Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

Canadian Science Advisory Secretariat
Pacific Region **Science Response 2014/052**

STOCK STATUS UPDATE AND QUOTA OPTIONS FOR THE GREEN SEA URCHIN *(STRONGYLOCENTROTUS DROEBACHIENSIS)* FISHERY IN BRITISH COLUMBIA, 2013-2016

Context

Stock assessments and quota options for British Columbia's Green Sea Urchin (*Strongylocentrotus droebachiensis*) fishery are conducted every three years. They provide advice to Fisheries and Oceans Canada (DFO) Fisheries Management for the development of the fishery's multi-year Integrated Fishery Management Plans (IFMPs). The last stock assessment was conducted in 2010 (Waddell et al. 2010). The present paper updates the previously published assessment results using the most recently available commercial catch and survey information. A new three-year IFMP for 2013-2016 will be developed following advice from this paper.

DFO Fisheries Management has requested advice for the Green Sea Urchin fishery in British Columbia (BC), by spring 2013, on the following: 1 - the ranges of sustainable harvest quotas for the commercial harvest areas (Pacific Fisheries Management Areas (PFMAs) 12, 13, 18 and 19); 2 - the risks or uncertainties associated with the range of harvest options; 3 - the recent trends in the local populations and population structure for Green Sea Urchins where data exist; and 4 - recommendations for additional research or stock assessment programs.

This paper assesses Green Sea Urchin stocks in regions of BC open to commercial fishing, through the analysis of fishery-dependent and fishery-independent data. The quota options presented are derived from a Bayesian assessment model that has been used in the assessment of BC's Green Sea Urchin stock since 2003 (Perry et al. 2003; Zhang and Perry 2005; Perry et al. 2006; Waddell et al. 2010). Modifications to the survey protocol, which took place in 2011, are described and results compared to previous methods.

This Science Response Report results from the Science Special Response Process of April 2013 on Stock Status Update and Quota Options for the Green Sea Urchin (*Strongylocentrotus droebachiensis*) Fishery in British Columbia, 2013-2016.

Background

Biology

Green Sea Urchins (Figure 1) are a benthic invertebrate with a wide geographic distribution, occurring in cool temperate waters in both the Pacific and Atlantic Oceans. In the Pacific, they occur from northern Washington State, through the Aleutian Islands, Alaska, and west to the Korean Peninsula, Kamchatka, Russia and Hokkaido, Japan. Green Sea Urchins occur intertidally and subtidally to depths of over 140 metres. Preferred habitat is rocky, gravel or shell substrates. Kelp and marine algae are their principal food.

Green Sea Urchins are broadcast spawners. Spawning is seasonal and varies by region, occurring from February to March in BC. The larval period can last from 7 to 22 weeks (Strathmann 1978). In southern BC, Green Sea Urchins reach sexual maturity at a test diameter of about 25 mm (Waddell et al. 2002) and the minimum legal size is 55 mm, which in Alaska correspond to 2-3 year olds and 4 year olds, respectively (Munk 1992).

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

Fishery

British Columbia's commercial harvest of Green Sea Urchins began in 1987. The fishery was managed with few restrictions until 1991, when license limitation was introduced to control record high effort and catches, followed by quota limitations in 1994 and an individual quota system with dockside validation in 1995.

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

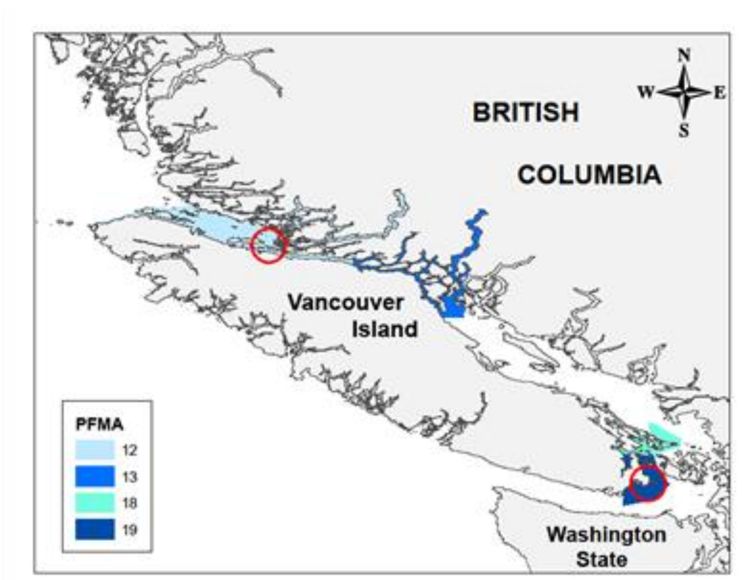

Figure 2. Map of southern British Columbia showing the four Pacific Fisheries Management Areas (12, 13, 18 and 19) open to the Green Sea Urchin fishery. Red circles denote survey locations.

Green urchins are hand-picked by SCUBA divers who work from small fishing vessels. Commercial fishing generally takes place from early fall to spring of the following year, with the highest market prices usually occurring around Christmas. The IFMP runs from September 1 to August 31. The commercial fishery is managed with a minimum 55 mm test diameter size, licence limitation, area quotas, individual quotas and area closures. The majority of the catch is shipped to the live market in Japan where the roe (called 'uni') is used to make sushi.

Analysis and Response

Fishery-dependent data

Fishery-dependent data were derived from harvest logbooks, validation logs and sales slip data.

Since the establishment of individual quotas in 1995 and until 2003/04, Green Sea Urchin landings have generally come close to achieving the quotas (Figure 3). From 2004 to the present, however, total landings, landed value and total effort have been the lowest since the inception of the fishery (Figures 3, 4 and 5). Over the last eight seasons, only 11-50 % of the quota has been landed (Figure 3). The low landings have been attributed to low demand and low prices for Canadian sea urchins and are not indicative of low stock abundance in BC.

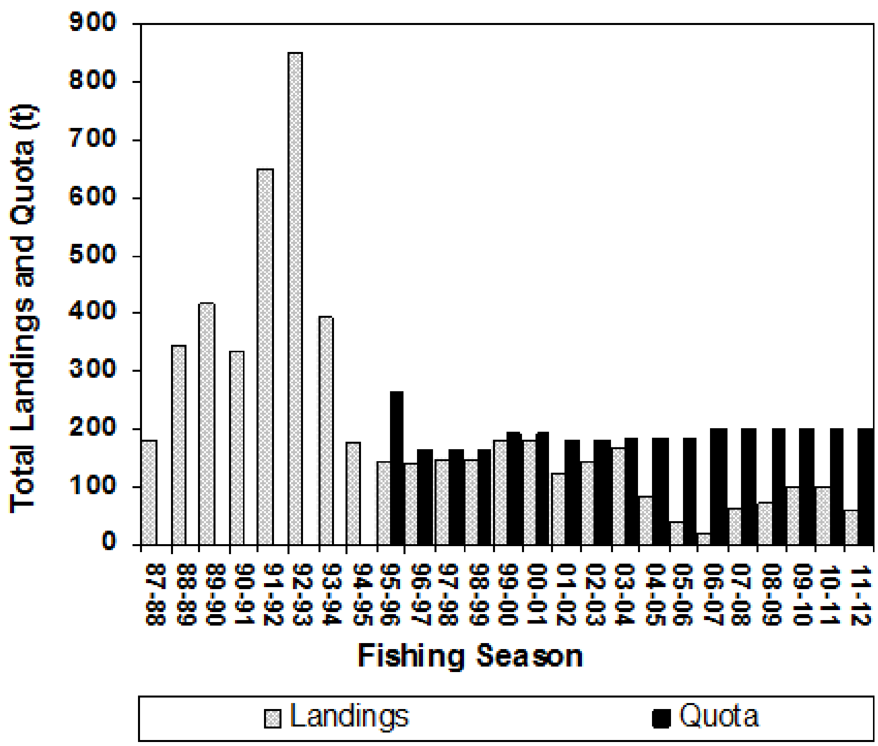

Figure 3. Total landings (from inception of the fishery and onwards; from fish slip data up to 1995, then from harvest and validation logs) and quota (from inception of individual quotas and dockside validation in 1995 and onwards) in metric tonnes by commercial fishing season.

Low demand for Canadian product over the last eight years has been attributed to competing supply from the Russian sea urchin fishery in the Kurile Islands off the east coast of Hokkaido, Japan (Krause 2006). The Russian sea urchin fishery is largely illegal, unregulated and unreported, and has been flooding the Japanese market with low cost product, lowering the demand and value for sea urchins from BC and other regions (Krause 2006) (Figure 4). Additional unfavourable factors for the BC Green Sea Urchin fishery are the rise of the Canadian dollar against the Japanese Yen, which is putting BC Green Sea Urchin in a higher price bracket, and weakness in the Japanese economy, which is reducing the consumption of mid-range luxury goods.

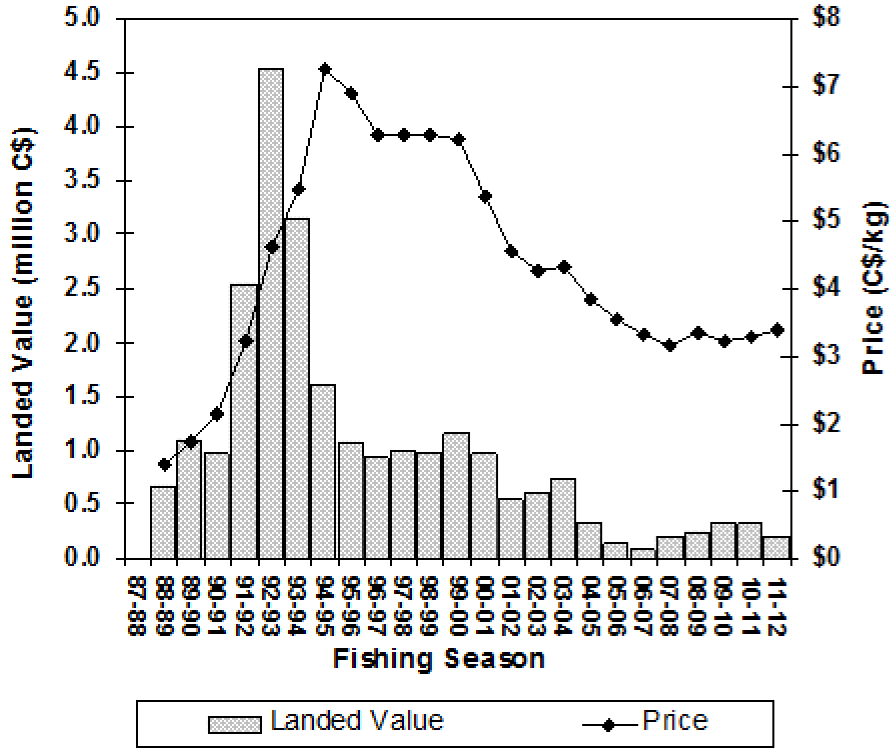

Figure 4. Landed value (million C$) and price per kg (C$/kg) by commercial fishing season.

One of the indications of stock health examined in this assessment is the trend in median catch per unit effort (CPUE). The median CPUE is used because it is more robust to outliers in effort data than other measures of central tendency such as the mean. The standard error of the median CPUE was calculated as in Waddell et al. (2010), by multiplying the standard error of the mean CPUE by 1.2533 (Sokal and Rohlf 2012). Since 1993, the median CPUE rose steadily until it reached a record high in 2008-09 (Figure 5). With the exception of the peak CPUE in 2008-09, median CPUEs have remained relatively constant for the past decade at levels higher than those observed at the onset of the fishery (Figure 5). Trends in median CPUE have been very similar between the NEVI and SEVI fishing regions in recent years (Figure 5).

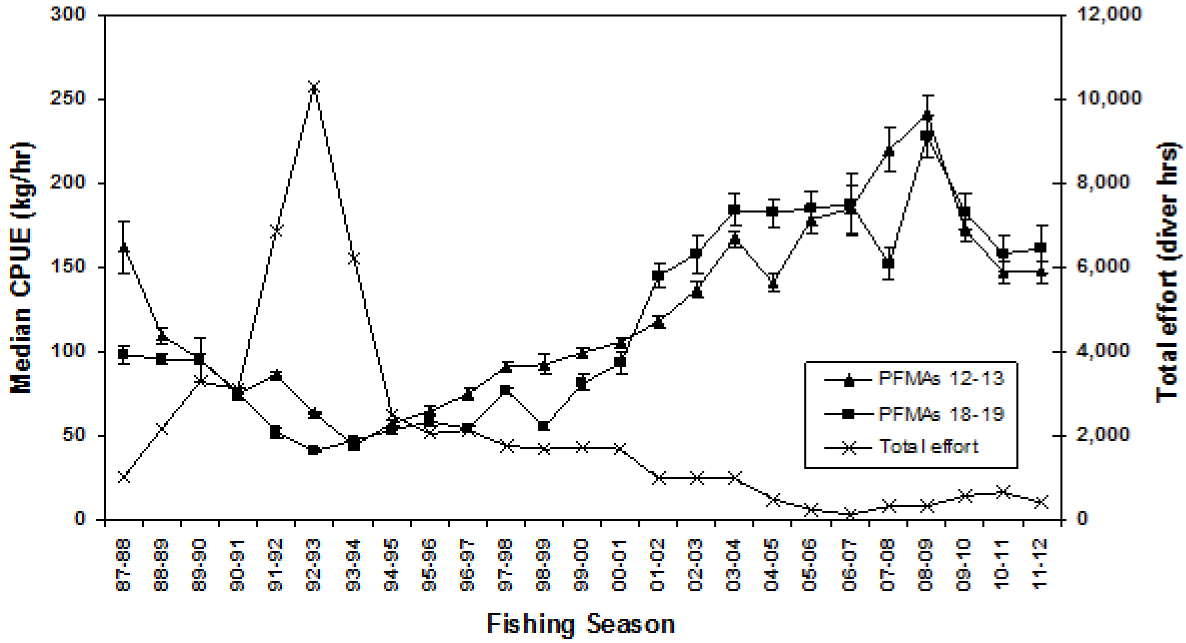

Figure 5. Median catch per unit effort (CPUE) (kg/hr) ± 1 standard error for PFMAs 12-13 and 18-19 and total effort (diver hours) by commercial fishing season.

Fishery-independent data

Survey protocol modifications

Fishery-independent data are obtained from SCUBA dive surveys at index sites (Figure 2). A dive survey protocol was developed in 1995 to study interannual variability in Green Sea Urchin abundance and the impacts of commercial fishing on Green Sea Urchin populations in PFMA 12 (Waddell and Perry 2012). The basic methods were as follows: the divers counted and measured urchins occurring within a one square meter quadrat that was flipped over the substrate for the length of each transect, following either a leadline or compass bearing. The transects ran perpendicular to the shoreline and/or depth contours, from deep to shallow, from 10 m (33 ft) below Chart Datum to 0 m below Chart Datum. The original protocol was to measure all Green Sea Urchins in all quadrats along transect lines, and to collect 9 urchins per transect for subsequent laboratory analyses of weight and size and to examine the quality of the roe. As densities increased in PFMA 12, the original survey protocol proved intensive and divers were not always able to survey the full length of all transects within the budgeted time frame. In 2002, the protocol was changed so that Green Sea Urchins were measured in every second quadrat at one of the three sublocations (Stephenson Islets), and an additional 10 urchins were collected for diameter, height and weight data only. High densities continued, however, and it was still difficult to complete the survey within the allotted time. For the PFMA 19 survey, which originated in 2008, quadrat subsampling was implemented from the start. A pattern of MEASURE – SKIP – MEASURE – SKIP was recommended for transects with lower densities and MEASURE – SKIP – COUNT – SKIP for transects with higher densities. Sampling patterns were at the divers’ discretion. Because of their length, transects in PFMA 19 still took a tremendous amount of time to complete.

In 2011, the survey protocol was modified to improve efficiency and reduce costs. The modifications included further subsampling of quadrats within transects and the discontinuation of biological sample collections, thereby allowing the same number of transects to be surveyed in less time. Quadrat subsampling is a common practice used in other invertebrate field sampling protocols in BC, including Red Sea Urchins (*Strongylocentrotus franciscanus)* (Leus et al. 2014), Pacific Geoduck (*Panopea generosa*) (Bureau et al. 2012), and Northern Abalone (*Haliotis kamtschatkana*) (Lessard and Egli 2011). The Green Sea Urchin survey protocol was changed to include surveying schemes which are dependent on transect length and that allow for a systematic method of skipping quadrats. For transects with lengths of 20 metres or less, the quadrat sampling scheme was changed to: MEASURE – SKIP – COUNT – SKIP. For transects with lengths of 21 – 100 metres, the scheme was changed to: MEASURE – SKIP – COUNT – SKIP – COUNT – SKIP. And for transects with lengths of over 100 metres, the scheme was changed to: MEASURE – SKIP – COUNT – SKIP – COUNT – SKIP – COUNT – SKIP – COUNT – SKIP. In a 'Measure' quadrat, depth, time, substrate and algae are recorded and every Green Sea Urchin is measured for test diameter. In a 'Skip' quadrat, no data are recorded and the quadrat is skipped. In a 'Count' quadrat, depth, time, substrate and algae are recorded and all Green Sea Urchins are counted but not measured. The new protocol requires the sampling scheme to begin in the first quadrat along the transect line that contains Green Sea Urchins.

In order to assess the effect of the new protocol on biomass density (g/m^2) estimates, survey data from 2000 to 2010 were subsampled to emulate the effect of the reduced sampling effort. Similar biomass density estimates were obtained from the subsampled datasets and the full datasets (Figure 6). Furthermore, the new protocol reduces costs, as surveys can now be completed in approximately half to two thirds the time.

Data-analysis modifications

The Green Urchin Analysis Program (GUAP) was developed in 2013 to estimate mean density of Green Sea Urchins from the past survey data, and is similar to the analysis program used to estimate densities in BC's Red Sea Urchin stock assessments (Leus et al. 2014). The analysis is based on the assumption of a continuous distribution of urchins between surveyed quadrats along the transect lines. The main differences between this analysis and the previous one (Waddell et al. 2010) are the use of interpolation to fill in data gaps resulting from quadrat subsampling and the use of an overall allometric relationship to convert test diameters to weight for years when supporting length-weight data were not collected (i.e., 2012 onwards), described below.

Within a transect, GUAP uses linear interpolation to estimate the number of urchins in the uncounted quadrats (skip quadrats) based on the number of urchins in the two closest counted and/or measured quadrats. Then, for each measured quadrat, the probability of an urchin being legal-size (≥55 mm) is generated from the observed size-frequencies and according to the beta distribution. The probability that an unmeasured urchin is either legal (≥ 55 mm) or sublegal (<55 mm) is called a size-class probability. Linear interpolation is used again to generate size-class probabilities for quadrats without measured urchins (count quadrats and skip quadrats) based on the size-class probabilities from the two closest measured quadrats. The two closest measured quadrats refer to the measured quadrat that precedes and follows the skip or count quadrat in question. If the skip or count quadrat is towards the end of a transect and there is no following measured quadrat, then size-class probability is derived through extrapolation from the preceding measured quadrat only.

For the calculation of biomass densities (g/m^2), the sampling unit is a transect. GUAP incorporates variability among transects through bootstrapping. Transects are re-sampled with replacement and each time a transect is re-sampled, the size-class probabilities of the unmeasured urchins are regenerated as described above. For each re-sample, the ratio-estimator is used to calculate the density for legal and sublegal size-classes. The re-sampling process is repeated and 1000 estimates of density are generated. The frequency of these estimates is used as a proxy for the distribution of density by size-class. The calculation of confidence bounds is further refined using Bias-corrected accelerated percentile intervals (Efron and Tibshirani 1993).

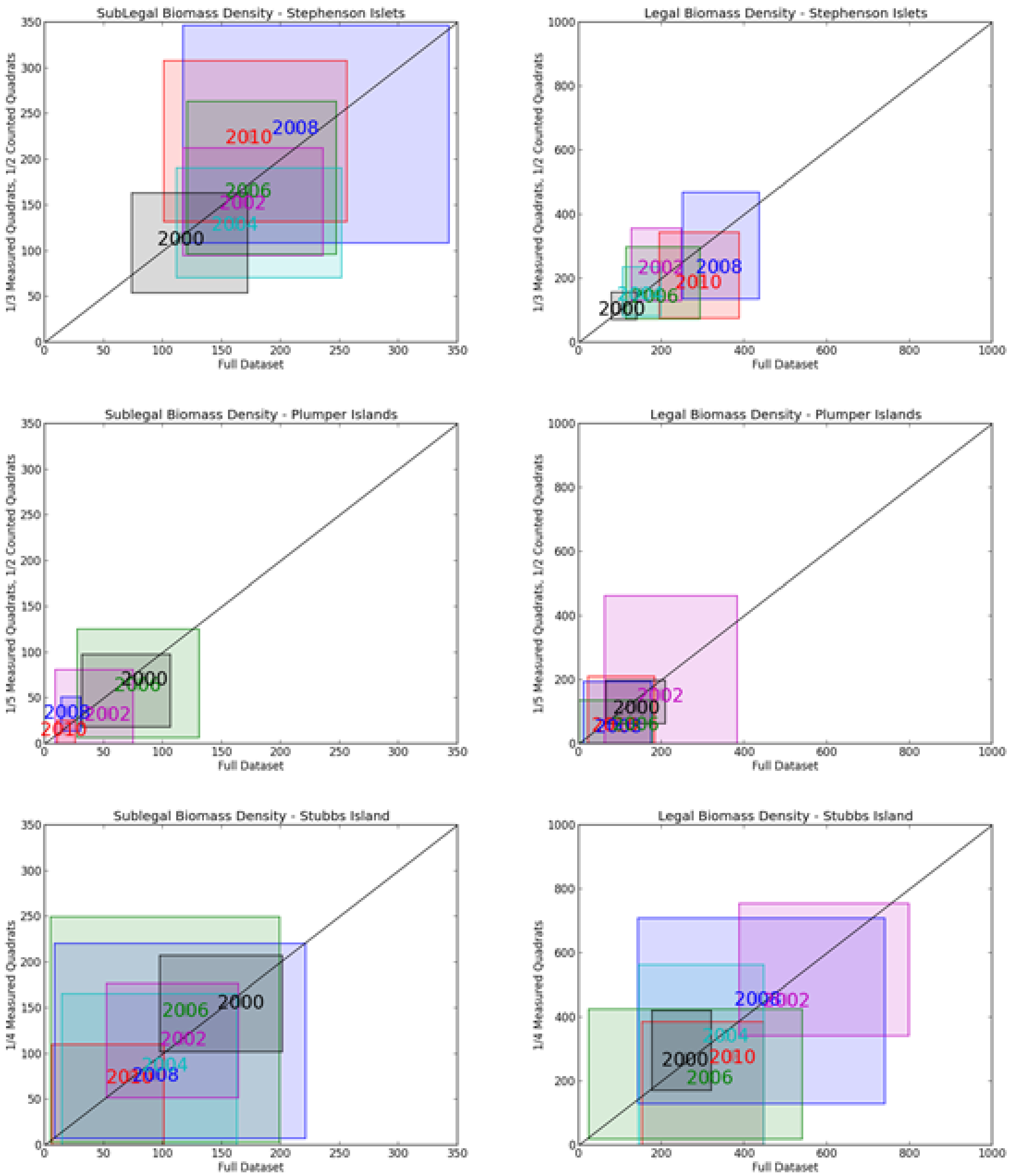

Figure 6. Biomass densities (g/m^2) for sublegal (<55 mm) and legal (≥55 mm) sized Green Sea Urchins, by sublocation in NEVI, for even years from 2000 to 2010, using the full dataset (x axis) versus a subsampled dataset that has been reduced to approximate the new survey protocol (y axis). Coloured rectangles are 95% confidence bounds.

Test diameter (TD) – weight relationships are used to convert the TD of measured Green Sea Urchins to weights. These weights are then used to calculate the mean sublegal and legal weights that are applied to the urchins in the counted and skipped quadrats. From 2002 to 2011, 19 urchins per transect were collected each year for laboratory measurements of size and weight, and a portion were dissected to obtain roe quality information. Prior to 2002, 9 urchins per transect were sampled. For all years when samples were taken, GUAP converts test diameters to weights using a method similar to the one used in Green Sea Urchin assessments since 2002: TD-weight relationships were derived separately for each of the sublocations within a survey using the laboratory measurements taken that year (Waddell and Perry 2005, 2006, 2007, 2012). In 2012, when samples were not collected, TDs were converted to weight using an overall allometric relationship derived from data from all Green Sea Urchin surveys to date where length-weight data were collected. The overall allometric relationship includes data from 29 surveys, 15 of which were conducted in PFMA 12, 10 of which were conducted in PFMA 18, two of which were conducted in PFMA 19, one of which was conducted in PFMA 20 and one that encompassed both PFMAs 18 and 19. The number of biological samples collected per survey ranged from 17 to 286. The overall allometric relationship is based on a hierarchical model and therefore each survey is weighted equally regardless of the number of samples collected. The overall allometric relationship reflects the among-sublocation/year variability in mean-weight at length that has been observed in Pacific coast Green Sea Urchin data collected to date (Figure 7).

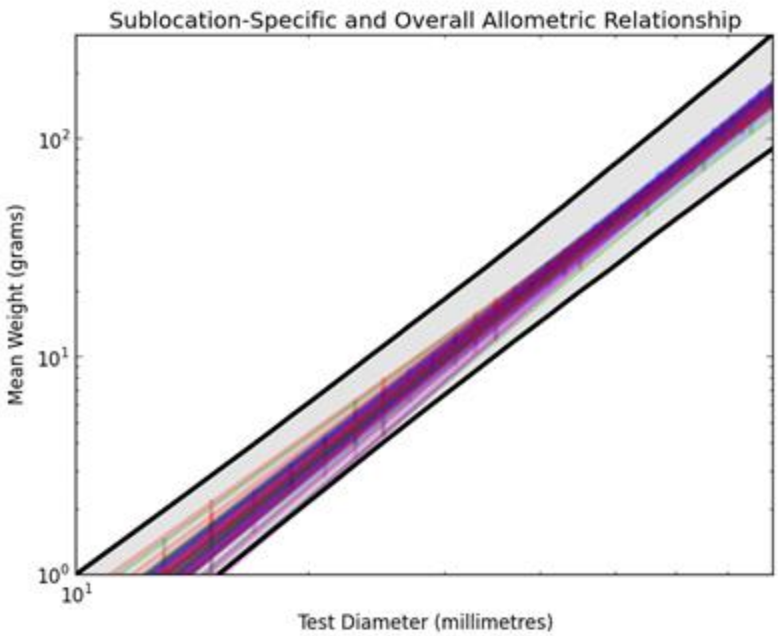

Figure 7. Mean weight-at-length on a logarithmic scale. Each coloured band with corresponding horizontal lines gives 95% confidence bounds on mean weight-at-length as calculated for a sublocation and a single year since 2000. The grey and black band shows 95% confidence bounds corresponding to the overall allometric relationship which is used when there is no supporting length-weight data.

A comparison of GUAP's estimates of biomass density (g/m^2) using the sublocation/year-specific and the overall allometric relationships indicates that the latter tends to produce biomass estimates that are the same or slightly higher and confidence intervals that are wider (Figure 8). Biomass density estimates are higher in the latter because, for smaller test diameters, the overall allometric equation predicts larger mean-weight at length than most of the sublocation/year-specific allometric relationships. For a 30 mm Green Sea Urchin, the difference is approximately 10%. This is likely due to a lack of small urchins in the sublocation/year-specific relationships; the sublocation-years with representation of small Green Sea Urchins agree better with the default allometric equation than those lacking small urchins.

Trends in populations and population structure

The first and longest series of surveys has been conducted in PFMA 12 (NEVI) region, where 14 fall surveys have been conducted since 1995. Fall surveys were conducted annually until

2004 and since then have been conducted every two years. There have been some significant increases and decreases in the densities of Green Sea Urchins between survey years, but generally the densities have been increasing since the inception of the survey (Figure 9). The mean biomass densities (g/m^2) of both legal- and sublegal-sized urchins reaching their highest observed values in the most recent survey of 2012 (Figure 9A). The mean test diameter has remained relatively unchanged, at around 50 mm, since 2006 and therefore the observed biomass density increase can be attributed to an increase in the numbers, not size, of both legal and sublegal-sized urchins (Figure 9B).

Transects at Stubbs Island and Plumper Island are within scientific research closures where the commercial harvest of Green Sea Urchins is not permitted, whereas transects at Stephenson Islets are within a harvested PFM Subarea that has been open to fishing annually. A comparison of biomass trends between the fished site and the control sites indicates that factors other than commercial fishing are impacting Green Sea Urchin populations (Figure 10). Biomass densities in recent years at control sites have either gone up (Plumper) or gone down (Stubbs) while biomass density at the fished site has been increasing since 2004.

Fishery-independent surveys have also been conducted in PFMA 19 (SEVI) in March 2008, March 2009, August 2009, March 2010 and March 2012. Legal-sized Green Sea Urchin mean biomass densities (g/m^2) showed an initial drop between March 2008 and March 2009 surveys, but have since remained relatively constant over the last four surveys (Figure 11A). Sublegal-sized Green Sea Urchin mean biomass densities (g/m^2) have remained virtually unchanged over the course of the surveys, but in 2012 they doubled from the previous survey in 2010 to their highest observed value (Figure 11A). The 2012 increase in sublegal-sized urchin density (#/m^2) (Figure 11B) indicates recruitment or immigration has likely taken place. Note that the previous assessment (Waddell et al. 2010) did not include fishery-independent data from PFMA 19 due to the short time series available in 2010. This assessment, however, does incorporate the data from the five surveys conducted in PFMA 19 into the Bayesian biomass dynamic model, thereby providing more reliable quota options for this region.

Ideally, age-frequency distributions are used to examine population structure; however, a reliable method to age Pacific Coast Green Sea Urchins has not yet been developed. In the absence of age information for the Green Sea Urchin, test-diameter frequency distributions from the four most recent dive surveys in PFMAs 12 and 19 were plotted to examine population structure (Figures 12 and 13). Test diameter is not a reliable index of age for Green Sea Urchins because they have the potential for discontinuous growth, where growth can fluctuate with the availability of food, vary seasonally and decrease with increasing age (Vadas 1977; Larson et al. 1980; Himmelman et al. 1983; Munk 1992; Vadas et al. 2002).

Test diameter frequency distributions show a broad range of sizes and appear bimodal in both regions from 2008 onwards (Figures 12 and 13). The presence of small size classes, when considered with the observed increase in sublegal density (Figures 9 and 11), could indicate that there has been successful recruitment and/or immigration.

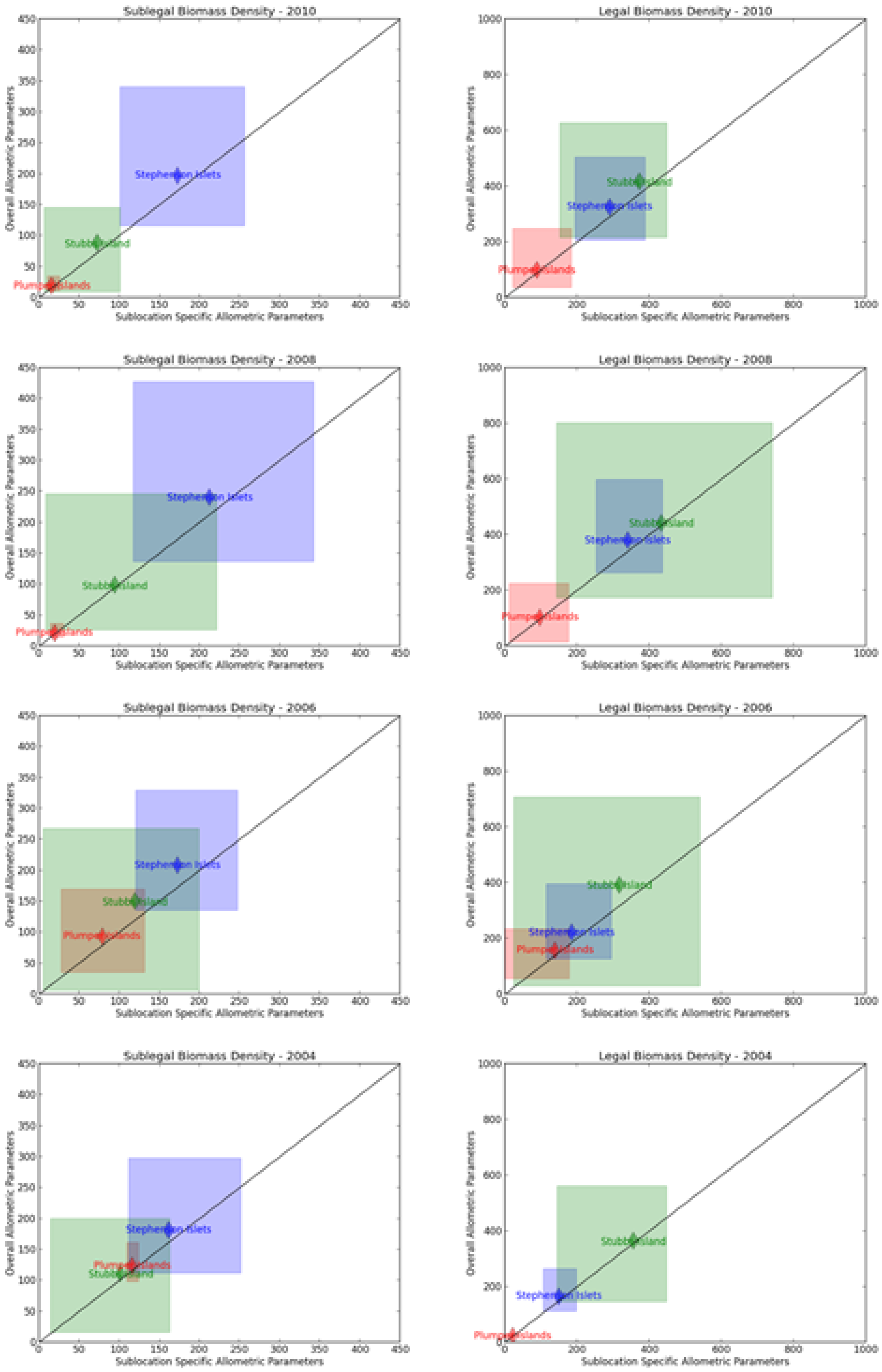

Figure 8. Mean biomass densities (g/m^2) (diamond centered in sublocation name) and 95% confidence intervals (edges of the coloured rectangles) for sublegal (<55 mm) and legal (≥55 mm) sized Green Sea Urchins estimated by the Green Urchin Analysis Program (GUAP) using PFMA 12 survey data from 2004, 2006, 2008 and 2010. The horizontal axes give biomass densities computed using test diameter – weight allometric relationships that are sublocation and year specific. The vertical axes give biomass densities computed using the GUAP's overall allometric relationship.

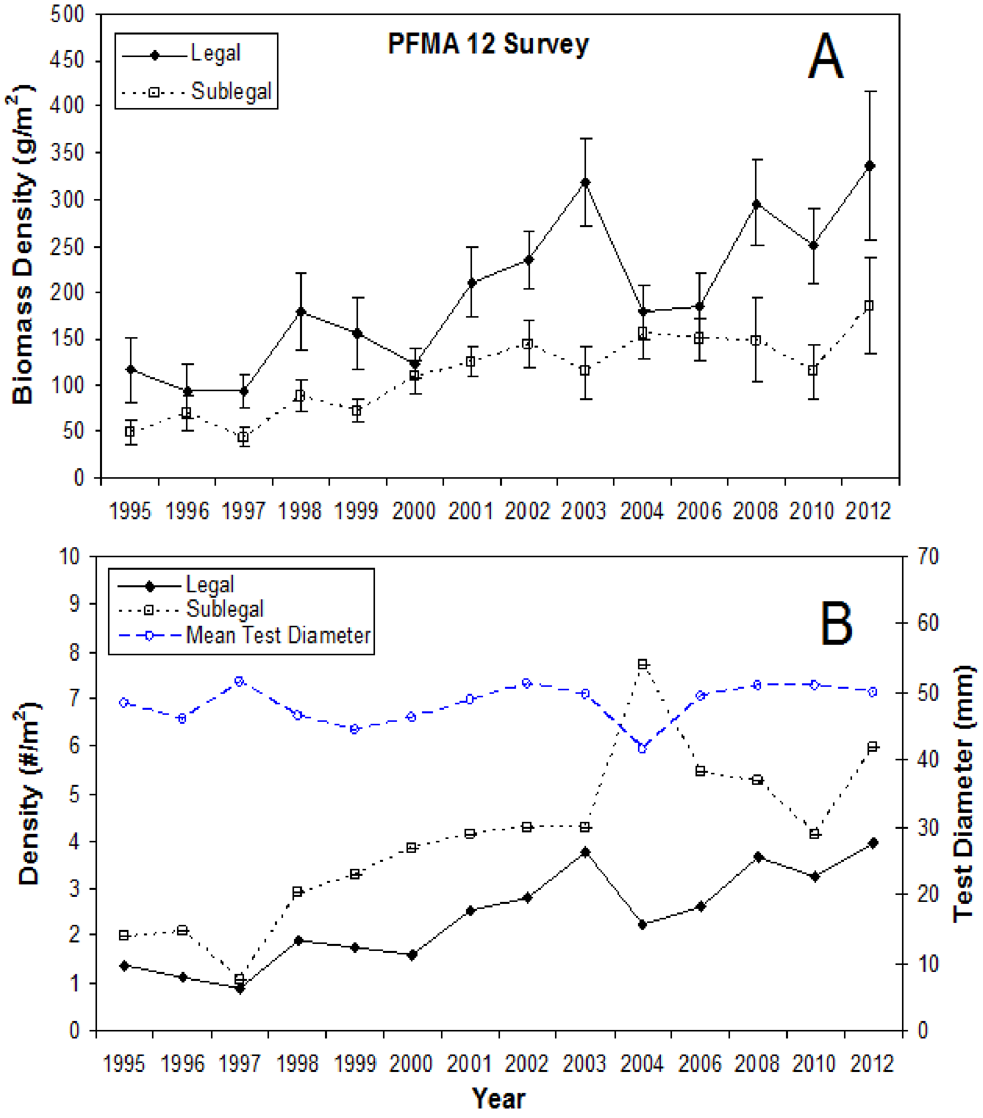

Figure 9. (A) Mean biomass density (g/m^2) ± 1 standard error and (B) mean density (urchins/m^2) estimates for legal (≥55 mm) and sublegal (<55 mm) sized Green Sea Urchins, and (B) overall mean test diameters estimated from fishery-independent dive surveys conducted at index sites in PFMA 12.

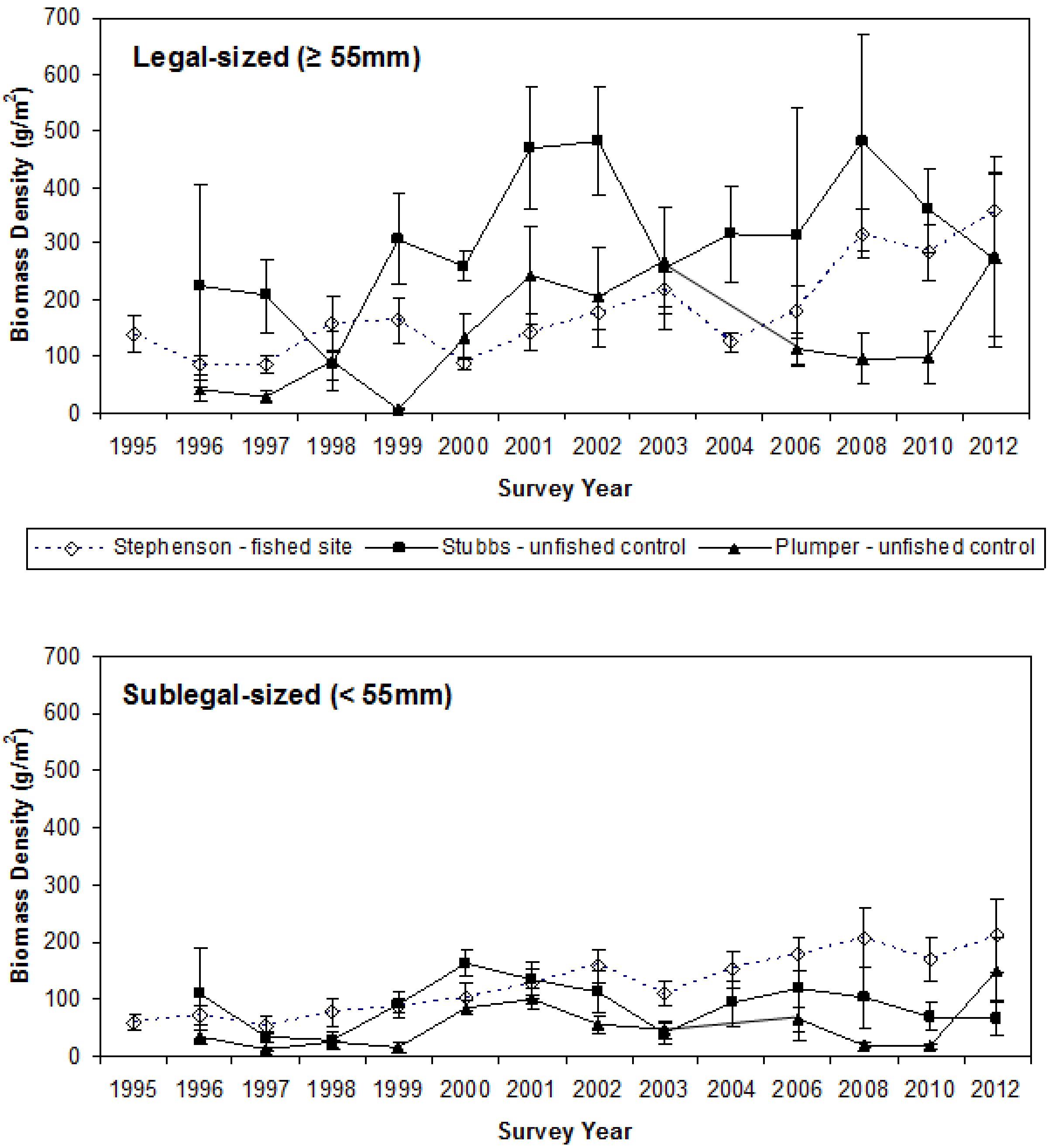

Figure 10. Mean biomass density (g/m^2) ± 1 standard error for legal (≥55 mm) and sublegal (<55 mm) sized Green Sea Urchins for the three sublocations [Stephenson (fished), Stubbs (unfished control) and Plumper (unfished control)] in the PFMA 12 dive survey. Only 1 transect was completed at Plumper Island in 2004 so data are not shown.

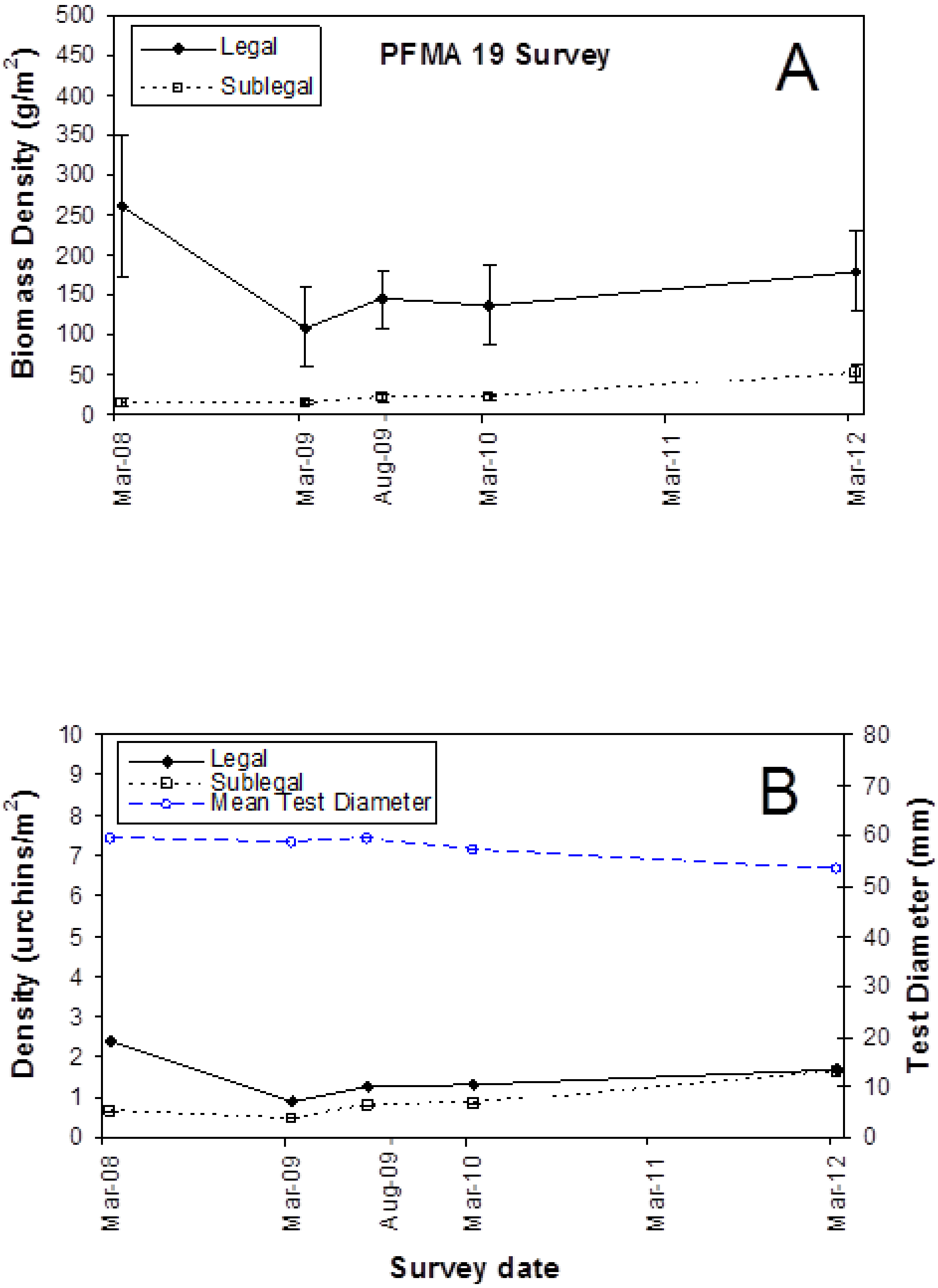

Figure 11. (A) Mean biomass density (g/m^2) +/- 1 standard error and (B) density (urchins/m^2) estimates for legal (≥55 mm) and sublegal (<55 mm) sized Green Sea Urchins and (B) overall mean test diameters (mm) estimated from fishery-independent dive surveys conducted at index sites in PFMA 19.

Quota Options

This assessment updates previously published quota options, using the same Bayesian biomass dynamic model that has been used in the assessment of BC's Green Sea Urchin stock since 2003 (Perry et al. 2003; Zhang and Perry 2005; Perry et al. 2006; Waddell et. al. 2010).

Model inputs include total catch and median CPUE (kilograms per diver hour) for each season of the commercial fishery from 1987-88 to 2011-12 and the total biomass estimates and standard errors of legal-sized Green Sea Urchins from 14 fall surveys at the index sites in PFMA 12 and from five surveys at the index sites in PFMA 19. Total biomass was calculated by multiplying GUAP's sublocation/year-specific biomass density (g/m^2) estimates by the total area of the seafloor (from 0 to 10 m below Chart Datum) as determined by the geographic information program Compugrid (Geo-Spatial Systems Ltd. 1996). The model was run separately for NEVI and SEVI, producing maximum sustainable yield (MSY) probability distributions for each region.

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

The LRPs for the NEVI and the SEVI regions are uncertain and could be any estimated MSY as represented by the posterior probability distributions from the Bayesian model. The TRPs are equivalent to various reductions from the median of the MSY posterior distribution and are presented in Table 1, along with the probabilities that the TRPs may be larger than the true MSY. For each of the two regions, the allocations of quota to each PFMA within the region are based on the proportion that area contributed to aggregate landings from the 1995-96 to 2011-12 fishing seasons (Table 1).

The median MSY estimates from the current assessment are similar to those of the previous assessment. For NEVI, the median MSY estimate of 306 t (metric tonnes) is slightly larger than the previous estimate of 298 t. For SEVI, the median MSY estimate of 74 t is slightly smaller than the last assessment's estimate of 78 t.

Since the 2006-07 fishing season, quotas have remained stable at 177.3 t in NEVI and 25.5 t in SEVI. If quotas were to remain at these levels for the next three year management plan, the probability that they could be equal to or larger than the true MSY would be 2.6% in NEVI and 1.0% in SEVI. These quotas are precautionary and represent low risk of over-exploitation.

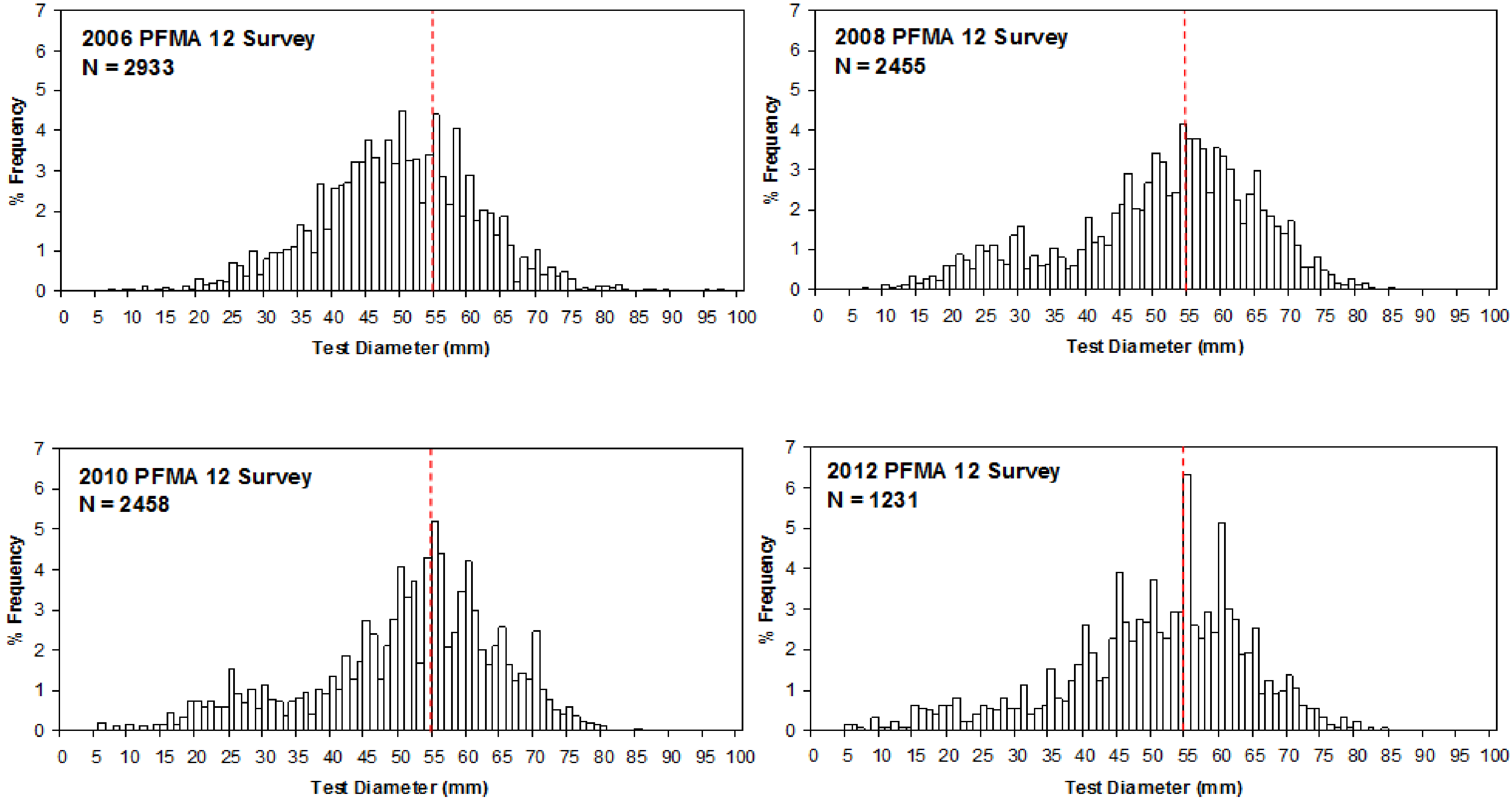

Figure 12. Percentage size-frequency distributions of Green Sea Urchin test diameters measured during the Fall 2006, 2008, 2010 and 2012 surveys in PFMA 12. Red dashed line marks the legal commercial harvest size of 55 mm.

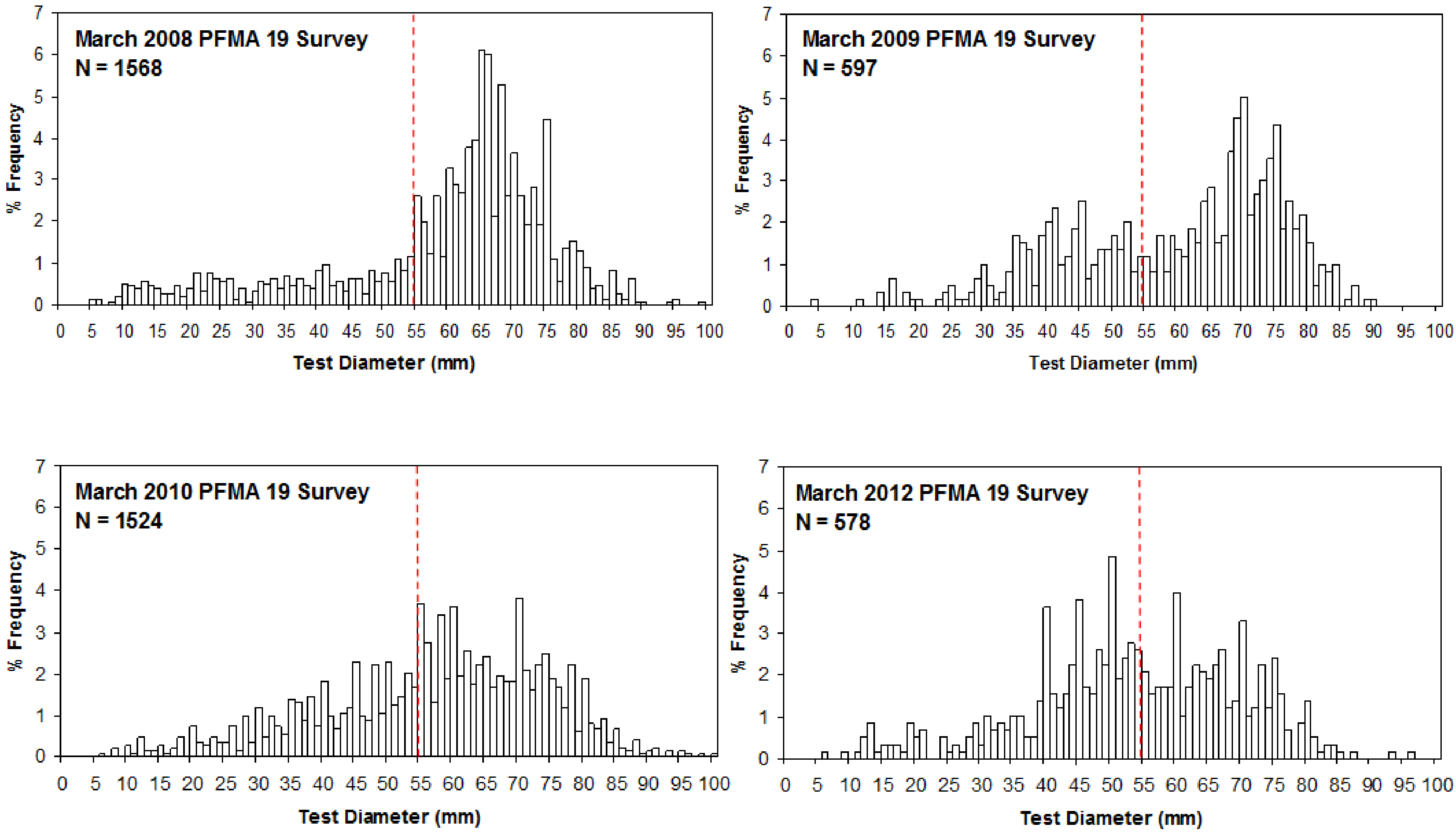

Figure 13. Percentage size-frequency distributions of Green Sea Urchin test diameters measured during the March 2008, 2009, 2010 and 2012 surveys in PFMA 19. Red dashed line marks the legal commercial harvest size of 55 mm.

Table 1. Target reference points (TRPs) in metric tonnes as reductions from the estimated median maximum sustainable yield (MSY), the probability the target reference point may be greater than the true MSY, and allocation of the total quota to each of the two fishing regions: (A) Northeast Vancouver Island (NEVI) and (B) Southeast Vancouver Island (SEVI).

A. NEVI	Target reference points (TRPs) (tonnes)r			Probability TRP ≥ true MSP
	PFMAs 12 & 13	PFMA 12	PFMA 13	
Estimated median MSY	305.60	191.31	114.29	0.500
90% of median MSY	275.04	172.18	102.86	0.336
80% of median MSY	244.48	153.04	91.44	0.189
70% of median MSY	213.92	133.91	80.01	0.084
60% of median MSY	183.36	114.78	68.58	0.031
50% of median MSY	152.80	95.65	57.15	0.012
40% of median MSY	122.24	76.52	45.72	0.004
30% of median MSY	91.68	57.39	34.29	<0.001
20% of median MSY	61.12	38.26	22.86	<0.001
10% of median MSY	30.56	19.13	11.43	<<0.001

B. SEVI	Target reference points (TRPs) (tonnes)r			Probability TRP ≥ true MSP
	PFMAs 18 & 19	PFMA 18	PFMA 19	
Estimated median MSY	73.84	29.16	44.66	0.500
90% of median MSY	66.44	26.24	40.19	0.379
80% of median MSY	59.06	23.33	35.73	0.261
70% of median MSY	51.67	20.41	31.26	0.173
60% of median MSY	44.29	17.50	26.80	0.105
50% of median MSY	36.01	14.58	22.33	0.055
40% of median MSY	29.53	11.66	17.86	0.022
30% of median MSY	22.15	8.75	13.40	0.004
20% of median MSY	14.76	5.83	8.93	<0.001
10% of median MSY	7.38	2.92	4.47	<<0.001

Sources of uncertainty

A source of uncertainty in this assessment relates to the fishery-dependent CPUE data, which are derived from logbooks that are completed by the harvesters. Firstly, CPUE data can be problematic because they can exhibit hyper-stability. This occurs when the CPUE remains high as successive aggregations are fished. Secondly, catch and effort data from the early years of the fishery (1987-1995) are considered uncertain, due to the boom nature of the fishery, variable recording diligence, differing levels of experience of the harvesters and different strategies of fishing. To address this problem, uncertainties about the catch and effort information in the first nine years of the fishery were incorporated into the biomass dynamic model. Specifically, the model assumes a coefficient of variation of 30% for the uncertainty about the catch and a coefficient of variation of 50% for the uncertainty about the CPUE. Since 1995, however, total landed weights have been measured dockside by Port Validators as part of the individual quota system and effort data have been more conscientiously recorded. Therefore, the model assumes that reported catches and estimated CPUEs represent the true values from 1996 onwards.

The fishery-independent data carry inherent uncertainties due to sampling methodology. Skipping quadrats, counting urchins in some quadrats but not measuring them and converting test diameters to weights using allometric relationships all contribute to uncertainty in density and biomass estimates. GUAP uses interpolation to estimate the number of urchins in the uncounted quadrats, parametric bootstrapping to incorporate uncertainties in the size-distribution of the urchins and non-parametric bootstrapping to incorporate uncertainties in density estimates among transects. Standard errors around density estimates are incorporated into the Bayesian Model.

A further uncertainty relates to the use of the overall allometric relationship to convert the test diameters of measured Green Sea Urchins to weights for years when length-weight data were not collected (2012 onwards). The estimated weights are used to calculate the mean sublegal and legal weights that are applied to the urchins in the counted and the skipped quadrats, which, along with the estimated weights of the measured urchins, are used to compute biomass density (g/m^2). The overall allometric relationship lumps survey data from the two commercially fished areas (NEVI and SEVI) and includes data from different times of the year. The suitability of applying this overall allometric relationship to Green Sea Urchins from individual surveys, whose test diameters may scale differently with weight, has not been evaluated.

An additional uncertainty relates to basing the allocation of quota among PFMAs on the proportion that each area contributed to landings from 1995-96 to 2011-12. This method carries a risk that a potential overexploitation may be perpetuated or that some PFMAs may become more exploited than intended if the Green Sea Urchin distributions and abundance change among areas over time. Fishery-independent surveys are being used to assess whether the latter is occurring.

Conclusions

Green Sea Urchins remain a small but important part of the BC dive fisheries. Mean density estimates in 2012 for both legal and sublegal-sized urchins from fishery-independent surveys in PFMA 12 were the highest since the inception of the survey in 1995 and density estimates for both legal and sublegal sized urchins from PFMA 19 surveys have been relatively constant over the past four years. With the exception of the peak CPUE in 2008-09, median CPUEs have remained relatively constant for the past decade at levels higher than those observed at the onset of the fishery. Recent CPUE data may be influenced by increased efficiency, compared to the early years of the fishery. Unit price for Green Sea Urchins has been low in the last eight years due to a decreased demand for BC product in the Japanese market. This has resulted in low landed value and low fishing pressure.

Advice

1) Quota options developed using a Bayesian biomass dynamic model are provided in Table 1 for both Northeast Vancouver Island (NEVI; PFMAs 12 & 13) and Southeast Vancouver Island (SEVI; PFMAs 18 & 19). Maximum sustainable yield (MSY) is set as a limit reference point (LRP) and target reference points (TRPs) are set as reductions from the median MSY.
2) The risks associated with the NEVI and SEVI quota options are defined in Table 1 as the probabilities that the TRPs are greater than the actual MSY (Table 1). Quotas established at their current levels of 177.3 t in NEVI and 25.5 t in SEVI would represent a 2.6% and a 1.0% risk, respectively, that the harvest levels are greater than the actual MSY.
3) The PFMA 12 and PFMA 19 fishery-independent surveys should be continued, on a regular basis, to provide a time series independent of the fishery for assessment of Green Sea Urchin population trends. Ideally, surveys should be expanded to include all unsurveyed PFMAs open to commercial harvest (i.e. PFMA 13 and PFMA 18).

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November 6, 2013

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This Report is Available from the

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ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2014. Stock status update and quota options for the Green Sea Urchin (*Strongylocentrotus droebachiensis*) fishery in British Columbia, 2013-2016. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/052.

Aussi disponible en français:

MPO. 2014. Mise à jour sur l'état du stock et options en matière de quotas pour la pêche aux oursins verts, Strongylocentrotus droebachiensis*, en Colombie-Britannique, 2013-2016. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2014/052.*