Appendix xx. Ecosystem and Socioeconomic Profile of the Saint Matthew Blue 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., *In Review*). 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 and partial ESP documents (Fedewa et al., 2019, Appendix E, pp. 99 - 120 and Fedewa et al., 2020, Appendix D, pp. 87 - 100) which are available within the Saint Matthew blue king crab (SMBKC) 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 SMBKC:

- In 2022, bottom temperatures returned to near-average and the cold pool extended into the majority of the St. Matthew Island management area. The return of cold-water habitat following a 2018-2019 heat wave suggests optimal conditions for the highly specific thermal and habitat requirements of SMBKC.
- Despite repeated fishery closures, SMBKC recruitment remains below-average, although recruit abundance increased from 2021 to 2022.
- SMBKC have experienced a steady decline in bottom water pH since 2017, reaching 7.82 in 2022. Persistent, corrosive bottom waters surrounding St. Matthew Island suggest potential impacts on shell formation, growth and survival of BKC although laboratory studies suggest that negative impacts are not likely until pH reaches 7.5.
- Above average chlorophyll-a biomass and benthic invertebrate density in recent years suggests optimal foraging conditions for both larval and benthic stages of SMBKC.
- The SMBKC fishery has remained closed to targeted fishing since 2015 (the 2015/2016 crab season).
- Incidental catch of SMBKC biomass in EBS groundfish fisheries during 2021 declined substantially from the previous year, to 359 kg, the lowest value in the available time series and continuing a declining trend observed since a recent high in 2017.

Modeling Considerations

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

- The highest ranked predictor variable (> 0.50 inclusion probability) in the advanced stage monitoring analysis was SMBKC recruit biomass. Due to concerns with autocorrelation in model-based estimates of mature male biomass, indicator importance tests in future SMBKC ESP updates will use recruitment estimates as a response variable.
- The advanced stage indicator 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 SMBKC 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). The ecosystem conceptual model highlights abiotic and biotic processes identified by each life stage from the literature, process studies and laboratory rearing experiments.

During the early life stages, successful settlement of BKC larvae has been linked to shallow, nearshore waters (<50m) and hard substrate such as shell hash, gravel or rock due to the reliance on crypsis to evade predation (Armstrong et al., 1985; Daly and Long, 2014). Unlike RKC, juvenile BKC lack a heavy covering of carapace spines and do not form pods to offer protection from predation, emphasizing the role of habitat complexity in BKC survival (Stevens, 2014). While late juvenile and adult BKC are less reliant on habitat with complex substrate, temperature and depth are habitat requisites given that mature female BKC migrate to relatively shallow, nearshore waters south of St. Matthew Island during the spring and summer months when bottom temperatures reach their maximum (Pengilly and Vanek, 2014). The biannual molt and reproductive strategy characteristic of BKC in contrast to most other *Paralithodes* spp. suggests that energetic restrictions imposed by temperature or prey conditions may be a limitation in reproductive dynamics (Webb, 2014; Jensen et al., 1985).

The socioeconomic conceptual model highlights fishery performance indicators that represent processes most directly involved in prosecution of the SMBKC 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. Implementation of the Crab Rationalization Program and the allocation of tradable crab harvest quota shares resulted in rapid consolidation of the SMBKC fleet and changed the timing of the fishery. These and other institutional changes continue to influence the geographic and inter-sectoral distribution of benefits produced by the SMBKC fleet.

Indicator Suite

The following list of indicators for SMBKC 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. 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., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Figure 2a and Figure 2b, respectively. Please note, we are not including the ROMS spring bottom temperature indicator at this time as more seasonal skill testing is necessary before use in a stock assessment context. A ROMS ocean acidification indicator was updated with current-year data, however the whole time series is presented as pH values instead of aragonite saturation states to simplify interpretation and relate to results of laboratory studies.

In addition, Saint Matthew Island summer bottom temperature and cold pool extent indicators were developed using EBS bottom trawl survey temperature data, whereas in the last partial SMBKC ESP, these respective indicators were developed from Bering 10K ROMS model hindcasts due to the cancellation of the 2020 EBS bottom trawl survey. Two socioeconomic indicators have been discontinued due to concerns over redundancy with the stock assessment model and in an effort to emphasize those indicators that are most closely associated with the health and condition of the stock. The two discontinued indicators are the following: are community-focused indicators - annual active processors in

the Bristol Bay red king crab fishery, annual active processors in the Saint Matthew Island blue king crab fishery, and annual local quotient of Saint Matthew Island blue king crab landed catch in Saint Paul Island - which are not directly associated with the condition of the stock and are thus not directly relevant to ABC or TAC decision-making. Detailed community information for BSAI crab fisheries, including the above indicators, are available in the Annual Community Engagement and Participation Overview (ACEPO) report (Wise et al., 2021). We did add one socioeconomic indicator of exvessel value of the Saint Matthew Island blue king crab fishery landings to be consistent with other ESP report cards.

Ecosystem Indicators:

Physical Indicators (Figure 2a. a-e)

a.) The areal extent of the summer cold pool (EBS bottom trawl survey stations with bottom temperatures < 2ºC; contact: Erin Fedewa). Proposed sign of relationship is positive.

b.) Summer bottom temperatures in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.

c.) Spring pH index in Saint Matthew Island from the Bering10K ROMS model (Pilcher et al., 2019) (contact: D. Pilcher). Proposed sign of relationship is positive.

d.) Summer wind stress (m/s) in Saint Matthew Island from NOAA/NCDC blended winds and Metop-A ASCAT satellite (Zhang et al., 2006, NOAA/NESDIS, CoastWatch) (contact: D. Robinson). Proposed sign of relationship is negative.

Lower Trophic Indicators (Figure 2a.f)

e.) Spring chlorophyll-a biomass in Saint Matthew Island from MODIS satellites (contact: M. Callahan and J. Nielsen). Proposed sign of relationship is positive

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

f.) Summer Pacific cod density in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is negative.

g.) Summer benthic invertebrate density in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey. 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.

h.) Annual blue king crab recruit abundance (105 - 119 mm CL) in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.

Socioeconomic Indicators: (all monetary values are inflation-adjusted to $2021 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 SMBKC fishery, representing relative efficiency of fishing effort (contact: B. Daly)

b.) Annual total potlifts in the SMBKC fishery, representing the level of fishing effort expended by the active fleet (contact: B. Daly)

c.) Annual number of active vessels in the SMBKC fishery, representing the level of fishing effort assigned to the fishery (contact: J. Lee)

d.) Estimated total incidental catch of SMBKC biomass (kg) in EBS groundfish fisheries (contact: J. Lee)

Economic Indicators (Figure 2b.e-h)

e.) Percentage of the annual SMBKC 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 ($2021) of SMBKC 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 SMBKC fishery 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 SMBKC 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 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.

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, economic, and community) 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 the current year 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 calendar year, through 2015 (noting that virtually all active harvest activity occurs prior to January), the last year that the fishery was open (corresponding to the 2015-2016 crab season), and incidental catch is reported for the most recent full calendar year (2021).

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the SMBKC 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 scored below average for 2022, while the lower trophic indicators were above average, and the upper trophic indicators were average (Figure 3). The fishery performance indicators scored below average for 2021, but this is based solely on one indicator (incidental catch of SMBKC biomass in EBS groundfish fisheries). There is no new information for the remaining socioeconomic indicators associated with the target SMBKC fishery, which has remained closed since the 2015-2016 season. Compared to the previously available data points, these scores reflect a further decrease 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, and a decrease for the fishery performance indicator.

Overall, trends in physical ecosystem indicators indicate a return to near-normal conditions near St. Matthew Island, with average bottom temperatures nearly 2.5°C colder than 2018-2019 heat conditions. Continued declines in pH are approaching a critical threshold for many Bering Sea crustacean stocks, although blue king crab may be capable of acclimating to acidic bottom waters at or around 7.8 (Long et al., 2017). A fairly large cold pool in 2022 suggests that SMBKC larvae likely hatched in mid-April, coinciding with average peak spring bloom in the Bering Sea (Stevens, 2006). Likewise, above-average chloropyll-*a* biomass in the St. Matthew Island management area indicates suitable primary production conditions for larval survival. Higher spring and summer surface winds in 2022 may have compromised prey encounter rates and SMBKC larval first-feeding success, although more research is needed to understand early life history processes of blue king crab.

While current-year updates for upper trophic level Pacific cod and benthic invertebrate indicators are not yet available following the conclusion of the 2022 EBS bottom trawl survey, both indicators were near-average in 2021. SMBKC recruitment still remains below the long-term average, although increased population abundances noted on the 2022 EBS bottom trawl survey coinciding with cold-water conditions may point to enhanced productivity in years with near-normal thermal conditions (Zacher et al., *in review*).

Intermediate Stage: Importance Test

We plan to update the second stage indicator analysis in 2024 and are exploring additional importance methods for SMBKC.

Advanced Stage: Research Model Test

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

Data Gaps and Future Research Priorities

Additional data on BKC life history characteristics (i.e. growth-per-molt data and molting probabilities) as well as estimates for natural mortality would aid in a better understanding of stage-specific vulnerabilities for the metric panel. In addition, process-based studies are necessary in order to identify links between larval survival, recruitment and environmental factors. Specifically, future laboratory and field research should focus on clarifying the range of optimal conditions for larval survival and successful larval retention and settlement in juvenile nursery areas. Examining larval drift patterns and spatial distributions of mature female BKC around St. Matthew Island in relation to habitat characteristics will help to inform essential fish habitat models and support the future development of a settlement success indicator. Developing a proxy for habitat quality in and around St. Matthew Island should also be prioritized, as metric assessment results highlighted several vulnerabilities related to habitat. Furthermore, given the prevalence of corrosive bottom water conditions in the SMBKC management area, continued

research efforts should focus on the potential impacts of ocean acidification on BKC physiology and the role pH levels may play in determining habitat use and spatial distributions of the stock.

In most socioeconomic dimensions, SMBKC fishery is relatively data rich in many respects. In the context of the ESP, however, the intermittent nature of the fishery and reliance on fishery-dependent socioeconomic data limits the available socioeconomic information to years when the fishery has opened. This complicates the depiction and/or interpretation of long-term averages for most socioeconomic indicators and suggests the need for development of indicators that are informative of social and economic factors relevant to the purposes of the ESP, but function on a continuous basis, including during years when the fishery is closed. Potential examples include estimation of current value of PSMFC QS assets, calculation of revenue share metrics for SMBKC processors and vessels identified with the SMBKC fishery on the basis of more continuous association than participation in the fishery during a particular year. Substantial improvements over the indicators reported above are feasible, however, are largely dependent on further development of clear objectives for the inclusion of social and economic indicators within the ESP framework.

SMBKC ESP developments for 2024 include: 1) updating the intermediate stage indicator analysis, 2) producing a Request for Indicators in January 2024 to highlight data gaps and propose new indicator contributions, 3) developing a habitat quality indicator using EFH and Fishing Effects model output, and 4) updating ecosystem and socioeconomic indicators and considerations prior to the 2024 Crab Plan Team meeting to inform SMBKC management and rebuilding.

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. This may result in a transition of socioeconomic indicators currently reported in this ESP to a different series of indicators in future ESPs. 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. 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 size or condition of species in the fishery. We could include this information as supportive evidence and perspective on many indicators monitored within the ESP.

As indicators are improved or updated, they may replace those in the current set of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. The annual request for indicators (RFI) for the SMBKC ESP will include these data gaps and research priorities along with a list of potential 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 SMBKC, 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	Summer Cold Pool SEBS SMBKC Survey	**low**	**low**	NA	**low**	neutral
	Summer Temperature Bottom SMBKC Survey	*high*	*high*	NA	*high*	neutral
	Spring pH SMBKC Model	**low**	**low**	**low**	**low**	**low**
	Summer Wind Stress SMBKC Satellite	**high**	neutral	neutral	neutral	**high**
Lower Trophic	Spring Chlorophylla Biomass SMBKC Satellite	neutral	neutral	neutral	neutral	*high*
Upper Trophic	Summer Pacific Cod Density SMBKC Survey	neutral	neutral	NA	neutral	NA
	Summer Benthic Invertebrate Density SMBKC Survey	neutral	*high*	NA	neutral	NA
	Annual Blue King Crab Recruit Abundance SMBKC Survey	**low**	neutral	NA	**low**	neutral

Table 1b. First stage socioeconomic indicator analysis for SMBKC, 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	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
Fishery Performance	Annual Blue King Crab CPUE SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Total Potlift SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Active Vessels SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Incidental Catch EBS Fishery	high	neutral	neutral	neutral	low
Economic	Annual Blue King Crab TAC Utilization SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Exvessel Value SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Exvessel Price SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Exvessel Revenue Share SMBKC Fishery	NA	NA	NA	NA	NA

Figures

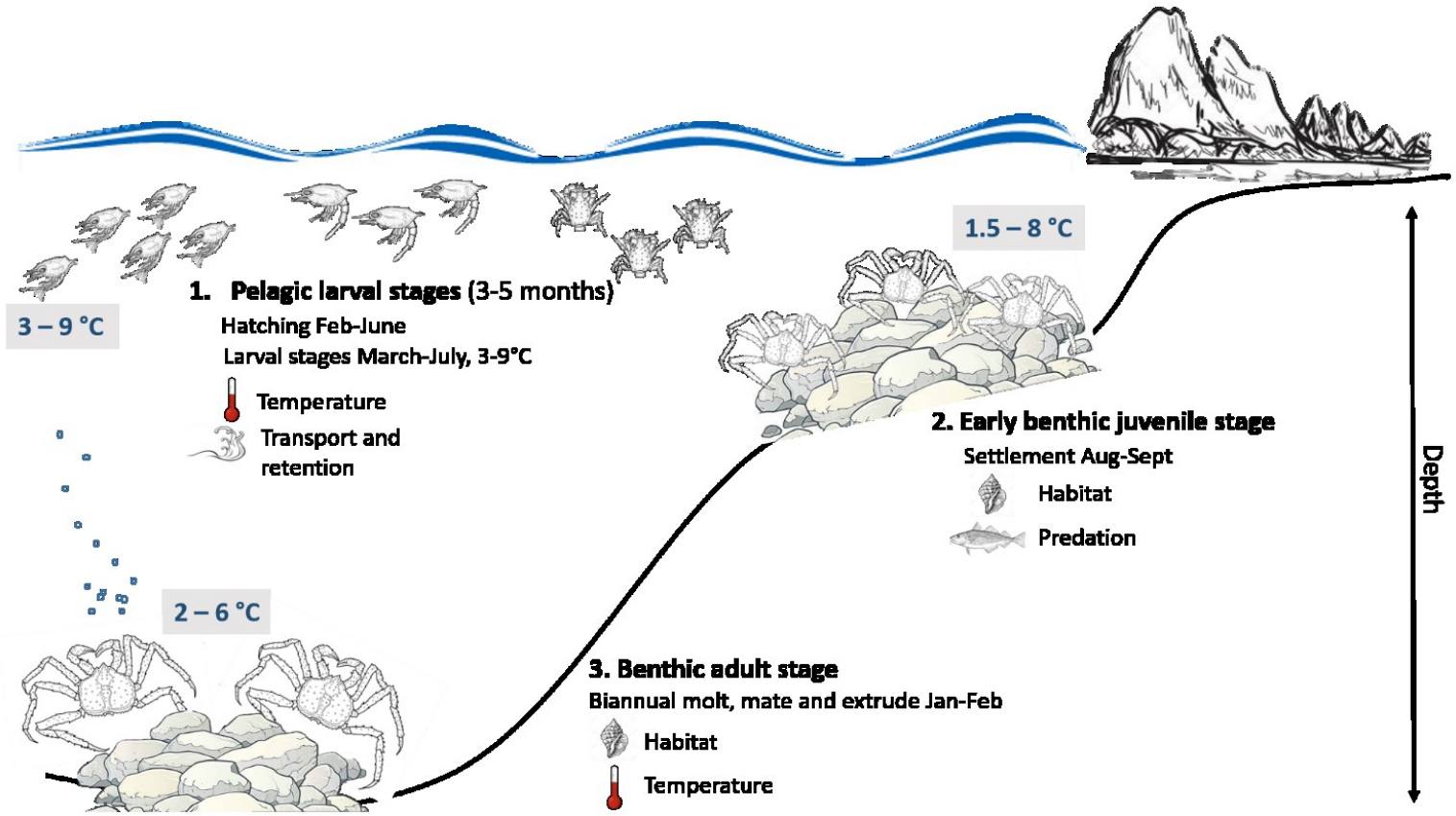

Figure 1a: Life history conceptual model for SMBKC summarizing ecological information and key ecosystem processes affecting survival by life history stage. Thermal requirements by life history stage were determined from BKC laboratory studies. Red text means increases in process negatively affect survival,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

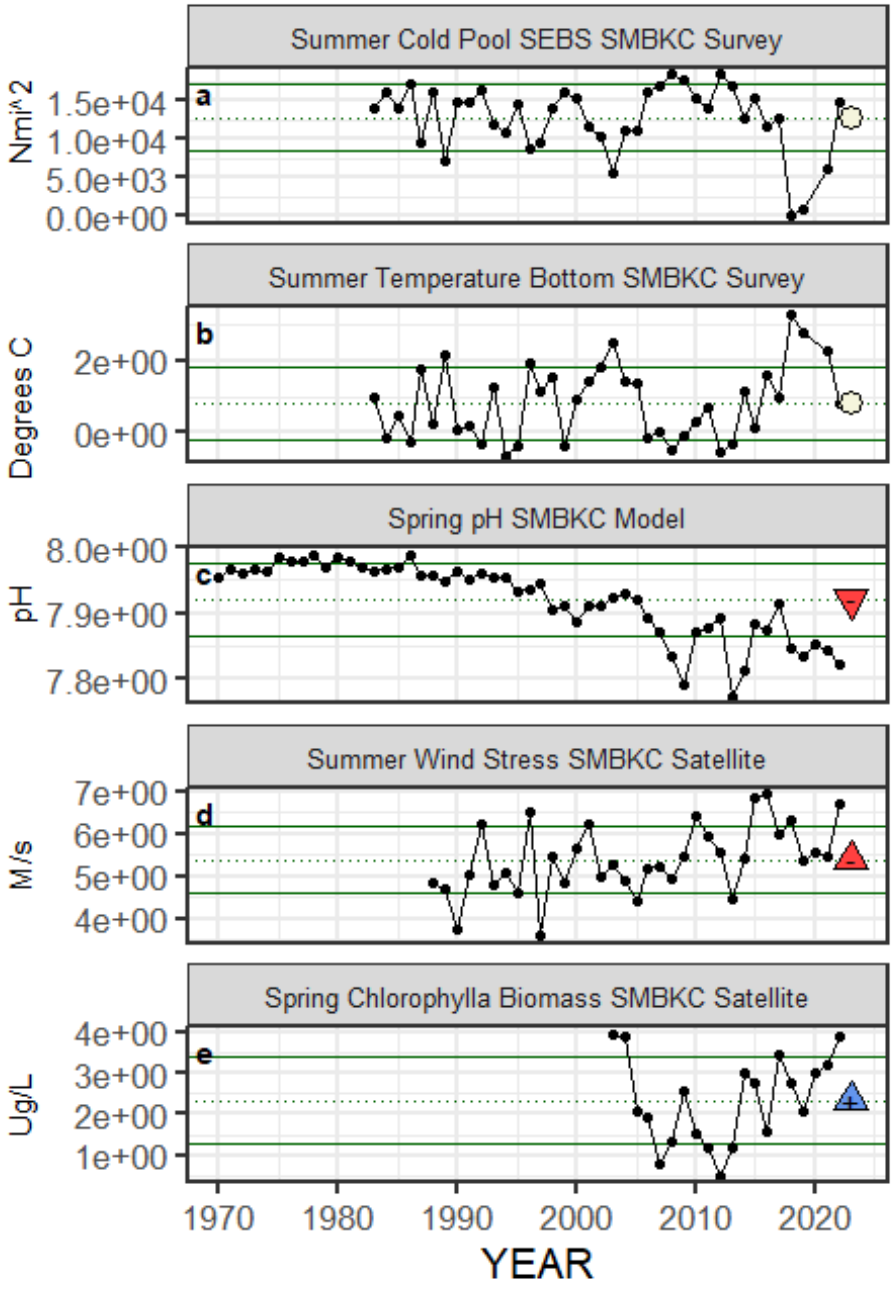

Figure 2a. Selected ecosystem indicators for SMBKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are 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).

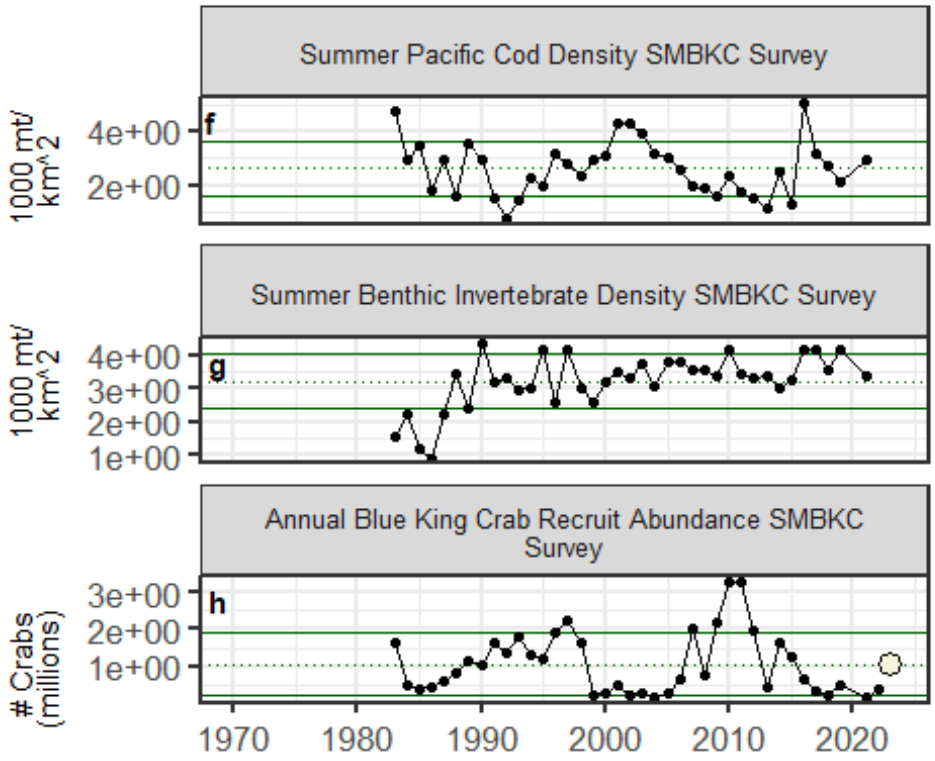

Figure 2a (cont.). Selected ecosystem indicators for SMBKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year 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).

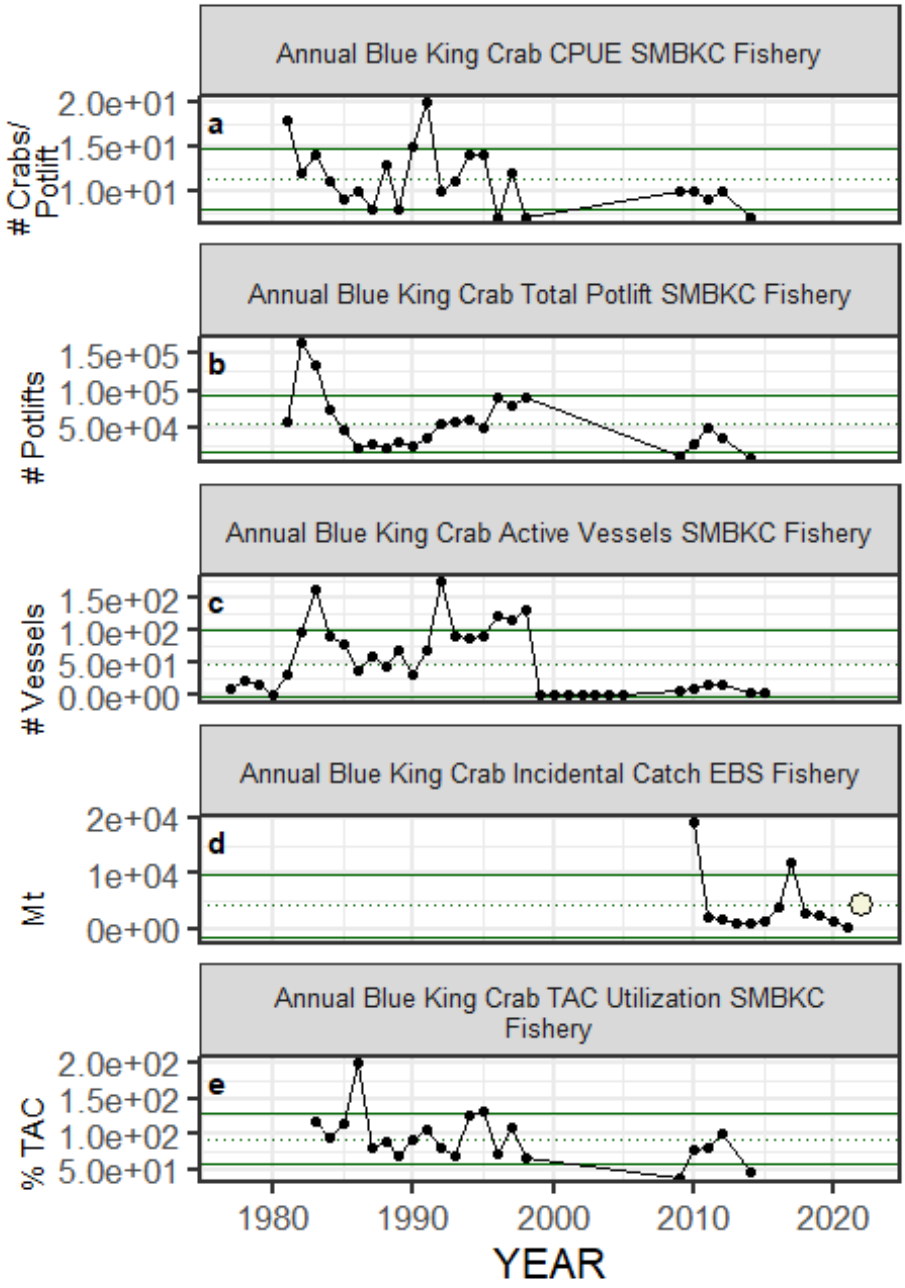

Figure 2b. Selected socioeconomic indicators for SMBKC with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data 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).

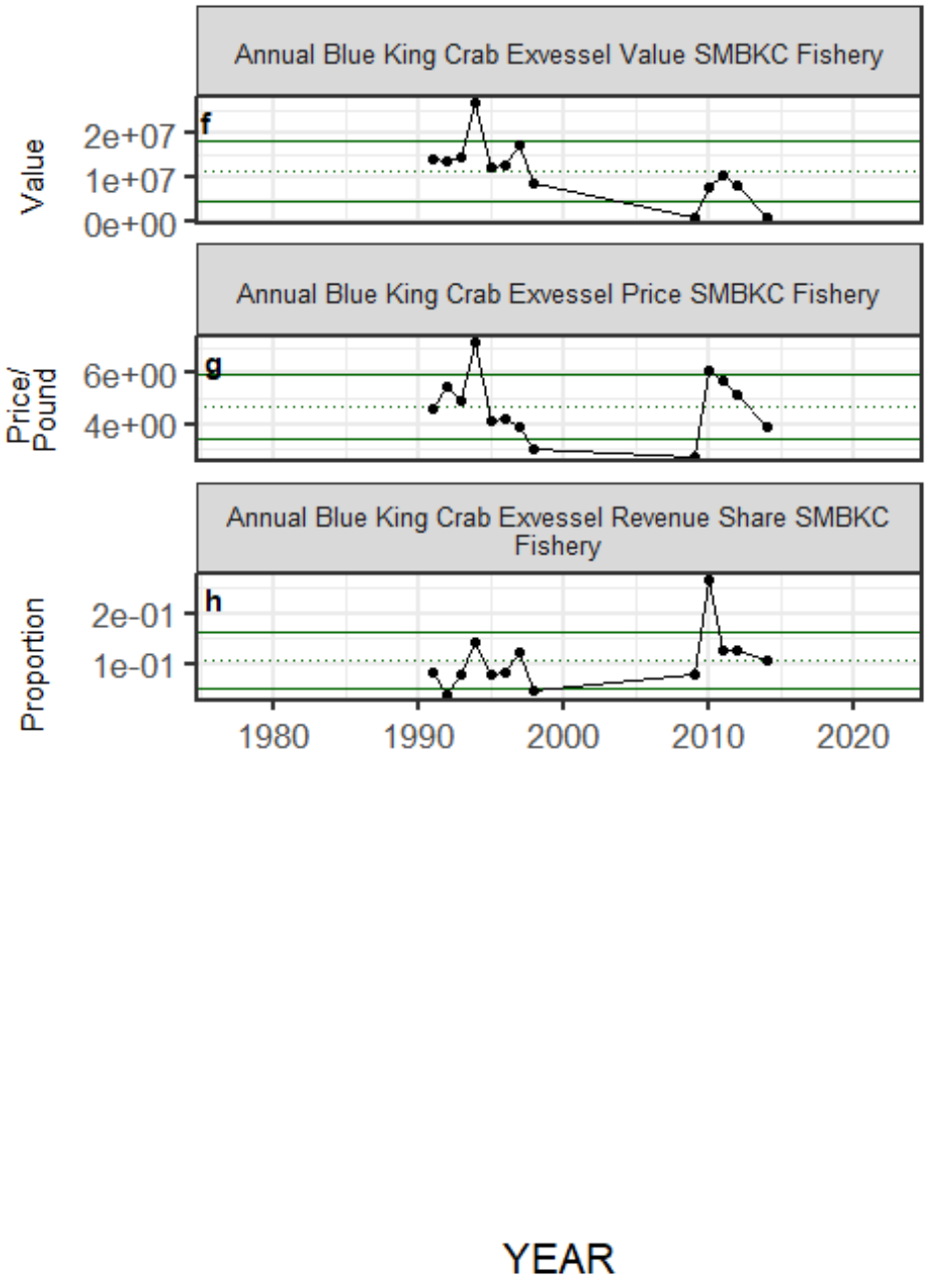

Figure 2b (cont.). Selected socioeconomic indicators for SMBKC with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current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

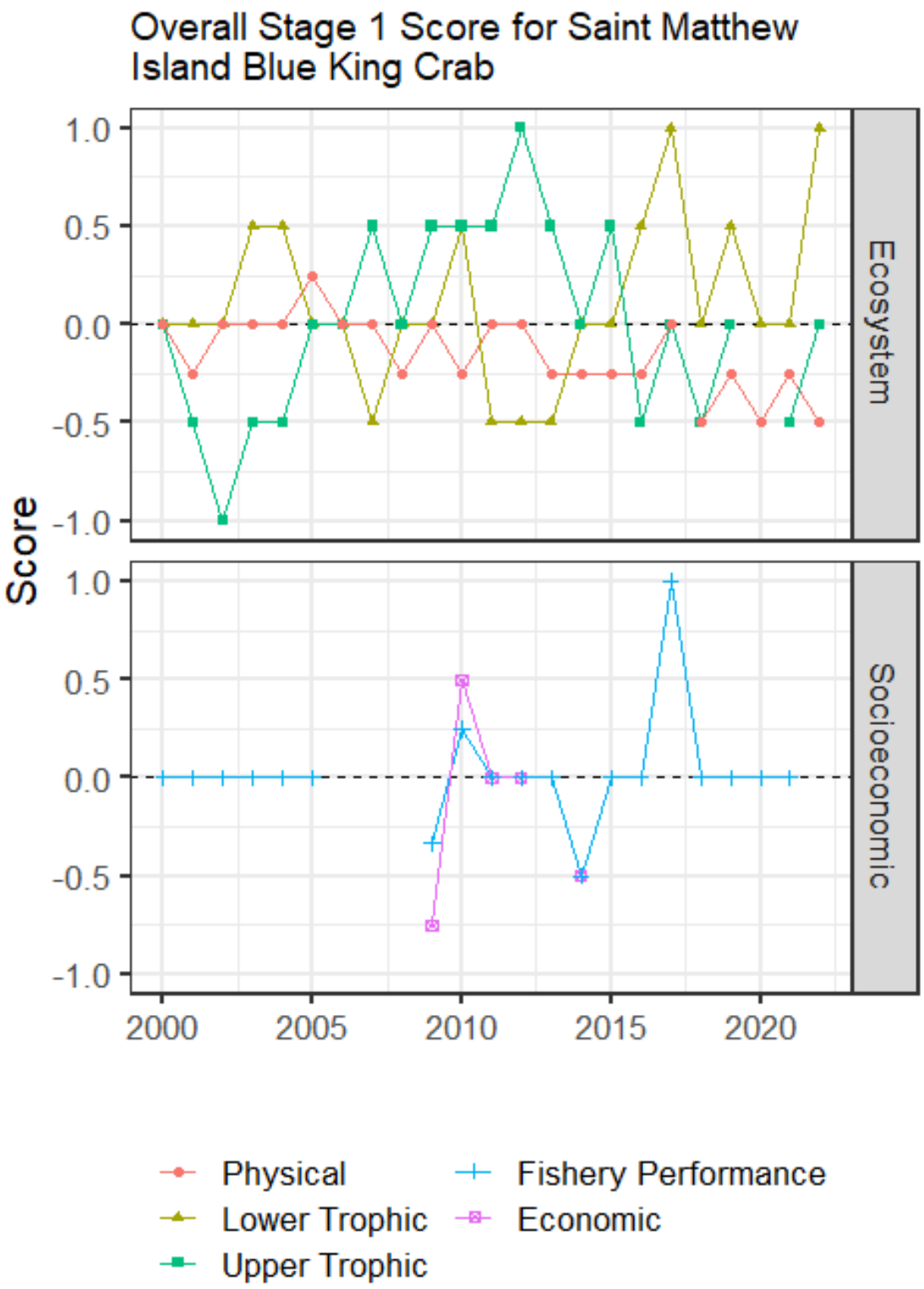

Figure 3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.