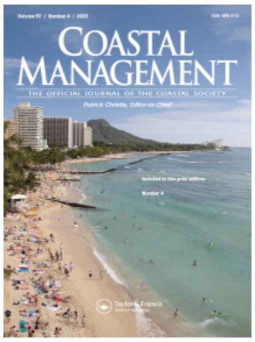


Taylor & Francis
Taylor & Francis Group

Coastal Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ucmg20

Introducing the Ecosystem and Socioeconomic Profile, a Proving Ground for Next Generation Stock Assessments

S. K. Shotwell, K. Blackhart, C. Cunningham, E. Fedewa, D. Hanselman, K. Aydin, M. Doyle, B. Fissel, P. Lynch, O. Ormseth, P. Spencer & S. Zador

COASTAL MANAGEMENT
https://doi.org/10.1080/08920753.2023.2291858

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Check for updates

Introducing the Ecosystem and Socioeconomic Profile, a Proving Ground for Next Generation Stock Assessments

S. K. Shotwell[a], K. Blackhart[b], C. Cunningham[c], E. Fedewa[d], D. Hanselman[e], K. Aydin[a], M. Doyle[f], B. Fissel[a], P. Lynch[b], O. Ormseth[a], P. Spencer[a] and S. Zador[a]

[a]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center (AFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Seattle, Washington, USA; [b]Assessment and Monitoring Division, Office of Science & Technology, NMFS, NOAA, Silver Spring, Maryland, USA; [c]College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Juneau, Alaska, USA; [d]Resource Assessment and Conservation Engineering Division, AFSC, NMFS, NOAA, Kodiak, Alaska, USA; [e]Auke Bay Laboratories Division, AFSC, NMFS, NOAA, Juneau, Alaska, USA; [f]Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington, Seattle, Washington, USA

ABSTRACT

Ecosystem-based fishery science is an important component of effective marine conservation and resource management. Implementation has progressed through large-scale comprehensive ecosystem status reports; however, integrating ecosystem research within the stock assessment process remains elusive. Primary obstacles include the lack of a consistent approach to including ecosystem and socioeconomic information into a stock assessment model and how to test its reliability for identifying future change. We introduce a methodology and reporting framework termed the Ecosystem and Socioeconomic Profile (ESP) to overcome these obstacles. The ESP facilitates the integration of ecosystem and socioeconomic factors within the stock assessment process through four steps that culminate in a focused, succinct, and meaningful communication of drivers for a given stock. The first ESP was produced for Alaska sablefish and we provide the general process to implement the ESP framework using results from the sablefish ESP. We conducted a data synthesis that allowed for the framework to be applied across multiple regions and stocks. ESPs are an efficient testing ground for developing ecosystem-linked stock assessments and provide a set of reporting tools that can be tailored to a variety of audiences in order to effectively merge the ecosystem, socioeconomic, and stock assessment disciplines.

KEYWORDS

ecosystem-based fisheries management; ecosystem indicators; integrated ecosystem assessment; next generation stock assessment

Introduction

The need to assess the interactions between fish stocks, their ecosystems, and human dimensions is well recognized. Indeed, the U.S. national standard guidelines of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) contain specific

CONTACT S. K. Shotwell kalei.shotwell@noaa.gov Alaska Fisheries Science Center, National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), 17109 Point Lena Loop Road, Juneau, Alaska, 99801, USA.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/08920753.2023.2291858.

language that requires the consideration of ecosystem and socioeconomic processes with regard to specifying optimum yield and informing Regional Fishery Management Councils (RFMCs) through stock assessment and fishery evaluation (SAFE) reports (16 U.S.C. 1851 (1,2)). Progress toward implementation of ecosystem-based fishery management (EBFM) has certainly been made (Dolan, Patrick, and Link 2016), particularly with improving definitions (Link and Browman 2017) and providing examples dispelling common myths that are seen as obstacles to this approach (Patrick and Link 2015). Comprehensive ecosystem and economic assessments have existed since the 1990s for many large marine ecosystems (e.g., Livingston 1999; Hiatt and Terry 1999), and many regions are now adopting a more formalized integrated ecosystem assessment (IEA) framework (Levin et al. 2009). A product of these comprehensive assessments are the ecosystem status reports (ESRs) that serve to provide a general sense of ecosystem and socioeconomic condition for U.S. RFMCs and other governing organizations (e.g., Zador and Yasumiishi, 2017; Karnauskas et al. 2017; Fissel et al. 2020; Gove et al. 2019; Harvey et al. 2020). These syntheses have been very useful in providing contextual advice for decision making and allow for adaptive communication within the fisheries management process (Zador et al. 2017). While many stock assessment reports include background or qualitative considerations of ecosystem and socioeconomic information, the uptake within the operational stock assessment model remains low and it is not clear how and when to include this information within the stock assessment process (Marshall et al. 2019). This may be largely due to the lack of a standardized framework that allows for consistent, rational, and tactical adjustments to the stock assessment model and report based on ecosystem and socioeconomic research. Alternative pathways for incorporating ecosystem and socioeconomic information directly into fishery management decisions rather than through the operational stock assessment model exist, but are not consistently identified (e.g., Zador et al. 2017; Marshall et al. 2019).

While the need for various types of ecosystem science has been at the forefront of effective marine conservation and resource management (Levin et al. 2009), we maintain that a standardization challenge continues to impede progress despite the improved clarity in the definitions of various levels of ecosystem management (Dolan, Patrick, and Link 2016). A consistent framework can be an effective communication tool to increase direct synthesis of ecosystem information within the stock assessment and evaluation process (Gaichas et al. 2016). In the United States, the stock assessment process uses a standardized reporting framework of traditional measures like biomass and demographic data (e.g., SAFE) that is fundamental to successful fishery management. Similarly, the ecosystem and socioeconomic assessment process follows the IEA methodology and the resulting status reports (e.g., ESR) are becoming standardized to assist with communication and maximize the benefit for informing fishery management decisions. However, the gap between the stock assessment and ecosystem or socioeconomic assessment process remains. Specifically, the broader ecosystem assessment outputs have been difficult to interpret at the stock level, and it often remains unclear how this information can directly inform management decisions (e.g., Tommasi et al. 2021). A standardized framework that brings together these often-siloed areas of expertise will efficiently and effectively complete the feedback loop between stock assessment, ecosystem/socioeconomic assessment, and fisheries management (e.g., Gaichas et al. 2016, Morrison et al. 2022).

Facilitating information flow and connections between stock assessments and ecosystem/socioeconomic assessments should allow for increased uptake of this information along the continuum of EBFM (Dolan, Patrick, and Link 2016). To accomplish this, we formally introduce the Ecosystem and Socioeconomic Profile (ESP) which is a standardized methodology and reporting framework, facilitating the integration of ecosystem and socioeconomic factors within the stock assessment and fisheries management process. Developing the ESPs is a commitment to a process that allows for creating a proactive communication strategy in response to change. Here we are building on the rich history of identifying ecosystem pressures on stocks (Hollowed, Bailey, and Wooster 1987; Megrey et al. 1996; Bailey et al. 2005; Peterson et al. 2014; Sagarese, Lauretta, and Walter 2017) and designing a framework that tests these linkages for providing advice. The ESP can be viewed as a stock-specific proving ground for potential operational use of ecosystem or socioeconomic information in quota setting and it bridges the gap between the stock assessment, ecosystem, and socioeconomic communities (Figure 1). The ESP builds off of recommendations for including ecosystem and socioeconomic information in stock assessment such as detailed in NOAA's Next Generation Stock Assessment Improvement Plan (NGSAIP; Lynch, Methot, and Link 2018). The concept of the ESP started in 2014 in anticipation of NGSAIP-type guidance and in response to a suggested revamping of current ecosystem considerations sections within the SAFE reports for the Alaska groundfish Fishery Management Plans (FMPs) of the North Pacific Fishery Management Council (NPFMC; Shotwell, Hanselman, and Belkin 2014). In response to review through the advisory bodies of the NPFMC, the ESP framework was developed and refined over the next several years through a case study using Alaska sablefish (Shotwell et al. 2016) and it formally

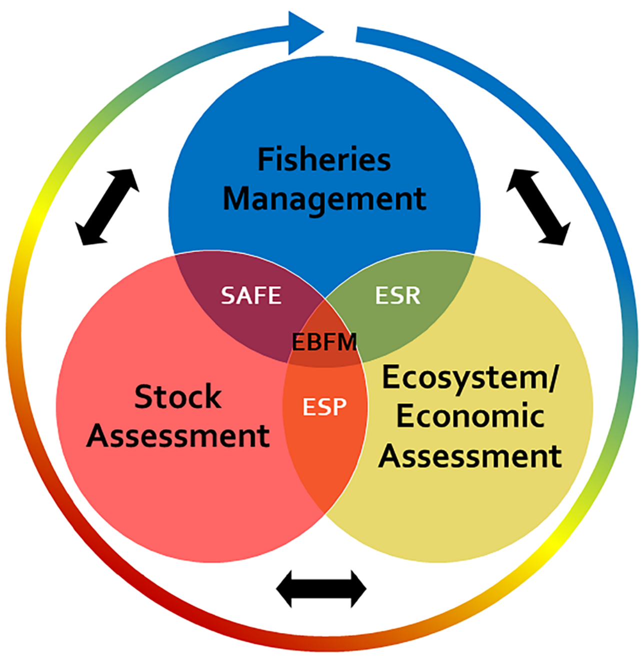


Figure 1. Feedback loop infographic of the primary disciplines in ecosystem-based fisheries management. SAFE: stock assessment fishery evaluation; ESR: ecosystem status report; ESP: ecosystem and socioeconomic profile; EBFM: ecosystem-based fishery management.

appeared in the Alaska sablefish SAFE as an appendix in 2017 (Hanselman et al. 2017). ESPs continue to be developed annually for sablefish and other stocks in Alaska (e.g., Hanselman et al. 2018, 2019; Dorn et al. 2019, 2020; Palof, Zheng, and Ianelli 2019, 2020; Goethel et al. 2020, 2022), and a series of workshops were also conducted at the Alaska Fisheries Science Center (AFSC) to develop and maintain the ESPs for the groundfish and crab stocks in the North Pacific region (Shotwell 2018, 2020).

Here, we describe the general process to implement the ESP framework. The primary goals of the ESP are to increase the integration of ecosystem and socioeconomic information within fishery management decisions and to establish a standardized communication pathway for products of EBFM research activities to inform scientists, stakeholders, and the public. To initiate this process for Alaska managed stocks, we capitalized on information collected *via* a suite of data initiatives that have been conducted over the past decade (please see Supplementary Material for a description of the United States (U.S.) national initiatives and the Alaska data collection process). A survey form was created for Alaska federally managed stocks that contained questions fulfilling the requirements of multiple data calls from these initiatives. Information regarding stock status, stock assessment parameters, distribution and biology, early life history, movement, habitat, prey, predators, ecosystem status, and economic status was collected for each stock or stock complex. The survey forms essentially created an ecological synthesis for each stock. Since these syntheses were created for multiple stocks (e.g., data-limited to data-rich, single stock to stock complex), the ESP framework is designed to be applied across multiple regions and on a wide variety of stocks. Next, we detail each step of the ESP process and resulting product, and for the purpose of illustration, we also include example data and graphics used in the Alaska sablefish ESP (Hanselman et al. 2019; Goethel et al. 2020, 2022) where appropriate.

ESP process

We developed a stepwise process to create the ESP for a given stock or stock complex. We suggest four primary steps to guide the ESP process (Figure 2). The first step is a focused effort to assess which stocks are priority stocks for conducting an ESP. The stock status and frequency, as well as the stock's vulnerability to a number of different pressures should be objectively reviewed with respect to other managed stocks in the region (e.g., Patrick et al. 2010; NMFS 2011; Methot 2015; Morrison et al. 2015; Lynch, Methot, and Link 2018) and combined with regional science research priorities to determine if the stock is a priority for producing an ESP. Given that each stock has differing levels of data availability, it is imperative to categorize these levels to set up appropriate and tangible regional research priorities. The second step is a synthesizing exercise that identifies vulnerabilities to overfishing, ecological pressures, and climate change throughout the life history of the stock. It begins with a thorough literature evaluation of ecosystem and socioeconomic processes driving stock dynamics and may be combined with developing a standard set of metrics from descriptive data available for the stock. This step creates an ecological synthesis of the stock and leads to developing a mechanistic understanding of the drivers for the stock. This leads to the third step to create and analyze a suite of stock-relevant indicators. This should include frequent monitoring and analysis of trends in these indicators using tests appropriate

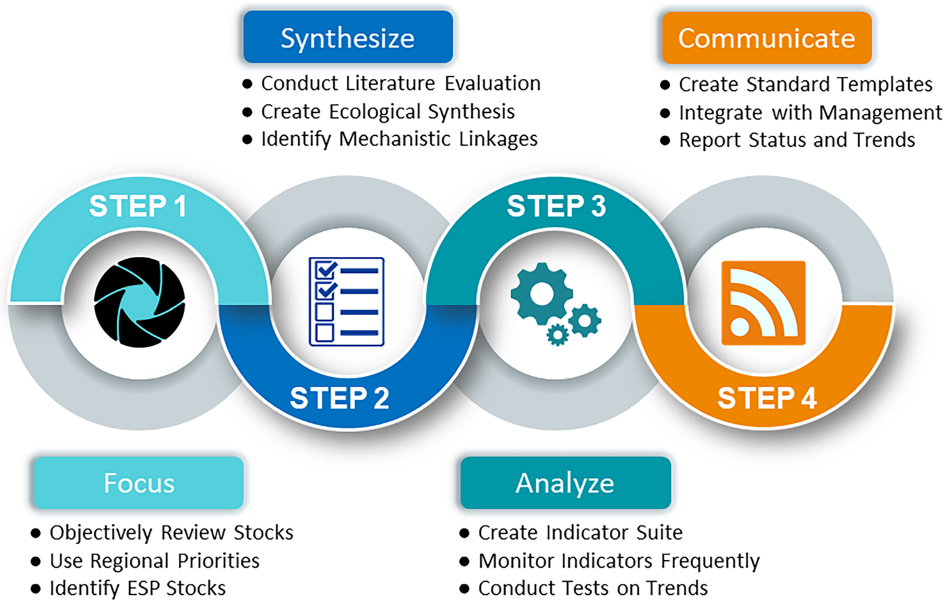


Figure 2. Ecosystem and socioeconomic profile (ESP) process describing the four steps from the initial focusing effort, to synthesizing and identifying mechanisms, then analyzing indicators and testing, and finally communicating the standardized report within the stock assessment cycle.

to the data available for the stock. The fourth and final step is to communicate the results of the first three steps through a set of standardized reporting templates that concisely conveys the status and trends of the leading indicators to fisheries managers within the stock assessment cycle.

Step 1 – focusing on ecosystem and socioeconomic priorities

Just as the complexity of an operational stock assessment is established to match the data available for that stock (Methot 2015), the inclusion of ecosystem or socioeconomic factors should be evaluated in a similar fashion. Prior to conducting an ESP in any area, it is important to categorize the data available for a given stock and evaluate the vulnerable life history attributes of the stock with respect to other stocks in the area to determine if an ESP is a priority to conduct. Science research priorities for the stock and recommendations from fisheries management councils or organizations should also be taken into consideration.

As a starting point, a data classification system such as the NOAA Fisheries Stock Assessment Classification System (Lynch, Methot, and Link 2018, see Supplemental Material for more details) may be used for determining which stocks have enough data to explore the influence of ecosystem or socioeconomic pressures on stock dynamics. The classification scores can be used as an initial rank for determining which stocks are candidates for developing an ESP. Stocks with higher scores across the data input categories such as catch, abundance, size/age composition, and life history data, and any consideration of ecosystem linkages could be potential candidates for an ESP because there are sufficient data for the stock and exploring ecosystem linkages is already a priority for the assessment. Stocks with only moderate stock-specific life history data may also be considered potential candidates for an ESP because stock-specific vulnerabilities to ecological pressures could be identified to allow for exploration of ecosystem or socioeconomic linkages. This allows for stocks that are considered data-limited in other input categories to be elevated for an ESP. These scores can be coupled with scores from other prioritization and vulnerability initiatives (e.g., Patrick et al. 2010; NMFS 2011; Methot 2015; Morrison et al. 2015, see Supplemental Material for more details) to provide additional support for conducting an ESP. Finally, ecosystem or socioeconomic science research priorities specific to a stock and/or recommendations from a regional fishery management council or organization may be used to make a final determination on if and when an ESP should be conducted.

We detail the results of these scores for Alaska sablefish as an example of how the overall data initiative scores combined with regional priorities could be used to justify conducting an ESP. Scores were compiled and summarized for all Alaska federally managed stocks for Stock Assessment Classification (Shotwell and Blackhart 2023), Stock Assessment Prioritization (Hollowed et al. 2016), and Habitat Assessment Prioritization (McConnaughey et al. 2017). A Productivity-Susceptibility Analysis (Ormseth and Spencer 2011) was completed for most of the Alaska groundfish stocks and a Climate Vulnerability Assessment (Spencer et al. 2019) was completed for a selection of Alaska groundfish and invertebrate stocks, particularly in the eastern Bering Sea. The prioritization scores for Alaska sablefish were overall relatively high due to the high commercial importance of this stock and early life history habitat requirements (13.8 in Table 2 of Hollowed et al. 2016; 16 in Table 2 of McConnaughey et al. 2017). The vulnerability scores were in the moderate range of all groundfish scores based on productivity, susceptibility (1.64 in Tables 2 and 3 of Ormseth and Spencer 2011), and sensitivity to future climate

Table 1. Sources for metric data of species in Alaska fishery management plans.

Database	Description	Reference
Fish Life History Database	Access to life history information for species in eastern Bering Sea, Aleutian Islands, and Gulf of Alaska federal management areas	Alaska Fisheries Science Center online database: https://access.afsc.noaa.gov/reem/LHWeb/Index.php
Ichthyoplankton Information System	Identify and access information on fish eggs and larvae collected in the northeast Pacific Ocean, Bering Sea, Chukchi Sea, and Beaufort Sea	Alaska Fisheries Science Center online database: https://access.afsc.noaa.gov/ichthyo/index.php
Stock SMART	Access to NOAA Fisheries stock assessment information through the Stock Status, Management, Assessment, and Resource Trends (SMART) web tool.	Alaska Fisheries Science Center online database: https://www.st.nmfs.noaa.gov/stocksmart?app=homepage
Species Information System	Access to information on status of U.S. federal managed stocks and stock assessment results and associated data	National Marine Fisheries Service online database: https://www.st.nmfs.noaa.gov/sisPortal/
FishBase	Access to summary information on fish life history, distribution, and various ecosystem and socioeconomic factors	Froese and Pauly (2018)
Productivity Susceptibility Analysis	An assessment of vulnerability in Alaska groundfish	Ormseth and Spencer (2011)
Climate Vulnerability Assessment	Trait-based climate vulnerability assessments in data-rich systems: an application to eastern Bering sea fish and invertebrate stocks	Spencer et al. (2019)
Habitat Assessment Prioritization	Habitat assessment prioritization for Alaska stocks: Report of the Alaska Regional Habitat Assessment Prioritization Coordination Team	McConnaughey et al. (2017)

Table 2. Subset of metrics used for the ecosystem and socioeconomic profiles (ESP) of the Alaska fishery management plan stocks.

Metric	Description	Vulnerability	Range	Threshold
Commercial Importance	Transformed landed value of stock relative to most valuable regional stock [3+]	High value stocks experience more fishing pressure	0 to 1	0.65 to 0.73
Constituent Demand	Index of demand for stock assessment excellence on 0 to 5 scale[3]	High value implies more societal demand	0 to 5	NA
Natural Mortality	Rate of mortality due to non-fishing related causes, reflects stock productivity[1]	High value means more non-fishing pressure	0.03 to 1	0.2 to 0.5
Recruitment Variability	Coefficient of variation for annual fluctuations in recruitment of young fish into a stock[3]	High value implies rapidly changing recruitment over time	0.3 to 1.6	0.3 to 0.9
Growth Rate*	Coefficient (k) that measures how fast stock reaches maximum size[1,2,3]	Low value implies longer-lived and lower productivity	0.02 to 0.45	0.1 to 0.25
Population Growth Rate	Combination of multiple population proxies (e.g., maximum age or length, natural mortality, maturity) and considering accuracy and precision of values[2]	High value implies a k-selected species, longer-lived, slower growth	2.3 to 3.7	2.5 to 3.5
Age 1st Maturity	Age at first maturity in years, often related to natural mortality and maximum age[1,2]	High value implies slower growth and lower productivity	1 to 19	2 to 5
Age 50% Maturity	Age at 50% maturity in years, often related to natural mortality and maximum age[1]	High value implies slower growth and lower productivity	3.6 to 36	NA
Mean Age	Best estimate of mean age in years using available age data or estimate of natural mortality[3]	High value implies longer-lived and lower productivity	2 to 31	NA
Maximum Age	Maximum age in years, inversely related to natural mortality[1,2]	High value implies longer-lived and lower productivity	2 to 157	10 to 25
Length 50% Maturity	Size at 50% maturity in centimeters, largest of males and females[2]	High value implies slower growth and lower productivity	13.5 to 130	NA
Maximum Length	Maximum size of fish in centimeters, largest of males and females[1,2]	High value implies lower productivity	16 to 195	55 to 155
Latitude Range*	Estimated difference in latitudinal limits (degrees) of the stock range[2]	Low value implies species sensitivity to a province	12 to 53	NA
Depth Range*	Estimated difference in depth range (meters) within the water column[1,2]	Low value implies species sensitivity to particular depth	75 to 2000	NA
Temperature Sensitivity	Range of temperatures over which species occurs, depth range and ocean provinces may be used[2]	High value implies species occurs in a narrow range of temperatures (<5 deg C), or is found within one province and has a limited depth distribution (<100 m)	1.55 to 3.2	2.5 to 3.5
Geographic Concentration	Index of extent that stock is concentrated in small areas (e.g., patchiness) on 1 to 3 scale[1]	High value implies more susceptibility to fishing pressure	1 to 3	1 to 3
Fecundity*	Number of eggs per female for a spawning event measured at age of 1st maturity[1]	Low value implies low population productivity	4.5 to 3,700,000	1000 to 100,000
Breeding Strategy Index	Winemiller's Index of parental investment as indicator of early life mortality on 1 to 14 scale[1]	High value implies more investment, lower productivity	0 to 8	0 to 4

(*Continued*)

Table 2. Continued.

Metric	Description	Vulnerability	Range	Threshold
Reproductive Strategy	Number of characteristics that suggest complexity in reproductive strategy[2]	High value means stock has four or more characteristics that suggest complexity in reproductive strategy	1.6 to 2.3	2.5 to 3.5
Spawning Cycle	Number of spawning events per year and number of seasons over which spawning occurs[2]	High value implies the spawning season occurs once a year over a brief period of time	2.2 to 3.8	2.5 to 3.5
Spawning Duration*	Duration of the spawning cycle in months[2]	Low value implies specific conditions for spawning	2 to 12	NA
Early Life History Survival Settlement	Biological and physical requirements for larval survival, nonspecific to specific	High value implies very specific requirements, dependence on environmental conditions	2 to 2.7	2.5 to 3.5
Dispersal Early Life History	Index of the stock dispersal ability based on dispersal distances or larval duration on 1 to 4 scale[2]	High value implies minimal larval dispersal	1 to 3.6	2.5 to 3.5
Adult Mobility	Index of stock mobility based on physical and behavioral ability to move on 1 to 4 scale[2]	High value implies stock as sessile adults	1 to 2.6	2.5 to 3.5
Habitat Specificity	Index based on stock being a habitat generalist or specialist and availability of habitat on 1 to 4 scale[2,4]	High value implies the stock is a specialist on restricted habitat	1 to 2.6	2.5 to 3.5
Habitat Dependence	Index based on how dependent stock is on habitat on 1 to 3 scale[4]	High value implies vital rates are influence by essential fish habitat	1 to 3	1 to 5
Prey Specificity	Index based on stock being a prey generalist or specialist as juvenile or adults on 1 to 4 scale[2]	High value implies the stock depends on one type of prey and is unable to switch	1 to 2.8	2.5 to 3.5
Ocean Acidification Sensitivity	Index of stock reliability on sensitive taxa to changes in ocean pH on 1 to 4 scale[2]	High value implies stock is or is dependent on sensitive taxa for food or habitat	1 to 2.8	2.5 to 3.5
Other Stressors	Index of detrimental impacts on stock from other stressors such as disease, pollution, food web shift, on 1 to 4 scale[2]	High value implies stock is impacted by four or more known stressors	1 to 2.2	2.5 to 3.5
Mean Trophic Level	Position of stock within larger fish community based on diet[1]	High value implies lower productivity	3.2 to 4.4	2.5 to 3.5
Ecosystem Importance (or Value) Bottom-Up	Index of stock contribution as forage or habitat in the ecosystem, on 1 to 5 scale[3]	High value implies stock major component for broad range of stocks	1 to 5	1.5 to 3
Ecosystem Importance (or Value) Top-Down	Index of stock contribution as predator or ecosystem interaction, on 1 to 5 scale[3]	High value implies change in stock abundance impacts broad range of stocks	0 to 5	1.5 to 3
Non-Catch Value	Index of value placed on the stock that is not associated with harvest (e.g., public sentiment for protection) on 0 to 5 scale[3]	High value implies more societal demand	0 to 5	NA

Metric names with brief description, suggested vulnerability, range of metric values (specific to Alaska groundfish stocks), and thresholds based on national initiative references (see table footnote). An asterisk (*) by metric name means the values have been reversed for comparison with other metrics (e.g. growth rate is reversed because lower growth rate is associated with low productivity which is associated with high vulnerability).

1 = PSA: productivity/susceptibility analysis (Patrick et al. 2010); 2 = CVA: climate vulnerability assessment (Morrison et al. 2015); 3= SAP: stock assessment prioritization (Methot 2015); 4 = HAP: habitat assessment prioritization (NMFS 2011).

3+ Commercial value was also used in the PSA and HAP, but not as a transformed value.

Table 3. Current indicator suite of Alaska sablefish ESP (reproduced from Hanselman et al. 2019 and Goethel et al. 2020).

Indicator Name	Type	Category	Description	Year
Annual Heatwave GOA Model	Ecosystem	Physical	Annual marine heatwave index is calculated from daily sea surface temperatures for 1981 through August 2019 from the NOAA High-resolution Blended Analysis Data for the central GOA (< 300 m). Daily mean sea surface temperature data were processed to obtain the marine heatwave cumulative intensity (MHWCI) (Hobday et al. 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the January 1983 through December 2012 time series (pers. commun., S. Barbeaux)	2019
Summer Temperature 250 m GOA Survey	Ecosystem	Physical	Summer temperature profiles were recorded during the annual longline survey along the continental slope using an SBE39 (Seabird Electronics) attached to the groundline approximately one-third of the way in from the shallow portion of a station (Malecha et al. 2019). In the GOA, 13 stations had complete temperature profiles for the entire timeseries (2005–2019). Annual anomalies from the 15-year mean can be calculated by station at discrete depths, and an index for each year can be represented by the mean of these anomalies at a chosen depth. Interpolation between actual depth recordings in a profile was conducted using weighted parabolic interpolation (Reiniger and Ross, 1968). The 250 m isobath was selected to represent deeper water at the shelf-slope break where adult sablefish are typically sampled (pers. commun., K. Siwicke)	2019
Spring Temperature Surface EGOA Satellite	Ecosystem	Physical	Late spring (May-June) daily sea surface temperatures (SST) for the eastern GOA (Watson, 2020) from the NOAA Coral Reef Watch Program which provides the Global 5 km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018). The data are served through the ERDDAP maintained by NOAA CoastWatch West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division. Available from 1985 to present (pers. commun., J. Watson)	2020
Spring Temperature Surface SEBS Satellite	Ecosystem	Physical	Late spring (May-June) daily sea surface temperatures (SST) for the southeastern Bering Sea (Watson, 2020) from the NOAA Coral Reef Watch Program which provides the Global 5 km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018). The data are served through the ERDDAP maintained by NOAA CoastWatch West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division. Available from 1985 to present (pers. commun., J. Watson)	2020
Spring Chlorophylla Peak EGOA Satellite	Ecosystem	Physical	Derived chlorophyll a concentration during spring seasonal peak (May) in the eastern GOA were obtained from MODIS satellite sensor at a 4×4 km resolution and aggregated 8-day composite. Peak timing of the spring bloom was calculated for the eastern GOA (EGOA) region (Watson et al. 2020) (pers. commun., J. Watson)	2020
Spring Chlorophylla Peak SEBS Satellite	Ecosystem	Physical	Derived chlorophyll a concentration during spring seasonal peak (May) in the southeastern Bering Sea were obtained from MODIS satellite sensor at a 4×4 km resolution and aggregated 8-day composite. Peak timing of the spring bloom was calculated for individual ADF&G statistical areas in the southeastern Bering Sea (SEBS) region (Nielson et al. 2020). Peak timing was then averaged across all statistical areas in order to weight each stat area equally. This is to avoid giving inner shelf areas more weight since the chlorophyll a biomass is higher in those areas during the peak. Data available from 2003 to present (pers. commun., J. Nielson)	2020
Annual Copepod Community Size EGOA Survey	Ecosystem	Lower Trophic	Abundance of copepod community size from the continuous plankton recorder (CPR) for the offshore waters of the eastern GOA split section (Ostle and Batten, 2020), 2002–2019 (pers. commun., C. Ostle)	2020

(*Continued*)

Table 3. Continued.

Indicator Name	Type	Category	Description	Year
Annual Copepod Community Size WGOA Survey	Ecosystem	Lower Trophic	Abundance of copepod community size from the continuous plankton recorder (CPR) for the offshore waters of the western GOA split section (Ostle and Batten, 2020), 2002–2020 (pers. commun., C. Ostle)	2020
Summer Euphausiid Abundance Kodiak Survey	Ecosystem	Lower Trophic	Summer euphausiid abundance is represented as the acoustic backscatter per unit area (sA at 120 kHz, m2 nmi-2) classified as euphausiids and integrated over the water column and then across the surveyed area to produce an annual estimate of acoustic abundance (sA * area, proportional to the total abundance of euphausiids). The index is for the Kodiak core survey area available for variable years historically and biennially since 2013 (Ressler et al. 2019) (pers. commun., P. Ressler)	2019
Annual Sablefish Growth YOY Middleton Survey	Ecosystem	Lower Trophic	An age-0 sablefish growth is calculated as the coefficient for the regression of length (mm) by Julian day for each year and effectively tracks the nearshore age-0 growth rate of sablefish. Data have been collected since 1978 by the Institute for Seabird Research and Conservation and analyzed by the U.S. Geological Service. (Arimitsu and Hatch, 2019) (pers. commun., M. Arimitsu)	2017
Summer Sablefish CPUE Juvenile Nearshore GOAAI Survey	Ecosystem	Upper Trophic	The ADF&G large mesh bottom trawl survey of crab and groundfish has been conducted annually from 1988 to present and samples on a fixed grid in the Kodiak to eastern Aleutian area. Sablefish catch-per-unit-effort and lengths were summarized for the survey region. Sablefish lengths generally consist of fish between ages 2–4 and can be considered an index of sablefish juveniles in the nearshore prior to returning to adult habitat (Spalinger 2015) (pers. commun., K. Spalinger)	2017
Summer Sablefish CPUE Juvenile GOA Survey	Ecosystem	Upper Trophic	Catch-per-unit-of-effort of juvenile sablefish (<400 mm, likely age-1,2) collected on summer bottom-trawl surveys from 1984 to present	2019
Annual Sablefish Mean Age Female Adult Model	Ecosystem	Upper Trophic	Mean age of sablefish female spawning stock biomass from the most recent sablefish stock assessment model, 1977 to present (pers. commun., D. Goethel)	2019
Annual Sablefish Age Evenness Female Adult Model	Ecosystem	Upper Trophic	Measure of evenness or concentration of age composition by cohort of female sablefish from the most recent sablefish stock assessment model, 1977 to present (pers. commun., D. Goethel)	2019
Summer Sablefish Condition Female Age4 GOA Survey	Ecosystem	Upper Trophic	Summer sablefish condition for age 4, mature female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly for otoliths in the annual GOA AFSC longline survey (legs 2–7 including slope and cross gully stations), 1996 to present (pers. commun., J. Sullivan and K. Siwicke)	2018
Annual Arrowtooth Biomass GOA Model	Ecosystem	Upper Trophic	Arrowtooth flounder total biomass (metric tons) from the most recent stock assessment model, 1977 to present	2019
Annual Sablefish Incidental Catch Arrowtooth Target GOA Fishery	Ecosystem	Upper Trophic	Incidental catch of sablefish in the GOA arrowtooth flounder fishery, data available from AKFIN, 1992 to present	2019

(*Continued*)

Table 3. Continued.

Indicator Name	Type	Category	Description	Year
Summer Sablefish Condition Female Adult GOA Survey	Ecosystem	Upper Trophic	Summer sablefish condition for large adult (>=750 mm) female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly for otoliths in the annual GOA AFSC longline survey (legs 2–7 including slope and cross gully stations), 1996 to present (pers. commun., J. Sullivan and K. Siwicke)	2019
Annual Sablefish Longline CPUE GOA Fishery	Socioeconomic	Fishery Performance	Catch-per-unit-of-effort of sablefish in tons from the longline fisheries in the GOA, 1996 to present (pers. commun., D. Goethel)	2019
Annual Sablefish Pot CPUE EBS Fishery	Socioeconomic	Fishery Performance	Catch per unit of effort of sablefish in tons estimated from the pot fisheries in the eastern Bering Sea, 1999 to present (pers. commun., D. Goethel)	2019
Annual Sablefish Incidental Catch BSAI Fishery	Socioeconomic	Fishery Performance	Incidental catch estimates of sablefish in the Bering Sea fisheries excluding the sablefish fishery provided by AKFIN, 1991 to present	2019
Annual Sablefish Incidental Catch GOA Fishery	Socioeconomic	Fishery Performance	Incidental catch estimates of sablefish in the GOA fisheries excluding the sablefish fishery provided by from AKFIN, 1991 to present	2019
Annual Sablefish Condition Female Adult GOA Fishery	Socioeconomic	Economic	Sablefish condition for large (>= 750 mm) female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly by observers for otoliths in the GOA fishery, 1999 to present (pers. commun., J. Sullivan and K. Siwicke)	2019
Annual Sablefish Condition Female Adult BSAI Fishery	Socioeconomic	Economic	Sablefish condition for large (>= 750 mm) female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly by observers for otoliths in the BSAI fishery, 1999 to present (pers. commun., J. Sullivan and K. Siwicke)	2019
Annual Sablefish Real Exvessel Value Fishery	Socioeconomic	Economic	Annual estimated real ex-vessel value measured in millions of dollars and inflation adjusted to 2019 USD (pers. commun., B. Fissel)	2018
Annual Sablefish Real Exvessel Price Fishery	Socioeconomic	Economic	Average real ex-vessel price per pound of sablefish measured in millions of dollars and inflation adjusted to 2019 USD (pers. commun., B. Fissel)	2019

Type is the main organizational heading of an indicator, either ecosystem or socioeconomic, for an ESP. Category is a sub-organizational heading for the indicator and falls into physical, lower trophic, or upper trophic options for ecosystem type indicators or fishery performance, economic, or community options for socioeconomic type indicators. Year is the year that the indicator was accepted into the sablefish ESP.

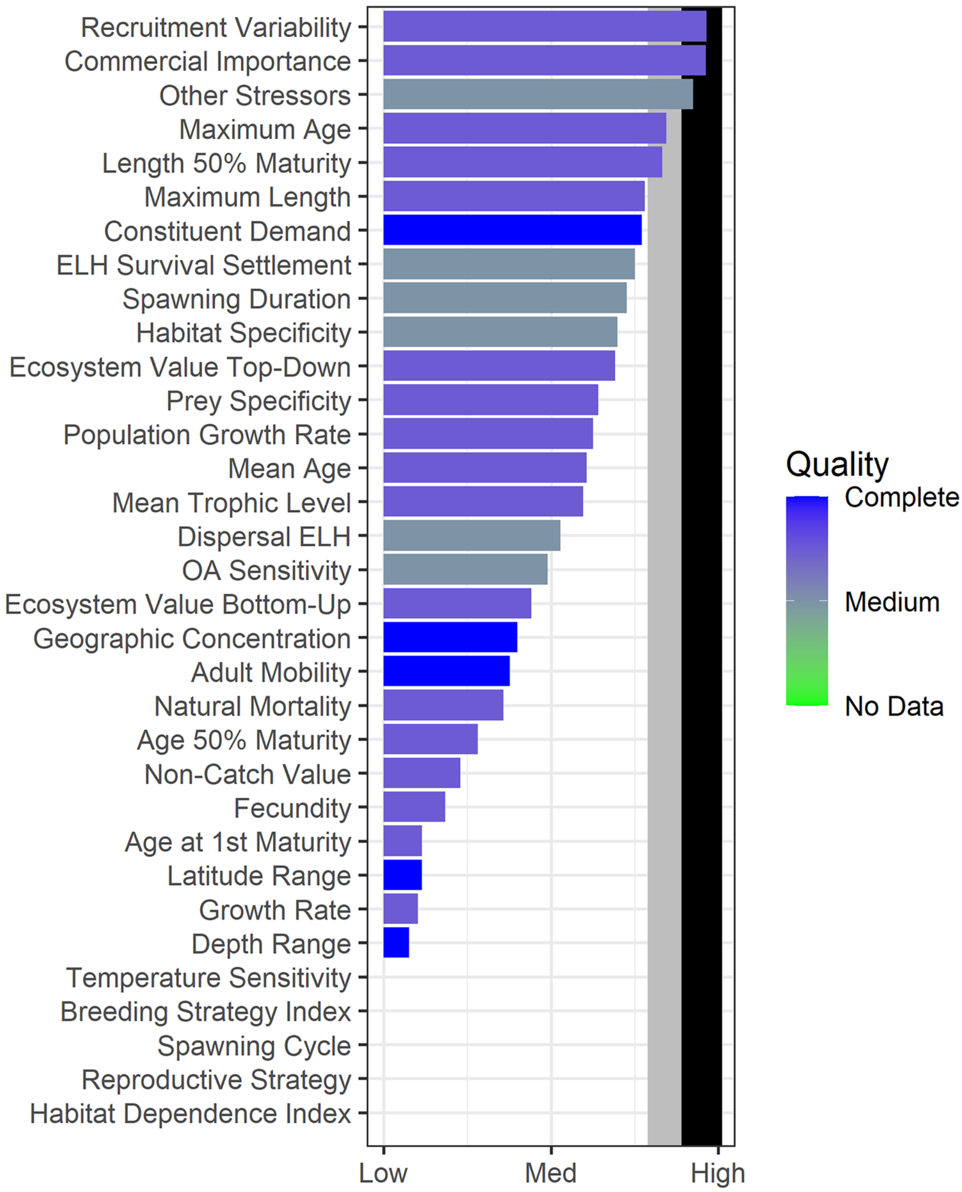


Figure 3. Metric panel for sablefish graded as percentile rank over all groundfish in the fishery management plan (black shaded bar representing the 90th percentile rank, gray shaded bar representing the 80th percentile rank). Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (please see Table 2 for metric attribute descriptions and refer to the subscripts in the descriptions for associated data initiatives).

exposure ("moderate" in Table 4 and Figure 5 of Spencer et al. 2019). The Stock Assessment Classification scores for Alaska sablefish suggest a data-rich stock with high-quality data over all categories (Shotwell and Blackhart 2023). Recent priorities set in the strategic science plan (AFSC, 2022) and specifically in the annual guidance memorandum for the AFSC support ecosystem research on Alaska sablefish (AFSC, 2016;

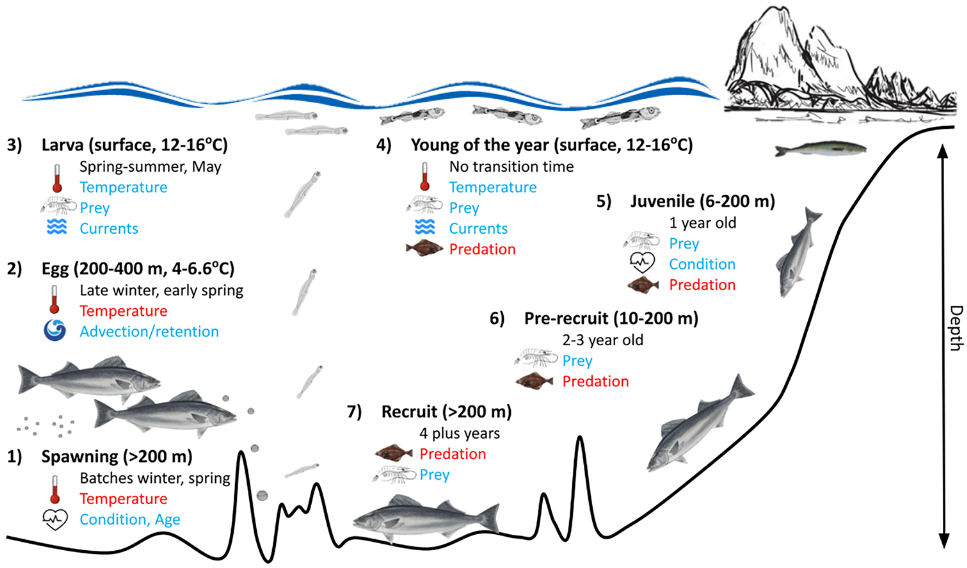


Figure 4. Life history conceptual model for sablefish summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

Stock/Complex:

Outline for Ecosystem and Socioeconomic Profile (ESP)

Executive Summary

- ❑ Short description of an ESP and summary of ecosystem and socioeconomic considerations from the recommendations section
- ❑ Response to Plan Team and SSC Recommendations
- ❑ Table of model performance where applicable

Introduction

Start with a short description of the ESP process with references

Justification & Data

- ❑ Stock-specific regional research priorities
- ❑ Scores in relevant national initiatives, stock assessment classification
- ❑ Brief description of data streams used, reference main SAFE
- ❑ Table of data sources, short description, references

Metrics Assessment

Identifies main processes, highlights mechanisms that lead to indicators

National Metrics

- ❑ Description and graph of relevant stock-specific measures collected in the national initiatives and associated stock vulnerabilities

Ecosystem Processes

- ❑ Summary of ecosystem processes that identify dominant pressures on the stock, evaluate by life history stage where possible with associated life history conceptual model and tables

Socioeconomic Processes

- ❑ Summary of socioeconomic processes that identify dominant pressures on the stock, evaluate by life history stage where possible with associated table of socioeconomic performance information

Indicators Assessment

Identifies the indicator suite and reviews the monitoring analyses

Indicator Suite

- ❑ Brief literature review on indicators previously explored for stock
- ❑ Description of indicator suite based on mechanisms identified in the metric assessment and literature review with time series graph

Indicator Monitoring Analysis

- ❑ Description of statistical tests for monitoring indicator suite (e.g., traffic light, importance methods, research ecosystem linked model)
- ❑ Supportive graphs and tables of statistical tests where relevant
- ❑ Table of model performance metrics (e.g. retrospective trends)

Recommendations

Summary of ecosystem and socioeconomic considerations for use in the main stock assessment

Ecosystem & Socioeconomic Considerations

- ❑ Summary conclusions from metric and indicator assessment

Data Gaps and Future Research Priorities

Description of metric or indicator data gaps, priorities for ecosystem and socioeconomic research that would support future versions of the ESP

Acknowledgements & Literature Cited

Figure 5. Ecosystem and socioeconomic profile (ESP) product infographic describing the four primary sections of the ESP report with guidelines on what to include in each section.

AFSC, 2017; AFSC, 2018), particularly with regard to understanding recent large recruitment fluctuations. Finally, the advisory bodies of the NPFMC have reviewed, supported, and recommended the ESP for Alaska sablefish since the initialization in 2017 (see minutes of the NPFMC Groundfish Plan Teams and Scientific and Statistical Committee, https://www.npfmc.org/library/meeting-minutes/) (North Pacific Fishery Management Council (NPFMC) 2017). These priorities, recommendations, and scores served as important evidence for creating and continuing to conduct an ESP for Alaska sablefish.

Step 2 – synthesizing ecosystem and socioeconomic information

When priority stocks for conducting an ESP are identified, a process of synthesizing the available information for the stock can then be initiated. This synthesis can be accomplished through a thorough literature search on any ecosystem and socioeconomic processes driving dynamics of the stock. A first pass of this literature review may be to collect a set of descriptive measures of the stock. These measures can be considered a baseline evaluation that is very similar to what is measured in a standard metabolic panel conducted by a medical practitioner. The results of the metabolic panel are used to find "out of range" values to identify potential concerns that should be followed up in more detail (e.g., high cholesterol is often linked to potential for heart disease). The stock baseline evaluation is similar, although it is more an application to identify stock traits or metrics that are vulnerable to overfishing, ecological pressures, or climate change. When merged together, these metrics may span a wide variety of categories and can be used to construct a stock metric panel. Relevant metrics should be chosen for similar types of stocks (e.g., groundfish, crab) and should be organized together for consistency with fishery management objectives and practices. The consistency in data collection allows for comparisons of these metric panels across stocks and may be useful for grouping stocks that have similar vulnerabilities. Furthermore, persistent data gaps across multiple stocks could be used to guide or direct process studies or surveys and respond to the data needs for a given region.

Some metrics may be estimated values (e.g., natural mortality, growth rate) with associated thresholds of low to high vulnerability (e.g., Methot 2015; Patrick et al. 2010). However, a number of metrics may also be categorical scores (e.g., ecosystem importance, prey specificity) with values ranging from low to high on a qualitative scale such as 1 to 4 (e.g., Morrison et al. 2015). In order to evaluate the metrics together and to simplify interpretation, it may be useful to put all the metrics on the same low to high vulnerability range by rescaling the values where necessary. The data could then be presented on a single metric panel for a given stock, as well as easily compared across stocks. Estimated values of the metrics could accompany the scaled metric panel and also include the range across stocks to aid interpretation. Using this approach, some metrics should be reversed so that high values always indicate a vulnerability and low values suggest resilience across all stocks. For example, a growth rate value should be reversed because lower growth rate is associated with low productivity which is associated with high vulnerability to overfishing (Patrick et al. 2010). Data quality could also be included to gauge how useful the metric is for identifying vulnerability in a given stock (Morrison et al. 2015). If there were no data available for a particular metric, then notation (e.g., "NA") could appear in the panel to highlight the data gap. In general, this often only occurs for estimated value metrics whereas for categorical scores, typically there is enough information to form some expert judgment and generate a score.

We provide an example of a metric panel that was used in the sablefish ESP for the purpose of illustration (Figure 3, updated from Hanselman et al. 2019). Here, we combined metrics that were both scores and values, and rescaled the values to simplify interpretation. Sources for these metrics are provided (Table 1) and a relevant subset of the available metrics (Table 2) were selected for all Alaska groundfish stocks. A percentile rank was used to create the final values for sablefish. The 80th and 90th percentile rank areas were provided to highlight metrics that cross into these zones indicating a high level of vulnerability for sablefish (Figure 3, gray and black shaded area). For ecosystem metrics, recruitment variability for sablefish fell within the 90th percentile rank of vulnerability. Maximum age, length at 50% maturity, maximum length, size at transformation, and predation stressors fell within the 80th percentile rank when compared to other groundfish stocks. For socioeconomic metrics, commercial value fell within the 90th percentile rank and constituent demand fell within the 80th percentile rank. Sablefish were relatively resilient for adult growth rate, range in latitude, range in depth, fecundity, breeding strategy, adult mobility, habitat dependence, and prey specificity. Recruitment variability for the sablefish stock is one of the highest among the Alaska groundfish stocks. Additionally, the older maximum age, 50% maturity, and larger maximum length are all characteristics of low productivity stocks (Patrick et al. 2010). Predation pressures on adult sablefish are also high due to the recent increases in depredation by sperm and killer whales during retrieval of longline gear (Hanselman et al. 2017). Sablefish is one of the most highly valued (both in terms of ex-vessel value per kilogram and total ex-vessel value) Alaska groundfish stocks relative to other Alaska groundfish stocks. The high value also explains the high constituent demand for excellence in the stock assessment. These initial results suggest that more in-depth information regarding mechanisms for the extreme recruitment variability and an evaluation of economic performance would be valuable for sablefish.

Once the more vulnerable attributes have been identified for a particular stock, a comprehensive processes evaluation should be conducted to build off the information in the stock metric panel and provide mechanistic understanding of stock health. The processes evaluation can be conducted for both ecosystem and socioeconomic factors and should be evaluated by life stage where possible to understand bottlenecks in the life history that may influence survival. Life history tables are very useful for compiling the major characteristics of the stock by life history stage with associated references. The table organizes the processes affecting survival at each life stage and is useful for identifying mechanistic relationships with the stock. An associated conceptual model is also very helpful for visualization. A conceptual model of the life history stages can include the basic information from the life history Tables (e.g., depth and temperature preferences) and identify proposed processes influencing survival at each life stage. A similar socioeconomic conceptual model could be built to represent performance indicators of the fishery that may reveal changes in the stock that are not identified by fishery independent data (e.g., spatial distribution of the fleet, gear changes, closures). Understanding when and where survival bottlenecks occur will be helpful for identifying mechanisms to explain changes in stock dynamics and for selecting relevant proxy indicators to monitor in the following step.

We provide an example of the conceptual model that was used in the sablefish ESP for the purpose of illustration (Figure 4, updated from Hanselman et al. 2019). A detailed life history table and associated summary of relevant ecosystem processes impacting survival were also created for sablefish (Hanselman et al. 2019, Appendix Tables 3C.2a, b). We then evaluated the different life history stages of sablefish (e.g., egg, larvae, juvenile, and adult) to gain mechanistic understanding of ecosystem processes influencing the sablefish stock. Supporting information from the literature, surveys, process studies, laboratory analyses, and modeling applications was also provided to detail the important drivers on the sablefish stock. An added value of preparing this information was bringing together experts from different but interrelated fields (stock assessment to process research in oceanography) to identify potentially vulnerable life history stages and important ecosystem drivers. Ecosystem drivers included temperature, condition, prey, currents, and predation, but the relative importance and directional effect of these drivers varied by life stage. For example, young-of-the-year (YOY) sablefish exhibit some thermal intolerance to very cold water (Sogard and Spencer 2004) and laboratory studies have shown a narrow optimal thermal range and different effects of temperature depending on fish size (Sogard and Olla 2001, Krieger et al. 2019). We used the conceptual model to highlight these ontogenetic temperature preferences, where the expected relationship to producing good (highlighted in blue) or poor (in red) stock conditions was included (Figure 4). The socioeconomic drivers were related to bycatch and value of small fish in the fishery as a result of several recent anomalously large year-classes for sablefish. The described processes and drivers for sablefish allowed for identification of a suite of indicators to monitor and analyze for explaining recruitment, fishery performance, and economic trends.

Step 3 – Analyzing ecosystem and socioeconomic indicators

Creating the indicator suite

Following the identification of the primary vulnerabilities from the stock metric panel and processes evaluation that comprise Step 2, it is important to select representative indicators or time-series to monitor. An indicator can be observational or modeled data but should be accessible, consistent, and timely at a scale that is relevant to the stock assessment into which it feeds. For some stocks, dedicated research projects have already been conducted to identify relevant indicators for continued monitoring. These projects may vary from small-scale laboratory or survey experiments to large-scale process studies within integrated ecosystem research programs (e.g., Sogard 2011; Sreenivasan and Heintz 2016; Dickson and Baker 2016). In general, however, process research tends to only focus on a select number of vulnerabilities of the stock, rather than viewing the vulnerabilities in a comprehensive manner throughout the life history of the stock. This has caused downstream inconsistencies in the predictability of indicators and increases the reluctance to use the indicators in operational management decisions (e.g., Stewart, Thorson, and Wetzel 2011; Pinsky, Mantua, and Rutgers University 2014). When combined with the synthesis detailed in Step 2 above, research project results can provide information on sources for developing a wide range of proxy indicators to monitor. Indicators can range from temporally and spatially-explicit continuous data series (e.g., Ladd, Cheng, and Salo 2016; Harvey et al. 2020) to categorical descriptions of vulnerability within the life history (e.g., Doyle and Mier 2016).

In general, indicators should represent the critical processes and drivers throughout the life history of the stock and be organized accordingly. Care should be taken to select a similar number of representative indicators across life stages so one stage does not have more influence than another. In all cases, it is imperative that indicators selected to be monitored in an ESP are reliably produced at the schedule of the stock assessment cycle as this is typically a requirement for uptake within the operational stock assessment process (Lynch, Methot, and Link 2018).

The indicator suite for the sablefish ESP was selected using vulnerabilities identified in the metric panel, information from the life history tables, and published literature on recruitment fluctuations for sablefish (Table 3, reproduced from Hanselman et al. 2019 and Goethel et al. 2020, Appendix 3C). Several overarching categories were used to organize these indicators that generally follow the categories used in the ESRs. Physical indicators representing temperature, transport, stratification, and match to the spring plankton bloom for the offshore pelagic life stages have been related to recruitment fluctuations of sablefish (Coffin and Mueter, 2015; Shotwell, Hanselman, and Belkin 2014; Gibson et al. 2019). Lower trophic indicators included zooplankton production and an age-0 sablefish growth index that have also been related to changes in sablefish recruitment (McFarlane and Beamish, 1992; Arimitsu and Hatch, 2019). Upper trophic indicators were developed using survey catches and stock assessment model output. Nearshore and offshore bottom trawl and longline surveys (Spalinger 2015; von Szalay and Raring 2018, Siwicke, Malecha, and Rodgveller 2021) collect data on sablefish. The bottom trawl surveys were used to develop indicators of juvenile catch-per-unit-of-effort (CPUE) that corroborated the recent recruitment events for sablefish, and are not used in the operational stock assessment model (Hanselman et al. 2019). Estimates of condition for juveniles and adults (Boldt et al. 2017) were used to create indicators of health and foraging conditions and were evaluated for each life stage separately because energy storage strategies differ (Hanselman et al. 2018, Appendix 3C). Relative biomass estimates of competitors and predators represent the foraging and predation landscape as sablefish transition from the nearshore to offshore environments. Composition measures such as mean age of female spawning biomass and age evenness of the population by cohort were useful for understanding how well sablefish buffer against or take advantage of environmental conditions. Relevant fishery performance and economic indicators for sablefish included CPUE by gear type, incidental catch in the Bering Sea fisheries, ex-vessel value and price of fish in the fishery. These indicators were useful for detecting early signals for potential shifts in fishery behavior and economic yield during large year-classes, particularly within the Bering Sea as this is the northern edge of the sablefish population distribution.

Indicator monitoring analysis

Monitoring these indicators within the third step of the ESP can be accomplished through a staged analysis approach tuned to the data availability for a given stock. This staged approach allows for ESPs to be created for all types of stocks from data-limited to data-rich, and provides avenues for understanding when and how to use the information in the ESP for informing management decisions. We propose beginning, intermediate, and advanced stages for this approach and provide examples for each stage using the Alaska sablefish stock.

Beginning stage. At the beginning stage of monitoring, a simple scoring approach can be used for understanding the potentially wide-range of indicators in a collective manner without the constraints of any preconceived model structure (Caddy 2015). A specified range of colors (e.g., red, white, blue) could correspond to shifting from poor through neutral to good conditions based on either known thresholds of the indicator or using an equal range or probability assumption of observed values. Simple integration algorithms of the indicators (e.g., sum of standardized values scaled to 1) can then be applied to determine an overall indication or score of stock health for the current year and optional weighting schemes could be used to stress indicator relevance (Caddy 2015). This stock health score can then be compared in a retrospective manner (e.g., the past 20 years) to understand the impact of indicator trends over time. For data-limited stocks, this approach may be the extent of the ESP monitoring capabilities, with the final indicator suite being used in a contextual manner to develop hypotheses for primary pressures influencing stock dynamics (e.g., see review by Caddy 2015).

We used a simple stock health scoring approach for the beginning stage monitoring of the sablefish ESP indicator suite (Table 3). The value for each indicator in each year was evaluated based on being greater than ("high"), less than ("low"), or within ("neutral") one standard deviation of the long-term mean of the time series. This followed the same methods used in the ESRs for the top ten indicators (e.g., Siddon 2020) for simplicity but other approaches such as transforming indicators prior to this evaluation are certainly viable and should be considered. We then assigned a "+1", "-1", or "0" to the indicator following whether the indicator corresponded to "high", "low", or "neutral" conditions. A sign based on the anticipated relationship between the indicator and the stock (generally shown in the conceptual model, Figure 4) was also applied to the indicator where possible. For example, if high surface temperature means good conditions for a stock such as sablefish, then a value above 1 standard deviation from the long-term mean gets a "+1". If high surface temperature means poor conditions for the stock, then a value above 1 standard deviation would get a "-1". A zero value would mean stable conditions and neutral. We then summed all the assigned values for a given year and category (e.g., physical, lower trophic, or upper trophic indicators) and divided them by the total indicators within that category to produce the score. We generated scores for each category of indicator and evaluated over the past twenty years to consider indicator performance. Sablefish scores indicated an overall above average physical environment during the recent larger recruitment events (2014 to 2021) with neutral to below average conditions for the lower and upper trophic indicators. For socioeconomic indicators, there was a steady increase in bycatch and subsequent drop in prices with the influx of small fish (Goethel et al. 2022, Appendix 3C).

Intermediate stage. For data-moderate to data-rich stocks, or for data-limited stocks with data-rich congeners, the stock health scoring approach could be further enhanced through an intermediate stage monitoring analysis that refines the suite of indicators with respect to individual time-varying stock assessment factors (e.g., recruitment, growth, mortality, selectivity). These factors may be estimated as time-varying in the operational assessment model or identified as a priority for time-varying estimation in a future research model. A subset of the indicator suite may adequately capture the drivers on the stock assessment factor(s) and a more advanced analysis of the nature of this relationship can be conducted. The statistical techniques for selecting the most parsimonious set of candidate predictor variables with the highest explanatory power are numerous and varied in their flexibility. Selecting one method over another depends on a number of important characteristics such as the quality of the data, the shape of the stock-indicator relationship, and the modeled error structure (Crawley 2007). It should be noted that the relationship between environmental pressures and ecosystem components are often non-linear in marine ecosystems and non-stationarity should be considered (Hunsicker et al. 2016). It may also be useful to compare results from a simple statistical method and a more flexible method to assess the stability and consistency in influential predictor variables and determine the importance of model assumptions.

The advantage of the intermediate stage monitoring is that the direction, magnitude, and level of uncertainty in the effect of each indicator covariate can be estimated. If the model structural uncertainty is taken into account, then an inclusion probability or the weight of evidence for the estimated relationship, can be estimated for a given covariate (Cunningham, Westley, and Adkison 2018). The indicators concerning the dominant stock assessment factor(s) can be weighted based on the inclusion probabilities and the sum product of the weighting and the standardized indicator values (also scaled to 1) could be used as the estimate of the stock health and include an estimate of uncertainty for the score. The intermediate stage monitoring can be rerun when new data are available to test if the most influential candidate variables remain the same over time. For data-moderate stocks or for data-rich stocks with highly uncertain parameter estimates, this intermediate stage may be the extent of the ESP monitoring. For data-rich stocks, if the stock-indicator relationships identified from the intermediate stage monitoring are fairly static over time and continue to have high explanatory power, then these covariates can be integrated into the stock assessment model for further testing in the advanced monitoring stage.

Understanding recruitment variability has been identified as a research priority for Alaska sablefish and we used Bayesian adaptive sampling (BAS) for the intermediate stage monitoring of the sablefish ESP (Hanselman et al. 2019). 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 averaged predictions for outcomes (O'Hara and Sillanpää 2009; Clyde, Ghosh, and Littman 2011). We first restricted the full indicator suite to the predictors that directly relate to recruitment deviations or serve as an index of recruitment (Hanselman et al. 2019, Appendix Figure 3C.10a). We then estimated the mean relationship between each predictor variable and log sablefish recruitment over time, with associated uncertainty in each estimated effect and the marginal inclusion probabilities for each predictor variable (Hanselman et al. 2019, Appendix Figure 3C.10b).

A higher inclusion probability indicated that the variable was a better predictor of sablefish recruitment. The consistently highly ranked predictor variables based on this process were the nearshore juvenile CPUE and incidental catch in the Gulf of Alaska that were both between 0.5 and 0.75 inclusion probability (Hanselman et al. 2019; Goethel et al. 2022).

Advanced stage. The last and most advanced stage of the monitoring analyses would involve directly including quantitative linkages in a research model run of the operational stock assessment model. This ecosystem research model generally involves directly adjusting specific model parameters or creating an index that reduces uncertainty by informing parameter estimates (Lynch, Methot, and Link 2018). The beginning and intermediate stage monitoring should provide the necessary building blocks for justifying an ecosystem research model and, in some cases, have already been fully developed as an exploratory exercise to investigate poor model diagnostics (e.g., Wilderbuer, Stockhausen, and Bond 2013; Field, Beyer, and He 2015; Sagarese, Lauretta, and Walter 2017; Barbeaux et al. 2021). Reports or manuscripts of these explorations can be referenced for more detailed information and summary results of the ecosystem research model could be presented in the ESP. Brief model diagnostics and predictive performance could also be included (e.g., cross validation and retrospective analyses). An assessment of the potential impact for including the ecosystem or socioeconomic linkage in the model (e.g., Deriso, Maunder, and Pearson 2008) could also be provided in both short- and medium-term stock projections (e.g., Shotwell, Hanselman, and Belkin 2014). Conducting this last analysis stage could be an avenue for testing and monitoring the ecosystem or socioeconomic linkage prior to integration within the operational stock assessment model. This would not be a requirement before use but could serve as a way to increase visibility of the ecosystem research model and allow time for managers to evaluate the benefits of including this information.

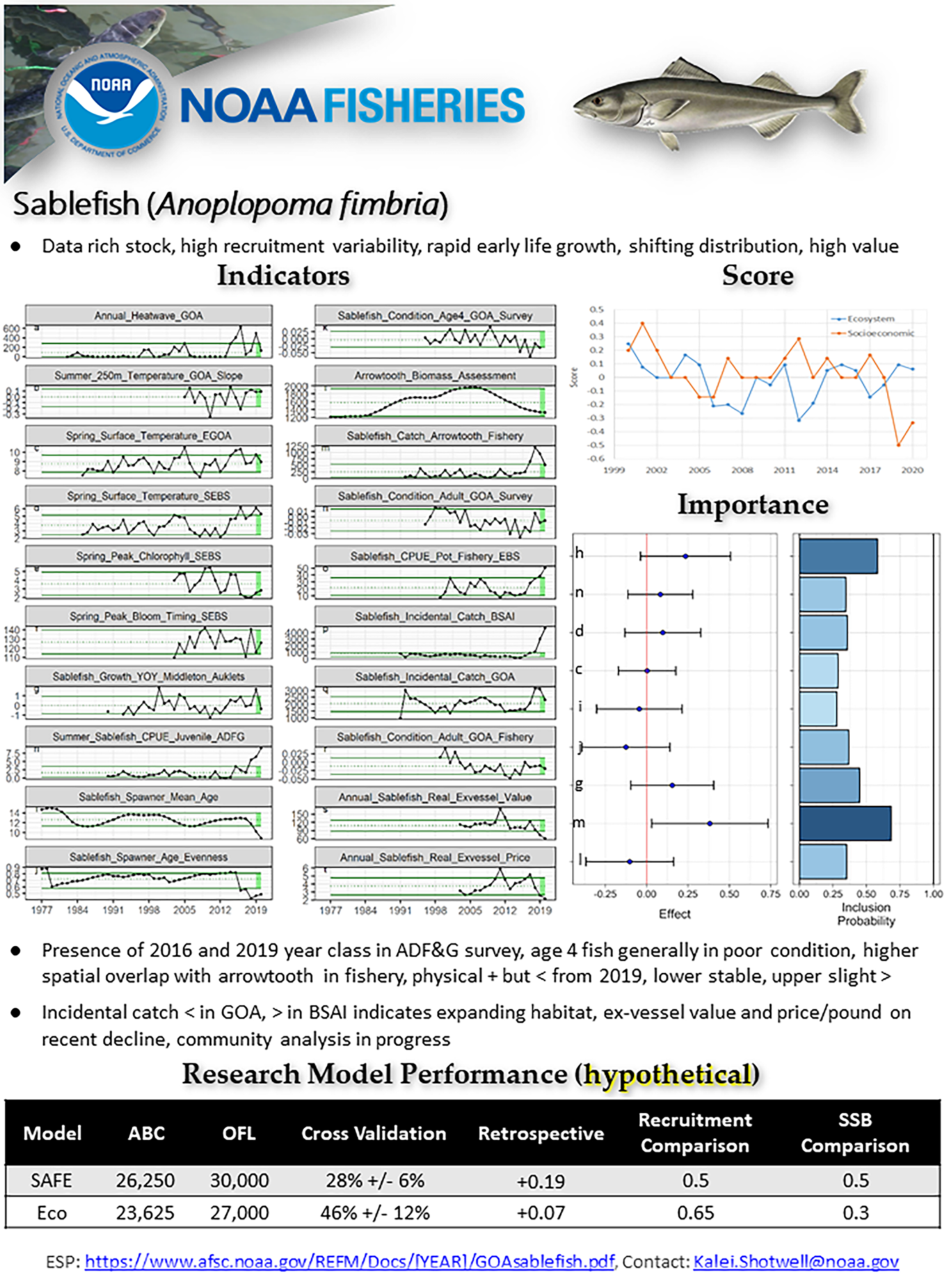
Recently, an update of the fishery catch-per-unit-effort (CPUE) indicator was added to the sablefish ESP to demonstrate the performance of a standardized combined gear (pot and hook-and-line) model-based index of abundance (Goethel et al. 2022, Cheng et al. 2023). This standardized CPUE index is being tested in a research version of the sablefish stock assessment model. The ESP provided an avenue for increasing the visibility of this index within the stock assessment review cycle. The research priorities of the sablefish assessment state that the refinement of the fishery abundance index aligns with best practices for using CPUE data and will likely be included in the next operational assessment model (Goethel et al. 2022). This is an example of the data flow from "proving ground" within the ESP to operational stock assessment model. In the future, the performance of the highly ranked predictor variables for sablefish recruitment from the intermediate stage monitoring could also be evaluated within the operational stock assessment model configuration. The nearshore juvenile CPUE indicator may be useful as an early signal of overwinter and nearshore residency success for the early to late juvenile stage and could be added as a survey of juvenile sablefish within the model. Other highly ranked indicators could be used as covariates to inform past recruitment deviations and help predict future recruitment events for sablefish.

Step 4 – reporting ecosystem and socioeconomic considerations

The final step of the ESP process concerns the development of a standardized reporting template to effectively and efficiently communicate the results of the ESP to the scientific research community, management organizations, stakeholders, and the public. The results of the previous three ESP steps should be presented according to the level of analysis and the prospective audience. We present two basic reporting templates that we developed for use in the Alaska stock assessment cycle. The first template is termed a full ESP report and is designed for formal review within the stock assessment cycle and would be attached or associated in some manner to the operational SAFE report. Whether organized as an appendix or integrated within the SAFE, the full ESP report (Figure 5) consists of four main sections: 1) an introduction and justification to state why the stock was a priority to produce an ESP, 2) a summary of the synthesis exercise on the primary vulnerabilities of the stock throughout the life history, 3) an assessment of the indicator suite and results of the statistical monitoring stages, and 4) a discussion of recommendations, caveats, data gaps and needs, and future ecosystem or socioeconomic research priorities for the stock. The full report could also have a set of standardized tables and graphics that support the different sections (see Figure 5 for suggestions) and will depend on the data availability for the stock. These standardized tables and graphics could be designed such that they can be easily and consistently reproduced with updated data on a schedule consistent with the stock's assessment cycle.

It is often the case that a rapid communication device is helpful to distill the most important elements of an analysis for increased efficiency in decisions. The second ESP template is called the ESP report card and would only include the basic elements of the ESP that resulted from the one-year update of indicators. A one to several page summary may be sufficient to communicate the primary results of the ESP and would allow for quick comparison of results between stocks (see Figure 6 as an example). This is very useful in a situation where a large number of fish stocks are assessed on an annual basis for setting annual catch limits or for an IEA program, and ESP authors that may need to synthesize information for many stocks at once. The report card template would include the same four main sections as described for the full ESP report, but only includes the relevant graphics and very limited text. Implementing dynamic reporting code (e.g., R Markdown) could be useful for producing the report cards quickly. The two ESP reporting templates will help bridge the reporting gap between the interface of the stock assessment and ecosystem or economic assessments and functionally complete the communication loop between all three disciplines of the stock assessment process (Figure 1).

Both types of ESP reporting templates have been completed for several stocks in the Alaska groundfish and crab FMPs. Full ESPs for Alaska sablefish, Gulf of Alaska (GOA) pollock, and St. Matthew blue king crab were completed in 2019 (Hanselman et al. 2019; Dorn et al. 2019, Palof, Zheng, and Ianelli 2019). In response to data gaps



Model	ABC	OFL	Cross Validation	Retrospective	Recruitment Comparison	SSB Comparison
SAFE	26,250	30,000	28% +/- 6%	+0.19	0.5	0.5
Eco	23,625	27,000	46% +/- 12%	+0.07	0.65	0.3

Figure 6. Draft example of the one-page template for providing a rapid communication of the sablefish ecosystem and socioeconomic profile (ESP). Please see Goethel et al. (2020), Appendix 3C, for a description of the indicators, score, and importance panels.

and research priorities identified in the full ESP reports, three updated ESPs were completed for these stocks the following year that included new information in the ecosystem and socioeconomic processes sections and several updated or new indicators for evaluation (Goethel et al. 2020; Dorn et al. 2020; Palof, Zheng, and Ianelli 2020).

Several new indicators were developed due to advances in accessibility to satellite data and ocean model output that filled a significant data gap due to loss of surveys during the global COVID-19 pandemic. Four more full ESP reports were completed for Bristol Bay red king crab in 2020 (Zheng and Siddeek 2020), eastern Bering Sea (EBS) and GOA Pacific cod in 2021, (Thompson et al. 2021; Barbeaux et al. 2021), and EBS snow crab in 2022 (Szuwalski 2022). Finally, a one-page draft report card has been developed for Alaska sablefish (Figure 6, updated from Hanselman et al. 2018) and will be used as a starting point for developing ESP rapid communications for several stocks in the future.

Management applications of the ESPs

Prior to the ESP, the ESRs provided broad ecosystem health indicators but generally without linkages to specific stocks (e.g., although important at the large marine ecosystem level, how would a seabird mass mortality event impact a specific stock of interest). The ESP helps identify connections between the broader ecosystem and specific stocks and the various elements of the ESP process and report products may be useful for improving fisheries management decisions. The focusing and synthesizing steps identify stocks with vulnerabilities in their life history that could benefit from including ecosystem or socioeconomic information in the assessment process and associated contextual discussions. The beginning and intermediate indicator analysis stages provide scores that can be used to adjust the level of the precautionary buffer between the acceptable biological catch and the overfishing limit (e.g., Trenkel 2018). If the stock indicators are in an overall poor state, the buffer could, for example, be increased to be more precautionary than that assumed under average conditions and shift away from the estimated overfishing limit. Qualitative thresholds for good to poor stock health scores can be determined by the regional fishery management councils or organizations and recommended based on the score (e.g., +/- 5% buffer for 20% increase or decrease in stock health score). This is functionally similar to the concept of any system of managing fish stocks where increased uncertainty in the stock assessment model yields more precautionary management. For example, the data on stock health not accounted for in the stock assessment model is addressing an underlying uncertainty that would be assumed under a default buffer size. The advanced stage ecosystem research model could be used to inform the underlying uncertainty specified in a probability-based buffer approach (e.g., P* calculation, Shertzer, Prager, and Williams 2008) and could be estimated from the ecosystem research model output compared to the operational model. Another method for changing the buffer in combination with these quantitative metrics could include informing the spawners-per-recruit (SPR) maximum sustainable yield (MSY) proxies to acknowledge times of high and low productivity (e.g., an acceptable biological catch (ABC) determined at $F_{45\%}$ instead of $F_{40\%}$ during poor conditions). In any case, one should consider the benefits and risks of increasing or decreasing the precautionary buffer in a gradual or rapid fashion as ecosystem linkages are evaluated to avoid causing shocks to the management system. A decision table could summarize results of a gradual or rapid shift in the buffer to show the impact relative to the operational model. Finally, the recommendation section at the end of the ESP report highlights the major ecosystem and socioeconomic considerations and can be helpful for discussions regarding adjustments from the recommended quota. For example, risk tables are now being developed for many stocks in Alaska (Dorn and Zador 2020) and information from the ESP summary has been used to inform the reduction from maximum ABC (e.g., Hanselman et al. 2019).

The ESPs have already been used in several management applications for crab and groundfish stocks in the North Pacific region. Generally, a summary presentation of the ESP is presented at the same time as the SAFE report for a given stock to the Plan Teams and Scientific and Statistical Committee (SSC) of the NPFMC. For the groundfish stocks, the stock-specific processes, indicators, and overall recommendations sections of the sablefish, GOA pollock, and Pacific cod ESPs have been summarized along with the large marine ecosystem information from the ESRs to create the ecosystem section of the risk table that is included within the harvest recommendations of the SAFE report. These summaries, along with considerations from the other three categories of the risk table (assessment, population dynamics, and fishery performance), were used to inform decisions to adjust the quotas from the maximum permissible ABC for several years (Hanselman et al. 2018, 2019; Dorn et al. 2019, 2020; Goethel et al. 2020; Barbeaux et al. 2021; Thompson et al. 2021). For crab stocks, the ESPs have been used contextually to inform buffers, rebuilding plans for overfished stocks, and total allowable catch (TAC) setting discussions. For example, the ESP indicators provided context for recruitment projections and future recovery potential when implementing a rebuilding plan for the overfished St. Matthew Island blue king crab stock (Palof, Zheng, and Ianelli 2019), and ESP indicators will continue to be an important monitoring tool during the rebuilding process for St. Matthew Island blue king crab and EBS snow crab stocks. Finally, the ESPs have identified several indicators that have potential for use in the operational stock assessment models, and lead authors of the associated stock assessments are currently testing these indicators in alternative models to present to the regional Plan Teams and SSC.

Discussion

The standardized methodology and reporting framework of the ESP completes the feedback loop between the stock assessment, ecosystem/socioeconomic assessment, and fishery management communities (Figure 1). The ESP process and products capitalize on data already collected for multiple stocks, formalize how this data informs the stock assessment process, increases visibility of tested mechanistic relationships for use in stock assessment models, and collects research priorities in one accessible location for use in future planning and setting strategic goals. Ultimately, the ESPs act as a "proving ground" for next generation stock assessments.

The ESPs allow for improved and consistent tracking of progress in ecosystem-based fisheries management (EBFM) through the stock-specific standardized reporting framework integrated within the stock assessment decision process. Classification systems such as those recently developed by NOAA Fisheries (Lynch, Methot, and Link 2018) can currently only track when ecosystem linkages are used in the operational stock assessment model, but have little information on progress made up to that point. The ESPs create a pathway for integrating ecosystem and socioeconomic information into management decisions that can be traced by multiple performance metrics of EBFM (specific, measurable, attainable, relevant, and time-based or SMART, Doran 1981). The ESPs include conceptual models, mechanistic processes, indicators, and analyses that can all be tracked and are specifically attuned and linked to a stock assessment. The two types of reporting templates can be updated and evaluated as new data are available and the reports themselves can easily be monitored because the ESPs are designed to be integrated into the stock assessment process. Performance metrics included in the ESP are essential for tracking indicators prepared for and ultimately used in ecosystem linked assessments, and assessing how well we are meeting our EBFM goals of including ecosystem and socioeconomic considerations within our stock assessments and decision-making process. Finally, the ESPs are designed for development within the stock assessment process, effectively creating an evaluation synergy between the stock assessment model and the ecosystem and socioeconomic information available for the stock. This could occur within the operational type of assessments as shown here through the example of Alaska sablefish within the NPFMC, or within a research type assessment perhaps specified within one of the terms of reference (e.g., defined in Lynch, Methot, and Link 2018). The coordinated timeline allows for increased opportunity for uptake of the information that will ultimately lead to more efficient and effective fishery management decisions.

As with any new framework, there are certainly areas for improvement. The information collected *via* the data initiatives is, for the most part, not based on life history stages; this lack of detail can make it difficult to correctly identify the full suite of potential vulnerabilities of stocks. Metric information by stage may help to pinpoint when and where the bottlenecks occur for a given stock and increase mechanistic understanding. There are also several metric categories that currently lack sufficient information for scoring on a stock-specific basis (e.g., subsistence), so associated vulnerabilities are difficult to identify. However, data availability varies by region, as does the relative importance of a given metric to managed stocks. The relevance of categories should be further investigated on a regional basis to aid in the development of refined regional metrics that could be added to the metric assessment section of the ESP. Additionally, many metrics were simplified to categorical scores so that similar information could be gathered across multiple regions (e.g., habitat vulnerability). Stock-specific metrics (e.g., thresholds, distributions, phenologies, energetic requirements) could be provided in addition to the categorical scores to improve understanding of the stock vulnerabilities and bottlenecks throughout the life history. Stage-based information combined with refined stock metrics will ultimately lead to more reliable indicators for monitoring.

A wide variety of ecosystem and socioeconomic indicators are potentially available for the ESP indicator analysis from the ecosystem or economic status reports (e.g., Karnauskas et al. 2017, Gove et al. 2019; Fissel et al. 2020, Siddon 2020; Harvey et al. 2020). However, many of these indicators were developed to assess the condition of the ecosystem as a whole and do not apply specifically to any given stock. This does not mean that the data do not exist to create stock-specific indicators, but instead highlights the focus of the ESRs as a tool to assess the current state of large marine ecosystems. However, many environmental indicators could be finely tuned to a more appropriate temporal or spatial scale to match the management area of the stock of interest. Conversely, some indicators have been developed for very specific process study research and apply to exceptionally small regions which are also not at the scale of fisheries management. Data from multiple small-scale study areas throughout a management region could potentially be combined using statistical methods such as spatial-temporal models (Thorson et al. 2015). These methods may also pave a path forward for the creation of innovative indicators to explore shifts in distribution and range expansion or contraction of an ecosystem or economic indicator over time (Thorson 2019). This effort will require project coordination and increased data accessibility to allow for the development of new indicators at the scales relevant to fisheries management. Also, shifts in mechanistic understanding and stock thresholds due to climate change are poorly understood and future efficacy of current indicators is unknown. Results from large interdisciplinary projects such as the Alaska Climate Integrated Modeling (ACLIM) project that are designed to understand long-term impacts of climate change on fish, fisheries, and fishing communities (Hollowed et al. 2020) may be able to provide projections of critical indicators (e.g., temperature, pH) under differing emissions scenarios for understanding future indicator potential to cross stock-specific thresholds within the ESRs and ESPs. Ultimately, collaborative research programs that aim to bring together a diverse set of individuals across disciplines have a high potential for accomplishing the necessary coordination to develop these indicators and keep them regularly updated.

Improvement in accessibility, consistency, and timeliness of indicators is necessary for implementation of ESPs. Researchers conducting process research are often disconnected from management processes and may not know the data gaps in stock assessments or how to apply their research to management. The ESP bridges that divide. Reliable web-based platforms are critical for improving access to indicators based on process study research and it will be important to invest in and maintain data management applications that are synced with the current stock assessment process. It will be necessary to build from existing data management systems already in place to improve coordination between data providers and data users. This will facilitate a transparent indicator submission and evaluation process for use in ESPs and ultimately ecosystem-linked assessments. Timing of indicators is important at two levels, 1) data availability and the frequency of updates to data that support the development of indicators, and 2) preparing and providing information for use in the stock assessments. Both of these processes need to occur well before the onset of the operational stock assessment schedule to allow for increased uptake. If there are significant time lags between data updates, this may preclude the usefulness of the information within the ESP because the stock assessment analyst cannot evaluate the indicators with respect to the operational stock assessment to fill data gaps and inform short-term projections. Coordinating reporting schedules of the various groups within any stock assessment process (e.g., teams, councils, organizations) may allow for some additional benefits such as adaptability in survey collections (e.g., decision making if areas to be surveyed are to be altered) and creation of "shovel ready" special projects. As with any shift in timelines, there are certain to be adjustments to any proposed schedule, but adaptability and willingness to work together will ultimately further our progress toward EBFM.

The creation of the ESPs is a significant step toward increasing the use of ecosystem and socioeconomic data within the stock assessment process. At the onset, developing an ESP requires coordination and commitment from a large variety of scientists in multiple disciplines and this interaction has created a team aspect of the ESPs that has helped to break down the silos between the stock assessment, ecosystem/socioeconomic assessment, and fisheries management communities. This sense of community from building an ESP together cannot be understated. Establishing roles and responsibilities for the various aspects of the ESP is essential for successful completion, and this organizational structure builds a sense of purpose in the team approach to ultimately create a more reliable and consistent product. The output of the ESP can also inform beyond the specific stock assessment. Recommendations, data gaps, and research priorities of the ESP can be used to prioritize extended survey operations, coordinate requests for research proposals, and develop strategic research plans. The ESP report card may be combined with an executive summary of the operational stock assessment to create a rapid communication tool for broadcasting the utility of the ecosystem or socioeconomic data to a wide variety of audiences. These short summaries would also be useful for comparing vulnerabilities across stocks and regions to potentially recognize an overarching system-level response (e.g., variable species response to a marine heat wave). Finally, the ESPs formally record the stepwise evaluation of ecosystem or socioeconomic data within the stock assessment process. This information is exceptionally valuable and can be combined with standard reporting requirements to track the development of our next generation stock assessment enterprise.

Acknowledgments

The authors thank the contributors of indicators to the ESPs, the editors of the ESP reports, and the stock assessment authors for their willingness to provide data, creating and reviewing the documents, and their time in making the ESPs possible. The authors thank the scientists from other institutions for their thoughtful comments and feedback in the manuscript review. The authors also thank Martin Dorn, Anne Hollowed, Sandra Lowe, Chris Lunsford, Cara Rodgveller, and James Thorson for their reviews, continued support, and useful ideas regarding the ESP framework. Finally, the authors thank the North Pacific Fishery Management Council's Groundfish and Crab Plan Teams, Scientific and Statistical Committee, and Ecosystem Committee for their helpful review and recommendations on the development of the ESPs.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Alaska Fisheries Science Center (AFSC). 2016. AFSC priorities and annual guidance for FY2017. Report Memo. 7 pp. https://www.afsc.noaa.gov/GeneralInfo/FINAL%20FY17%20AFSC%20AGM%20v3.pdf

Alaska Fisheries Science Center (AFSC). 2017. AFSC priorities and annual guidance for FY2018. Report Memo. 6 pp. https://www.afsc.noaa.gov/program_reviews/2017/2017_Core_Documents/FY18%20AFSC%20AGM.pdf

Alaska Fisheries Science Center (AFSC). 2018. AFSC priorities and annual guidance memorandum for FY2019. Report Memo. 5 pp.

Alaska Fisheries Science Center (AFSC). 2022. Alaska Fisheries Science Center Strategic Plan FY 2023-FY2027. Report Memo. 26 pp. https://media.fisheries.noaa.gov/2022-02/AFSC-SSP_31JAN22_508_0.pdf

Arimitsu, M., and S. Hatch. 2019. Arimitsu (USGS) and Hatch (ISRC). Gulf Watch Alaska Long-Term Monitoring Program.

Bailey, K. M., L. Ciannelli, N. A. Bond, A. Belgrano, and N. C. Stenseth. 2005. Recruitment of walleye pollock in a physically and biologically complex ecosystem: A new perspective. *Progress in Oceanography*. 67 (1-2):24–42. doi: 10.1016/j.pocean.2005.06.001.

Barbeaux, S., B. Ferriss, B. Laurel, M. Litzow, S. McDermott, J. Nielsen, W. Palsson, K. Shotwell, I. Spies, and M. Wang. 2021. Assessment of the Pacific cod stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Boldt, J., C. Rooper, and J. Hoff. 2017. Gulf of Alaska groundfish condition. In *Ecosystem status report 2017: Gulf of Alaska, stock assessment and fishery evaluation report*, ed. S. Zador and E. Yasumiishi, Anchorage, AK: North Pacific Fishery Management Council.

Caddy, J. F. 2015. The traffic light procedure for decision making: Its rapid extension from fisheries to other sectors of the economy. *Global Journal of Science Frontier Research* 15 (1):30.

Cheng, M. L. H., C. J. Rodgveller, J. A. Langan, and C. J. Cunningham. 2023. Standardizing fishery-dependent catch-rate information across gears and data collection programs for Alaska sablefish (*Anoplopoma fimbria*). *ICES Journal of Marine Science* 80 (4):1028–42. doi: 10.1093/icesjms/fsad037.

Clyde, M. A., J. Ghosh, and M. L. Littman. 2011. Bayesian adaptive sampling for variable selection and model averaging. *Journal of Computational and Graphical Statistics* 20 (1):80–101. doi: 10.1198/jcgs.2010.09049.

Coffin, B., and F. Mueter. 2015. Environmental covariates of sablefish (Anoplopoma fimbria) and Pacific ocean perch (Sebastes alutus) recruitment in the Gulf of Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:194–209. doi: 10.1016/j.dsr2.2015.02.016.

Cope, J. M., J. DeVore, E. J. Dick, K. Ames, J. Budrick, D. L. Erickson, J. Grebel, G. Hanshew, R. Jones, L. Mattes, et al. 2011. An approach to defining stock complexes for U.S. west coast groundfishes using vulnerabilities and ecological distributions. *North American Journal of Fisheries Management* 31 (4):589–604. doi: 10.1080/02755947.2011.591264.

Coral Reef Watch. 2018. Updated daily. NOAA Coral Reef Watch Version 3.1 Daily Global 5-km Satellite Coral Bleaching Degree Heating Week Product, Jun. 3, 2013-Jun. 2, 2014. College Park, Maryland, USA: NOAA Coral Reef Watch. Data set accessed through the ERDDAP server from West Coast Node CoastWatch, https://coralreefwatch.noaa.gov/satellite/hdf/index.php., https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html

Crawley, M. J. 2007. *The R book*. John Wiley & Sons, Ltd., Chichester, UK, 637 pp.

Cunningham, C. J., P. A. Westley, and M. D. Adkison. 2018. Signals of large scale climate drivers, hatchery enhancement, and marine factors in Yukon River Chinook salmon survival revealed with a Bayesian life history model. *Global Change Biology* 24 (9):4399–416. doi: 10.1111/gcb.14315.

Deriso, R. B., M. N. Maunder, and W. H. Pearson. 2008. Incorporating covariates into fisheries stock assessment models with application to Pacific herring. *Ecological Applications: A Publication of the Ecological Society of America* 18 (5):1270–86. doi: 10.1890/07-0708.1.

Dickson, D. M. S., and M. R. Baker. 2016. Introduction to the North Pacific Research Board Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP): Volume I. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:1–5. doi: 10.1016/j.dsr2.2016.08.005.

Dolan, T. E., W. S. Patrick, and J. S. Link. 2016. Delineating the continuum of marine ecosystem-based management: A US fisheriesreference point perspective. *ICES Journal of Marine Science* 73 (4):1042–50. doi: 10.1093/icesjms/fsv242.

Doran, G. T. 1981. There's a S.M.A.R.T. way to write management's goals and objectives. *Management Rev* 70 (11):35–6.

Dorn, M. W., A. L. Deary, B. E. Fissel, D. T. Jones, N. E. Lauffenburger, W. A. Palsson, L. A. Rogers, S. A. Shotwell, K. A. Spalinger, and S. G. Zador. 2019. Assessment of the Walleye Pollock stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Dorn, M. W., A. L. Deary, B. E. Fissel, D. T. Jones, M. Levine, A. L. McCarthy, W. A. Palsson, L. A. Rogers, S. K. Shotwell, K. A. Spalinger, et al. 2020. Assessment of the walleye pollock stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Dorn, M. W., and S. G. Zador. 2020. A risk table to address concerns external to stock assessments when developing fisheries harvest recommendations. *Ecosystem Health and Sustainability* 6 (1):1–11.

Doyle, M. J., and K. L. Mier. 2016. Early life history pelagic profiles of selected commercially important fish species in the Gulf of Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:162–93. doi: 10.1016/j.dsr2.2015.06.019.

Field, J. C., S. G. Beyer, and X. He. 2015. *Status of the Chilipepper rockfish, Sebastes goodie, in the California* Current for 2015.

Fissel, B., M. Dalton, B. Garber-Yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, C. Seung, K. Sparks, M. Szymkowiak, et al. 2020. Economic status of the groundfish fisheries off Alaska, 2019. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BSAI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Froese, R. and D. Pauly, eds. 2018. FishBase. World Wide Web electronic publication. www.fishbase.org

Gaichas, S. K., R. J. Seagraves, J. M. Coakley, G. S. DePiper, V. G. Guida, J. A. Hare, P. J. Rago, and M. J. Wilber. 2016. A framework for incorporating species, fleet, habitat, and climate interactions into fishery management. *Frontiers in Marine Science* 3:105. doi: 10.3389/fmars.2016.00105.

Gibson, G. A., W. T. Stockhausen, K. O. Coyle, S. Hinckley, C. Parada, A. Hermann, M. Doyle, and C. Ladd. 2019. An individual-based model for sablefish: Exploring the connectivity between potential spawning and nursery grounds in the Gulf of Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 165:89–112. doi: 10.1016/j.dsr2.2018.05.015.

Goethel, D. R., D. H. Hanselman, C. J. Rodgveller, K. H. Fenske, S. K. Shotwell, K. B. Echave, P. W. Malecha, K. A. Siwicke, and C. R. Lunsford. 2020. Assessment of the Sablefish stock in Alaska. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Goethel, D. R., C. J. Rodgveller, K. B. Echave, S. K. Shotwell, K. A. Siwicke, D. H. Hanselman, P. W. Malecha, M. Cheng, M. Williams, K. Omori, et al. 2022. Assessment of the Sablefish stock in Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Gove, J. M., J. Lecky, W. J. Walsh, R. J. Ingram, K. Leong, I. D. Williams, J. J. Polovina, J. A. Maynard, R. Whittier, L. Kramer, et al. 2019. West Hawai'i integrated ecosystem assessment ecosystem status report. Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-19-001, 46. p. doi: 10.25923/t3cc-2361.

Hanselman, D., C. Rodgveller, C. Lunsford, and K. Fenske. 2017. Assessment of the Sablefish stock in Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D. H., C. J. Rodgveller, K. H. Fenske, S. K. Shotwell, K. B. Echave, P. W. Malecha, and C. R. Lunsford. 2018. Assessment of the Sablefish stock in Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D. H., C. J. Rodgveller, K. H. Fenske, S. K. Shotwell, K. B. Echave, P. W. Malecha, and C. R. Lunsford. 2019. Assessment of the Sablefish stock in Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Harvey, C., N. Garfield, G. Williams, N. Tolimieri, K. Andrews, K. Barnas, E. Bjorkstedt, S. Bograd, J. Borchert, C. Braby, et al. 2020. Ecosystem Status Report of the California Current for 2019–20: A Summary of Ecosystem Indicators Compiled by the California Current Integrated Ecosystem Assessment Team (CCIEA). U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-160.

Hiatt, T., and J. Terry. 1999. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: Economic status of the groundfish fisheries off Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fisheries Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501, 100. pp.

Hobday, A. J., L. V. Alexander, S. E. Perkins, D. A. Smale, S. C. Straub, E. C. Oliver, J. A. Benthuysen, M. T. Burrows, M. G. Donat, M. Feng, et al. 2016. A hierarchical approach to defining marine heatwaves. *Progress in Oceanography* 141:227–38. doi: 10.1016/j.pocean.2015.12.014.

Hollowed, A. B., K. M. Bailey, and W. S. Wooster. 1987. Patterns in recruitment of marine fishes in the Northeast Pacific Ocean. *Biological oceanography* 5 (2):99–131. doi: 10.1080/01965581.1987.10749508.

Hollowed, A. B., K. Aydin, K. Blackhart, M. Dorn, D. Hanselman, J. Heifetz, S. Kasperski, S. Lowe, and K. Shotwell. 2016. *Discussion paper stock assessment prioritization for the North Pacific fishery management council: methods and scenarios*. Report to North Pacific Fisheries Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501, 17. pp.

Hollowed, A. B., K. K. Holsman, A. Haynie, A. Hermann, A. Punt, K. Aydin, J. Ianelli, S. Kasperski, W. Cheng, A. Faig, et al. 2020. Integrated modelling to evaluate climate change impacts on coupled social-ecological systems in Alaska. *Frontiers in Marine Science* 6:775. doi: 10.3389/fmars.2019.00775.

Hunsicker, M. E., C. V. Kappel, K. A. Selkoe, B. S. Halpern, C. Scarborough, L. Mease, and A. Amrhein. 2016. Characterizing driver–response relationships in marine pelagic ecosystems for improved ocean management. *Ecological Applications: A Publication of the Ecological Society of America* 26 (3):651–63. doi: 10.1890/14-2200.

Karnauskas, M., C. R. Kelble, S. Regan, C. Quenée, R. Allee, M. Jepson, A. Freitag, J. K. Craig, C. Carollo, L. Barbero, et al. 2017. Ecosystem status report update for the Gulf of Mexico. *NOAA Technical Memorandum NMFS-SEFSC* 706:51.

Krieger, J. R., A. Sreenivasan, and R. Heintz. 2019. Temperature-dependent growth and consumption of young-of-the-year sablefish Anoplopoma fimbria: Too hot, too cold or just right? *Fisheries Research* 209:32–9. doi: 10.1016/j.fishres.2018.09.005.

Ladd, C., W. Cheng, and S. Salo. 2016. Gap winds and their effects on regional oceanography Part II: Kodiak Island, Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:54–67. doi: 10.1016/j.dsr2.2015.08.005.

Laman, N., and S. Rohan. 2020. Gulf of Alaska Groundfish condition. In *Ecosystem status report 2020: Gulf of Alaska, stock assessment and fishery evaluation report*, ed. B. Ferriss and S. Zador. Anchorage, AK: North Pacific Fishery Management Council.

Levin, P. S., M. J. Fogarty, S. A. Murawski, and D. Fluharty. 2009. Integrated ecosystem assessments: Developing the scientific basis for ecosystem-based management of the ocean. *PLoS Biology* 7 (1):e14. doi: 10.1371/journal.pbio.1000014.

Link, J. S., and H. I. Browman. 2017. Operationalizing and implementing ecosystem-based management. *ICES Journal of Marine Science* 74 (1):379–81. doi: 10.1093/icesjms/fsw247.

Livingston, P. ed. 1999. Ecosystem considerations for 2000, appendix D. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 140 pp.

Lynch, P. D., R. D. Methot, and J. S. Link eds. 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-183, 127 p. doi: 10.7755/TMSPO.183., https://spo.nmfs.noaa.gov/sites/default/files/TMSPO183.pdf

Malecha, P., C. Rodgveller, C. Lunsford, and K. Siwicke. 2019. *The 2018 longline survey of the Gulf of Alaska and eastern Aleutian Islands on the FV Alaskan Leader: Cruise Report AL-18-01*. AFS Processed Rep. 2019-02, 30 p. Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service, Seattle WA.

Marshall, K. N., L. E. Koehn, P. S. Levin, T. E. Essington, and O. P. Jensen. 2019. Inclusion of ecosystem information in US fish stock assessments suggests progress toward ecosystem-based fisheries management. *ICES Journal of Marine Science* 76 (1):1–9. doi: 10.1093/icesjms/fsy152.

McConnaughey, R. A., K. E. Blackhart, M. P. Eagleton, and J. Marsh. 2017. Habitat assessment prioritization for Alaska stocks: Report of the Alaska Regional Habitat Assessment Prioritization Coordination Team. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-361, 102 p.

McFarlane, G. A., and R. J. Beamish. 1992. Climatic influence linking copepod production with strong year-classes in sablefish, Anoplopoma fimbria. *Canadian Journal of Fisheries and Aquatic Sciences* 49 (4):743–53. doi: 10.1139/f92-083.

Megrey, B. A., A. B. Hollowed, S. R. Hare, S. A. Macklin, and P. J. Stabeno. 1996. Contributions of FOCI research to forecasts of year-class strength of walleye pollock in Shelikof Strait, Alaska. *Fisheries Oceanography* 5 (s1):189–203. doi: 10.1111/j.1365-2419.1996.tb00092.x.

MethotJr., R. D. ed. 2015. Prioritizing fish stock assessments. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-F/SPO-152, 31. p.

Morrison, W. E., M. W. Nelson, J. F. Howard, E. J. Teeters, J. A. Hare, R. B. Griffis, J. D. Scott, and M. A. Alexander. 2015. Methodology for assessing the vulnerability of marine fish and shellfish species to a changing climate. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-OSF-3, 48. p.

Morrison, W., T. L. Rankin, S. A. Oakes, C. J. Harvey, S. Lucey, E. Keiley, M. Mackey, K. Abrams, and K. Osgood eds. 2022. Investigating and improving applications of ecosystem status reports in u.s. fisheries management. Report from a 2021 Workshop organized by the National Marine Fisheries Service Ecosystem-Based Fisheries Management Working Group. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-OSF-11, 44. p.

Nielsen, J. M., L. Eisner, J. Watson, J. C. Gann, C. W. Mordy, S. W. Bell, C. Harpold, D. Crouser, and P. Stabeno. 2020. Spring satellite chlorophyll-a concentrations in the Eastern Bering Sea. In *Ecosystem status report 2020: Gulf of Alaska, stock assessment and fishery evaluation report*, ed. B. Ferriss and S. Zador. Anchorage, AK: North Pacific Fishery Management Council.

NMFS. 2011. *Habitat Assessment Prioritization*. A Report by the Habitat Assessment Prioritization Working Group. Internal Report, NMFS White Paper. Office of Science and Technology, NMFS, NOAA. Silver Spring, MD, 41. p.

North Pacific Fishery Management Council (NPFMC). 2017. Report of the Scientific and Statistical Committee to the North Pacific Fishery Management Council December 4th-6th, 2017. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501, 40. pp.

O'Hara, R. B., and M. J. Sillanpää. 2009. A review of Bayesian variable selection methods: What, how and which. *Bayesian Analysis* 4 (1):85–118. doi: 10.1214/09-BA403.

Ormseth, O. A., and P. D. Spencer. 2011. An assessment of vulnerability in Alaska groundfish. *Fisheries Research*. 112 (3):127–33. doi: 10.1016/j.fishres.2011.02.010.

Ostle, C., and S. Batten. 2020. Continuous plankton recorder data from the Northeast Pacific, 2000–2019. In *Ecosystem status report 2020: Gulf of Alaska, stock assessment and fishery evalu-*

ation report, ed. B. Ferriss and S. Zador. Anchorage, AK: North Pacific Fishery Management Council.
Palof, K., J. Zheng, and J. Ianelli. 2019. *Saint Matthew Island Blue King Crab Stock Assessment 2019*. In Stock assessment and fishery evaluation report for the Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.
Palof, K., J. Zheng, and J. Ianelli. 2020. *Saint Matthew Island Blue King Crab Stock Assessment 2020*. In Stock assessment and fishery evaluation report for the Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.
Patrick, W. S., and J. S. Link. 2015. Myths that continue to impede progress in ecosystem-based fisheries management. *Fisheries* 40 (4):155–60. doi: 10.1080/03632415.2015.1024308.
Patrick, W. S., P. Spencer, J. Link, J. Cope, J. Field, D. Kobayashi, P. Lawson, T. Gedamke, E. Cortés, O. A. Ormseth, et al. 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. *Fishery bulletin. United States*, 108:305–22.
Peterson, W. T., J. L. Fisher, J. O. Peterson, C. A. Morgan, B. J. Burke, and K. L. Fresh, NOAA. 2014. Applied fisheries oceanography: Ecosystem indicators of ocean conditions inform fisheries management in the California Current. *Oceanography* 27 (4):80–9. doi: 10.5670/oceanog.2014.88.
Pinsky, M. L., and N. J. Mantua, Rutgers University. 2014. Emerging adaptation approaches for climate ready fisheries management. *Oceanography* 27 (4):146–59. doi: 10.5670/oceanog.2014.93.
Reiniger, R., and C. Ross. 1968. A method of interpolation with application to oceanographic data. *Deep Sea Research and Oceanographic Abstracts* 15 (2):185–93. doi: 10.1016/0011-7471(68)90040-5.
Ressler, P. H, And this one. 2019. Gulf of Alaska Euphausiids. In *Ecosystem Considerations for 2019, Stock Assessment and Fishery Evaluation Report*. Technical report, ed. S. Zador and E. Yasumiishi. Anchorage, AK: North Pacific Fishery Management Council.
Sagarese, S. R., M. V. Lauretta, and J. F. Walter. 2017. Progress towards a next-generation fisheries ecosystem model for the northern Gulf of Mexico. *Ecological Modelling* 345:75–98. doi: 10.1016/j.ecolmodel.2016.11.001.
Shertzer, K. W., M. H. Prager, and E. H. Williams. 2008. A probability-based approach to setting annual catch levels. *Fish. Bull., U.S* 106 (3):225–32.
Shotwell, S. K., and K. Blackhart. 2023. Stock assessment classification and gap analysis for federally managed stocks in the Alaska Ecosystem Complex. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-465, 75. p.
Shotwell, S. K., D. H. Hanselman, and I. M. Belkin. 2014. Toward biophysical synergy: Investigating advection along the Polar Front to identify factors influencing Alaska sablefish recruitment. *Deep Sea Research Part II: Topical Studies in Oceanography* 107:40–53. doi: 10.1016/j.dsr2.2012.08.024.
Shotwell, S. K., D. H. Hanselman, S. Zador, and K. Aydin. 2014. Proposed framework for stock-specific ecosystem considerations (SEC) in Alaskan groundfish fishery management plans. Report to Joint Groundfish Plan Team, September 2014. 25 p. Summarized in meeting minutes online at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=9c189ee7-0f9f-4286-be40-cd887d68ffff.pdf&fileName=1-GFPT%20Minutes%20914.pdf
Shotwell, S. K., D. H. Hanselman, S. Zador, and K. Aydin. 2016. Stock-specific Profiles and Ecosystem Considerations (SPEC) for Alaska groundfish fishery management plans. Report to Joint Groundfish Plan Team, September 2016. 15 p. https://meetings.npfmc.org/CommentReview/DownloadFile?p=f2f6e20b-bc55-4d0a-9825-c1b562022253.pdf&fileName=Stock_Profile_and_Ecosystem_Considerations_September_PT_2016.pdf
Shotwell, S. K. 2018. Update on the Ecosystem and Socioeconomic Profile (ESP). Report to Joint Groundfish Plan Team, September 2018. 11 p. https://meetings.npfmc.org/CommentReview/DownloadFile?p=d467ccc4-a136-4d63-b445-fdc6d0fe4629.pdf&fileName=ESP_Update_PT-0918_Shotwell.pdf
Shotwell, S. K. 2020. Update on the Ecosystem and Socioeconomic Profile (ESP) in the Alaska groundfish and crab fishery management plans. Report to Joint Groundfish Plan Team,

September 2020. 18 p. https://meetings.npfmc.org/CommentReview/DownloadFile?p=8f5233fb-3b62-4571-9b49-8bb7ce675916.pdf&fileName=ESP_Shotwell.pdf

Siddon, E. 2020. Ecosystem Status Report 2020: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Siwicke, K., P. Malecha, and C. Rodgveller. 2021. The 2020 longline survey of the Gulf of Alaska and eastern Aleutian Islands on the FV Alaskan Leader: Cruise Report AL-20-01. AFSC Processed Rep. 2021-02, 33 p. Auke Bay Laboratories, Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 17109 Point Lena Loop Road Juneau, AK 99801.

Sogard, S. M. 2011. Interannual variability in growth rates of early juvenile sablefish and the role of environmental factors. *Bulletin of Marine Science* 87 (4):857–72. doi: 10.5343/bms.2010.1045.

Sogard, S. M., and B. L. Olla. 2001. Growth and behavioral responses to elevated temperatures by juvenile sablefish Anoplopoma fimbria and the interactive role of food availability. *Marine Ecology Progress Series* 217:121–34. doi: 10.3354/meps217121.

Sogard, S. M., and M. L. Spencer. 2004. Energy allocation in juvenile sablefish: Effects of temperature, ration and body size. *Journal of Fish Biology.* 64 (3):726–38. doi: 10.1111/j.1095-8649.2004.00342.x.

Spalinger, K. 2015. *Operational plan: Large-mesh bottom trawl survey of crab and groundfish: Kodiak, Chignik, South Peninsula, and Eastern Aleutian management districts–standard protocol 2015-2019*. Alaska Department of Fish and Game, Regional Operational Plan ROP.CF.4K.2015.20, Kodiak.

Spencer, P. D., A. B. Hollowed, M. F. Sigler, A. J. Hermann, and M. W. Nelson. 2019. Trait-based climate vulnerability assessments in data-rich systems: An application to eastern Bering sea fish and invertebrate stocks. *Global Change Biology* 25 (11):3954–71. doi: 10.1111/gcb.14763.

Sreenivasan, A., and R. Heintz. 2016. Estimation of the relationship between growth, consumption, and energy allocation in juvenile pacific cod (*Gadus microcephalus*) as a function of temperature and ration. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:154–61. doi: 10.1016/j.dsr2.2016.04.004.

Stewart, I. J., J. T. Thorson, and C. Wetzel. 2011. Status of the U.S. sablefish resource in 2011. Pacific Fishery Management Council, Portland, OR. 442 p. http://www.pcouncil.org/wp-content/uploads/Sablefish_2011_Assessment.pdf.

Szuwalski, C. 2022. An assessment for eastern Bering Sea snow crab. In Stock assessment and fishery evaluation report for the Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Thompson, G. G., S. Barbeaux, J. Conner, B. Fissel, T. Hurst, B. Laurel, C. A. O'Leary, L. Rogers, S. K. Shotwell, E. Siddon, et al. 2021. Assessment of the Pacific cod stock in the Eastern Bering Sea. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands. North Pacific Fishery Mngt. Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Thorson, J. T., A. O. Shelton, E. J. Ward, and H. Skaug. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES Journal of Marine Science* 72 (5):1297–310. doi: 10.1093/icesjms/fsu243.

Thorson, J. T. 2019. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. *Fisheries Research.* 210:143–61. doi: 10.1016/j.fishres.2018.10.013.

Tommasi, D., Y. deReynier, H. Townsend, C. J. Harvey, W. H. Satterthwaite, K. N. Marshall, I. C. Kaplan, S. Brodie, J. C. Field, E. L. Hazen, et al. 2021. A case study in connecting fisheries management challenges with models and analysis to support ecosystem-based management in the California current ecosystem. *Frontiers in Marine Science* 8:624161. doi: 10.3389/fmars.2021.624161.

Trenkel, V. M. 2018. How to provide scientific advice for ecosystem-based management now. *Fish and Fisheries* 19 (2):390–8. doi: 10.1111/faf.12263.

von Szalay, P. G., and N. W. Raring. 2018. Data Report: 2017 Gulf of Alaska bottom trawl survey, U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-374, 260. p.

Watson, J. T. 2020. Satellite-derived Sea Surface Temperature and Marine Heatwaves in the Gulf of Alaska. In *Ecosystem status report 2020: Gulf of Alaska, stock assessment and fishery evaluation report*, ed. B. Ferriss and S. Zador. Anchorage, AK: North Pacific Fishery Management Council.

Watson, J. T., J. C. Gann, and J. M. Nielsen. 2020. Satellite-derived chlorophyll-a trends in the Gulf of Alaska. In *Ecosystem status report 2020: Gulf of Alaska, stock assessment and Fishery Evaluation Report*, ed. B. Ferriss and S. Zador. Anchorage, AK: North Pacific Fishery Management Council.

Wilderbuer, T., W. Stockhausen, and N. Bond. 2013. Updated analysis of flatfish recruitment response to climate variability and ocean conditions in the Eastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 94:157–64. doi: 10.1016/j.dsr2.2013.03.021.

Zador, S., K. Holsman, K. Aydin, and S. Gaichas. 2017. Ecosystem Considerations in Alaska: The value of qualitative assessment. *ICES Journal of Marine Science* 74 (1):421–30. doi: 10.1093/icesjms/fsw144.

Zador, S., and E. Yasumiishi ed. 2017. Ecosystem considerations 2017 Status of the Gulf of Alaska Marine Ecosystem. In Stock Assessment and Fishery Evaluation Report, North Pacific Fisheries Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 215. pp.

Zheng, J., and M. S. M. Siddeek. 2020. Bristol Bay Red King Crab Stock Assessment in Fall 2020. In Stock assessment and fishery evaluation report for the Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.