



HARVEST ADVICE FOR PACIFIC SARDINE (*SARDINOPS SAGAX*) IN BRITISH COLUMBIA WATERS FOR 2022

Context

The northern subpopulation of Pacific Sardine (*Sardinops sagax*) in the eastern Pacific Ocean (California Current Ecosystem) has a distribution that can range between Baja California to southeast Alaska. In winter and spring months, most of this stock has the tendency to occur in waters off the California coast in association with spawning. Prior to, and during summer months, large aggregations of Pacific Sardine migrate from spawning habitat to more northern waters mainly to forage. Migratory patterns can be affected by age structure, population size and oceanographic conditions. Typically, most Pacific Sardines that migrate into British Columbia (BC) waters are the larger and older fish in the population. Pacific Sardine have not been fished in BC waters since 2012 due to reduced migration (a general absence of Pacific Sardine in BC waters) and formal fishery closures in 2015 to 2021.

Fisheries and Oceans Canada (DFO) adopted a harvest control rule in 2013 that applies a harvest rate to an estimate of age-1 year and older (age-1+) biomass that exceeds 150,000 t to calculate potential harvest options for the BC sardine fishery (DFO 2013). As described in the 2013 [Science Advisory Report](#), a range in harvest rates from 3-5% was selected to calculate potential harvest options. The age-1+ biomass estimate used in the harvest control rule is acquired from stock assessment efforts conducted by the United States (US) National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA).

The 2022 assessment process of the northern subpopulation of Pacific Sardine by NMFS occurred in March and April 2022. Based on the 2020 stock assessment methods described by Kuriyama et al. (2020), the 2022 assessment model was informed by updated data through to December 2021 (Kuriyama et al. 2022).

DFO Fisheries Management requested that Science Branch incorporate the most recent stock assessment estimate of age 1+ biomass for the northern subpopulation of Pacific Sardine into the DFO sardine harvest control rule.

The objectives of this report are to:

1. Report the results of applying the harvest control rule for a range of harvest rates from 0.03 to 0.05 in increments of 0.01, if the expected stock biomass is above the escapement buffer of 150,000 tonnes.
2. Identify uncertainties associated with this harvest advice.

A formal Canadian stock assessment was not conducted in 2022 so the following advice is based on the multi-year method approved in 2013 (DFO 2013). As such, for additional information about Science recommendations, uncertainties, and future considerations, readers are referred to DFO (2013).

This Science Response results from the Regional Peer Review of May 6, 2022 on Harvest Advice for Pacific Sardine (*Sardinops sagax*) in British Columbia Waters for 2022.

Background

Population assessment

The US NMFS assesses the status and population trends of the Pacific Sardine northern subpopulation in the eastern Pacific Ocean (also known as the California Current Ecosystem stock) using a statistical catch-at-age model on the Stock Synthesis platform (Methot and Wetzel 2013; Kuriyama et al. 2020). The 2022 stock assessment is informed by data collected from 2005 to December 2021 from fishery-independent acoustic-trawl surveys over a core survey region; fishery independent nearshore acoustic-trawl survey efforts and aerial survey efforts (collectively referred to as being part of a California Coastal Pelagic Species Survey, or CCPSS); fishery landings, and fishery dependent and independent biological samples (Kuriyama et al. 2022). The acoustic-trawl survey biomass estimation was partitioned into two time series, with catchability (Q) set to 1 for 2005-2014 and Q calculated based on the ratio between total acoustic-trawl survey biomass estimates and aerial survey estimates for 2015-2019 and 2021 (Kuriyama et al. 2022).

The 2022 stock assessment update was based on the 2020 assessment methods (Kuriyama et al. 2020) with updates that included:

- new acoustic-trawl survey data and index estimates for 2021 spring and summer surveys (due to COVID-19 pandemic restrictions, 2020 spring and summer acoustic-trawl surveys were canceled);
- updated age data for the 2016 summer acoustic-trawl survey;
- updated catch landing information for July- December 2019 and January-June 2020 periods;
- new catch data for July- December 2020;
- new age and catch data (preliminary estimates) for January-June 2021 and July-December 2021 periods; and
- preliminary catch estimates for January- June 2022.

With the collection of new information and major modeling uncertainties, there is interest in: 1) having workshops to review assessment methods associated with utilizing nearshore survey information; 2) developing updated recruitment parameters and methods to estimate fishing mortality and exploitation rates; and 3) reviewing stock structure information and assumptions associated with partitioning catch and survey observations into northern and southern sardine subpopulations.

BC Pacific Sardine fishery harvest control rule

DFO Fisheries Management adopted a harvest control rule in 2013 that incorporates a July estimate (forecast) of the population's age-1+ biomass, a cutoff value of 150,000 tonnes, and a harvest rate. The cutoff value of 150,000 tonnes is consistent with the cutoff value used in the US harvest guideline. The harvest rate is applied to the difference between the estimated age-1+ biomass above the cutoff and the cutoff biomass. As described in the 2013 review (DFO 2013), a range in harvest rates (h) from 3-5% was selected in the calculation of potential harvest allowances. The equation for the calculation of a fishing season's potential total allowable (TAC_t , tonnes) for a season starting in year " t " is:

$$TAC_t = h (B_{1+,t} - 150,000),$$

where

h = harvest rate

$B_{1+,t}$ = forecast age-1+ biomass (tonnes), July

150,000 = cutoff value (tonnes)

No harvest is recommended when the forecast of age-1+ biomass ($B_{1+,t}$) is less than 150,000 tonnes.

This Science Response provides the recommended 2022 BC Pacific Sardine fishery harvest options based on the use of this harvest control rule and the 2022 US NMFS forecast for the stock's July 2022 age-1+ biomass.

Analysis and Response

Biomass

Recent estimates of age 1+ biomass of Pacific Sardine from the California Current northern subpopulation from the 2022 update to the 2020 stock assessment methods are reported below (from Kuriyama et al. 2022), followed by a brief overview of trends in sardine observations made in BC waters.

Age-1+ sardine biomass showed an overall decreasing trend from 2006, reaching historically low levels in recent years (Table 1). Estimates of recruitment of young fish also decreased notably after 2005-2006, with some relatively moderate to small increases detected over the 2009-2010 and 2018-2020 seasons, respectively. The age-1+ biomass maximum likelihood estimate for the July 2022 forecast of the northern sardine subpopulation was 27,369 tonnes, with a coefficient of variation (CV) of approximately 31%, corresponding to a 90% credibility interval of approximately 16,660 to 44,962 tonnes.

Few or no sardines have been observed in BC waters from 2013 to 2021 in fisheries, surveys or other sources, consistent with curtailed migration and/or stock size. Average estimates of Pacific Sardine trawl catch densities (a catch per unit effort index) from a west coast of Vancouver Island summer pelagic ecosystem night trawl survey conducted in 2006, and 2008-2014 showed a decreasing trend, with no sardines observed in 2013 or 2014. During the summers of 2015, 2016, 2018 and 2019, small amounts of sardine were detected off the west coast of Vancouver Island in trawl catches from other multi-species surveys (i.e., led by DFO or NOAA) and none were detected in 2017. In 2020, DFO and NMFS trawl surveys were cancelled due to the COVID-19 pandemic. In 2021, a DFO summer Integrated Pelagic Ecosystem Science survey, which was planned to survey waters off the north and west coasts of Vancouver island, was cancelled due to an unexpected mechanical breakdown on the research vessel, and the NMFS summer acoustic-trawl survey did not include coverage into BC waters.

BC fishery exploitation

The commercial BC sardine fishery was reinitiated in 2002 following a closure in 1947 (Ware 1999; DFO 2012). Most fishing occurred from July to October in association with seasonal sardine migratory behaviour (DFO 2012). During the 2002-2012 period, the annual total allowable catch (TAC) increased as a result of management decisions (DFO 2012). Prior to 2008, landings were relatively low (less than 5,000 tonnes), increased considerably from 2007 to 2012 (up to a maximum of 22,223 tonnes in 2010), and were zero in 2013 through to 2021, with fishery closures from 2015 to 2021 (Table 1). Since 2002, total landings of the northern subpopulation (catches from BC, Washington, Oregon, California and Ensenada Mexico

combined) were highest in 2007 and lowest in 2016. In recent years, the majority of total landings has been from Mexican waters, see Kuriyama et al. (2022) for details.

Unlike in past DFO Pacific Sardine harvest advice Science Responses (i.e. 2014-2021), the current report calculates annual BC fishery exploitation as BC fishery catch landings (C_t) divided by the estimated age-0+ biomass (instead of age-1+ biomass) in July of year t . This change was made to better reflect the range in age composition caught by fishing fleets, which includes age-0 fish. Trends in annual estimates of BC fishery exploitation show an increase from $\leq 1\%$ prior to 2009 to a peak in 2012 (approximately 5%), followed by 0% in 2013-2021 (Table 1).

Table 1: A summary of recent Pacific Sardine fishery BC TAC, BC landings and total landings of the northern subpopulation for the west coast of North America (BC, Washington, Oregon, California and Ensenada, Mexico). Also shown are Kuriyama et al. (2022) estimates of July age-0+ and age-1+ biomass (B_{0+} , B_{1+}) and coefficients of variation (CV) for age-1+ biomass for a given year, and BC fishery exploitation for years 2005-2021 with respect to age-0+ biomass. Total landings (age-0+ fish) for 2002-2005 are from Hill et al. (2016) and total landings for 2006-2021 are from Kuriyama et al. (2022). Note the value for 2021 total landings is a preliminary estimate. TAC, landings, and biomass values are in metric tonnes.

Calendar Year	BC TAC	BC Landings (C)	Total Landings	Biomass (B_{0+} , July)	Biomass (B_{1+} , July)	CV (% B_{1+} , July)	BC Exploitation (% C/B_{0+} , July)
2002	5,040	822	96,344	--	--	--	--
2003	9,000	1,006	84,311	--	--	--	--
2004	15,000	4,259	87,699	--	--	--	--
2005	15,200	3,266	94,149	1,738,010	1,442,360	11.94	0.19
2006	13,500	1,558	92,413	1,880,400	1,747,160	9.57	0.08
2007	19,800	1,507	134,365	1,445,920	1,387,170	8.01	0.10
2008	12,491	10,435	112,959	1,402,250	1,354,070	6.7	0.74
2009	18,196	15,334	100,085	795,962	739,032	6.05	1.93
2010	23,166	22,223	97,876	604,692	521,502	5.92	3.68
2011	21,917	20,719	91,890	584,536	579,406	6.24	3.54
2012	27,279	19,129	121,950	380,786	376,823	8.77	5.02
2013	25,477	0	73,595	203,593	200,341	13.03	0
2014	17,174	0	23,581	118,361	114,503	16.31	0
2015	0	0	2,994	82,556	78,850	14.46	0
2016	0	0	644	90,487	79,864	12.86	0
2017	0	0	9,536	68,603	61,977	14.39	0
2018	0	0	9,979	70,639	57,214	14.23	0
2019	0	0	12,474	168,607	40,954	11.12	0
2020	0	0	30,571	139,028	77,066	13.76	0
2021	0	0	48,419	176,007	48,856	13.44	0

Uncertainties

Key uncertainties associated with the 2020 and 2022 US NMFS assessment of the northern subpopulation of Pacific Sardine identified in Kuriyama et al. (2020, 2022) and Stock Assessment Review (STAR; 2020) are related to:

1. The partitioning of catch and biomass observations from California and Mexican waters into northern and southern Pacific Sardine subpopulations based on surface water temperatures (16.7°C) and assessment model fits to pre-2015 data. This partitioning is confounded by the uncertainty in the movements and mixing of sardine between northern and southern subpopulations.

2. The assumption that catch taken from near Ensenada, Mexico, over calendar year 2021 and part of 2022, is equal to previous year landing estimates. This assumption was used due to the lack of available information on catch amounts taken from the Ensenada area in the terminal seasons prior to the stock assessment.
3. Estimating catchability (Q) of surveyed biomass within and outside the acoustic-trawl survey area and assigning species identification and species target strength to acoustic trawl survey observations (when available).
4. Nearshore CCPSS survey methods and observations, such as: a) the inability to purse seine and groundtruth biomass from large schools that make up a large proportion of the visual estimates; b) the ability to collect biological samples to confirm species compositions; and, c) the spatial and temporal mismatch between the CCPSS aerial survey and AT survey.
5. The validity of an environmental temperature index to inform fishery management procedures.
6. A lack of reliable methods to characterize or project recruitment abundance.

Uncertainties and concerns identified in past DFO science advisory reviews related to BC Pacific Sardine fishery harvest advice (e.g. DFO 2013) include:

7. Unknown effects of setting harvest allowances independently of the US and Mexico;
8. Unknown effects of fisheries regionally targeting different age components of the population on stock structure and reproductive capacity;
9. Concerns about incidental capture of other species in the sardine fishery; and
10. Concerns about the effects of removing sardine from important foraging habitat of sardine predators.

Harvest options

The July 2022 forecasted age-1+ biomass for the Pacific Sardine northern subpopulation is 27,369 tonnes. Although the uncertainty associated with this estimate is large (i.e. CV=31%), the 90% credibility interval associated with the July 2022 estimate of age 1+ biomass is well below the fishery cutoff of 150,000 tonnes. Based on the harvest control rule adopted in 2013, no allowable fishery harvest is recommended for the 2022 fishing season.

Conclusions

It is recommended that there should be no allowable targeted harvest of Pacific Sardine in BC waters in 2022.

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