Appendix 1. Ecosystem and Socioeconomic Profile of the Pacific Cod stock in the EBS - Report Card

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*With Contributions from:*

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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 ESP and partial ESP documents for further information regarding the ecosystem and socioeconomic linkages for this stock (*list references*).

## Management Considerations

Summary conclusions from ESP for ABC (risk table)

## Modeling Considerations

Summary of indicators with high importance in the Bayesian adaptive sampling routine and discussion of which indicators have had consistent high importance. List of research ecosystem model runs that are currently ongoing and potential for operational use in the future.

# Assessment

## Ecosystem and Socioeconomic Processes

One paragraph description of ecosystem and socioeconomic (if available) conceptual model(s)

## Indicator Suite

One paragraph description of LME level indicators relevant to stock (ESR summary)

### Ecosystem Indicators:

1.) Physical Indicators

a.) Anomalies of average daily sea-ice extent relative to 1978-2010 mean computed over ice-retreat season of March through May: Anomalies of average daily sea-ice extent relative to 1978-2010 mean computed over ice-retreat season of March through May (contact: Muyin Wang)

Status and trends: NA

Influential factors: NA

b.) Spring to summer (April-June) daily sea surface temperatures (SST) for the southeastern Bering Sea shelf from the NOAA Coral Reef Watch Program: Spring to summer (April-June) daily sea surface temperatures (SST) for the southeastern Bering Sea shelf from the NOAA Coral Reef Watch Program (contact: Jordan Watson)

Status and trends: While inter-annual variability is evident, a generally increasing trend is apparent (from both linear and non-linear smoothers). However, a cold stanza is a dominant feature for a portion of the time series. Recent years appear remarkably warmer than the majority of the time series.

Influential factors: Um, global climate change?

c.) Summer (July-September) bottom temperatures over the southeastern Bering Sea shelf from the Bering 10K ROMS-NPZ model: Summer (July-September) bottom temperatures over the southeastern Bering Sea shelf from the Bering 10K ROMS-NPZ model (contact: Kelly Kearney)

Status and trends: At 3.30C, 2021 conditions were slightly warmer than the average simulated SEBS mean bottom temperature between 1970-2021 (2.79C), following slightly cooler than average conditions in 2021 (2.41C). In the summer, much of the SEBS region bottom water was very close to the 2C threshold used to define the cold pool, with a resultng cold pool index indicating warm conditions (2021: 0.17, 1970-2021 mean: 0.35). As has been the case since 2018, no below-0C water remained in the summer. When compared to previous years, conditions most closely resemble 2004 and 1982 in terms of summer bottom temperature patterns and seasonal evolution of the cold pool indices. These years were all classified as warmer than average, but not extreme, with a spatial pattern showing patches of summer <2C water in both the northern and southern parts of the southeast middle shelf, some <1C water in the northern parts of the SEBS region, and no <0C water.

Influential factors: NA

d.) Anomalies of average daily sea-ice extent relative to 1978-2010 mean computed over ice-advance season of December through February: Anomalies of average daily sea-ice extent relative to 1978-2010 mean computed over ice-advance season of December through February (contact: Muyin Wang)

Status and trends: NA

Influential factors: NA

e.) North Pacific Index (NPI) calculated as the area-weighted sea level pressure (SLP) from November to March over the region 30Â°N-65Â°N, 160Â°E-140Â°W: North Pacific Index (NPI) calculated as the area-weighted sea level pressure (SLP) from November to March over the region 30Â°N-65Â°N, 160Â°E-140Â°W (contact: Muyin Wang)

Status and trends: NA

Influential factors: NA

2.) Lower Trophic Indicators

a.) Peak timing of the spring bloom averaged across individual ADF&G statistical areas in the southeastern Bering Sea from the MODIS satellite: Peak timing of the spring bloom averaged across individual ADF&G statistical areas in the southeastern Bering Sea from the MODIS satellite (contact: Jens Nielsen)

Status and trends: 2021 spring bloom timing was close to the long-term mean peak timing

Influential factors: NA

b.) Summer euphausiid abundance for the eastern Bering Sea shelf from the AFSC acoustic survey: Summer euphausiid abundance for the eastern Bering Sea shelf from the AFSC acoustic survey (contact: Patrick Ressler)

Status and trends: NA

Influential factors: NA

3.) Upper Trophic Indicators

a.) Arrowtooth flounder total biomass from the most recent stock assessment model in the EBS: Arrowtooth flounder total biomass from the most recent stock assessment model in the EBS (contact: Kalei Shotwell)

Status and trends: NA

Influential factors: NA

b.) Summer Pacific cod area occupied estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data: Summer Pacific cod area occupied estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data (contact: Jason Conner)

Status and trends: NA

Influential factors: NA

c.) Summer Pacific cod center of gravity eastings estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data: Summer Pacific cod center of gravity eastings estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data (contact: Jason Conner)

Status and trends: NA

Influential factors: NA

d.) Summer Pacific cod center of gravity northings estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data: Summer Pacific cod center of gravity northings estimated by a spatio-temporal model using the package VAST on AFSC EBS bottom trawl survey data (contact: Jason Conner)

Status and trends: NA

Influential factors: NA

e.) Summer condition for adult (>=460 mm) Pacific cod from the AFSC EBS shelf bottom trawl survey: Summer condition for adult (>=460 mm) Pacific cod from the AFSC EBS shelf bottom trawl survey (contact: Sean Rohan)

Status and trends: In 2021, the morphometric condition of adult Pacific cod in the EBS was neutral (i.e., near the time series average) which continues the pattern of neutral morphometric condition during the prior two survey years (2018–2019). Morphometric condition near the times series average in recent years (2018–2021) represents an increase in morphometric condition after three consecutive years with negative morphometric condition in 2015–2017. Historically, the morphometric condition of adult Pacific cod increased from the time series minimum in 1999 (a ‘cold’ year with an early survey start) to the time series maximum in 2003. After 2003, morphometric condition decreased towards the time series mean and has fluctuated within one standard deviation of the time series mean from 2006–2021, except for 2012, 2015, and 2017, years wit morphometric condition >1 standard deviation below the mean.

Influential factors: Many factors contribute to variation in morphometric condition so it is unclear which specific factors contributed to neutral condition of adult Pacific cod in the EBS in 2021. Factors that may contribute to variation in morphometric condition include environmental conditions that affect prey quality and temperature-dependent metabolic rates, survey timing, stomach fullness of individual fish, fish migration patterns, and the distribution of samples within survey strata. Temperature is an important factor that can influence the morphometric condition of Pacific cod by influencing metabolic rates, prey availability, and prey quality. Historically in the eastern Bering Sea (EBS), ‘cold’ years (with a small cold pool) were associated with negative morphometric condition (e.g., 1999, 2012) and warm years (e.g., 2002-2005) were associated with positive morphometric condition. However, during recent (2018–2021) exceptionally warm recent years, the morphometric condition of Pacific cod has been neutral for adult and juvenile Pacific cod in the EBS. Temperature can negatively affect growth rates if prey resources are insufficient to make up for increased metabolic demand. In GOA, elevated temperatures during the 2014–2016 marine heatwave in the Gulf of Alaska were associated with lower growth rates of Pacific cod and lower morphometric condition in 2015 (adults and juveniles combined), likely because diminished prey resources during the heatwave were insufficient to make up for increased metabolic demand (Barbeaux et al., 2020). Additional information about the groundfish morphometric condition indicator and factors that can influence estimates of morphometric condition based on length-weight residuals in the Gulf of Alaska are described in Rohan and Prohaska (In prep).

f.) Summer condition for juvenile (<460 mm) Pacific cod from the AFSC EBS shelf bottom trawl survey: Summer condition for juvenile (<460 mm) Pacific cod from the AFSC EBS shelf bottom trawl survey (contact: Sean Rohan)

Status and trends: In 2021, the morphometric condition of juvenile Pacific cod in the EBS was neutral (within one standard deviation of the time series mean), which continues the trend of neutral morphometric condition during the prior two survey years (2018–2019). Neutral morphometric condition in recent years (2018–2021) represents a departure from negative condition in 2017 (~ 1 standard deviation below the mean) and highly positive condition in 2016 (~2 standard deviations above the mean). Historically, the morphometric condition of juvenile Pacific cod increased from the time series minimum in 1999 (a ‘cold’ year with an early survey start) to the second highest value in 2003. After 2003, morphometric condition decreased towards the time series mean and has fluctuated within one standard deviation of the time series mean from 2006–2021, except for 2009 (>1 standard deviation below the mean) and the record high in 2016 (>2 standard deviations above the mean).

Influential factors: Many factors contribute to variation in morphometric condition so it is unclear which specific factors contributed to neutral condition of juvenile Pacific cod in the GOA in 2021. Factors that may contribute to variation in morphometric condition include environmental conditions that affect prey quality and temperature-dependent metabolic rates, survey timing, stomach fullness of individual fish, fish migration patterns, and the distribution of samples within survey strata. Temperature is an important factor that can influence the morphometric condition of Pacific cod by influencing metabolic rates, prey availability, and prey quality. Historically in the eastern Bering Sea (EBS), ‘cold’ years (with a small cold pool) were associated with negative morphometric condition (e.g., 1999, 2012) and warm years (e.g., 2002-2005) were associated with positive morphometric condition. However, during recent (2018–2021) exceptionally warm recent years, the morphometric condition of Pacific cod has been neutral for adult and juvenile Pacific cod in the EBS. Temperature can negatively affect growth rates if prey resources are insufficient to make up for increased metabolic demand. In GOA, elevated temperatures during the 2014–2016 marine heatwave in the Gulf of Alaska were associated with lower growth rates of Pacific cod and lower morphometric condition in 2015 (adults and juveniles combined), likely because diminished prey resources during the heatwave were insufficient to make up for increased metabolic demand (Barbeaux et al., 2020). Additional information about the groundfish morphometric condition indicator and factors that can influence estimates of morphometric condition based on length-weight residuals in the Gulf of Alaska are described in Rohan and Prohaska (In prep).

### Socioeconomic Indicators:

1.) Fishery Performance Indicators

2.) Economic Indicators

a.) Annual real ex-vessel price per pound of EBS Pacific cod from fish ticket information: Annual real ex-vessel price per pound of EBS Pacific cod from fish ticket information (contact: Ben Fissel)

Status and trends: NA

Influential factors: NA

b.) Annual estimated real ex-vessel value of EBS Pacific cod: Annual estimated real ex-vessel value of EBS Pacific cod (contact: Ben Fissel)

Status and trends: NA

Influential factors: NA

c.) Annual estimated real revenue per unit effort measured in weeks fished of EBS Pacific cod: Annual estimated real revenue per unit effort measured in weeks fished of EBS Pacific cod (contact: Ben Fissel)

Status and trends: NA

Influential factors: NA

3.) Community Indicators

a.) Regional quotient of Pacific cod for harvesting revenue of the highly engaged community of Unalaska Dutch Harbor: Regional quotient of Pacific cod for harvesting revenue of the highly engaged community of Unalaska Dutch Harbor (contact: Sarah Wise)

Status and trends: NA

Influential factors: NA

b.) Regional quotient of Pacific cod for processing revenue of the highly engaged community of Unalaska Dutch Harbor: Regional quotient of Pacific cod for processing revenue of the highly engaged community of Unalaska Dutch Harbor (contact: Sarah Wise)

Status and trends: NA

Influential factors: NA

## Indicator Monitoring Analysis

References for statistical tests for monitoring indicator suite by stage where relevant

### Beginning Stage: Traffic Light Test

One paragraph summary of indicator status and trends over time and last five years trend Report scores by category (if applicable) and overall ecosystem and socioeconomic indicators.

### Intermediate Stage: Importance Test

One paragraph summary of importance results with analysis of highly explanatory variables for stock assessment input of interest (e.g., recruitment estimates)

### Advanced Stage: Research Model Test

Update on ecosystem linked model in development and link to relevant literature or report on model

# Data Gaps and Future Research Priorities

Copy from full ESP

# Tables

Table 1: First stage ecosystem indicator analysis for Pacific Cod, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and sablefish (blue = good conditions for sablefish, red = poor conditions, white = average conditions). A gray fill and text = "missing" will appear if there were no data for that year.

| **Indicator category** | **Indicator** | **2017 Status** | **2018 Status** | **2019 Status** | **2020 Status** | **2021 Status** |
| --- | --- | --- | --- | --- | --- | --- |
| Physical | Winter Spring North Pacific Index Model | neutral | *high* | neutral | *high* | neutral |
| Winter Sea Ice Advance BS Satellite | **low** | **low** | **low** | neutral | NA |
| Spring Sea Ice Retreat BS Satellite | **low** | **low** | **low** | neutral | NA |
| Spring Summer Temperature Surface SEBS Satellite | neutral | **high** | **high** | **high** | neutral |
| Summer Temperature Bottom SEBS Model | neutral | **high** | **high** | neutral | neutral |
| Lower Trophic | Spring Chlorophylla Peak SEBS Satellite | **low** | *high* | neutral | neutral | neutral |
| Summer Euphausiid Abundance EBS Survey | NA | neutral | NA | NA | NA |
| Upper Trophic | Summer Pacific Cod Condition Juvenile EBS Survey | neutral | neutral | neutral | NA | neutral |
| Summer Pacific Cod Condition Adult EBS Survey | **low** | neutral | neutral | NA | neutral |
| Summer Pacific Cod Center Gravity East EBS Model | neutral | **low** | *high* | NA | neutral |
| Summer Pacific Cod Center Gravity North EBS Model | **high** | **high** | **high** | NA | **high** |
| Summer Pacific Cod Area Occupied EBS Model | neutral | neutral | neutral | NA | neutral |
| Annual Arrowtooth Biomass EBS Model | neutral | neutral | **high** | **high** | NA |

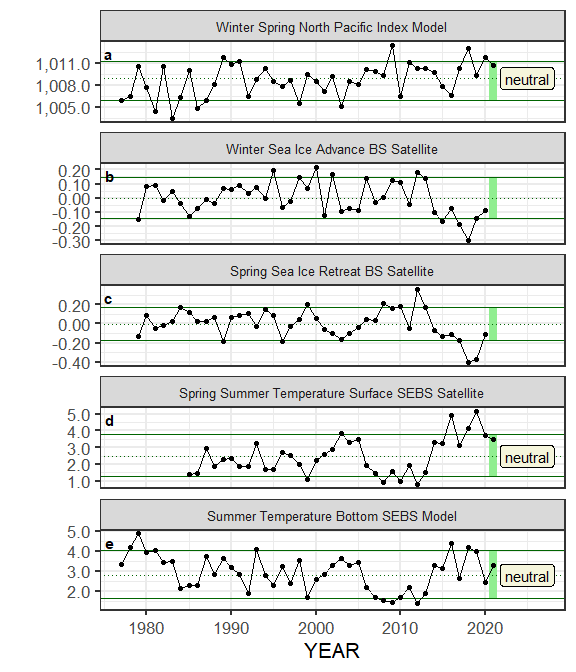
Table 2: First stage socioeconomic indicator analysis for Pacific Cod, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and sablefish (blue = good conditions for sablefish, red = poor conditions, white = average conditions). A gray fill and text = "missing" will appear if there were no data for that year.

| **Indicator category** | **Indicator** | **2017 Status** | **2018 Status** | **2019 Status** | **2020 Status** |
| --- | --- | --- | --- | --- | --- |
| Economic | Annual Pacific Cod Real Exvessel Value EBS Fishery | neutral | *high* | neutral | neutral |
| Annual Pacific Cod Real Exvessel Price EBS Fishery | neutral | neutral | neutral | *high* |
| Annual Pacific Cod Real Revenue Per Unit Effort EBS Fishery | neutral | *high* | *high* | *high* |
| Community | Annual Pacific Cod RQ Harvesting Revenue Dutch Harbor Fishery | neutral | neutral | neutral | NA |
| Annual Pacific Cod RQ Processing Revenue Dutch Harbor Fishery | neutral | neutral | **low** | NA |

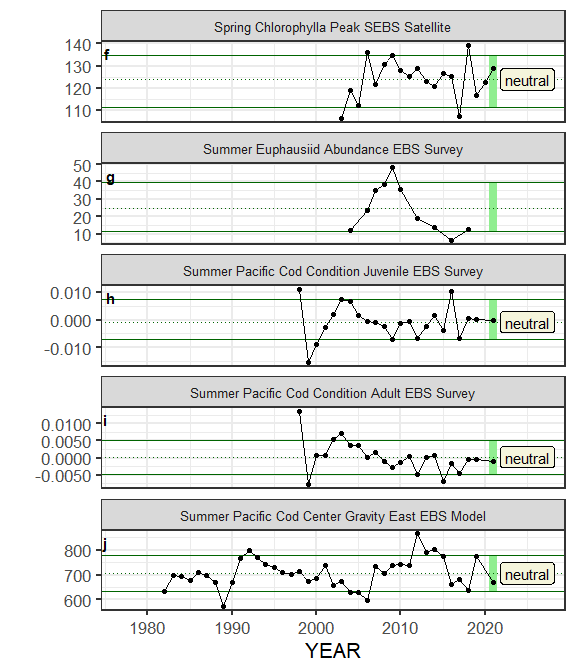
# Figures



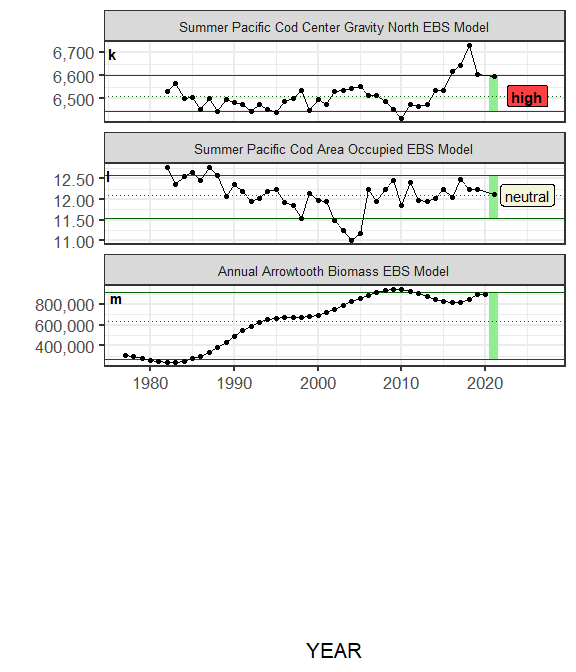
##### Figure 1. Life history conceptual model for Pacific Cod summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.



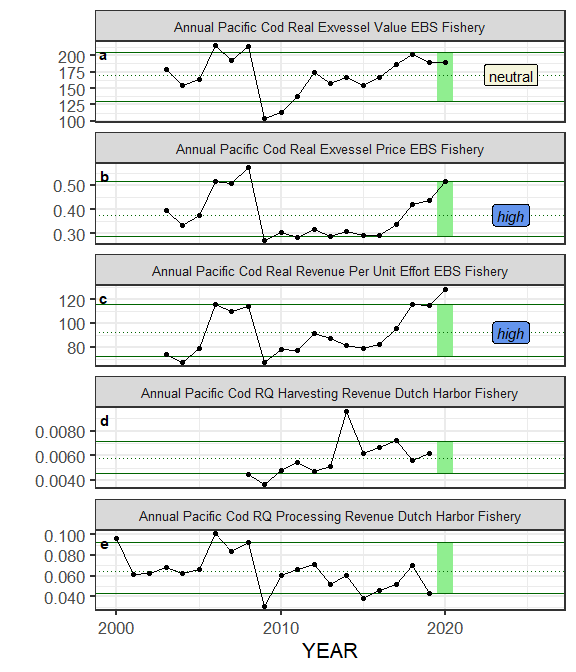
##### Figure ??. Selected ecosystem indicators for Pacific Cod with time series ranging from 1961 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results.



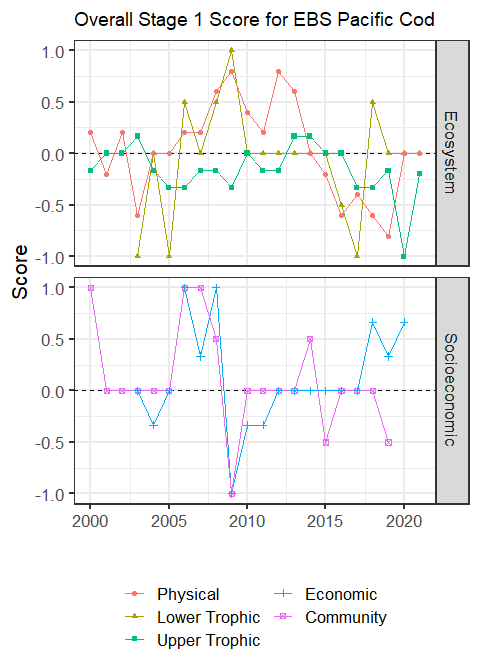
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##### Figure 3. Simple traffic light score for overall ecosystem and socioeconomic categories from 2000 to present.



##### Figure 4. Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (95% confidence intervals) with log Pacific Cod recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set