Appendix C. Ecosystem and Socioeconomic Profile of the Bristol Bay Red King Crab Stock - Report Card

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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., *Accepted*). 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 document (Fedewa et al., 2020, Appendix E, pp. 172-204) which is available within the Bristol Bay red king crab (BBRKC) 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 BBRKC:

- In 2023, bottom temperatures and the spatial extent of the cold pool remained near-average in Bristol Bay. Summer bottom temperatures were well-within the thermal range of juvenile and adult red king crab.
- Red king crab have experienced a steady decline in bottom water pH in the past two decades, reaching 7.91 in 2023. Continued declines to threshold pH levels of 7.8 could negatively affect juvenile red king crab growth, shell hardening and survival.
- Sockeye salmon abundance in the eastern Bering Sea continues to remain well above average, and may represent increased predation on larval BBRKC. Anomalously low levels of chlorophyll-a in 2023 indicate a less pronounced spring bloom and poor feeding conditions for larval BBRKC.
- Despite a high density of mature females at a single station on the 2023 bottom trawl survey, mature female spatial extent has remained above-average since 2019. The relatively large spatial footprint of mature females in recent years can be attributed to an increased use of habitats in central Bristol Bay that have historically been avoided in years when <1°C waters extended into Bristol Bay.
- The BBRKC fishery was closed to targeted fishing for the second consecutive season, representing severe economic hardships for industry.
- Incidental catch of BBRKC in EBS groundfish fisheries has remained near-average for the most recent 2018 – 2021 period.

Modeling Considerations

The following are the summary results from the intermediate and advanced stage monitoring analyses for BBRKC:

- The highest ranked predictor variables (> 0.50 inclusion probability) in the intermediate stage monitoring analysis were: Pacific cod biomass, cold pool extent and benthic invertebrate biomass. Due to concerns with non-stationarity in longer ecosystem time series, indicator importance tests in future BBRKC ESP updates will explore additional statistical methods.
- 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 BBRKC 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 RKC life history stage (Figure 1a) and 2) socioeconomic performance metrics (Figure 1b). Please refer to the last full ESP document (Fedewa et al., 2020) for more details.

Indicator Suite

The following list of indicators for BBRKC is organized by categories: three for ecosystem indicators (physical, lower trophic, and upper trophic) and two for socioeconomic indicators (fishery performance and economic). A title, short description and contact name for the indicator contributor are provided. We also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant, and specify the lag applied if the indicator was tested in the intermediate stage indicator analysis. Please refer to the last full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions and proposed mechanistic linkages for this stock (Fedewa et al., 2020). Time series of the ecosystem and socioeconomic indicators are provided in Figure 2a and Figure 2b, respectively. Modifications to ecosystem indicators in 2023 include: 1) Chlorophyll-*a* concentrations derived from MODIS have now been replaced with a European Space Agency (ESA) GlobColour blended satellite product because the satellites that hold the MODIS instruments will soon be retired due to changes in their orbits, 2) due to BBRKC fisheries closures, 2021 – 2022 estimates for BBRKC mean distance to shore were derived from October pop-up locations of acoustically tagged mature males, and 3) methods for spatially averaging pH were corrected slightly for 2023 hindcasts produced from the Bering10K ROMS model. These modifications will preclude direct comparison to indicator timeseries in previous ESP documents.

Ecosystem Indicators:

Physical Indicators (Figure 2a.a-e)

- a.) Winter-spring **Arctic Oscillation** index from the NOAA National Climate Data Center (contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged seven years for intermediate stage indicator analysis.
- b.) The **areal extent of the summer cold pool** (EBS bottom trawl survey stations with bottom temperatures < 2ºC; contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.
- c.) **Summer bottom temperatures** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged 6 years.
- d.) Spring (February – April 15) **pH index** in Bristol Bay from the Bering10K ROMS model (Pilcher et al., 2019) (contact: D. Pilcher). Proposed sign of the relationship is positive and the time series is lagged 6 years for intermediate stage indicator analysis.
- e.) **Summer wind stress** (m/s) in Bristol Bay from NOAA/NCDC blended winds and Metop-A ASCAT satellite (Zhang et al., 2006, NOAA/NESDIS, CoastWatch) (contact: D. Robinson). Proposed sign of the relationship is negative and the time series is lagged seven years for intermediate stage indicator analysis.

Lower Trophic Indicators (Figure 2a.f)

- f.) April – June average **chlorophyll-a concentration** in Bristol Bay, calculated with the ESA GlobColour blended satellite product (4km resolution, 8 day composite data) from MODIS satellites (contact: M. Callahan and J. Nielsen). Proposed sign of the relationship is positive and the time series is lagged seven years for intermediate stage indicator analysis.

Upper Trophic Indicators (Figure 2a.g-l)

g.) September **juvenile sockeye salmon abundance** in the EBS from the AFSC Bering Arctic Subarctic Integrated Survey (contact: E. Yasumiishi). Proposed sign of the relationship is negative and the time series is lagged seven years for intermediate stage indicator analysis.
h.) Summer **Pacific cod density** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is negative and the time series is lagged one year for intermediate stage indicator analysis.
i.) Summer **benthic invertebrate density** in Bristol Bay. Invertebrates include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes. (contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged one year for intermediate stage indicator analysis.
j.) Summer **mature male red king crab area occupied** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is negative.
k.) Summer **mature female red king crab area occupied** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is negative.
l.) Annual **male red king crab catch distance from shore** in Bristol Bay during the fishery (contact: L. Zacher). Proposed sign of the relationship is positive.

Socioeconomic Indicators: (all monetary values are inflation-adjusted to $2022 value)

Fishery Performance Indicators (Figure 2b. a-d)

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

Economic Indicators (Figure 2b. e-h)

e.) Percentage of the annual BBRKC **total allowable catch** (TAC) (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing (contact: B. Garber-Yonts)
f.) Annual **ex-vessel value** ($2022) of the BBRKC fishery landings, representing gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)
g.) Annual **ex-vessel price per pound** ($2021) of BBRKC landings, representing per-unit gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)
h.) Annual **ex-vessel revenue share**, expressed as average proportion of total annual gross landings revenue from all fisheries earned from BBRKC landings by vessels active in the fishery (contact: J. Lee)

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, 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.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light 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 ecosystem indicators and the stock (generally shown in Figure 1a and specifically by indicator in the Indicator Suite, Ecosystem Indicators section) is also assigned to the indicator where possible. 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 and economic performance) indicators 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 or text code for the relationship with the stock (Tables 1a,b) and evaluate each year's status in the historical indicator time series graphic (Figures 2a,b) for each ecosystem and socioeconomic indicator. Socioeconomic indicators representing the target fishery are reported by fishery year through 2020, the last year that the fishery was open (noting that virtually all active harvest activity occurs prior to January). Incidental catch is reported for the most recent full calendar year (2021, in this case).

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the BBRKC 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 report card. Overall, the physical and lower trophic indicators scored below average for 2023, while the upper trophic indicators were average (Figure 3). Compared to 2022 traffic light scores, recent year results are the same for previous-year physical and lower trophic indicators, and an increase for the upper trophic indicators. The fishery performance and economic indicators were not updated for the most recent fishery year (2022) due to the closure of the fishery.

Overall, trends in physical ecosystem indicators suggest a return to near-normal conditions in Bristol Bay, and very similar conditions to those reported in 2022. Average bottom temperatures in 2023 were nearly 2°C colder than 2018-2019 heat conditions, and cold pool spatial extent in Bristol Bay was near-average. Furthermore, a positive phase Arctic Oscillation index in winter 2022/2023 may suggest favorable conditions for BBRKC productivity (Szuwalski et al., 2021), although continued declines in pH that are approaching a critical threshold for negative effects on growth, shell hardening and survival remain concerning (Long et al., 2013; Swiney et al., 2017). Although 2023 updates for juvenile sockeye salmon abundance were not yet available for this document, recent years have seen the largest Bristol Bay sockeye runs on record and may be indicative of increased predation on larval RKC. Near-average wind stress in Bristol Bay suggests suitable conditions for larval first-feeding success, however, chlorophyll-a concentrations during the 2023 spring bloom were the lowest on record in Bristol Bay. Sea ice extent in March suggests that while the bloom timing was near-average (J. Nielsen, personal communication), low chlorophyll-a concentrations indicate less diatoms in the water column, which are a critical prey source for larval RKC (Paul et al., 1989).

Current-year values for upper trophic level Pacific cod and benthic invertebrate indicators are not yet available following the conclusion of the 2023 EBS bottom trawl survey. However, both indicators are on an upward trend following below-average estimates for both indicators in 2018. Spatial extent of mature male BBRKC remains above-average, and tagging data suggests that males have remained in central to northern stations in Bristol Bay in the past few years relative to cold years when they tend to aggregate closer to shore along the Alaska Peninsula (Zacher et al., 2018). Likewise, spatial extent of mature female BBRKC remained above-average in 2023 despite below-average abundances and nearly 40% of the mature female catch occurring at a single station on the EBS bottom trawl survey (Zacher et al. *in review*). Overall, the general northeastern shift in the BBRKC population coinciding with relatively large spatial distributions in the past 5 years can likely be attributed to the lack of cold waters <1°C within central Bristol Bay (Loher and Armstrong, 2005).

Pre-2021 trends in fishery performance and economic indicators correspond to an ongoing decline in TACs issued in the BBRKC fishery since 2014. Effort in the fishery, as indicated by the number of active vessels and total number of potlifts, continued the slow downward trend observed since 2010. Total potlifts reached the lowest point on record during the 2020-2021 fishing season, while CPUE increased somewhat relative to the previous three seasons, but remained at a relative low compared to the post-rationalization period overall. Ex-vessel price declined slightly for the 2020-2021 season, but remained relatively high compared to the post-rationalization period overall. Consistent with substantial declines in TACs since 2016-2017, gross ex-vessel revenue aggregated over all landings, and the percentage share of total annual landings revenue represented by BBRKC landings for those vessels active in the fishery during 2020-2021 continued the sharp declining trend observed over the recent period, with both reaching historical lows and aggregate revenue reaching the lowest level on record. Due to fishery closures in 2021 and 2022, social and economic indicator information is extremely limited for most recent years. However, we note that these missing data should, instead, emphasize the economic hardships being faced by the BBRKC crab harvesters and processors during these closure periods.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and BBRKC recruitment (survey abundance of immature male BBRKC, 95 – 120mm), and to assess the strength of support for each hypothesis. In this intermediate stage analysis, the full set of indicators is first winnowed to the predictors that have been identified as potential drivers of BBRKC recruitment, and highly correlated covariates are removed. While we generally aim to further restrict potential covariates to those that can provide the longest model run and incorporate the most recent estimate of recruitment, BBRKC Bayesian adaptive sampling model runs incorporating the longest time series (1988 – 2023) resulted in very poor fits to observed BBRKC recruitment (Fig. 4d) and are therefore limited in utility for fishery managers. Poor model performance may be due to highly variable recruitment in the late 1980's to 1990's, and a more recent shift in environmental conditions consistent with non-stationarity in climate drivers. Thus, we instead present BAS model results from the shorter time series (2005 – 2023), and will continue to explore additional statistical techniques that are more robust to non-stationarity.

We provide the mean relationship between each predictor variable and BBRKC recruitment over time for the final model (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). A higher probability indicates that the variable is a better candidate predictor of BBRKC recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process are 1) Pacific cod biomass, 2) cold pool spatial extent, and 3) benthic invertebrate biomass. The direction of these effects were consistent with hypothesized directional relationships identified in peer-reviewed literature. Past studies have noted statistically significant correlations between Pacific cod biomass and red king crab recruitment (Zheng and Kruse, 2006; Bechtol and Kruse, 2010; Szuwalski et al., 2021). The direct mechanism for a relationship between the cold pool extent and BBRKC recruitment in this analysis remains unclear, and to our knowledge, no studies to date have linked BBRKC recruitment to benthic prey biomass.

Advanced Stage: Research Model Test

At this time, we do not have any ecosystem research models to report for BBRKC.

Data Gaps and Future Research Priorities

Environmental conditions are rapidly changing in the eastern Bering Sea and continued research is needed to identify thermal thresholds and BBRKC responses to multiple stressors across life stages. Low stock recruitment in the past decade warrants building a better understanding of early life history processes to identify critical bottlenecks that will support the development of meaningful larval indicators. Future laboratory and field research should, for example, better resolve the range of optimal environmental conditions for embryo survival and successful settlement in juvenile nursery areas. Evaluating RKC phenology relative to spring bloom timing may be useful for predicting larval condition and subsequent survival to settlement. Additionally, evaluating larval drift patterns and identifying essential fish habitat for benthic juvenile RKC may support the development of a larval retention or settlement success indicator.

Likewise, the dramatic increase in Bristol Bay sockeye salmon coinciding with declines in BBRKC recruitment in recent years emphasizes the importance of understanding predator-prey interactions and spatiotemporal overlap of major pelagic predators with BBRKC larval stages. Juvenile salmon diet studies conducted from 1984-1992 (Farley 2001, unpublished data) reported that juvenile sockeye salmon consumption of red king crab zoea exceeded 45% in several years, suggesting potential links between salmon predation and BBRKC recruitment. In more recent years, the Bering-Aleutian Salmon International Survey has taken place in late-September following peak settlement of BBRKC, and there appears to be no ongoing efforts to characterize diets of juvenile sockeye salmon in earlier summer months when BBRKC are likely important prey items. Furthermore, because the survey is biennial and occurs in September, data gaps across the time series preclude use of the indicator in monitoring analyses, and indicator updates are unavailable for the current-year ESP. Future efforts should focus on exploring additional larval predator datasets that are more timely and consistent. In addition, additional groundfish stomach data outside of the summer survey time series would inform predation mortality during the molt when RKC are highly vulnerable.

Potential climate-driven shifts in BBRKC spatial distributions also underscore the importance of assessing fishery interactions with trawl and pot gear relative to BBRKC migration patterns, molt-mate timing and spawning habitat. Fishing effects, habitat disturbance metrics and essential fish habitat (EFH) maps are currently estimated by crab species across the scale of the Bering Sea shelf instead of by individual crab stock, which greatly limits their utility. Future efforts should aim to develop spatial maps identifying fishery interaction hotspots for BBRKC by month and across years, and to develop stock and life history-specific vulnerability assessments of fishing effects. Overall, we highlight the continued importance of developing a mechanistic understanding of driver-response relationships to facilitate the inclusion of ecosystem indicators in future management strategies for BBRKC.

We plan to further evaluate the information provided in the Economic SAFE and ACEPO report to determine what socioeconomic indicators could be provided in the ESP that are not redundant with those reports and related directly to stock health. Additional consideration of the timing of the economic and community reports, which are delayed by 1-2 years (depending on the data source) from the annual stock assessment cycle, should also be undertaken. We emphasize the importance of developing community indicators that effectively communicate the economic hardships currently being faced by industry under multiple Bering Sea crab fishery closures. The Scientific and Statistical Committee (SSC) recently recommended that local knowledge, traditional knowledge, and subsistence information may be helpful for understanding recent fluctuations in stock health, shifts in stock distributions, or changes in fishing behavior. Although a skipper survey was piloted in the 2022 snow crab ESP report card (Fedewa et al. 2022), recent fishery closures have prevented the uptake of this local knowledge into 2023 ESP products.

As indicators are improved or updated, they may replace those in the current suite of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. Additional indicators proposed for the 2024 BBRKC ESP include: 1) BBRKC mature female clutch fullness, as a measure of fecundity or reproductive potential, 2) the ratio of red king crab caught in the BBRKC management district and the Northern district, as a measure for spatial distribution shifts northward outside of management boundaries, and 3) indicators that quantify overlap between crab and fishing gear during vulnerable life history periods, and metrics of vulnerable to these fishing gear interactions. The annual request for information (RFI) for the BBRKC ESP will include these data gaps and research priorities along with a list of additional new indicators that could be developed for the next full ESP assessment.

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Tables

Table 1a. First stage ecosystem indicator analysis for BBRKC, 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	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
Physical	Winter Spring Arctic Oscillation Index Model	neutral	*high*	neutral	neutral	neutral
	Summer Cold Pool SEBS BBRKC Survey	**low**	NA	**low**	neutral	neutral
	Summer Temperature Bottom BBRKC Survey	*high*	NA	neutral	neutral	neutral
	Spring pH BBRKC Model	**low**	**low**	**low**	**low**	**low**
	Summer Wind Stress BBRKC Satellite	**high**	neutral	**high**	neutral	neutral
Lower Trophic	Spring Chlorophylla Biomass SEBS Inner Shelf Satellite	neutral	neutral	neutral	**low**	**low**
Upper Trophic	Summer Sockeye Salmon Abundance EBS Survey	NA	NA	NA	**high**	NA
	Summer Pacific Cod Density BBRKC Survey	*low*	NA	neutral	neutral	NA
	Summer Benthic Invertebrate Density BBRKC Survey	neutral	NA	neutral	neutral	NA
	Summer Red King Crab Male Area Occupied BBRKC Model	**high**	NA	neutral	**high**	neutral
	Summer Red King Crab Female Area Occupied BBRKC Model	**high**	NA	**high**	neutral	neutral
	Annual Red King Crab Catch Distance Shore BBRKC Fishery	*high*	neutral	neutral	neutral	NA

Table 1b. First stage socioeconomic indicator analysis for BBRKC, 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 Red King Crab CPUE BBRKC Fishery	neutral	neutral	neutral	NA	NA
	Annual Red King Crab Total Potlift BBRKC Fishery	neutral	neutral	low	NA	NA
	Annual Red King Crab Active Vessels BBRKC Fishery	neutral	neutral	neutral	NA	NA
	Annual Red King Crab Incidental Catch EBS Fishery	neutral	neutral	neutral	neutral	NA
Economic	Annual Red King Crab TAC Utilization BBRKC Fishery	neutral	neutral	neutral	NA	NA
	Annual Red King Crab Exvessel Value BBRKC Fishery	low	low	low	NA	NA
	Annual Red King Crab Exvessel Price BBRKC Fishery	high	high	high	NA	NA
	Annual Red King Crab Exvessel Revenue Share BBRKC Fishery	neutral	neutral	neutral	NA	NA

Figures

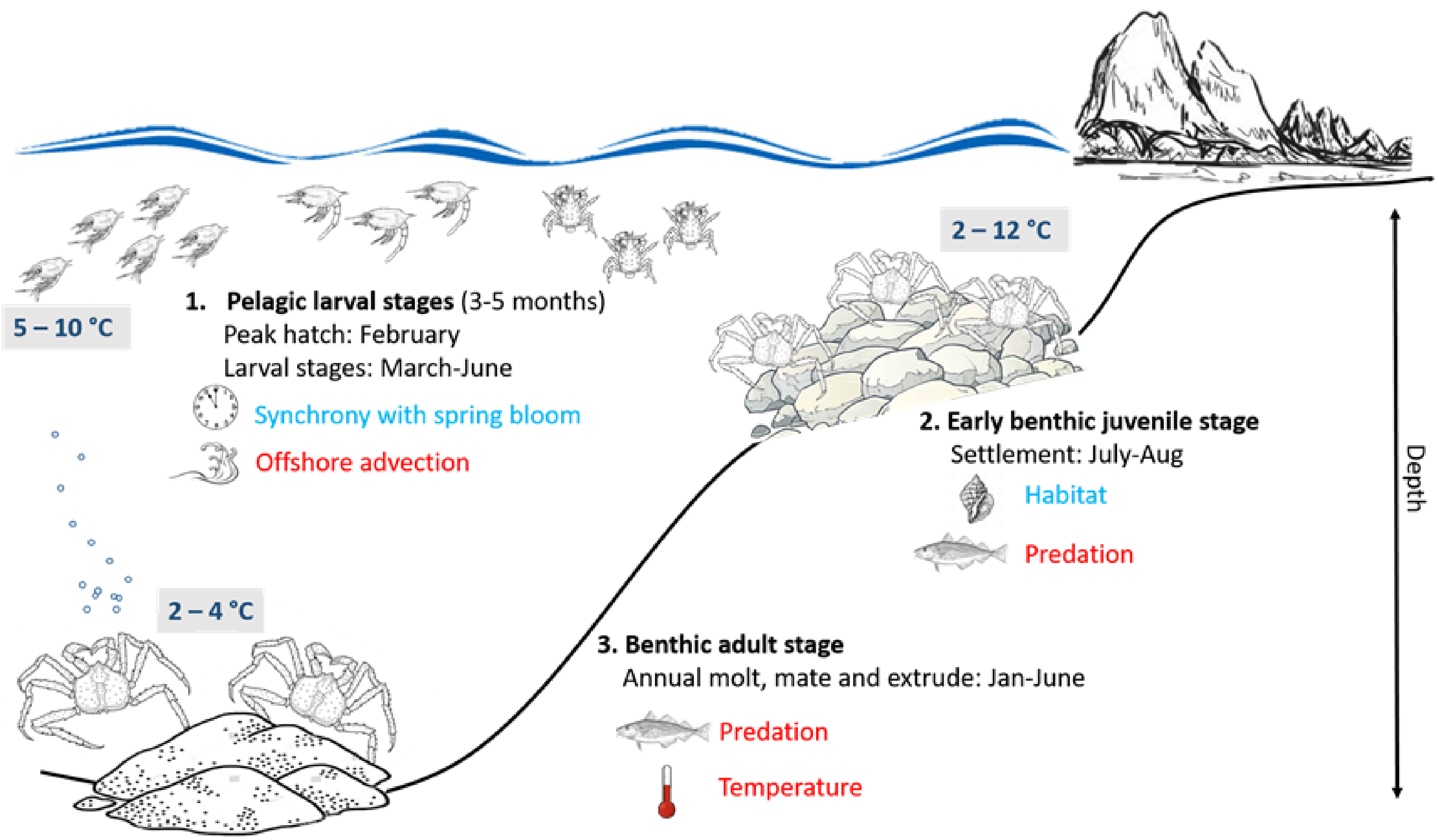

Figure 1a: Life history conceptual model for BBRKC summarizing ecological information and key ecosystem processes affecting survival by life history stage. Thermal requirements by life history stage were determined from RKC laboratory studies. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

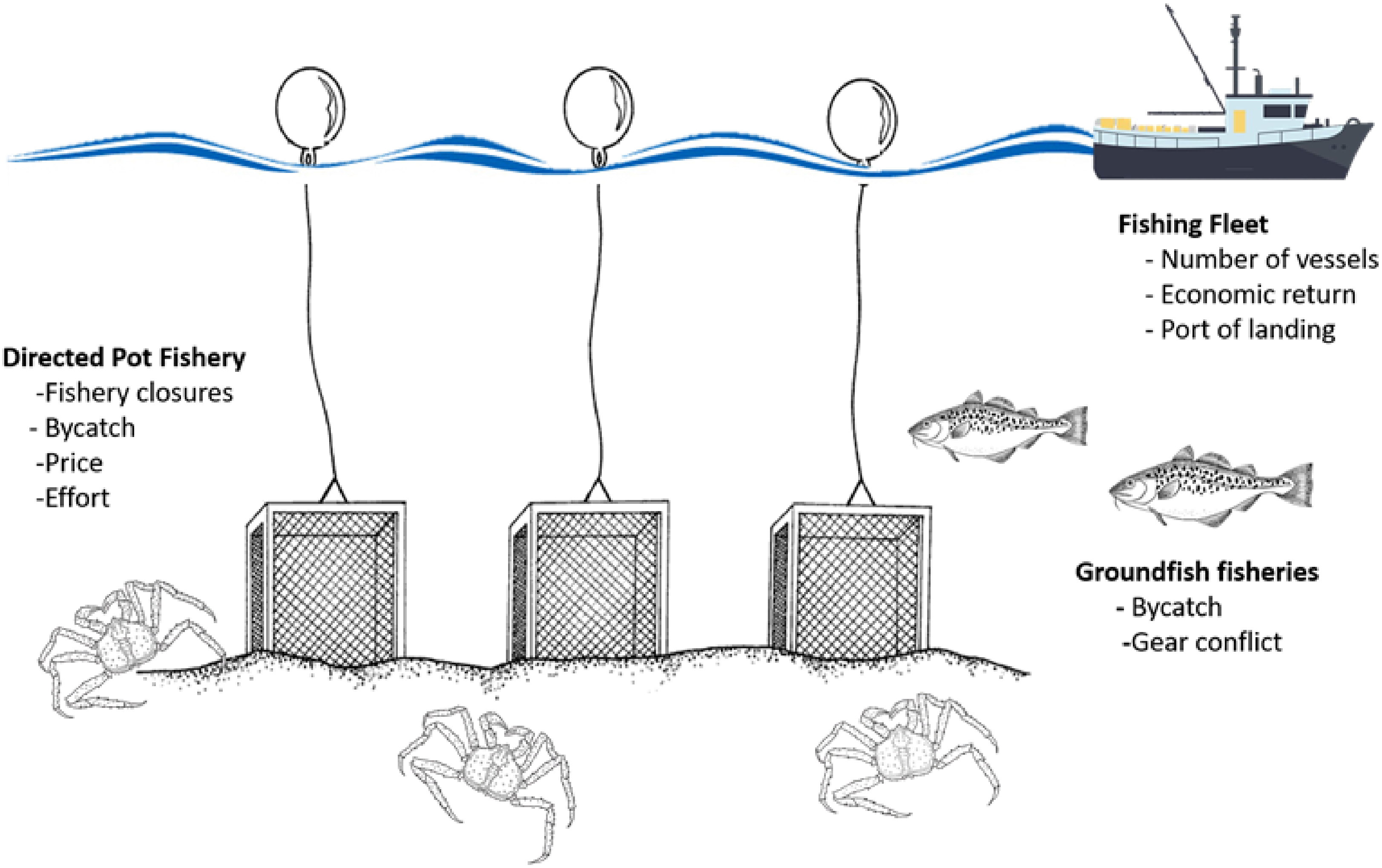

Figure 1b: Conceptual model of socioeconomic performance metrics for BBRKC that may identify dominant pressures on the Bristol Bay red king crab stock.

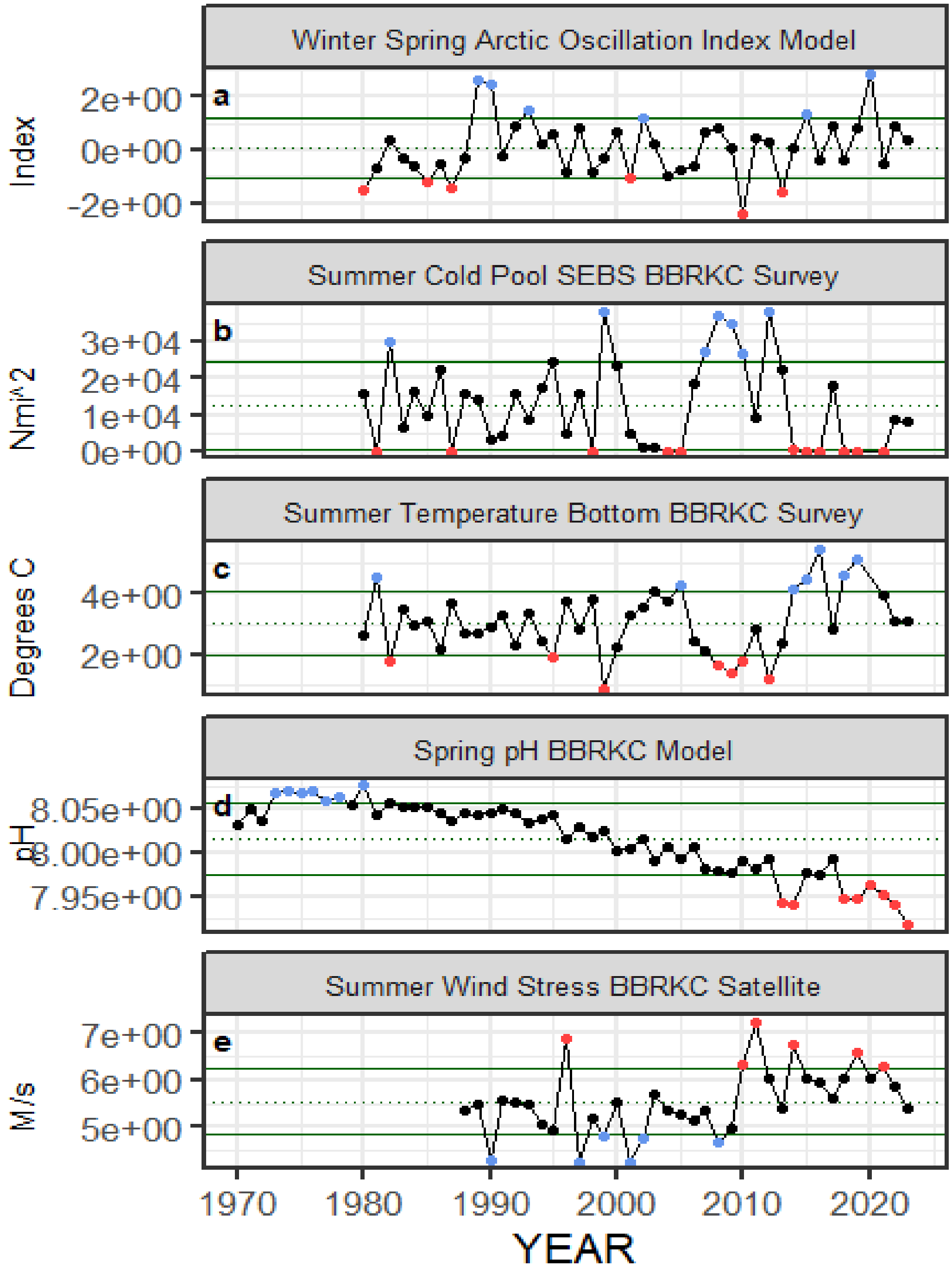

Figure 2a. Selected ecosystem indicators for BBRKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock, black circle for neutral.

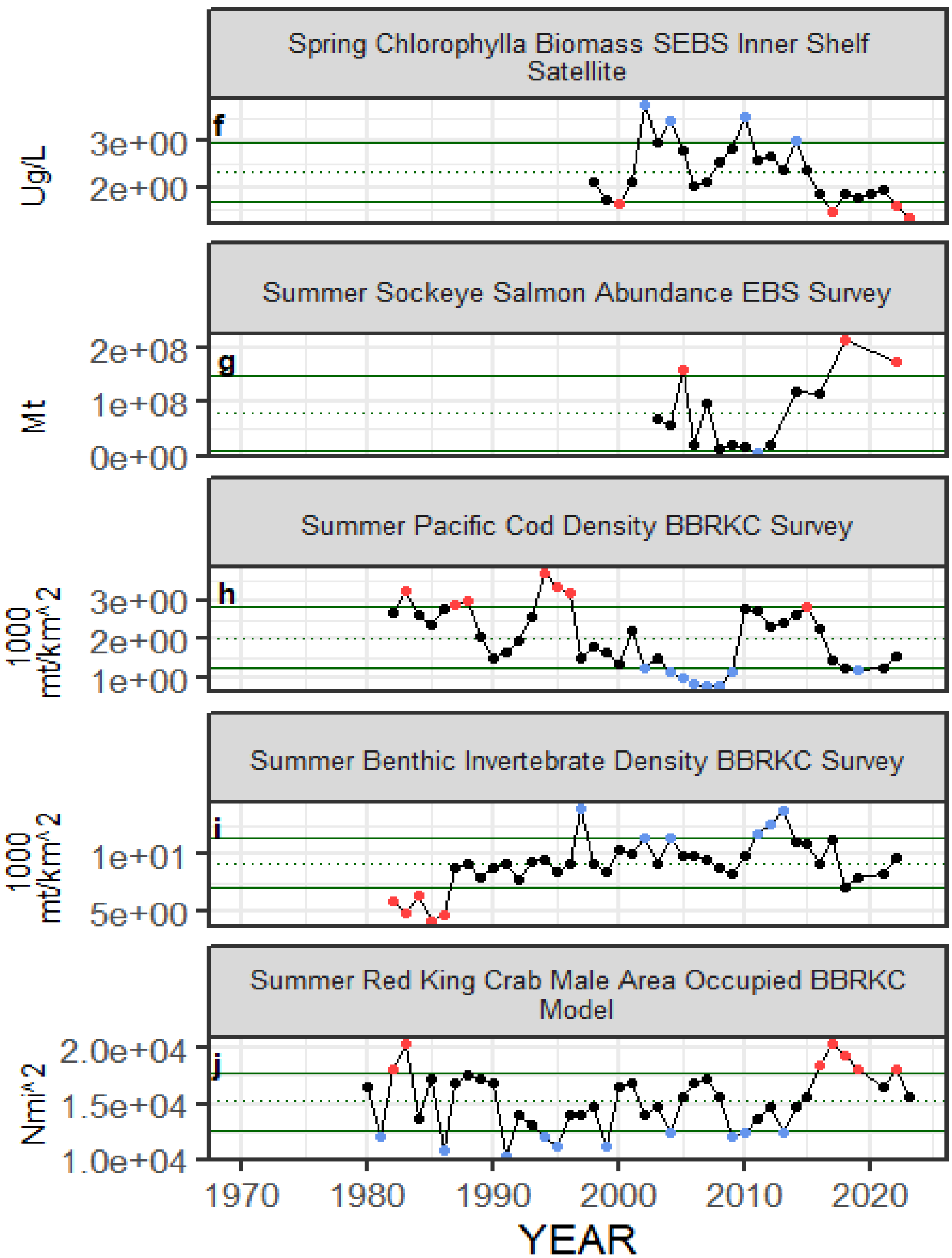

Figure 2a (cont.). Selected ecosystem indicators for BBRKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock, black circle for neutral.

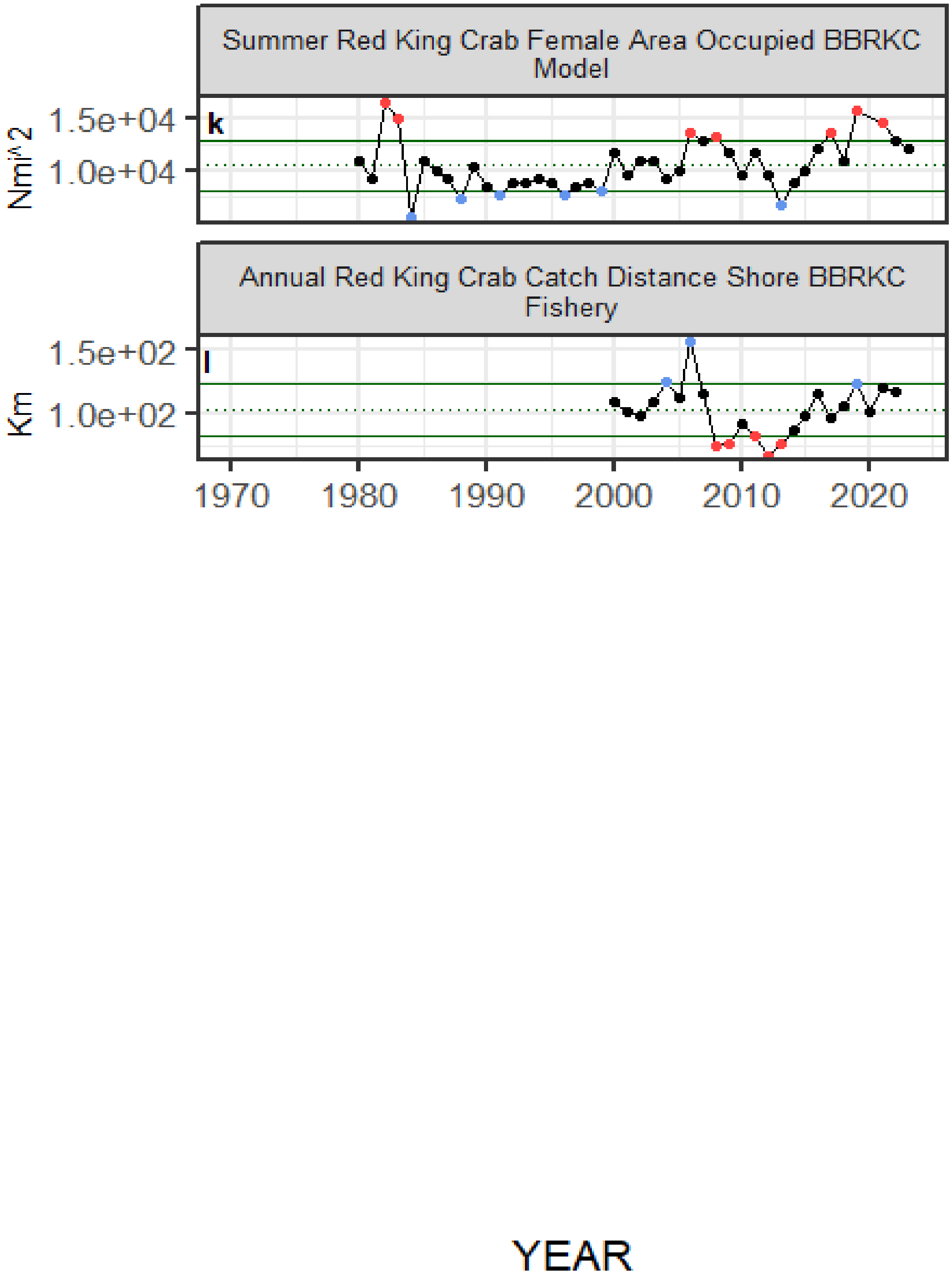

Figure 2a (cont.). Selected ecosystem indicators for BBRKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock, black circle for neutral.

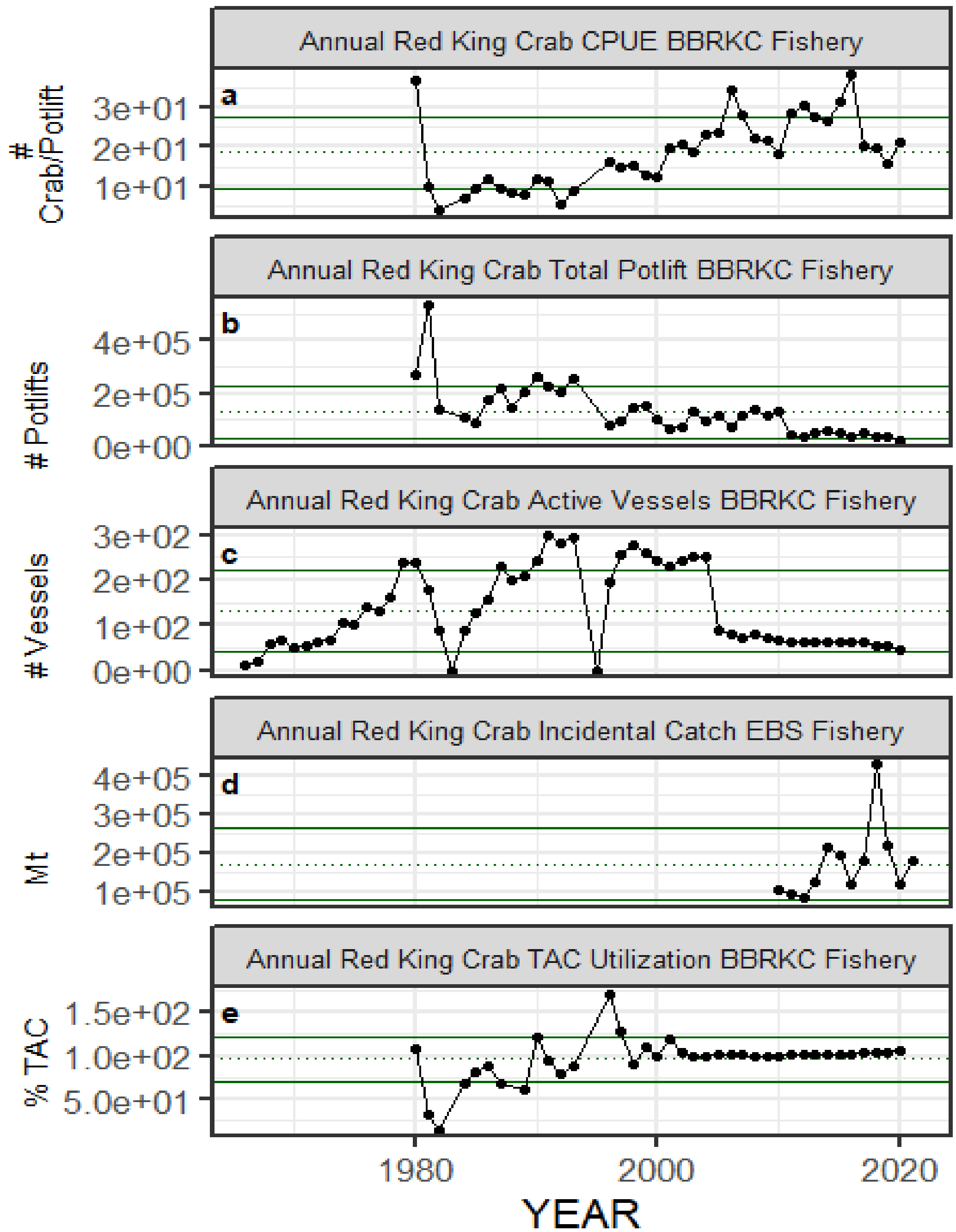

Figure 2b. Selected socioeconomic indicators for BBRKC with time series ranging from 1966 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

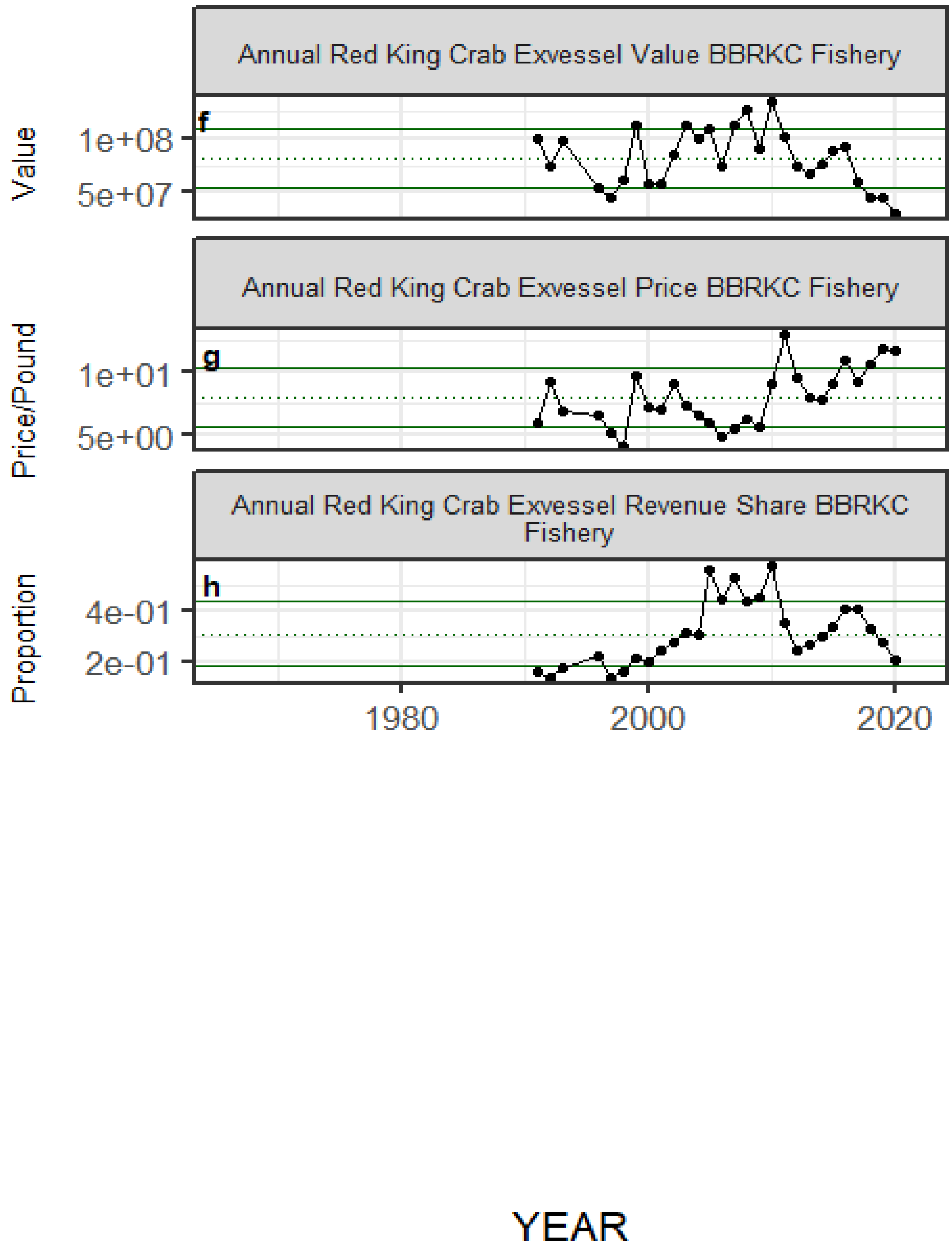

Figure 2b (cont.). Selected socioeconomic indicators for BBRKC with time series ranging from 1966 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

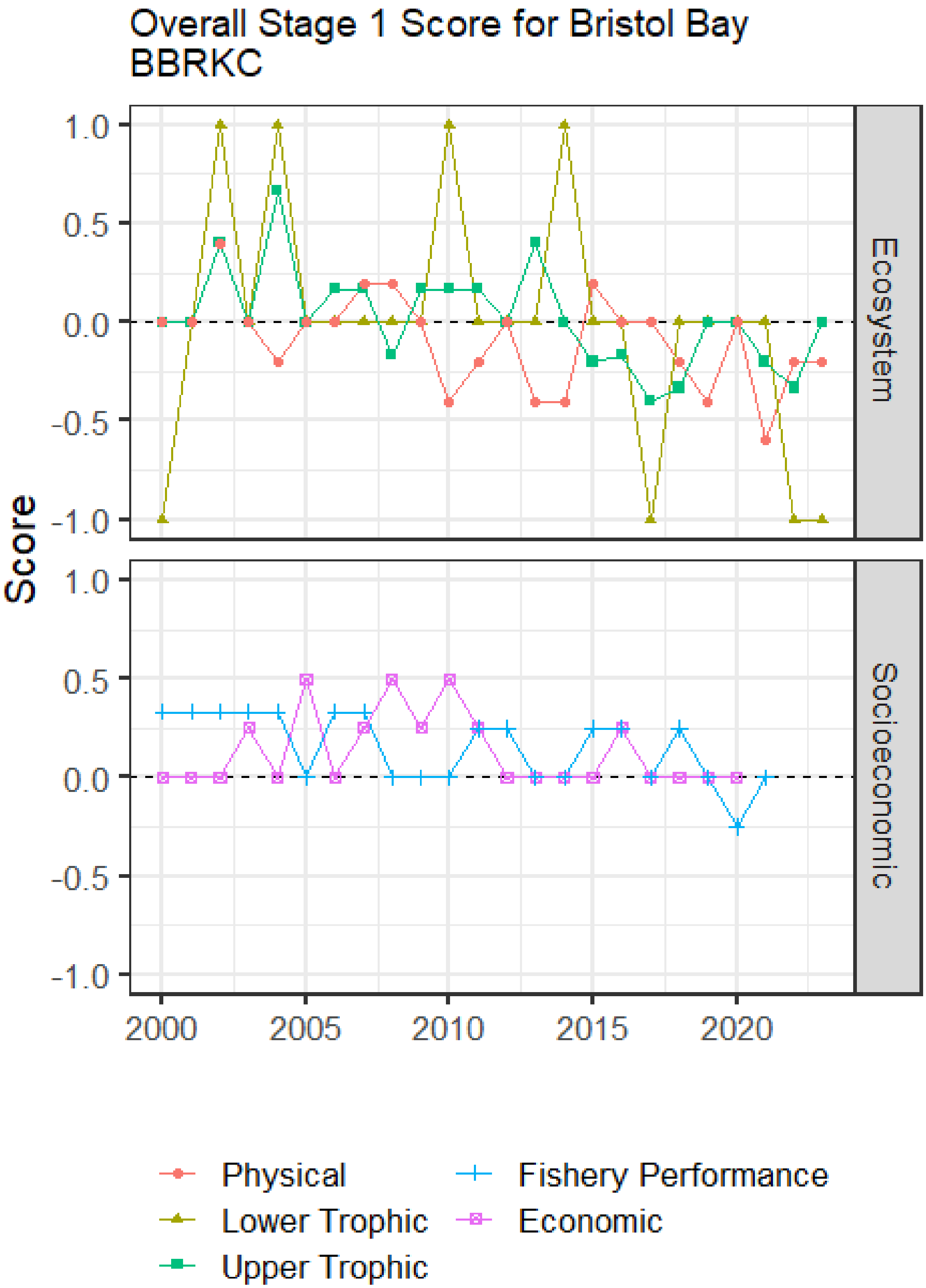

Figure 3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.

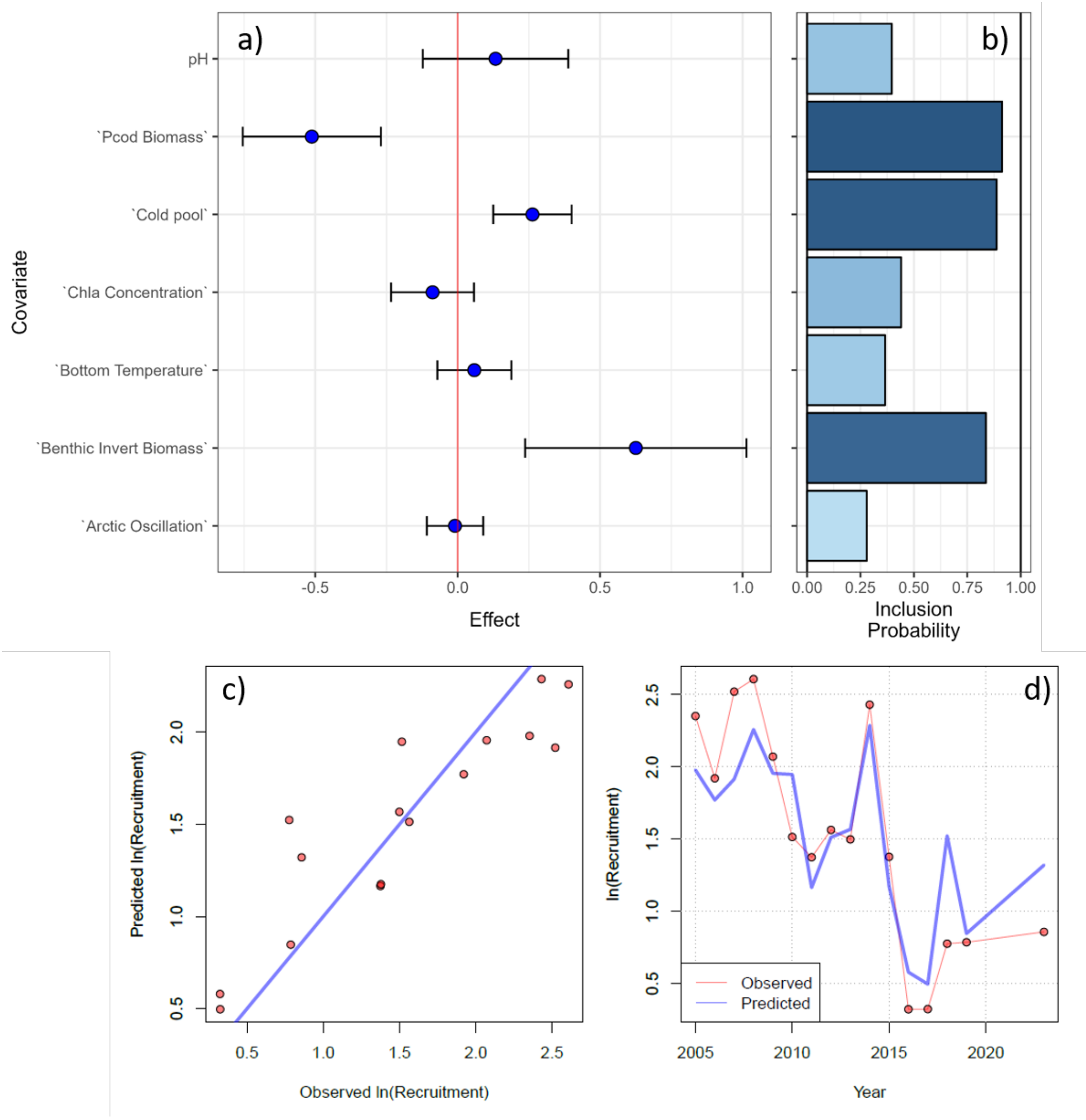

Figure 4. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed Bristol Bay red king crab recruitment (male survey abundance 95 – 120mm): a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the abbreviated recruitment time series (2005 – 2021).