-2022 directed fisheries.

Metrics Assessment

We first provide the analysis of the national initiative data used to generate the baseline metrics for this second step of the ESP process and then provide more specific analyses on relevant ecosystem and/or socioeconomic processes. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and improve mechanistic understanding of ecosystem or socioeconomic pressures on the stock.

National Metrics

The national initiative data were summarized into a metric panel (Figure 1) that acts as a first pass ecosystem and socioeconomic synthesis. Metrics ranged from estimated values to qualitative scores of population dynamics, life history, or economic data for a given stock (see Shotwell et al., *In Review* for more details). To simplify interpretation, the metrics were rescaled by using a percentile rank for EBS snow crab relative to all other stocks in the groundfish and crab FMPs. Additionally, some metrics were inverted so that all metrics could be compared on a low to high scale between all stocks in the FMPs. These adjustments allowed for initial identification of vulnerable (percentile rank value is high) and resilient (percentile rank value is low) traits for EBS snow crab. Data quality estimates were also provided from the lead stock assessment author (0 or green shaded means no data to support answer, 4 or purple shaded means complete data), and if there were no data available for a particular metric then an "NA" would appear in the panel. EBS snow crab did have a few data gaps for the metric panel namely mean trophic level, growth rate, and recruitment variability as these categories were not well understood for crab stocks. Data quality ranged from no data to good for the remaining metrics. The metric panel gives context for how EBS snow crab relate to other groundfish and crab stocks in the FMPs and highlights the potential vulnerabilities for the EBS snow crab stock.

The 80th and 90th percentile rank areas are provided to highlight metrics indicating a high level of vulnerability for EBS snow crab (Figure 1). Spawning cycle and fecundity fell within the 80th percentile rank when compared to other stocks in the groundfish and crab FMPs. Latitude range, ocean acidification sensitivity, commercial importance, habitat dependence, early life history survival and settlement, complexity in reproductive strategy, spawning duration, and temperature sensitivity all fell within the 90th percentile rank. EBS snow crab were relatively resilient for breeding strategy, geographic concentration, maximum length, length at 50% maturity, predation stressors, prey specificity, and dispersal during early life history.

Ecosystem Processes

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

After molting to maturity, female snow crab mate and extrude new egg clutches each spring, which remain attached to pleopods on the female's abdomen for a full year prior to hatching (Watson, 1970). Fecundity is positively correlated with female size, and primiparous females have a lower fecundity than multiparous females (Sainte-Marie, 1993). The optimal range for embryo development is 0 to 3°C, although laboratory studies indicate that incubation temperatures below 0°C can trigger diapause or a biennial reproduction cycle (Webb et al., 2007). Peak hatching of snow crab larvae occurs in April (Armstrong et al., 1981) and phyto-detritus may act as a chemical cue for larval release (Starr et al., 1994). Larval duration for each of the two zoeal stages is approximately 30 days (Incze et al., 1982). A longer larval stage associated with cooler temperatures may leave larvae more vulnerable to pelagic predators for a prolonged period. Furthermore, historical larval year-class failures have coincided with low zooplankton abundance over the middle shelf and low water column stability, suggesting that increased larval mortality is related to less favorable feeding conditions (Incze et al., 1987) and mismatches between larval release and the spring bloom (Somerton 1982). Likewise, laboratory studies suggest that relatively high prey densities are required for successful feeding in snow crab zoeae (Paul et al., 1979). Major predators of larval snow crab include yellowfin sole (Armstrong et al., 1981), walleye pollock, jellyfish and juvenile salmon (Kruse et al., 2007).

Snow crab larvae settle from late August to the end of October (Conan et al., 1992). Early benthic instars are cryptic and concentrate in shallow, cold water habitats (Lovrish et al., 1995; Murphy et al., 2010). Previous laboratory studies have shown that adequate energetic stores are prerequisites for molting, growth, and survival in snow crab early life history stages (e.g. Lovrich and Ouellet, 1994), indicating that variability in energetic reserves could represent a potential recruitment bottleneck in snow crab. Likewise, increased warming and declines in sea ice are expected to decrease benthic juvenile snow crab prey resources supplied to the benthos through decreased benthic-pelagic flux (Copeman et al., 2021). Both settlement intensity and early benthic survival are likely critical determinants of year-class strength in snow crab (Sainte-Marie et al., 1996), and successful advection to areas of suitable temperature and muddy substrate are thought to be critical criteria for juvenile survival (Dionne et al., 2003). Density-dependence may also play a regulatory role due to high rates of cannibalism and potential prey resource limitation in juvenile nurseries (Lovrich and Sainte-Marie 1997). Previous studies have shown that Pacific cod, sculpin, skates and halibut are major predators of juvenile snow crab (Livingston et al., 1993; Livingston and deReynier, 1996; Lang et al., 2003) and the cold pool may provide refuge from predators like Pacific cod that avoid waters less than 2°C (Ciannelli and Bailey, 2005). Juvenile snow crab are especially vulnerable to predation and cannibalism during and immediately following molting.

Spatial patterns in juvenile and adult snow crab distribution are determined largely by ontogenetic migrations linked to size- and sex-specific thermal requirements. Immature snow crab concentrate in colder, shallow waters of the NBS and EBS middle shelves, historically avoiding thermal habitats >2°C (Kolts et al., 2015; Murphy, 2020). Likewise, primiparous female snow crab appear to track near-bottom temperature during a northeast to southwest ontogenetic migration to warmer waters near the shelf break (Ernst et al., 2005; Parada et al., 2010). Shifts in centers of abundance of mature female snow crab relative to prevailing currents may affect larval supply to nursery areas (Zheng and Kruse, 2006) and thermal occupancy patterns of snow crab depend on the availability of cold water habitat (Fedewa et al., 2020). While 2°C may represent a critical temperature threshold for immature snow crab (Murphy, 2020), negative effects on metabolic processes are not apparent in mature snow crab until temperatures exceed 7°C (Foyle et al., 1989). Temperature also influences molt timing (Dutil et al., 2010), growth rates (Yamamoto et al., 2015), energy stores (Hardy et al., 2000), and body condition (Dutil et al., 2010) of snow crab in the laboratory.

Socioeconomic Processes

As described below, the set of socioeconomic indicators proposed in this ESP are categorized as Fishery Performance and Economic Performance indicators. Fishery Performance indicators are intended to represent processes most directly involved in prosecution of the EBS snow crab fishery, and thus have the potential to differentially affect the condition of the stock depending on how they influence the timing, spatial distribution, selectivity, and other aspects of fishing pressure. Economic Performance indicators are intended to capture observable dimensions of key economic drivers of fishery performance and fleet behavior. This ESP also summarizes results from an industry-led Skipper Survey as a means to provide community indicators through extracting local stakeholder knowledge. The fifteen question survey distributed to snow crab skippers following the 2021/2022 fishing season focused on comparisons to the previous 2020/2021 snow crab season in regards to 1) perceived abundance of industry preferred males, sub-legal males, immature males and females, 2) changes in fishing behavior (e.g. fishing deeper, longer soak times), 3) motivation for changes in fishing behavior (e.g. weather, empty pots, heavy sorting), and 4) the amount of sorting. Questions directed at perceived abundance and catch sorting comparisons between seasons were recorded with quantitative responses including a) >25% increase, b) 10 - 25% increase, c) within +/- 10%, d) 10 - 25% decrease, or e) >25% decrease. We see the Skipper Survey as a means to provide context for the development of meaningful community indicators in the near-future, and to identify socioeconomic outcomes for the snow crab fleet.

Notwithstanding these categorical distinctions of indicators, the social and economic processes that affect -- and are affected by -- the condition of the stock are complex and interrelated at different time scales. While the complex of reciprocal linkages between condition of the EBS snow crab stock and fishery and economic performance-related processes may be hypothesized in principal, no conceptual model currently exists that is adequate to support practical predictive application of socioeconomic indicators comparable to that of ecosystem indicators for informing the snow crab assessment. A further distinction of most observable socioeconomic processes from ecosystem processes associated with the EBS snow crab fishery is that data collection and monitoring of many aspects of socioeconomic processes is conducted during or following the fishing season, such that the most recent available data point may be lagged by up to two years behind the current assessment, and as such, cannot be captured in indicators that provide advance information for use in informing the current stock assessment. As such, in the context of the ESP, available time series of socioeconomic indicators are largely limited to providing a general frame of reference regarding socioeconomic factors associated with historic fishery management, to inform interpretation of historic patterns observed in other data series captured in the assessment and, potentially, stimulating research on linkages between socioeconomic processes and stock condition.

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

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

While these and other elements of CR program design facilitated similar operational and economic efficiencies in the harvest sector, with more limited consolidation of processing capacity to somewhat fewer locations, and fewer plants in some ports, they have also limited some economic adjustments that would likely have occurred in their absence. Most notably, North regional designation of a large fraction of EBS snow crab IFQ has likely maintained a larger proportion of landings to St. Paul Island than would have occurred otherwise. St. Paul Island has historically and to-date received the largest share of EBS snow crab landings, with Akutan, King Cove, and Unalaska/Dutch Harbor representing the other principal landing ports for EBS landings historically and to-date. See the Council's 10-Year Program Review for the CR Program for detailed description and analysis of program structure and management (Council, 2017).

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

Indicators Assessment

We first provide information on how we selected the indicators for the third step of the ESP process and then provide results on the indicators analysis. In this indicator assessment a time-series suite is first created that represents the critical processes identified by the metric assessment. These indicators must be useful for stock assessment in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of stages that are statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al., In Review). A short description and contact name for the indicator contributor are provided below. We also include the anticipated lag and sign of the proposed relationship between the indicator and the stock population dynamics for indicator analyses where relevant.

Indicator Suite

Ecosystem Indicators

Physical Indicators (Figure 3a.a-c)

a) Winter-spring Arctic Oscillation index from the NOAA National Climate Data Center (contact: E. Fedewa). Proposed sign of relationship is negative and the time series is lagged five years for intermediate stage indicator analysis

b) The areal extent of the summer cold pool as EBS bottom trawl survey stations with bottom temperatures < 2ºC (contact: E. Fedewa). Proposed sign of relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.
c) January winter sea ice concentration in the Bering Sea (contact: E. Fedewa). Proposed sign of relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.

Lower Trophic Indicators (Figure 3a.d-e)

d) Derived chlorophyll-*a* concentration during spring and summer season (April, May, June) in the northern middle southeastern Bering Sea from the MODIS satellite (contact: M. Callahan and J. Nielsen). Proposed sign of relationship is positive.
e) Summer benthic invertebrate density, determined from EBS bottom trawl survey stations included in the 50th percentile of mean snow crab CPUE. Invertebrates include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes. (contact: E. Fedewa). Proposed sign of relationship is positive.

Upper Trophic Indicators (Figure 3a.f-k)

f) Mean bottom temperature weighted by immature snow crab CPUE at each station of the EBS summer bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is negative.
g) Prevalence of immature snow crab showing visual evidence of Bitter Crab Syndrome during the summer EBS bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is negative.
h) Mean carapace width of male snow crab at 50% probability of maturation, as determined from maturity curves developed from EBS bottom trawl survey data (contact: J. Richar). Proposed sign of relationship is positive.
i) Area occupied, calculated as the minimum area containing 95% of the cumulative mature male snow crab (>95mm) CPUE during the EBS summer bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.
j) CPUE-weighted average latitude of the mature male snow crab stock (>95mm) during the EBS summer bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.
k) The daily summer consumption of snow crab by Pacific cod in the EBS, estimated from Pacific cod diet compositions, EBS trawl survey CPUE, and temperature adjusted length-specific maximum consumption rates (contact: K. Aydin). Proposed sign of relationship is negative and the time series is lagged two years for intermediate stage indicator analysis.

Socioeconomic Indicators

Fishery Performance Indicators (Figure 3b.a-e)

a.) Annual number of active vessels in the snow crab fishery, representing the level of fishing effort assigned to the fishery (contact: J. Lee)
b.) Annual catch-per-unit-effort (CPUE), expressed as mean number of crabs per potlift, in the snow crab fishery, representing relative efficiency of fishing effort (contact: B. Daly)
c.) 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: B. Daly)
d.) Annual incidental catch of snow crab in EBS groundfish fisheries (contact: J. Lee)
e.) Annual total potlifts in the snow crab fishery, representing the level of fishing effort expended by the active fleet (contact: B. Daly)

Economic Indicators (Figure 3b.f-i)

f.) Percentage of the annual EBS snow crab total allowable catch (TAC) (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing (contact: B. Daly) g.) Annual snow crab ex-vessel price per pound, representing per-unit gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)

h.) 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: J. Lee)

i.) Annual snow crab ex-vessel value of the snow crab fishery landings, representing gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)

Community Indicators

j.) Alaska Bering Sea Crabbers (ABSC) Skipper Survey, distributed to captains following the 2021/2022 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: C. Lescher)

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. These analyses gradually increase in complexity depending on the stability of the indicator for monitoring the ecosystem or socioeconomic process and the data availability for the stock (Shotwell et al., *In Review*). The beginning stage is a relatively simple score based on 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, biomass, 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 testing a research ecosystem linked model and output can be compared with the current operational model to understand information on retrospective patterns, prediction performance, and comparisons of other model output such as terminal spawning stock biomass or mean recruitment. This stage provides an on-ramp for introducing an alternative ecosystem linked stock assessment model to the current operational stock assessment model and can be used to understand the potential reduction in uncertainty by including the ecosystem information.

At this time, we report the results of the beginning and intermediate stages of the indicator monitoring analysis for EBS snow crab and a review of current ecosystem linked modeling developments for the advanced stage.

Beginning Stage: Simple Score

We use a simple scoring calculation for the beginning stage evaluation. Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long-term mean. A sign based on the anticipated relationship between the indicator and the stock (Figure 2) is also assigned to the indicator where possible for ecosystem indicators only. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a +1 score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a -1 score. All values less than or equal to one standard deviation from the long-term mean are average and receive a 0 score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. We provide the category scores for the past twenty years as the majority of indicators were available throughout this time period (Figure 4).

The scores over time allow for comparison of the indicator performance and the history of stock productivity. We also provide five year indicator status tables with a color or text code for the relationship with the stock (Table 3) and evaluate the current year status in the historical indicator time series graphic (Figure 3) for each ecosystem and socioeconomic indicator.

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the EBS snow crab stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels for the ecosystem indicators then evaluate the fishery performance and economic indicators as listed above. Here, we concentrate on updates since the last ESP. Overall, the physical indicators were average, while the lower and upper trophic indicators were above average (Figure 4). The fishery performance and economic indicators scored average for 2022, but the economic score is based on only one indicator. Compared to the previous data point, this is an increase from below average for the physical indicators, an increase from average for the lower trophic indicators, an increase from below average for the upper trophic indicators, a decrease for the fishery performance indicators, and a decrease for the economic indicators.

Following the 2019-2020 highest Arctic Oscillation index in history (Zhang et al., 2021), the winter-spring Arctic Oscillation index returned to near-normal in 2022, although still remains in a positive phase. Poor snow crab recruitment has been associated with positive values of the Arctic Oscillation (Szuwalski et al., 2021), suggesting that large-scale weather and climate anomalies in 2019/2020 could have impacted stock productivity. Cold pool spatial extent and sea ice concentration in 2022 were average, indicating a return to near-normal conditions in the Bering Sea following anomalously warm temperatures and record low sea ice concentration in 2018-2019.

Lower trophic level indicators include chlorophyll-*a* biomass and benthic invertebrate biomass, both of which represent potential prey resources for pelagic and benthic snow crab stages. Chlorophyll-*a* biomass was well above average in 2022, characteristic of a large, productive spring bloom. Although 2022 benthic invertebrate density estimates are not yet available, 2021 density increased due to large catches of purple-orange sea stars. For the upper trophic level indicators, male snow crab area occupied and juvenile disease prevalence remained near-average in 2022. The mature male snow crab center of distribution shifted north in 2021 and has remained north in 2022, potentially indicating temperature-driven distributional shifts (Orensanz et al., 2005). Temperatures occupied by immature snow crab declined dramatically in 2022 from record-high temperatures in 2018-2021, suggesting that cold-water habitat critical for evading groundfish predators was widely available to juveniles. Following a dramatic reduction in male size at 50% probability of maturation in 2021, size at maturity increased by over 10mm in 2022 to remain just below the long-term average. While this indicator is indicative of population-level shifts in the average size at maturity, temporal trends may be driven by recruitment variability and cohort effects (Murphy 2021).

Fishery performance indicators are reported through calendar year 2022 (corresponding to the 2021-2022 crab season), with the exception of incidental catch in the (currently ongoing) EBS groundfish fisheries, reported through 2021. The active snow crab fleet during 2022 declined to 42 vessels, the lowest level since 1977 at the beginning of the time series, and approximately 68% of the average number of vessels participating during the previous five years. Relative to the substantially reduced TAC (less than 13% of the previous year and less than 20% of the previous five-year average), less consolidation of fishing activity occurred than would be expected based on economic efficiency, and it is unclear if other factors driving this level of vessel participation will persist if TAC levels remain comparably low. CPUE in the fishery declined from 218 the previous year to 124 legal crab per potlift, and total potlifts declined from 172 thousand in 2021 to 37 thousand, with both indicators approaching the lower bound of one standard deviation below the long term (1991-current) average, respectively. The latitude of the center of gravity of fishing activity during 2022 shifted somewhat south compared to the previous year, but remained approximately two standard deviations greater than the long-term average. Incidental catch in EBS groundfish fisheries during 2021 declined for a fourth consecutive year to 77 thousand kg, approaching the lower bound of the long-term range of variation. TAC utilization reached 99% for the 2021-2022 snow crab fishery, however, fishing extended later than usual, with four vessels making landings later than May 15.

Economic performance indicators included in this ESP are reported through calendar year 2021, the most recent year for which data are available. With a TAC of 18.37 thousand metric tons, the highest since the 2014-2015 crab season, combined with historically high market values for snow crab driven by high consumer demand during the first two years of the covid-19 pandemic, estimated ex-vessel revenue in the snow crab fishery during 2021 exceeded $219 million, approaching the upper bound of one standard deviation above the long-term (1991-2021) average. Average ex-vessel price per pound reached a historical high in 2021, increasing by 25% from 2020, to $4.97 per pound, greater than two standard deviations higher than the historical average since 1991 (adjusted for inflation). As a result of the historically high ex-vessel value of the snow crab fishery during 2021, combined with the closure or reduced TAC levels in most crab and other fisheries targeted by the snow crab fleet, ex-vessel revenue share increased to an unprecedented 85% of total annual ex-vessel landings revenue, summed across all fisheries in which snow crab vessel landed catch during the 2021 calendar year. Although 2022 data is not yet available for economic performance indicators, news reports and other information indicate that market demand for crab and other premium seafood products contracted sharply in 2022, suggesting that economic returns for most or all of the fleet active during the 2021-2022 snow crab season were poor and many vessels likely operated at a loss.

While results from the 2021/2022 ABSC Skipper Survey were precluded from indicator monitoring analyses, we report summarized responses from thirteen skippers directed at comparisons between the 2021/2022 fishery and the prior 2020/2021 season. When asked to compare perceived abundances of snow crab on the fishing grounds, 38% of skippers reported that commercial sized males had decreased more than 25% and 31% of skippers reported that sub-commercial sized males had decreased more than 25%. While 23% of skippers noted that they fished deeper compared to the previous season, another 23% noted no significant changes in behavior and attributed their motivation to fish historic grounds to smaller quotas during the 2021/2022 season. In response to the sorting of dirty shell or small crab, 38% of skippers replied that discarding decreased more than 25% from last season. Finally, 70% of skippers noted an increase in Pacific cod in crab pots compared to the past season.

Intermediate Stage: Importance Analysis

Bayesian adaptive sampling (BAS) was used for the intermediate stage statistical analysis to quantify the association between hypothesized predictors and EBS snow crab recruitment, and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this intermediate analysis, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment, indicators are lagged to reflect hypothesized relationships with recruitment, and highly correlated covariates are removed (Figure 5). Prior to model runs, winter sea ice extent and immature snow crab temperature of occupancy were removed from the dataset as they are highly correlated with cold pool extent, and all three covariates likely represent similar linkages to the stock. We further restrict potential covariates to those that can provide the longest model run and through the most recent estimate of recruitment that is well estimated. This resulted in a model run from 1995 through 2021 (excluding 2007 and 2020) for EBS snow crab. We then provide the mean relationship between each predictor variable and log EBS snow crab recruitment over time (Figure 5, left side), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 5, right side). A higher probability indicates that the variable is a better candidate predictor of EBS snow crab recruitment. The highest ranked predictor variable based on this process was cold pool extent, although all marginal inclusion probabilities were < 0.5 and the model had very little explanatory power in predicting snow crab recruitment (Figure 5).

The BAS method requires observations of all predictor variables in order to fit a given data point. This method estimates the inclusion probability for each predictor, generally by looking at the relative likelihood of all model combinations (subsets of predictors). If the value of one predictor is missing in a given year, all likelihood comparisons cannot be computed. When the model is run, only the subset of observations with complete predictor and response time series are fit. It is possible to effectively trick the model into fitting all years by specifying a 0 (the long-term average in z-score space) for missing predictor values. However, this may bias inclusion probabilities for time series that have more zeros and result in those time series exhibiting low inclusion probability, independent of the strength of the true relationship. Due to this consideration of bias, we only fit years with complete observations for each covariate at the longest possible time frame. This resulted in a smaller final subset of covariates. We plan to explore alternate model runs to potentially include more covariates in the future.

We also compared results from two different BAS models: one model using estimates of male snow crab recruitment from the 2021 approved assessment model, and another model using NOAA bottom trawl survey design-based recruitment estimates. Design-based recruitment estimates were calculated as area-swept abundance of 50-65mm immature male snow crab to account for lower catchability of smaller crab in NOAA survey gear (Somerton et al., 2013), whereas estimates of recruitment from the assessment incorporate catchability and length composition data to determine cohort size. Overall, results indicated improved fits to recruitment estimates from the assessment, thus only results from this BAS model are presented.

Advanced Stage: Research Model

New research models are currently being explored to assess potential mechanisms for increased mortality (e.g. bitter crab syndrome, cod predation, cannibalism) in 2018-2019 (Szuwalski et al., *in prep*).

Conclusion

The EBS snow crab ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the metric and indicator assessment we provide the following summary for ecosystem and socioeconomic indicators:

Ecosystem Indicators

In summary, physical indicators reveal much more favorable conditions for snow crab in 2022 following the 2018-2019 heat wave. Sub-0°C temperatures occupied by immature snow crab suggest that survival may be optimal for a new cohort of juveniles evident in the 2022 NOAA bottom trawl survey (Zacher et al., *in review*). Likewise, above-average chlorophyll-*a* biomass and benthic invertebrate density may be indicative of increased prey resources for larval and benthic stages of snow crab. Pacific cod consumption and bitter crab syndrome prevalence reached all-time highs in 2016 and may have been attributed to 2018-2019 mortality events, although both indices have returned to near-average in recent years. Northerly shifts in male snow crab centers of abundance in 2021-2022 have coincided with continued declines in mature male biomass, and may be a distributional response to recent warming in the Bering Sea.

Socioeconomic Indicators

All of the socioeconomic indicators associated with the snow crab target fishery included in this ESP exhibited substantial deviation from historical patterns during the most recent period for which data are available. During 2022, the number of active vessels in the fishery fell to 42, the lowest level since 1977, but, with the historically low TAC set for the 2021-2022 season and early evidence of sharply reduced market value, likely exceeding the number of vessels that could be financially sustained at similarly reduced production levels. Results from an industry skipper survey highlight concerns with perceived low abundance on the fishing grounds and changes in fishing behavior attributed to reductions in the 2021/2022 snow crab TAC. Historically low CPUE in 2022, and the continued spatial shift of fishing activity far to the north of historical fishing grounds, reflected adverse fishing conditions. A historically high ex-vessel price during 2021, combined with a relatively high TAC level, contributed to strong economic performance in the snow crab fishery during 2021. However, the ex-vessel revenue share indicator increased for 2021 to an unprecedented 85% share of the fleet's total gross landings revenue for the year, reflecting increased dependence on the snow crab fishery. The continued limited availability of alternative fishing targets for the fleet, combined with high operating costs associated with adverse fishery performance indicators noted above, without the mitigating (though limited) effect of high ex-vessel price observed for the previous year, is evidence of severe economic stress on the snow crab fleet and dependent stakeholders and communities during 2022.

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 production, physiological condition and responses to thermal stress.

Refinements or updates to existing indicators may also be warranted given the limited inference resulting from stage 2 modeling efforts. Spatial scales for physical and lower trophic level indicators may need to be refined to overlap with spatial distributions across ontogeny. The development of Essential Fish Habitat maps for snow crab by life history stage would provide spatial bounds to subset physical and lower trophic level datasets. Furthermore, replacing chlorophyll-*a* biomass estimates with size fractionation data might better clarify the role of diatoms in enhancing larval survival.

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. Lacking a conceptual framework for capturing linkages between social and economic drivers, fishing behavior, and condition of the crab stock, it is difficult to conceive how a narrow suite of socioeconomic indicators in the context of the ESP may meaningfully inform the snow crab stock assessment or harvest specification process, beyond providing important context. 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 1: List of data sources used in the ESP evaluation. Please see the main EBS snow crab SAFE document, the Ecosystem Considerations Report (Siddon, 2021) and the Economic Status Report (Garber-Yonts *et al.,* 2021) for more details.

Title	Description	Years	Extent
AFSC Bottom Trawl Survey	Bottom trawl survey of groundfish in June through August, eastern Bering Sea using Poly Nor'Eastern trawl on stratified random sample grid, catch per unit of effort in metric tons	1982 – present	Gulf of Alaska annual
REEM Diet Database	Food habits data and associated analyses collected by the Resource Ecology and Ecosystem Modeling (REEM) Program, AFSC on multiple platforms	1990 – present	Gulf of Alaska annual
MODIS	4 km Moderate Resolution Imaging Spectroradiometer (MODIS) ocean color data aggregated 8-day composites.	2003-present	Global
Copernicus Earth Observation Program	Time series of monthly sea ice extent for Arctic and Antarctic, produced from the ERA5 Reanalysis	1979-present	Arctic/Antarctic
NOAA National Climate Data Center	Monthly large-scale climate indices constructed by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service's Climate Prediction Center	1950-present	North Pacific annual
ADF&G Crab Observer program data	Snow crab catch and effort data (number of active vessels, total pots lifted, and CPUE), sourced from Alaska Department of Fish and Game (ADF&G) Annual Fishery Management Report	1980-2019	Alaska
ADF&G fish ticket database	Volume, value, and port of landing for Alaska crab and groundfish commercial landings; data processed and provided by Alaska Fisheries Information Network	1992-2019	Alaska
ABSC Skipper Survey	Fishery-dependent survey from Alaska Bering Sea Crabbers (ABSC) delivered to captains of the EBS snow crab fleet following the conclusion of the fishery for a given year	2000-2002	Bering Sea

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

Stage	Habitat & Distribution	Phenology	Age, Length, Growth	Energetics	Diet	Predators/Competitors
Egg	Clutch of embryos brooded under the female's abdomen until hatching	240 days at 6°C to 353 days at -1°C; cold temperatures trigger a 2-year reproductive cycle(1)	Egg diameter: 644.4-772.1 µm(2)	Optimal: 0°C – 3°C(3)	Yolk	Nemertean worms and amphipods feed on egg clutches
Larvae	Pelagic; concentrated in the upper 20m over the middle shelf(4)	April-June hatch	Mean carapace length: 1.25mm	Optimal: 6.9°C – 9.1°C(5)	Diatoms, small copepods	Jellyfish, juvenile pollock and Pacific salmon
Juvenile	Benthic; found in mud and gravel habitat in 1°C bottom temperatures (50-100m depth)	Peak settlement in October, later benthic stages molt annually in the spring	10-12 benthic instar stages until final molt to maturity(6)	Growth indices highest at 5°C(7)	Crustaceans, bivalves, polychaetes(8)	Pacific cod, flatfish, sculpins, crab(9)
Adult	Benthic: sand and mud bottoms (70-200m depth)	6-7+ years, migration to shallow waters in spring to mate	Average size range at terminal molt: females 47-59 mm CW, males 73-101mm CW(10)	Growth is optimum at 4°C(11)	Polychaetes, crustaceans, echinoderms, mollusks(12)	Pacific cod, halibut, skates(13)

Note: Subscripts in table correspond to the following citations in sequential order 1. Webb et al., 2006, 2. Moriyasu and Lanteigne, 1998, 3. Webb et al., 2007, 4. Armstrong et al., 1981, 5. Yamamoto et al., 2017, 6. Sainte-Marie et al., 1995, 7. Yamamoto et al., 2015, 8. Kolts et al., 2013, 9. Lang et al., 2003, 10. Murphy 2021, 11. Foyle et al., 1989, 12. Divine et al., 2017, 13. Livingston et al., 1993

Table 2b. Key processes affecting survival by life history stage for EBS snow crab.

Stage	Processes Affecting Survival	Relationship to EBS snow crab
Egg	1. Temperature	Temperature direct affects the duration of incubation(1)
Larvae	1. Synchrony with spring bloom 2. Offshore advection	Larval growth and survival is dependent on high concentrations of diatoms(2). Advection to areas overlying suitable bottom temperatures and substrate likely improves larval survival(3)
Juvenile	1. Cold pool and sea ice extent 2. Predation	Pacific cod predation is a major source of immature snow crab mortality and the cold pool provides predator refuge for juvenile snow crab(4)
Adult	1. Benthic production 2. Temperature	Food availability may drive patterns in growth, energetic condition and survival of snow crab. Shifts in the spatial extent of snow crab are driven by bottom temperatures and cold pool dynamics in the EBS(5)

Note: Subscripts in table correspond to the following citations in sequential order 1. Webb et al., 2007, 2. Paul et al., 1979, 3. Parada et al., 2010, 4. Livingston, 1989, 5. Fedewa et al., 2020

Table 3a: First stage ecosystem indicator analysis for EBS 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**	**2018 Status**	**2019 Status**	**2020 Status**	**2021 Status**	**2022 Status**
Physical	Winter Spring Arctic Oscillation Index- Model	neutral	neutral	**high**	neutral	neutral
	Summer Cold Pool- SEBS Survey	**low**	**low**	NA	**low**	neutral
	Winter Sea Ice Advance BS- Satellite	**low**	neutral	neutral	neutral	neutral
Lower Trophic	Chlorophyll-*a* Biomass SEBS- Satellite	neutral	neutral	*high*	neutral	*high*
	Summer Benthic Invertebrate Density- SEBS Survey	neutral	neutral	NA	neutral	NA
Upper Trophic	Summer Snow Crab Juvenile Temperature Occupancy	**high**	**high**	NA	**high**	neutral
	Summer Snow Crab Juvenile Disease Prevalence	neutral	neutral	NA	neutral	neutral
	Annual Snow Crab Male Size Maturity- Model	**low**	neutral	NA	**low**	neutral
	Summer Snow Crab Male Area Occupied- SEBS Survey	**low**	**low**	NA	neutral	neutral
	Summer Snow Crab Male Center Distribution- SEBS Survey	neutral	neutral	NA	*high*	*high*
	Summer Snow Crab Consumption Pacific Cod- Model	**high**	neutral	NA	neutral	NA

Table 3b: First stage socioeconomic indicator analysis for EBS 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.

Indicator category	**Indicator**	**2018 Status**	**2019 Status**	**2020 Status**	**2021 Status**	**2022 Status**
Fishery Performance	Annual Snow Crab Active Vessels EBS Fishery	neutral	neutral	neutral	neutral	low
	Annual Snow Crab CPUE Fishery	neutral	neutral	neutral	neutral	neutral
	Annual Snow Crab Potlift Fishery	neutral	neutral	neutral	neutral	neutral
	Annual Snow Crab Center Distribution EBS Fishery	neutral	high	neutral	high	high
	Annual Snow Crab Incidental Catch EBS Fishery	neutral	neutral	neutral	neutral	NA
Economic	Annual Snow Crab TAC Utilization EBS Fishery	neutral	neutral	neutral	neutral	neutral
	Annual Snow Crab Exvessel Value EBS Fishery	neutral	neutral	neutral	neutral	NA
	Annual Snow Crab Exvessel Price EBS Fishery	high	high	high	high	NA
	Annual Snow Crab Exvessel Revenue Share EBS Fishery	neutral	neutral	high	high	NA

Figures

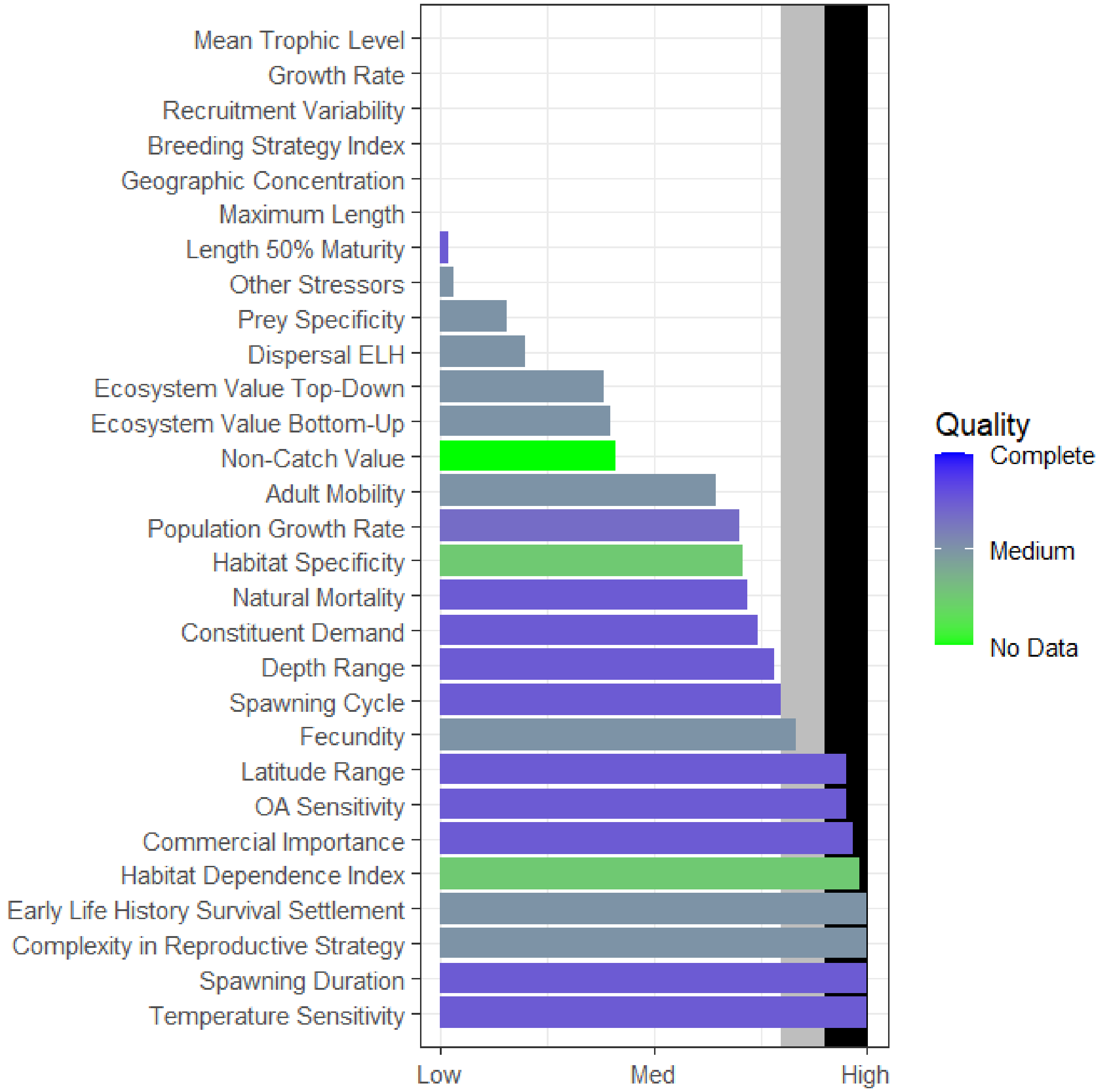

Figure 1: Baseline metrics for EBS snow crab graded as percentile rank over all groundfish and crab in the FMPs. Gray and black vertical bars indicate 80th and 90th percentile over all stocks. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions and thresholds).

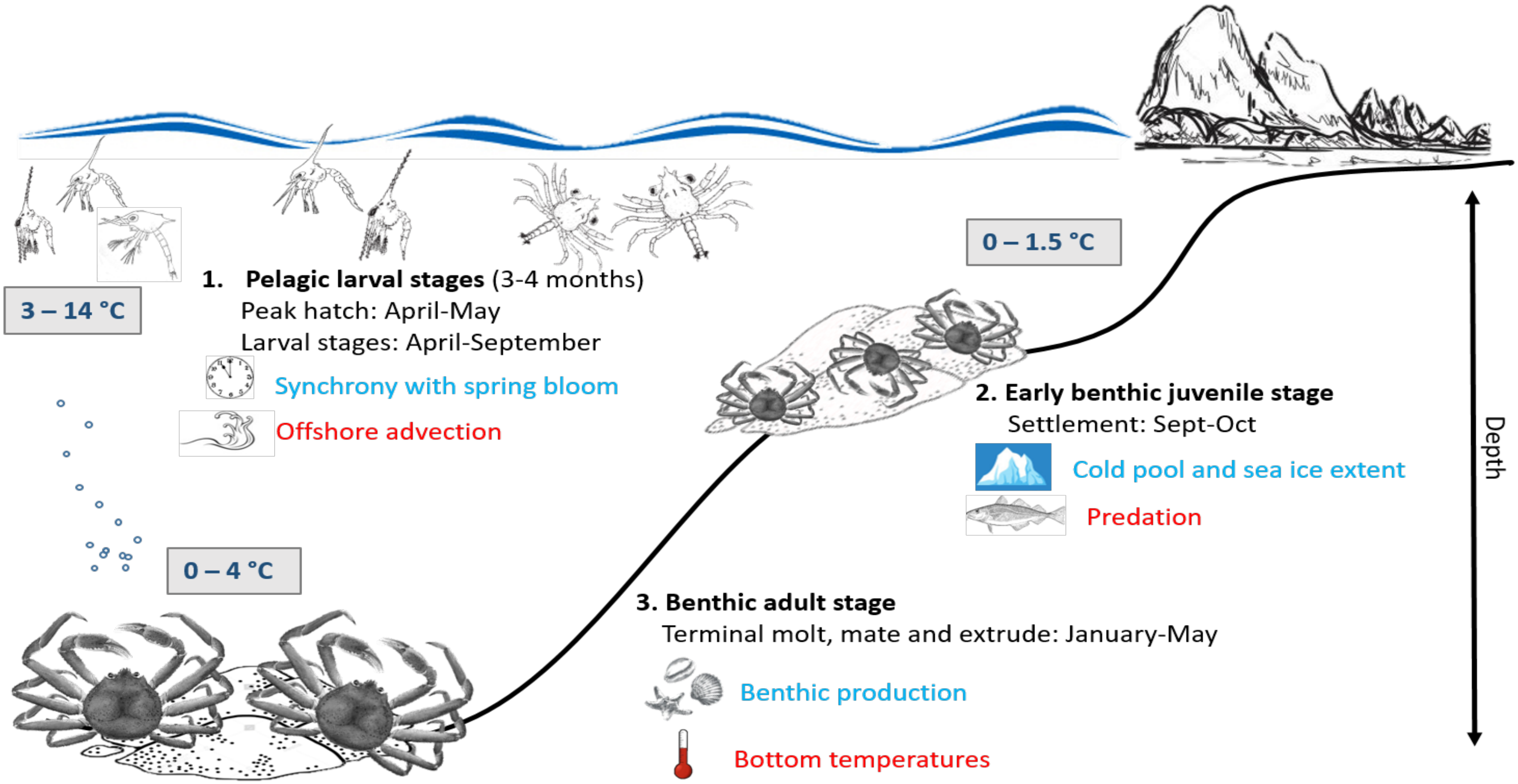

Figure 2. Life history conceptual model for EBS snow crab summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

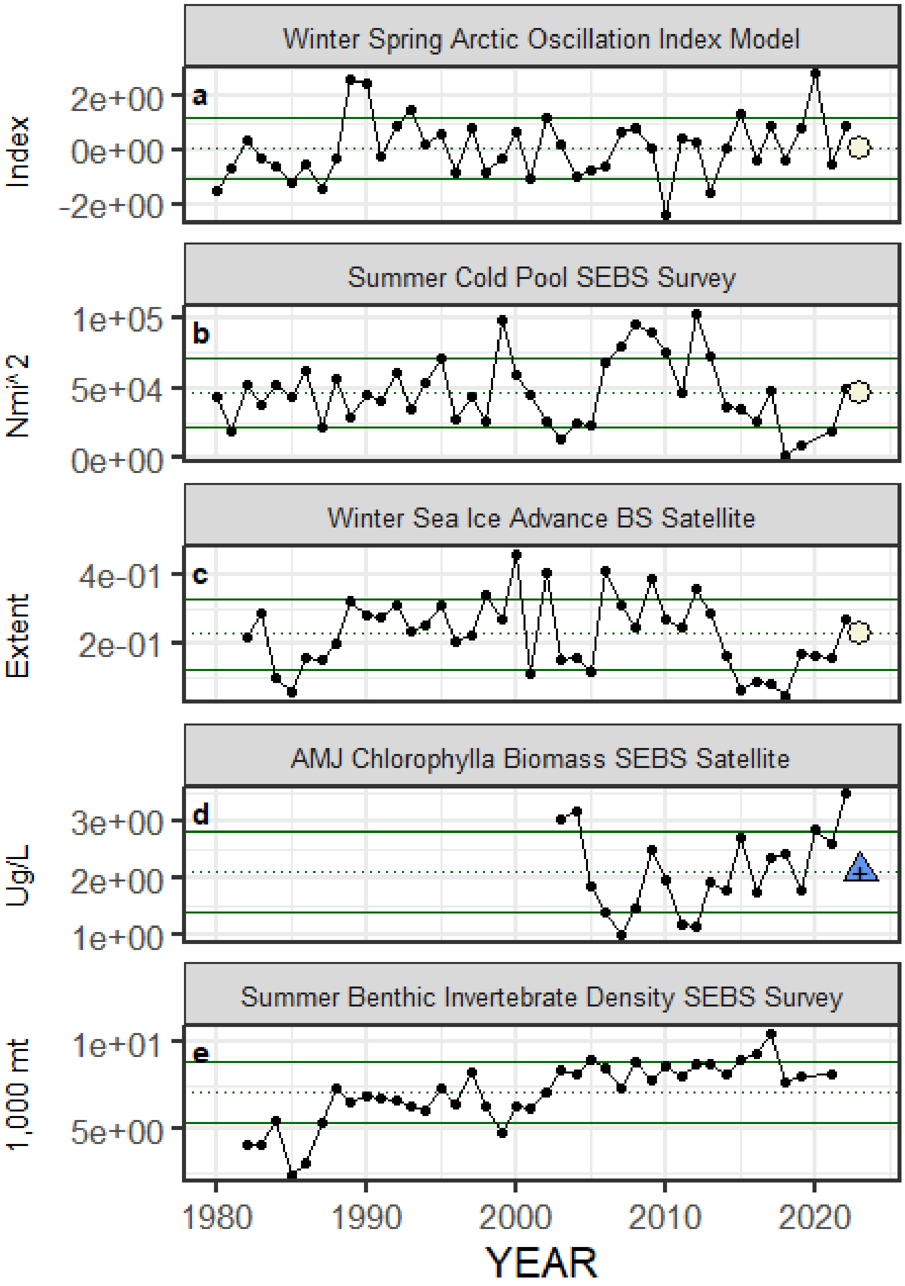

Figure 3a. Selected ecosystem indicators for EBS snow crab with time series ranging from1980 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

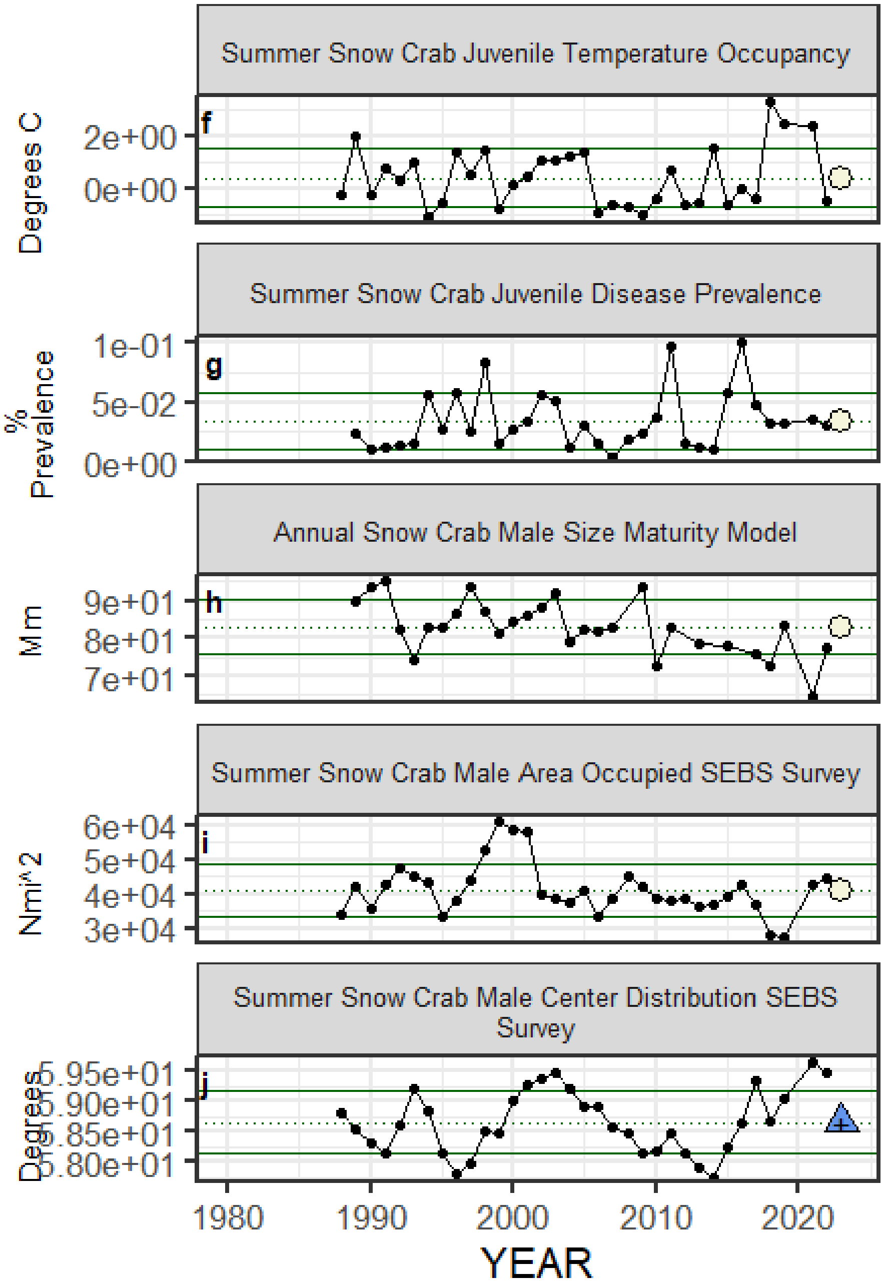

Figure 3a (cont.). Selected ecosystem indicators for EBS snow crab with time series ranging from1980 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

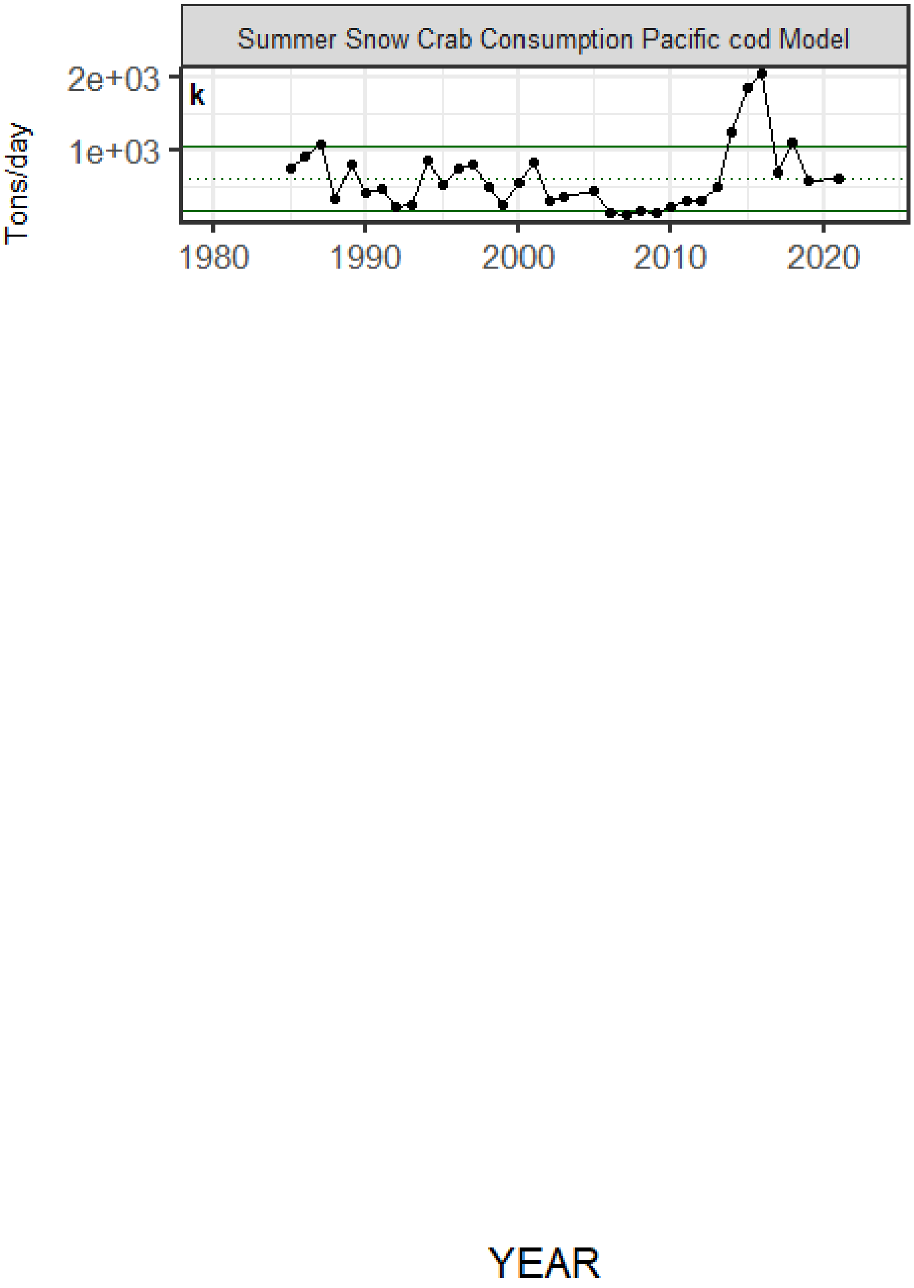

Figure 3a (cont.). Selected ecosystem indicators for EBS snow crab with time series ranging from1980 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

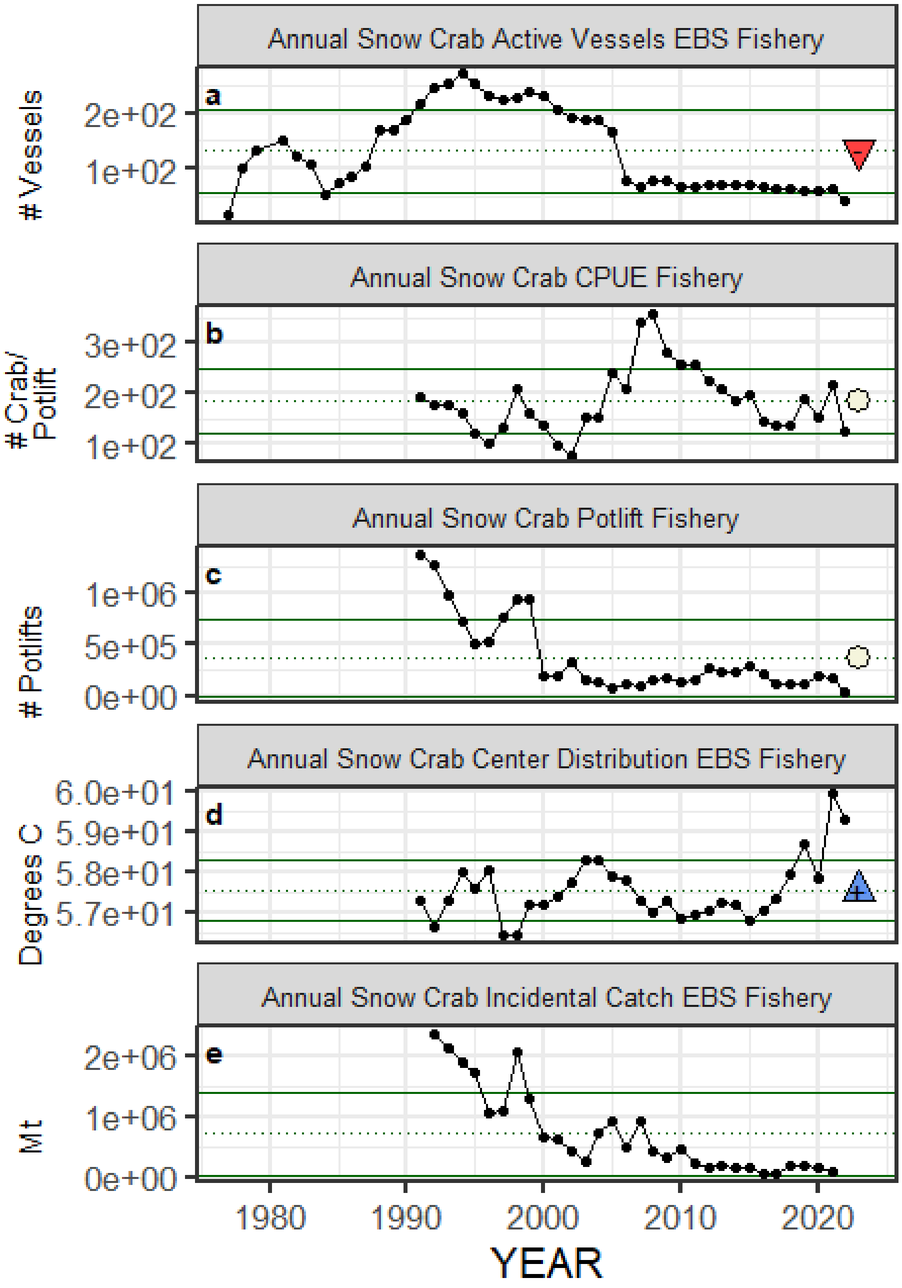

Figure 3b. Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation from the time series mean, color represents proposed relationship for stock, white circle for neutral).

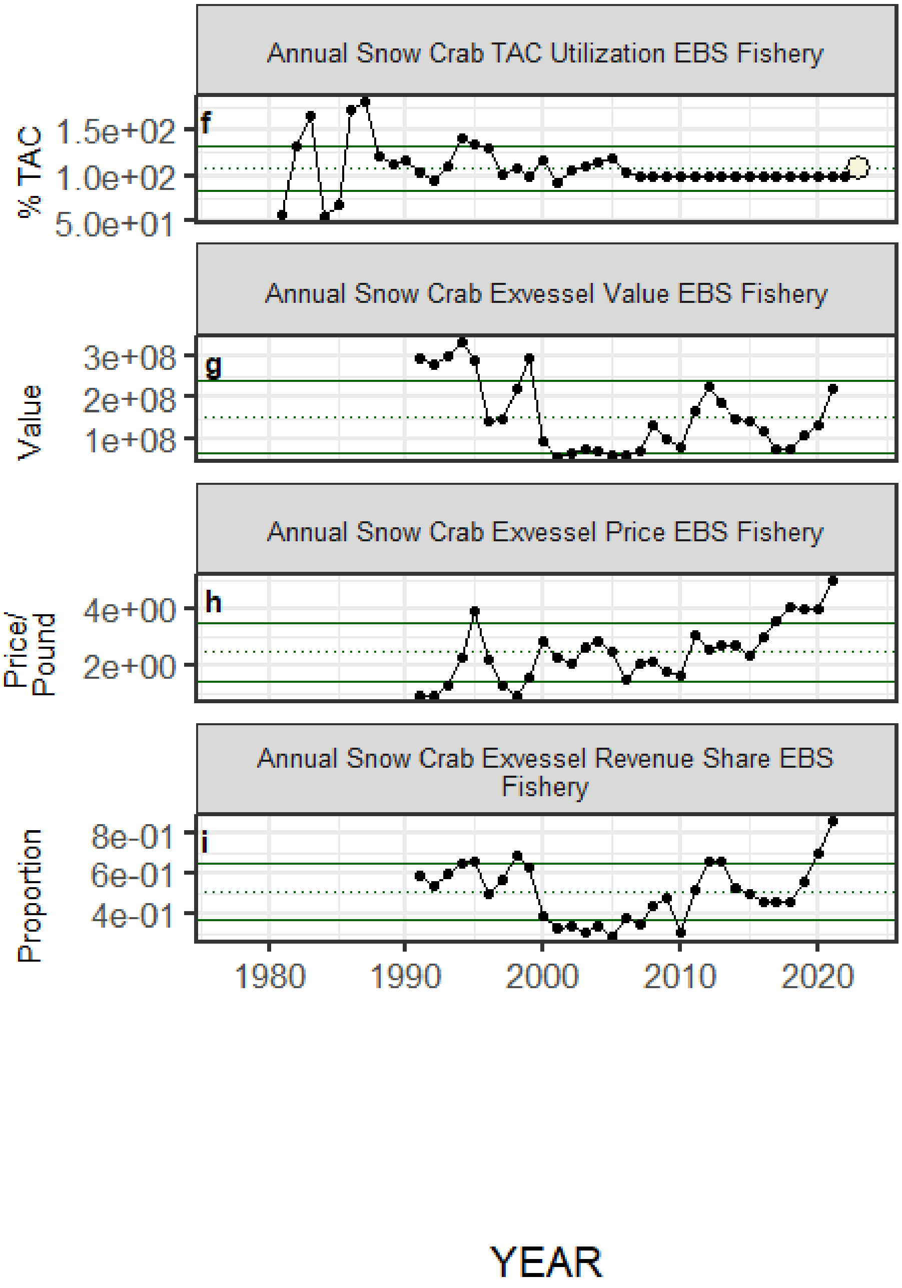

Figure 3 (cont.). Selected socioeconomic indicators for EBS snow crab with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation from the time series mean, color represents proposed relationship for stock, white circle for neutral).

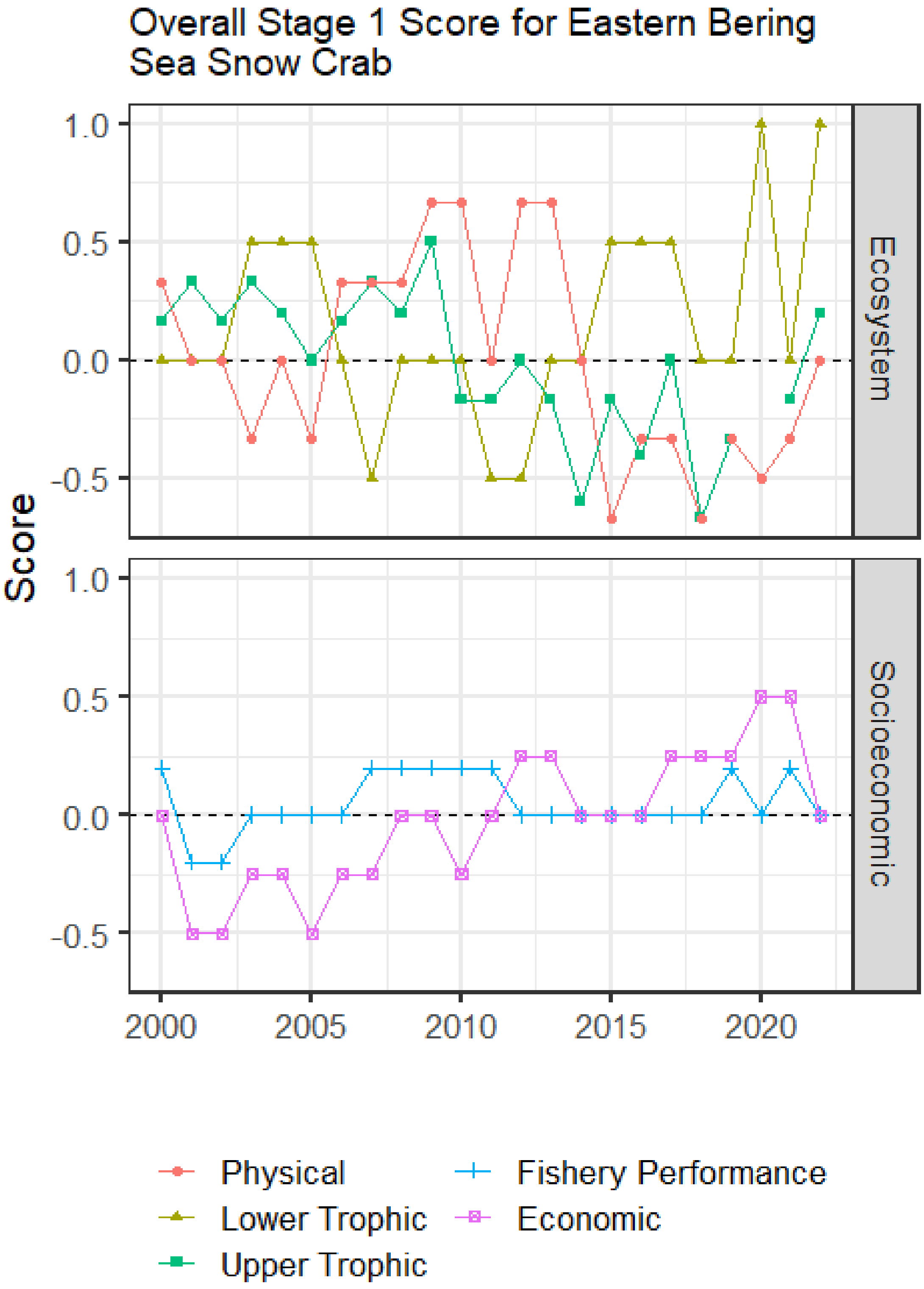

Figure 4. Simple score from beginning stage indicator analysis for ecosystem and socioeconomic categories from 2000 to present.

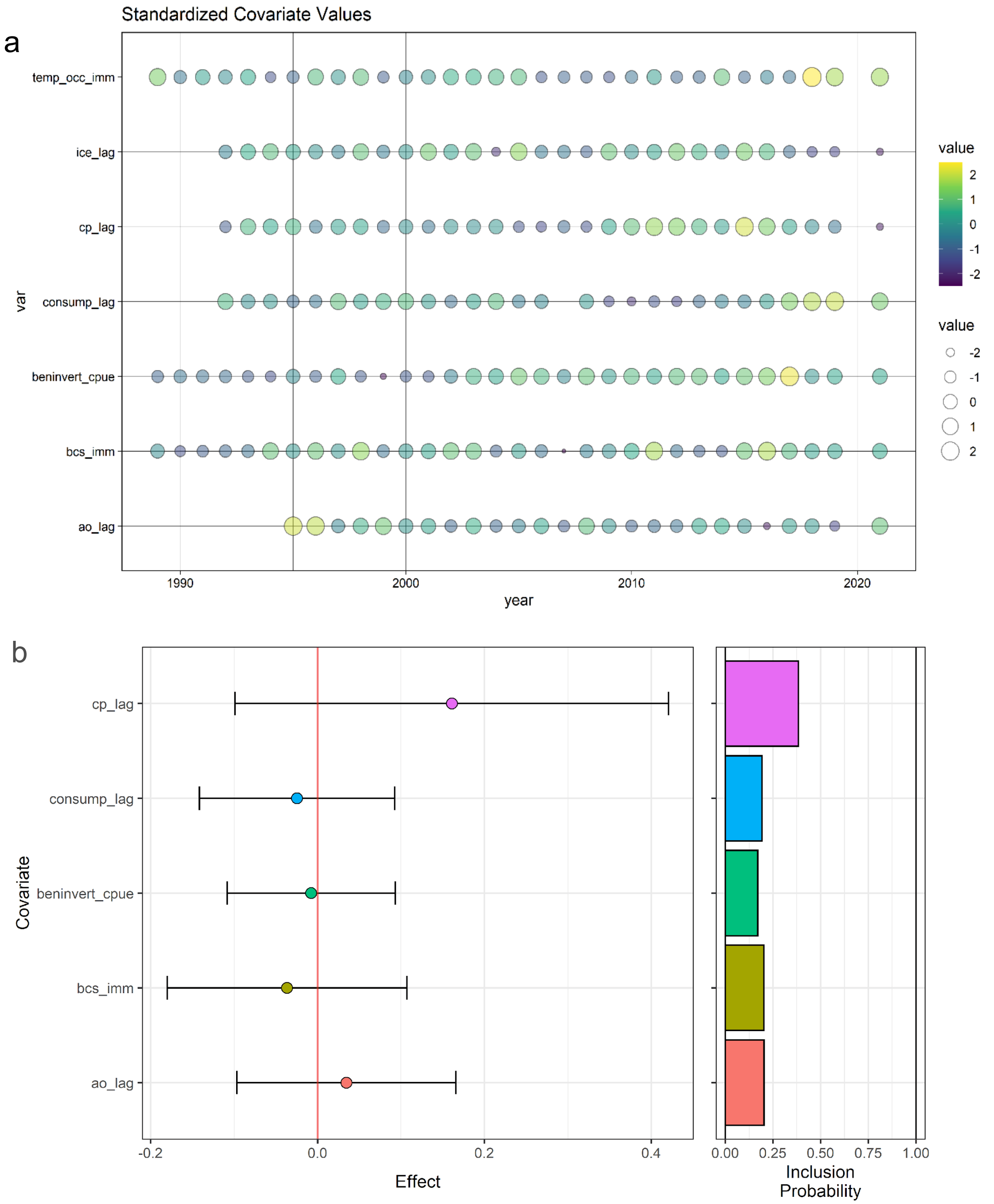

Figure 5. Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (95% confidence intervals) with log EBS male snow crab model estimated recruitment (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.