Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/036

THE IDENTIFICATION OF PROVISIONAL REFERENCE POINTS AND HARVEST RATE OPTIONS FOR THE COMMERCIAL RED SEA URCHIN (*MESOCENTROTUS FRANCISCANUS*) FISHERY IN BRITISH COLUMBIA

Red Sea Urchins, Mesocentrotus franciscanus (Photo courtesy of Pauline Ridings).

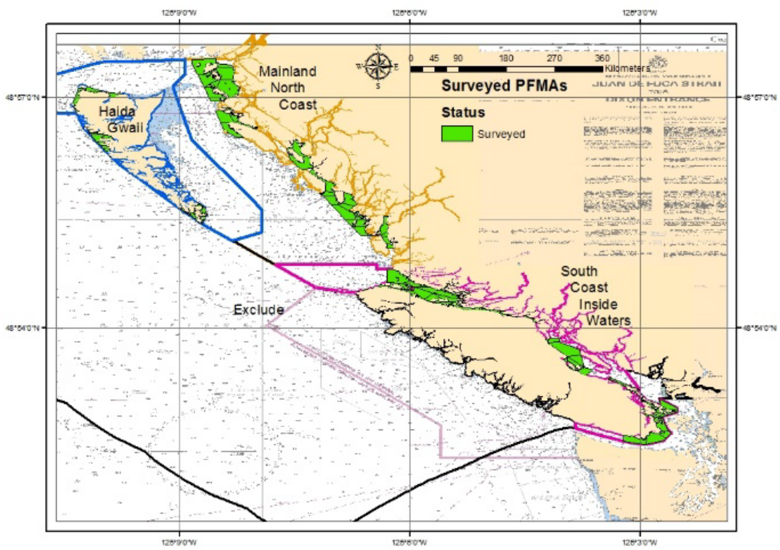

Figure 1. Map of British Columbia with green shading showing the location of the Pacific Fisheries Management Subareas where Red Sea Urchin fishery-independent SCUBA dive surveys were conducted from 1994 to 2016. Haida Gwaii region is outlined in blue, Mainland North Coast region in orange, and South Coast Inside Waters in pink.

Context

The Red Sea Urchin (Mesocentrotus franciscanus) (RSU) fishery in British Columbia (BC) is currently managed using an annual harvest rate of 2% (Leus et al. 2014). This harvest rate was derived using a modified Gulland surplus production model; a model used when a stock is data limited and in the early stages of exploitation (Gulland 1971). The RSU fishery is no longer in the early stages of exploitation, commercial harvesting has been occurring for 48 years. To date, almost 25 years of urchin density and size data have been gathered through fishery-independent dive surveys. These data and the exploitation history of the fishery warrant a re-evaluation of the 2% harvest rate through the development of new models. Further, the existing RSU harvest strategy lacks reference points that reflect conservation thresholds required under DFO's Sustainable Fisheries Framework (DFO 2009a).

Fisheries and Oceans Canada (DFO) Fisheries Management requested that Science Branch provide advice on the application of a range of harvest rates for the following regions of the coast: Haida Gwaii, the Mainland North Coast, and the Inside Waters between Vancouver Island and the Mainland. In addition, provisional reference points were identified. The impacts of a range of harvest rates were evaluated against the provisional reference points to determine sustainable harvest rates in accordance *with the DFO Precautionary Approach (DFO 2009b). Advice in this report will be used to establish reference points and update the RSU harvest rates implemented in some of BC's RSU fishery.*

This Science Advisory Report is from the Feb 13, 2019 Identification of candidate reference points and harvest rate options for the commercial Red Sea Urchin (Mesocentrotus franciscanus) fishery in British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- An annual harvest rate of 2%, derived using a modified Gulland surplus production model (Gulland 1971; Leus et al. 2014), has been used as part of the Red Sea Urchin (RSU) Assessment Framework for most of the BC coast since 1994. The accumulation of a substantial amount of biological data on RSU in BC allows for the development of new models and warrants a re-evaluation of the impact of the current 2% harvest rate.
- Previously published biological parameters using British Columbia (BC) fishery-independent data and a new length-based simulation modelling approach were used to provide advice on the application of a range of possible RSU commercial fishery harvest rates for Haida Gwaii (Pacific Fishery Management Area [PFMA] 1, 2, 101 and 102), the Mainland North Coast (PFMAs 3 to 10 and 103 to 110), and the South Coast Inside Waters between Vancouver Island and the Mainland (PFMAs 11 to 20, 28, 29 and 111).
- To evaluate the impact of the range of harvest rates, the concept of serious harm was considered in the identification of a provisional Limit Reference Point (LRP) and Upper Stock Reference (USR). Reference Points were not previously identified for BC's RSU commercial fishery, and the current work aligns this fishery with the Sustainable Fisheries Framework (DFO 2009a) and DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO Precautionary Approach) (DFO 2009b).
- An empirical approach was used for establishing Reference Points, based on RSU density estimates in Sea Otter (*Enhydra lutris*) inhabited areas. Areas where Sea Otters have been present for several years may indicate the highest harvesting pressure under which biologically viable RSU populations can be maintained. The estimated RSU mean densities in areas of California, Washington State and BC where Sea Otters have been established for at least five years, ranged from 0 to 1.13 RSU/m^2 (Table 1) and reference points were developed using a locally relevant, long-term data set (Watson and Estes 2011).
- The recommended LRP and USR are 0.3 mature RSU/m^2 and 0.6 mature RSU/m^2, on RSU habitat, respectively; mature RSU are defined as ≥ 50 mm test diameter and RSU habitat is defined as hard substrate larger than gravel (>0.25 cm), where mud is not the predominant substrate.
- New length-based population models were developed, and mature density estimates were projected forward 100 years using statistical length-based simulation models. Decision tables showing the probability of breaching Reference Points after varying time periods and for a range of harvest rates (2-24%) were provided to inform Fisheries Management decisions.
- The results for the 100th year of the model simulations are shown as an example from the simulation range (Table 2), and Fisheries Managers can choose to implement management actions from the range of simulated results, according to management objectives.

- RSU populations are above the USR in Haida Gwaii, the Mainland North Coast, and the South Coast Inside Waters between Vancouver Island and the Mainland, individually and when they are combined.

INTRODUCTION

An annual harvest rate of 2%, applied to estimated current exploitable biomass (biomass of RSU with test diameters [TD] ranging from 90-140 mm), has been used for most of the BC coast since 1994 (DFO 2018a). The 2% harvest rate was derived using a modified Gulland surplus production model (Gulland 1971), which is a model intended for use when a stock is in the early stages of harvest. However, commercial RSU harvesting has been occurring for 48 years in BC and fishery-independent dive surveys have been conducted since 1994. The accumulation of a substantial amount of biological information on RSU in BC allows for the development of new models and a re-evaluation of the impact of the 2% harvest rate derived from the modified Gulland model.

Advice was provided on the application of a range of possible commercial harvest rates for Haida Gwaii (PFMAs 1, 2, 101 and 102), the Mainland North Coast (PFMAs 3 to 10 and 103 to 110), and the South Coast Inside Waters between Vancouver Island and the Mainland (PFMAs 11 to 20, 28, 29 and 111), using published biological estimates from BC fishery-independent data and a new length-based simulation modelling approach. To evaluate the impact of the range of harvest rates, the concept of serious harm was considered in the identification of a provisional LRP and USR. Reference Points were not previously identified for BC's RSU commercial fishery, and this work aligns this fishery with the Sustainable Fisheries Framework (DFO 2009a) and DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO Precautionary Approach) (DFO 2009b). Finally, to the extent possible, the status of RSU was assessed relative to the provisional Reference Points.

ANALYSIS

Data and Methods

An empirical approach for establishing Reference Points, based on historical density estimates in areas occupied by Sea Otters, was used. It is known that Sea Otters are important keystone predators that suppress urchin densities, and when Sea Otters are present, RSU persist at low densities. Estimates of RSU densities from studies conducted in Sea Otter-inhabited areas of BC, Washington and California were compiled to examine how low RSU densities were driven by predation and whether RSU populations persisted.

Statistical length-based simulation models were developed to quantitatively evaluate impacts of alternative harvest rates on the reduction of mature RSU densities and the probabilities of breaching the Reference Points. Parameter values for the models were formulated using biological information from previous studies (Zhang et al. 2008, 2011) and fishery-independent surveys conducted in commercially harvested areas of BC from 1994 to 2016. While there is a substantial amount of fishery-independent data on RSU, these data do not represent a continuous time-series. Simulations were conducted by region, using the Tanaka and the Logistic dose-response growth models, separately. Simulated populations were constructed, using different mortality rates for two size classes as well as adult-juvenile spine canopy effects, and subjected to harvest rates between 2 and 24%, through 100 years of simulation. The impact of the alternative harvest rates was estimated by the probability of breaching the Reference Points. Probability of breaching the LRP or USR for a given year was calculated as the proportion of the replicates in which mature RSU densities were lower than the LRP or USR for that year.

Stock status was assessed using data from RSU fishery-independent SCUBA dive surveys conducted in commercially harvested areas of BC from 1994 to 2016 (Campbell et al. 1999; Leus et al. 2014). RSU habitat was defined as containing a substrate of gravel or larger (>0.25 cm), where mud is not the predominant substrate. Substrate data was used to remove quadrats that were not suitable. Mean mature RSU densities and their associated confidence bounds were estimated using survey data from the DFO Red Urchin Analysis Program (Lochead et al. 2015).

Results

The compilation of RSU densities from areas where Sea Otters have been established for at least five years revealed RSU mean densities ranging from 0 to 1.13 RSU/m^2, with a mean of 0.18 ± 0.077(1 S.E.) and a median of 0.04 RSU/m^2 (Table 1). In contrast to this work, this summary of RSU densities includes all size classes, not just mature RSU (>50 mm TD).

*Table 1. Summary of estimated mean Red Sea Urchin densities (RSU/m^2) ± error estimate (SE = standard error), year, location, number of years of Sea Otter occupancy, and the reference from SCUBA surveys conducted within diveable depths (approximately 0 – 18 m) in areas occupied by Sea Otters for at least 5 years (NP = not provided; * Standard deviation, not SE).*

Year(s)	Mean density (RSU/m^2)	Error (± 1 SE)	Location	Sea Otter occupancy (Years)	Reference
1967	<0.01	NP	Point Piňos, CA	5	Ebert 1968 *in* Lowry and Pearse 1973
1967	0.03	NP	Point Piňos, CA	5	Faro 1970 *in* Lowry and Pearse 1973
1972-1973	0.01	NP	Pacific Grove, CA	10-11	Lowry and Pearse 1973
1972-1981	0.1	± 0.08	Pacific Grove, CA	10-11	Pearse and Hines 1987
1987	0.02	± 0.14*	Cape Alava, Olympic Peninsula, WA	18	Kvitek et al. 1989
1987	0.0	± 0.0*	Cape Johnson, Olympic Peninsula, WA	18	Kvitek et al. 1989
1997	0.05	± 0.03	Goose Group, Central Coast of BC	8	D. Bureau, pers. comm.[1]
1988	0.2	± 0.1	Checleset Bay, WCVI, BC	11	Watson and Estes 2011
1994	0.1	± 0.0	Checleset Bay, WCVI, BC	17	Watson and Estes 2011
2007	0.3	± 0.1	Checleset Bay, WCVI, BC	30	Watson and Estes 2011
2013	0.01	± 0.00	Checleset Bay, WCVI, BC	36	J. Watson, pers. comm.[2]

Year(s)	Mean density (RSU/m^2)	Error (± 1 SE)	Location	Sea Otter occupancy (Years)	Reference
2007	0.01	± 0.0	Kyuquot Sound, WCVI, BC	17	Watson and Estes 2011
2013	0	± 0	Kyuquot Sound, WCVI, BC	23	J. Watson, pers. comm.[2]
2010-2011	0.25	± 1.54	Central Coast of BC	12 - 30	L. Lee et al. 2016; pers. comm.[3]
2010-2011	0.06	± 0.28	WCVI, BC	22 - 38	L. Lee et al. 2106; pers. comm.[3]
2012	0.04	± 0.03	Tofino, WCVI, BC	6	D. Leus, pers. comm.[4]
2013	1.13	± 0.31	Central Coast of BC	~ 23	Burt et al. 2018; pers.comm.
2014	0.82	± 0.62	Central Coast of BC	~ 24	Burt et al. 2018; pers.comm.

[1]Dominique Bureau, Aquatic Science Biologist, DFO, Nanaimo, BC, 2018, personal communication.
[2]Dr. Jane Watson, Professor Emeritus, Vancouver Island University, Nanaimo, BC, January 2019, personal communication.
[3]Dr. Lynn Lee, Marine Ecologist, Gwaii Haanas Parks Canada, Haida Gwaii, BC, 2019, personal communication.
[4]Dan Leus, Aquatic Science Biologist, DFO, Nanaimo, BC, 2017, personal communication.

From the range in Table 1, we recommend setting the LRP at 0.3 mature RSU/m^2 in urchin habitat. Specifically, the LRP is breached when the median of the bootstrapped sampling distribution of the mean spatial density of RSU, within urchin habitat, is less than 0.3 mature (≥ 50 mm TD) RSU/m^2. Here we specify spatial density, which is in units of RSU/m^2, to clearly differentiate it from linear density, which is in units of RSU/m of shoreline. Linear density is used for the calculation of quota options as described in the current assessment framework (Leus et al. 2014). This value, 0.3 RSU/m^2 from Watson and Estes (2011), was identified as the LRP because it was from BC in an area where Sea Otters have been established for at least 30 years (Bigg and MacAskie 1988), it was the longest time series of RSU density data in Sea Otter occupied areas (25 years) and it was the highest value of the Watson and Estes data (2011). Based on the approach used for setting the USR for Walleye Pollock (*Theragra chalcogramma*) (DFO 2018b) and Green Sea Urchins (*Strongylocentrotus droebachiensis*) (DFO 2018c), the USR was set at twice the LRP, i.e., 0.6 mature RSU/m^2 on urchin habitat. Specifically, the USR is breached when the median of the bootstrapped sampling distribution of the mean, spatial RSU density is less than 0.6 mature (≥ 50 mm TD) RSU/m^2 on urchin habitat.

Applying the recommended LRP and USR to mature RSU densities was recommended, rather than densities of all sizes, for three reasons: (1) recruitment events can cause large fluctuations in the number of small RSU observed during surveys, and (2) the size range for harvestable (TD = 90-140 mm) and legal-sized (TD ≥ 90 mm) RSU could change as a result of Fisheries Management actions or market-driven factors, and (3) the density of mature RSU is biologically important as it represents the spawning stock. Because the studies reviewed to select the LRP targeted urchin habitat, it is recommended that the LRP and USR be applied to RSU densities only within RSU habitat.

Table 2. Summary table of probabilities of mature (≥ 50 mm TD) Red Sea Urchin densities breaching the Upper Stock Reference (USR) and the Limit Reference Point (LRP) after the 100th simulation year at various harvest rates (2 to 24%) for Haida Gwaii, Mainland North Coast and South Coast Inside Waters, using the Tanaka and the Logistic Growth models.

Region	Growth Model	Reference Point	Probability of reaching reference point after 100 years, by harvest rate											
			2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%
Haida Gwaii	Tanaka	USR	0	0.005	0.035	0.075	0.115	0.135	0.160	0.195	0.220	0.240	0.260	0.270
		LRP	0	0	0	0	0	0.005	0.005	0.010	0.015	0.020	0.030	0.030
	Logistic	USR	0	0.015	0.05	0.085	0.135	0.18	0.205	0.23	0.28	0.305	0.325	0.35
		LRP	0	0	0	0	0.015	0.015	0.015	0.015	0.030	0.030	0.035	0.035
North Coast	Tanaka	USR	0	0	0.030	0.040	0.080	0.175	0.215	0.240	0.255	0.305	0.320	0.350
		LRP	0	0	0	0	0	0.005	0.005	0.010	0.010	0.010	0.010	0.020
	Logistic	USR	0	0.015	0.05	0.085	0.135	0.180	0.205	0.230	0.280	0.305	0.325	0.350
		LRP	0	0	0	0.005	0.005	0.005	0.010	0.015	0.025	0.025	0.025	0.025
South Coast	Tanaka	USR	0.08	0.625	0.805	0.895	0.910	0.920	0.935	0.955	0.955	0.960	0.970	0.970
		LRP	0	0	0.045	0.145	0.250	0.290	0.355	0.440	0.465	0.505	0.515	0.545
	Logistic	USR	0	0.350	0.770	0.880	0.930	0.950	0.965	0.970	0.975	0.975	0.975	0.975
		LRP	0	0	0	0.020	0.095	0.180	0.275	0.350	0.395	0.430	0.495	0.550

Stock status was assessed using data from RSU fishery-independent surveys conducted in commercially harvested areas of BC from 1996 to 2016, when an annual harvest rate of 2% was applied. Red Sea Urchin stock status is above the USR, and therefore in the Healthy Zone, for all three regions of interest combined and individually. The estimated medians of the bootstrapped sampling distribution of the mean, mature RSU density, on all quadrats identified as RSU habitat, were:

- 2.51 RSU/m^2 (95% CI: 2.11-3.25) for Haida Gwaii
- 1.70 RSU/m^2 (95% CI: 1.57-1.95) for the Mainland North Coast
- 0.89 RSU/m^2 (95% CI: 0.81-1.06) for the South Coast Inside Waters
- 1.44 RSU/m^2 (95% CI: 1.37-1.61) for all three regions combined

Ecosystem Considerations

The models presented in the paper do not take into account the impact of Sea Otter predation on RSU populations. Sea Otters were first transplanted to the west coast of Vancouver Island in 1969 and have since expanded their range along the BC coast (Bigg and MacAskie 1978; Nichol et al. 2015). Sea Otter predation on RSU is expected to affect urchin abundance and their population trajectories, which may differ from the RSU population projections presented in these analyses. As the distribution and abundance of Sea Otters continues to change along the coast, other ecosystem effects will likely occur. The long term effects of this change may vary or be influenced by other environmental factors (Shelton et al. 2018).

Sources of Uncertainty

In this identification of provisional Reference Points and harvest options for BC's RSU fishery, the sources of uncertainty that were not quantitatively incorporated include:

- The potential harvest rate analyses assume that:
  - the distribution of recruitment densities observed in the survey data reflects the year-to-year distribution of recruitment densities, for each region examined;
  - the population of RSU is in equilibrium. That is, the size frequency distribution and densities of the RSU populations are constant and do not change over time for each region of the coast;
  - the mortality rates applied to two different size classes and fitted to these models represents those of the RSU populations in the regions of interest and that these mortality rates are constant and do not change over space (within regions) and time.
- RSU along the BC coast form a meta-population. A stock-recruitment relationship cannot be defined for RSU in the traditional sense because planktonic larval duration is long, and recruitment to one location is unlikely to be linked to the reproductive capacity at that location. Without the ability to model larval movement, recruitment and settlement, it is not possible to determine which populations act as sources of larvae to other populations along the coast (Allen et al. 2018).
- Broadcast spawners such as RSU may be subject to both pre- and post-dispersal Allee effects (Allee 1931, Quinn et al. 1993). Low densities of adult RSU may cause the pre-dispersal effect of reduced fertilization efficiency (Levitan et al. 1992) (the model does not incorporate this).

- The data and models available at this time are not able to discern the biologically relevant spatial scale at which to assess stock status, particularly due to the uncertainties around source-sink population dynamics. The need for future work on the spatial scale at which to apply the Reference Points was highlighted.
- The data used to assess stock status were derived from the RSU survey program (Campbell et al. 1999; Leus et al. 2014), which was designed to estimate biomass at the PFM Area or Subarea level for the purpose of providing quota options, and not to provide representative data for the assessment of stock status. These data may not represent the entire metapopulation along the BC coast, because non-fished areas are not represented.

CONCLUSIONS AND ADVICE

The work described here represents an improvement over the previous science advice (Leus et al. 2014) on the RSU fishery for the following reasons: it is based on new models that take advantage of the large amount of fishery-independent data collected in BC and previously published biological parameters also based on BC fishery-independent data. The provisional Reference Points developed also align BC's RSU fishery with the DFO Precautionary Approach (DFO 2009b).

RSU stock status is above the recommended USR of 0.6 mature RSU/m^2 (on urchin habitat) for all three regions combined (1.44 ± 0.07 RSU/m^2) and for each region individually: Haida Gwaii (2.51 ± 0.4 RSU/m^2), Mainland North Coast (1.70 ± 0.13 RSU/m^2) and South Coast Inside Waters (0.89 ± 0.08 RSU/m^2).

1. Recommend setting the LRP and USR at 0.3 and 0.6 mature (>50mm TD) RSU/m^2, respectively, within RSU habitat;
2. Recommend consideration of the probabilities of breaching Reference Points outlined in Decision Tables 12-23 of the research document to set regional RSU harvest rates within Haida Gwaii, Mainland North Coast and South Coast Inside Waters regions;
3. Develop a survey design and monitoring program for RSU that allows the collection of time-series abundance and size data in representative areas of the coast for use in population monitoring and stock status assessments.

OTHER CONSIDERATIONS

Climate change is expected to cause a wide variety of impacts to oceans and marine organisms. Climate change is multifaceted and is predicted to affect sea water temperature, dissolved oxygen concentration, salinity as well as ocean carbonate chemistry (Ocean Acidification; OA)(Harley et al. 2006). OA may affect some calcifying organisms, like urchins, as corrosive concentrations of aragonite and calcite ($CaCO_3$) become more prevalent. Although more research is required to better understand the effects of OA alone and when combined with other climate stressors (Hales et al. 2015), the existing evidence indicates that OA may have negative direct and indirect effects on echinoderms (Haigh et al. 2015). Increasing sea temperatures may also affect the relative abundance and distribution of species (Harley et al. 2006) as well as the influence and virulence of pathogens (Burge et al. 2014).

Beginning in 2013, sea star wasting disease spread across the northeast Pacific, beginning in Washington State, causing wide spread declines of at least 20 species of sea stars from Southern California to Alaska (Stockstad 2014). The timing of peak declines coincided with anomalously warm sea surface temperatures (Harvell et al. 2019) and these high temperatures may have led to weak immune responses, in some asteroids, to a densovirus. This decline included a top predator of RSU, *Pycnopodia helianthoides*, and its decline is believed to have caused a trophic cascade in BC waters leading to an increased abundance of urchins (Schultz et al. 2016). As seen in this example, increasing sea temperature could lead to an increase in frequency of disease outbreaks due to decreased host immunity, increased virulence of pathogens or pathogen range expansion as well as far reaching direct and indirect effects to marine ecosystems (Burge et al. 2014).

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SOURCES OF INFORMATION

This Science Advisory Report is from the Feb 13, 2019 Identification of candidate reference points and harvest rate options for the commercial Red Sea Urchin (*Mesocentrotus franciscanus*) fishery in British Columbia. 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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ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2019. The identification of provisional reference points and harvest rate options for the commercial Red Sea Urchin (*Mesocentrotus franciscanus*) fishery in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/036.

Aussi disponible en français :

MPO. 2019. Détermination des points de référence provisoires et des options de taux de récolte pour la pêche commerciale de l'oursin rouge (Mesocentrotus franciscanus) en Colombie-Britannique. Secr. can. de consult. sci. du MPO, Avis sci. 2019/036.