Appendix D. Ecosystem and Socioeconomic Profile of the Saint Matthew Blue King Crab Stock

Erin Fedewa, Brian Garber-Yonts and Kalei Shotwell

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With Contributions from:

Curry Cunningham, Kelly Kearny, Jens Nielsen, Katie Palof, Darren Pilcher, Jon Richar, Dale Robinson and Jordan Watson

Executive Summary

National initiative and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Saint Matthew blue king crab (SMBKC) due to the stock's current overfished status and poor recruitment in recent years. Scores for stock assessment prioritization, habitat prioritization, climate vulnerability assessment, and data classification analysis were moderate to high. Furthermore, in 2018 when the stock was declared overfished, the Crab Plan Team requested an evaluation of ecosystem factors to inform the stock rebuilding plan.

We follow the standardized template for conducting an ESP and present results of applying the ESP process through a metric and subsequent indicator assessment. We use information from a variety of data streams available for the SMBKC stock. Analysis of the ecosystem and socioeconomic processes for SMBKC 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.

Please refer to the last full ESP document for further information regarding the ecosystem and socioeconomic linkages for this stock (Fedewa et al., 2019, available online within the SMBKC SAFE, Appendix E, pp. 99-120 at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=6ffde3ce-67be-4139-b165-cbff9062da06.pdf&fileName=C4%206%20SMBKC%20SAFE%202019.pdf).

Summary of Changes in Assessment Inputs

Changes in the Metric or Indicator Data

The 2020 SMBKC ESP update includes a suite of new ecosystem indicators that were developed from remote sensing data and Bering10K ROMS model output hindcasts. The suite of socioeconomic indicators for SMBKC remain unchanged due to the continued closure of the fishery while the stock rebuilds.

Changes in the Indicator Analysis

We have included the addition of a Stage 2 Importance Test in the Indicator Analysis section of the 2020 SMBKC ESP update. Results from the analysis are outlined below.

Summary of Results

Important ecosystem and socioeconomic processes that may identify dominant pressures on the SMBKC stock were reviewed in the last full ESP document. We updated the suite of ecosystem indicators for SMBKC using these mechanistic linkages or hypothesized relationships. Specifically, the addition of spring bottom temperature, wind stress and chlorophyll *a* indicators likely represent environmental conditions and prey availability for BKC early life stages. Please reference the 2019 full SMBKC ESP document for complete descriptions of indicators that occurred in the last full ESP. Any changes in methodology for indicators developed in 2019 are outlined below, as well as full descriptions for new indicators.

Indicator Suite

<u>Ecosystem Indicators:</u>

1.) Physical Indicators
   - Cold Pool Index: Due to the cancelation of the 2020 EBS summer bottom trawl survey, the cold pool index was calculated from ROMS model output as the fraction of the EBS

survey area with bottom waters less than 2°C on July 1 of each year (Kearney et al., 2020).

- Summer Bottom Temperature: Due to the cancelation of the 2020 EBS summer bottom trawl survey, June-July bottom temperatures were averaged within the SMBKC management area from ROMS model output (Kearney et al., 2020).
- Spring Bottom Temperature: Average of Feb-March bottom temperatures within the SMBKC management boundary from ROMS model output (Kearney et al., 2020).
- Corrosivity Index: Percent of the SMBKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April (D. Pilcher, *pers. commun.*, 2020)
- Chlorophyll *a* Biomass: April-June average chlorophyll-a biomass within the St. Matthew region of the Bering Sea; calculated with 8-day composite data from MODIS satellites (J. Nielsen, *pers. commun.*, 2020)
- Wind Stress: June ocean surface wind stress within the SMBKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites (Zhang et al., 2006, NOAA/NESDIS, CoastWatch)

2.) Biological Indicators

- Pacific Cod Biomass: Pacific cod comprise the majority of total biomass in the Benthic Predator Biomass indicator developed for the 2019 full ESP document. As such, we refined a predation indicator to solely include pacific cod biomass within the SMBKC management area.
- Benthic Invert Biomass
- SMBKC Recruit Biomass (Palof, *pers. commun*, 2020)

<u>Socioeconomic Indicators:</u>

1.) Fishery Performance Indicators

- CPUE (mean no. of crabs per potlift): Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift.
- Total Potlifts: Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery.
- Vessels active in fishery: Annual count of crab vessels that delivered commercial landings of SMBKC to processors.
- SMBKC male bycatch biomass: Incidental bycatch biomass estimates of male BBRKC (tons) in trawl and fixed gear fisheries

2.) Economic Indicators

- TAC Utilization (%): Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.
- SMBKC ex-vessel revenue share (% of total exvessel revenue): SMBKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in SMBKC during the respective year.
- Ex-vessel price per pound: commercial value per unit (pound) of SMBKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.

3.) Community Indicators

- Processors active in fishery: Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year. This provides an indicator of the level of participation of buyers in the market for SMBKC landings.
- Local Quotient of SMBKC landed catch in Saint Paul: Ex-vessel value share of SMBKC landings to communities on St. Paul Island, as percentage of total value of commercial landings to St. Paul processors from all commercial Alaska fisheries, as aggregate

percentage over all landings during the respective year. St Paul represents the principal port of landing for the SMBKC fishery during the post-rationalization period, representing from 78% to 100% of all purchased landings in the fishery. The local quotient (LQ) represents the share of community landings attributed to SMBKC in relation to revenue from all other species landed in the community during years when the fishery was opened.

Indicator Analysis

We provide an update to the list and time-series of ecosystem and socioeconomic indicators (Tables 1-2, Figures 1-2) and then report the results of the first and second stage statistical tests for the indicator analysis with the inclusion of current-year data. The third stage has not yet been completed, and will require more indicator development and review of the ESP modeling applications.

Stage 1: Traffic Light Test

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the most current year where available (Tables 1-2). Details of the analysis can be found in the 2019 full ESP document.

Current year trends suggest relatively average environmental conditions for the SMBKC stock in 2020, although SMBKC recruit biomass is still well below the long-term average (Figure 1). While summer bottom temperatures in the St. Matthew management area were 1-2°C below 2018-2019 temperatures, the region still experienced warmer than average conditions relative to the long-term mean. However, a larger fraction of bottom waters were < 2°C in 2020 compared to previous years. The addition of a corrosivity indicator suggests that SMBKC are exposed to significant interannual variability in the aragonite saturation state of bottom waters. All stations within the SMBKC management area contained under-saturated bottom waters ($\Omega arag < 1$) in spring 2020 which suggests potential consequences for shell formation following the spring molt, as well as reduced condition and survival of embryos and larval stages.

Chlorophyll *a* biomass was above the long-term average in 2020, suggesting a more intense spring bloom and good first-feeding conditions for BKC larvae. Likewise, June wind speeds around St. Matthew Island were near-average in 2020 and on a downward trend since 2015, which may promote increased larval encounter rates with diatom prey. Current-year data for benthic invertebrate and Pacific cod biomass indicators were not available due to the cancellation of the EBS bottom trawl survey. Benthic invertebrate biomass has remained high since the late 1980's (possibly coinciding with a 1989 regime shift in the North Pacific), while Pacific cod biomass has been on a downward trend after reaching an all-time high in 2016.

With the exception of SMBKC male bycatch, all socioeconomic indicators in Table 2 are derived from SMBKC fishery data reported from the most recent open season (2015/16), and thus are not updated in this report. Bycatch of SMBKC in the groundfish fisheries during 2019 was near the lower bound of the historical range, and was slightly reduced from 2018.

Stage 2: Importance Test

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and SMBKC mature male biomass (MMB), 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 second test, the full set of indicators is first winnowed to the predictors that could directly relate to MMB, and have consistent temporal data coverage. We then provide the mean relationship between each predictor variable and log MMB over time (Figure 3a), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 3b). A higher probability indicates that the variable is a better candidate predictor of SMBKC MMB. The highest ranked predictor variables (≥ 0.25 inclusion probability) were: SMBKC recruit biomass, summer bottom temperatures, and benthic invertebrate biomass. Unfortunately, due to the nature of the BAS model only being able to fit years with complete observations for each covariate, the final subset of covariates was quite small and creates a significant data gap. Despite this shortcoming, predictive performance of the BAS model appears to generally capture SMBKC MMB trends across the time series (Figure 3d).

Ecosystem Considerations

- Despite repeated fishery closures, SMBKC mature male biomass and recruitment estimates remain below-average following a 1989 regime shift in the Bering Sea, suggesting that environmental factors may be impeding recruitment success and stock recovery.
- Highly specific thermal optimums and habitat requirements of SMBKC likely limit mobility in response to warmer than average bottom temperatures and shifting predator distributions in the Bering Sea.
- Large catches of Pacific cod in the St. Matthew Island management boundary in 2016 preceded declines in BKC mature male biomass, recruitment, and the overfished declaration in 2018.
- Trend modeling for SMBKC ecosystem indicators revealed near-average conditions for SMBKC in 2020, although persistent, corrosive bottom waters surrounding St. Matthew Island suggest potential impacts on shell formation, growth and survival of BKC.

Socioeconomic Considerations

- Vessel engagement in the SMBKC fishery as measured by annual counts of active vessels during years that the fishery has opened, has declined relative to the pre-rationalization period reflecting consolidation of the crab fleet following rationalization.
- In the most recent open seasons, the active fleet has been reduced to 3-4 vessels, with TAC utilization also declining to 26% during the 2015/16 season.
- Ex-vessel revenue share and the Local Quotient for Saint Paul both reached high values during 2010, concurrent with a peak in ex-vessel price; large declines in both metrics over the subsequent open seasons, despite relatively high ex-vessel prices during the next four open SMBKC seasons indicate that both vessels and processors active during those years have shifted into other fisheries.

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 aide 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. Examining larval drift patterns and spatial distributions of mature 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 larval retention indicator. Developing an EFH habitat indicator for SMBKC 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.

Responses to SSC and Plan Team Comments on ESPs in General

"Regarding ESPs in general, the SSC recommends development of a method to aggregate indices into a score that could be estimated over time and compared to stock history. One potential pathway forward may be to normalize and use an unweighted sum of all the indicators where all time series overlap, or just assign +1 or -1 to each indicator so that a neutral environment would be zero." (SSC, February 2020, pg. 7)

A presentation on a scoring option for the indicator suite was provided in the ESP Model Workshop in March 2020. The score used a simple +1, 0, and -1 assignment to the indicator based on whether the current year was above, within, or below 1 standard deviation from the mean for the time series. Sablefish and GOA pollock were provided as case studies and scores were calculated historically for the past 15 years. The score timeline trajectory was also evaluated with respect to the general ecosystem and socioeconomic considerations provided in the ESP documents. We plan to provide this score in next year's ESPs for SMBKC and hope for feedback on the method.

Responses to SSC and Plan Team Comments Specific to this ESP

"*The SSC is very pleased to see the Ecosystem and Socioeconomic Profile for SMBKC. The conceptual model was appreciated especially by those that are less familiar with crab life history characteristics. The introduction of some new ecosystem indicators was a good start. It was noted that the stock showed a high vulnerability to ocean acidification (OA), so if there is a way to index OA in the ESP that might be a good addition."* (SSC, Oct, 2019, pg. 12)

In response to this recommendation, we updated the 2020 SMBKC ecosystem indicator suite to include a Corrosivity Index developed from Bering10K ROMS output. This index, representing the percent of SMBKC management area containing low pH bottom waters undersaturated in aragonite, will provide the means to highlight vulnerabilities across BKC life stages to acidified conditions.

"The SMBKC ESP provides a tool to track, for the first time, the socioeconomic context of a fishery that has not successfully provided for the continuous, sustained participation of fishing communities over time. The SSC recommends that the ESP be augmented to track indices of community engagement and dependency, by community or aggregations of communities, across the relevant vessel and processing sectors and, for the years following rationalization, quota share ownership by community by share type. Where data confidentiality constraints dictate, the analysts should consider the use of regional as well as local quotient indicators." (SSC, Oct, 2019, pg. 12)

This recommendation has not been accomplished in this update. AFSC is currently developing a dedicated annual report to accompany the Crab and Groundfish Economic SAFE reports, focused on providing comprehensive analysis and monitoring of community participation and engagement in groundfish and crab fisheries. The Annual Community Engagement and Participation Overview

(ACEPO) will provide detailed, community-level metrics of fishery participation, including income and employment, and ownership of vessel, plant, permit and quota share assets. Development of methods and indices for effectively capturing these and other dimensions of management effects on communities is currently concentrated on producing the ACEPO report. It is expected that this will provide the basis for identifying reduced-form indicators of community effects that will be suitable for incorporation in ESPs in the future.

Acknowledgements

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Table 1. First stage ecosystem indicator analysis for St. Matthew blue king crab (SMBK), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for SMBKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Cold Pool Index	Fraction of the EBS BT survey area with bottom water less than 2°C on 1 July of each year from Bering10K ROMS model output hindcasts	●
Summer Bottom Temperature	Average of June-July bottom temperatures (° C) within the SMBKC management boundary from the Bering 10K ROMS model output hindcasts	●
Corrosivity Index	Percent of the SMBKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April	+
Spring Bottom Temperature	Average of Feb-March bottom temperatures (° C) within the SMBKC management boundary from the Bering 10K ROMS model output hindcasts	●
Wind Stress	June ocean surface wind stress within the SMBKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites	●
Chlorophyll-a Biomass	April-June average chlorophyll-a biomass within the St. Matthew region; calculated with 8-day composite data from MODIS satellites	●
Pacific cod biomass	Biomass (1,000t) of Pacific cod within the SMBKC management boundary on the EBS bottom trawl survey	●
Benthic invertebrate biomass	Combined biomass (1,000t) of benthic invertebrates within the SMBKC management boundary on the EBS bottom trawl survey	+
SMBKC Pre-recruit Biomass	Model estimates for SMBKC recruitment. Includes male crab (90-104 mm CL) that will likely enter the fishery the following year.	●

Table 2. First stage socioeconomic indicator analysis for St. Matthew blue king crab (SMBK), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for SMBKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Vessels active in fishery	Annual count of crab vessels that delivered commercial landings of SMBKC to processors[1]	●
TAC Utilization	Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.	●
Total Potlifts	Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery	+
CPUE	Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift	●
Ex-vessel price per pound	Commercial value per unit (pound) of SMBKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.	●
SMBKC ex-vessel revenue share	SMBKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in SMBKC during the respective year.	●
Processors active in fishery	Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year.	-
Local Quotient of SMBKC landed catch in St. Paul	Ex-vessel value share of SMBKC landings to communities on St. Paul Island, as percentage of total value of commercial landings to St. Paul processors from all commercial Alaska fisheries, aggregate percentage over all landings during the respective year.	●
SMBKC Male Bycatch in Groundfish Fishery	Incidental bycatch biomass estimates of male SMBKC (tons) in trawl and fixed gear fisheries	●

[1]Includes crab catcher/processors that harvested and processed SMBKC catch on-board.

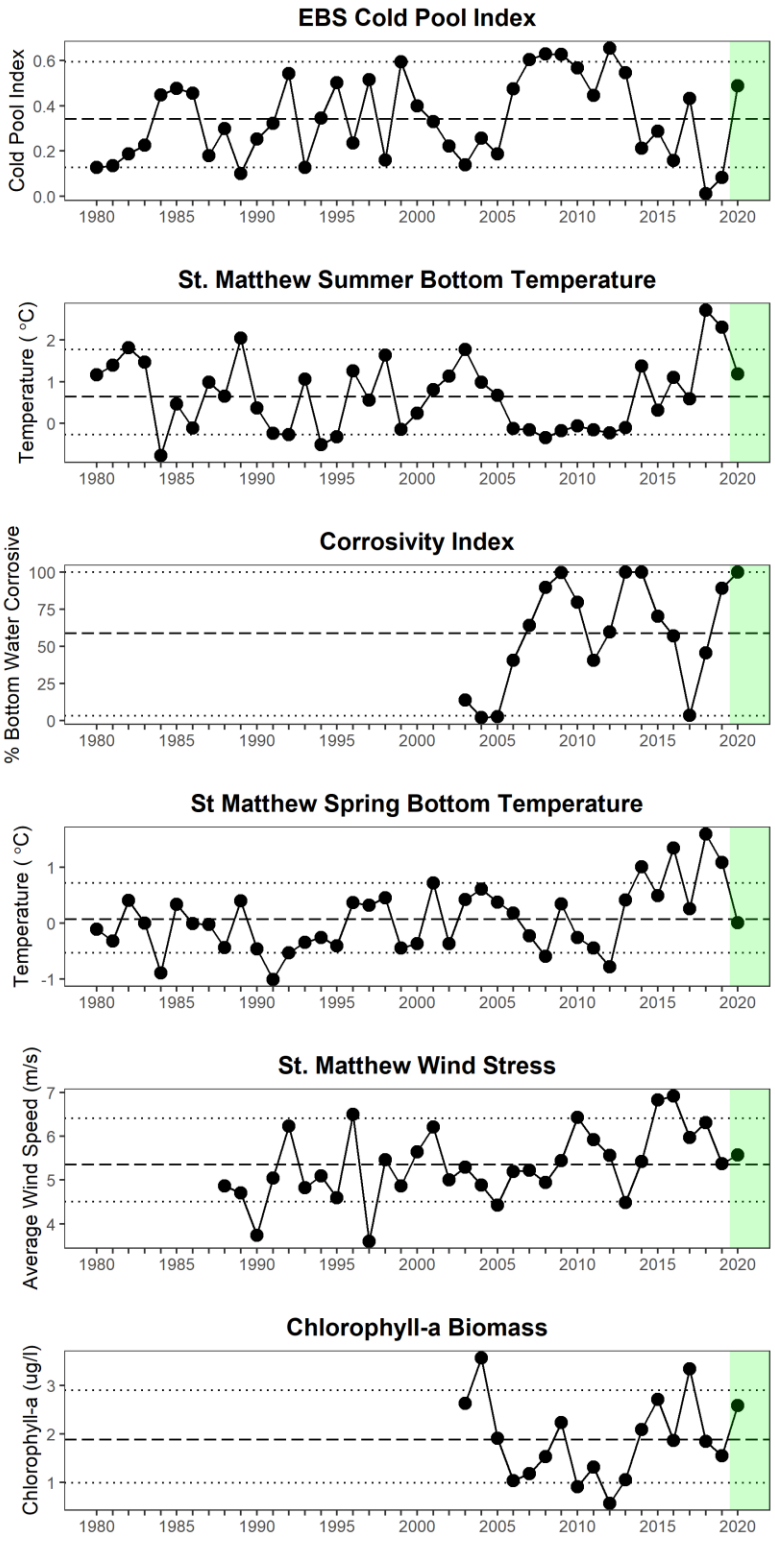

Figure 1. Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

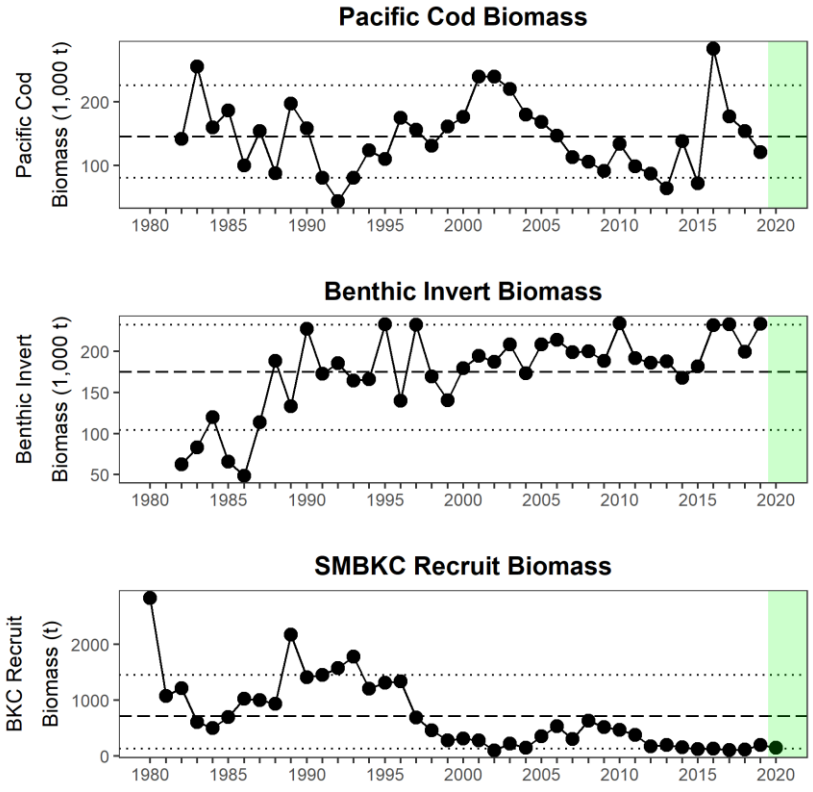

Figure 1. (cont.) Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

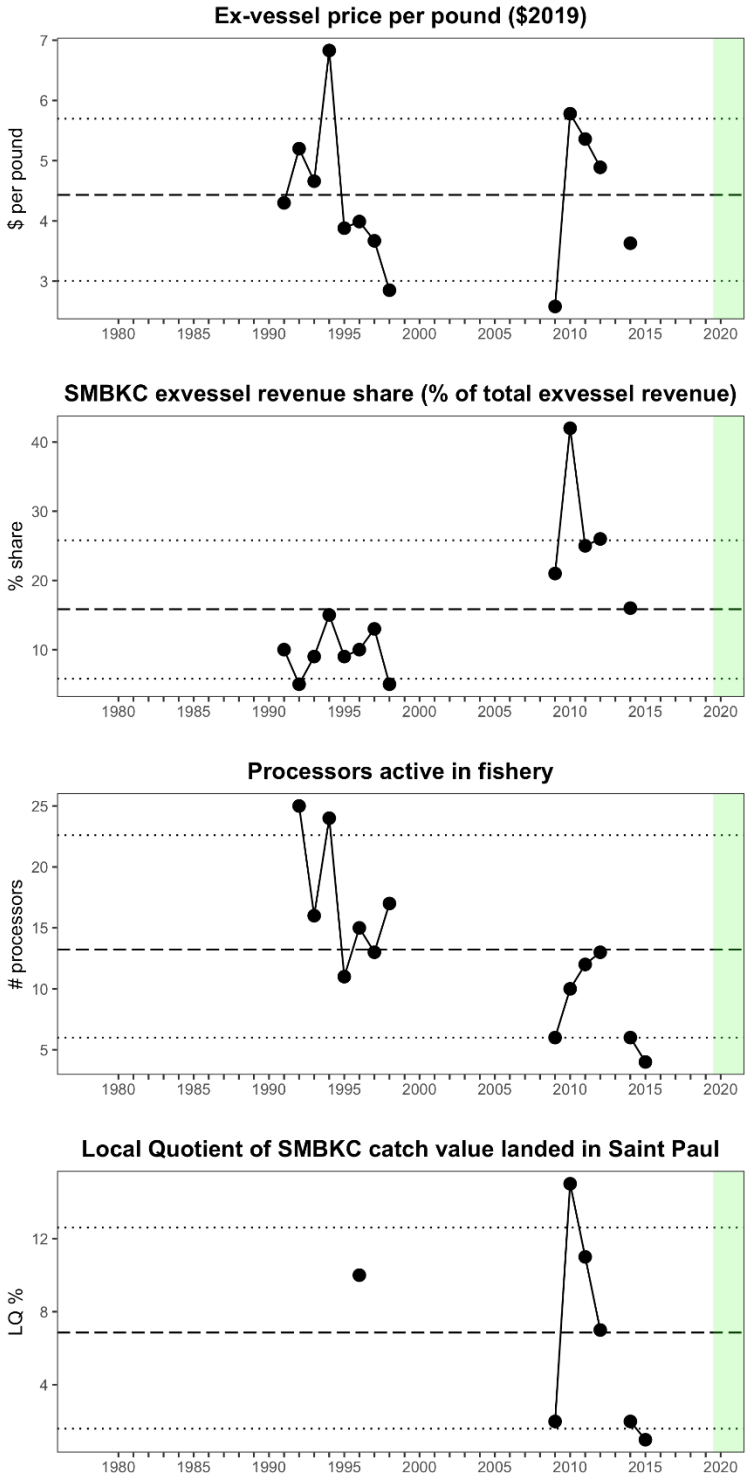

Figure 2. Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

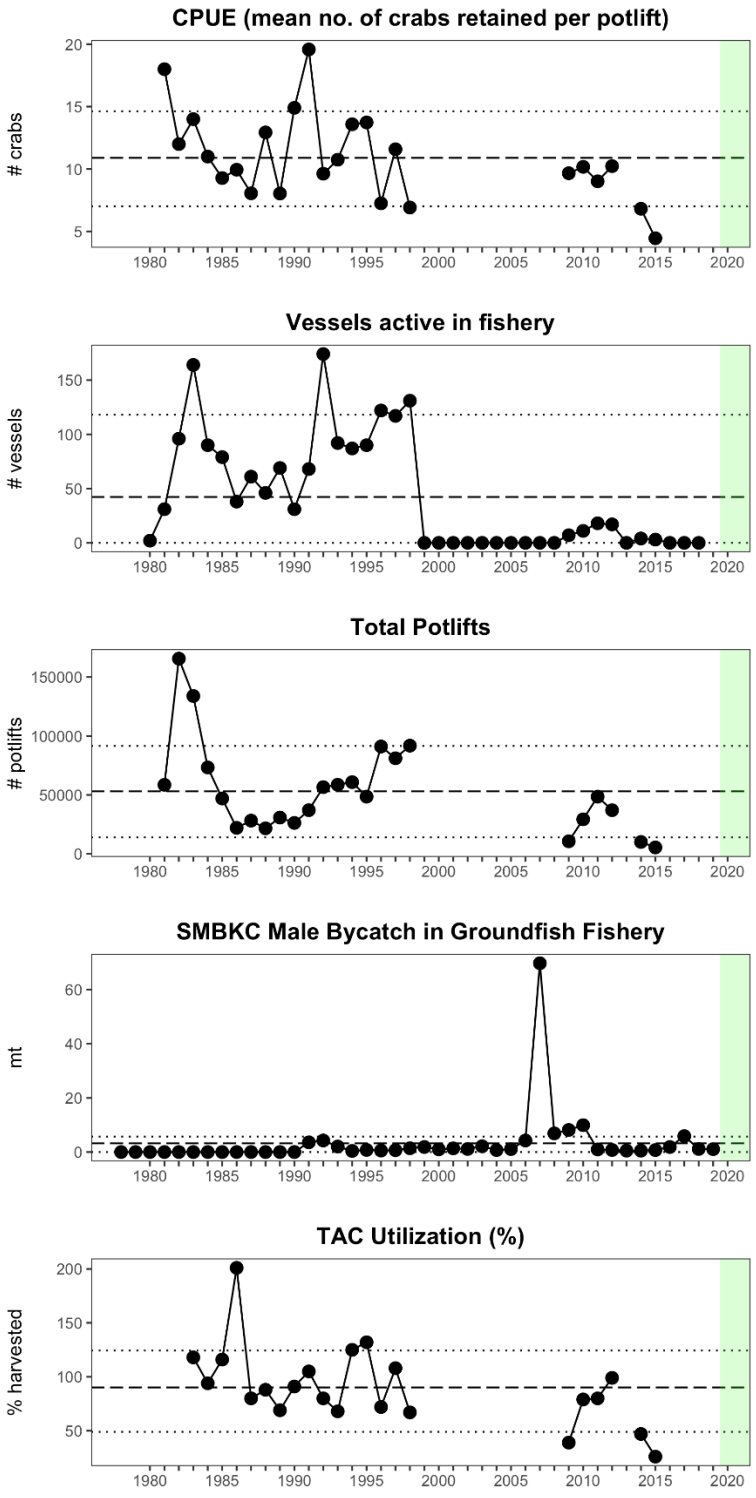

Figure 2. (cont.) Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

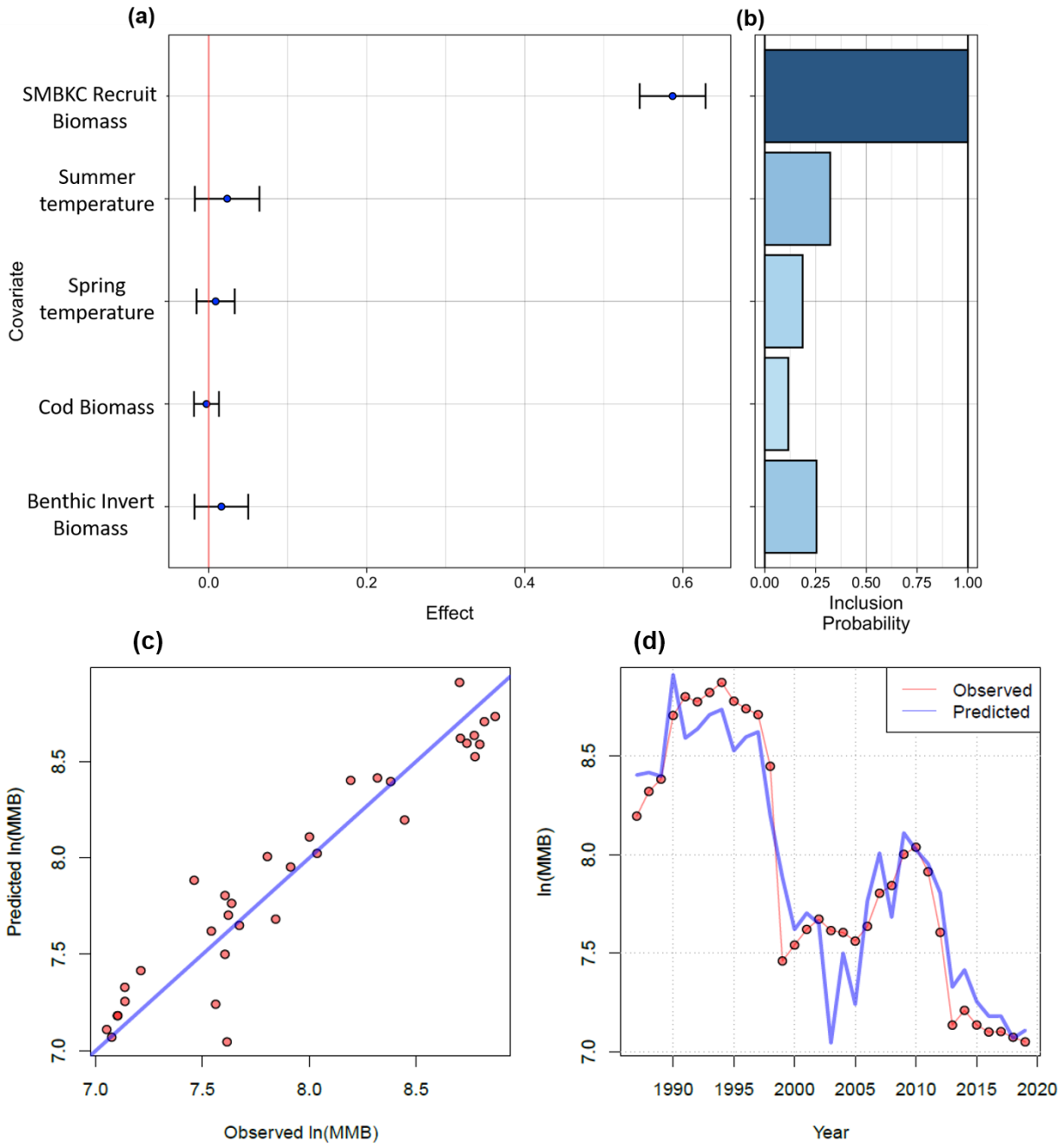

Figure 3. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed St. Matthew blue king crab mature male biomass: a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the MMB time series.