# Instructions

* Do not remove any "#" or "{-}" in section titles, or change any inline code chunks that start with "`r params$...`". They are necessary for the creation of the final document. They will not show up in the final document.
* All figures and tables should be identified by a **unique** keyword(s) in the "chunk\_name" column of their respective spreadsheet. The keyword(s) should NOT contain any spaces or underscores. Periods and dashes are permissible. **When referencing figures and tables in the text, please use the format: Figure \@ref(fig:keyword) and Table \@ref(tab:keyword)**, NOT "Figure 1" "Table 1" etc. This is necessary for the creation of the final document. The formatting will be normal in the final document.
* References should be documented in the .bib file. **When citing a reference in the text, please use the format: [@keyword]. Use @keyword if you don’t want the authors’ names in parentheses. Use [-@keyword] to suppress the authors’ names. Separate multiple references within brackets with ; for example [@keyword; @keyword]**
* Tables should include:
  + List of data sources used in the ESP evaluation
  + Ecological information table by life history stage
  + Key processes table by life history stage
  + Economic performance report tables
  + Ecosystem indicator description table with traffic light of most recent year
  + Socioeconomic indicator description table with traffic light of most recent year
* Figures should include:
  + Baseline metric panel with percentile and data quality shading
  + Life history conceptual model summarizing ecological information and key processes by life history stage
  + Species distribution model of suitable habitat by life history stage [optional]
  + Phenology of mean abundance by life history stage with relevant environmental climatologies [optional]
  + Energy content by life history stage [optional]
  + Predation mortality and diet composition for adult and juvenile stages [optional]
  + Socioeconomic conceptual model [optional]
  + Community dependence graphics [optional]
  + Time series of ecosystem and socioeconomic indicators following ecosystem status report
  + Importance model output where relevant [optional]
  + Simplified one-page summary template of ESP report (when code developed)
* Anything written above the "Executive Summary" heading will be deleted from the final document.

# # Executive Summary {-}

National initiatives and North Pacific Fishery Management Council (NPFMC) recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for the `r params$region` (`r params$region\_abbreviation`) `r params$fish` stock. In addition, annual guidelines for the Alaska Fisheries Science Center (AFSC) support research that improves our understanding of environmental and climate forcing of ecosystem processes with a focus on variables that can provide direct input into or improve stock assessment and management. The `r params$region\_abbreviation` `r params$fish` ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for `r params$region\_abbreviation` `r params$fish`, and may be considered a proving ground for potential use in the main stock assessment.

We use information from a variety of data streams available for the `r params$region\_abbreviation` `r params$fish` stock and present results of applying the ESP process through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic processes for `r params$region\_abbreviation` `r params$fish` by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment or other management decisions.

## ## Ecosystem Considerations {-}

* Summary conclusions from metric or indicator assessment

## ## Socioeconomic Considerations {-}

* Summary conclusions from metric assessment or indicator assessment

## ## Responses to SSC and Plan Team Comments on ESPs in General {-}

## ## Responses to SSC and Plan Team Comments Specific to this ESP {-}

*"The SSC noted the relatively strong correlations for snow crab and BBRKC with the Arctic Oscillation, and suggests this could be further explored to determine the mechanism. The SSC requests that the CPT or the crab assessment authors examine recruitment estimates across crab stocks to see if they share a common underlying pattern. The SSC recommends that an Ecosystem and Socioeconomic Profile (ESP) be developed for EBS snow crab as time allows that carefully considers what indicators directly affect this stock"* (SSC, October 2020, pg. 16)

# # Introduction {-}

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating it with the stock assessment. A consistent approach has been lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. This new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process [Shotwellinreview]. The ESP uses data collected from a variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Sigleretal2017; Dornetal2018; Lynchetal2018) and recommended by the NPFMC groundfish and crab Plan Teams and the Scientific and Statistical Committee (SSC).

This ESP for `r params$region\_abbreviation` `r params$fish` (Chionoecetes opilio) follows the template for ESPs [Shotwellinreview] and replaces the previous ecosystem considerations section in the main `r params$region\_abbreviation` `r params$fish` stock assessment and fishery evaluation (SAFE) report. Information from the original ecosystem considerations section may be found in Szuwalski (2021).

The ESP process consists of the following four steps:

1. Evaluate national initiative and stock assessment classification scores [Lynchetal2018] along with regional research priorities to assess the priority and goals for conducting an ESP.
2. Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.
3. Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.
4. Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

## ## Justification {-}

National initiatives and NPFMC recommendations support conducting an ESP for the `r params$region\_abbreviation` `r params$fish` stock. The high commercial importance of the stock and the early life history habitat requirements created a high score for both stock assessment and habitat assessment prioritization (Hollowedetal2016; McConnaugheyetal2017). The vulnerability scores were in the low to moderate of all groundfish scores based on productivity, susceptibility [OrmsethSpencer2011], and sensitivity to future climate exposure [Spenceretal2019]. The new data classification scores for GOA Pacific cod suggest a data-rich stock with high quality data for catch, size/age composition, abundance, life history categories, and ecosystem linkages [Lynchetal2018]. These initiative scores and data classification levels suggest a high priority for conducting an ESP for `r params$region\_abbreviation` `r params$fish` particularly given the high level of life history information and current application of ecosystem linkages in the stock assessment model for natural mortality and catchability. Additionally, AFSC research priorities support studies that improve our understanding of environmental and climate forcing of ecosystem processes with focus on variables that provide direct input into stock assessment and management. Specifically, research that improves our understanding of `r params$fish` dynamics in the `r params$region`.

## ## Data {-}

Initially, information on `r params$region\_abbreviation` `r params$fish` was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 2016. These include (but are not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment categorization. Data derived from this effort served as the initial starting point for developing the ESP metrics for stocks in the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) groundfish fishery management plans (FMP) and the BSAI king and tanner crab FMP. Please see @Shotwellinreview, for more details.

Data used to generate ecosystem metrics and indicators for the `r params$region\_abbreviation` `r params$fish` ESP were collected from a variety of laboratory studies, remote sensing databases, fisheries surveys, regional reports and fishery observer data collections \@ref(tab:data). Results from laboratory studies were specifically used to inform metrics and indicators relating to thermal tolerances, phenology and energetics across RKC life history stages. Larval indicator development utilized datasets from the NOAA Bering Arctic Subarctic Integrated Survey (BASIS) and blended satellite data products from NOAA, NASA and ESA. Data for late-juvenile through adult RKC stages were derived from the annual NOAA eastern Bering Sea bottom trawl survey and fishery observer data collected during the BBRKC fishery. Information on RKC habitat use was derived from essential fish habitat (EFH) model output and maps (Figure 3; Laman et al., 2017) as well as laboratory studies and collaborative RKC tagging efforts. Data from the NOAA Resource Ecology and Ecosystem Modeling (REEM) food habits database were used to determine species compositions of benthic predators on commercial crab species.

Data used to generate socioeconomic metrics and indicators were derived from fishery-dependent sources, including commercial landings data for BBRKC collected in ADFG fish tickets and the BSAI Crab Economic Data Report (EDR) database (both sourced from AKFIN), and effort statistics reported in the most recent ADFG Annual Management Report for BSAI shellfish fisheries estimated from ADF&G Crab Observer program data (Leon et al. 2017).

# # Metrics Assessment {-}

## ## National Metrics {-}

Description of measures collected in the national initiatives relevant to the stock FMP

Description of ecosystem and socioeconomic stock vulnerabilities

Ecosystem metrics example: high recruitment variability (standard deviation of log recruitment estimates > 0.9), low fecundity, and small hatch size indicate vulnerabilities in early life

Socioeconomic metrics example: high commercial importance, high constituent demand indicate high value to fisheries and communities and vulnerability to fishing pressure

Graph of national initiative metric panel

## ## Ecosystem Processes {-}

Data evaluated over ontogenetic shifts (e.g., embryo, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. As a first attempt, we summarized important ecosystem processes or potential bottlenecks across snow crab life history stages from the literature, process studies and laboratory rearing experiments. Details on why these processes were highlighted, as well as the potential relationship between ecosystem processes and stock productivity are described below.

After molting to maturity, female snow crab mate and extrude new egg clutches each spring, which remain attached to pleopods on the female’s abdomen for a full year prior to hatching (Watson, 1970). Fecundity is positively correlated with female size, and primiparous females have a lower fecundity than multiparous females (Sainte-Marie, 1993). The optimal range for embryo development is 0 to 3&deg;C, although laboratory studies indicate that incubation temperatures below 0&deg;C can trigger diapause or a biennial reproduction cycle (Webb et al., 2007). Peak hatching of snow crab larvae occurs in April (Armstrong et al., 1981) and phyto-detritus may act as a chemical cue for larval release (Starr et al., 1994). Larval duration for each of the two zoeal stages is approximately 30 days (Incze et al., 1982). A longer larval stage associated with cooler temperatures may leave larvae more vulnerable to pelagic predators for a prolonged period. Furthermore, historical larval year-class failures have coincided with low zooplankton abundance over the middle shelf and low water column stability, suggesting that increased larval mortality is related to less favorable feeding conditions (Incze et al., 1987) and mismatches between larval release and the spring bloom (Somerton 1982). Likewise, laboratory studies suggest that relatively high prey densities are required for successful feeding in snow crab zoeae (Paul et al., 1979) Major predators of larval snow crab include yellowfin sole (Armstrong et al., 1980), walleye pollock, jellyfish and juvenile salmon (Kruse et al., 2007).

Snow crab larvae settle between late August to the end of October (Conan et al., 1992). Early benthic instars are cryptic and concentrate in shallow, cold water habitats (Lovrish et al., 1995; Murphy et al., 2010). Previous laboratory studies have shown that adequate energetic stores are prerequisites for molting, growth, and survival in snow crab early life history stages (e.g. Lovrich and Ouellet, 1994), indicating that variability in energetic reserves could represent a potential recruitment bottleneck in snow crab. Both settlement intensity and early benthic survival are likely critical determinants of year-class strength in snow crab (Sainte-Marie et al., 1996), and successful advection to areas of suitable temperature and muddy substrate are thought to be critical criteria for juvenile survival (Dionne et al., 2003). Density-dependence may also play a regulatory role due to high rates of cannibalism (Lovrich and Sainte-Marie 1997) and potential prey resource limitation in juvenile nurseries. Previous studies have shown that Pacific cod, sculpin, skates and halibut are major predators of juvenile snow crab (Livingston et al., 1993; Livingston and deReynier, 1996; Lang et al., 2003) and the cold pool may provide refuge from predators like Pacific cod that avoid waters less than 2&deg;C (Ciannelli and Bailey, 2005). Juvenile snow crab are especially vulnerable to predation and cannibalism during and immediately following molting.

Spatial patterns in juvenile and adult snow crab distribution are determined largely by ontogenetic migrations linked to size- and sex-specific thermal requirements. Immature snow crab concentrate in colder, shallow waters of the NBS and EBS middle shelves, and have historically avoided thermal habitats >2&deg;C (Kolts et al., 2015; Murphy, 2020). Likewise, primiparous female snow crab appear to track near-bottom temperature during a northeast to southwest ontogenetic migration to warmer waters near the shelf break (Ernst et al., 2005; Parada et al., 2010). Shifts in centers of distribution of mature female snow crab relative to prevailing currents may affect larval supply to nursery areas (Zheng and Kruse, 2006) and thermal occupancy patterns of snow crab depend on the availability of cold water habitat (Fedewa et al., 2020). While 2&deg;C may represent a critical temperature threshold for immature snow crab (Murphy, 2020), negative effects on metabolic processes are not apparent in mature snow crab until temperatures exceed 7◦C (Foyle et al., 1989). Temperature also influences molt timing (Dutil et al., 2010), growth rates (Yamamoto et al., 2015), energy stores (Hardy et al., 2000), and body condition (Dutil et al., 2010) of snow crab in the laboratory.

## ## Socioeconomic Processes {-}

As described below, the set of socioeconomic indicators proposed in this ESP are categorized as Fishery Performance and Economic Performance and Community Effects indicators. Fishery Performance indicators are intended to represent processes most directly involved in prosecution of the EBS snow crab fishery, and thus have the potential to differentially affect the condition of the stock depending on how they influence the timing, spatial distribution, selectivity, and other aspects of fishing pressure. Economic Performance and Community Effects indicators are intended to capture key dimensions of the economic and social processes through which outputs, benefits and other effects flowing from commercial exploitation of the fishery are generated and distributed. Notwithstanding these categorical distinctions, the social and economic processes that affect, and are affected by, the condition of the stock are complex and interrelated at different time scales. Moreover, these processes are strongly influenced by the institutional structures of fishery management, which develop over time and include both discrete measures undertaken by in-season management, as well as comprehensive structural changes that induce complex, multidimensional change affecting numerous social and economic processes. Implementation of the Crab Rationalization (CR) Program in 2005 is an example of the latter (a full summary of the management history of the EBS snow crab fishery is beyond the scope of the ESP; see Nichols, et al., 2019).

A key distinction of most observable socioeconomic processes from ecosystem processes associated with the EBS snow crab fishery is that they occur during the fishery, and as such, cannot be captured in indicators that provide advance information for use in informing the current stock assessment. Moreover, data collection and monitoring of many aspects of socioeconomic processes is conducted following the fishing season such that the most recent available data point may be lagged by up to two years behind the current assessment. As such, in the context of the ESP, time series of socioeconomic indicators are largely limited to informing interpretation of historic patterns observed in other data series captured in the assessment, or to providing general context regarding the effects of historic fishery management.

Among other changes, the CR program resulted in rapid consolidation of the EBS snow crab fleet, from a high of 272 vessels in 1994 to 78 during the first year of the CR program, which has subsequently further consolidated to 59 vessels operating in the 2020/21 season. Allocation of tradable crab harvest quota shares, with leasing of annual harvest quota, facilitated fleet consolidation and improved operational and economic efficiency of the fleet, changing the timing of the fishery from short derby seasons to more extended seasons, and inducing extensive and ongoing changes in harvest sector ownership, employment, and income. Crab processing sector provisions of the CR program include allocation of transferable processing quota shares (PQS), leasing of annual processing quota and custom-processing arrangements that enable PQS holders that do not operate a processing plant to purchase IFQ crab landings and direct them to a processing plant for custom processing, and community protection measures, including regional designation on harvest quota, requiring associated catch to be landed to ports within a specified region. While these and other elements of CR program design facilitated similar operational and economic efficiencies in the sector, with more limited consolidation of processing capacity to somewhat fewer locations, and fewer plants in some ports, they have also limited some economic adjustments that would likely have occurred in their absence. Most notably, North regional designation of a large fraction of EBS snow crab IFQ has likely maintained a larger proportion of landings to St. Paul Island than would have occurred otherwise. St. Paul Island has historically and to-date received the largest share of EBS snow crab landings, with Akutan, King Cove, and Unalaska/Dutch Harbor representing the other principal landing ports for EBS landings historically and to-date. See the Council’s 10-Year Program Review for the CR Program for detailed description and analysis of program structure and management (Council, 2017).

These and other institutional changes continue to influence the geographic and inter-sectoral distribution of benefits produced by the EBS snow crab fleet, both through direct ownership and labor income in the EBS snow crab harvest and processing sectors, and indirect social and economic effects on fishery-dependent communities throughout Alaska and greater Pacific Northwest region. The full range of fishery, economic, and social processes cannot be captured within the scope of the ESP framework, and more comprehensive set of metrics and indicators intended to inform EBS snow crab fishery management and annual harvest specifications are provided in the annual Crab Economic SAFE.

# # Indicators Assessment {-}

## ## Indicator Suite {-}

Brief literature review on ecosystem or socioeconomic indicators previously explored for stock that are currently available or updatable

### ### Ecosystem Indicators {-}

```{r, eco\_ind}

eco <- AKesp::list\_indicators(data = params$esp\_data, indicator\_type = "Ecosystem")

cat(eco)

```

### ### Socioeconomic Indicators {-}

```{r, socio\_ind}

socio <- AKesp::list\_indicators(data = params$esp\_data, indicator\_type = "Socioeconomic")

cat(socio, sep = "\n\n")

```

## ## Indicator Monitoring Analysis {-}

Description of statistical tests for monitoring indicator suite by stage where relevant (Stage 1: scoring test, Stage 2: importance test, Stage 3: modeling test)

Supportive graphs and/or tables of statistical tests where relevant

# # Recommendations {-}

Summary of main considerations separated by ecosystem and socioeconomic categories

## ## Ecosystem Considerations {-}

* Summary conclusions from metric assessment
* Summary conclusions from indicator assessment

## ## Economic Considerations {-}

* Summary conclusions from metric assessment
* Summary conclusions from indicator assessment

## ## Data Gaps and Future Research Priorities {-}

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

# # Acknowledgements {-}

Include contributors, internal reviewers, Groundfish/Crab Plan Teams, SSC, AFSC personnel and divisions, other state, national, international contributing agencies

# # Literature Cited {-}

Include reference numbers at the end of the citations from the life history table

Include DOI or links to papers where possible

**<div** **id**="refs"**></div>**