Survey Results of Green Sea Urchin (*Strongylocentrotus droebachiensis*) Populations in Haro Strait, British Columbia, March 2008, March and August 2009, and March 2010

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by

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ABSTRACT

Waddell, B. 2017. Survey results of Green Sea Urchin (*Strongylocentrotus droebachiensis*) populations in Haro Strait, British Columbia, October, March 2008, March and August 2009, and March 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3208: viii + 69 p.

This report presents the results of the initial four surveys of a continuing series of Green Sea Urchin (*Strongylocentrotus droebachiensis*) surveys, undertaken jointly between Fisheries and Oceans Canada (DFO) and industry (West Coast Green Urchin Association - WCGUA) in Haro Strait, British Columbia, between March 2008 and March 2010. These surveys are complementary to a similar continuing series of Green Sea Urchin surveys conducted in Queen Charlotte Strait, originating in October 1995. Data were collected by SCUBA divers using the transect-quadrat method, and include information on size and abundance of Green Sea Urchins, gonad weight and quality, and on the depth and substrate. The long-term objectives are to assess variability in Green Sea Urchin populations over time to monitor harvest impacts.

RÉSUMÉ

Waddell, B. 2017. Survey results of Green Sea Urchin (*Strongylocentrotus droebachiensis*) populations in Haro Strait, British Columbia, October, March 2008, March and August 2009, and March 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3208: viii + 69 p.

Le présent rapport décrit les résultats des quatre premiers de la série de relevés de l'oursin vert (*Strongylocentrotus droebachiensis*), menés conjointement par Pêches et Océans Canada (MPO) et l'industrie (West Coast Green Urchin Association [WCGUA]) dans le détroit de Haro, en Colombie-Britannique, entre mars 2008 et mars 2010. Ces relevés sont la suite d'une série similaire ininterrompue de relevés de l'oursin vert menés dans le détroit de la Reine-Charlotte depuis octobre 1995. Les données ont été recueillies par des plongeurs selon la méthode des transects et des quadrats, et comprennent des renseignements sur la taille et l'abondance des oursins verts, le poids et la qualité des gonades, ainsi que la profondeur et le substrat. Les objectifs à long terme sont d'évaluer la variabilité des populations d'oursins verts au fil du temps afin de surveiller les impacts de la récolte.

INTRODUCTION

Green Sea Urchins (*Strongylocentrotus droebachiensis*) have been commercially harvested in British Columbia (BC) by hand-picking by divers since 1987. The majority of the product is shipped live to the Asian market. Regulated by Fisheries and Oceans Canada (DFO), this fishery is currently managed using a minimum size limit (55 mm test diameter), limited entry licensing, seasonal restrictions (usually open to fishing commencing in September and ending in March or April, with occasional extended openings for small, local markets), restricting fishing areas, area quotas, and by an Individual Quota (IQ) system. As a condition of licence, fishers are required to complete harvest logbooks and charts and submit them to DFO. The logbooks contain information on the dates and locations where Green Sea Urchins were caught, divers' names, length of time spent fishing each day (i.e. effort), diving depths, and the total weight of urchins removed (i.e. catch; DFO 2016a). Logbooks continue to be a vital source of information for developing stock assessments for this species.

Up until late 1995, harvest logbooks and commercial sales slips, were the only sources of information available for use in Green Sea Urchin stock assessments and management decisions. Other vital data, such as information on sublegal-sized urchins, size frequencies of the whole population, urchin densities, roe quality and quantity, or habitat associations were unobtainable from the commercial data. Therefore fishery-independent Green Sea Urchin surveys were initiated in late 1995 to obtain this information. A cooperative arrangement between DFO, Industry and First Nations (KTFC, or Kwakiutl Territorial Fisheries Commission) was developed and a series of Green Sea Urchin surveys began in October, 1995 in Queen Charlotte Strait in Pacific Fishery Management Area (PFMA) 12 (Waddell et al. 1997, 2002, 2003; Waddell and Perry 2005, 2006, 2007, 2012).

The Green Sea Urchin commercial fishery currently occurs in two regions on the BC coast—the northeast coast of Vancouver Island (PFMAs 12 and 13), and the southeast coast of Vancouver Island (PFMAs 18 and 19). Although surveys continued in PFMA 12, it was recognized that fishery-independent surveys were needed for the southern region (southeast coast of Vancouver Island). Fulford Reef, a small but productive reef in Haro Strait near Victoria (PFMA 19; Figure 1) was selected for surveying, as at the time, it was targeted by the commercial fishery. For example, in both 2007/08 and 2008/09 fishing seasons, the majority of the PFMA 19 quota was removed from this one site (80% and 78%, respectively). A scientific survey protocol, similar to one used for the long time series in PFMA 12, was developed, and a new series of Green Sea Urchin surveys began in PFMA 19 in March 2008.

The long-term objective of the PFMA 19 Green Sea Urchin scientific survey is to monitor changes in Green Sea Urchin populations at a key commercial fishery location. To meet this objective, Green Sea Urchin densities, size measurements, and samples for gonad quantity and quality were obtained, at the same time each year. Data from these surveys have been previously used in stock assessments for this species, analyzed in a

broader context using sophisticated techniques (DFO 2014, 2016b; Lochead et al. 2015; Waddell et al. 2010). This report has a different purpose; it presents data from these surveys at a more detailed level for each survey site (Fulford Reef, and the Chain Islets separately, rather than combined), using simpler techniques, and computes total biomass at each of the survey sites. The report also includes commercially harvests for comparison.

METHODS

(a) SURVEY DESIGN

The PFMA 19 survey was designed by DFO, using the transect-quadrat method, similar to the PFMA 12 surveys (Waddell and Perry 2012). Site selection was made by DFO with input from the West Coast Green Urchin Association (WCGUA, fishing industry members). DFO organized, supervised and conducted the surveys. WCGUA boats and divers were hired through a Joint Project Agreement to work alongside DFO boats and divers.

(i) Location

We aimed to design a survey that included two nearby sites with consistently large quantities of legal-sized Green Sea Urchins; one that was open to commercial harvesting and fished regularly most years, and a second site that had not been previously harvested, either commercially or recreationally. The second site was to act as a control for monitoring population changes due to natural variations alone. Fulford Reef, located NNE of the Chatham Islands (48°26.75’ N, 123°14.40’ W; Figure 2) was selected to represent the site open to commercial fishing; six transects were assigned there. Unfortunately, no control site was established, as all nearby locations of Green Sea Urchins had previously been open to fishing. Nevertheless, the Chain Islets, a nearby location where an abundant number of legal-sized Green Sea Urchins were consistently present, was selected as a second survey site (i.e., a comparison site [not a control site]). It has been, and continues to be, open to commercial harvest, but with lower recent fishing effort. This site is located between Mayor Channel and Plumper Passage; (48°25.30’ N, 123°16.00’ W; Figure 3), and has four transects, including one at Lewis Reef, one at Caroline Reef and one at Virtue Rock.

(ii) Depth Range

Transect lines were randomly selected and drawn on the chart prior to arriving at the survey location. The lines were restricted to bottom depths between 0 and 10 m (33 ft) below Chart Datum (CD). This depth range was selected for two reasons: 1) charts have 10 m depth contours, making is easier to calculate the bottom area, and 2) for safety reasons, we avoided decompression dives. The surveys required divers to conduct many long dives over the course of each day. If they were surveying at deeper depths, they would have reached their dive time limits at an earlier time and introduced additional decompression concerns. Therefore, surveying at deeper depths would have taken longer and incurred further safety concerns. The divers would have likely got colder faster as well.

(iii) Survey Timing

Comparing results between two surveys, one just prior to the commencement of the commercial fishing season in the fall (September in PFMA 19), and the second immediately following the area closure (usually in early spring), as we did for the first three survey years in PFMA 12 (Waddell et al. 1997, 2002, 2003), was a good approach for examining changes in the local Green Sea Urchin populations over the course of the fishery's season. However, this was not possible for PFMA 19, as resources were insufficient for performing two surveys a year in one PFMA. In addition, an annual fall survey time series was already established in a different PFMA, which reduced the availability of resources (e.g. boats, divers and equipment) at this time of year. Therefore, the new annual survey time series in Haro Strait was initiated in the spring for PFMA 19 (March 2008), just following, or just prior to, the usual closure of the fishery in March. Surveys were repeated in March 2009 and March 2010 for seasonal consistency and comparison. In addition, a survey was conducted in August 2009, just prior to the commercial opening. This allowed us to observe both the changes in the Green Sea Urchin populations between the start and finish of one fishing season (August 2009 and March 2010), and between the end of one fishing season and the start of the next season (i.e. during the fishing closure between March 2009 and August 2009).

(iv) Sampling Pattern

To sample, a 1 m^2 aluminum quadrat was flipped along a transect line, and with each flip, one of three different procedures took place: (1) the quadrat was skipped (S), meaning no information was recorded; (2) the quadrat was counted (C), meaning that all urchins (Green, Red, and Purple) were counted and recorded by species; or (3) the quadrat was measured (M), meaning that the test diameter (TD) of each Green Sea Urchin was measured and recorded, while Red and Purple Sea Urchins were only counted. The transect lines at Fulford Reef were generally longer than transect lines in the Chain Islets (47 to 303 m versus 18 to 81 m, respectively), so the sampling patterns were slightly different. Depending on the survey, the sampling pattern at Fulford Reef was usually M-S-M-S-M, but was occasionally M-C-M-C-M or M-S-C-S-M all along the transect lines, whereas at Chain Islets, the sampling pattern was usually M-M-M-M-M (i.e. all quadrats were measured) or M-S-M-S-M, and occasionally M-C-M-C-M. Regardless of the pattern, at least every second quadrat was consistently measured or counted all along the transect line.

(b) DATA COLLECTION – FIELD AND LAB

These surveys were conducted co-operatively by DFO and the West Coast Green Urchin Association (WCGUA, fishing industry members) on March 3-5, 2008, March 8, 2009, August 27-28, 2009, and March 24-25, 2010. There were two dive teams (i.e. two boats), each with one industry and one DFO diver, one boat driver (industry or DFO), one dive tender (industry or DFO), and one observer/recorder (DFO) for each survey. Industry provided the vessels CFV '*Emma III*' and CFV '*CCC*', while DFO provided the '*Pallasi*' and the '*C68*'.

The transect positions were selected while planning the first survey with the WCGUA in 2008 and marked on a chart prior to arriving at the survey area. Fulford Reef is oval-shaped with three main centrally-located shallow areas that are not exposed during low tides (Figure 1), making the visual orientation of the transect lines from the water surface more difficult than orienting lines perpendicular to shore or a rocky outcropping, as in the PFMA 12 surveys. The objective was to run transect lines perpendicular to the depth contours, starting at 10.0 m (33 ft) below CD and continuing up to zero CD. As a result, the transect lines had to be run from the deep to the east and west sides of each of the reef's shallow areas in order to survey the full depth spectrum. Selection of the transect locations was done *a priori* (i.e. in the office and without reconnaissance dives), and are therefore considered randomly selected. Note that during the initial survey, the angles of the transect lines were slightly adjusted in the field for the divers to best physically manage the strong currents. In contrast, at the Chain Islets, all transect lines ran perpendicular to an island or rocky outcropping and were able to encompass all levels of the depth spectrum. Their locations were also selected in the office, without prior reconnaissance dives. Computer software ("Tides and Currents for Windows" [Nautical Software Inc. 1995]) was used to calculate the tide levels for every five minutes so that the depth to CD could be pre-determined before each dive commenced. A weighted (lead) line was laid from shallow to deep to mark the transect line, with surface marker buoys indicating both ends. Note the transect lines were not permanently marked/installed; lead line was temporarily laid down to mark the transect lines and, while effort was made to place transects in the same locale (using GPS), lines could not be repeated exactly in the same position for each survey.

Beginning at the deep end, divers descended to the starting depth (10 m below CD [i.e. 10 m + current tide height in meters]) on the lead line, placed a 1 m^2 aluminum quadrat on the substrate beside the lead line, and measured the TD (using aluminum urchin calipers) of all Green Sea Urchins within the quadrat. In addition, all Red (*Mesocentrotus franciscanus*) and Purple (*Strongylocentrotus purpuratus*) Sea Urchins were counted. All urchins were removed from the quadrat as they were being measured to avoid repeating measurements. An urchin was considered to be in a quadrat if one-half or more of its body was within the quadrat's boundaries. Sometimes Green Sea Urchins were under vegetation, rocks, or in crevices; all visible surfaces were explored in order to find all sea urchins. One diver completed the measuring while the other diver recorded the data on waterproof paper. In addition to TD measurements, the start time, depth (in feet), substrate and type of vegetation were also recorded for each quadrat. Then the quadrat frame was rolled over along the lead line in the direction of shallower depth and the procedure was repeated (or skipped or counted, depending on the sampling pattern), all along the full length of the transect to a depth of zero Chart Datum.

The surface personnel recorded the GPS position for both the start and finish of the transect lines, as well as the divers' start and finish times for each transect (for use in calculating tide height from CD), and the weather and water conditions.

Starting in the August 2009 survey, a Green Sea Urchin of each of three size classes ("small", "medium" and "large") was randomly collected along the transect lines

from each of three approximate depth intervals ("deep", "mid-depth" and "shallow" sections) of each transect during the surveys for later laboratory analyses. These nine Green Sea Urchins from each transect were measured for size (TD and test height) and whole wet weight, and then dissected to obtain roe quality information. In addition, another ten urchins were randomly collected along the transect line for size and weight information only (i.e. they were not dissected). These latter samples were all measured on the same day as they were collected, whereas all of the other urchins were measured and dissected on the day following collection. For each of the dissected urchins, the following data were recorded: TD; test height; total wet weight (whole weight); drained weight (cracked open, turned over and left to drain for a few minutes); gutted weight (drained, with stomach and contents removed, but gonads included); gonad weight; gonad colour; gonad texture; and sex. Gonad colour was given a qualitative rating code of 0 (unknown [i.e. lost during processing], or no gonad present), 1 (orange/yellow), 2 (yellow with other colours), 3 (brown/red) or 4 (very pale orange). Gonad texture was also given a qualitative rating code of 0 (unknown [i.e. lost], or no gonad present), 1 (firm), 2 (semi-firm), or 3 (flimsy).

All raw data collected from Green Sea Urchin fishery-independent surveys are stored in a database in DFO's Shellfish Data Unit at the Pacific Biological Station (PBS) in Nanaimo, BC, Canada.

(c) DATA ANALYSES

(i) Size Ranges

For most of the analyses in this report, the data have been separated into three different size classes: legal-sized (TD $\geq$ 55 mm); sublegal-mature (25 mm $\leq$ TD < 55 mm); and sublegal-immature (or immature; TD < 25 mm). The mature/immature size of 25 mm TD was approximated from the dissection roe quality and maturity data of previous studies (Waddell et al. 2002), in which 100% of Green Sea Urchins < 25 mm were immature (no gonad present) compared with 6% of urchins $\geq$ 25 mm being immature.

(ii) Data Adjustments

Occasionally divers started surveying deeper than the starting depth of 10 m below CD, or they continued surveying shallower than 0 m CD. Since the area estimates for Fulford Reef and the Chain Islets are based on the area between the 0 and 10 m isobaths, and Green Sea Urchins are usually sparse at depths greater than 10 m below CD, the divers' original field data were truncated to include only data collected between 0 and 10 m (33 ft) below CD for the overall density, total biomass, biomass density, and density by substrate calculations. The original (unadjusted) data were used for all other calculations presented in this report.

Urchins in some quadrats were only counted and not measured, depending on the sampling pattern chosen for a transect. These unmeasured (or "unknown") urchins were incorporated into the data analyses. The estimates of legal and sublegal urchins within the unmeasured urchins were calculated using the proportions of measured legal-sized and sublegal-sized urchins of all the measured urchins. These values were then added to

the number of measured legal-sized and sublegal-sized urchins to calculate the total numbers of each of these size classes. These adjustments of the data to include unmeasured urchins in the data analyses were made for many of the tables, including density by transect and site, density by depth range, and the biomass estimates.

Note that MS Excel spreadsheets are used for many of our calculations, and that each result from a sequence of calculations is not rounded off. Therefore, any minor differences between calculations and values shown in the tables are due to rounding errors.

(iii) Densities

Mean and total densities of Green Sea Urchins for each transect within each of the survey sites (Fulford Reef and Chain Islets) were calculated as described by Jamieson and Schwarz (1998) for a "complete cluster" sampling design. This type of survey design is suitable for Green Sea Urchins, as it is characterized by: (1) having non-independent quadrats within a transect (e.g. if one quadrat has a high number of urchins, then adjacent quadrats are likely to have high numbers as well); (2) having varying transect lengths among the transects; and (3) all urchins are counted within each transect. Quadrat counts may be quite variable within a transect (the cluster), but the pattern among clusters will be similar (Jamieson and Schwarz 1998). The appropriate calculation for the mean density (of a particular size class of urchins, $\overline{D}$) is:

(1) $$\overline{D} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} L_i}$$

and for the standard error of density is:

(2) $$SE(\overline{D}) = \sqrt{\frac{1}{\overline{L}^2}\frac{1}{n}\frac{\sum (U_i - L_i\overline{D})^2}{n-1}}$$

with n = the number of transects sampled in a particular site;

U_i = the total number of urchins of the appropriate size class in transect i, $i = 1,2,...,n$;

L_i = the total number of quadrats in transect i; and

$\overline{L}$ = $\frac{1}{n}\sum_{i=1}^{n} L_i$, the average area of the transects in the site.

Since the area of a quadrat is 1 m^2, L_i is also equal to the area of the transect.

In previous surveys in PFMA 12, all urchins were counted in every quadrat for each transect, thus satisfying the Jamieson and Schwarz (1998) third rule for a complete cluster sampling design. However, counting or measuring urchins in every quadrat in

transects on Fulford Reef in particular, was not feasible. This area has a gradual slope from the 0 to 10 m below CD depth zone, making the transect lines very long (up to 305 m), and would take an inordinate length of time for the divers to survey (count/measure) every quadrat. Divers would be faced with fatigue from fighting the strong currents on the reef, becoming excessively cold from increased time underwater, and at risk of approaching decompression dive time limits. There would also be logistic problems of requiring and supplying more dive tanks per transect line, and the survey taking more time than can be budgeted. Since Green Urchins have a "contagious" (non-independent) spatial distribution (i.e. if one quadrat has a high number of urchins, then adjacent quadrats are likely to have high numbers as well), sampling (by either measuring or counting) urchins evenly and consistently in every second quadrat along the transect lines (as indicated in the Methods, (a) Survey Design, (iii) Sampling Pattern section) will produce similar results as sampling in every transect (DFO 2014). Note though, that in calculating density using this sampling method, the L in Equations 1 and 2 is replaced with C, the total number of *measured and/or counted* quadrats in a transect, (noting that if a quadrat has been measured, there is a count as well) to make Equations 3 and 4:

(3) $$\overline{D} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} C_i}$$

and the standard error of density is:

(4) $$SE(\overline{D}) = \sqrt{\frac{1}{\overline{C}^2}\frac{1}{n}\frac{\sum (U_i - C_i\overline{D})^2}{n-1}}$$

with n = the number of transects sampled in a particular site;

U_i = the total number of urchins of the appropriate size class in transect i, $i = 1,2,...,n$;

C_i = the total number of *measured and/or counted* quadrats in transect i; and

$\overline{C}$ = $\frac{1}{n}\sum_{i=1}^{n} C_i$, the average area of the total number of *measured and/or counted quadrats* per transect in the site.

In the results that follow, standard errors have not been calculated for the individual transects since the transect has been defined as the (cluster) sample unit, and therefore the (n-1) term in the denominator of the equation for the standard error goes to zero. In the calculation of urchin densities by depth range and substrate type, however, the quadrats have been considered as the sampling unit, and distributed among the various depth and substrate categories. This reduces (but does not entirely eliminate) the problem of non-independence among adjacent quadrats. Therefore standard errors about the mean densities for these classifications have been calculated using standard

formulae (e.g. as found in Sokal and Rohlf (1981) and as implemented with MS Excel 2010).

(iv) Densities by Depth Range

When calculating densities of Green Sea Urchins by depth range, the actual depth below CD had to be determined for each quadrat, which depended on the continually changing tide height. The method for calculating this has changed slightly over the years. Initially, (Waddell et al. 1997, 2002, 2003), the mean tide height above CD over a transect was calculated and subtracted from all depth gauge readings for that transect. It was later considered that the tide could sometimes change significantly over the length of a dive, especially if it took a long time to survey a transect; the method was thus altered (Waddell and Perry 2005, 2006). First, the number of minutes spent at each tide height (rounded feet) above CD over the length of each transect was determined, using the "Tides and Currents for Windows" program (Nautical Software Inc. 1995) set for every one minute. Next the tide height above CD was calculated for each quadrat by proportioning the dive time over the whole transect according to the number of quadrats in each transect. Then the tide height above CD was subtracted from the depth gauge reading recorded for each quadrat, to give the approximate adjusted depth below CD. However, we further considered that some quadrats would take longer than others to survey, especially ones that had high densities of urchins, so the method was further modified (Waddell and Perry 2007). Instead of proportioning the number of quadrats over the dive time at each tide height, we calculated the mean number of urchins measured per minute, and how much time was spent at each tide height. The numbers of urchins were then calculated for each tide height. By utilizing MS Excel's 'Name Box' to quickly count number of urchins, we were able to estimate at which quadrat the tide height would have changed, and entered the appropriate tide height. The tide height above CD was subtracted from the depth gauge reading recorded for each quadrat, to give the approximate adjusted depth below CD. Note that the depth readings were initially recorded in feet and then converted to meters for the report because the divers' depth gauges measure in feet.

(v) Densities by Substrate Type

The three most abundant substrates were recorded for each quadrat in order of prominence, using a numeric code. However, in this report, the substrate analysis was only performed for the most dominant substrate per quadrat. Note that between the March 2008 and March 2009 surveys, the protocol for recording substrate codes used by the PBS Shellfish Data Unit changed. The numeric code "8", representing "shell" in 2008 was eliminated and replaced by two new codes, "9", representing "crushed shell" and "10", representing "whole shell". These changes are reflected in the tables and figures in this report.

(vi) Densities by Vegetation Type

A similar recording method was used for vegetation as for substrate (i.e. alpha-numeric codes). However, there are some problems associated with the vegetation data that make it difficult to interpret results (i.e. varying levels of identification and

classification of possibly the same species), therefore vegetation data are not presented in this report. However, these data are available from the PBS Shellfish Data Unit.

(vii) Mean Individual Urchin Weights

Green Sea Urchins were only collected from Fulford Reef and the Chain Islets for dissection and measurement purposes during the August 2009 and March 2010 surveys. In our past studies in PFMA 12, TD and total wet weight data collected in the laboratory were used to develop TD-weight regressions, which were then used to convert the individual TDs of Green Sea Urchins measured in the field to individual weights. However, considering the samples from PFMA 19 were collected during two different times of the year, and that many urchin samples collected in the March 2010 survey were already spawning, we felt these data were inadequate for developing correct TD-weight regressions for each of the two sites or for the sites combined (as previously done in the PFMA 12 reports). Gonad development would be different in August than in March, and there would be weight loss for both the gonad and total wet weights for those urchins in the spawning process. Therefore, these data are only presented in the dissection tables in this report, and not used for further analyses. Instead, we used the allometric formulae from the most recent DFO Science Response (DFO 2016b) for the TD to weight conversions:

$$\bar{W} = 0.001042 * TD^{2.728} * 1.013 \quad (5)$$

where $\bar{W}$ is the mean weight at size (in grams), and 1.013 is the random error factor (DFO 2016b). It was developed using lab measurements (n=3,706) from all DFO Green Sea Urchin surveys performed since 1995 on the coasts of Vancouver Island (PFMAs 12, 13, 18, 19 and 20), and was applied to all TD field measurements in the PFMA 19 surveys. The mean individual urchin weight ($\bar{W}_j$) was then calculated for each size class (j), within each survey. The standard error about the mean weight for each size class ($SE(\bar{W}_j)$) was determined by calculating the standard deviation of the mean weights and dividing by the square root of the sample size.

(viii) Mean Abundance:

The mean abundances (*N*; of each size class [at each site within each survey]) were calculated by multiplying the mean density ($\bar{D}$, as urchins per square meter) by the area (A; defined as the area of the sea bottom that lies between the 0.0 and 10.0 m [below CD] contour lines):

$$N_j = (\bar{D}_j)(A) \quad (6)$$

where $_j$ subscripts the three size classes. Area was determined for each survey site using ArcMap v. 9.2. It was assumed A was known without error, and errors in mean density and mean weight, and among size classes, were independent and random (throughout all equations). The approximate areas were 129,353 m^2 for Fulford Reef and 865,070 m^2 for the Chain Islets.

(ix) Mean Biomass Density:

The mean biomass density (BD , in grams per square meter) was calculated for each size category by multiplying the mean individual wet weight ($\overline{W}_j$, in grams per urchin) by the mean density:

(7) $$BD_j = (\overline{W}_j)(\overline{D}_j)$$

The standard error of the mean biomass density was calculated as:

(8) $$SE(BD_j) = \left[\sum_{j=1}^{3} \left[\left(\left(\frac{SE(W)_j}{\overline{W}_j} \right)^2 + \left(\frac{SE(D)_j}{\overline{D}_j} \right)^2 \right)^{\frac{1}{2}} (BD_j) \right]^2 \right]^{\frac{1}{2}}$$

(x) Total Biomass:

The total biomass (B_j) was calculated for each size class, within each survey site:

(9) $$B_j = \sum_{j=1}^{3} (\overline{W}_j)(\overline{D}_j)(A)$$

The standard error of the total biomass for a particular site, which includes the uncertainties in the mean weight by size category and mean density, was calculated as:

(10) $$SE(B_j) = \left[\sum_{j=1}^{3} \left[\left(\left(\frac{SE(W)_j}{\overline{W}_j} \right)^2 + \left(\frac{SE(D)_j}{\overline{D}_j} \right)^2 \right)^{\frac{1}{2}} (B_j) \right]^2 \right]^{\frac{1}{2}},$$

with symbols as previously defined, and assuming that the area (A, used within the calculation for B_j) is known without error. Again, further assumption is that the errors in mean density and mean weight, and among size classes, are independent and random.

(xi) Exploitation:

In order to determine the impact of commercial fishing on Green Sea Urchin stocks at Fulford Reef and the Chain Islets, we calculated exploitation by the fishing industry using the following equation:

(11) $$Expl = \frac{B_{landed}}{B_{pre-fishery}},$$

with standard error defined by:

(12) $$SE(Expl) = (Expl) \left[\left(\frac{SE(B_{landed})}{B_{landed}} \right)^2 + \left(\frac{SE(B_{pre-fishery})}{B_{pre-fishery}} \right)^2 \right]^{\frac{1}{2}}.$$

B_{landed} is the biomass removed from Fulford Reef or the Chain Islets by commercial fishing, with standard error $SE(B_{landed})$; $B_{pre-fishery}$ is the pre-fishery biomass (either Fulford Reef or the Chain Islets), with standard error $SE(B_{pre-fishery})$, defined here as either the total biomass or the biomass of legal-sized urchins at the start of the fishery, and *Expl* is the exploitation of green urchins (with standard error *SE(Expl)*), defined as a proportion of the pre-fishery biomass (either total or legal-sized only). The biomass removed by the fishery (B_{landed}) at Fulford Reef and the Chain Islets was determined by examining harvest logbook data, dockside validation records, and charts of fishing locations submitted with these records (stored in the DFO Shellfish Data Unit at PBS), and tabulating the total landings per survey location. The precise error of the dockside weight measurements for validation is unknown, but considered to be small, therefore $SE(B_{landed})$ was set at 1% of B_{landed}.

Canadian scientific data is reported using the metric system (e.g. grams, kilograms, tonnes, etc.), whereas Canadian fishery landings data are measured using the Imperial system (e.g. ounces, pounds, tons, etc.). To convert pounds to kilograms, pounds are multiplied by 0.4536, or to convert kilograms to pounds, kilograms are multiplied by 2.2046.

RESULTS

Fulford Reef proved difficult to survey due to its frequent strong currents and lack of good land detail upon which to line up and lay transect lines. Consequently, there was some transect alignment variation between surveys at this location.

(a) MARCH 2008 SURVEY

Six transect lines were surveyed at Fulford Reef (Table 1, Figure 2), and four transects were surveyed in the Chain Islets (Figure 3) during the March 3 – 5, 2008 survey. The weather was very windy, and seas were choppy.

(i) Fulford Reef

Number, Size and Weight: Green Sea Urchins were measured in 353 quadrats and counted in 115, for a total of 468 quadrats surveyed (a total of 1,218 urchins) at Fulford Reef (Table 2). After adjusting for unmeasured urchins, 75.5% were legal-sized, 13.7% were sublegal-mature-sized, and 10.8% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the March 2008 survey at Fulford Reef is shown in Figure 4a. Mean TDs and weights for measured urchins from Fulford Reef were 67.4 ± 0.3 mm and 105.9 ± 1.5 g for legal-sized urchins, 40.6 ± 0.9 mm and 28.8 ± 1.6 g for sublegal-mature urchins, and 15.8 ± 0.6 mm and 2.4 ± 0.2 g for sublegal-immature urchins (Table 3).

Density: After adjusting for the unmeasured urchins, the mean total, legal, sublegal-mature and sublegal-immature densities at Fulford Reef were 2.60 ± 0.80 urchins/m^2, 1.96 ± 0.71 urchins/m^2, 0.36 ± 0.11 urchins/m^2, and 0.28 ± 0.13 urchins/m^2,

respectively (Table 4). The highest total (5.91 urchins/m^2), legal (4.90 urchins/m^2), and sublegal-mature (0.82 urchins/m^2) densities occurred on Transect 5 (Table 4), while the highest densities of sublegal-immature (1.09 urchins/m^2) Green Sea Urchins were observed on Transect 3.

Depth: The highest mean total (5.34 ± 1.56 urchins/m^2) and legal-sized (3.90 urchins/m^2) Green Sea Urchin densities all occurred in the 1.8 to 3.0 m (6.0 to 10.0 ft) below CD depth range (65 quadrats; Table 5; Figure 5a), whereas the highest sublegal-sized density (2.14 urchins/m^2) occurred in the shallowest depth range (-1.2 to 0.0 m or -4.0 to 0.0 ft above CD, 11 quadrats). Densities generally decreased with depth.

Substrate: The most frequently surveyed substrate, creviced bedrock (341 quadrats), also had the highest total (3.39 ± 0.44 urchins/m^2), legal (1.48 urchins/m^2), sublegal (0.50 urchins/m^2) and unknown size densities (1.41 urchins/m^2; Table 6 and Figure 6a). No urchins were observed on sand or shell substrates.

(ii) Chain Islets

Number, Size and Weight: Green Sea Urchins were measured in 183 and counted in 15 quadrats, for a total of 198 quadrats surveyed (a total of 980 urchins) at the Chain Islets (Table 2). After adjusting for unmeasured urchins, 76.9% were legal-sized, 18.6% were sublegal-mature-sized, and 4.5% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the March 2008 survey at the Chain Islets is shown in Figure 7a. Mean TDs and weights for urchins from the Chain Islets were 67.9 ± 0.3 mm and 107.9 ± 1.3 g for legal-sized urchins, 42.3 ± 0.7 mm and 31.5 ± 1.2 g for sublegal-mature urchins, and 18.9 ± 0.9 mm and 3.7 ± 0.4 g for sublegal-immature urchins (Table 8).

Density: After adjusting for the unmeasured urchins, the mean total, legal, sublegal-mature and sublegal-immature densities at the Chain Islets were 4.95 ± 1.72 urchins/m^2, 3.81 ± 1.40 urchins/m^2, 0.92 ± 0.31 urchins/m^2, and 0.22 ± 0.12 urchins/m^2, respectively (Table 9). The highest total (9.63 urchins/m^2) and sublegal-mature (2.48 urchins/m^2) densities occurred on Transect 1CN (Table 9), while the highest densities of legal and sublegal-immature (6.77 and 0.61 urchins/m^2, respectively) Green Sea Urchins were observed on Transect 2CN.

Depth: The highest mean total (8.20 ± 1.59 urchins/m^2) and legal-sized (6.88 urchins/m^2) Green Sea Urchin densities occurred in the 1.8 to 3.0 m (6.0 to 10.0 ft) below CD depth range (44 quadrats; Table 10; Figure 8a), whereas the highest sublegal-sized density (2.05 urchins/m^2) occurred in deeper waters (7.9 to 9.1 m or 26.0 to 30.0 ft above CD, 11 quadrats).

Substrate: The most frequently surveyed substrate, creviced bedrock (174 quadrats), also had the highest total (5.53 ± 0.82 urchins/m^2), legal (3.70 urchins/m^2), sublegal (1.15 urchins/m^2) and unknown size densities (0.68 urchins/m^2; Table 11 and Figure 9a). No urchins were observed on cobble, sand or shell substrates. Pea gravel was not sampled.

(iii) Dissection Data

There no were samples collected for dissection purposes for this survey.

(iv) Abundance and Biomass Estimates

The mean total density at Fulford Reef in March 2008 (2.60 ± 0.80 urchins/m^2; Table 4) was extrapolated over the total area between zero and 10 m below CD (129,353 m^2), to estimate there were 336,649 ± 104,125 Green Sea Urchins of all sizes at this site (Table 7). This included 254,007 ± 91,482 legal-sized, 46,158 ± 13,707 sublegal-mature, and 36,208 ± 16,583 immature Green Sea Urchins. The total biomass density was 218.82 ± 74.97 g/m^2, of which 207.87 ± 74.91 g/m^2 was legal-sized urchins. Multiplying the individual weights (Table 3) with the abundances gave total biomasses of 26.9 ± 9.7 t, 1.3 ± 0.4 t, and 0.1 ± 0.04 t for legal-sized, sublegal-mature and sublegal-immature Green Sea Urchins at Fulford Reef in March 2008 (Table 7). The overall total biomass was 28.3 ± 9.7 t.

The mean total density at the Chain Islets in March 2008 (4.95 ± 1.72 urchins/m^2; Table 9) was extrapolated over the total area between zero and 10 m below CD (865,070 m^2) to determine there were 4,281,660 ± 1,490,999 Green Sea Urchins of all sizes at this site (Table 7). This included 3,294,256 ± 1,214,095 legal-sized, 795,165 ± 269,224 sublegal-mature, and 192,238 ± 107,503 immature Green Sea Urchins (Table 7). The total biomass density was 440.70 ± 151.83 g/m^2, of which 410.93 ± 151.51 g/m^2 was legal-sized urchins. The total biomass in the Chain Islets in March 2008 was 381.2 ± 131.3 t (Table 7). This was comprised of 355.5 ± 131.1 t of legal-sized urchins, 25.0 ± 8.5 t of sublegal-mature urchins, and 0.7 ± 0.4 t of sublegal-immature urchins.

(b) MARCH 2009 SURVEY

Six transect lines were surveyed at Fulford Reef (Table 1, Figure 2) on March 8, 2009. The weather was changeable throughout the day, with partially overcast skies and intermittent bright sun, and dark snow/rain clouds in the distance. It snowed heavily on March 9, 2009, causing a lack of visibility and forcing the Chain Islets portion of the survey to be cancelled.

(i) Fulford Reef

Number, Size and Weight: Green Sea Urchins were measured in all 442 quadrats surveyed (except for one partially measured quadrat) at Fulford Reef (a total of 613 urchins; Table 2). After adjusting for unmeasured urchins, 64.8% were legal-sized, 32.8% were sublegal-mature-sized, and 2.4% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the March 2009 survey at Fulford Reef is shown in Figure 4b. Mean TDs and weights for urchins from Fulford Reef were 70.2 ± 0.4 mm and 117.6 ± 1.7 g for legal-sized urchins, 42.3 ± 0.5 mm and 30.8 ± 0.9 g for sublegal-mature urchins, and 16.9 ± 1.3 mm and 2.8 ± 0.5 g for sublegal-immature urchins (Table 3).

Density: After adjusting for the unmeasured urchins, the mean total, legal, sublegal-mature and sublegal-immature densities at Fulford Reef were 1.39 ± 0.39 urchins/m^2, 0.90 ± 0.29 urchins/m^2, 0.45 ± 0.09 urchins/m^2, and 0.03 ± 0.01 urchins/m^2,

respectively (Table 4). The highest total (2.98 urchins/m^2), legal (1.91 urchins/m^2), and sublegal-mature (1.06 urchins/m^2) densities occurred on Transect 5 (Table 4), while the highest densities of sublegal-immature (0.08 urchins/m^2) Green Sea Urchins were observed on Transect 3.

Depth: The highest mean total (4.84 ± 2.37 urchins/m^2) and legal-sized (3.60 urchins/m^2) Green Sea Urchin densities occurred in the 1.8 to 3.0 m (6.0 to 10.0 ft) below CD depth range (50 quadrats; Table 12; Figure 5b), whereas the highest sublegal-sized density (2.00 urchins/m^2) occurred in the shallowest depth range (-1.2 to 0.0 m or -4.0 to 0.0 ft above CD, 7 quadrats).

Substrate: Smooth bedrock and creviced bedrock were the most frequently surveyed substrates (141 and 127 quadrats, respectively), and had the highest total (1.99 ± 0.87 and 2.02 ± 0.55 urchins/m^2), legal (1.44 and 1.17 urchins/m^2) and sublegal-sized densities (0.55 and 0.64 urchins/m^2urchins; Table 13 and Figure 6b). No urchins were observed on crushed shell, and mud was not sampled.

(ii) Chain Islets

The Chain Islets portion of the survey was cancelled due to snow.

(iii) Dissection Data

There no were samples collected for dissection purposes for this survey.

(iv) Abundance and Biomass Estimates

The mean total density at Fulford Reef in March 2009 (1.39 ± 0.39 urchins/m^2;Table 4) was extrapolated over the total area between zero and 10 m below CD to estimate there were 179,397 ± 49,962 Green Sea Urchins of all sizes at this site (Table 14). This included 116,476 ± 38,116 legal-sized, 58,823 ± 14,554 sublegal-mature, and 4,390 ± 1,614 immature Green Sea Urchins. The total biomass density was 119.97 ± 34.84 g/m^2, of which 105.87 ± 34.67 g/m^2 was legal-sized urchins. Multiplying the individual weights with the abundances gave total biomasses of 13.7 ± 4.5 t, 1.8 ± 0.5 t, and 0.01 ± 0.005 t for legal-sized, sublegal-mature and sublegal-immature Green Sea Urchins at Fulford Reef in March 2009 (Table 14). The overall total biomass was 15.5 ± 4.5 t.

(c) AUGUST 2009 SURVEY

Six transect lines were surveyed at Fulford Reef (Table 1, Figure 2) on August 27 and 28, 2009, and three transects were surveyed at the Chain Islets (Figure 3) on August 28, 2009 (the fourth transect was not surveyed due to lack of time). The first day was sunny and warm, with a 3 knot wind and calm water, and the second day had high overcast skies and calm water in the morning, and light ripple in the afternoon.

(i) Fulford Reef

Number, Size and Weight: Green Sea Urchins were measured in 591 and counted in 123 quadrats, for a total of 714 quadrats surveyed (a total of 1,161 urchins) at

Fulford Reef (Table 2). After adjusting for unmeasured urchins, 55.6% were legal-sized, 35.7% were sublegal-mature-sized, and 8.7% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the August 2009 survey at Fulford Reef is shown in Figure 4c. Mean TDs and weights for urchins from Fulford Reef were 69.4 ± 0.3 mm and 115.0 ± 1.5 g for legal-sized urchins, 41.9 ± 0.5 mm and 30.9 ± 0.8 g for sublegal-mature urchins, and 19.1 ± 0.5 mm and 3.7 ± 0.2 g for sublegal-immature urchins (Table 3).

Density: After adjusting for the unmeasured urchins, the mean total, legal, sublegal-mature and sublegal-immature densities at Fulford Reef were 1.63 ± 0.48 urchins/m^2, 0.90 ± 0.31 urchins/m^2, 0.58 ± 0.17 urchins/m^2, and 0.14 ± 0.03 urchins/m^2, respectively (Table 4). The highest total (3.96 urchins/m^2), legal (2.30 urchins/m^2), sublegal-mature (1.39 urchins/m^2), and sublegal-immature (0.27 urchins/m^2) densities all occurred on Transect 5 (Table 4).

Depth: The highest mean total (3.30 ± 1.82 urchins/m^2), legal-sized (1.85 urchins/m^2), and sublegal (1.45 urchins/m^2) Green Sea Urchin densities all occurred in the 0.3 to 1.5 m (1.0 to 5.0 ft) below CD depth range (33 quadrats; Table 15; Figure 5c).

Substrate: Although creviced bedrock was the most frequently surveyed substrate (489 quadrats), the boulder substrate (99 quadrats) had the highest total (3.91 ± 1.46 urchins/m^2), legal (2.07 urchins/m^2) and sublegal-sized (1.81 urchins/m^2) Green Sea Urchin densities (Table 16 and Figure 6c). No urchins were observed on substrates of pea gravel, mud and whole shell, although these substrates were sampled infrequently.

(ii) Chain Islets

Number, Size and Weight: Green Sea Urchins were measured in all 130 quadrats surveyed in the Chain Islets (Table 2). Of the total 622 Green Sea Urchins sampled, 75.6% were legal-sized, 20.7% were sublegal-mature-sized, and 3.7% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the August 2009 survey in the Chain Islets is shown in Figure 7b. Mean TDs and weights for urchins from the Chain Islets were 71.1 ± 0.4 mm and 123.4 ± 0.1.9 g for legal-sized urchins, 43.5 ± 0.7 mm and 33.9 ± 1.3 g for sublegal-mature urchins, and 18.2 ± 0.9 mm and 3.3 ± 0.3 g for sublegal-immature urchins (Table 8).

Density: The mean total, legal, sublegal-mature and sublegal-immature densities at Chain Islets in August 2009 were 4.78 ± 1.00 urchins/m^2, 3.62 ± 0.41 urchins/m^2, 0.99 ± 0.61 urchins/m^2, and 0.18 ± 0.14 urchins/m^2, respectively (Table 9). The highest total (9.65 urchins/m^2), legal (5.53 urchins/m^2), sublegal-mature (3.59 urchins/m^2), and sublegal-immature (0.53 urchins/m^2) densities all occurred on Transect 1CN (Table 9).

Depth: The highest mean total (8.24 ± 3.06 urchins/m^2) and legal-sized (6.76 urchins/m^2) Green Sea Urchin densities occurred in the 4.9 to 6.1 m (16.0 to 20.0 ft) below CD depth range (21 quadrats; Table 17; Figure 8b). The highest sublegal (1.80 urchins/m^2) density occurred slightly shallower in the 3.3 to 4.8 m (11.0 to 15.0 ft) below CD depth range.

Substrate: Although creviced bedrock was the most frequently surveyed substrate (80 quadrats), the cobble substrate (7 quadrats) had the highest total (10.57 ± 5.45 urchins/m^2), legal (8.71 urchins/m^2) and sublegal-sized (1.86 urchins/m^2) Green Sea Urchin densities (Table 18 and Figure 9b). No urchins were observed on substrates of sand or crushed shell, but these substrates were sampled infrequently. Gravel and whole shell substrates were not sampled.

(iii) Dissection Data

Complete lab measurements (from dissections) were taken from 74 Green Sea Urchins randomly collected from both locations (see sample size 2 in

Table 19), and an additional 9 Green Sea Urchins were measured for test height, TD and total wet weight only (see sample size 1 in

Table 19).

Legal-sized Green Sea Urchins randomly selected from Fulford Reef (n=25) and the Chain Islets (n=14) had similar measurements, with mean test heights of 39.5 ± 1.5 mm and 38.7 ± 1.3 mm, mean TDs of 72.2 ± 2.2 mm and 73.0 ± 2.9 mm, and mean wet weights of 125.0 ± 10.7 g and 131.7 ± 13.8 g, respectively (

Table 19). Mean stomach weights and gonad weights were also similar for legal-sized urchins from Fulford Reef (18.7 ± 2.3 g and 16.2 ± 1.6 g, respectively) and the Chain Islets (22.2 ± 2.3 g and 14.6 ± 2.0 g).

Note it was difficult to determine sex in this survey, most likely because the roe was not ripe in August in many of the urchins. Usually Green Sea Urchins are harvested in the fall and winter, as this is when the gonads are large and the roe is in best condition. Roe quality is measured by both colour and texture; the highest quality roe has a bright orange/yellow colour and a firm texture. During the August 2009 survey, the percentage of highest roe quality (both colour and texture = 1, the highest grade) for legal and sublegal-sized urchins was 27.3% and 25.0%, respectively, at Fulford Reef (Table 20), and 14.3% and 10.0%, respectively, at the Chain Islets.

The mean percent roe recovery rate (the total gonad weight of all grades combined, divided by the total drained weight of all urchins sampled, multiplied by 100%) is usually highest in the late winter to early spring, just before spawning occurs. In August 2009 in PFMA 19, the mean percent roe recovery rate for legal-sized Green Sea Urchins was 18.9% at Fulford Reef and 16.6% at the Chain Islets (Table 20).

Since August is not considered the prime time for harvesting, and no other dissection data have been collected for this time period in other studies in BC, we decided not to perform regression analyses on the data to develop TD-weight or TD-gonad weight relationships for this survey. Instead, we applied the allometric formulae from the most recent DFO Green Sea Urchin Science Response (DFO 2016b) to convert the field-measured TDs to obtain individual weights. However, a regression analysis was performed to develop allometric formulae for the TD-height relationship, as this relationship is not affected by the seasonally-changing gonad weights. Results were

similar for both linear and power (a non-linear) regressions in terms of the regression line produced and the coefficient of determination R^2 calculated, but since R^2 is not a reliable measure of goodness-of-fit for non-linear regressions (Spiess and Neumeyer 2010), we decided to use a linear regression with a zero intercept. TD-height regressions for the August 2009 survey are shown in Figure 10, and Figure 11a and 11b (see figures for equations).

(iv) Abundance and Biomass Estimates

The mean total density at Fulford Reef in August 2009 (1.63 ± 0.48 urchins/m^2; Table 4) was extrapolated over the total area between zero and 10 m below CD to determine there were 210,335 ± 62,347 Green Sea Urchins of all size at this site (Table 21). This included 116,853 ± 40,663 legal-sized, 75,184 ± 22,470 sublegal-mature, and 18,298 ± 3,677 immature Green Sea Urchins. The total biomass density was 112.34 ± 36.56 g/m^2, of which 103.88 ± 36.16 g/m^2 was legal-sized urchins. Multiplying the individual weights with the abundances gave total biomasses of 13.4 ± 4.7 t, 2.3 ± 0.7 t, and 0.1 ± 0.01 t for legal-sized, sublegal-mature and sublegal-immature Green Sea Urchins at Fulford Reef in August 2009 (Table 21). The overall biomass was 15.8 ± 4.7 t.

The mean total density at the Chain Islets in August 2009 (4.78 ± 1.00 urchins/m^2; Table 9) was extrapolated over the total area between zero and 10 m below CD to determine there were 4,139,027 ± 863,935 Green Sea Urchins of all sizes at this site (Table 21). This included 3,127,561 ± 354,947 legal-sized, 858,416 ± 528,341 sublegal-mature, and 153,051 ± 123,097 sublegal-immature Green Sea Urchins. The total biomass density was 480.47 ± 54.83 g/m^2, of which 446.28 ± 50.76 g/m^2 was legal-sized urchins. Multiplying the individual weights with the abundances gave total biomasses of 386.1 ± 43.9 t of legal-sized urchins, 29.1 ± 17.9 t of sublegal-mature urchins, and 0.5 ± 0.4 t of sublegal-immature Green Sea Urchins at the Chain Islets in August 2009 (Table 21). The overall biomass was 415.6 ± 47.4 t.

(d) MARCH 2010 SURVEY

Six transect lines were surveyed at Fulford Reef (Table 1, Figure 2) and three transects were surveyed in the Chain Islets (Figure 3) during the March 24 - 25, 2010 survey (the fourth transect at Chain Islets was not surveyed due to strong, increasing tidal current). The first day was sunny with a light haze and a 12 knot wind, and the waters were choppy. On the second day there was light rain with no wind, and the water was calm.

(i) Fulford Reef

Number, Size and Weight: Green Sea Urchins were measured in all 587 quadrats surveyed at Fulford Reef (Table 2). Of the total 995 Green Sea Urchins sampled, 54.6% were legal-sized, 39.7% were sublegal-mature-sized, and 5.7% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the March 2010 survey at Fulford Reef is shown in Figure 4d. Mean TDs and weights for urchins from Fulford Reef were 67.8 ± 0.4 mm and 108.5 ± 1.7 g for legal-sized urchins, 41.7 ± 0.4 mm and 30.2 ±

0.7 g for sublegal-mature urchins, and 16.8 ± 0.7 mm and 2.8 ± 0.2 g for sublegal-immature urchins (Table 3).

Density: The mean total, legal, sublegal-mature and sublegal-immature densities at Fulford Reef in March 2010 were 1.69 ± 0.45 urchins/m^2, 0.92 ± 0.28 urchins/m^2, 0.67 ± 0.17 urchins/m^2, and 0.10 ± 0.02 urchins/m^2, respectively (Table 4). The highest total (3.05 urchins/m^2), legal (1.90 urchins/m^2), and sublegal-immature (0.16 urchins/m^2) densities all occurred on Transect 6 (Table 4), while the highest densities of sublegal-mature (1.08 urchins/m^2) Green Sea Urchins were observed on Transect 2.

Depth: The highest mean total (6.63 ± 3.53 urchins/m^2), legal-sized (4.50 urchins/m^2), and sublegal (2.13 urchins/m^2) Green Sea Urchin densities all occurred in the 0.3 to 1.5 m (1.0 to 5.0 ft) below CD depth range (16 quadrats; Table 22; Figure 5d).

Substrate: Creviced bedrock was the most frequently surveyed substrate (228 quadrats) and had the highest total (2.40 ± 0.42 urchins/m^2), legal (1.30 urchins/m^2) and sublegal-sized (1.10 urchins/m^2) Green Sea Urchin densities (

Table 23 and Figure 6d). No urchins were observed on substrates of pea gravel, sand, and crushed shell. Mud was not sampled for Green Sea Urchins during this survey.

(ii) Chain Islets

Number, Size and Weight: Green Sea Urchins were measured in 158 quadrats and counted in 13, for a total of 171 quadrats surveyed (a total of 760 urchins) at the Chain Islets (Table 2). After adjusting for unmeasured urchins, 76.1% were legal-sized, 22.2% were sublegal-mature-sized, and 1.7% were sublegal-immature-sized urchins (Table 2). The size frequency distribution for the March 2010 survey at the Chain Islets is shown in Figure 7c. Mean TDs and weights for urchins from the Chain Islets were 67.8 ± 0.5 mm and 109.1 ± 2.1 g for legal-sized urchins, 44.8 ± 0.7 mm and 35.8 ± 1.3 g for sublegal-mature urchins, and 20.9 ± 1.1 mm and 4.5 ± 0.5 g for sublegal-immature urchins (Table 8).

Density: The mean total, legal, sublegal-mature and sublegal-immature densities at Chain Islets in March 2010 were 4.44 ± 3.60 urchins/m^2, 3.38 ± 2.83 urchins/m^2, 0.99 ± 0.74 urchins/m^2, and 0.08 ± 0.05 urchins/m^2, respectively (Table 9). The highest total (8.95 urchins/m^2), legal (7.01 urchins/m^2), sublegal-mature (1.81 urchins/m^2), and sublegal-immature (0.13 urchins/m^2) densities all occurred on Transect 3CN (Table 9).

Depth: The highest mean total (13.91 ± 2.78 urchins/m^2) and legal-sized (9.74 urchins/m^2) Green Sea Urchin densities occurred in the 1.8 to 3.0 m (6.0 to 10.0 ft) below CD depth range (23 quadrats; Table 24; Figure 8c). The highest sublegal (4.38 urchins/m^2) density occurred slightly shallower in the 0.3 to 1.5 m (1.0 to 5.0 ft) below CD depth range.

Substrate: Crushed shell had the highest total (16.33 ± 8.57 urchins/m^2), legal (7.33 urchins/m^2), sublegal-sized (2.33 urchins/m^2) and urchins of unknown size (6.67 urchins/m^2) densities (Table 25 and Figure 9c), but note only three quadrats of this substrate were sampled. Although smooth bedrock was the most frequently surveyed (78 quadrats), no Green Sea Urchins were observed on this substrate. Cobble, pea gravel, sand and mud substrates were not sampled.

(iii) Dissection Data

Complete lab measurements (from dissections) were taken from 58 Green Sea Urchins randomly collected from both locations (see sample size 2 in Table 26), and an additional 83 Green Sea Urchins were measured for test height, TD and total wet weight only (see sample size 1 in Table 26). These additional measurements were taken in order to calculate a more accurate TD/wet weight relationship (i.e., by providing a larger sample size) without spending an inordinate amount of time with the other measurements.

Legal-sized Green Sea Urchins randomly selected from Fulford Reef (n=60) and the Chain Islets (n=20) had similar measurements, with mean test heights of 37.0 ± 0.7 mm and 38.9 ± 1.2 mm, mean TDs of 66.4 ± 1.2 mm and 67.0 ± 1.7 mm, and mean wet weights of 100.5 ± 5.5 g and 98.3 ± 7.8 g, respectively (Table 26). Mean stomach weights and gonad weights for legal-sized urchins at Fulford Reef (n=19) were 14.1 ± 1.0 g and 16.9 ± 2.2 g, respectively (Table 26). The sample size of dissected legal-sized urchins at the Chain Islets was very small (n=3). It should also be noted that many of the Green Sea Urchins that were collected for measurements and dissection in this survey began spawning shortly after collection, so the various weight measurements should not be considered very representative. Because of this, we decided not to perform regression analyses on these data to develop TD-weight or TD-gonad weight relationships for this survey. Instead, we again used the allometric formulae from the most recent DFO Green Sea Urchin Science Response (DFO 2016b) to convert the field-measured TDs to obtain individual weights.

Spawning does not affect the TD-height relationship, so allometric formulae were developed for the March 2010 survey, using linear regressions within Excel (Figure 12, and Figure 13a and 13b; see figures for equations).

Data showing the percentage of highest roe quality and the mean percent roe recovery rate at Fulford Reef and the Chain Islets during the March 2010 survey are presented in Table 20. However, spawning had obviously occurred in many of the sampled urchins, so these data are somewhat meaningless.

(iv) Abundance and Biomass Estimates

The mean total density at Fulford Reef in March 2010 (1.69 ± 0.45 urchins/m^2; Table 4) was extrapolated over the total area between zero and 10 m below CD to determine there were 219,261 ± 58,766 Green Sea Urchins of all sizes at this site (Table 27). This included 119,657 ± 36,323 legal-sized, 87,043 ± 22,080 sublegal-mature and 12,561 ± 2,468 immature Green Sea Urchins. The total biomass density was 121.00 ±

30.93 g/m^2, of which 100.39 ± 30.50 g/m^2 was legal-sized urchins. Multiplying the individual weights with the abundances gave total biomasses of 13.0 ± 3.9 t, 2.6 ± 0.7 t, and 0.04 ± 0.01 t for legal-sized, sublegal-mature and sublegal-immature Green Sea Urchins at Fulford Reef in March 2010 (Table 27). The overall total biomass was 15.7 ± 4.0 t.

The mean total density at the Chain Islets in March 2010 (4.44 ± 3.60 urchins/m^2; Table 9) was extrapolated over the total area between zero and 10 m below CD to determine there were 3,844,756 ± 3,116,929 Green Sea Urchins of all sizes at this site (Table 27). This included 2,924,038 ± 2,445,184 legal-sized, 854,952 ± 639,892 sublegal-mature, and 65,766 ± 46,901 immature Green Sea Urchins. The total biomass density was 404.42 ± 309.58 g/m^2, of which 368.68 ± 308.44 g/m^2 was legal-sized urchins. The total biomass in the Chain Islets in March 2010 was 349.9 ± 267.8 t (Table 27). This was comprised of 318.9 ± 266.8 t of legal-sized urchins, 30.6 ± 23.0 t of sublegal-mature urchins, and 0.3 ± 0.2 t of sublegal-immature urchins.

(e) THE FISHERY

The BC commercial Green Sea Urchin fishery began in 1987. As it developed over the years, there have been many management restrictions implemented in order to regulate this fishery (e.g. Perry et al. 2002, DFO 2016a). These include restrictions in the number of licenses and in harvesting techniques (hand-picking by divers only), a minimum size limit of 55 mm, management area closures, area quotas, Individual Quotas (IQs), and specific fishing seasons. PFMAs 12, 13, 18, and 19 were open to Green Sea Urchin commercial fishing over the course of these four surveys. Historically, the Green Sea Urchin fishing season generally started around November 1-15 and ended approximately March 15 (depending on roe condition). However, in PFMA 19 (where this study occurs) in 2009, the fishery began (and continued) opening in early September. During all fishing seasons 2007/08 to 2009/10, the annual quota allowed for PFMA 19 was 26,450 lbs (12 t; DFO 2006, 2008, 2009).

At the time of the fishery-independent surveys, there was a continual oversupply of Russian Green Sea Urchins on the Japanese market which caused the global price of Green Sea Urchins to drop dramatically. Japanese buyers were not as interested in buying BC Green Sea Urchins because they had an ample supply from Russia, for a lower price. As a result of this lowered demand, only a portion of the Total Allowable Catch (TAC) for Green Sea Urchins was harvested for several years. Starting in about the 2000/01 fishing season, market forces were largely responsible for underachieving the TAC, and was not reflective of stock status (DFO 2016b). The low point was in 2006/07, when only 10.9% of the TAC was achieved for the whole BC Green Sea Urchin fishery. During the 2007/08, 2008/09 and 2009/10 fishing seasons (when our fishery-independent surveys took place), only 32.1%, 36.0% and 50.0% of the BC TACs were harvested, respectively (DFO 2010).

Despite the fishery achieving a low overall percentage of the TAC available for BC, the fishery did achieve almost the entire quota for PFMA 19. In the 2007/08, 2008/09 and

2009/10 fishing seasons, 100%, 98% and 90% of PFMA 19's quotas were achieved, respectively (Table 28). The 2008/09 PFMA 19 quota was achieved in the first 26 days of the season (Table 29), and 80% and 78% of the PFMA 19 quota were harvested from Fulford Reef in 2007/08 and 2008/09, respectively. Twenty percent of the quota was harvested from the Chain Islets in these same seasons (Table 28, Figure 14). In the 2009/10 fishing season, however, only 26% of the PFMA 19 quota was harvested from Fulford Reef, while 56% of PFMA 19's quota was harvested from the Chain Islets, and 8% was harvested elsewhere within PFMA 19 (Table 28, Figure 14).

(f) FISHERY EXPLOITATION

Fishery exploitation is represented by the amount of legal-sized Green Sea Urchins harvested from each of Fulford Reef and the Chain Islets by the fishing industry over the fishing season, divided by the legal-sized biomass at each of these locations just prior to the opening of the fishery. However, the biomass estimates from the three March surveys all represent the end of a fishing season. The only biomass estimate obtained just prior to the start of the commercial fishing season was in August 2009, meaning we were only able to calculate fishing exploitation for the 2009/10 fishing season. In PFMA 19 during this season, the exploitation of legal-sized urchins was 0.232 ± 0.081 at Fulford Reef and 0.017 ± 0.002 at the Chain Islets.

DISCUSSION

Data collected during these scientific surveys were previously used in Green Sea Urchin stock assessments (DFO 2014, 2016b; Lochead et al. 2015; Waddell et al. 2010). In those reports, the data were analyzed in a broader context, whereas in the current report, the data have been analyzed at a more detailed level. The authors of past reports (DFO 2014, 2016b) used a program called Green Urchin Analysis Program (GUAP; Lochead et al. 2015), that uses a transect as the sampling unit, and combines the transects from both survey sites (Fulford Reef and Chain Islets) to determine the mean biomass density for PFMA 19 as a whole. The current report presents data from the survey area at a more detailed level, using a quadrat as the sampling unit, as described in Jamieson and Schwarz (1998) for a "complete cluster" sampling design. Rather than combining results from both survey sites, results for each of the two survey sites are analyzed separately and compared. In addition to density and biomass density, total biomass is computed for each site.

(a) SIZE DISTRIBUTION CHANGES

The percentage of legal-sized urchins at Fulford Reef decreased substantially with each survey, from 75.5% in March 2008 to 54.6% in March 2010 (Table 2). In contrast, the percentage of legal-sized urchins at the Chain Islets in March 2008 (76.9%) was almost the same as Fulford Reef, but remained relatively unchanged over the course of surveys (75.6% to 76.1%; Table 2). The percentage of sublegal-mature Green Sea Urchins at Fulford Reef increased from 13.7% in March 2008 to 32.8% in March 2009, and then increased slightly with each survey to 39.7%, whereas at the Chain Islets, the percentage of sublegal-mature urchins only increased slightly, from 18.6% in March 2008 to 22.2% in March 2010 (Table 2). There were only small percentages of immature Green

Sea Urchins observed during all surveys at both Fulford Reef (ranging from 2.4% to 10.8%) and the Chain Islets (ranging from 1.7% to 4.5%), indicating low juvenile recruitment.

Changes in size frequency distribution are difficult to analyze and interpret, as Green Sea Urchins have the potential for discontinuous growth, which can fluctuate with the availability and species of vegetation (Himmelman et al. 1983, Larson et al. 1980, Vadas 1977, Vadas et al. 2002). Although we do not have information on changes in vegetation availability at our survey sites, we assume the vegetation species remained the same or similar. Munk (1992) produced von Bertalanffy estimates of mean size-at-age for Green Sea Urchins in Alaska, and estimated that ages 1.0 through 4.0 were 9.9, 29.3, 44.0 and 55.1 mm. Using this information, we assume that Green Sea Urchins at Fulford Reef and the Chain Islets are in the sublegal-immature size class at age 1.0, in the sublegal-mature size class at age 2.0 and age 3.0, and could reach the legal size limit (>= 55 mm) by about age 4.0 (Waddell and Perry 2012). We use these only as general guidelines in interpreting the general pattern of each size distribution and how they changed between surveys. Munk (1992) also noted that the modes become obscure after age 3 as growth slows and they merge with a multi-age group above 50 mm. We expect there are many age classes with wide variations in test diameter, so that individual modes blend together and camouflage separate age classes.

The March 2008 size frequency distributions show high proportions of Green Sea Urchins larger than 55 mm (legal size limit, and potentially 4 years old and older) and low proportions of urchins smaller than 55 mm for both Fulford Reef and the Chain Islets. This seems to indicate, therefore, that there was likely a high juvenile recruitment event that occurred at least 4 years previous to 2008 (~2004 or earlier), and there was low recruitment between 2004 and 2008. This agrees with previous results found in PFMA 12, where juvenile recruitment was moderate in 2003 and extremely high in 2004 (Waddell and Perry 2006), followed by very low recruitment in 2006 (Waddell and Perry 2007). There was also moderate recruitment observed in 2008 and 2010 in PFMA 12 (Waddell and Perry 2012; no surveys in 2005, 2007 or 2009). The extremely high juvenile recruitment observed in PFMA 12 in 2004 likely also occurred in PFMA 19, and was responsible for the large skewed distribution observed in the March 2008 size frequency distributions for both survey sites. After each survey (and fishing season) at Fulford Reef, the large skewed distribution eased as more legal-sized urchins were removed. By March 2010, the size frequency distribution appears more balanced, with legal-sized urchins representing 54.6% of the population and sublegal urchins representing 45.4%. The size frequency distribution at the Chain Islets did not show this change between surveys, and remained skewed to the right in March 2010.

(b) DENSITY

(i) General Changes

When comparing between Fulford Reef and the Chain Islets, the highest mean densities of both legal-sized and sublegal-mature urchins consistently occurred at the Chain Islets in all surveys, usually by a factor of 2 or more. However, densities of immature urchins were similar at both locations (0.28 ± 0.13/m^2 at Fulford Reef and 0.22

± 0.12/m^2 at Chain Islets in March 2008, 0.14 ± 0.03/m^2 and 0.18 ± 0.14/m^2 in August 2009, and 0.10 ± 0.02/m^2 and 0.08 ± 0.05/m^2 in March 2010, respectively).

The mean density of legal-sized Green Sea Urchins decreased by more than half (54%) at Fulford Reef between March 2008 (1.96 ± 0.71/m^2) and March 2009 (0.90 ± 0.29/m^2), and then remained unchanged in August 2009 and March 2010. In contrast, there was only a small decrease in legal-sized densities from March 2008 to March 2009 at the Chain Islets (3.81 ± 1.40/m^2 to 3.38 ± 2.83/m^2). Note that during the 2008/09 fishing season, 80% of the PFMA 19 quota came from Fulford Reef and 20% came from the Chain Islets, that there was a fishing closure between the March 2009 and August 2009 surveys, and that 20% of the PFMA 19 quota came from Fulford Reef during the 2009/10 fishing season (Table 28).

Densities of sublegal-mature urchins at Fulford Reef increased with each survey, and doubled within two years (from 0.36 ± 0.11/m^2 in March 2008, to 0.67 ± 0.17/m^2 in March 2010), whereas sublegal-mature urchins at the Chain Islets remained relatively the same from one survey to the next (from 0.92 ± 0.31/m^2 in March 2008, to 0.99 ± 0.74/m^2 in March 2010). The low densities of immature Green Sea Urchins (ranging from 0.03 ± 0.01/m^2 to 0.28 ± 0.12/m^2 over the two survey locations from March 2008 to March 2010) indicate there were no major spawning events at either Fulford Reef or the Chain Islets from the spring of 2007 to 2010, or if there were, recruitment was poor. In PFMA 12 in 2004, juvenile recruitment was considered high when the sublegal-immature densities ranged from 1.20 ± 0.24/m^2 to 2.58/m^2 over the three survey locations (Waddell and Perry 2006).

Very small urchins can be difficult to see when surveying, as they can fit into small crevices or hide in algae, and the abilities of divers to spot them vary. Therefore immature urchin densities should only be considered approximate.

(ii) Changes with Depth

Green Sea Urchins in this study area generally occurred in greater densities in shallower waters, and decreased in density with increasing depth. Himmelman (1986) also observed Green Sea Urchin abundances generally decreased at greater depths. However, there were subtle differences in depth distributions between Fulford Reef and the Chain Islets, and between size classes in our surveys.

In the first two surveys at Fulford Reef, the highest densities of legal-sized and sublegal-sized Green Sea Urchins were observed in the 1.8 to 3.0 m below CD and 1.2 to 0.0 m above CD depth ranges, respectively. On the other hand, in the last two surveys, the legal-sized and sublegal-sized urchins were both in the 0.3 to 1.5 m below CD depth range (meaning the larger urchins moved up and the smaller urchins moved deeper). In comparison, the depth preferences were quite variable at the Chain Islets over the course of the surveys. The legal-sized urchins were in the 1.8 to 3.0 m below CD depth range in March 2008 and March 2010, but were observed at a deeper range (4.9 to 6.1 m below CD) in August 2009. The urchins may have moved deeper in August to avoid warmer water temperatures or ultraviolet radiation associated with the shallower

depths. In contrast, the sublegal-sized urchins at the Chain Islets were observed in highest densities in deeper survey depths (7.9 to 9.1 m below CD) in March 2008, mid-range depths (3.3 to 4.8 m below CD) in August 2009, and in shallower depths (0.3 to 1.5 m below CD) in March 2010. While their presence in deeper waters in August than in March 2010 follows the same pattern as legal-sized urchins, and is again possibly due to avoidance of warmer water temperatures in the shallows in August, it is difficult to ascertain why the highest densities of sublegal-sized urchins were observed at even deeper depths in March 2008. However, there was a moderate number of unknown-sized Green Sea Urchins counted in one quadrat in the deeper depth in March 2008, and it is possible that our ratio estimator of legal to sublegal urchins that was applied to the unknown-sized urchins gave an incorrect result for this observation (i.e. there may actually have been more legal-sized and less sublegal-sized urchins in this particular quadrat). However, Green Sea Urchins were often observed in higher densities at deeper depth intervals in our surveys in PFMA 12 (Waddell and Perry 2006, 2012), at one particular site (the Plumper Islands). It is possible that urchins at that site may depend more upon drift algae than attached algae, which may be deposited at deeper depths, with urchins moving deeper to find it. This may apply to urchins in the Chain Islets as well.

(iii) Changes with Substrate

The type of substrate where the highest densities of urchins were observed varied with survey and site, but generally did not seem to vary with urchin size class. Creviced bedrock was the dominant (most frequently surveyed) substrate in most surveys, followed by smooth bedrock. The highest mean total densities of Green Sea Urchins were observed on creviced bedrock in Fulford Reef in March 2008, 2009 and 2010, and in the Chain Islets in March 2008. In August 2009, total mean densities were highest on boulders at Fulford Reef and on cobble in the Chain Islets, but this may be more due to the urchins moving to deeper (cooler) depths in August, or to searching for food rather than choosing to move to different substrates. In March 2010, the highest total densities in the Chain Islets were observed on crushed shell substrate, but the sample size was only 3 quadrats. Crushed shell was not sampled very often, and Green Sea Urchins were not usually present on this type of substrate (unusual observation). However, there were also high densities of Green Sea Urchins on usual substrates (e.g. creviced bedrock [n=67] and boulders [n=10]) at this same survey and site.

Part of the difference in substrate observations may be due to different divers involved in the surveys, using different criteria for determining substrate types, especially between the smooth and creviced bedrock, even though the divers are given guidelines for determining between the substrates. Additionally, the transect lines were not in the exact same location for each survey. Regardless, the general trend over all the surveys was that Green Sea Urchins were observed in this survey area more consistently and in higher densities on bedrock (creviced and smooth), boulders, cobble and crushed shell, less frequently on gravel or pea gravel, and almost never on sand, mud or whole shell.

(c) MEASUREMENTS AND DISSECTIONS

No attempt was made to develop allometric equations for the test diameter (TD)-weight or TD-gonad weight relationships, as there were many sampling inconsistencies:

1. Dissections were not performed in March 2008 and March 2009, and sample sizes for dissections were small for both the August 2009 and March 2010 surveys.
2. Dissections have never been done before in August in our surveys, in any of the PFMAs, and this is not usually considered the prime time of year for harvesting Green Sea Urchin roe.
3. Many of the samples collected in March 2010 began spawning before being dissected.

Therefore we used the allometric equation from the most recent DFO (2016b) Green Sea Urchin assessment to determine individual urchin weights from TDs. This equation was developed using all data from all past surveys in all BC locations 1995 to 2014 (n=3,706) and provides a robust estimate of weight. However, it should be noted that preliminary analysis suggests the morphology of Green Sea Urchin tests in the southern Strait of Georgia (PFMAs 18 and 19) may be different than those in the northern Strait of Georgia (PFMA 12). Based on observations from many years of surveys, Green Sea Urchins in the northern part of the Strait of Georgia appear to have shorter heights than those in the southern Strait of Georgia, meaning urchins in the south appear rounder while those in the north appear flatter. The implication is that urchins in the south could weigh more than urchins in the north with the same TD, due to the higher height in the southern Strait of Georgia urchins. A more detailed analysis of these data is beyond the scope of this report (collected from many past surveys) but could be determined in the future, and a more refined TD-weight relationship could be developed. In the meantime, we felt using the TD-weight relationship from the most recent DFO Science Response (DFO 2016b) was the most appropriate methodology.

Note it was difficult to determine sex in the August 2009 survey, most likely because the roe was not ripe in August in many of the urchins. Usually Green Sea Urchins are harvested in the fall and winter, as this is when the gonads are large and the roe is in the best condition.

Roe quality is categorized by both colour and texture; the highest quality roe has a bright orange/yellow colour and a firm texture. During the August 2009 survey, roe quality was higher (both colour and texture = 1, the highest grade) at Fulford Reef for both legal and sublegal-sized urchins (27.3% and 25.0%, respectively; Table 20) than at the Chain Islets (14.3% and 10.0%). These values are low in comparison to values observed at other times of the year and in other locations, as expected (e.g. in PFMA 12 in November 2010, highest roe quality was 22.6% to 75.0% for legal-sized urchins, and 25.0% to 41.7% for sublegal urchins; Waddell et al. 2012). Roe quality was low in March 2010, as the survey occurred after some of the urchins started spawning.

The mean percent roe recovery rate (the total gonad weight of all grades combined, divided by the total drained weight of all urchins sampled, multiplied by 100%) is usually highest in the late winter to early spring, just before spawning occurs. However,

roe recovery rates in March 2010 are considered incomplete, as spawning was already occurring at the time of sample collection. In August 2009 in PFMA 19, the mean percent roe recovery rate for legal-sized Green Sea Urchins was 18.9% at Fulford Reef and 16.6% at the Chain Islets (Table 20). There are no mean roe recovery rates determined for any other location in BC in August 2009 for comparison. However, in PFMA 12, mean roe recovery rates for legal-sized urchins ranged from 14.7% to 16.9% at the 3 surveyed locations in October 2008, and from 13.1% to 14.5% at 2 surveyed locations in November 2010 (Waddell and Perry 2012). Therefore, in comparison, the mean roe recovery rates for Fulford Reef and Chain Islets in August 2009 are high, and support the earlier opening of the fishery (September) in this PFMA than in PFMA 12.

(d) CHANGES IN BIOMASS DENSITY AND TOTAL BIOMASS

The area of the Chain Islets is more than six times larger than the area of Fulford Reef. Accordingly, the numbers and total biomass of Green Sea Urchins were always highest for the Chain Islets, and the large difference in these values made it difficult to compare between the two locations. Therefore, we also calculated the biomass density (grams per square meter) to enable comparisons on a relative scale between Fulford Reef and the Chain Islets over time, and with any other location, past or future. The total biomass of legal sized urchins (legal biomass) was also calculated for each location.

(i) Legal-sized Green Sea Urchins

The number of legal-sized Green Sea Urchins at Fulford Reef decreased by approximately 137,500 (54%) between March 2008 and March 2009 and then remained generally unchanged through to March 2010. The total biomass and biomass density of legal-sized urchins at Fulford Reef also decreased by half (49%) between March 2008 and March 2009, and then stayed relatively the same over the next two surveys. Note that during the 2008/09 fishing season, 80% of the PFMA 19 quota came from Fulford Reef and 20% came from the Chain Islets, that there was a fishing closure between the March 2009 and August 2009 surveys, and that 20% of the PFMA 19 quota came from Fulford Reef during the 2009/10 fishing season (Table 28).

The number of legal-sized urchins at the Chain Islets also decreased between March 2008 and August 2009 (no March 2009 survey at this location), by approximately 167,000 urchins, but this only represented an 11% reduction, likely due to its larger area and population size. At the same time, the total biomass and biomass density of legal-sized urchins at Chain Islets increased by 9% between March 2008 and August 2009, likely due to growth of individual urchins during the fishery closure. There was also a longer time period between surveys at Chain Islets (by 5 months) than at Fulford Reef, since there was no March 2009 survey at the Chain Islets. The mean TDs and weights were the largest during the August 2009 survey at the Chain Islets, but this, however, does not fully explain the large decrease in legal numbers at this location. Green Sea Urchins may have been harvested mainly in the area of our survey transects, and not evenly throughout the survey location (i.e. perhaps there was an uneven distribution of urchin harvesting). A small decrease in numbers on the transects at the Chain Islets could have resulted in an amplified total decrease in our calculations over its large area. By the March 2010 survey, the legal numbers at the Chain Islets decreased by 6.5%, and

the total biomass and biomass densities decreased by 17%. Note that 56% of Area 19's TAC was removed from the Chain Islets in 2009-10, while 26% was removed from Fulford Reef (Table 28).

When comparing legal biomass density between Fulford Reef and the Chain Islets, the Chain Islets had double the biomass density of Fulford Reef in March 2008 (411 g/m^2 to 208 g/m^2, respectively), 4.5 times as much in August 2009, and more than 3.5 times as much by March 2010. However, when comparing total legal biomass between Fulford Reef and the Chain Islets, the Chain Islets had 13 times the biomass at Fulford in March 2008 (335.5 to 27 t, respectively), 28 times as much in August 2009, and more than 25 times as much by March 2010, due to its larger area.

(ii) Sublegal-sized Green Sea Urchins

In contrast to legal-sized urchins, the number of sublegal-mature urchins at Fulford Reef increased each survey, by 89% overall between March 2008 and March 2010. The pattern was the same for sublegal-mature biomass density and total biomass, with an overall increase of 98% and 95%, respectively. The number of sublegal-mature urchins at the Chain Islets also increased between March 2008 and August 2009 and then remained relatively the same to March 2010, with an overall increase of 7.5%. The biomass density and total biomass of sublegal-mature urchins at the Chain Islets both had an overall increase of 22% over the surveys.

(e) FISHERY EXPLOITATION

Estimates of the fishery exploitation rate of legal-sized Green Sea Urchins were only possible for the 2009/10 fishing season because only the August 2009 survey provided a biomass estimate just prior to the fishing season.

The fishery exploitation rate was estimated at 0.232 ± 0.081 for Fulford Reef after removing 3.12 t. In contrast, the fishery exploitation rate estimated at the Chain Islets was 0.017 ± 0.002 after commercial harvest of 6.7 t. In the previous two fishing seasons (2007/08 and 2008/09), there were 3 times as much removed from Fulford Reef (9.57 t and 9.37 t, respectively), and during this same period, 3 times less urchins were harvested from the Chain Islets (2.41 t and 2.35 t, respectively). Note that the overall Total Allowable Catches are set for the fishery over PFMA 19 which contains both of these fishing areas.

Comparing fishery exploitation rates between PFMA 19 in 2009/10 with PFMA 12 in 2008/09 at the Stephenson Islets (0.033 ± 0.004, Waddell and Perry 2012), shows that rates were far higher at Fulford Reef.

There are many reasons for these variations in fishery exploitation rates, both intrinsic to the surveys themselves or due to extrinsic fishery factors such as markets. For instance, total biomass estimates are derived directly from density estimates, which vary depending on the transects surveyed (not always the same), and by the individual weights of the legal-sized green urchins, which vary between surveys. Commercial harvests from Fulford Reef or the Chain Islets during any particular fishing season are

influenced by the density of legal-sized green urchins available for harvesting, and also by the dynamics of the fishery, such as the supply and demand of the market, the price per pound, directions from the processors to the fishers, fishery management regulations and changes, other fisheries competing for harvesters' time, weather conditions, and various other industry-related factors. In addition, the Japanese market for urchin roe has been in flux since about 2001/02. The amount of commercial harvest of Green Sea Urchins is less influenced by the amount of legal-sized urchins available for harvesting and more influenced by the dynamics of the market. Although the demand for BC product was low during 2009/10, and less fishing occurred overall due to low price for product as a result of competition from other countries (especially Russia), fishing continued at a high rate in PFMA 19, especially at Fulford Reef. This is most likely due to its good quality roe and close proximity to a large city centre (Victoria, BC).

(f) SOURCES OF UNCERTAINTY

Green Sea Urchins have a wider depth distribution than those considered in this report, therefore the estimated biomass calculated in this report are conservative. The criterion we used to estimate the "total area" of Green Sea Urchin habitat for the biomass calculations was "all area within a depth range of 0 to 10 m below CD". The majority of Green Sea Urchins are usually found within this depth range, and this is the depth range that commercial divers generally harvest. However, Green Sea Urchins are known to inhabit deeper depths so total biomass estimates are underestimated. These deeper habitat depths may act as refugia, out of the usual range of harvest by divers.

SUMMARY

This report examines data from the first four Green Sea Urchin surveys in PFMA 19, at two survey locations, Fulford Reef and the Chain Islets, from March 2008 to March 2010. Fulford Reef is a small, but productive reef that has been targeted by commercial harvesting in this PFMA. There is no comparable control site (protected from harvests) in this area. Instead, the nearby Chain Islets was selected as a second survey site. It has a survey area (defined as area with depths between 0 and 10 m below Chart Datum) 6.7 times larger than Fulford Reef. This location is also commercially fished, but generally not as intensely as Fulford Reef.

The first survey (March 2008) revealed a strong year class, likely from 2004 (or earlier), that was represented by a predominately legal-sized population in both Fulford Reef and the Chain Islets (75.5% and 76.9%, respectively). This corresponds with observations in PFMA 12 of a very strong year class in 2004, followed by several weak or moderate year classes (Waddell and Perry 2006). The size frequency distribution at Fulford Reef changed substantially between the March 2008 and March 2009 surveys. During the 2008/09 fishing season, PFMA 19 opened in early September 2008, with an expected closure in March 2009. Instead, 98% of the quota allotted to PFMA 19 was harvested within the first 26 days of the season, with 78% of the TAC coming from Fulford Reef, and 20% from the Chain Islets. The legal density decreased by 54% between the March 2008 and March 2009 surveys at Fulford Reef, and the total legal biomass and biomass density decreased by 49%. In contrast, there were no significant

changes at either location in densities, biomass density or total biomass between the March 2009 and August 2009 surveys, a time that corresponds to the fishing season closure. During the 2009/10 fishing season, 90% of the PFMA 19 TAC was achieved, of which 26% was harvested at Fulford Reef, 56% was harvested in the Chain Islets, and 9% was harvested from another locations. There were small decreases in density, biomass density and total biomass at Fulford between the August 2009 and March 2010 surveys, and larger decreases in these parameters at the Chain Islets. By the March 2010 survey, Fulford Reef's size distribution appeared more balanced, with legal-sized urchins representing 54.6% of the population and sublegal urchins representing 45.4%, while at the Chain Islets, 76.1% of the population remained legal-sized, and only 23.9% represented sublegal urchins. The Chain Islets had a much larger population than Fulford Reef, so these changes in numbers of legal-sized urchins at Fulford Reef would have represented a smaller proportion of the overall population.

Sublegal-mature urchins increased at both locations with each survey. At Fulford Reef between March 2008 and March 2010, the number of sublegal-mature urchins increased by 89%, biomass density increased by 98% and total biomass increased by 95%. At the Chain Islets during the same time period, the number of sublegal-mature urchins only increased by 7.5%, and the biomass density and total biomass increased by 22%.

Preliminary analysis suggests the morphology of Green Sea Urchin tests in the southern Strait of Georgia (PFMAs 18 and 19) may be different than those in the northern Strait of Georgia (PFMA 12), and this should be investigated further as differences would influence area biomass estimates. Northern Strait of Georgia urchins appear to have shorter heights than Southern Strait of Georgia urchins, so urchins in the south appear rounder than those in the north. The implication is that urchins in the south could weigh more than urchins in the north with the same test diameter, due to the higher height and volume in the southern Strait of Georgia urchins. A more detailed analysis of these data should be performed in the future.

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TABLES

Table 1. Green Sea Urchin commercial fishery and fishery-independent survey timeline of events in Pacific Fishery Management Area (PFMA) 19. Table includes information on the vessels involved and the number (No.) of transects surveyed by site, for all Green Sea Urchin surveys, March 2008 to March 2010. (WCGUA = owned by a commercial fisher of the West Coast Green Urchin Association, DFO = owned by Fisheries and Oceans Canada).

Dates	Events	Vessels Involved	No. of Transects Surveyed	
			Fulford Reef	Chain Islets
Sept. 21, 2007	PFMA 19 opens for commercial harvest			
March 3-5, 2008	March 2008 survey conducted	WCGUA's *'Emma III'* and DFO's *'Pallasi'*	6	4
March 21, 2008	PFMA 19 closes			
Sept. 3, 2008	PFMA 19 opens for commercial harvest			
Sept. 29, 2008	PFMA 19 closed – PFMA quota met			
March 8, 2009	March 2009 survey conducted	WCGUA's *'Emma III'* and DFO's *'Pallasi'*	6	0
August 27-28, 2009	August 2009 survey conducted	WCGUA's *'Emma III'* and DFO's *'C68'*	6	3
Sept. 11, 2009	PFMA 19 opens for commercial harvest			
March 24-25, 2010	March 2010 survey conducted	WCGUA's *'CCC'* and DFO's *'Pallasi'*	6	3
March 31, 2010	PFMA 19 closes			

Table 2. Green Sea Urchin number and percentage sampled at Fulford Reef and Chain Islets, by survey date. (M = quadrats where urchins measured; C = quadrats where urchins counted only; T = measured plus counted quadrats; N = number; P = percentage; Legal ≥ 55 mm test diameter [TD]; Sublegal-mature 25 mm ≤ TD < 55 mm TD; Sublegal-immature < 25 mm; Unknown = unmeasured; Total Number = total number of Green Sea Urchins measured). Note the quadrat measuring/counting/skipping scheme varied between transects and surveys. Numbers in the brackets in the lighter font indicate actual measured values while the darker font indicates best estimates ("unknowns" were proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and a zero value was assigned to the unknowns).

Survey Date	Site	No. of Quads	N or P	Number of Legal	Number of Sublegal-mature	Number of Sublegal-immature	Number of Unknown	Total Number
March 3-5, 2008	**Fulford Reef**	468 T 353 M 115 C	N P	**919** (525) **75.5%** (43.1%)	**167** (102) **13.7%** (8.4%)	**131** (80) **10.8%** (6.6%)	**0** (511) **0%** (42.0%)	**1,218**
	Chain Islets	198 T 183 M 15 C	N P	**754** (657) **76.9%** (67.0%)	**182** (169) **18.6%** (17.2%)	**44** (35) **4.5%** (3.6%)	**0** (119) **0%** (12.1%)	**980**
March 8, 2009	**Fulford Reef**	442 T 442 M 0 C	N P	**397** (380) **64.8%** (62.0%)	**201** (191) **32.8%** (31.2%)	**15** (15) **2.4%** (2.4%)	**0** (27) **0%** (4.4%)	**613**
	Chain Islets	Not surveyed	-	-	-	-	-	**-**
August 27-28, 2009	**Fulford Reef**	714 T 591 M 123 C	N P	**645** (619) **55.6%** (53.3%)	**415** (368) **35.7%** (31.7%)	**101** (91) **8.7%** (7.8%)	**0** (83) **0%** (7.1%)	**1,161**
	Chain Islets	130 T 130 M 0 C	N P	**470** **75.6%**	**129** **20.7%**	**23** **3.7%**	**0** **0%**	**622**
March 24-25, 2010	**Fulford Reef**	587 T 587 M 0 C	N P	**543** **54.6%**	**395** **39.7%**	**57** **5.7%**	**0** **0%**	**995**
	Chain Islets	171 T 158 M 13 C	N P	**578** (397) **76.1%** (52.2%)	**169** (122) **22.2%** (16.1%)	**13** (10) **1.7%** (1.3%)	**0** (231) **0%** (30.4%)	**760**

Table 3. Fulford Reef Green Sea Urchin test diameter (TD) and weight by date and size category. Sample size, mean and standard error of TD in millimeters (mm) and weight in grams (g) randomly sampled at Fulford Reef. (SE = standard error; Legal ≥ 55 mm TD; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD).

Date	Size	Sample Size	Mean TD (mm)	SE of Mean TD (mm)	Mean Weight (g)	SE of Mean Weight (g)
March 2008	Legal	523	67.4	0.3	105.9	1.5
	Sublegal-Mature	104	40.6	0.9	28.8	1.6
	Sublegal-Immature	80	15.8	0.6	2.4	0.2
March 2009	Legal	381	70.2	0.4	117.6	1.7
	Sublegal-Mature	201	42.3	0.5	30.8	0.9
	Sublegal-Immature	15	16.9	1.3	2.8	0.5
August 2009	Legal	619	69.4	0.3	115.0	1.5
	Sublegal-Mature	368	41.9	0.5	30.9	0.8
	Sublegal-Immature	91	19.1	0.5	3.7	0.2
March 2010	Legal	543	67.8	0.4	108.5	1.7
	Sublegal-Mature	395	41.7	0.4	30.2	0.7
	Sublegal-Immature	57	16.8	0.7	2.8	0.2

Table 4. Fulford Reef Green Sea Urchin mean biomass density (urchins/meter squared) by transect , with overall standard errors. (M = quadrats with measured urchins; C = quadrats with counted urchins; T = total quadrats (measured plus counted); L = total length of transect (metres; includes skipped quadrats); Legal ≥ 55 mm TD; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD; Unknown = unmeasured; Total Density = density of all urchins combined). The bold numbers in the brackets indicate calculations where the unknowns have been proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and assigning a zero value to the unknowns. These are considered the best estimates of the two values given.

Transect Number	Number of Quadrats				Legal Density	Sublegal – Mature Density	Sublegal – Immature Density	Unknown Density	Total Density
	M	C	T	L					
1	68	0	68	135	**0.12**	**0.18**	**0.03**	**0.00**	**0.32**
2	124	0	124	247	**1.10**	**0.16**	**0.36**	**0.00**	**1.62**
3	27	27	54	54	0.63 **(2.22)**	0.13 **(0.46)**	0.31 **(1.09)**	2.72 **(0.00)**	**3.80**
4	47	0	47	47	0.17 **(0.19)**	0.32 **(0.34)**	0.15 **(0.15)**	0.04 **(0.00)**	**0.68**
5	38	39	77	153	2.34 **(4.90)**	0.39 **(0.82)**	0.09 **(0.19)**	3.09 **(0.00)**	**5.91**
6	49	49	98	186	1.62 **(2.74)**	0.18 **(0.32)**	0.02 **(0.03)**	1.27 **(0.00)**	**3.09**
March 08 Totals or Avg.	353	115	468	822	1.12 ± 0.32 **(1.96 ± 0.71)**	0.22 ± 0.04 **(0.36 ± 0.11)**	0.17 ± 0.07 **(0.28 ± 0.13)**	1.09 ± 0.56 **(0.00)**	**2.60 ± 0.80**
1	66	0	66	131	**0.05**	**0.18**	**0.06**	**0.00**	**0.29**
2	79	0	79	157	**0.78**	**0.35**	**0.00**	**0.00**	**1.14**
3	74	0	74	147	**0.55**	**0.36**	**0.08**	**0.00**	**1.00**
4	64	0	64	127	**0.27**	**0.30**	**0.03**	**0.00**	**0.59**
5	64	0	64	127	1.64 **(1.91)**	0.91 **(1.06)**	**0.02**	0.42 **(0.00)**	**2.98**
6	95	0	95	189	**1.60**	**0.49**	**0.02**	**0.00**	**2.12**
March 09 Totals or Avg.	442	0	442	878	0.86 ± 0.28 **(0.90 ± 0.29)**	**0.43 ± 0.09 (0.45 ± 0.09)**	**0.03 ± 0.01**	0.06 ± 0.06 **(0.00)**	**1.39 ± 0.39**
1	71	59	130	130	**0.17**	0.17 **(0.18)**	**0.08**	0.01 **(0.00)**	**0.42**
2	150	0	150	299	**1.45**	**0.43**	**0.15**	**0.00**	**2.04**
3	97	0	97	193	**0.21**	**0.10**	**0.04**	**0.00**	**0.35**
4	61	64	125	125	0.13 **(0.34)**	0.23 **(0.60)**	0.05 **(0.13)**	0.66 **(0.00)**	**1.06**
5	90	0	90	179	**2.30**	**1.39**	**0.27**	**0.00**	**3.96**
6	122	0	122	243	**1.11**	**0.96**	**0.20**	**0.00**	**2.27**
August 09 Totals or Avg.	591	123	714	1169	0.87 ± 0.33 **(0.90 ± 0.31)**	0.52 ± 0.18 **(0.58 ± 0.17)**	0.13 ± 0.03 **(0.14 ± 0.03)**	0.12 ± 0.11 **(0.00)**	**1.63 ± 0.48**
1	105	0	105	209	**0.10**	**0.29**	**0.07**	**0.00**	**0.46**
2	143	0	143	285	**1.36**	**1.08**	**0.13**	**0.00**	**2.57**
3	99	0	99	197	**0.59**	**0.18**	**0.05**	**0.00**	**0.82**
4	46	0	46	91	**0.50**	**0.63**	**0.04**	**0.00**	**1.17**
5	97	0	97	187	**0.69**	**0.67**	**0.08**	**0.00**	**1.44**
6	100	0	100	199	**1.90**	**0.99**	**0.16**	**0.00**	**3.05**
March 10 Totals or Avg.	590	0	590	1168	**0.92 ± 0.28**	**0.67 ± 0.17**	**0.10 ± 0.02**	**0.00**	**1.69 ± 0.45**

Table 5. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in March 2008 by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	11	2.14	2.14	4.27 ± 1.78
1 to 5	0.3 to 1.5	46	1.97	1.01	2.98 ± 0.84
6 to 10	1.8 to 3.0	65	3.90	1.44	5.34 ± 1.56
11 to 15	3.3 to 4.8	96	3.52	0.74	4.26 ± 0.90
16 to 20	4.9 to 6.1	127	1.23	0.50	1.72 ± 0.37
21 to 25	6.4 to 7.6	64	0.64	0.09	0.73 ± 0.43
26 to 30	7.9 to 9.1	37	0.03	0.00	0.03 ± 0.03
31 to 35	9.4 to 10.7	21	0.00	0.00	0.00 ± 0.00
36 to 40	11.0 to 12.2	0	-	-	-

Table 6. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in March 2008 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
1	Smooth Bedrock	10	0.10	0.10	0.00	0.20 ± 0.13
2	Creviced Bedrock	341	1.48	0.50	1.41	3.39 ± 0.44
3	Boulders	34	0.18	0.18	0.53	0.88 ± 0.50
4	Cobble	8	0.00	0.13	0.00	0.13 ± 0.13
5	Gravel	42	0.00	0.05	0.00	0.05 ± 0.03
6	Pea gravel	21	0.71	0.00	0.52	1.24 ± 0.82
7	Sand	11	0.00	0.00	0.00	0.00
8	Shell	1	0.00	0.00	0.00	0.00

Table 7. Green Sea Urchin abundance (number), biomass density (grams/meter squared), and biomass (tonnes) in March 2008 by site and size category, with standard errors (incorporates urchins of unknown size [i.e. "unknowns"]). (Legal ≥ 55 mm test diameter [TD]; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD). Weight estimates used to determine biomass estimates were calculated using TD-weight relationships from DFO (2016b) and applied to the field survey TD measurements.

Size Category	Fulford Reef	Chain Islets
Number of Legal-sized	254,007 ± 91,482	3,294,256 ± 1,214,095
Number of Sublegal-mature	46,158 ± 13,707	795,165 ± 269,224
Number of Sublegal-immature	36,208 ± 16,583	192,238 ± 107,503
Total Number (all sizes)	336,649 ± 104,125	4,281,660 ± 1,490,999
Legal Biomass Density	207.87 ± 74.91 g/m^2	410.93 ± 151.51 g/m^2
Sublegal-mature Biomass Density	10.27 ± 3.08 g/m^2	28.94 ± 9.84 g/m^2
Sublegal-immature Biomass Density	0.68 ± 0.31 g/m^2	0.83 ± 0.47 g/m^2
Total Biomass Density	218.82 ± 74.97 g/m^2	440.70 ± 151.83 g/m^2
Biomass of Legal-size	26.89 ± 9.69 t	355.49 ± 131.07 t
Biomass of Sublegal-mature	1.33 ± 0.40 t	25.03 ± 8.51 t
Biomass of Sublegal-immature	0.09 ± 0.04 t	0.72 ± 0.41 t
Total Biomass	28.31 ± 9.70 t	381.24 ± 131.34 t

Table 8. Chain Islets Green Sea Urchin test diameter (TD) and weight by date and size category. Sample size, mean and standard error of TD in millimeters (mm) and weight in grams (g) randomly sampled at Fulford Reef. (SE = standard error; Legal ≥ 55 mm TD; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD).

Site	Size	Sample Size	Mean TD (mm)	SE of Mean TD (mm)	Mean Weight (g)	SE of Mean Weight (g)
March 2008	Legal	658	67.9	0.3	107.9	1.3
	Sublegal-Mature	169	42.3	0.7	31.5	1.2
	Sublegal-Immature	34	18.9	0.9	3.7	0.4
August 2009	Legal	485	71.1	0.4	123.4	1.9
	Sublegal-Mature	135	43.5	0.7	33.9	1.3
	Sublegal-Immature	26	18.2	0.9	3.3	0.3
March 2010	Legal	397	67.8	0.5	109.1	2.1
	Sublegal-Mature	122	44.8	0.7	35.8	1.3
	Sublegal-Immature	10	20.9	1.1	4.5	0.5

Table 9. *Chain Islets Green Sea Urchin sample mean biomass density (urchins/meter squared) by transect, with overall standard errors. (M = quadrats with measured urchins; C = quadrats with counted urchins; T = total quadrats [measured plus counted]; L = total length of transect [metres; includes skipped quadrats]; Legal ≥ 55 mm TD; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD; Unknown = unmeasured; Total Density = density of all urchins combined). The bold numbers in the brackets indicate calculations where the unknowns have been proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and assigning a zero value to the unknowns. These are considered the best estimates of the two values given.*

Transect Number	Number of Quadrats				Legal Density	Sublegal – Mature Density	Sublegal – Immature Density	Unknown Density	Total Density
	M	C	T	L					
1CN	27	0	27	27	**6.59**	**2.48**	**0.56**	**0.00**	**9.63**
2CN	16	15	31	31	3.65 **(6.77)**	0.48 **(0.90)**	0.32 **(0.61)**	3.84 (0.00)	**8.29**
3CN	76	0	76	76	**4.32**	**0.78**	**0.07**	**0.00**	**5.16**
4CN	64	0	64	64	**0.59**	**0.44**	**0.08**	**0.00**	**1.11**
March 08 Totals or Avg.	183	15	198	198	3.32 ± 1.22 **(3.81 ± 1.40)**	0.85± 0.31 **(0.92 ± 0.31)**	0.18 ± 0.09 **(0.22 ± 0.12)**	0.60 ± 0.69 **(0.00)**	**4.95 ± 1.72**
1CN									
2CN									
3CN									
4CN									
March 09 Totals or Avg.									
1CN	17	0	17	17	**5.53**	**3.59**	**0.53**	**0.00**	**9.65**
2CN	32	0	32	32	**2.72**	**1.09**	**0.38**	**0.00**	**4.19**
3CN	81	0	81	81	**3.57**	**0.41**	**0.02**	**0.00**	**4.00**
4CN									
August 09 Totals or Avg.	130	0	130	130	**3.62 ± 0.41**	**0.99 ± 0.61**	**0.18 ± 0.14**	**0.00**	**4.78 ± 1.00**
1CN	12	0	12	23	**2.00**	**2.17**	**0.25**	**0.00**	**4.42**
2CN									
3CN	66	13	79	79	4.72 **(7.01)**	1.22 **(1.81)**	0.09 **(0.13)**	2.92 **(0.00)**	**8.95**
4CN	80	0	80	80	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
March 10 Totals or Avg.	158	13	171	182	2.32 ± 1.90 **(3.38 ± 2.83)**	0.71 ± 0.51 **(0.99 ± 0.74)**	0.06 ± 0.04 **(0.08 ± 0.05)**	1.35 ± 1.19 **(0.00)**	**4.44 ± 3.60**

Table 10. Chain Islets Green Sea Urchin mean density (urchins/meter squared) in March 2008 by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	1	1.00	0.00	1.00 ± 1.00
1 to 5	0.3 to 1.5	30	2.81	1.62	4.43 ± 1.99
6 to 10	1.8 to 3.0	44	6.88	1.33	8.20 ± 1.59
11 to 15	3.3 to 4.8	52	4.01	1.08	5.10 ± 1.34
16 to 20	4.9 to 6.1	29	2.21	0.86	3.07 ± 2.15
21 to 25	6.4 to 7.6	25	3.16	1.08	4.24 ± 2.17
26 to 30	7.9 to 9.1	11	0.23	2.05	2.27 ± 1.34
31 to 35	9.4 to 10.7	6	0.00	0.00	0.00 ± 0.00

Table 11. Chain Islets Green Sea Urchin mean density (urchins/meter squared) in March 2008 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
	Smooth Bedrock	0	-	-	-	-
2	Creviced Bedrock	174	3.70	1.15	0.68	5.53 ± 0.82
3	Boulders	10	0.80	0.30	0.00	1.10 ± 0.62
4	Cobble	3	0.00	0.00	0.00	0.00
5	Gravel	8	0.63	0.13	0.00	0.75 ± 0.75
6	Pea gravel	0	-	-	-	-
7	Sand	1	0.00	0.00	0.00	0.00
8	Shell	2	0.00	0.00	0.00	0.00

Table 12. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in March 2009 by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	7	0.29	2.00	2.29 ± 1.04
1 to 5	0.3 to 1.5	19	3.07	1.72	4.79 ± 2.03
6 to 10	1.8 to 3.0	50	3.60	1.24	4.84 ± 2.37
11 to 15	3.3 to 4.8	68	1.59	0.76	2.35 ± 0.86
16 to 20	4.9 to 6.1	88	0.14	0.16	0.30 ± 0.14
21 to 25	6.4 to 7.6	96	0.11	0.22	0.33 ± 0.10
26 to 30	7.9 to 9.1	112	0.24	0.27	0.51 ± 0.19
31 to 35	9.4 to 10.7	6	0.00	0.00	0.00
36 to 40	11.0 to 12.2	0	-	-	-

Table 13. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in March 2009 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
1	Smooth Bedrock	141	1.44	0.55	0.00	1.99 ± 0.87
2	Creviced Bedrock	127	1.17	0.64	0.21	2.02 ± 0.55
3	Boulders	72	0.25	0.49	0.00	0.74 ± 0.20
4	Cobble	20	0.00	0.15	0.00	0.15 ± 0.11
5	Gravel	36	0.31	0.17	0.00	0.47± 0.47
6	Pea gravel	24	0.00	0.04	0.00	0.04 ± 0.04
7	Sand	15	0.00	0.13	0.00	0.13 ± 0.09
9	Mud	0	-	-	-	-
10	Crushed Shell	4	0.00	0.00	0.00	0.00
11	Whole Shell	3	0.00	0.33	0.00	0.33 ± 0.33

Table 14. Green Sea Urchin abundance (number), biomass density (grams/meter squared), and biomass (tonnes) in March 2009 by site and size category, with standard errors (incorporates urchins of unknown size [i.e. "unknowns"]). (Legal ≥ 55 mm test diameter [TD]; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD). Weight estimates used to determine biomass estimates were calculated using TD-weight relationships from DFO (2016b) and applied to the field survey TD measurements.

Size Category	Fulford Reef	Chain Islets
Number of Legal-sized	116,476 ± 38,116	Not surveyed
Number of Sublegal-mature	58,823 ± 14,554	Not surveyed
Number of Sublegal-immature	4,390 ± 1,614	Not surveyed
Total Number (all sizes)	179,397 ± 49,962	Not surveyed
Legal Biomass Density	105.87 ± 34.67 g/m^2	Not surveyed
Sublegal-mature Biomass Density	14.00 ± 3.48 g/m^2	Not surveyed
Sublegal-immature Biomass Density	0.10 ± 0.04 g/m^2	Not surveyed
Total Biomass Density	119.97 ± 34.84 g/m^2	Not surveyed
Biomass of Legal-size	13.70 ± 4.48 t	Not surveyed
Biomass of Sublegal-mature	1.81 ± 0.45 t	Not surveyed
Biomass of Sublegal-immature	0.01 ± 0.005 t	Not surveyed
Total Biomass	15.52 ± 4.51 t	Not surveyed

Table 15. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in August 2009 by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	1	0.00	1.00	1.00
1 to 5	0.3 to 1.5	33	1.85	1.45	3.30 ± 1.82
6 to 10	1.8 to 3.0	106	1.46	1.11	2.58 ± 1.15
11 to 15	3.3 to 4.8	190	1.54	1.20	2.74 ± 0.53
16 to 20	4.9 to 6.1	105	1.11	0.48	1.59 ± 0.86
21 to 25	6.4 to 7.6	151	0.15	0.26	0.41 ± 0.07
26 to 30	7.9 to 9.1	97	0.12	0.12	0.25 ± 0.06
31 to 35	9.4 to 10.7	42	0.00	0.10	0.10 ± 0.05
36 to 40	11.0 to 12.2	7	0.00	0.00	0.00

Table 16. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in August 2009 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
1	Smooth Bedrock	7	0.00	0.14	0.00	0.14 ± 0.14
2	Creviced Bedrock	489	0.78	0.50	0.16	1.44 ± 0.25
3	Boulders	99	2.07	1.81	0.03	3.91 ± 1.46
4	Cobble	25	0.60	0.92	0.00	1.52 ± 0.95
5	Gravel	24	0.00	0.08	0.04	0.13± 0.07
6	Pea gravel	2	0.00	0.00	0.00	0.00
7	Sand	46	0.33	0.22	0.00	0.54 ± 0.22
9	Mud	13	0.00	0.00	0.00	0.00
10	Crushed Shell	8	0.13	0.13	0.00	0.25 ± 0.16
11	Whole Shell	1	0.00	0.00	0.00	0.00

Table 17. Chain Islets Green Sea Urchin mean density (urchins/meter squared) in August 2009 by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	1	1.00	0.00	1.00 ± 1.00
1 to 5	0.3 to 1.5	2	0.50	0.50	1.00 ± 1.00
6 to 10	1.8 to 3.0	22	2.91	0.45	3.36 ± 1.13
11 to 15	3.3 to 4.8	56	4.45	1.80	6.25 ± 1.72
16 to 20	4.9 to 6.1	21	6.76	1.48	8.24 ± 3.06
21 to 25	6.4 to 7.6	10	0.40	0.20	0.60 ± 0.40
26 to 30	7.9 to 9.1	18	0.56	0.61	1.17 ± 0.61
31 to 35	9.4 to 10.7	16	0.88	0.31	1.19 ± 0.40

Table 18. Chain Islets Green Sea Urchin mean density (urchins/meter squared) in August 2009 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
1	Smooth Bedrock	0	-	-	-	-
2	Creviced Bedrock	80	3.36	1.53	0.00	4.89 ± 1.22
3	Boulders	26	4.35	0.58	0.00	4.92 ± 2.09
4	Cobble	7	8.71	1.86	0.00	10.57 ± 5.45
5	Gravel	0	-	-	-	-
6	Pea gravel	5	5.20	0.40	0.00	5.60 ± 5.60
7	Sand	6	0.00	0.00	0.00	0.00
9	Mud	2	0.50	0.00	0.00	0.50 ± 0.50
10	Crushed Shell	4	0.00	0.00	0.00	0.00
11	Whole Shell	0	-	-	-	-

Table 19. Summary results of measurements taken during Green Sea Urchin dissections in the August 2009 survey. (Legal ≥ 55 mm test diameter [TD]; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD; SE = standard error; Gutted Weight = stomach and contents removed; Gonad Colour: 0=unknown or no sample, 1=orange/yellow, 2=yellow with other colours, 3=brown/red, 4=very pale orange; Gonad Texture: 0 = unknown or no sample, 1 = firm, 2 = semi-firm, 3 = flimsy; Sex: 1 = male, 2 = female, 3 = juvenile or unknown. Sample Size 1 is for test height, TD and total wet weight. Sample Size 2 is for all other calculations).

Summary Information			LOCATION					
			FULFORD REEF			CHAIN ISLETS		
			Legal	Sublegal-mature	Sublegal–immature	Legal	Sublegal–mature	Sublegal–immature
Sample Size 1			25	32	2	14	10	0
Mean Test Height (mm) ± SE			39.5 (± 1.5)	24.4 (± 1.0)	13.5 (± 0.5)	38.7 (± 1.3)	24.9 (± 1.2)	-
Mean Test Diameter (mm) ± SE			72.2 (± 2.2)	42.2 (± 1.5)	23.5 (± 0.5)	73.0 (± 2.9)	43.5 (± 2.2)	-
Mean Total Wet Weight (g) ± SE			125.0 (± 10.7)	30.1 (± 2.7)	6.1 (± 0.6)	131.7 (± 13.8)	29.9 (± 4.2)	-
Sample Size 2			22	26	2	14	10	0
Mean Drained Weight (g) ± SE			85.6 (± 6.6)	22.1 (± 2.1)	4.9 (± 0.1)	87.6 (± 8.5)	21.7 (± 2.7)	-
Mean Gutted Weight (g) ± SE			64.3 (± 4.9)	15.3 (± 1.6)	3.5 (± 0.3)	65.5 (± 6.6)	15.9 (± 2.2)	-
Mean Stomach and Contents Weight (g) ± SE			18.7 (± 2.3)	5.5 (± 0.7)	1.4 (± 0.2)	22.2 (± 2.3)	5.8 (± 0.7)	-
Sex	**% Male**		36	8	0	64	10	-
	% Female		18	12	0	21	30	-
	% Unknown		45	81	100	14	60	-
Gonad	**Mean Weight (g) ± SE**		16.2 (± 1.6)	2.1 (± 0.4)	0.0 (± 0.0)	14.6 (± 2.0)	1.7 (± 0.4)	-
	Colour Proportion	**0**	0.14	0.31	0.00	0.00	0.00	-
		1	0.36	0.65	0.50	0.29	0.90	-
		2	0.59	0.27	0.50	0.50	0.00	-
		3	0.05	0.00	0.00	0.21	0.10	-
		4	0.00	0.00	0.00	0.00	0.00	-
	Texture Proportion	**0**	0.14	0.31	0.00	0.00	0.00	-
		1	0.82	0.38	0.50	0.64	0.10	-
		2	0.14	0.46	0.50	0.36	0.90	-
		3	0.05	0.08	0.00	0.00	0.00	-

*Table 20. August 2009 and March 2010 Green Sea Urchin survey comparisons of percentage of highest roe quality (roe with best colour and texture) and mean roe recovery rates (total gonad weight divided by total drained weight). (Sample size = total number of urchins with roe; Inc = incomplete information, as some colour and texture data were not collected. * Note some spawning was occurring at the time of collection in the March 2010 survey, so results may be incomplete).*

Location and Date	Sample Size		Highest Quality Roe		Mean Roe Recovery Rates	
	Legal	Sublegal	Legal	Sublegal	Legal	Sublegal
Fulford Reef August, 2009	22	24	27.3%	25.0%	18.9%	9.3%
Chain Islets August, 2009	14	10	14.3%	10.0%	16.6%	7.9%
Fulford Reef March, 2010	23	26	26.1%	0.0%	6.9% *	8.8% %*
Chain Islets March, 2010	3	5	Inc	Inc	11.2% *	9.8% *

Table 21. Green Sea Urchin abundance (number), biomass density (grams/meter squared), and biomass (tonnes) in August 2009 by site and size category, with standard errors (incorporates urchins of unknown size [i.e. "unknowns"]). (Legal ≥ 55 mm test diameter [TD]; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD). Weight estimates used to determine biomass estimates were calculated using TD-weight relationships from DFO (2016b) and applied to the field survey TD measurements.

Size Category	Fulford Reef	Chain Islets
Number of Legal-sized	116,853 ± 40,663	3,127,561 ± 354,947
Number of Sublegal-mature	75,184 ± 22,470	858,416 ± 528,341
Number of Sublegal-immature	18,298 ± 3,677	153,051 ± 123,097
Total Number (all sizes)	210,335 ± 62,347	4,139,027 ± 863,935
Legal Biomass Density	103.88 ± 36.16 g/m^2	446.28 ± 50.76 g/m^2
Sublegal-mature Biomass Density	17.94 ± 5.37 g/m^2	33.61 ± 20.74 g/m^2
Sublegal-immature Biomass Density	0.52 ± 0.11 g/m^2	0.58 ± 0.47 g/m^2
Total Biomass Density	122.34 ± 36.56 g/m^2	480.47 ± 54.83 g/m^2
Biomass of Legal-size	13.44 ± 4.68 t	386.07 ± 43.91 t
Biomass of Sublegal-mature	2.32 ± 0.70 t	29.08 ± 17.94 t
Biomass of Sublegal-immature	0.07 ±0.01 t	0.50 ± 0.41 t
Total Biomass	15.83 ± 4.73 t	415.64 ± 47.43 t

Table 22. Fulford Reef Green Sea Urchin in March 2010 mean density (urchins/meter squared) by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	6	2.50	1.67	4.17 ± 2.82
1 to 5	0.3 to 1.5	16	4.50	2.13	6.63 ± 3.53
6 to 10	1.8 to 3.0	95	2.89	2.02	4.92 ± 1.10
11 to 15	3.3 to 4.8	161	0.63	0.80	1.43 ± 0.30
16 to 20	4.9 to 6.1	89	0.18	0.44	0.62 ± 0.19
21 to 25	6.4 to 7.6	100	0.57	0.26	0.83 ± 0.34
26 to 30	7.9 to 9.1	104	0.05	0.18	0.23 ± 0.09
31 to 35	9.4 to 10.7	29	0.03	0.10	0.14 ± 0.07
36 to 40	11.0 to 12.2	0	-	-	-

Table 23. Fulford Reef Green Sea Urchin mean density (urchins/meter squared) in March 2010 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
1	Smooth Bedrock	177	1.10	0.70	0.00	1.80 ± 0.55
2	Creviced Bedrock	228	1.30	1.10	0.00	2.40 ± 0.42
3	Boulders	59	0.75	1.07	0.00	1.81 ± 0.43
4	Cobble	12	0.00	0.25	0.00	0.25 ± 0.18
5	Gravel	71	0.04	0.10	0.00	0.14 ± 0.10
6	Pea gravel	5	0.00	0.00	0.00	0.00
7	Sand	11	0.00	0.00	0.00	0.00
9	Mud	0	-	-	-	-
10	Crushed Shell	3	0.00	0.00	0.00	0.00
11	Whole Shell	10	0.10	0.00	0.00	0.10 ± 0.10

Table 24. Chain Islets Green Sea Urchin mean density (urchins/meter squared) in March 2010 by size and by depth range (feet and meters) below Chart Datum(CD). (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Total = all sizes). The unmeasured urchins have been proportioned into legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns.

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-4 to 0	-1.2 to 0.0	2	0.00	0.00	0.00
1 to 5	0.3 to 1.5	8	8.63	4.38	13.00 ± 2.88
6 to 10	1.8 to 3.0	23	9.74	4.17	13.91 ± 2.78
11 to 15	3.3 to 4.8	39	6.23	1.56	7.79 ± 1.47
16 to 20	4.9 to 6.1	11	2.27	0.55	2.82 ± 1.17
21 to 25	6.4 to 7.6	4	0.00	0.00	0.00
26 to 30	7.9 to 9.1	5	0.00	0.20	0.20 ± 0.20
31 to 35	9.4 to 10.7	5	0.00	0.00	0.00

Table 25. Chain Islets Green Sea Urchin mean density (urchins/meter squared) in March 2010 by size and primary substrate type. (Legal ≥ 55 mm TD; Sublegal < 55 mm TD; Unknown = unmeasured; Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density
1	Smooth Bedrock	78	0.00	0.00	0.00	0.00
2	Creviced Bedrock	67	4.67	1.46	2.81	8.94 ± 1.32
3	Boulders	10	4.60	2.00	2.10	8.70 ± 2.91
4	Cobble	0	-	-	-	-
5	Gravel	10	1.60	0.60	0.20	2.40 ± 0.90
6	Pea gravel	0	-	-	-	-
7	Sand	0	-	-	-	-
9	Mud	0	-	-	-	-
10	Crushed Shell	3	7.33	2.33	6.67	16.33 ± 8.57
11	Whole Shell	3	0.00	0.33	0.00	0.33 ± 0.33

Table 26. Summary results of measurements taken during Green Sea Urchin dissections in the March 2010 survey. Note many urchins began spawning during dissection, so weights are only approximate. (Legal ≥ 55 mm TD; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD; SE = standard error; Gutted Weight = stomach and contents removed; Gonad Colour: 0=unknown or no sample, 1=orange/yellow, 2=yellow with other colours, 3=brown/red, 4=very pale orange; Gonad Texture: 0 = unknown or no sample, 1 = firm, 2 = semi-firm, 3 = flimsy; Sex: 1 = male, 2 = female, 3 = juvenile or unknown. Sample Size 1 is for test height, TD and total wet weight. Sample Size 2 is for all other calculations).

Summary Information			LOCATION					
			FULFORD REEF			CHAIN ISLETS		
			Legal	Sublegal-mature	Sublegal–immature	Legal	Sublegal–mature	Sublegal–immature
Sample Size 1			60	48	0	20	13	0
Mean Test Height (mm) ± SE			37.0 (± 0.7)	23.1 (± 0.5)	-	38.9 (± 1.2)	25.3 (± 1.5)	-
Mean Test Diameter (mm) ± SE			66.4 (± 1.2)	41.3 (± 0.9)	-	67.0 (± 1.7)	44.1 (± 2.4)	-
Mean Total Wet Weight (g) ± SE			100.5 (± 5.5)	25.4 (± 1.4)	-	98.3 (± 7.8)	30.6 (± 4.2)	-
Sample Size 2			19	30	0	3	6	0
Mean Drained Weight (g) ± SE			68.9 (± 5.0)	20.5 (± 1.4)	-	72.6 (± 5.6)	22.8 (± 5.2)	-
Mean Gutted Weight (g) ± SE			54.8 (± 4.5)	13.9 (± 1.1)	-	49.4 (± 4.6)	14.4 (± 3.7)	-
Mean Stomach and Contents Weight (g) ± SE			14.1 (± 1.0)	6.6 (± 0.4)	-	23.2 (± 1.4)	8.4 (± 1.5)	-
Sex	**% Male**		32	23	-	100	50	-
	% Female		63	7	-	0	0	-
	% Unknown		5	70	-	0	50	-
Gonad	**Mean Weight (g) ± SE**		16.9 (± 2.2)	1.7 (± 0.4)	-	8.1 (± 3.4)	1.9 (± 1.1)	-
	Colour Proportion	**0**	0.00	0.13	-	0.67	0.83	-
		1	0.63	0.70	-	0.00	0.17	-
		2	0.05	0.10	-	0.00	0.00	-
		3	0.00	0.00	-	0.00	0.00	-
		4	0.32	0.07	-	0.33	0.00	-
	Texture Proportion	**0**	0.00	0.13	-	0.67	0.83	-
		1	0.32	0.00	-	0.00	0.00	-
		2	0.11	0.50	-	0.00	0.00	-
		3	0.58	0.37	-	0.33	0.17	-

Table 27. Green Sea Urchin abundance (number), biomass density (grams/meter squared), and biomass (tonnes) in March 2010 by site and size category, with standard errors (incorporates urchins of unknown size [i.e. "unknowns"]). (Legal ≥ 55 mm test diameter [TD]; Sublegal-mature 25 mm ≤ TD < 55 mm; Sublegal-immature < 25 mm TD). Weight estimates used to determine biomass estimates were calculated using TD-weight relationships from DFO (2016b) and applied to the field survey TD measurements.

Size Category	Fulford Reef	Chain Islets
Number of Legal-sized	119,657 ± 36,323	2,924,038 ± 2,445,184
Number of Sublegal-mature	87,043 ± 22,080	854,952 ± 639,892
Number of Sublegal-immature	12,561 ± 2,468	65,766 ± 46,901
Total Number (all sizes)	219,261 ± 58,766	3,844,756 ± 3,116,929
Legal Biomass Density (g/m^2)	100.39 ± 30.50 g/m^2	368.68 ± 308.44 g/m^2
Sublegal-mature Biomass Density	20.35 ± 5.17 g/m^2	35.40 ± 26.54 g/m^2
Sublegal-immature Biomass Density	0.27 ± 0.05 g/m^2	0.34 ± 0.25 g/m^2
Total Biomass Density (g/m^2)	121.00 ± 30.93 g/m^2	404.42 ± 309.58 g/m^2
Biomass of Legal-size (t)	12.56 ± 3.81 t	318.93 ± 266.82 t
Biomass of Sublegal-mature (t)	2.59 ± 0.66 t	30.63 ± 22.96 t
Biomass of Sublegal-immature (t)	0.04 ± 0.01 t	0.29 ± 0.21 t
Total Biomass (t)	15.18 ± 3.87 t	349.85 ± 267.81 t

Table 28. Green Sea urchin commercial fishery harvest details for PFMA 19, (Statistical Area 19-4; where the study area is located) and Fulford Reef and the Chain Islets. The total allowable catch (TAC) for PFMA 19 was 26,450 lbs (12.0 t) for every fishing season from 2007/08 to 2009/10. (Data from fishing logbook data, courtesy of DFO Shellfish Data Unit, PBS, Nanaimo, B.C.)

Fishing Season	PFMA 19 Harvested (lbs)	% PFMA 19 TAC achieved	Fulford Reef Harvested	% PFMA 19 TAC (Fulford)	Exploitation at Fulford Reef	Chain Islets Harvested	% PFMA 19 TAC (Chain)	Exploitation at Chain Islets	% PFMA 19 TAC (Remainder)
2007/08	26,402 lbs (11.98 t)	99.80%	21,097 lbs (9.57 t)	79.8%	Unknown – no survey Fall 2007	5,305 lbs (2.41 t)	20.1%	Unknown – no survey Fall 2007	0%
2008/09	25,836 lbs (11.72 t)	97.70%	20,649 lbs (9.37 t)	78.1%	Unknown – no survey Fall 2008	5,187 lbs (2.35 t)	19.6%	Unknown – no survey Fall 2008	0%
2009/10	23,787 lbs (10.79 t)	89.90%	6,884 lbs (3.12 t)	26.0%	0.232 ± 0.081	14,763 lbs (6.70 t)	55.8%	0.017 ± 0.002	8.1%

Table 29. Chronology of commercial fishing events and associated harvests and survey biomass estimates of legal-sized Green Sea Urchins at Fulford Reef and the Chain Islets. Note catch has been converted from pounds to kilograms. (Data from fishing logbook data, courtesy of DFO Shellfish Data Unit, PBS, Nanaimo, B.C.)

Events	Dates	Amount Harvested or Legal Biomass (t)	
		Fulford Reef	Chain Islets
2007/08 Fishing Season	Sep 21/07 to Mar 21/08	9.57 t	2.41 t
March 2008 Survey	March 3-5/08	26.89 (± 9.69) t	355.49 (± 131.1) t
NO FISHING	Mar 21/08 to Sep 3/08	-	-
2008/09 Fishing Season	Sep 3/08 to Sep 29/08	9.37 t	2.35 t
NO FISHING	Sep 30/08 to Mar 8/09	-	-
March 2009 Survey	Mar 8/09	13.70 (± 4.48) t	-
NO FISHING	Mar 8/09 to Sep 11/09	-	-
August 2009 Survey	Aug 27-28/09	13.44 (± 4.68) t	386.07 (± 43.91) t
2009/10 Fishing Season	Sep 11/09 to Mar 31/10	3.12 t	6.70 t
March 2010 Survey	Mar 24-25/10	12.56 ± 3.81 t	318.93 ± 266.82 t

FIGURES

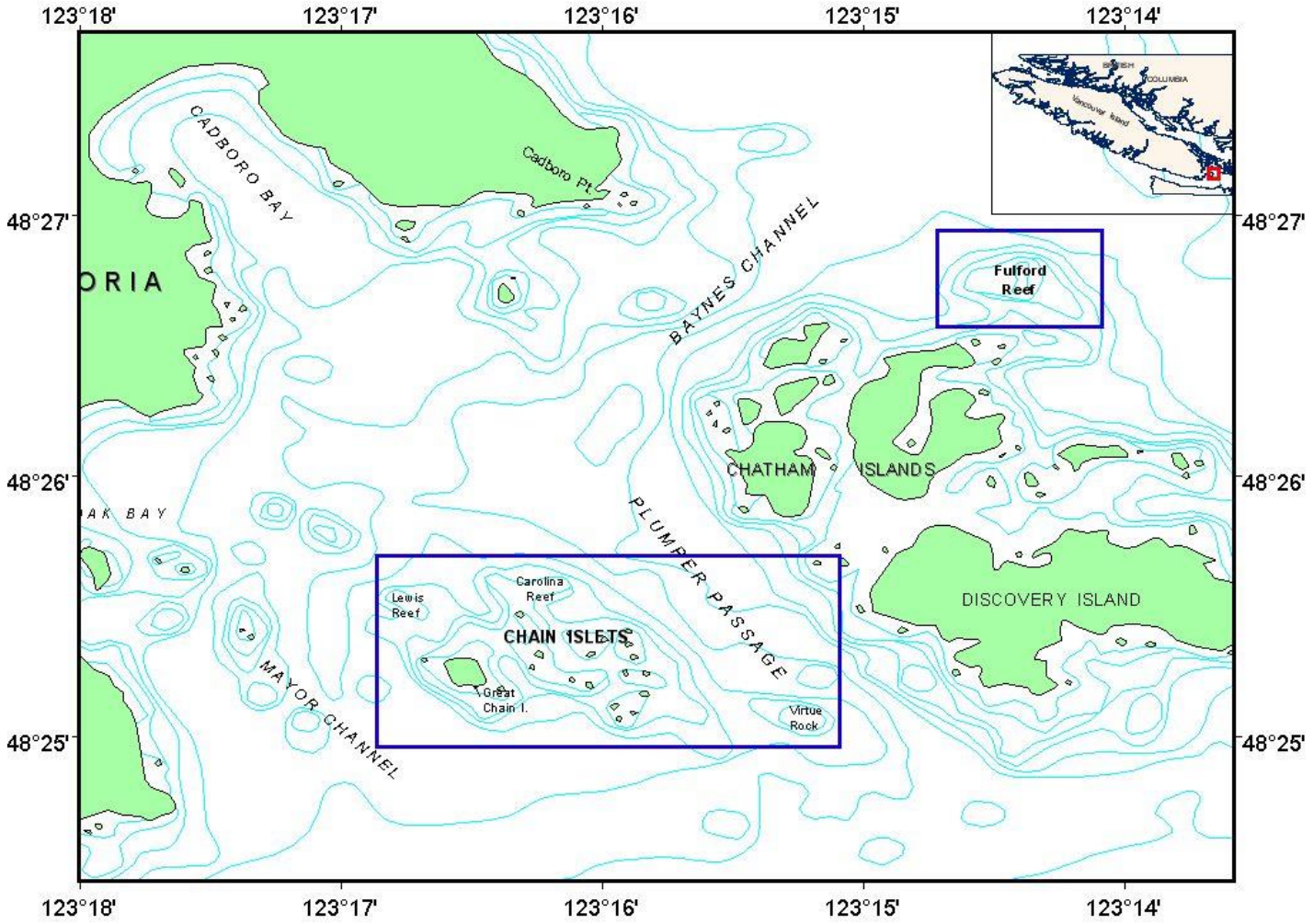

Figure 1. Site locations for the March 2008, March 2009, August 2009 and March 2010 Green Sea Urchin surveys in PFMA 19, near Victoria (Fulford Reef [see Figure 2] and the Chain Islands [see Figure 3]).

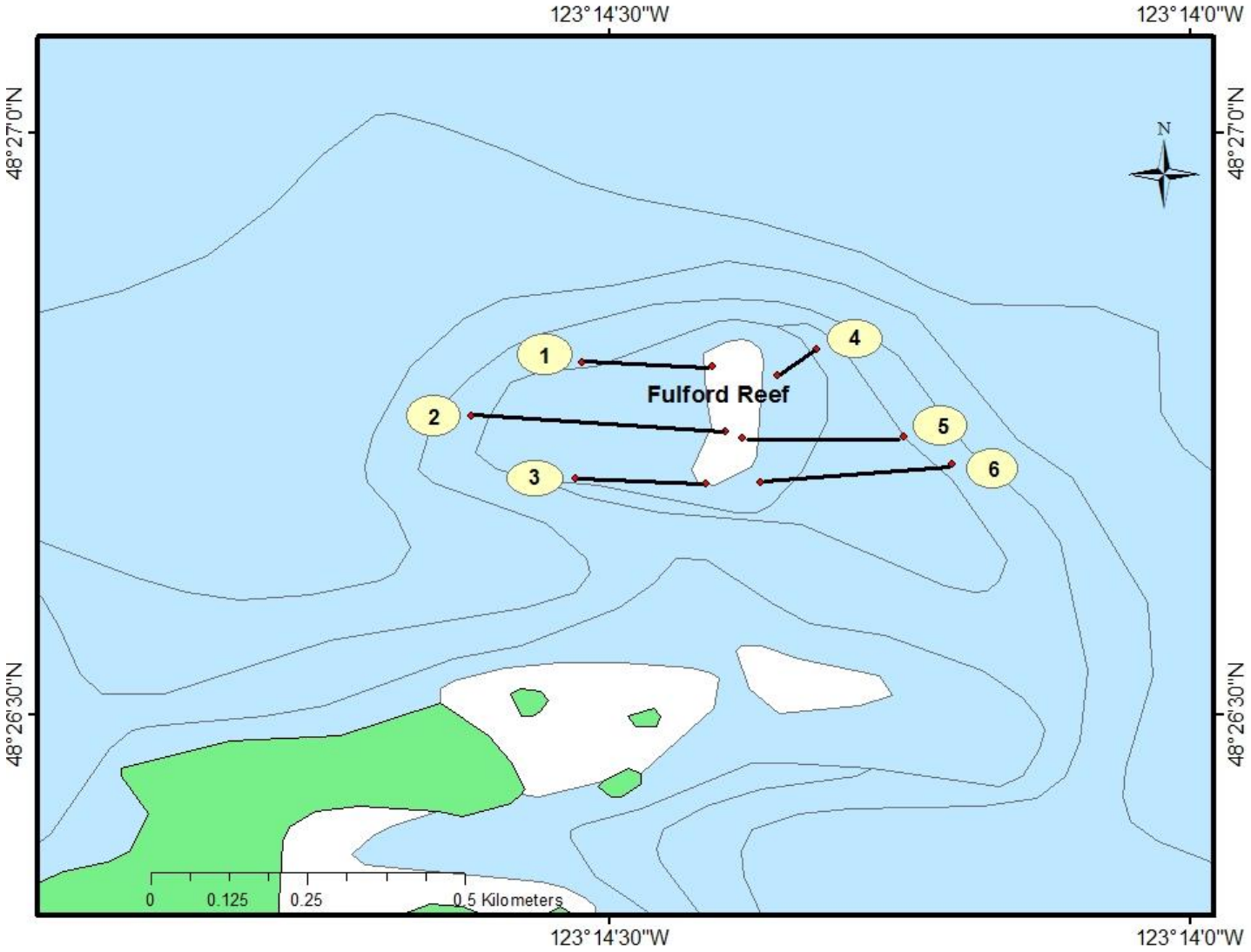

Figure 2. Fulford Reef Green Sea Urchin survey transects by number and location (black lines with red end points).

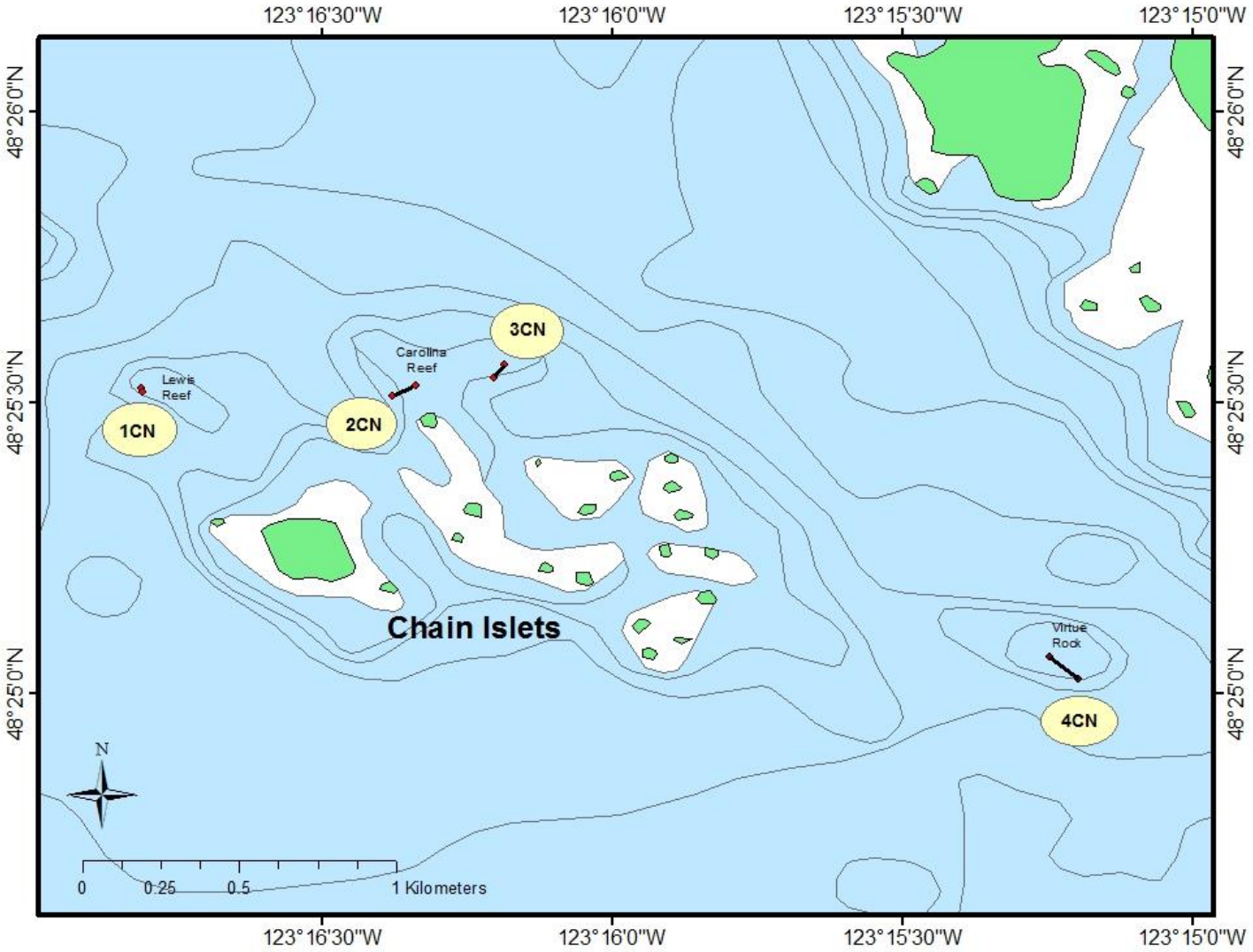

Figure 3. Chain Islets Green Sea Urchin survey transects by number and location (black lines with red end points).

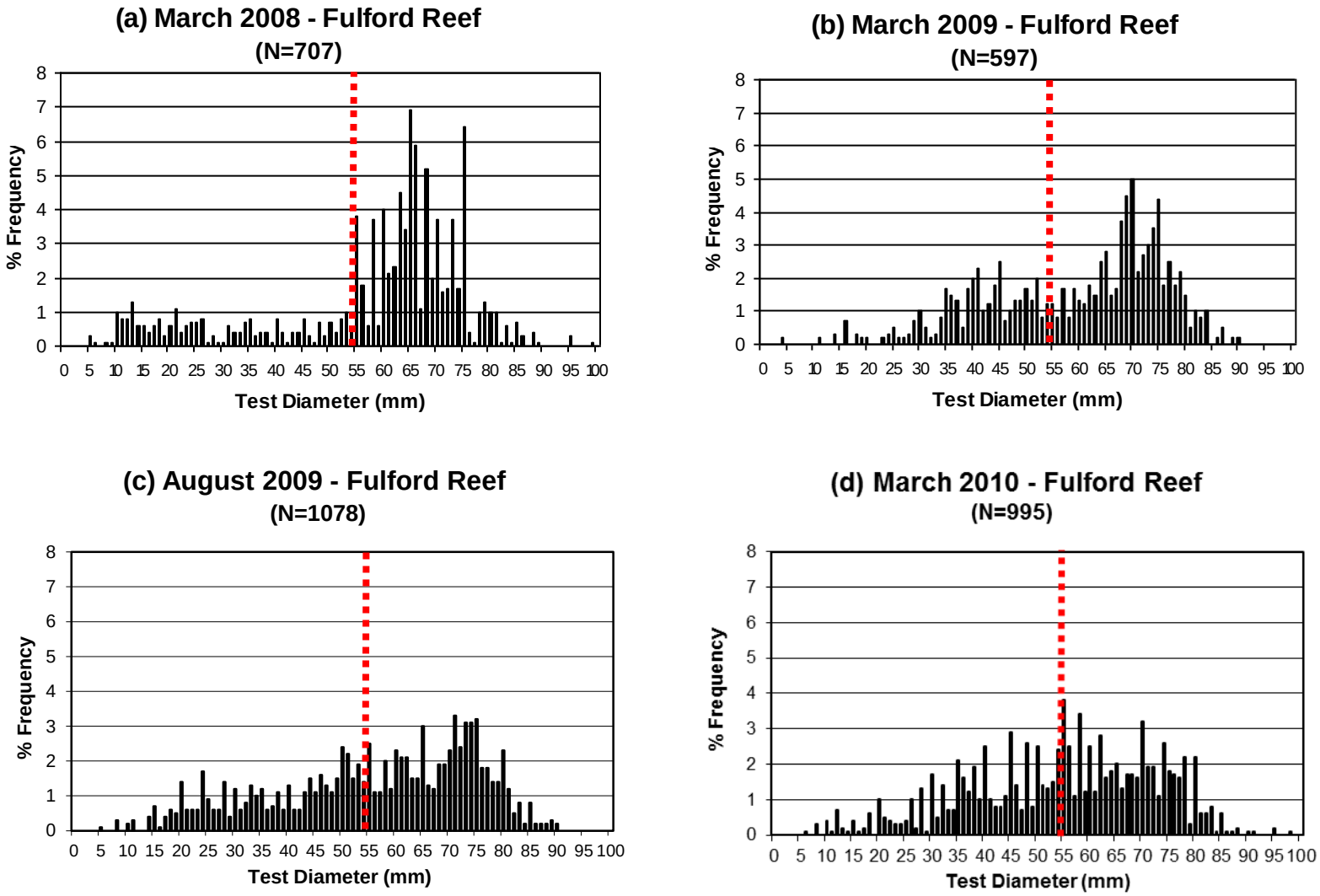

Figure 4. Fulford Reef Green Sea Urchin size (test diameter in millimeters) distributions in: (a) March 2008; (b) March 2009; (c) August 2009; and (d) March 2010. Note the fishery minimum size limit is 55 mm.

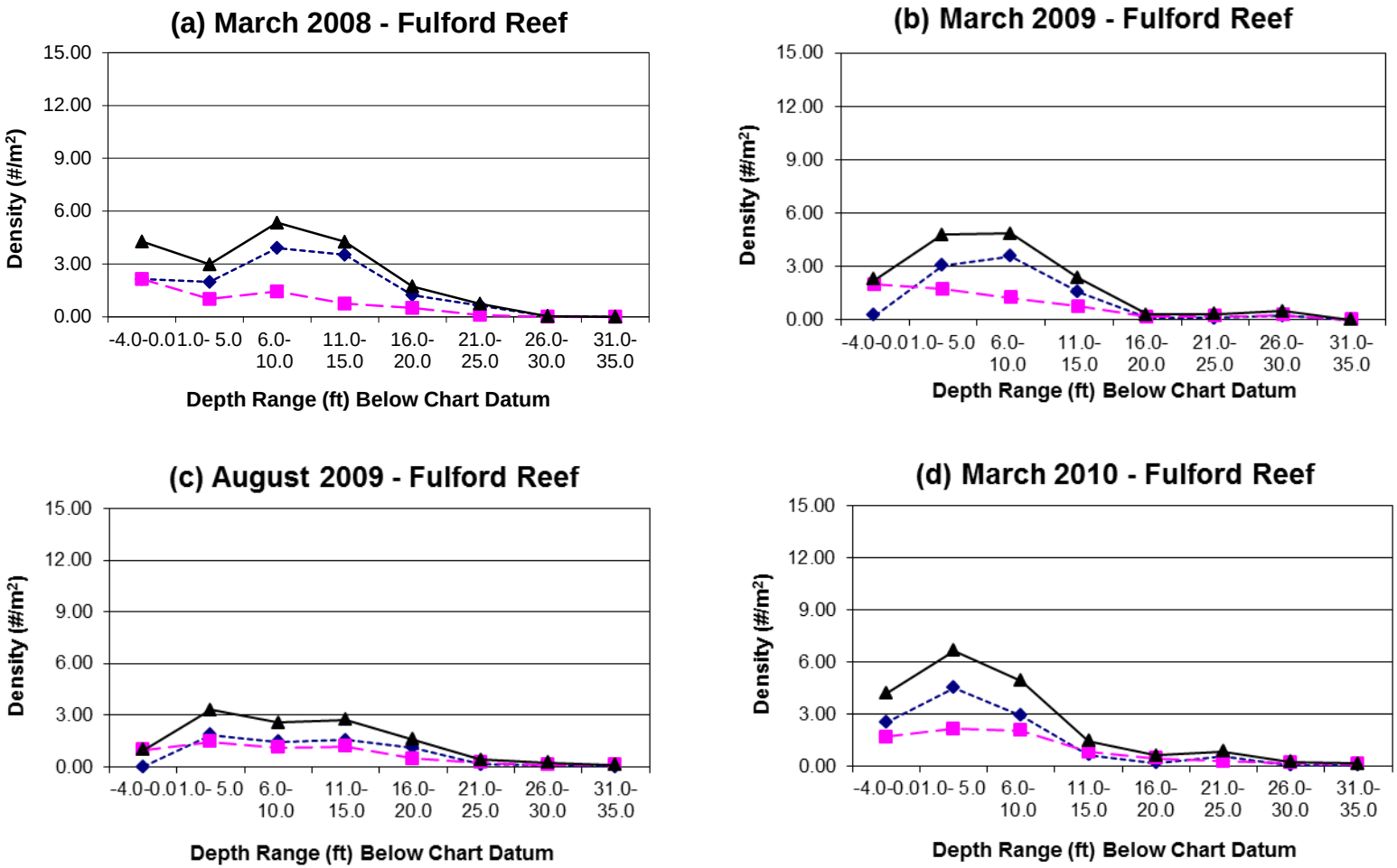

Figure 5. *Fulford Reef Green Sea Urchin mean density (number per square meter) by depth range (feet) below Chart Datum in: (a) March 2008; (b) March 2009; (c) August 2009; and (d) March 2010. (All sizes [total] = black triangles, legal size = blue diamonds, and sublegal size = red squares).*

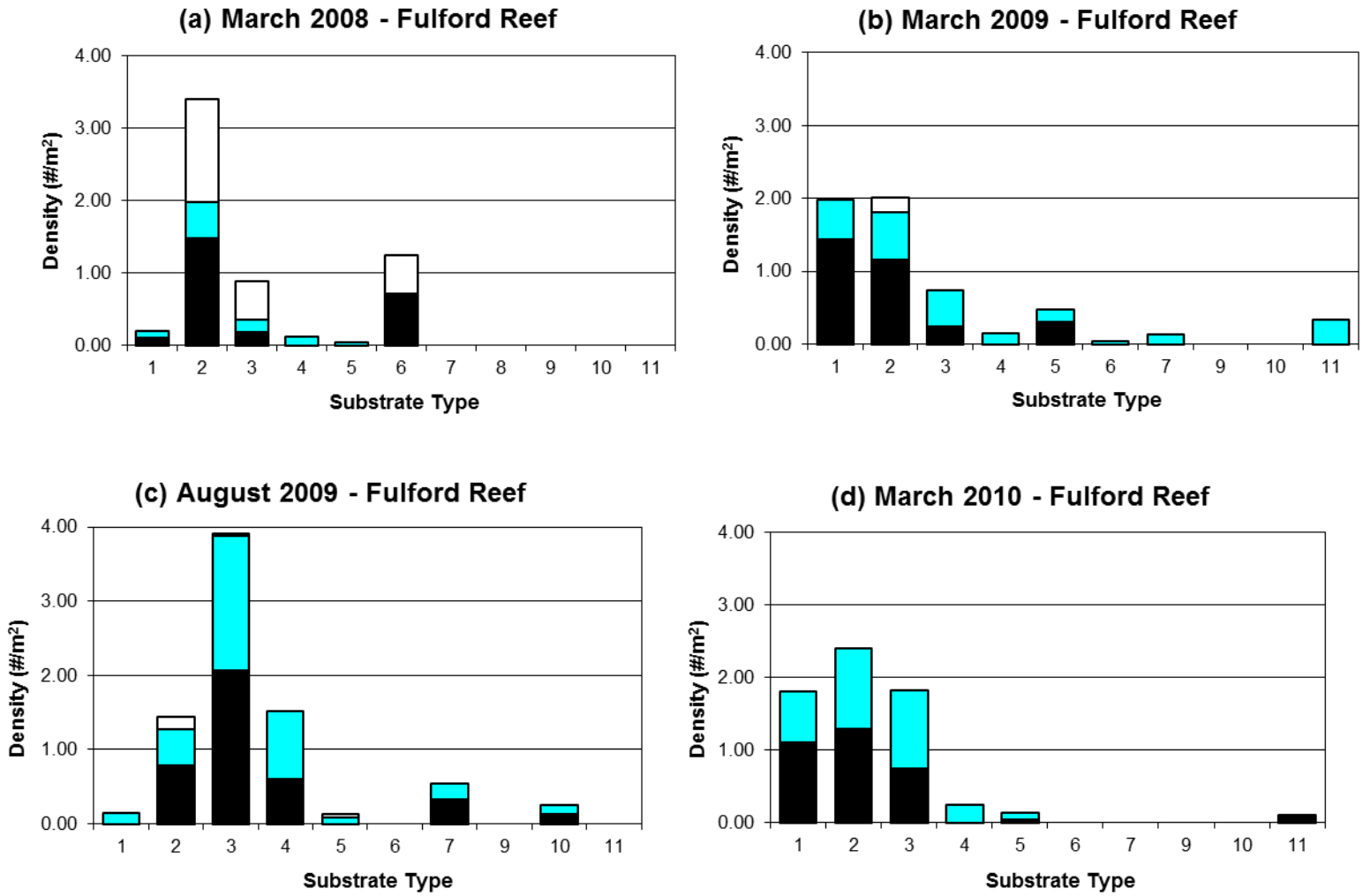

Figure 6. *Fulford Reef Green Sea Urchin mean density (number per square meter) by primary substrate type in: (a) March 2008; (b) March 2009; (c) August 2009; and (d) March 2010. (See Tables 7 or 14 for the keys to the substrate codes). Black = legal size; blue = sublegal size; white = unknown size (unmeasured).*

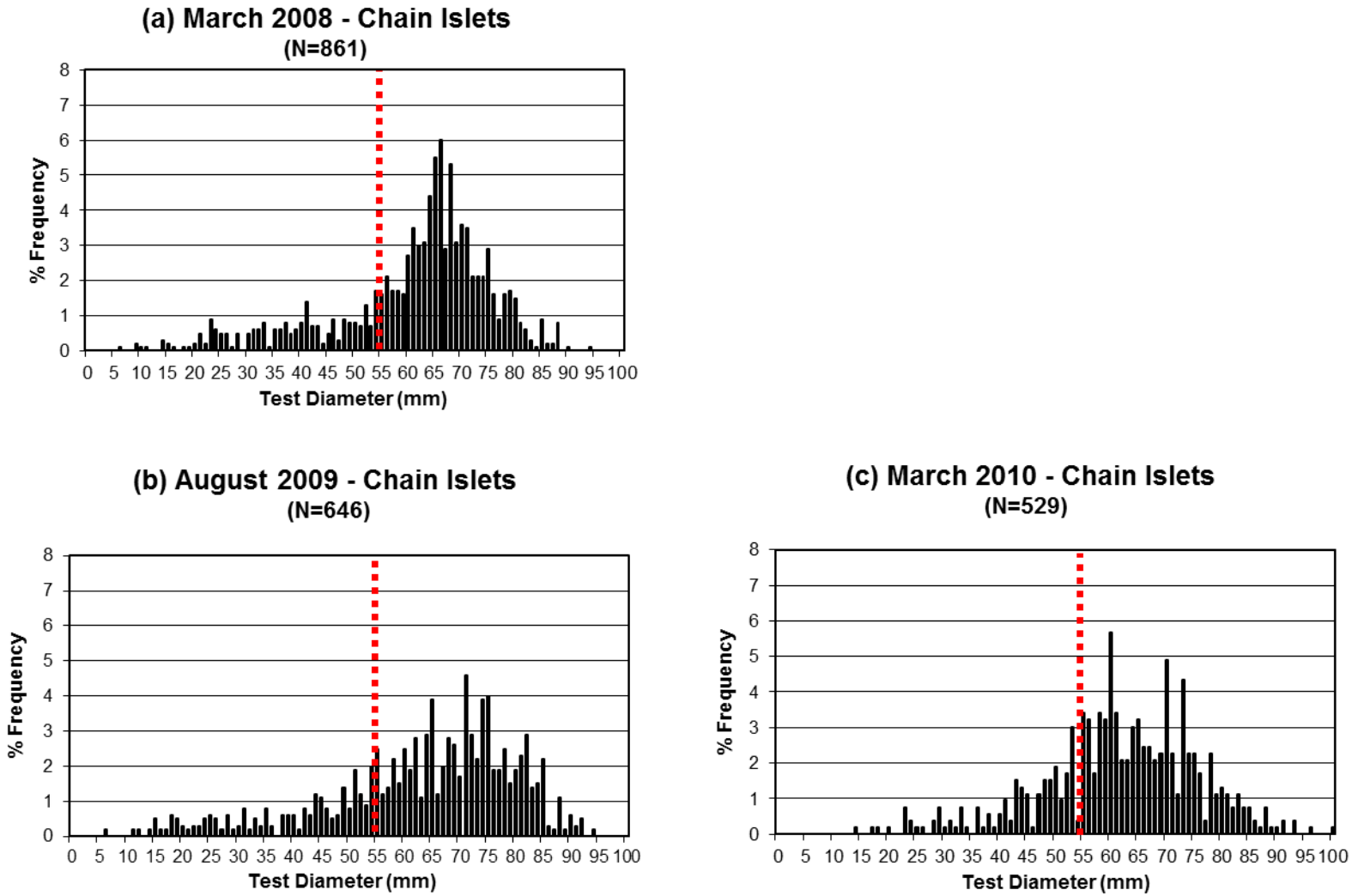

Figure 7. Chain Islets Green Sea Urchin size (test diameter in millimeters) distributions in (a) March 2008; (b) August 2009; and (c) March 2010. Note the fishery minimum size limit is 55 mm.

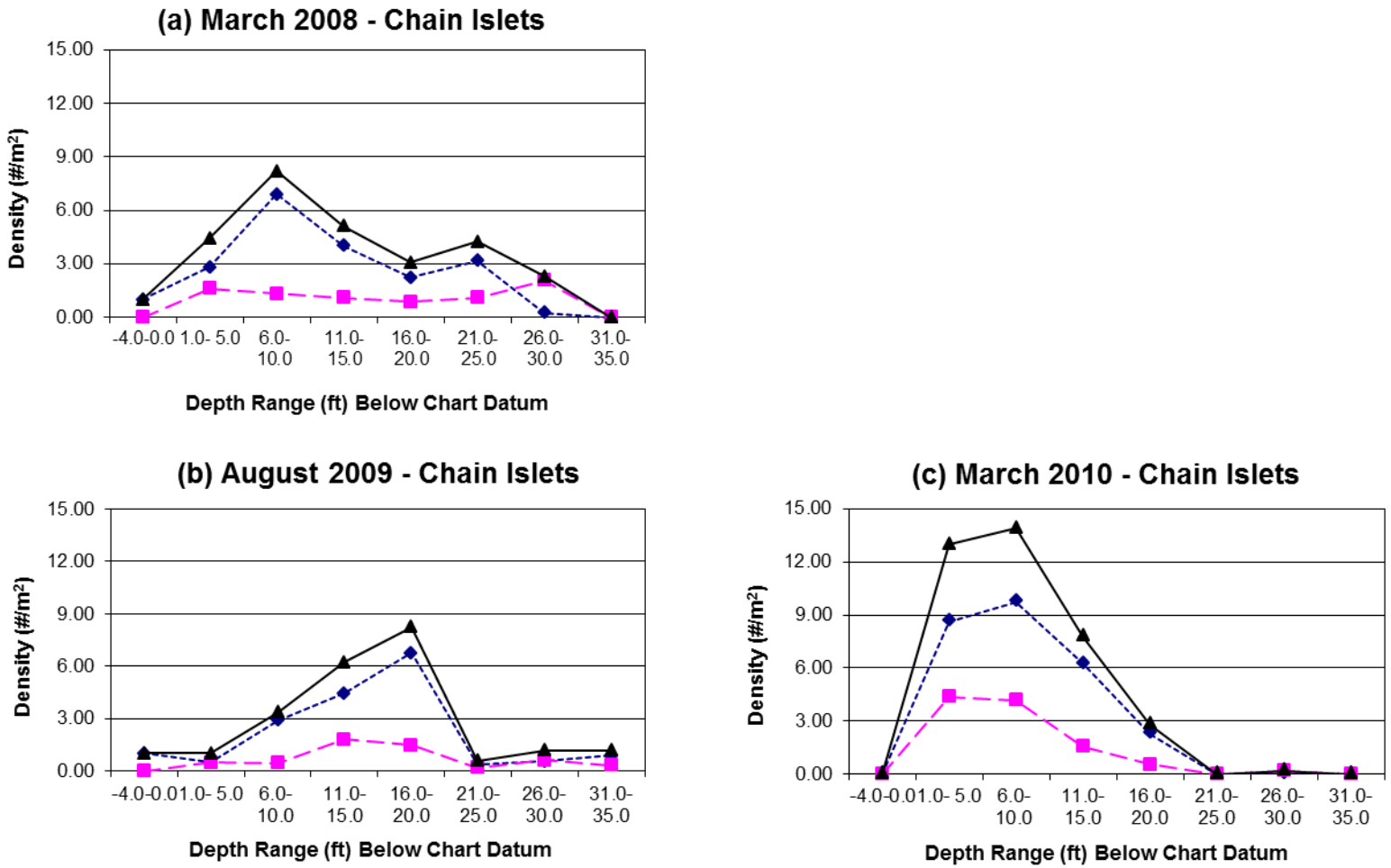

Figure 8. Chain Islets Green Sea Urchin mean densities (number per square meter) by depth range (feet) below Chart Datum in: (a) March 2008, (b) August 2009, and (c) March 2010. (Black triangles = all sizes [total]; blue diamonds = legal size; red squares = sublegal size).

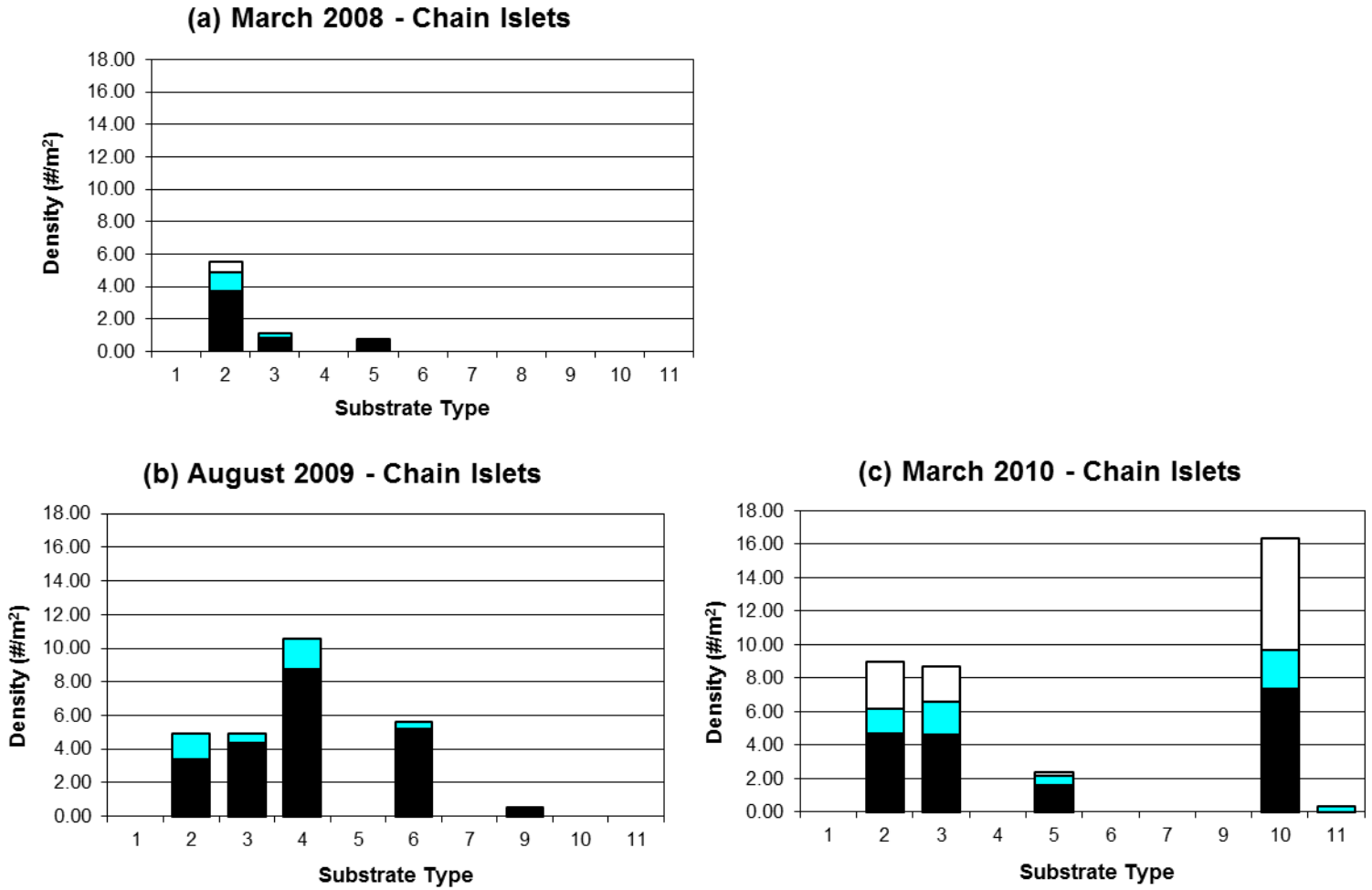

Figure 9. Chain Islets Green Sea Urchin mean density (number per square meter) by primary substrate type in: (a) March 2008; (b) August 2009; and (c) March 2010. See Tables 11 or 19 for the keys to the substrate codes. Black = legal size; blue = sublegal size; white = unknown size (unmeasured).

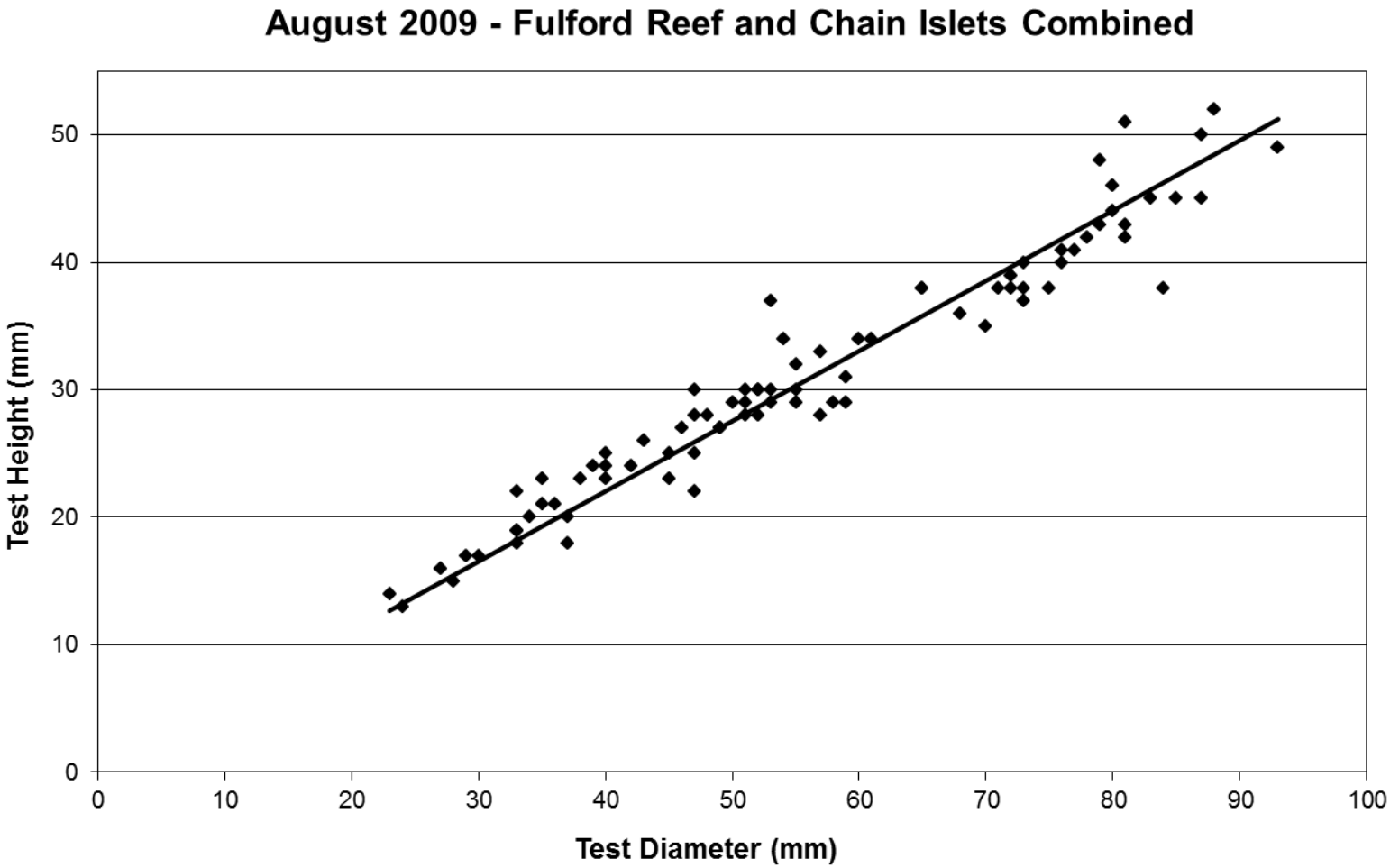

Figure 10. Relationship between Green Sea Urchin test diameter (TD, in millimeters) and test height (millimeters) in August 2009, for both sites combined: TEST HEIGHT (mm) = 0.551(TD), R^2 = 0.935, n=83.

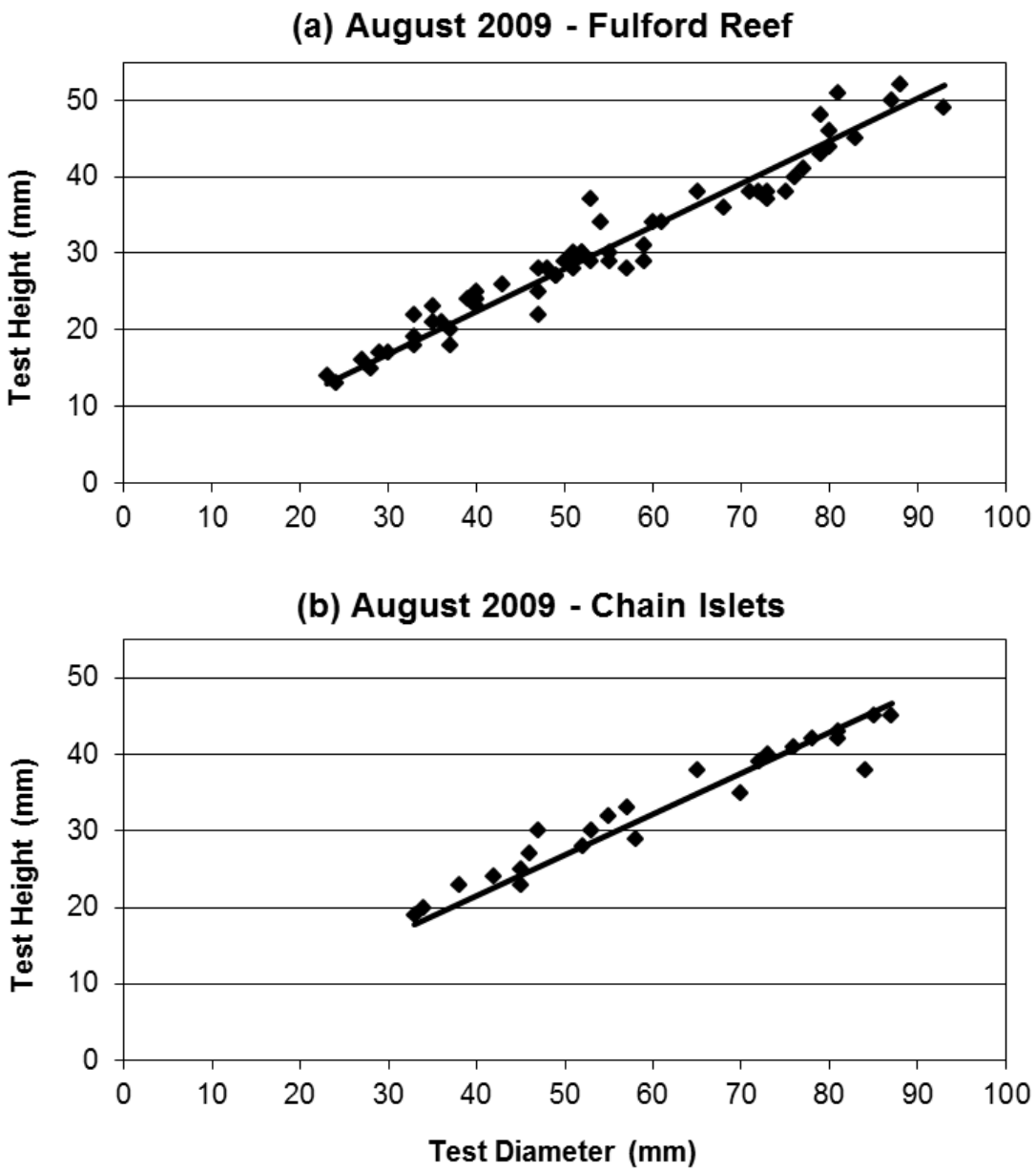

Figure 11. Relationships between Green Sea Urchin test diameter (TD, in millimeters) and test height (millimeters) calculated in August 2009 for sublocations:
(a) Fulford Reef (TEST HEIGHT (mm) = 0.558(TD), R^2 = 0.9445, n=59);
(b) Chain Islets (TEST HEIGHT (mm) = 0.5367(TD), R^2 = 0.9129, n=24).

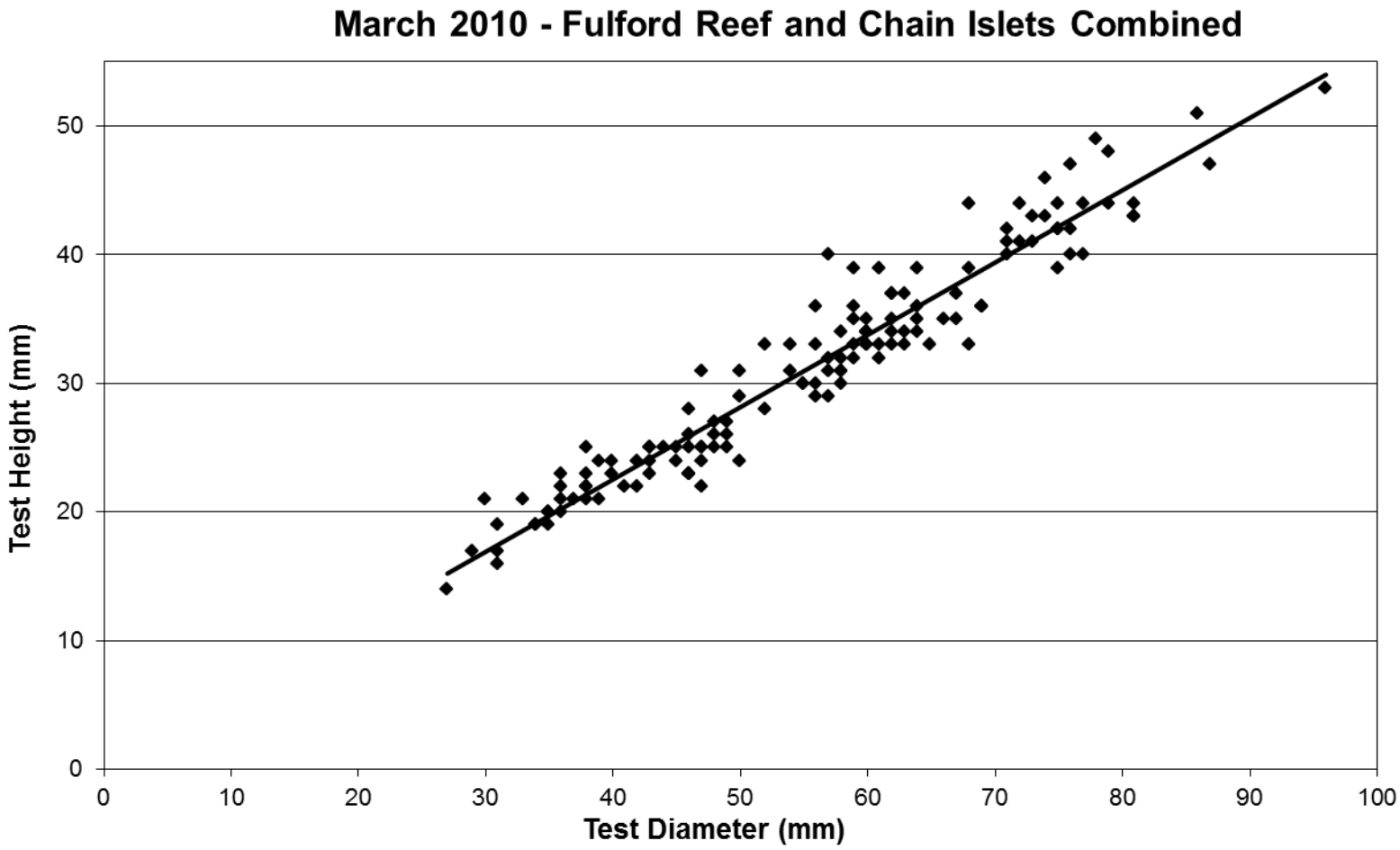

Figure 12. Relationship between Green Sea Urchin test diameter (TD, in millimeters) and test height (millimeters) in March 2010, for both sites combined : TEST HEIGHT (mm) = 0.5628(TD), R^2 = 0.9273, n=141.

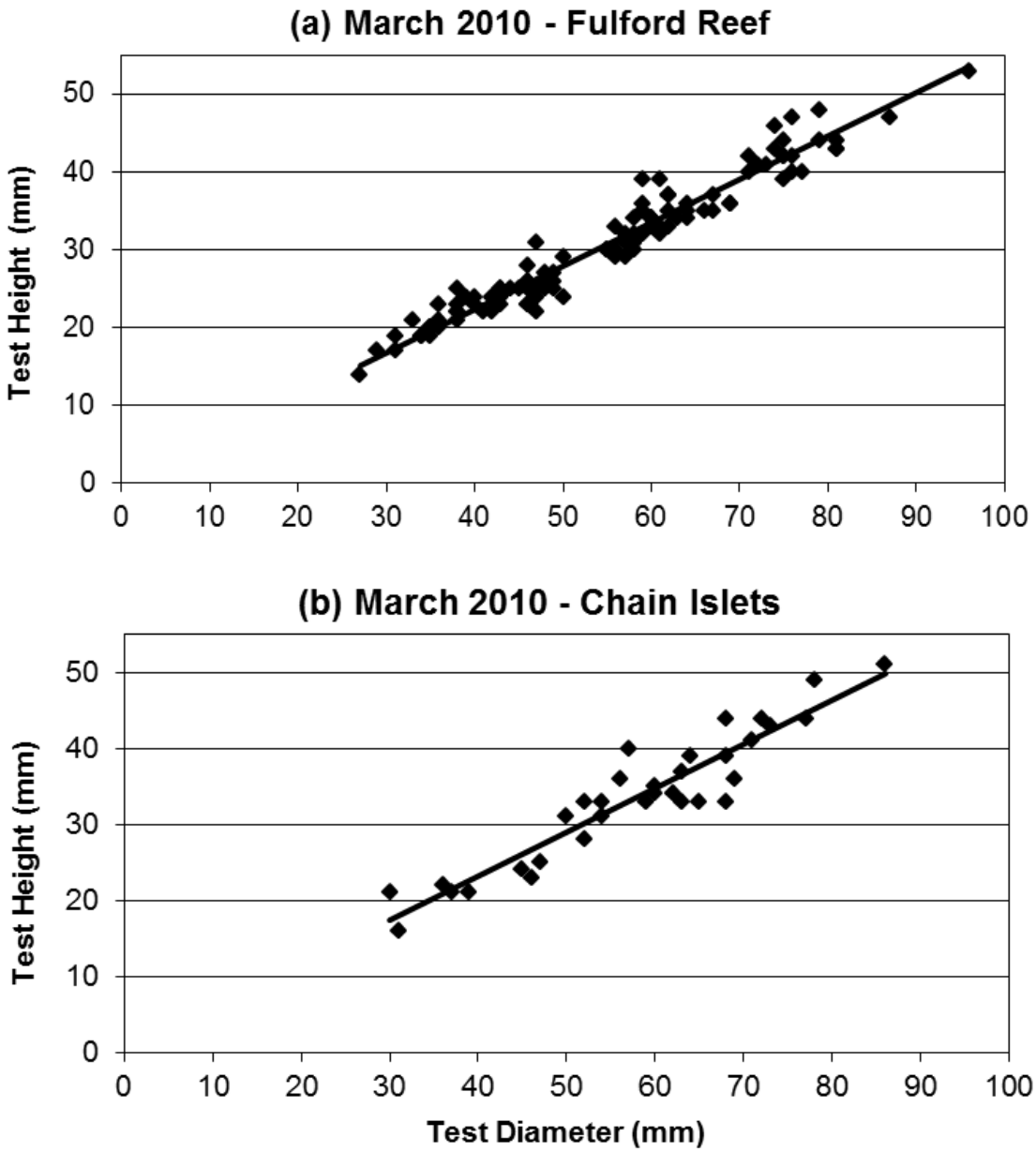

Figure 13. Relationships between Green Sea Urchin test diameter (TD, in millimeters) and test height (millimeters) calculated in March 2010 for sublocations:
(a) Fulford Reef (TEST HEIGHT (mm) = 0.5574(TD), R^2 = 0.9441, n=108);
(b) Chain Islets (TEST HEIGHT (mm) = 0.5794(TD), R^2 = 0.8871, n=33).

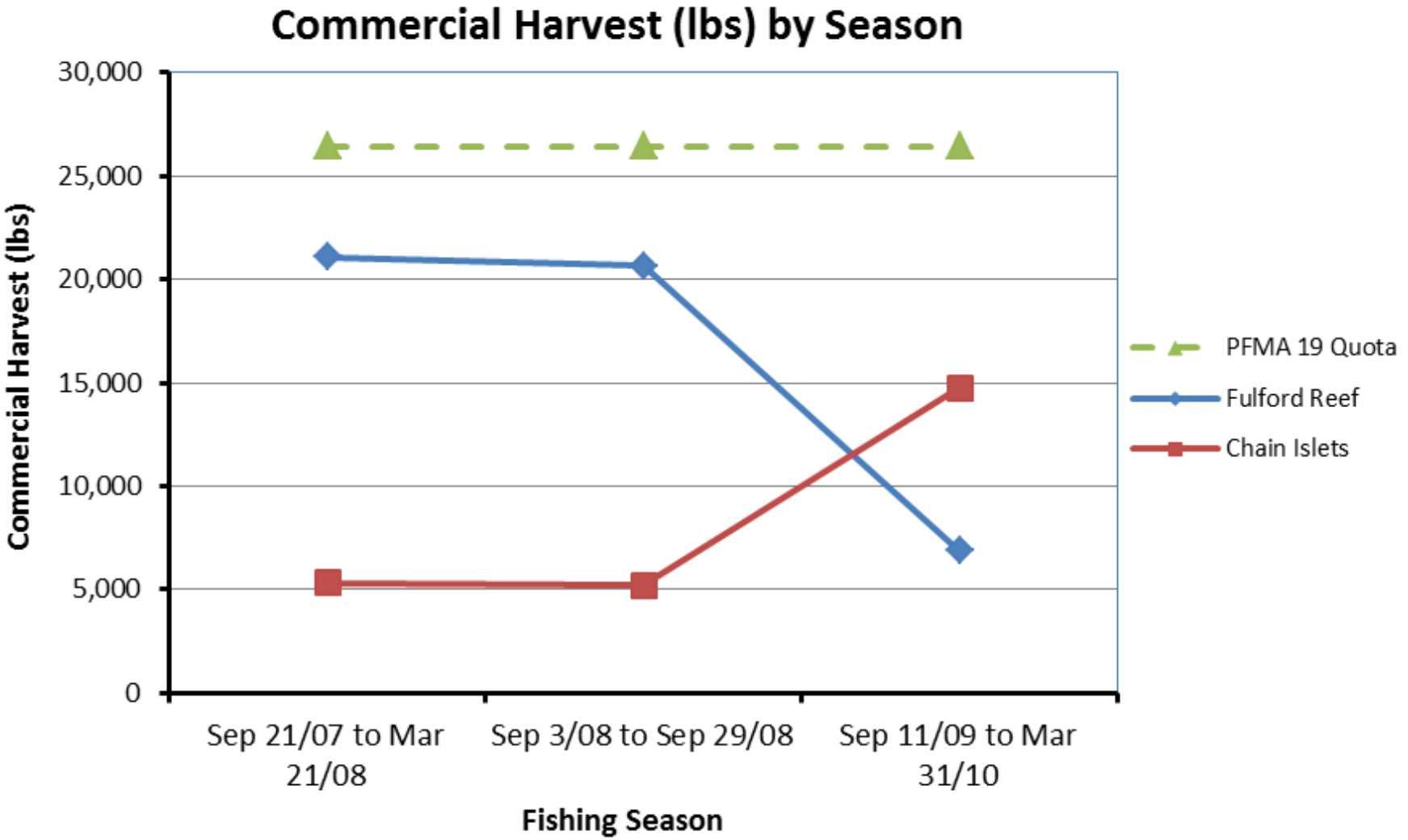

Figure 14. Green Sea Urchin commercial harvest (in pounds) at Fulford Reef and the Chain Islets by fishing season.

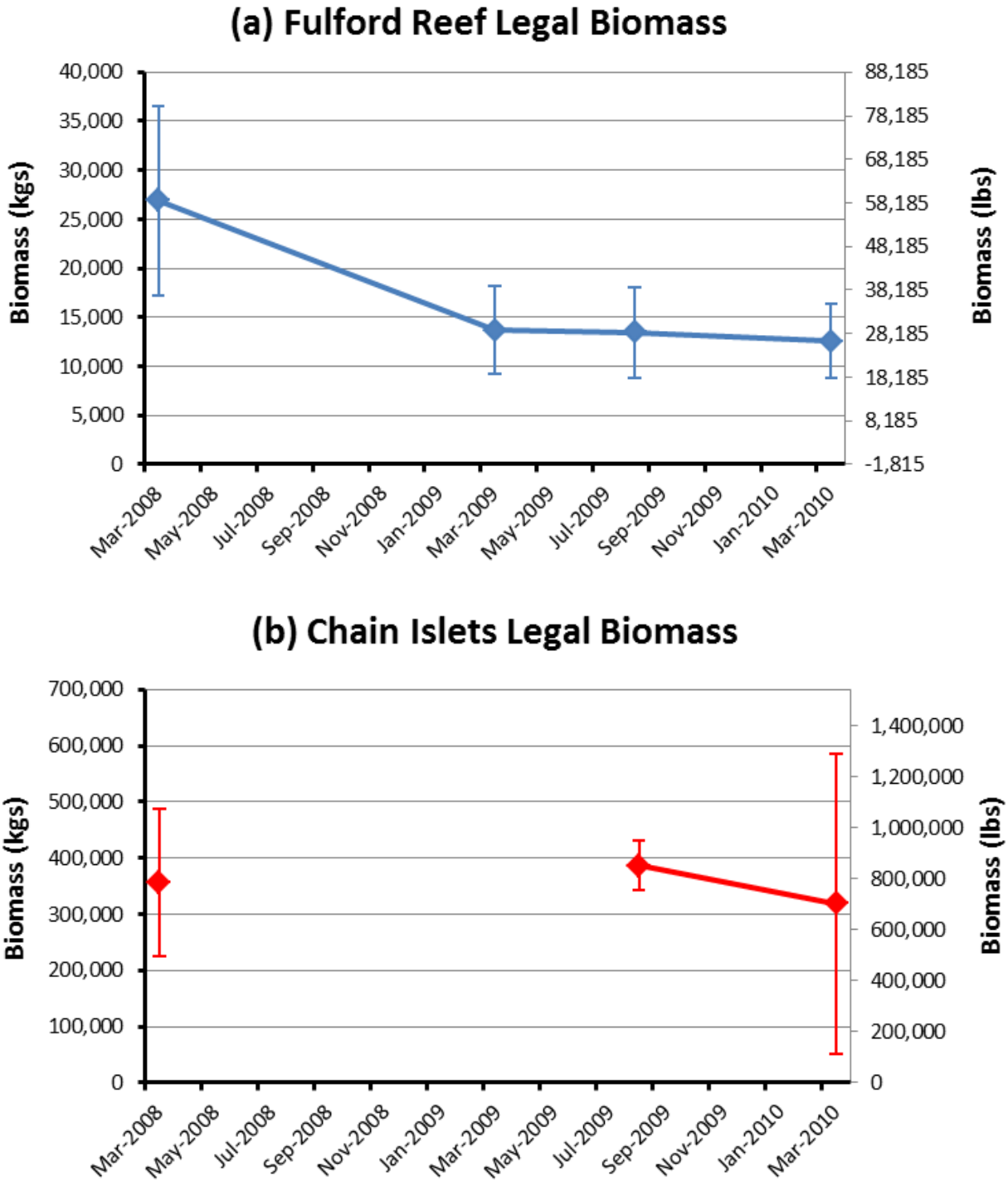

Figure 15. The biomass estimates of legal-sized Green Sea Urchins at: (a) Fulford Reef, and (b) the Chain Islets from fishery-independent surveys.