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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2023/006

DEVELOPMENT OF BIOLOGICAL REFERENCE POINTS AND A PRECAUTIONARY APPROACH FRAMEWORK FOR THE DUNGENESS CRAB (*CANCER MAGISTER*) FISHERY IN CRAB MANAGEMENT AREAS I AND J

Dungeness Crab. Photo Credit: Brendan Aulthouse

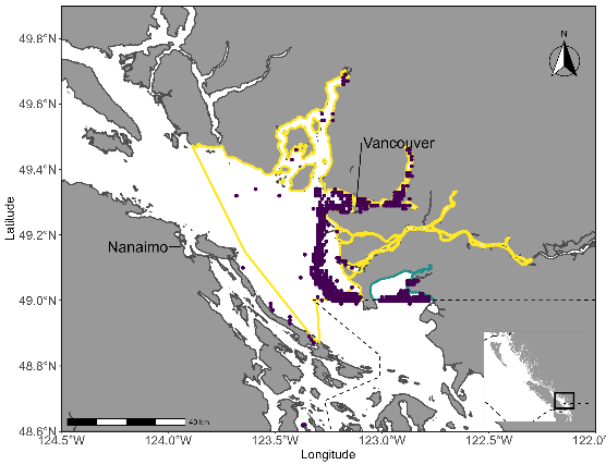

Figure 1. Commercial catch and fishery-independent data were collected in Crab Management Areas (CMAs) I and J. Polygons represent Crab Management Areas I (yellow) and J (green). Points indicate locations of Fisheries and Oceans Canada (DFO) Dungeness Crab trap surveys.

Context:

*Fisheries and Oceans Canada (DFO) manages the Dungeness Crab (*Cancer magister*) trap fishery, which consists of seven Crab Management Areas (CMAs; A, B, E, G, H, I, and J). Although some differences exist between the CMAs, Dungeness Crab fisheries are primarily managed based on a '3 S' (size, sex, and season) management strategy. This management strategy is designed to protect the reproductive stock by allowing sexually mature sublegal male crabs to reproduce one to two breeding seasons prior to recruiting into the fishery, as well as to protect female crabs and softshell crabs during moulting periods.*

The catch along the Pacific Coast has fluctuated between and within CMAs on both annual and decadal scales. Although a similar management strategy has been in place since the early 1900s, recent declines in commercial catch for CMAs I and J, along with heightened awareness of the effects of changing environmental conditions, have elevated concerns regarding the long term sustainability of the fishery. Compliance with DFO's Precautionary Approach (PA) policy requires that a management strategy include reference points that define three zones of stock status ("Healthy", "Cautious", and "Critical") and the removal reference for each zone. DFO Fisheries Management has requested that DFO Science develop biological reference points to help determine the stock status of the Fraser River Dungeness Crab Management Areas (I & J), relative to abundance trends.

February 2023

The advice arising from the Regional Peer Review process will be used to inform resource managers on stock status, including the need for evaluating alternative harvest strategies. The advice may also provide a framework for developing biological reference points and a method for assessing abundance trends in other CMAs. Crab Management Areas I and J currently have the most comprehensive DFO fishery independent survey data, making them a logical starting point for developing reference points coast-wide.

This Science Advisory Report is from the February 28-March 1 and October 26th 2022 regional peer review on the Development of biological reference points and retrospective evaluation of abundance trends in Crab Management Areas I and J. 2022. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Three methods were used to estimate reference points: an empirical method using biomass at maximum sustainable yield proxies, a stock recruitment-based method, and a simulation model-based method. Determinations of stock status were made for 2019.
- The stock status indicator and reference points were estimated primarily using fishery-independent survey data. Commercial data collected from service providers and logbooks were used to estimate model parameters such as exploitation rates, softshell periods, and sex ratios. A three year running median of female catch per unit effort (CPUE) was used as the indicator in order to account for cyclical fluctuations of the crab population.
- Reference points were expressed in terms of standardized CPUE. Female CPUE was used as the main indicator because it represents the reproductive potential of the stock. Sublegal standardized CPUE was used as a secondary indicator to provide additional information. Decision makers could consider the long- and short-term trends in annual sublegal male crab CPUE, but this indicator will not be used to formally describe stock status.
- Empirical limit reference points were estimated at 0.228 (B_{mean}) and 0.310 (B_{max}) standardized female CPUE.
- The stock recruitment limit reference point was estimated at 0.439 standardized female CPUE.
- The simulation limit reference point was estimated at 0.3 standardized female CPUE.
- The stock recruitment relationship is highly uncertain, and simulation reference points rely on many assumptions There are fewer concerns about the performance of the empirically derived reference points.
- The 2019 stock status for Dungeness Crab in Crab Management Areas (CMAs) I and J is in the Cautious zone between the Limit Reference Point (LRP) and the Upper Stock Reference (USR), using the empirical reference points. The work undertaken validates the methodologies for reference point estimation for CMAs I and J.
- The degree to which climate change will affect Dungeness Crab populations in British Columbia is unknown. Productivity may change due to fluctuations in ocean temperature, acidity, and oxygen concentration. Coastwide populations may also be affected by changes in larval transport due to changing ocean circulation.
- The degree of connectivity of subpopulations of Dungeness Crab in British Columbia is currently uncertain. Further analyses and definition of the stock is required before estimating reference points coastwide. There is a high degree of trap competition in CMA I and J. This competition likely decreases the survey CPUE, and may alter trends in survey CPUE

through time. This observation should be accounted for in future analysis by including data from other sources (e.g., commercial data).

- The analysis recommends applying the empirically-based methodology for determining reference points for the Dungeness Crab in CMAs I and J using female CPUE. It also recommends using the three year running median of standardized female CPUE as the stock status indicator.

BACKGROUND

Fisheries and Oceans Canada (DFO) manages the Dungeness Crab (*Cancer magister*) trap fishery, which consists of seven Crab Management Areas (CMAs; A, B, E, G, H, I, and J). Although some differences exist between the CMAs, Dungeness Crab fisheries are primarily managed based on a '3 S' (size, sex, and season) management strategy. This management strategy is designed to protect the reproductive stock by allowing sexually mature sublegal male crabs to reproduce one to two breeding seasons prior to recruiting into the fishery, as well as to protect female crabs and softshell crabs during moulting periods.

The catch along the Pacific Coast has fluctuated between and within CMAs on both annual and decadal scales. Although a similar management strategy has been in place since the early 1900s, recent declines in commercial catch for CMAs I and J, along with heightened awareness of the effects of changing environmental conditions, have elevated concerns regarding the long term sustainability of the fishery.

In 2009, DFO implemented the Sustainable Fisheries Framework (SFF) which is a suite of policies that provides the foundation for an ecosystem-based and precautionary approach to fisheries management in Canada (DFO 2009). The precautionary approach relies on the definition of limit and upper stock biological reference points to delineate three zones of stock status ("Healthy", "Cautious", and "Critical") and the removal reference for each zone. Recent amendments to Canada's *Fisheries Act* and the inclusion of the Fish Stocks provisions require that fish stocks be managed at sustainable levels, specifically at levels above the limit reference point. The limit reference point represents the spawning biomass below which serious harm may occur to the stock.

DFO Fisheries Management has requested that DFO Science develop biological reference points to help determine the stock status of the Fraser River Dungeness Crab Management Areas (I and J), relative to abundance trends.

ANALYSIS

Data

The primary data used were collected in DFO fishery-independent surveys. These data were used to estimate the stock recruitment relationship, and construct a time-series of abundance indices for legal-sized male, sublegal-sized male, and female Dungeness Crab. The survey data were collected in CMAs I and J over 30 years (1988-2019).

Commercial data from catch sampling and logbooks were also used to estimate additional model parameters. The catch sampling program has been in place since 2009. Logbooks have been used since 1990, but only logbooks after 2000 were used due to concerns about logbook accuracy. Fishery independent survey data were standardized using a generalized linear model. The data were standardized to account for changes in environmental conditions, survey methodology, and crab and fishery behavior.

Methods

Three sets of reference points were estimated as follows: empirical methods using biomass at maximum sustainable yield proxies, a stock-recruitment relationship, and a simulation-based model.

Empirical reference points were estimated using the mean and maximum value of standardized CPUE for female crabs. The stock recruitment reference points were estimated using the Beverton-Holt stock recruitment relationship, with the limit reference point set at the female CPUE that resulted in 50% of maximum recruitment. The USR was set at double this value. The simulation-based model assumes lower levels of recruitment at low spawner values, to account for changes in population dynamics or environmental conditions. We used this simulation model with the previously estimated empirical reference points in order to estimate the simulation reference points.

Abundance trends were estimated for legal-sized male, sublegal-sized male, and female crab using the standardized survey CPUE. Qualitative trends were assessed in this abundance index, and then the female abundance trends were compared to the estimated reference points. A three year running median in CPUE was used to assess the abundance trends.

A reference point was considered to be breached when the indicator (three year running median of standardized female CPUE) is below that reference point, with a probability of 0.5 or greater.

The uncertainty was estimated around the three year running median and the estimated reference points in a Bayesian framework. The fishery independent survey CPUE was standardized using a Bayesian model, which produced a posterior distribution for all model parameters (including the “year effects”). A posterior distribution of the year effects was used to generate posterior distributions of the three year running median, empirical, and stock recruitment reference points, by taking each posterior draw as a candidate model fit. The simulation reference points are deterministic and do not support estimation of uncertainty.

Results

Estimation of Reference Points

- All reference points are expressed in terms of standardized female crabs per trap.

Empirical Reference Points

- LRP_{mean} : 0.228, LRP_{max} : 0.310
- USR_{mean} : 0.456, USR_{max} : 0.620

The mean values should be used as the Precautionary Approach framework favors the B_{Mean} method (i.e., B_{MSY} based on the mean of the time series) over the B_{Max} method (i.e., B_{MSY} based on the maximum observed annual survey CPUE). This is especially relevant as the fishery predates the fishery-independent survey. We therefore cannot assume that B_{Max} is representative of the unfished biomass.

Stock-Recruitment Reference Points

- LRP: 0.439
- USR: 0.878

Simulation Reference Points

- LRP: 0.3

- USR: 0.5

Abundance Trends

Legal-sized Male Crabs

- Legal-size male Dungeness Crabs in CMAs I and J show considerable variation cycling between high and low abundance throughout the time-series. Standardized CPUE ranges from 0.358 to 1.856.

Sublegal-sized Male Crabs

- Sublegal sized male Dungeness Crabs in CMAs I and J also show considerable variation with same cycles appear as with the legal-sized males. The minimum standardized CPUE of 0.939 occurred in 2009 with a maximum standardized CPUE value of 4.339 observed in 1989.

Female Crabs

- Cycles of female Dungeness Crabs in CMAs I and J were less apparent than for the sublegal and legal size males. The time series for female abundance has declined since the start of the survey, but has been stable for the past ~15 years (Figure 2). The female standardized CPUE also reached a minimum value in 2009 (CPUE of 0.174). The maximum observed CPUE was 1.438, observed in 1988.

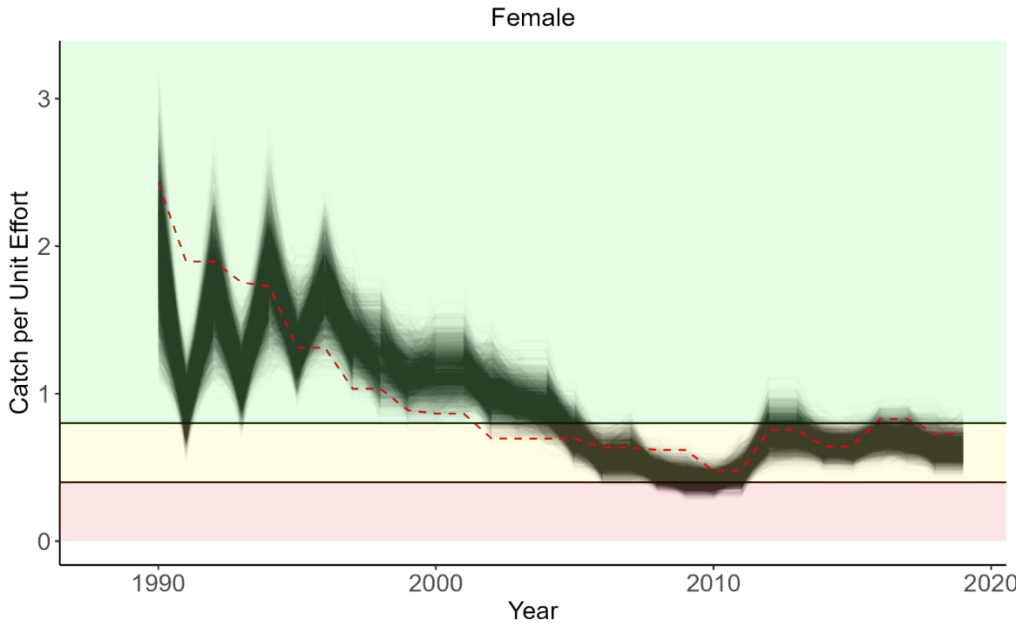

Figure 2. Time series of female stock status standardized CPUE. Each black line represents a sample three-year running median from the Bayesian standardization model. The coloured background represents a stock status zone, delineated by the LRP (CPUE = 0.4) and USR (CPUE = 0.8). The red line represents the unstandardized estimate of the three-year running median of female CPUE.

Sources of Uncertainty

B_{Mean} Reference Points

It was assumed that the entire time series (1988-2019) represents a “productive” time period from which we could estimate the B_{MSY} proxy. This approach was based on previous risk assessments which have consistently considered the stock to be healthy. Changes in

productivity through time would result in biased estimates of B_{MSY} proxies, and the subsequent reference points. It is reasonable that the productivity of the stock has been consistent, based on relatively consistent survey indices and commercial landings.

Crab Population Dynamics

Crab populations are mainly driven by environmental factors, which results in considerable natural variability in crab abundance year-to-year. Using the annual index of survey CPUE as the stock status indicator could result in the stock entering the cautious or critical zone from natural variability alone. We attempt to account for this variability by smoothing the time series of survey CPUE with a three year running median. Similar smoothing could be achieved in the future through the use of stock assessment models.

Survey Timing

Crabs were typically sampled during the DFO crab survey in May and October each year. Given changes in crab behavior through the year, coupled with passive sampling methods, there is the possibility of failing to sample crabs in these short survey sampling events, and therefore mischaracterizing abundance. This issue could also result from changes in survey timing year-to-year, which was common in the early years of the survey. This uncertainty may be reduced by including data from other sources (e.g., larval data, commercial data).

Trap Competition

There is likely a high degree of trap competition in CMAs I and J, because of the high degree of effort in a small area. Fishery traps typically use more effective bait than the DFO traps, meaning crabs will be more likely to enter fishery traps than DFO traps. This behaviour likely decreases the survey CPUE, and may alter trends in survey CPUE through time, and it should be accounted for in future analysis by including data from other sources (e.g., commercial data).

Climate Change

Changes in ocean conditions due to climate change are a major concern for many marine species, including Dungeness Crab. The productivity of Dungeness Crab in the future is uncertain due to possible changes in ocean temperature, acidity, and oxygen concentration (Berger et al. 2021). Increasingly hypoxic ocean conditions will be particularly harmful for the adult life stage. Hypoxia may be unlikely in the Fraser delta, due to the constant supply of oxygenated fresh water, but could be a concern in other regions. Larval life stages are expected to be adversely effected by decreasing ocean pH, due to the impact on calcified structures. These changes in ocean conditions may manifest in increased natural mortality or decreased productivity. The coastwide population of Dungeness Crab in British Columbia (BC) may also be affected by changes in larval transport, due to changes in ocean circulation (McConnaughey and Armstrong 1995). In the Dungeness Crab fisheries in Oregon and California, most of the fluctuations in abundance are due to oceanographic conditions affecting juvenile life stages, not due to fishing pressure (Shanks and Roegner 2007).

FUTURE WORK

Development of future reference points for Areas I and J as well as coastwide will benefit from including additional data, such as that from larval studies. A monitoring project for Dungeness Crab larvae in the Salish Sea is being led by the Hakai Institute, which complements an existing project led by the Pacific Northwest Crab Research Group in the southernmost portion of the Salish Sea. These data can be used to better understand Dungeness Crab connectivity and recruitment. In addition, data collection in Boundary Bay (CMA J) may improve if data from the United States portion of the bay are included in the assessments. Survey data on adult and

larval stages, as well as commercial data, can be integrated using stock assessment models. This works provides a first step towards developing an assessment framework, and associated reference points, for Dungeness Crab in British Columbia.

CONCLUSION AND ADVICE

The empirical methods using maximum sustainable yield proxies are recommended for setting reference points for Dungeness Crabs in CMAs I and J. Specifically, reference points should be based on the mean value of the time series (LRP_{Mean} and USR_{Mean}). These empirical reference points are simple to compute, unlike the stock-recruitment and simulation reference points.

It is recommended to set a LRP at 0.228 female standardized CPUE for CMAs I and J. It is recommended to set a USR at 0.456 female standardized CPUE for CMAs I and J.

Female Dungeness Crab abundance has declined since the start of the survey in 1988, yet has been stable for the past ~15 years. The 2019 Dungeness Crab stock in CMAs I and J were assessed as being in the cautious zone using the female indicator. Future work should explore the use of the methods outlined in this paper to estimate reference points for Dungeness Crabs in other CMAs in British Columbia, with particular emphasis on the empirical method. This approach may require further analysis of commercial catch sex ratios, the modification of existing sampling programs, and the implementation of new sampling programs, where none exist, to develop indices of abundance.

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 28-March 1, and October 26, 2022 regional peer review on the Development of biological reference points and retrospective evaluation of abundance trends in Fraser River Dungeness Crab (Management Areas I and J). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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THIS REPORT IS AVAILABLE FROM THE:

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ISSN 1919-5087
ISBN 978-0-660-46989-8 N° cat. Fs70-6/2023-006E-PDF

Correct Citation for this Publication:

DFO. 2023. Development of Biological Reference Points and a Precautionary Approach Framework for the Dungeness Crab (*Cancer Magister*) Fishery in Crab Management Areas I and J. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/006.

Aussi disponible en français :

*MPO. 2023. Établissement de points de référence biologiques et élaboration d'un cadre de l'approche de précaution pour la pêche du crabe dormeur (*Cancer magister*) dans les zones de gestion du crabe I et J. Secr. can. des avis. sci. du MPO. Avis sci. 2023/006.*