Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat
Pacific Region **Science Response 2018/054**

STOCK STATUS UPDATE FOR GREEN SEA URCHIN *(STRONGYLOCENTROTUS DROEBACHIENSIS)* IN BRITISH COLUMBIA AND HARVEST OPTIONS FOR THE FISHERY IN 2018 TO 2021

Context

British Columbia's Green Sea Urchin (*Strongylocentrotus droebachiensis*) stocks are assessed every two to three years using the assessment model developed by Perry et al. (2003). The last assessment was conducted in 2016 (DFO 2016b) and used to inform the Pacific Region's Green Sea Urchin 2016-2018 Integrated Fishery Management Plan (IFMP) (DFO 2016a). The present assessment provides updated advice, based on the inclusion of new data, for the development of the next IFMP in 2018.

Fisheries and Oceans Canada (DFO) Fisheries Management has requested advice for the Green Sea Urchin fishery in British Columbia (BC), by spring 2018, on the following:

1. candidate reference points for Green Sea Urchins consistent with the DFO Precautionary Approach;
2. current status of Green Sea Urchins relative to the suggested reference points;
3. ranges of sustainable harvest options and their associated risks for the commercial quota areas;
4. recent trends in the local populations and population structure for Green Sea Urchins;
5. uncertainties in the data and methods; and,
6. additional research or stock assessment programs.

This assessment updates previously published time series data and provides new harvest options for the 2018-2019 to 2020-2021 Green Sea Urchin fishery. Methods remain unchanged, employing a Bayesian biomass dynamic model used in the assessment of BC's Green Sea Urchin stocks since 2003 (Perry et al. 2003, Zhang and Perry 2005, Perry et al. 2006, Waddell et. al. 2010, DFO 2014, DFO 2016b). This assessment updates the model results with the most recently available commercial catch (fishery-dependent) and survey (fishery-independent) information.

The reference points used for Green Sea Urchins in BC since 2003, although precautionary, do not enable the estimation of stock status relative to the stock zones, and are therefore not considered compliant with the DFO Precautionary Approach (PA) (DFO 2009). This assessment provides candidate reference points that are based on density rather than a maximum sustainable yield (MSY) metric, and allow assessment of stock status relative to the three zones, as identified in the DFO PA: healthy, cautious and critical.

This Science Response results from the Science Response Process of April 2018 on Stock Status Update and Harvest Options for the Green Sea Urchin *(Strongylocentrotus droebachiensis*) fishery in British Columbia, 2018-2021.

Background

The Green Sea Urchin (Figure 1) is a benthic marine invertebrate with a wide geographic distribution, occurring in cool temperate circumpolar waters of the Atlantic and Pacific Oceans. In the Pacific, they occur from northern Washington State, North through to the Aleutian Islands, Alaska, South through Kamchatka, Russia and Hokkaido, Japan and West to the Korean Peninsula. Green Sea Urchins occur from the intertidal to depths of over 140 metres. Their preferred habitat is rocky, gravel or shell substrates. Kelp and other marine algae are their principal food, and they are an important food source for sea stars, crabs, large fish, and Sea Otters (*Enhydra lutris).*

Green Sea Urchins have separate sexes and are broadcast spawners. Spawning is seasonal and varies by location, occurring from February to March in BC. The larval period ranges from 7 to 22 weeks (Strathmann 1978). In southern BC, Green Sea Urchins begin to mature at a minimum test diameter (TD) of 25 mm (Waddell and Perry 2005) and the minimum legal harvest size is 55 mm TD. In Alaska, these TDs correspond to 2-3 year olds and 4 year olds, respectively (Munk 1992). Growth is variable and is dependent on food supply and environmental conditions.

Green Sea Urchins are the target of commercial, recreational and traditional Food, Social, Ceremonial (FSC) fisheries. Recreational and FSC harvests are unknown, but believed to be minimal. The commercial harvest is hand-picked by SCUBA divers working from small vessels. Both male and female urchins are harvested for their gonads, or roe. Commercial harvest typically takes place from early fall to spring of the following year, just prior to spawning. The commercial fishery is managed with a minimum 55 mm TD size limit, license limitation, limited area openings, area quotas and individual quotas. Details of the management of the fishery are provided in the IFMP (DFO 2016a).

BC's Green Sea Urchin commercial fishery currently takes place in two regions of the coast: Northeast Vancouver Island, which includes Pacific Fisheries Management Areas (PFMAs) 11, 12 and 13, and Southeast Vancouver Island, which includes PFMAs 18, 19 and 20 (Figure 2). The two regions are assessed separately. The previous assessments included PFMAs 12, 13, 18 and 19, only. PFMAs 11 and 20 were re-opened to commercial harvest in 2016 after being closed since 2006 due to low market demand.

Figure 1. Green Sea Urchins (Strongylocentrotus droebachiensis). Photo courtesy of Pauline Ridings.

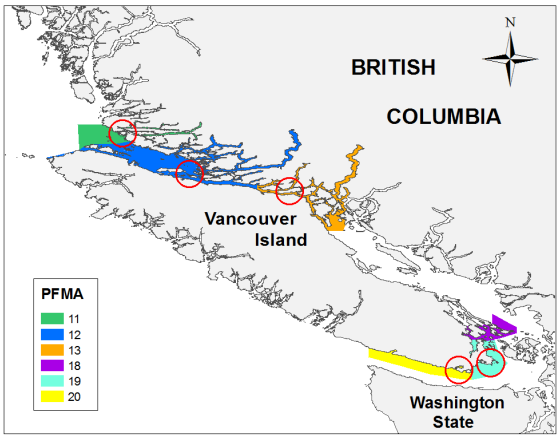

Figure 2. Map of southern British Columbia showing the six Pacific Fisheries Management Areas (PFMAs 11, 12, 13, 18, 19 and 20) open to the Green Sea Urchin fishery. Red circles denote locations of recent surveys.

Analysis and Response

Indicators of the stock status

Fishery-dependent data

The trend in fishery-dependent catch per unit effort (CPUE, in kilograms of urchins harvested per diver hour) is used as one of the two indicators of stock status in this assessment, along with survey derived abundance indices. Log CPUE and log survey-derived biomass were shown to have an approximately linear relationship, providing evidence that CPUE indicates stock status (Zhang and Perry 2005). The catch and effort data were derived from harvest logbooks, validation logs and prior to 1995, from sales slip data. Catch and effort data from the early years of the fishery (1987-1995) are uncertain because of the boom nature of the fishery, variable recording diligence, and different strategies of fishing (Perry et al. 2003). To address uncertainties associated with the CPUE data, the Bayesian model used to generate harvest options for this fishery incorporates larger uncertainties in catch and effort data for the developing years of the fishery, as well as randomly variability in CPUE. The median CPUE values with standard errors were chosen to represent CPUE trends because it is more robust to outliers in effort data than the mean (Perry and Waddell 1998).

Perry et al. (2002) described three periods in the history of the fishery: the developing period (1987 to 1990), the crisis period (1991 to 1993), and the rebuilding period (1994 to 2002) (Figures 3, 4 and 5) (DFO, 2016b). Landings below the total allowable catch (TAC) for fishing seasons 2004-2005 to 2011-2012 (Figure 5) were due to low market demand and are not believed to be reflective of stock status. Markets have improved recently and the 2016-2017 TAC was fully achieved. Although a slight decline in median CPUE has been observed since the 2012-13 season, overall, median CPUE in recent years was high relative to the onset of the fishery. Trends in median CPUE have been similar between the two fishing regions (Figure 4).

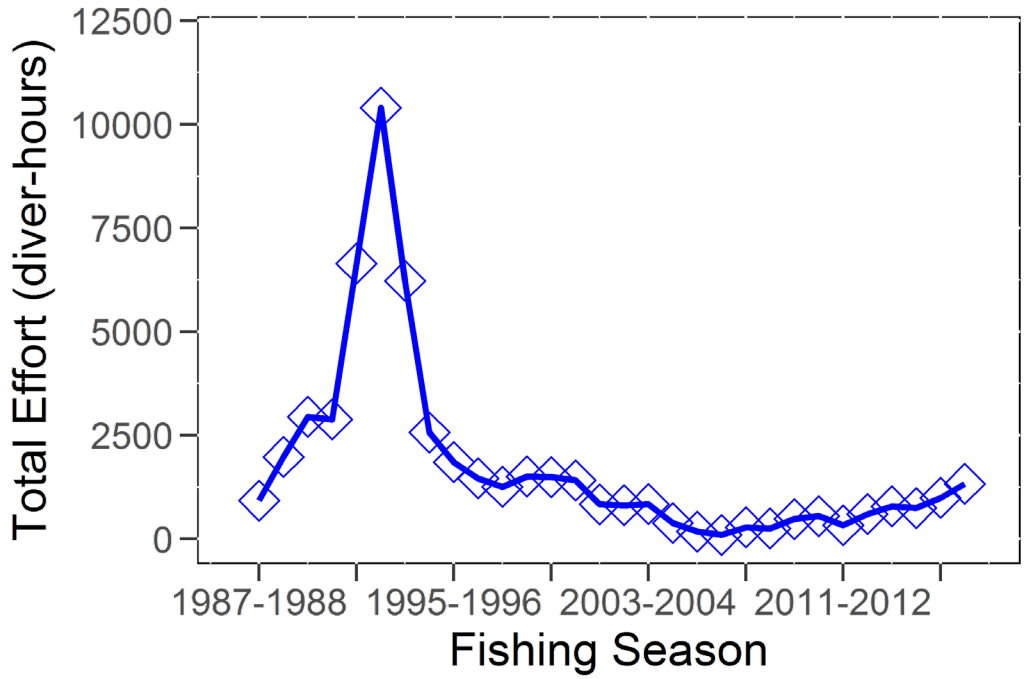

Figure 3. Total Effort (diver hours) for Green Sea Urchin harvesting in PFMAs 11, 12, 13, 18, 19 and 20 combined, for commercial fishing seasons 1987-1988 to 2016-2017. Data are from harvest logbooks, validation logs and prior to 1995, from sales slip data.

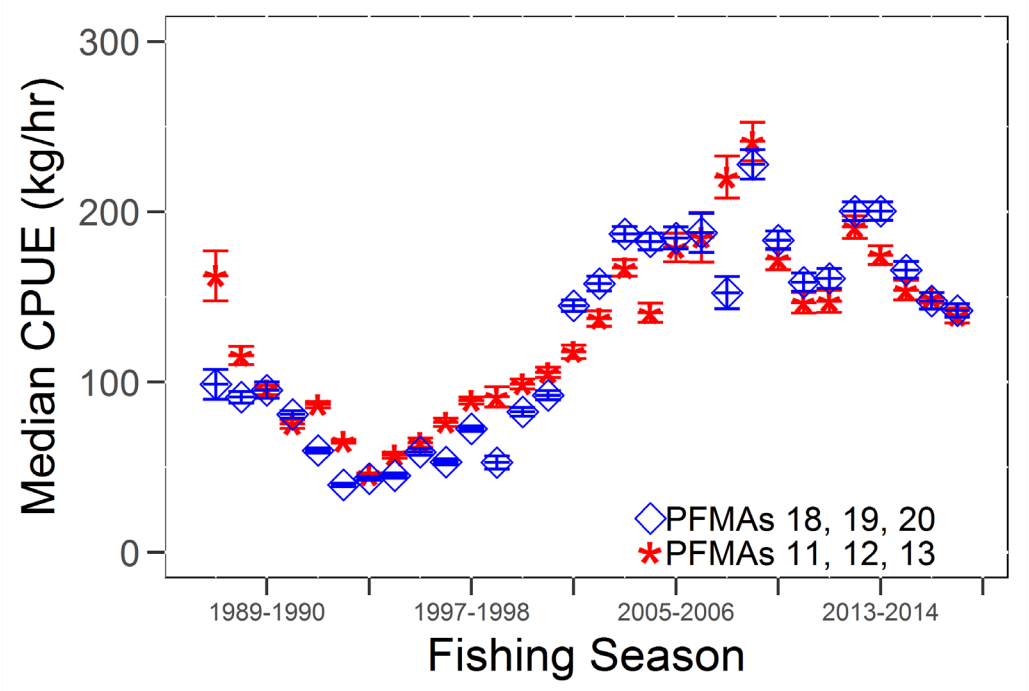

Figure 4. Median catch per unit effort (CPUE) (kg/hr) ± standard error for PFMAs 11, 12 and 13 (red stars) and 18, 19 and 20 (blue diamonds) for commercial fishing seasons 1987-1988 to 2016-2017. Data are from harvest logbooks, validation logs and prior to 1995, from sales slip data.

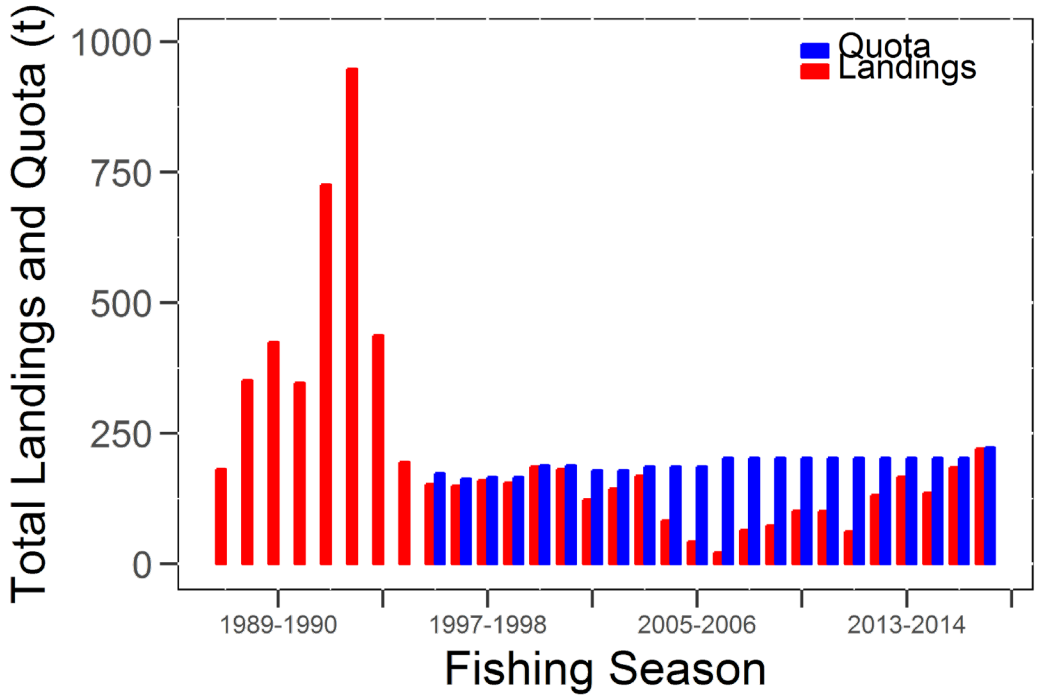

Figure 5. Total landings of Green Sea Urchins (from sales slip data up to 1994, then from harvest and validations logs) and quota (Total Allowable Catch: TAC, from inception of individual quotas and dockside validation in 1995 and onwards) in metric tonnes (t) for commercial fishing seasons 1987-1988 to 2016-2017, in PFMAs 11, 12, 13, 18, 19 and 20.

Fishery-independent data

Fishery-independent dive surveys have been conducted jointly by the Department of Fisheries and Oceans Canada (DFO), the West Coast Green Urchin Association (WCGUA)[1] and more recently, the Pacific Urchin Harvester Association (PUHA) and the A-Tlegay Nations. The main objectives of the surveys are to monitor trends in Green Sea Urchin abundance in the areas on BC's coast that are open to commercial harvest, and to generate time series abundance indices that are used, along with CPUE, as indicators of stock status in this assessment.

The longest time series of surveys has been conducted in Queen Charlotte Strait, in PFMA 12, on Northeast Vancouver Island, since 1995 (Waddell et al. 1997, Waddell et al. 2002, Waddell and Perry 2005, 2006, 2007, 2012) (Figure 2). The survey area on Southeast Vancouver Island is located in Haro Strait, in PFMA 19, and has been surveyed biannually, annually or biennially since 2008 (Waddell 2017) (Figure 2). Since the last stock status update (DFO 2016b), fishery-independent surveys have been conducted in PFMA 11 (Sept. 2016), PFMA 12 (Sept. 2016), PFMA 13 (Sept. 2016), PFMA 19 (March 2016) and PFMA 20 (Sept. 2017). There were no additional surveys in PFMA 18 (last surveyed in 2008).

Mean densities and their associated confidence bounds were estimated from survey data using the Green Sea Urchin Analysis Program (GUAP) (Lochead et al. 2015). The individual weights of measured urchins were estimated from an allometric relationship that was developed from

[1] In 2015 the WCGUA dissolved and members joined the Pacific Urchin Harvesters Association (PUHA).

data collected from the northeast and southeast regions of Vancouver Island during surveys from 1996 to 2010 (Lochead et al. 2015).

From 2002 to 2010, biological samples were collected during the surveys and provided length-weight data. For these years, parameter values were estimated separately for each survey using data from biological samples taken that year (Waddell and Perry 2005, 2006, 2007, 2012).

Biological sampling was discontinued in 2011. For surveys where no length-weight data were collected, all available length-weight data were pooled to estimate values of the allometric parameters. The sample size of the pooled data was 3706, from 69 survey/index site/year combinations conducted in areas open to commercial harvest (PFMAs 12, 18 and 19). The corresponding mean weight-at-length was estimated using the equation for the mean of a lognormal distribution (Gelman et al. 2004):

$$\bar{W} = \exp\left(-6.866 + 2.728 * log(TD) + \frac{0.160^2}{2}\right)$$

or,

$$\bar{W} = 0.001042 * TD^{2.728} * 1.013$$

For each transect, the mean weight and proportion of legal- (TD≥55 mm) and sublegal-sized (TD<55 mm) urchins were estimated from TD measurements recorded in the measured quadrats (see survey protocol, DFO 2014, Waddell et al. 2010). These means were then applied to urchins from the other quadrats. Based on this analysis, the population and biomass could be estimated for both legal- and sublegal-sized urchins, for each transect.

Trends in populations and population structure

The first survey of PFMA 11 was conducted in September 2016 when 12 transects were completed. The legal-sized population density was 0.1 urchins/m^2 (SE 0.1) and the sublegal-sized population density was 1.0 urchins/m^2 (SE 0.5). Within the sublegal-sized population, the immature urchins (TD<25 mm) had a population density of 0.2 urchins/m^2 (SE 0.1). Similarly, the biomass density for legal-sized urchins was 10.6 g/m^2 (SE 5.4), the sublegal-sized biomass density was 26.8 g/m^2 (SE 14.0) and the immature biomass density was 0.5 g/m^2 (SE 0.4). Mean TD for the 2016 survey was 43 mm.

PFMA 12 was surveyed annually or biennially from 1995 to 2016. From the initial three surveys in 1995, 1996 and 1997, population and biomass densities in PFMA 12 for both legal- and sublegal-sized urchins have increased by a factor of approximately three up to 2008, and since then they have remained relatively stable (Figure 6). Legal-sized population density ranged from 0.9 (SE 0.2) to 1.4 urchins/m^2 (SE 0.3) in 1995 through 1997, increasing to between 3.5 urchins/m^2 (SE 0.5) and 4.0 urchins/m^2 (SE 0.7) in 2012 to 2016. Sublegal-sized population density ranged from 1.1 urchins/m^2 (SE 0.3) to 2.1 urchins/m^2 (SE 0.5) in 1995 through 1997, and then increased in 2012 to 2016 when they ranged from 6.0 urchins/m^2 (SE 1.1) to 8.1 urchins/m^2 (SE 1.3). Legal-sized biomass density ranged from 93.6 g/m^2 (SE 18.1) to 116.8 g/m^2 (SE 35.7) in 1995 through 1997, and increased to between 320.6 g/m^2 (SE 64.8) and 336.5 g/m^2 (SE 79.0) in 2012 through 2016. Sublegal-sized biomass density ranged from 43.3 g/m^2 (SE 11.1) to 70.1 g/m^2 (SE 19.0) in 1995 through 1997 and increased to between 149.7 g/m^2 (SE 36.5) and 226.1 g/m^2 (SE 43.6) in 2012 to 2016. The estimated mean TD was

relatively stable at around 50 mm from 2006 to 2012 and decreased slightly to 47 mm in 2014 and 2016 (Figure 6).

Transects in PFMA 12 are separated into three sub-locations: Stubbs Island, Plumper Islands and Stephenson Islets. Stubbs and Plumper Islands are in a research closure, and therefore the four transects within each of those sub-locations act as unfished controls against the ten transects at Stephenson Islets where commercial harvest is permitted. There are no clear trends between biomass densities at fished versus unfished sites (Figure 7), suggesting factors other than fishing may be affecting biomass density trends.

Surveys in the Hardwick and Thurlow Islands area of PFMA 13 were conducted in March of 2004 and September of 2016. Nine and 16 transects were completed in 2004 and 2016 respectively, eight of which were repeated at the same locations. With only two surveys completed 12 years apart, there are insufficient data to interpret trends. The legal-sized population density was 0.4 urchins/m^2 (SE 0.1) in 2004 and 2.8 urchins/m^2 (SE 0.7) in 2016, while the sublegal-sized population density was 2.5 urchins/m^2 (SE 0.7) in 2004 and 10.0 urchins/m^2 (SE 1.9) in 2016. Within the sublegal-sized population, the immature population density was 0.4 urchins/m^2 (SE 0.3) in 2004 and 4.2 urchins/m^2 (SE 1.2) in 2016. Similarly, biomass density for the legal-sized population in PFMA 13 was 29.8 g/m^2 (SE 7.3) and 326.0 g/m^2 (SE 97.5) in 2004 and 2016, respectively, while the biomass density of sublegal-sized urchins was 47.9 g/m^2 (SE 14.6) and 161.0 g/m^2 (SE 30.4) in 2004 and 2016, respectively. The biomass density for immature urchins was 0.6 g/m^2 (SE 0.2) and 7.1 g/m^2 (SE 2.5) in 2004 and 2016, respectively. Mean TD was 36 mm in 2004 and 35 mm in 2016.

Surveys were conducted in PFMA 18 in 1997, 1998, 1999, 2000, 2001, 2003 and 2008. There has been no survey activity in PFMA 18 since 2008.

Surveys were conducted in PFMA 19 from 2008 to 2016 (Figure 8). Population densities for legal-sized urchins decreased from 2.4 urchins/m^2 (SE 0.6) in 2008 to 0.9 urchins/m^2 (SE 0.3) in 2009 and then increased to 3.0 urchins/m^2 (SE 0.6) in 2014 and 2.5 urchins/m^2 (SE 0.6) in 2016. Biomass densities of legal-sized urchins follow the same trend dropping from 260.8 g/m^2 (SE 89.6) in 2008 to 109.1 g/m^2 (SE 50.6) in 2009, but increasing to 287.5 g/m^2 (SE 56.5) in 2014 and 260.8 g/m^2 (SE 61.0) in 2016, approximating 2008 estimates (Figure 8). The population density of sublegal-sized urchins increased from 0.5 urchins/m^2 (SE 0.0) in 2009 to a peak of 2.5 urchins/m^2 (SE 0.5) in 2014, approximately five times the 2009 levels, then decreased to 1.5 urchins/m^2 (SE 0.4) in 2016 to around triple those observed in 2009. Sublegal-sized biomass densities followed a similar trend, with a six fold increase from 14.0 g/m^2 (SE 3.4) in 2009 through to a peak of 81.9 g/m^2 (SE15.0) in 2014, and then a decrease to 34.6 g/m^2 (SE 7.9) in 2016 where levels were approximately double those in 2009 (Figure 8). The mean TD remained at 59 mm in 2008 and 2009 but decreased to 53, 54 and 53 mm through 2012, 2014 and 2016 respectively (Figure 8). The observed small increase in legal-sized population density and larger increase in sublegal-sized population density, since 2008 and 2009, results in a greater proportion of sublegal-sized urchins and translates to a lower mean TD for the combined size categories.

PFMA 20 was surveyed in September 2017 when 21 transects were completed. The legal-sized population density was 1.7 urchins/m^2 (SE 0.5) while the sublegal-sized population density was 1.3 urchins/m^2 (SE 0.5). Within the sublegal-sized population, the immature population had a density of 0.03 urchins/m^2 (SE 0.01). Similarly, the biomass density for legal-sized population was 183.0 g/m^2 (SE 58.0) while the sublegal-sized biomass density was 44.1 g/m^2 (SE 17.9). The immature biomass density was 0.08 g/m^2 (SE 0.05). Mean test diameter for the 2017

survey was 58 mm. A previous survey of PFMA 20 in 2000 had five transects, covering too small an area to be comparable to these results.

A reliable method to age Green Sea Urchins has not yet been developed. The growth-band aging method used in other echinoids has been proven unreliable in this species (Russell and Meredith 2000). Therefore, population structure continues to be inferred by examining size distributions.

Size frequency distributions for all years in all PFMAs show a broad range of test diameters suggesting a wide range of age classes are likely represented (Figure 9, 10, 11, 12 and 13).

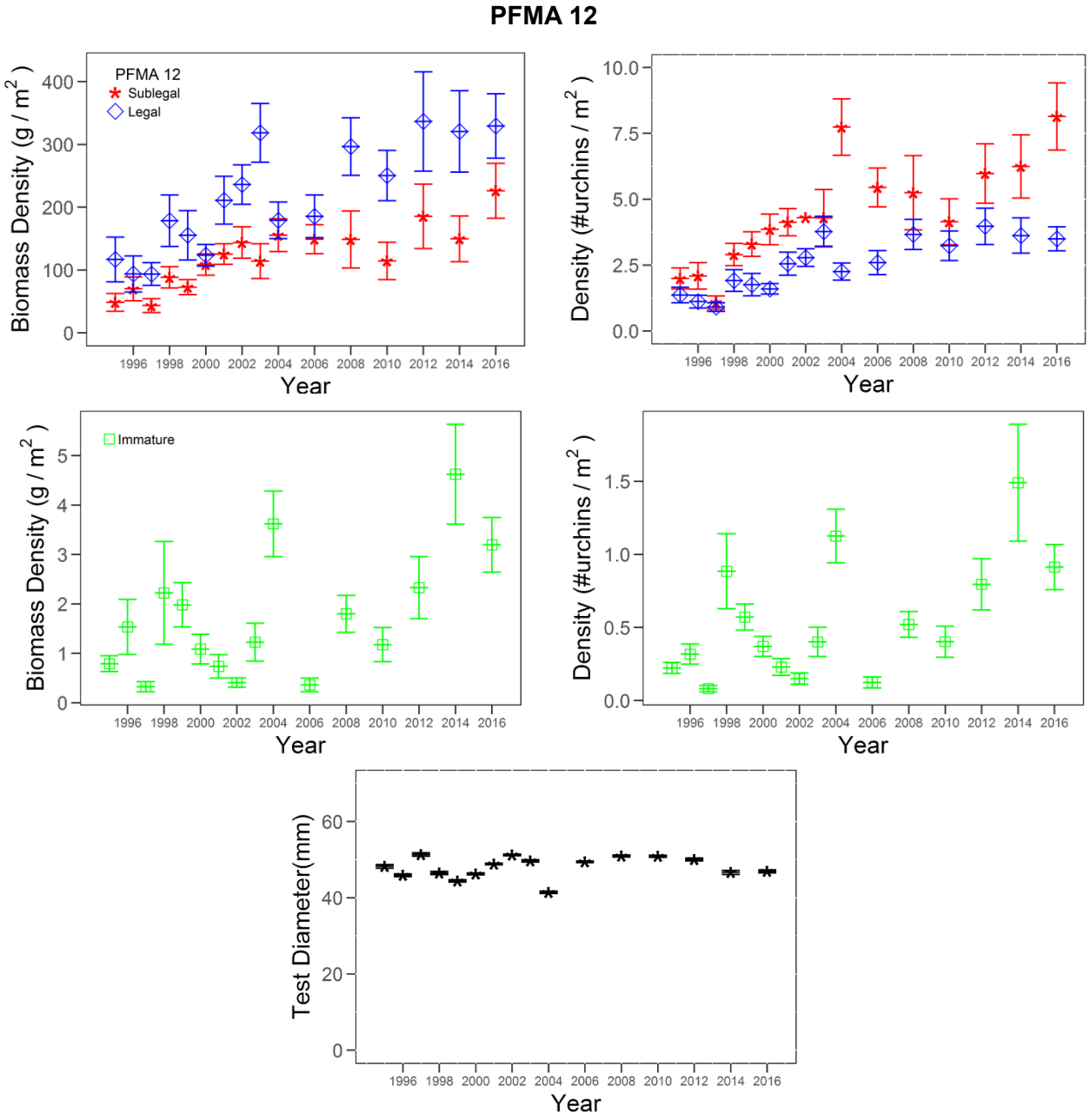

Figure 6. Means estimated for Green Sea Urchins in PFMA 12 (+/- one standard error). Biomass densities (g/m^2) shown in the left panels and population densities (# urchins/m^2) in the right panels. The top row of panels show estimated values for legal- (≥55 mm) and sublegal-sized (<55 mm, includes immature) urchins. The middle row of panels show estimated values for immature (<25 mm) urchins. The bottom panel shows the mean test diameter for all urchins. In some cases, the standard errors are small and appear within the markers. Data are from fishery-independent dive surveys.

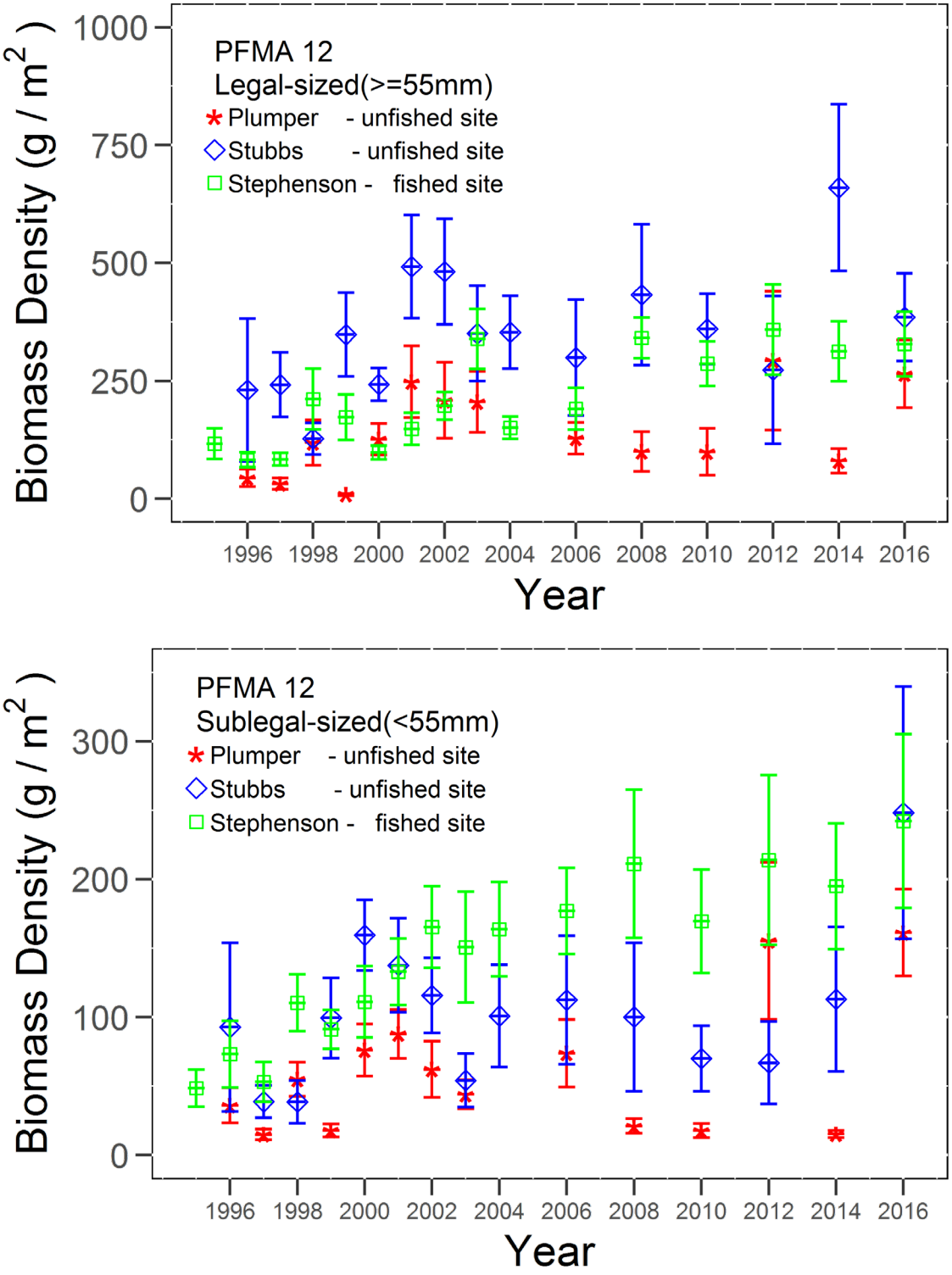

Figure 7. Mean biomass densities (g/m^2) +/- one standard error for legal- (≥55 mm) (top panel) and sublegal-sized (<55 mm) (bottom panel) Green Sea Urchins for the three sub-locations [Stephenson Islets (fished), Stubbs Island (unfished control) and Plumper Islands (unfished control)] in the PFMA 12 dive surveys. Only one transect was completed at Plumper Island in 2004 so data are not shown.

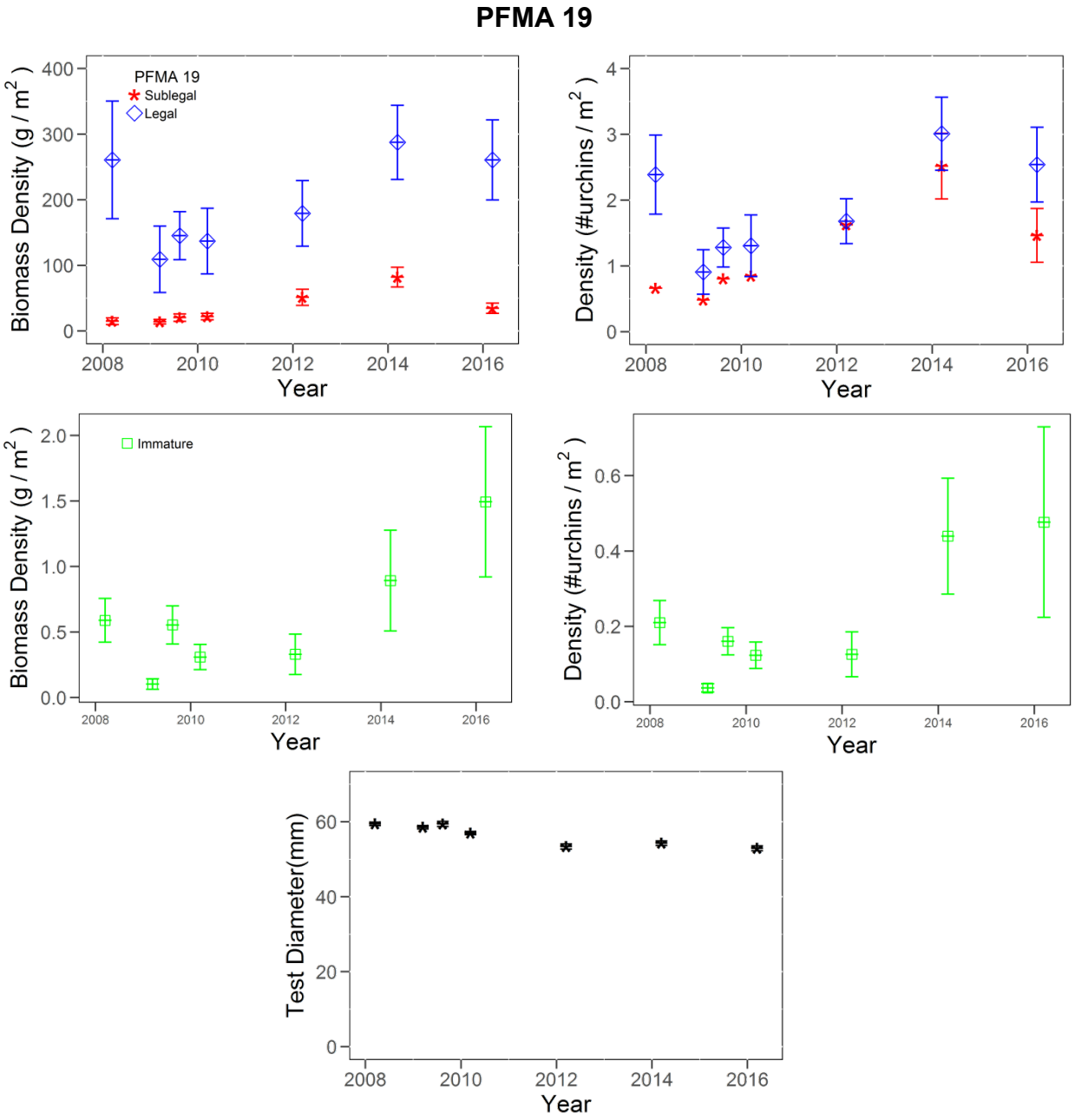

Figure 8. Means estimated for Green Sea Urchins from PFMA 19 (+/- one standard error). Biomass densities (g/m^2) shown in the left panels and population densities (# urchins/m^2) shown in the right panels. The top row of panels show estimated values for legal- (≥55 mm) and sublegal-sized (<55 mm, includes immature) urchins. The middle row of panels show estimated values for immature (<25 mm) urchins. The bottom panel shows the mean test diameter for all urchins. In some cases, the standard errors are small and appear within the markers. Data are from fishery-independent dive surveys.

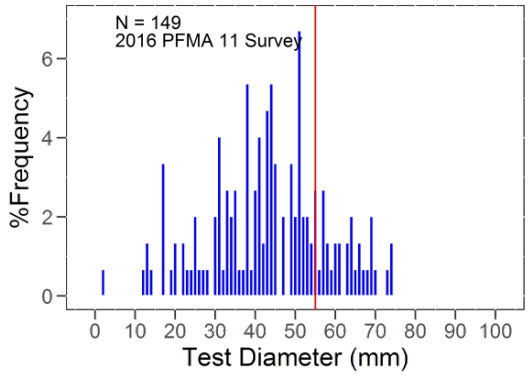

Figure 9. Size frequency distribution of Green Sea Urchin test diameters (mm) measured during the September 2016 survey in PFMA 11. Red line marks the minimum legal commercial harvest size of 55 mm.

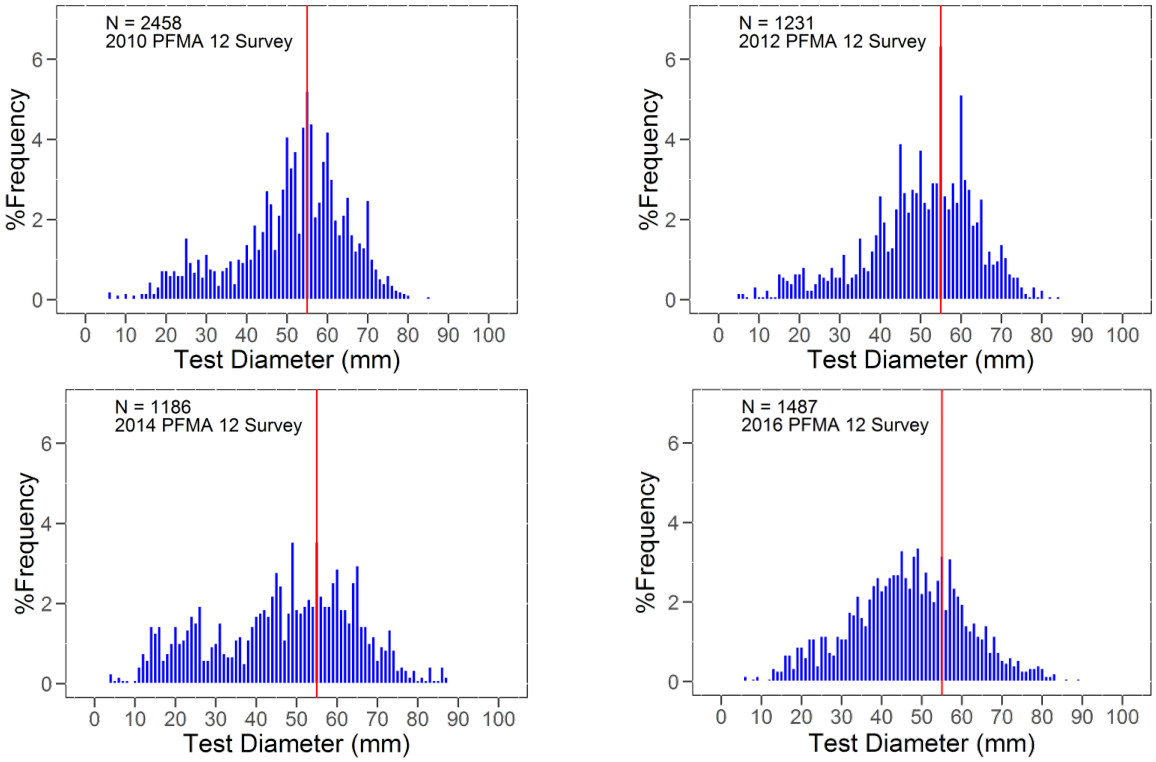

Figure 10. Size frequency distributions of Green Sea Urchin test diameters (mm) measured during the fall surveys of PFMA 12 in 2010 (top left), 2012 (top right), 2014 (bottom left) and 2016 (bottom right). Red lines mark the minimum legal commercial harvest size of 55 mm.

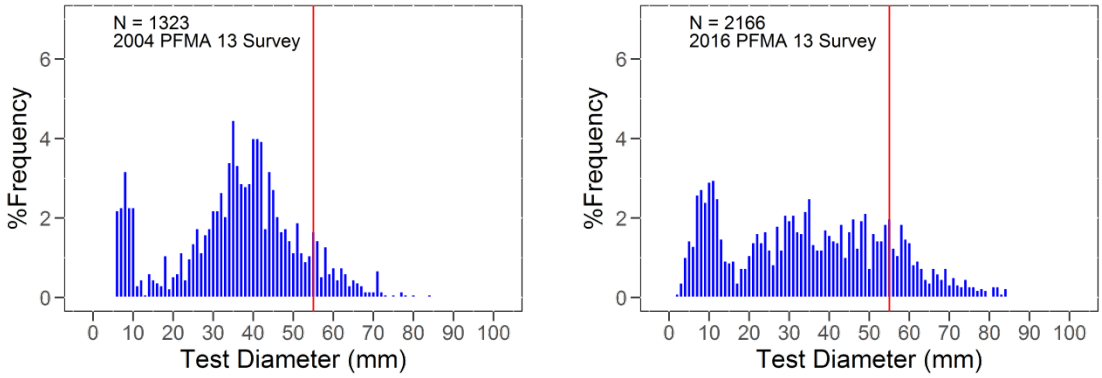

Figure 11. Size frequency distributions of Green Sea Urchin test diameters (mm) measured during the March 2004 (left) and September 2016 (right) surveys in PFMA 13. Red lines mark the minimum legal commercial harvest size of 55 mm.

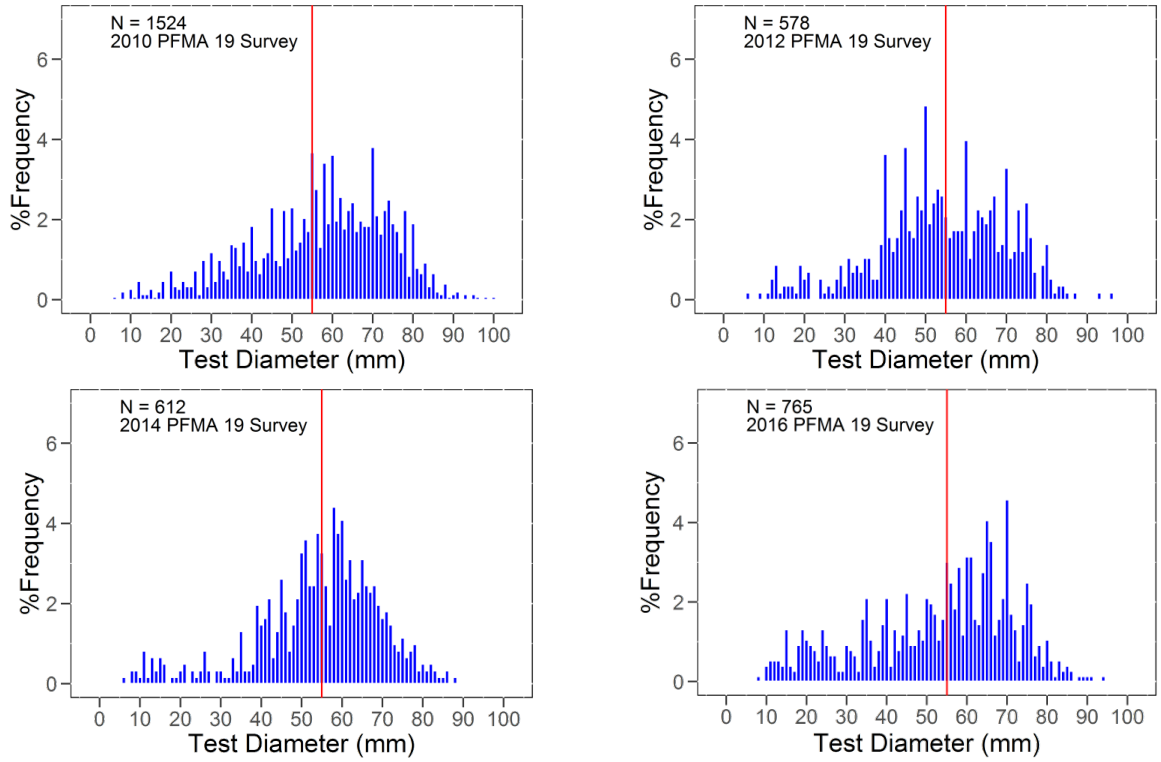

Figure 12. Size frequency distributions of Green Sea Urchin test diameters (mm) measured during the March surveys of PFMA 19 in 2010 (top left), 2012 (top right), 2014 (bottom left) and 2016 (bottom right). Red lines mark the minimum legal commercial harvest size of 55 mm.

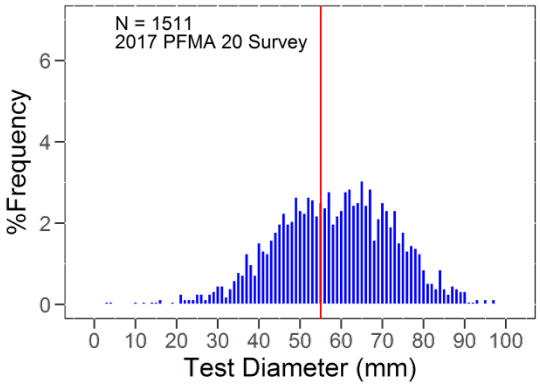

Figure 13. Size frequency distribution of Green Sea Urchin test diameters (mm) measured during the September 2017 survey in PFMA 20. Red line marks the minimum legal commercial harvest size of 55 mm.

Harvest Options

This assessment updates previously published time series data and provides new harvest options for the 2018-2019 to 2020-2021 Green Sea Urchin fishery Bayesian biomass dynamic model used in the assessment of BC's Green Sea Urchin stocks since 2003 (DFO 2016b). The model incorporates both fishery-dependent and fishery-independent data with individual analyses for Northeast Vancouver Island and for Southeast Vancouver Island, producing maximum sustainable yield (MSY) posterior probability distributions for each region. The allocation of harvest options to each PFMA within a region is based on the proportion of total historic landings from each PFMA from the 1995-1996 to 2016-2017 fishing seasons (Table 1).

This assessment takes into account the recent fishery expansion back into historically fished PFMAs in both regions (PFMA 11 in Northeast Vancouver Island and PFMA 20 in Southeast Vancouver Island). Fishery-independent survey data from PFMA 12 along with total catch and CPUE data from PFMAs 11, 12, 13 were included as inputs to the model for Northeast Vancouver Island. Similarly, fishery-independent survey data from PFMA19 along with total catch and CPUE data from PFMAs 18, 19, 20 were included as inputs to the model for Southeast Vancouver Island. The current assessment differs from previous assessments, in that total catch and CPUE data from PFMAs 11 and 20 were included in the model whereas previous assessments included total catch and CPUE data from PFMAs 12 and 13 only for Northeast Vancouver Island and PFMAs 18 and 19 only for Southeast Vancouver Island. See DFO (2014) and Waddell et al. (2010) for more detailed descriptions of model inputs.

The median MSY estimates (median of the estimated posterior probability distribution for MSY) for each region are uncertain and could be any MSY as represented by the posterior probability distributions from the Bayesian model. The harvest options are various reductions from the estimated median of the MSY posterior probability distribution, along with the probabilities that the harvest options may be larger than the true MSY (Table 1).

The median MSY for Northeast Vancouver Island was estimated at 310 metric tonnes (t) in the current stock status update, and median MSY estimates were 298 t, 306 t and 302 t in 2010, 2013 and 2016, respectively. The median MSY for Southeast Vancouver Island was estimated at 95 t in the current stock status update, and in 2010, 2013 and 2016 median MSY estimates were 78 t, 74 t and 76t, respectively (2016b). From the 1995-1996 to 2016-2017 fishing seasons, PFMAs 11 and 20 were only harvested for seven and nine out of 22 seasons,

respectively, and had relatively low landings during the few active fishing seasons, causing the harvest options to be relatively small.

From the 2006-2007 through to the 2015-2016 fishing seasons, fishery managers kept the Green Sea Urchin commercial fishery quotas stable at 177.3 t in Northeast Vancouver Island and 25.5 t in Southeast Vancouver Island. The quotas were increased in the 2016-2018 IFMP (DFO 2016a) in both areas because the fishery expanded back into historically fished PFMAs 11 and 20. The 2016-2018 quota for Northeast Vancouver Island was 209.5 t while Southeast Vancouver Island was 36.4 t. If the same commercial fishery quotas are used for the next IFMP, the predicted probability that the quota exceeds the true MSY is 5.4% for Northeast Vancouver Island and 1.1% for Southeast Vancouver Island.

Table 1. Harvest options in metric tonnes as percentages of the estimated median Maximum Sustainable Yield (MSY), the percent probability that the option may be greater than or equal to the true MSY, and allocation of the total harvest to each of the Regions and open Pacific Fisheries Management Areas: A. Northeast Vancouver Island: PFMAs 11, 12 and 13; and B. Southeast Vancouver Island: PFMAs 18, 19 and 20.

A. Northeast Vancouver Island

Percentage of median MSY	Harvest Options (tonnes)				% Probability Harvest Option ≥ true MSY
	PFMAs 11, 12 & 13	PFMA 11	PFMA 12	PFMA 13	
100	310.2	1.5	191.0	117.7	50.0
90	279.2	1.4	171.9	105.9	33.1
80	248.2	1.2	152.8	94.1	17.8
70	217.1	1.1	133.7	82.4	6.9
60	186.1	0.9	114.6	70.6	2.2
50	155.1	0.8	95.5	58.8	0.6
40	124.1	0.6	76.4	47.1	0.2
30	93.1	0.5	57.3	35.3	<0.001
20	62.0	0.3	38.2	23.5	<0.001
10	31.0	0.2	19.1	11.8	<<0.001

B. Southeast Vancouver Island

Percentage of median MSY	Harvest Options (tonnes)				% Probability Harvest Option ≥ true MSY
	PFMAs 18, 19 & 20	PFMA 18	PFMA 19	PFMA 20	
100	95.0	30.0	58.4	6.6	50.0
90	85.5	27.0	52.6	5.9	35.5
80	76.0	24.0	46.7	5.3	23.1
70	66.5	21.0	40.9	4.6	13.8
60	57.0	18.0	35.0	3.9	7.7
50	47.5	15.0	29.2	3.3	3.9
40	38.0	12.0	23.4	2.6	1.4
30	28.5	9.0	17.5	2.0	0.3
20	19.0	6.0	11.7	1.3	<0.001
10	9.5	3.0	5.8	0.7	<<0.001

Sources of uncertainty

There are uncertainties related to the data and the assumptions necessary to develop the model used in this assessment. The estimation of MSY is based on a productivity model with inherent uncertainties. The production model combines growth, recruitment, and mortality into one production function, and does not take into account the interactions and temporal effects of these processes. This model represents an approximation of the population dynamics that is simplified compared to more complex fisheries models, such as age-structured models. For instance, the model assumes that surplus production (amount of increase in biomass of the stock) at any given year is related to the biomass in the previous year, without considering a time lag for larvae or juveniles to grow before contributing to the harvestable biomass, and also implies a closed population. Various harvest options are provided with associated probability levels that an adopted harvest option would be larger than the true MSY. Fishery managers can therefore choose the level of risk in the management of the fishery.

There is also uncertainty around the allometric relationship used in these analyses. The allometric relationship assumes stationarity, however this assumption was not tested. It was assumed that post-2011 mean weights can be represented by the pooled average of the pre-2011 weights. Size trends over time and location to location differences were not investigated. Future work should test the assumption of stationarity in size distributions over time and across locations

Additional uncertainty relates to the way harvest options are allocated among PFMAs within each region. The allocation among PFMAs (within a region) is based on the proportion that each PFMA contributed to landings from 1995-1996 to 2016-2017. This method carries a risk of over- or under-exploitation if Green Sea Urchin distribution and abundance change among these areas over time.

Precautionary Approach

The minimum elements of the harvest strategy component of the DFO PA include the establishment of three stock zones delineated by a LRP and Upper Stock Reference (USR) (DFO 2009). Although precautionary, the reference points used since 2003 did not enable the estimation of stock status relative to the stock zones (healthy, cautious and critical), and were therefore not considered compliant with the DFO PA. This assessment provides candidate reference points that are compliant with the DFO PA.

The Limit and Target Reference Points referred to in past Green Sea Urchin stock assessments were established in 2003 (Perry et al. 2003), prior to the implementation of DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO Precautionary Approach) (DFO 2009). In previous Green Sea Urchin stock assessments the Limit Reference Point (LRP) was the median MSY from the posterior distribution, defined as the level that harvest should not exceed. Previous stock assessments recommended that quotas should be set sufficiently below the median MSY to ensure there was a low probability that the harvest would be larger than the true MSY.

A suggested approach in the DFO PA policy (DFO 2009), is to use B_{msy} (the biomass at which maximum sustainable yield is achieved) or a proxy as a base for delineating the stock status zones. In the case of Green Sea Urchins, there is a paucity of data with which to estimate B_{msy}. This assessment suggests an empirical approach for establishing provisional reference points based upon historical estimates of population density for legal-sized urchins. Weight estimation methods have changed over time, resulting in biomass densities that are not directly comparable throughout the time series (see Fishery-independent data Section, above). Thus,

population density (urchins/m^2) is preferred over biomass density (g/m^2) for the reference point unit of measure.

The lowest estimated density in the 21-year time series of surveys in PFMA 12 was 0.9 urchins/m^2 in 1997, and the Northeast Vancouver Island stock subsequently increased without any remedial intervention by Fisheries Managers (Figure 6). Similarly, the lowest estimated density for the 8-year time series of surveys in PFMA 19 was 0.9 urchins/m^2 in 2009, and the Southeast Vancouver Island stock also subsequently increased without remedial intervention by Fisheries Managers (Figure 8). For the PFMA 12 and 19 survey time series (Figure 6, Figure 8), D_{min} is the minimum observed mean population density of legal-sized Green Sea Urchins (urchins/m^2).

PFMA 12 D_{min} = 0.9 urchins/m^2 (SE 0.2) (in 1997) (Figure 6)

PFMA 19 D_{min} = 0.9 urchins/m^2 (SE 0.3) (in 2009) (Figure 8)

Since both stocks have demonstrated the ability to increase from a density of 0.9 legal-sized urchins per metre-squared, without reducing harvest, that density is considered a suitable USR for both stocks.

Based on evidence as described below, the LRP could be arbitrarily set at 0.5*D_{min} which is equivalent to 0.5*USR.

Therefore:

USR = 0.9 urchins/m^2

LRP = 0.5*USR = 0.45 urchins/m^2

There is evidence that Green Sea Urchin stocks can persist even when densities decline to values much lower than this suggested LRP. Sea Otters are known predators of many shellfish species, including sea urchins. In Surge Bay, Southeast Alaska, where Sea Otters were established in the early 1970's, mean Green Sea Urchin densities were 0.08 urchins/m^2 in 1978 and 0.16 urchins/m^2 in 1988 (Estes and Duggins 1995). These density estimates are for all size categories combined, so the mean legal-size density would have been be lower than these values. Green Sea Urchin populations in Surge Bay sustained themselves at these low levels between 1978 and 1988, and the candidate reference points are well above these measured densities.

The estimated mean density of legal-sized urchins in 2016 was 8.1 urchins/m^2 in PFMA 12 and 2.5 urchins/m^2 in PFMA 19. This places the Green Sea Urchin stocks in the Healthy Zone in both areas. Review of the assessment model should occur if estimates of mean density of legal-sized urchins in either PFMA 12 or PFMA 19 surveys fall below the USR for two consecutive triennial surveys or fall below the LRP in any survey year.

Conclusions and Advice

Green Sea Urchins remain a small but important dive fishery in BC. The fishery suffered from low market demand from 2004 to 2012, but landings have since increased. In the 2016-2017 fishing season the TAC was fully achieved, reflecting improvements in, or recovery of market demand. Concurrent with the rebound in market demand, the most recent Green Sea Urchin densities, observed in 2016 during PFMA 12 and 19 surveys, were among the highest observed since the beginning of the time series (1995-2016 for PFMA 12; 2008-2016 in PFMA 19).

1. Based on mean legal-size density results of the PFMA 12 and 19 surveys, adopt

a. USR = 0.9 legal-sized Green Sea Urchins/m^2

b. LRP = 0.45 legal-sized Green Sea Urchins/m^2

for both the Northeast and Southeast regions of Vancouver Island. Review of the assessment model should occur if estimates of mean density of legal-sized Green Sea Urchins in either PFMA 12 or PFMA 19 surveys fall below the USR for two consecutive triennial surveys or fall below the LRP in any survey year.

2. In 2016, mean legal-size density was 8.1 urchins/m^2 in PFMA 12 and 2.5 urchins/m^2 in PFMA 19, indicating Green Sea Urchin stocks are in the Healthy Zone in both areas.
3. Harvest options developed using a Bayesian biomass dynamic model are provided in Table 1 for both Northeast Vancouver Island (PFMAs 11, 12, 13) and Southeast Vancouver Island (PFMAs 18, 19, 20). The risks associated with the harvest options are defined in Table 1 as the probabilities that the harvest options are greater than or equal to the true MSY.
4. The PFMA 12 and PFMA 19 fishery-independent surveys should be continued on a regular basis to provide a fishery-independent time series of density estimates for monitoring Green Sea Urchin population trends.

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