STOCK STATUS UPDATE AND HARVEST OPTIONS FOR THE GREEN SEA URCHIN (*STRONGYLOCENTROTUS DROEBACHIENSIS*) FISHERY IN BRITISH COLUMBIA, 2016-2019

Context

British Columbia's Green Sea Urchin (*Strongylocentrotus droebachiensis*) stock is assessed every three years. The previous assessment was conducted in 2013 (DFO 2014) and was used to inform the development of the Pacific Region's Green Sea Urchin fishery 2013-2016 Integrated Fishery Management Plan (IFMP). This assessment will provide updated advice for the development of the new IFMP.

DFO Fisheries Management has requested advice for the Green Sea Urchin fishery in British Columbia (BC), by spring 2016, on the following:

1. The ranges of sustainable harvest options for the commercial harvest areas (Pacific Fisheries Management Areas (PFMAs) 12, 13, 18 and 19);
2. The risks or uncertainties associated with the range of harvest options;
3. The recent trends in the local populations' abundance and population size structure for Green Sea Urchins where data exist;
4. Recommendations for additional research or stock assessment programs.

This paper assesses Green Sea Urchin stocks in regions of BC open to commercial harvest through the analysis of fishery-dependent and fishery-independent data. The quota options presented are derived from a previously published Bayesian assessment model (Perry et al. 2003, Zhang and Perry 2005) which has been used in the assessment of BC's Green Sea Urchin stock since 2003 (Perry et al. 2003, Perry et al. 2006, Waddell et al. 2010, DFO 2014). This publication updates the results with the most recently available commercial catch and survey information.

This Science Response Report results from the Science Response Process of April 6, 2016 on Stock Status Update and Quota Options for the Green Sea Urchin (*Strongylocentrotus droebachiensis*) Fishery in British Columbia, 2016-2019.

Background

Green Sea Urchins (Figure 1) are a benthic 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, through the Aleutian Islands, Alaska, and west to the Korean Peninsula, Kamchatka, Russia and Hokkaido, Japan. Green Sea Urchins occur intertidally and subtidally to depths of over 140 metres. Preferred habitat is rocky, gravel or shell substrates. Kelp and 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 region, occurring from February to March in BC. The larval period can last from 7 to 22 weeks (Strathmann 1978). In southern BC, Green Sea Urchins reach sexual maturity at a test diameter (TD) of about 25 mm (Waddell et al. 2002) and the minimum legal size is 55 mm TD, which in Alaska correspond to 2-3 year olds and 4 year olds, respectively (Munk 1992). Growth is highly variable and is dependent on food supply and environmental conditions.

Green Sea Urchins are the target of a commercial harvest, a recreational harvest and a traditional Food, Social, Ceremonial (FSC) harvest by First Nations. The catch by recreational and FSC harvesters is largely unknown, but is believed to be minimal. The commercial harvest is conducted by SCUBA divers who hand-pick urchins while working from small vessels. Divers harvest when and where roe quality is best. 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 harvest restrictions and licensing limitation are provided in the IFMP (DFO 2013).

BC's Green Sea Urchin commercial fishery currently takes place in two regions of the coast: Northeast Vancouver Island, which includes PFMAs 12 and 13, and Southeast Vancouver Island, which includes PFMAs 18 and 19 (Figure 2). The two regions are assessed separately.

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

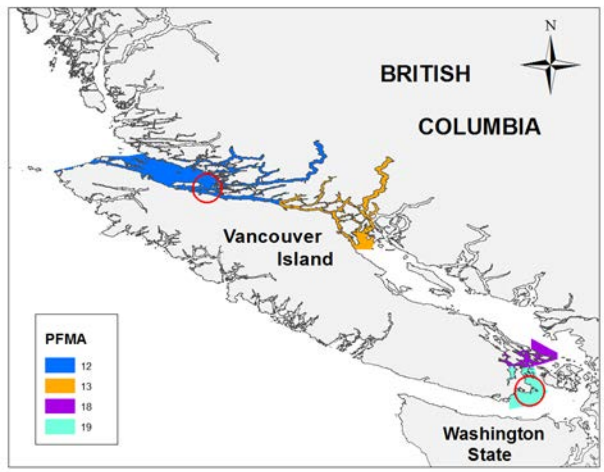

Figure 2. Map of southern British Columbia showing the four Pacific Fisheries Management Areas (12, 13, 18 and 19) open to the Green Sea Urchin fishery. Red circles denote locations of the index site surveys.

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 by dive hour) is used as an indicator of stock status in this assessment. The catch and effort data were derived from harvest logbooks, validation logs and prior to 1995, from sales slip data. The median CPUE value was chosen to show trends because it is more robust to outliers in effort data than the mean. Variability around CPUE is expressed as the standard error of the median, which was calculated as in Waddell et al. (2010) and DFO (2014) by multiplying the standard error of the mean CPUE by 1.2533 (Sokal and Rohlf 2012).

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 present) (Figures 3, 4 and 5). During the developing period of the fishery, landings (Figure 5) and effort (Figure3) increased while median CPUE (Figure 4) began a slow decline. The crisis period followed, when landings and effort peaked, median CPUE continued to decline, and harvesters reported having to dive deeper to locate enough marketable urchins. At the onset of the rebuilding period (1994 – present), an Individual Quota system was initiated which gave each licence an equal share of the total allowable catch (TAC). Other management measures were put in place, including closed areas and area quotas, resulting in a stabilization of effort and increases in median CPUE. A subsequent period of low market demand has since occurred, beginning in 2004 and continuing to the 2013-14 fishing season. In BC, the result has been a period of low effort and variable, but relatively high, median CPUE.

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).

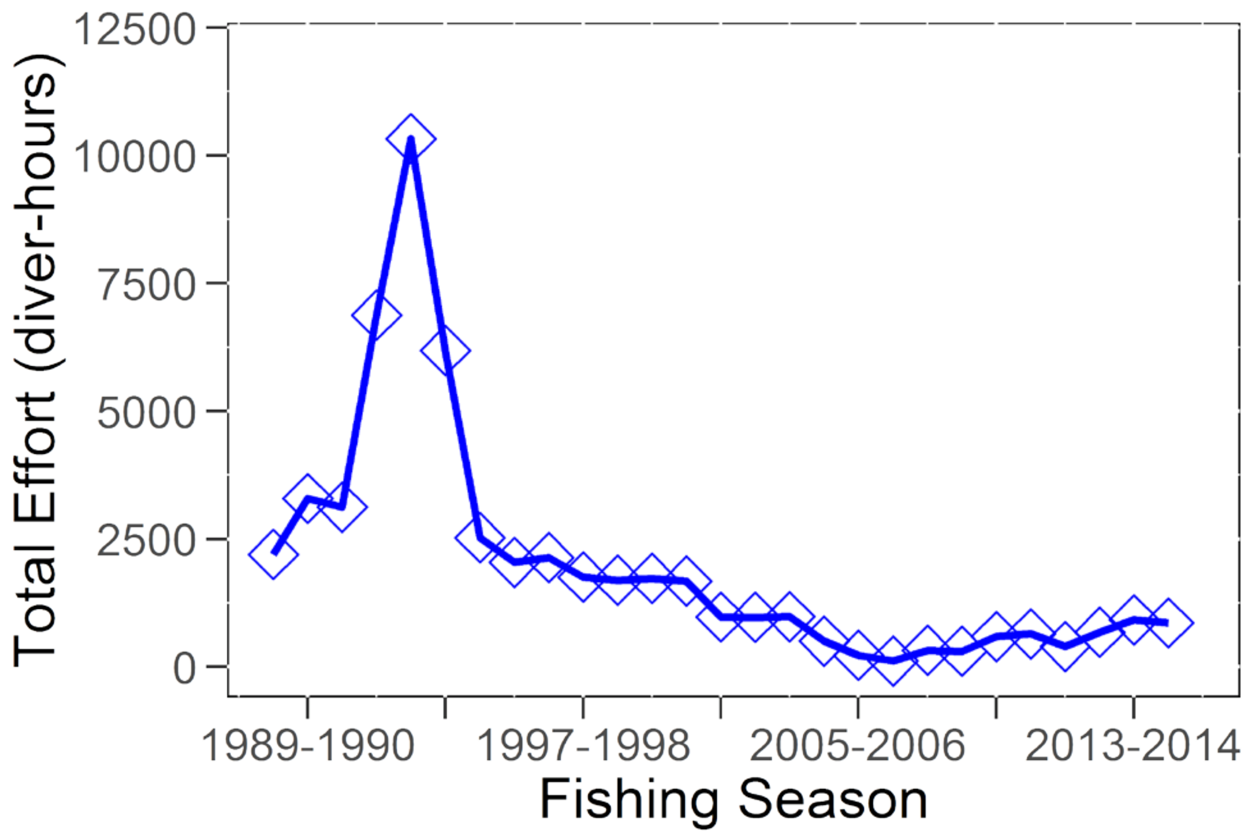

Figure 3. Total Effort (diver hours) for PFMAs 12, 13, 18 and 19 combined.

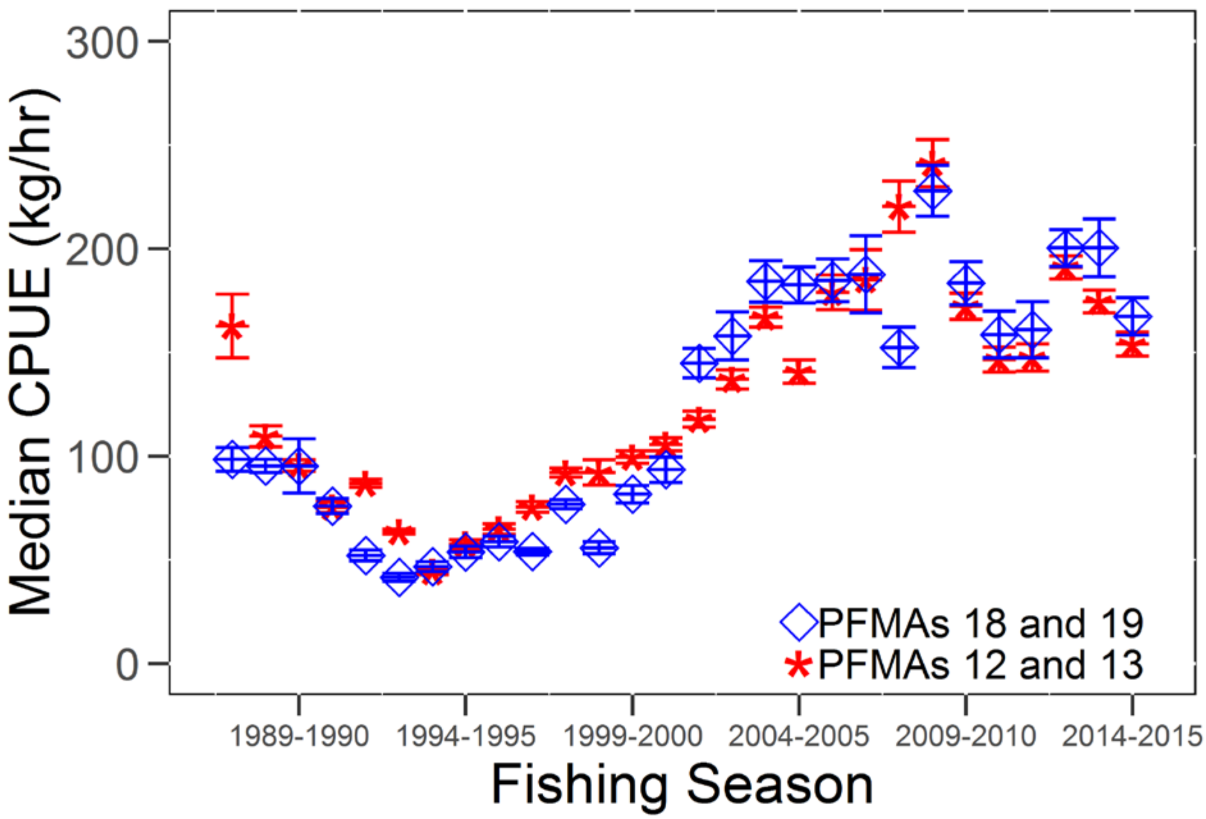

Figure 4. Median catch per unit effort (CPUE) (kg/hr) ± standard error for PFMAs 12-13 (red stars) and 18-19 (blue diamonds) by commercial fishing season.

Landings below the TAC for fishing seasons 2004-05 to 2011-12 (Figure 5) were due to low market demand and are not believed to be reflective of stock status. Markets have improved recently and 82% and 67% of the TAC was achieved in the 2013-14 and 2014-15 fishing seasons, respectively. Preliminary data from the 2015-16 fishing season suggests that upwards of 90% of the TAC will be achieved.

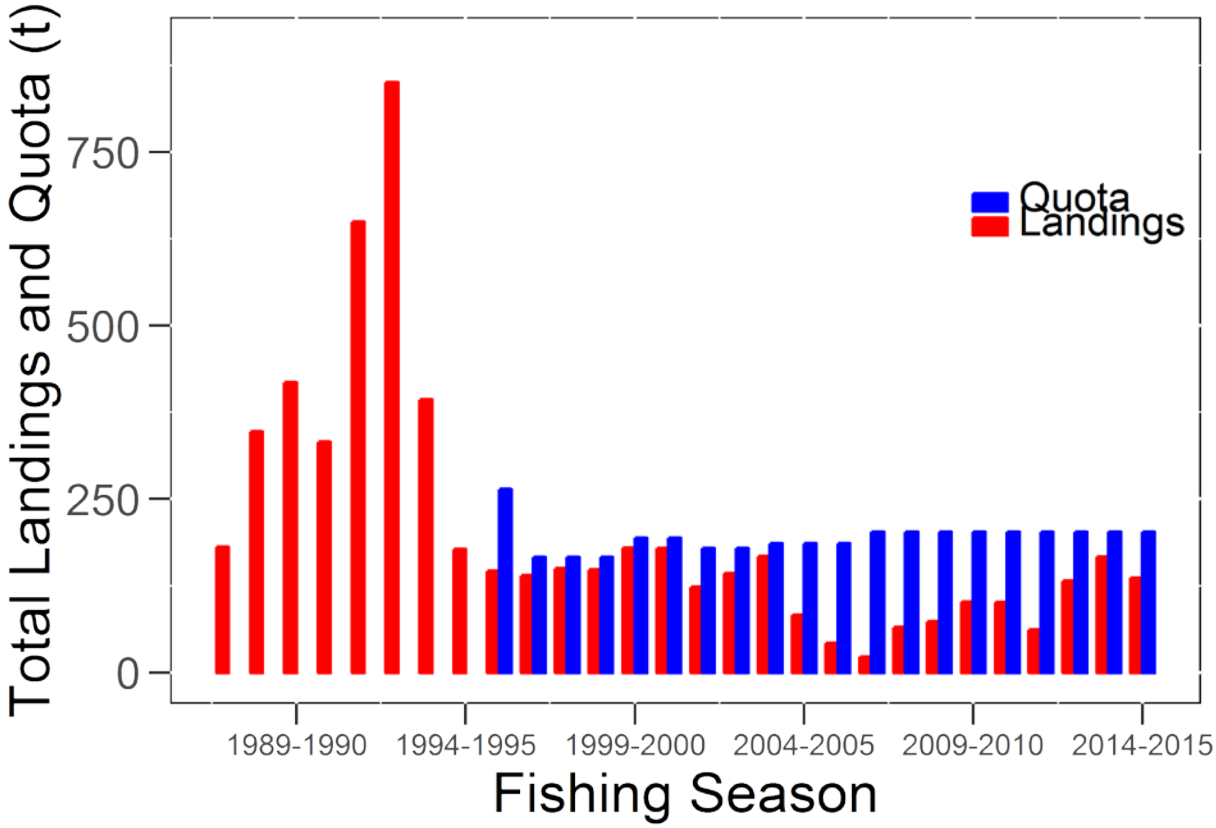

Figure 5. Quota (red bars) (from fish slip data up to 1995, then from harvest and validations logs) and total allowable catch (TAC) (blue bars) (from inception of individual quotas and dockside validation in 1995 and onwards) in metric tonnes by commercial fishing season, for PFMAs 12, 13, 18 and 19.

Fishery-independent data

Fishery-independent dive surveys at index sites have been conducted jointly by the Department of Fisheries and Oceans Canada (DFO) and the West Coast Green Urchin Association (WCGUA)[1]. The main objective of the surveys is to monitor Green Sea Urchin populations in the two areas on BC's coast that are open to commercial harvest.

The first and longest time-series of surveys has been conducted at index sites in Queen Charlotte Strait, in PFMA 12, on Northeast Vancouver Island, where 15 fall and 3 spring surveys have been conducted since 1995 (Waddell et al. 1997, Waddell et al. 2002, Waddell and Perry 2005, Waddell and Perry 2006, Waddell and Perry 2007, Waddell and Perry 2012) (Figure 2). The index sites on Southeast Vancouver Island are located in Haro Strait, in PFMA 19, and have been surveyed in March 2008, March 2009, August 2009, March 2010, March 2012 and March 2014 (Figure 2).

Within a survey, transects are grouped into sub-locations. A sub-location is defined as an area within an index site that is distinct because of its geographic location and/or its fishing history.

Mean densities and their associated confidence bounds were estimated from survey data using the Green Sea Urchin Analysis Program (GUAP) (Lochead et al. 2015). Transects are the primary sampling units, with linear interpolation used to estimate values for skipped quadrats

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

and quadrats where urchins were counted but not measured. Interpolated values include quadrat depth, the number of green sea urchins in a quadrat and the size class (legal TD ≥ 55 mm and sublegal TD < 55 mm) proportion for a quadrat. See DFO 2015 and Waddell et al. 2010 for a detailed description of the survey protocol.

The individual weights of measured urchins were estimated from an allometric relationship (Waddell et al. 2010):

$$W = \alpha * TD^{\beta} * \exp(\varepsilon)$$

Or in its lognormal form:

$$W = \exp(\varphi + \beta * \log(TD) + \varepsilon)$$

Where:

- W is the weight at size (g)
- TD is the test diameter (mm)
- α,β and φ are model parameters
- $\varphi = \log(\alpha)$
- ε is the random error
- $\varepsilon \sim Normal(0, \sigma^2)$

The corresponding mean-weight-at-length can be estimated using the equation for the mean of a lognormal distribution (Gelman et al. 2004):

$$\bar{W} = \exp\left(\varphi + \beta * log(TD) + \frac{\sigma^2}{2}\right)$$

Where:

- $\bar{W}$ is the mean-weight at size
- σ^2 is the variance of the random error

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 sub-location within a 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 was collected, all available length-weight data was pooled to estimate values of the allometric parameters. Sample size of the pooled data was 3706, from 69 survey/sub-location/year combinations conducted in areas open to commercial harvest (PFMAs 12, 18 and 19). The pooled data was treated as a simple random sample with no allowances made for sample or population sizes from individual sub-locations. For the pooled data, the estimated parameter values are:

- φ =-6.866
- $\alpha = 0.001042$
- $\beta = 2.728$
- $\sigma = 0.1597$

So,

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

or,

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

For each transect, the mean weight and proportion of legal and sublegal urchins are estimated from TD measurements recorded in the measured quadrats. These means are then applied to urchins from the counted and skipped quadrats. Based on this analysis, the population and biomass can be estimated for both legal and sublegal urchins, for each transect.

As described in Lochead et al. (2015), the ratio estimator (Cochran 1977) is applied to abundance estimates from individual transects to generate estimates of mean density (population or biomass) for sublocations within a survey and bootstrapping (Efron and Tibshirani 1993) is used to generate confidence bounds on the estimated mean densities.

Trends in populations and population structure

From 1995 to 2014 at index sites in PFMA 12, population densities (number of Green Sea Urchins/m^2) and biomass densities (g/m^2) have been increasing for both legal (TD ≥ 55 mm) and sublegal (TD < 55 mm) urchins (Figure 6). Population densities and biomass densities from 2014 are relatively unchanged since 2008, and are approximately three times what they were in 1995 (Figure 6). The estimated mean TD was steady at 50mm from 2004 to 2012, and dropped slightly to 47mm in 2014 (Figure 6).

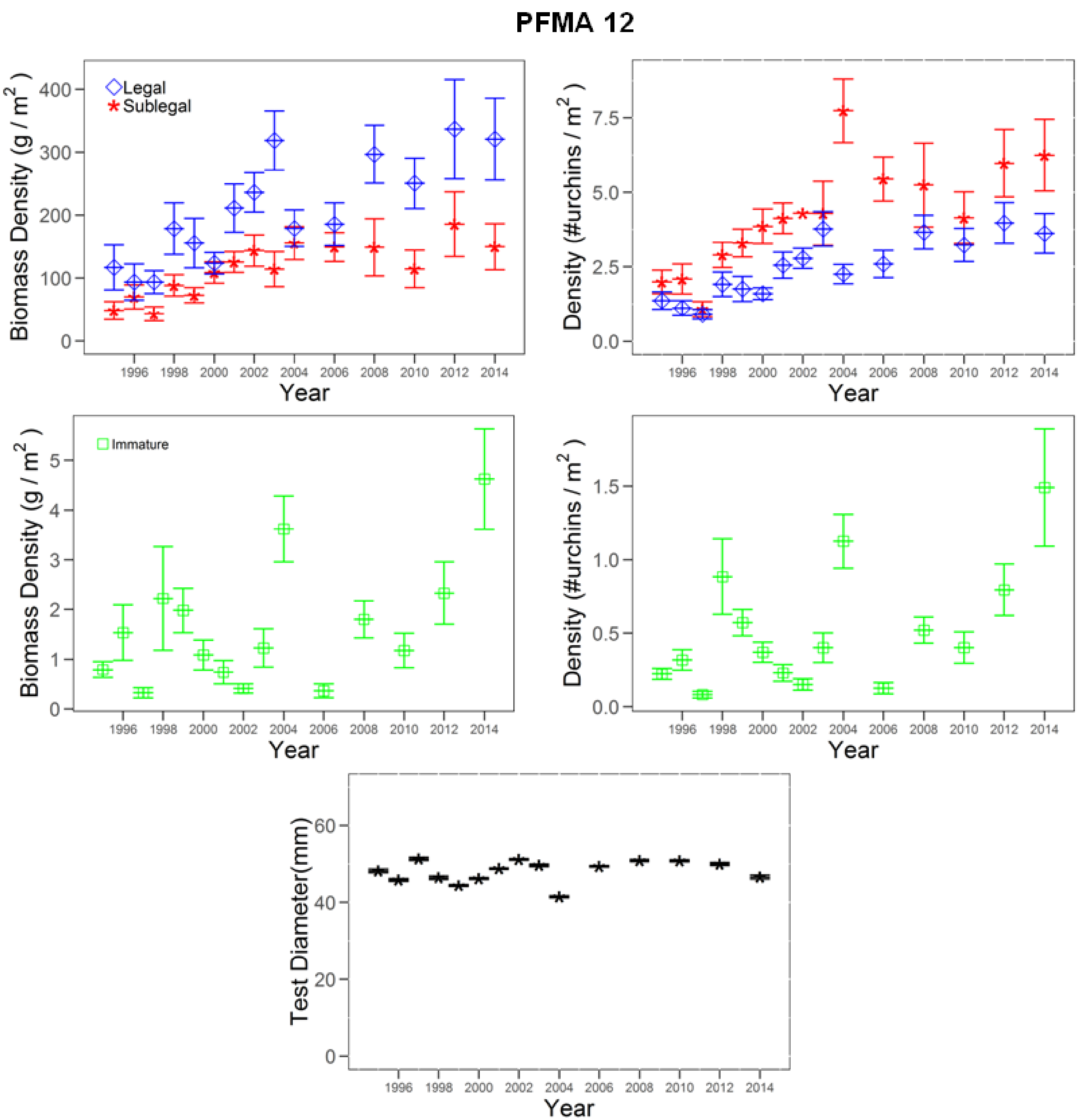

Figure 6. Means estimated for Green Sea Urchins from PFMA 12 (+/- one standard error). Biomass density (g/m^2) is shown on the left and population density (# urchins/m^2) is shown on the right. The top row shows estimated values for legal (≥55 mm) and sublegal (<55 mm, includes immature) urchins. The middle row shows estimated values for immature (<25 mm) urchins. The bottom plot shows the mean test diameter for all sizes. In some cases, the standard errors are small and appear within the markers.

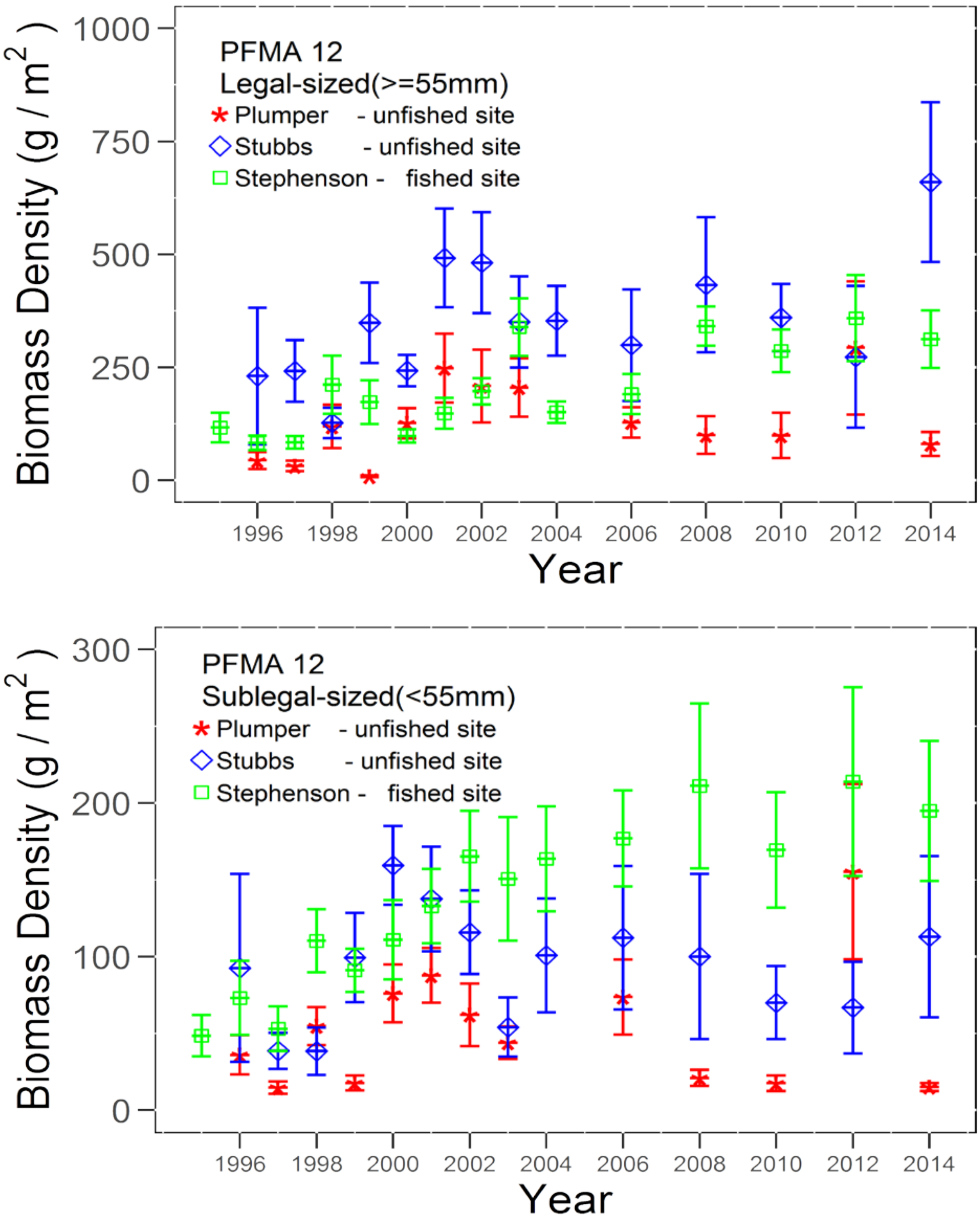

Figure 7. Mean biomass density (g/m2) ± standard error for legal (≥55 mm) (top) and sublegal (<55 mm) (bottom) Green Sea Urchins for the three sub-locations [Stephenson Islets (fished), Stubbs Island (unfished control) and Plumper Islands (unfished control)] in PFMA 12 dive surveys. Only 1 transect was completed at Plumper Island in 2004 so data are not shown.

Index sites in PFMA 12 are separated in three sub-locations: Stubbs Island, Plumper Islands and Stephenson Islets. Stubbs and Plumper Islands are in a year-round research closure, and therefore the four transects within each of those sub-locations act as unfished controls against the ten harvested transects at Stephenson Islets. In 2014, for both legal and sublegal sized urchins, biomass densities (g/m^2) went up at Stubbs Is. and down at Plumper Is., and remained relatively constant at Stephenson Islets (Figure 7) suggesting that factors other than fishing may be affecting biomass density trends.

With survey data from PFMA 19 now spanning 6 years, trends are becoming apparent. Both population and biomass densities of legal sized urchins dropped from 2008 to 2009 and since then have been increasing with the 2014 estimates near those of 2008 (Figure 8). Densities of sublegal urchins have been rising with 2014 population and biomass densities about 4 and 6 times, respectively, of those observed in 2008 (Figure 8). Mean TD has decreased from 59 mm in 2008 to 54 mm in 2014. The observed small increase in legal population density and larger increase in sublegal population density results in a greater ratio of sublegal to legals and translates to a lower mean TD.

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 is inferred by examining size distributions.

Percent immature (< 25mm TD) in PFMA 19 was 4.4%, 5.9% and 5.7% in 2010, 2012 and 2014, respectively. Percent immature in PFMA12 was 6.0%, 6.4% and 15.6% in 2010, 2012 and 2014, respectively. For PFMA 12 in 2014, the highest estimated mean density of immatures since 1995 (Figure 6), combined with the increase in percent immature from previous years, indicates that strong recruitment has occurred and/or could be attributed to reduced predation of immature urchins following the widespread mortality of sea stars along the Canadian Pacific Coast in 2013 (Hewson et al. 2014). In PFMA 12, size frequency distributions were similar for 2010 and 2012 (Figure 9). In PFMA 19, size frequency distributions were similar for 2010, 2012 and 2014 (Figure 10).

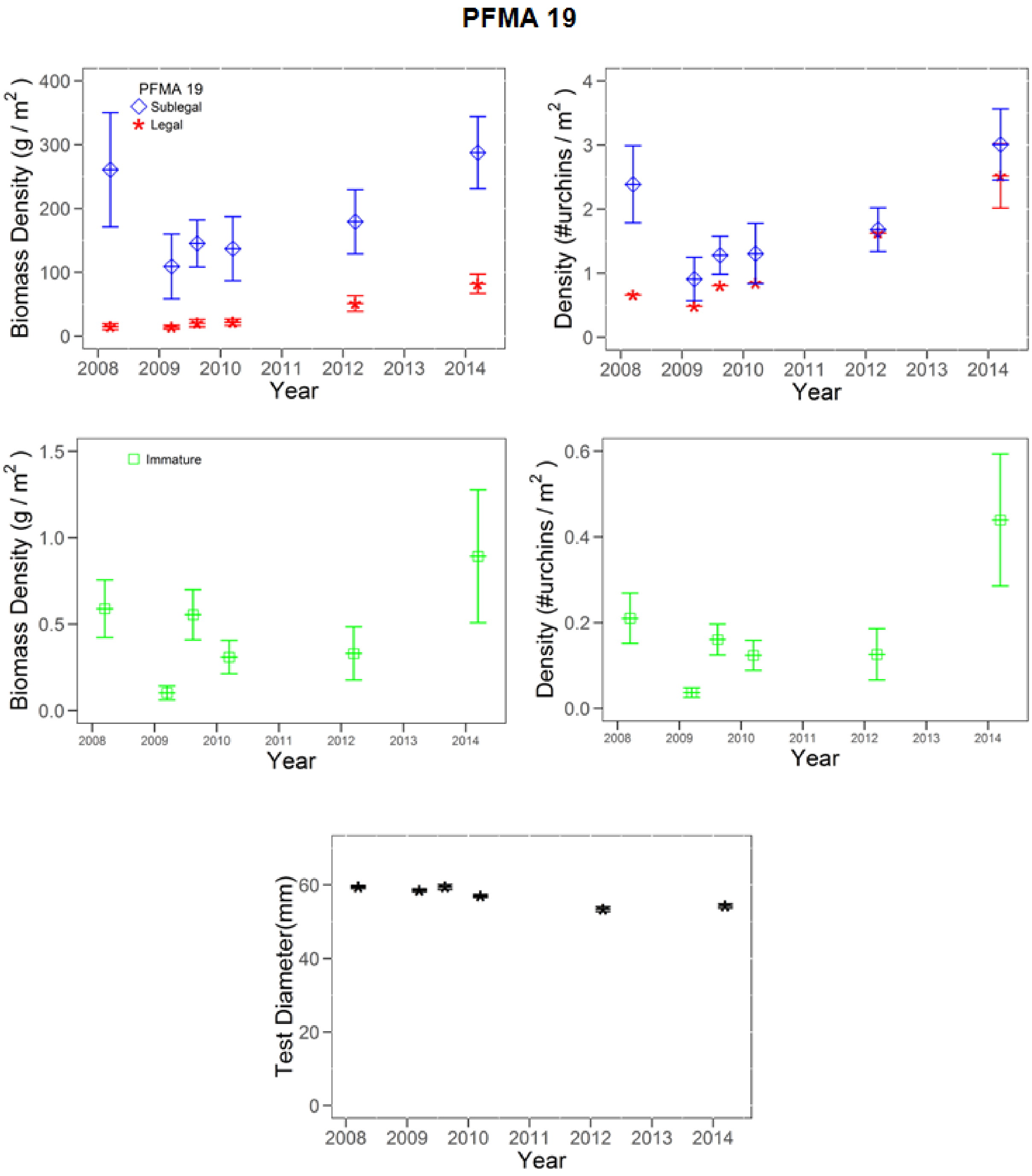

Figure 8. Means estimated for Green Sea Urchins from PFMA 19 (+/- one standard error). Biomass density (g/m^2) is shown on the left and population density (# urchins/m^2) is shown on the right. The top row shows estimated values for legal (≥55 mm) and sublegal (<55 mm, includes immature) urchins. The middle row shows estimated values for immature (<25 mm) urchins. The bottom plot shows the mean test diameter for all sizes. Estimates are made from data collected during fishery-independent dive surveys. In some cases, the standard errors are small and appear within the markers.

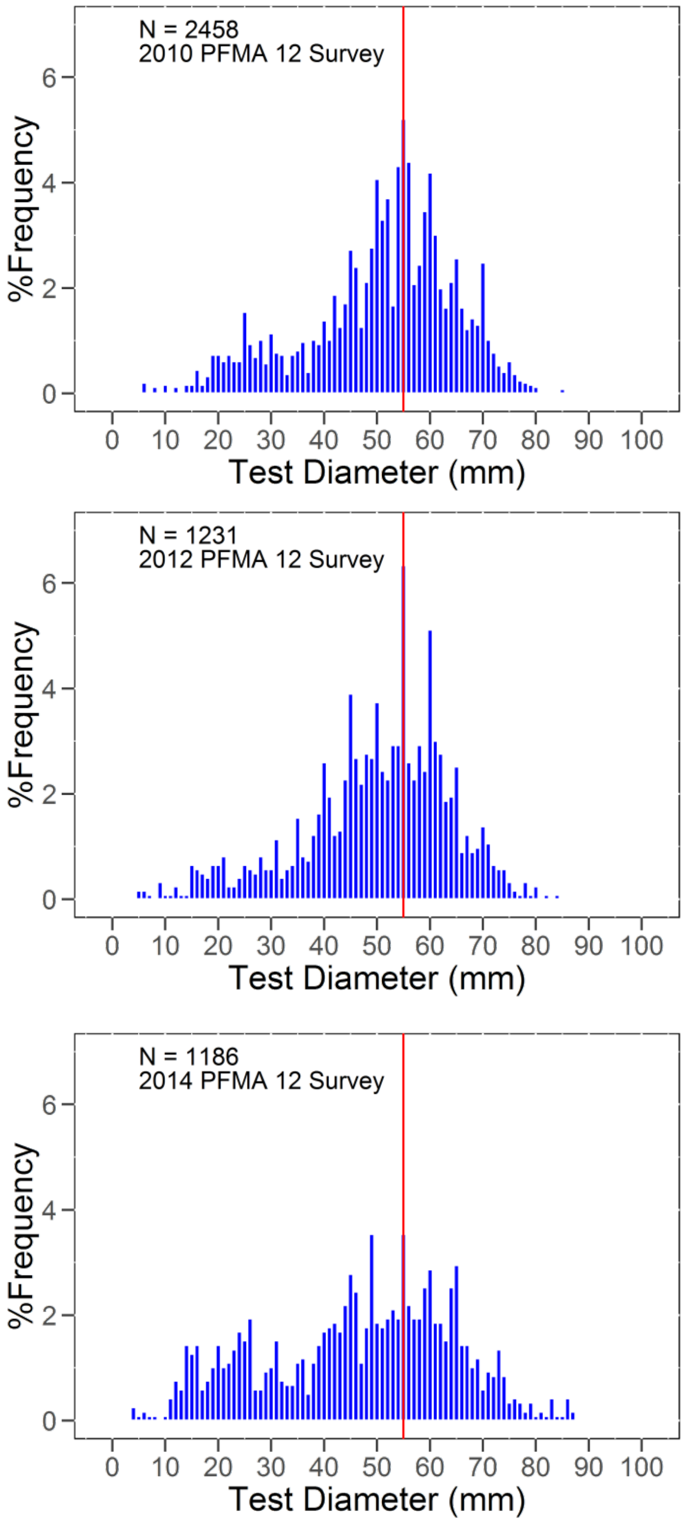

Figure 9. Size frequency distributions of Green Sea Urchin test diameters measured during the fall 2010 (top graph), 2012 (middle graph) and 2014 (bottom graph) surveys in PFMA 12. Red lines mark the minimum legal commercial harvest size of 55 mm.

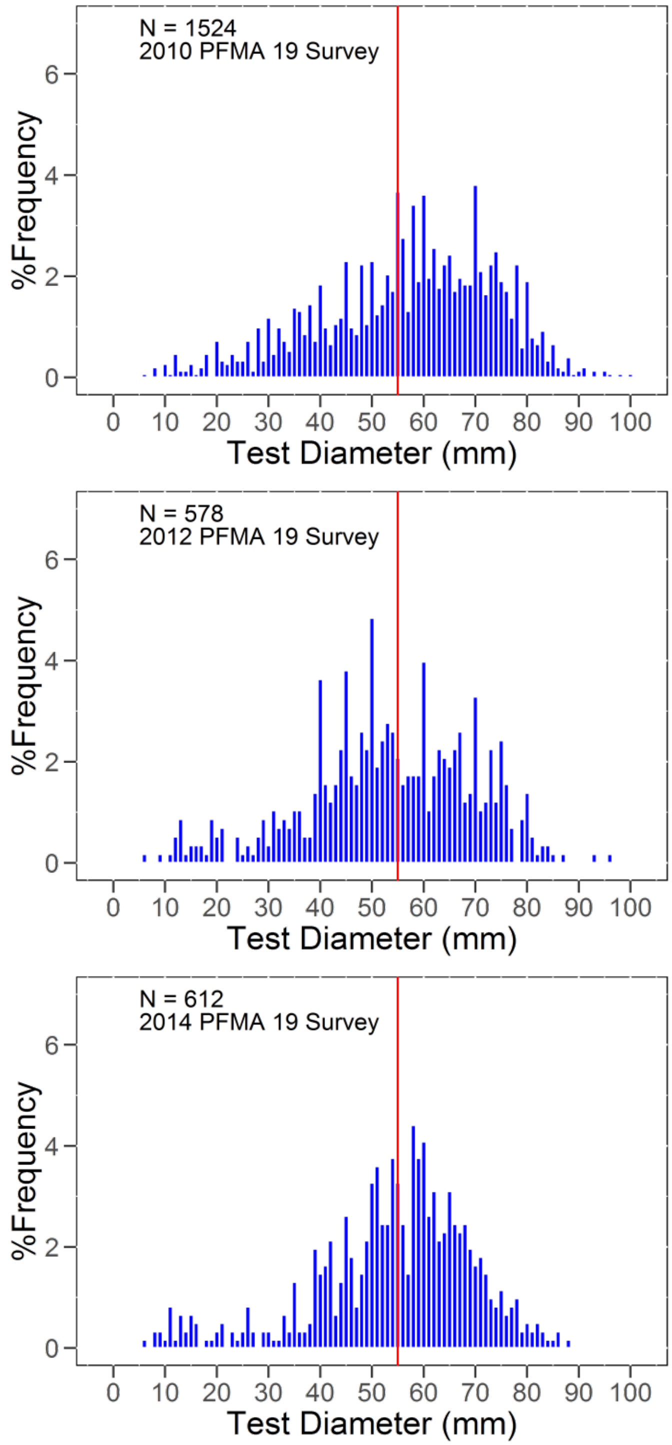

Figure 10. Size frequency distributions of Green Sea Urchin test diameters measured during the March 2010 (top graph), 2012 (middle graph) and 2014 (bottom graph) surveys in PFMA 19. Red lines mark the minimum legal commercial harvest size of 55 mm.

Harvest options

This assessment updates previously published time-series of data and provides new harvest options for the 2016/17 to 2018/19 Green Sea Urchin fishery, using the same Bayesian biomass dynamic model that has been used in the assessment of BC's Green Sea Urchin stock since 2003 (Perry et al. 2003, Zhang and Perry 2005, Perry et al. 2006, Waddell et. al. 2010, DFO 2014). Model inputs were described in DFO (2014) with separate runs for Northeast Vancouver Island and Southeast Vancouver Island, producing maximum sustainable yield (MSY) probability distributions for each region.

Traditionally, MSY values have been considered targets which management should try to achieve (Mace 2001). However, many of the assumptions of traditional surplus production models may be violated in a fishery such as the commercial Green Sea Urchin fishery (no change in gear efficiency, constant catchability in time, space and across ages, a linear relationship between CPUE and effort and equal availability of the fish to the fishery) (Zhang and Perry 2005). The present approach, adopted in 2003, is precautionary and defines values of MSY to be limit reference points (LRPs) which management actions should ensure are not exceeded. The target reference points (TRPs), to which management actions should aim, should be set sufficiently far from the LRP so that there is a low probability that the TRP is larger than the actual MSY.

The LRPs for each region are uncertain and could be any MSY as represented by the posterior probability distributions from the Bayesian model. The TRPs are defined as various reductions from the estimated median of the MSY posterior distribution, along with the probabilities that the TRPs may be larger than the true MSY (Table 1). For each region, the allocation of harvest options to each PFMA within the region is based on the proportion of aggregate landings from each PFMA from the 1995-96 to 2014-15 fishing seasons (Table 1).

The median MSY estimates have remained relatively stable in the last 6 years. The median MSY estimate for Northeast Vancouver Island is 302 t in the current assessment, close to the 298 t and 306 t estimates for 2010 and 2013, respectively. The median MSY estimate for Southeast Vancouver Island is 76 t, similar to both the 2010 and 2013 estimates of 78 t and 74 t, respectively.

Since the 2006-07 fishing season, fishery managers have 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. If the same commercial fishery quotas are used for the new IFMP, there would be a 2.5% probability for Northeast Vancouver Island and a 0.6% probability for Southeast Vancouver Island that the quotas are greater than or equal to the true MSY values.

Table 1. Target reference points (TRPs) in metric tonnes as reductions from the estimated median maximum sustainable yield (MSY), the % probability the target reference point (TRP) may be greater than or equal to the true MSY, and allocation of the total quota to each of the two fishing regions: (A) PFMAs 12 and 13 and (B) PFMAs 18 and 19.

A. PFMAs 12 and 13	Target reference points (TRPs) (tonnes)			% Probability TRP ≥ true MSY
	PFMAs 12 & 13	PFMA 12	PFMA 13	
Estimated median MSY	302.30	186.76	115.54	50.0
90% of median MSY	272.07	168.08	103.99	33.9
80% of median MSY	241.84	149.41	92.43	18.5
70% of median MSY	211.61	130.73	80.88	7.8
60% of median MSY	181.38	112.06	69.32	2.9
50% of median MSY	151.15	93.38	57.77	1.0

A. PFMAs 12 and 13	Target reference points (TRPs) (tonnes)			% Probability TRP ≥ true MSY
	PFMAs 12 & 13	PFMA 12	PFMA 13	
40% of median MSY	120.92	74.70	46.22	0.4
30% of median MSY	90.69	56.03	34.66	<0.1
20% of median MSY	60.46	37.35	23.11	<0.1
10% of median MSY	30.23	18.68	11.55	<<0.1

B. PFMAs 18 and 19	Target reference points (TRPs) (tonnes)			% Probability TRP ≥ true MSY
	PFMAs 18 & 19	PFMA 18	PFMA 19	
Estimated median MSY	75.90	27.90	48.00	50.0
90% of median MSY	68.31	25.11	43.20	36.4
80% of median MSY	60.72	22.32	38.40	24.7
70% of median MSY	53.13	19.53	33.60	15.1
60% of median MSY	45.54	16.74	28.80	8.9
50% of median MSY	37.95	13.95	24.00	4.8
40% of median MSY	30.36	11.16	19.20	1.9
30% of median MSY	22.77	8.37	14.40	0.4
20% of median MSY	15.18	5.58	9.60	<0.1
10% of median MSY	7.59	2.79	4.80	<<0.1

Sources of uncertainty

The uncertainties are generally related to the data and the simplifying assumptions necessary to develop mathematical and statistical models that are used to analyze the data.

As with virtually all quantitative analyses, model error contributes to uncertainty. The estimation of maximum sustainable yield is based on a productivity model which carries inherent uncertainties. The production model lumps growth, reproduction, and mortality into one production function, ignoring interactions and temporal effects of these processes. This model represents a simplified approximation of the population dynamics, lacking some realism when 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. Therefore, MSY thus calculated needs to be treated with some caution. Various quota options were provided with associated probability levels that an adopted quota would be larger than the estimated MSY. Fishery managers can therefore choose the level of risk considered tolerable in the management of the fishery.

An additional uncertainty relates to way quota is allocated between PFMAs within each region. The allocation of quota between PFMAs (within a region) is based on the proportion that each PFMA contributed to landings from 1995-96 to 2014-15. This method carries a risk that a potential historic overexploitation may be perpetuated or that some PFMAs may become more exploited than intended if the Green Sea Urchin distributions and abundance change among areas over time.

Conclusions

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 from the last three fishing seasons have been closer to the TAC, which has remained constant, indicating that market demand may be improving. Since 2002-03, fishery-dependent CPUE data have remained at levels equal to or higher than those observed at the onset of the fishery in 1987. In PFMA 12, population and biomass densities of both legal and sublegal sized Green Sea Urchins from the 2014 survey were similar to those of surveys since 2008, and were approximately triple what they were in 1995. In PFMA 19, population and biomass densities of legal urchins were near those observed in the first survey year of 2008, and estimates for sublegal urchins have been rising since 2008.

Advice

1. Harvest options developed using a Bayesian biomass dynamic model are provided in Table 1 for both Northeast Vancouver Island (PFMAs 12 & 13) and Southeast Vancouver Island (PFMAs 18 & 19). Maximum sustainable yield (MSY) is set as a limit reference point (LRP) and target reference points (TRPs) are set as reductions from the median MSY. The risks associated with the harvest options are defined in Table 1 as the probabilities that the TRPs are greater than the actual MSY (Table 1).
2. The PFMA 12 and PFMA 19 fishery-independent surveys should be continued, on a regular basis, to provide a time-series independent of the fishery for monitoring of Green Sea Urchin population trends.
3. The Green Sea Urchin survey program should be expanded to include index sites in all un-surveyed PFMAs open to commercial harvest (i.e. PFMA 13 and PFMA 18).

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Sources of Information

This Science Response Report results from the Science Response Process of April 6, 2016 on Stock Status Update and Quota Options for the Green Sea Urchin (*Strongylocentrotus droebachiensis*) Fishery in British Columbia, 2016-2019.

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