Survey Methods for Red Sea Urchin (*Stronglocentrotus Franciscanus*) Populations on Submerged Reefs: A Case Study Using the Tree Nob Group, British Columbia, 2007

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by

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ABSTRACT

Leus, D., Hajas, W., and Lochead, J. 2017. Survey methods for Red Sea Urchin (*Strongylocentrotus franciscanus*) populations on submerged reefs: A case study using the Tree Nob Group, British Columbia, 2007. Can. Tech. Rep. Fish. Aquat. Sci. 3205: vi + 22 p.

A variant of the existing shoreline survey method for stock assessment of Red Sea Urchins (RSU) is presented for submerged reefs that have no or low association with a shoreline. The submerged reef survey method was applied in a survey of the Tree Nob Group (Pacific Fishery Management Area 4-13) conducted from September 24 to 30, 2007. Transect locations were selected from a 10.85 km^2 area. Analysis of the survey data resulted in estimated mean spatial biomass density estimates of 718 g/m^2 and 678 g/m^2 for RSU with test diameters of (TD) $\geq$90mm and 90-140 mm respectively. Of all measured RSU (n=4439), 6.7% were $\leq$50 mm TD while 15% of sublegal size RSU (TD<90mm) were $\leq$50 mm TD. The submerged reef survey method produced an estimate of maximum sustainable yield for RSU with TD 90-140mm of 147 tonnes, consistent with the previously accepted bed area assessment method as well as Fishing Industry estimates. This method is considered appropriate for RSU populations located on submerged reefs not adjacent to shoreline.

RÉSUMÉ

Leus, D., Hajas, W., and Lochead, J. 2017. Survey methods for Red Sea Urchin (*Strongylocentrotus franciscanus*) populations on submerged reefs: A case study using the Tree Nob Group, British Columbia, 2007. Rapp. tech. can. sci. halieut. aquat. 3205: vi + 22 p.

Une variante de la méthode existante de relevé sur le rivage utilisée pour l’évaluation du stock d’oursins rouges est présentée pour les récifs submergés qui ne sont pas ou sont peu connectés à un rivage. Cette méthode de relevé des récifs submergés a été appliquée dans le cadre d’un relevé de l’archipel Tree Nob Group (secteur de gestion des pêches du Pacifique 4-13) effectué du 24 au 30 septembre 2007. L’emplacement des transects a été choisi dans une zone de 10,85 km^2. Une analyse des données du relevé a donné lieu à une biomasse spatiale moyenne estimée et à des estimations de la densité de 718 g/m^2 et de 678 g/m^2 pour l’oursin rouge, ainsi qu’à des diamètres du test (DT) $\geq$90 mm et de 90 à 140 mm respectivement. De tous les oursins rouges mesurés (n=4439), 6,7 % faisaient $\leq$50 mm de DT, tandis que 15 % des oursins rouges de taille inférieure à la taille réglementaire (DT<90 mm) faisaient $\leq$50 mm de DT. La méthode de relevé des récifs submergés a produit une estimation du rendement maximal soutenu des oursins rouges ayant une DT de 90-140 mm de 147 tonnes, ce qui est conforme à la méthode d’évaluation de la superficie du gisement précédemment acceptée et aux estimations de l’industrie de la pêche. Cette méthode est jugée appropriée pour les populations d’oursins rouges situées dans les récifs submergés qui ne sont pas adjacents au rivage.

INTRODUCTION

The Red Sea Urchin (*Strongylocentrotus franciscanus)* is harvested throughout its distribution in the north-east Pacific from the southern tip of Baja California to Alaska (Kato and Schroeter 1985). Red Sea Urchins (RSU) are harvested commercially and by coastal First Nations groups for their gonads (roe). Commercially harvested RSU are processed for their roe (called “uni”) which is sold primarily to Japanese markets, while First Nations communities consume the roe for Food, Social and Ceremonial purposes. RSU have been commercially harvested in British Columbia (BC) from the early 1970’s with landed wholesale values in the last several years ranging from approximately $5 million to $10 million. Management practices and fishery history are outlined in Campbell and Harbo (1991), Campbell et al. (1999, 2001) and Leus et al. (2014).

Field surveys of RSU have been conducted in BC from the 1970’s to present (Atkins et al. 2006a-h; Tzotzos et al. 2003a-d; Bureau et al. 2000a-d; Sloan et al. 1987; Adkins et al. 1981 and Breen et al. 1978 and 1976) with biomass estimates calculated as a product of density estimates from field surveys and estimates of habitat area (Leus et al. 2014).

Since the late 1990’s, stock assessment of RSU in BC has been based on the assumption that an RSU bed (primarily shallow subtidal rocky substrate) exists in a band approximately parallel and adjacent to the shoreline (Jamieson and Schwartz 1998). Until 2007, RSU were managed on a spatial basis (Campbell et al. 2001). The amount of habitat was expressed as the area of the known RSU beds. Correspondingly, the density was expressed in units such as ‘grams of biomass per metre squared’.

In Leus et al. (2014), several concerns were raised about the ability to estimate RSU habitat in terms of bed area. The concerns were related to bed area being defined by harvesting (fishing) events, which were not measured empirically in the field, did not include a proportion of different substrate types and did not include areas of commercially unexploited habitat (that may have contained RSU). The 2014 publication recommended quantifying habitat in terms of a length of corresponding shoreline with the density of RSU measured in units such as ‘grams or numbers per metre of shoreline’. Starting with the 2007/2008 fishing season, density has been presented relative to metres of shoreline.

Thus far, the same survey protocol has supported both the shoreline and bed area methods of calculating RSU density. In this protocol, transects are positioned perpendicular to shore from the surface to a diver’s gauge depth of 50 feet. However, in some locations there are significant amounts of RSU habitat where this protocol is difficult to apply or is not effective because the beds cannot be defined according to position along shoreline. Usually these areas consist of submerged reefs that rise up from deeper than 50 feet but do not reach the sea surface. In these situations the existing protocol does not capture these RSU populations as they extend beyond the end point of the transect.

The objective of this paper is to present a survey method that provides density and biomass estimates for RSU in areas that are not associated with shoreline, as an alternative to the existing shoreline RSU survey method. Comparison is made between

(1) the previously employed bed area method, (2) the shoreline method, (3) the submerged reef method and (4) Industry estimates.

To help characterize biotic and abiotic factors in surveyed areas, as has been done in historical survey reports (Atkins et al. 2006a-h; Tzotzos et al. 2003a-d; Bureau et al. 2000a-d), a metric for recruitment, the general characterization of predominant substrates and RSU density by depth range and size category are presented.

METHODS

SITE DESCRIPTION

Pacific Fishery Management (PFM) Area 4-13, was selected for this survey through consultation with the Pacific Urchin Harvesters Association (PUHA) and Resource Managers at DFO. This paper refers to this area as “The Tree Nob Group”. It is an example of an important commercial RSU bed that cannot be defined in terms of shoreline. The Tree Nob Group consists of several rocky islands and shoaling rocks surrounded by rocky submerged reefs (Figure 1). These reefs typically continue to depths of 9-18 metres (m) with sand and gravel channels between the reefs. All areas are highly exposed and experience tidal exchanges of up to 7 m.

SURVEY DESIGN AND PROTOCOL

Canadian Hydrographic Survey (CHS) chart # 395701 for the Tree Nob Group was imported into Arcview 3.2 (ESRI Corporation 1999) and the survey area subdivided into three sites based on geographical grouping of islands, exposure to prevailing weather and potential barriers to immigration and emigration to RSU populations (Figure 1). The area enclosed by the 0 m and 10 m isobaths was selected to survey as these depths are accessible by SCUBA diving. Sea-surface area was calculated for the 0-10 m CHS bathymetric layer for each site in ArcView 3.2.

Starting points for 100 transects were randomly located with the random point generator extension in Arcview 3.2 in the 0-10 m bathymetric layer for the selected survey area. Transect direction was determined by assigning randomly generated numbers (http://www.randomizer.org) from 1 to 360 to magnetic compass heading for each transect. The resulting transects were treated as a random sample, as per Jamieson and Schwarz (1998). Transect length was set at 60 metres to maximize the collection of data while adhering to SCUBA diving operational limits. Transect locations were plotted using marine navigational software NobelTec 6.2 (Jeppesen 2002) on a laptop computer that was taken into the field.

The survey was carried out during 24-30 September, 2007. The commercial fishing vessel “McLaughlin Bay” and a crew of three divers participated in the survey. NobelTec 6.2 software (Jeppesen 2002) connected to a Garmin handheld GPS (76CSx) was used to determine transect start point (GPS accuracy was ±5 m). A leadline was lowered from the survey vessel to mark the transect start location and then strung out, for 60 m length, in the pre-determined random direction. A 20 m float line was attached to the start of the leadline.

At some locations, tidal current and bathymetry caused bunching of the leadline as it was lowered into the water, resulting in shortening of transects to less than 60 m. Due to logistical restrictions associated with equipment and SCUBA diving, divers were not always able to stretch the lead line back out while underwater. Despite surveying deeper transects at lower tides, some were also shortened when they extended deeper than 18 m. Transects were not surveyed if the vessel's sounder indicated more than half the transect was greater than 18 m deep.

Each transect was surveyed by a two-diver team descending down the float marking the start. Transects were divided into 1 x 1 metre quadrats placed to the right of the leadline. Every second quadrat was sampled until the end of the lead line or a gauge depth of 18 m was reached. The test diameters (TD) of all urchins inside the sampled quadrats were measured with callipers (accurate to 1mm) by one diver while the other diver recorded data on underwater paper. Gauge depth, date, time, primary, secondary and tertiary substrate type, algae species and percent coverage for canopy, understory, turf and percentage coverage for encrusting and drift algae were recorded for each sampled quadrat. Substrate types were recorded as one of 11 classes: 1-bedroock smooth, 2-bedrock crevices, 3-boulder, 4-cobble, 5-gravel, 6-pea gravel, 7-sand, 9-wood, 10-shell crushed, 11-shell whole and 0- mud. Substrate classes were later binned for analyses into primarily hard (1-bedrock smooth, 2-bedrock crevices and 3-boulder), moderate (4-cobble, 5-gravel and 11-shell whole) and soft (6-pea gravel, 7-sand, 10-shell crushed, 9-mud and 0-wood) categories. Date and time were used to standardise gauge depth to chart datum. To accommodate logistical constraints associated with SCUBA diving, some transects that may have required multiple dives due to high RSU density, had RSU counted but not measured in some quadrats.

DATA ANALYSIS

Estimation of population density and biomass density

Details of the methods used for estimating population density and biomass density are found in Leus et al. (2014) and Lochead et al. (2015). Campbell et al. (2001) showed that BC harvesters preferentially fish specific size classes. Density calculations in this paper are presented for all legal harvest sized RSU (TD>90mm) as well as the commercially targeted size range (TD 90-140mm).

For the previously employed bed area method, the shoreline method and the submerged reef method, population and biomass densities were estimated within 1 m^2 quadrats along randomly chosen transects. Population density refers to the number of individuals per unit of habitat and is expressed in units of 'number of animals per square metre of habitat' (bed area and submerged reef methods) or 'number of animals per metre of shoreline' (shoreline method). Biomass density refers to the weight of individuals per unit of habitat and is expressed in units of 'grams per square metre of habitat' (bed area and submerged reef methods) or 'grams per metre of shoreline' (shoreline method). Population density was estimated by counting the total number of urchins observed in each transect. Since quadrats along the transect were subsampled, linear interpolation was used to estimate the number of urchins in the unsurveyed quadrats. Population density was converted to biomass density by applying the length-weight relationship in Lochead et al. (2015) to each measured urchin. These weights were then used to calculate the size-category-specific mean weights for each transect. These mean weights, combined with estimated number of unmeasured urchins and unmeasured urchin size proportions, were used to estimate the biomass density of unmeasured urchins in the transect for each size category.

Population and biomass densities were estimated per site and for combined sites, with transects used as the fundamental sampling unit. The values were estimated with confidence bounds using a ratio estimator (Cochran 1977) and boostrapping (Efron and Tibshirani 1993).

Shoreline method: No comparable shoreline survey has been conducted in PFMA 4-13, so population and biomass density estimates were derived using data from nearby surveys as per Leus et al. (2014). Shoreline population and biomass density estimates were calculated using the average density from 111 transects (total length of 6031m) conducted in PFMAs 4-1, 4-2, 4-4, 4-5, and 4-9 in 1995 (unpublished) and 2003 (Atkins et al. 2006d).

Standardizing units by estimating maximum sustainable yield

Shoreline and submerged reef methods: Shoreline-based biomass density estimates are in linear units of 'grams per metre of shoreline' which is not directly comparable to the area-based units of 'grams per square metre of habitat' used in the submerged reef method presented in this paper. To allow direct comparison of empirically derived biomass density estimates with estimates of maximum sustainable yield (MSY) from Industry, biomass density estimates were converted to biomass and then to MSY by applying the modified surplus production model used in the current RSU assessment framework (Leus et al. 2014). The resulting MSYs are not intended to be used as quota options but are rather presented as a metric for evaluating the proposed submerged reef survey method. Here, as in Leus et al. (2014), a range of estimates for MSY are provided by applying equation 1 (below) to the mean, the upper and the lower confidence bounds of the current biomass estimate. We provide sums of upper and lower confidence bounds by site, as Leus et al. (2014) does by PFM Subarea, to illustrate the range of options that Resource Managers would hypothetically be able to choose from.

Shoreline-based biomass density estimates were first converted to biomass by multiplying them by shoreline length associated with urchin habitat in PFMA 4-13. The submerged-reef-based biomass density estimates were converted to biomass by multiplying them by area surveyed (see 'Survey design and protocol', above). Then, the modified surplus production model was used to estimate MSY (Leus et al. 2014). The model assumes that the MSY occurs when the maximum sustainable fishing mortality is equal to (M).

$$MSY = X*M*B_c \qquad (1)$$

Where: B_c is the current biomass; M is the instantaneous natural mortality rate (assumed to be 0.10 for fishable legal size RSU in BC); and, X is a correction factor of 0.2 to incorporate a safeguard, so that a sustainable fishing mortality rate is well below the calculated MSY.

Bed area method: MSY had already been calculated using the previously employed bed area method in the quota options paper by Campbell et al. (2001). The value of MSY was taken directly from that publication as the 2002-2003 quota option for PFMA 4-13 with M = 0.10.

Industry estimate: The estimate of spatial area used in the Campbell et al. (2001) 2002-2003 MSY calculation for PFMA 4-13 was based on fishery-dependant data (reported harvest areas) which harvesters claimed did not include all potentially fishable beds. Industry (PUHA) estimated a MSY of 136 tonnes for Tree Nob based on their knowledge of the area. Resource Managers set the quota at the Industry estimate of 136 tonnes. In some data limited areas of BC, quotas are largely based on historical landings and estimates from PUHA, corroborated by survey data from adjacent areas. The 2003-2006 quotas for Tree Nob of 136 tonnes were derived in this manner (DFO 2003, 2004, 2005 and 2006).

Comparison among sites – submerged reef method

Differences in biomass density estimates among sites using the submerged reef method were tested using a series of analyses of variance (ANOVAs) for unbalanced datasets. The corresponding null hypothesis was that mean density was not different between sites. Transect lengths were assumed to be uniform for the sake of the analyses. Biomass was estimated as a product of biomass density (g/m^2) and sea-surface-area surveyed for both PFM Subarea and site.

Recruitment

Recruitment (R_T) for the RSU population in the Tree Nob Group was expressed as a percentage of the total measured population that were ≤50 mm TD (Adkins et al. 1981, Breen et al. 1976, 1978). To reduce possible bias in this estimate resulting from prior commercial harvesting of the ≥90 mm TD size range, recruitment was also expressed as a percentage of the sublegal (TD<90mm) size population that measured ≤50 mm TD (Tegner and Dayton 1981).

RESULTS

SURVEY LOGISTICS

Of the 100 transect locations selected in the survey area, 61 were completed (Table 1) with an average length of 55.2 m. Three transects in the Triple Island area (# 39, 59 and 71) were excluded for safety reasons and 36 transects were excluded due to excessive depth. No commercial harvesting was recorded in the survey area during the nine months prior to the survey.

SUBSTRATE AND HABITAT

A total of 1718 quadrats were sampled during the survey: 1047 were categorized as primarily hard substrate (60.9%), 209 as primarily moderate substrate (12.2%) and 462 as primarily soft substrate (26.9%). There were no quadrats observed with mud or wood substrate (Table 2). The hardest substrate categories were observed in the three shallowest depth ranges (5.0 m chart datum and shallower) with substrate softening with increasing depth (Table 3). All transects were categorized as highly exposed (exposure value 8).

DENSITY AND BIOMASS ESTIMATES

Population density, for all sizes of RSU combined, was highest in the 0 – 2.5 m depth range and lowest in the > 12.5 m depth range relative to chart datum (Table 3). Mean population density for all sizes of RSU was 2.66 urchins/m^2 and mean biomass density was 901 g/m^2. For RSU measuring 90-140mm TD, the mean population density was 1.42 urchins/m^2 with a mean biomass density of 678 g/m^2 (Table 4a). Mean population and biomass densities differed significantly among size categories (Table 4b).

SIZE FREQUENCY DISTRIBUTIONS

Of the 4439 measured RSU, 55.2% were legal size (≥90mm TD) while 6.7% were ≤50mm (R_T). Of the legal size population, 97.6% of individuals were 90-140mm TD while 15.0 % of the sublegal population (<90mmTD) were ≤50mm TD (R_S). The mean TD was 91.1mm (range 8mm to 164mm). Data are summarized in Table 5 and graphed in Figure 2.

ANNUAL MAXIMUM SUSTAINABLE YIELD FOR COMPARISON

Treating the Tree Nob Group as a single area, the submerged reef method produced an estimate of mean annual MSY for RSU with TD 90-140 mm of 147 tonnes (90% confidence bounds 120-162 tonnes) (Table 6a). Partitioning the Tree Nob Group into three sites resulted in estimates of mean annual MSY of 20 (90% confidence bounds 9-27 tonnes), 55 (90% confidence bounds 41-67 tonnes) and 73 (90% confidence bounds 55-85 tonnes) tonnes (Table 6b).

The existing shoreline survey method produced a mean annual MSY estimate of 19 tonnes (90% confidence bounds 15-28 tonnes) for RSU with TD 90-140 mm in the Tree Nob Group (Leus et al. 2014) (Table 6c).

The previously employed bed area method that was used to calculate 2002/2003 quota options for Tree Nob gave a MSY estimate for 90-140mm RSU of 124 tonnes (Campbell et al. 2001).

Industry estimated MSY for the Tree Nob Group at 136 tonnes.

DISCUSSION

The submerged reef method of stock assessment of RSU presented in this report provides an estimate of RSU abundance in areas not associated with adjacent shoreline and which are therefore not accounted for in the current shoreline method in the existing assessment framework (Leus et al. 2014). In the Tree Nob Group, the shoreline method provides an unrealistically low estimate of MSY of 15 to 28 tonnes for commercially targeted, legal-size RSU (TD 90-140mm). The submerged reef method produces an estimate of 120 to 162 tonnes, which is more consistent with both the mean estimate of

124 tonnes from the previously employed bed area method and the Industry estimate of 136 tonnes.

The submerged reef method improves on the bed area method by including previously unaccounted for submerged reefs and by using fishery independent data. This is likely to provide more accurate estimates of true RSU biomass. This also addresses concerns of Leus et al. (2014) that bed areas were being defined solely by fishing events. The submerged reef method defines a survey area based on fishery-independent CHS navigational charts that may include both RSU habitat and non-habitat. The previously employed bed area method and the current shoreline method use fishery-dependent data (reported harvest areas) which may not include all RSU populations. More of the RSU population can be identified with the submerged reef method, but at the expense of potentially increased survey time and decreased precision.

Providing results by site may help to identify low density sub-populations. In this case study, PFM Subarea 4-13 was divided into three sites which had statistically different densities. The site boundaries were based on barriers to immigration and emigration, which, when present, may increase the risk of overharvest at any site. Assessing individual sub-populations of RSU on smaller spatial scales provides Resource Managers with information on localized sub-populations, which can better inform decisions and reduce the risk of overharvesting locally low density areas.

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Table 1. Transect summary for the Tree Nob Red Sea Urchin survey (Sept 24-30, 2007). Transects not listed were excluded due to excessive depth or safety issues.

Transect	Latitude (N)		Longitude (W)		Depth (m) chart datum		Time		Total Time (minutes)	Transect Length(m)	Number Quadrats	Number RSU Counted	Population Density (RSU/m^2)	Biomass Density (g/m^2)
					Minimum	Maximum	Start	End						
1	54	16.783	130	51.561	3.90	7.10	14:55	15:06	11	59	30	70	2.33	370.34
2	54	17.170	130	51.159	-0.12	3.90	11:47	12:16	29	59	30	153	5.10	586.50
5	54	15.218	130	48.965	6.68	9.02	16:41	16:50	9	55	28	21	0.75	142.51
6	54	16.779	130	51.309	0.67	4.15	13:40	14:04	24	59	30	143	4.77	674.96
9	54	15.123	130	48.142	-0.82	1.74	14:40	15:06	26	59	30	160	5.33	889.15
10	54	15.863	130	52.442	5.82	10.09	14:56	15:08	12	39	20	38	1.90	259.72
11	54	14.646	130	51.665	-1.04	2.71	12:04	12:09	5	61	31	0	0.00	0.00
12	54	14.820	130	52.494	2.80	11.92	11:39	11:55	16	43	22	58	2.64	461.15
13	54	14.766	130	52.538	0.40	4.63	10:59	11:29	30	45	23	199	8.65	742.93
14	54	15.462	130	48.805	5.85	9.51	13:19	13:32	13	53	27	39	1.44	354.47
15	54	15.189	130	47.974	7.44	8.35	14:20	14:28	8	59	30	15	0.50	106.48
16	54	16.343	130	52.583	7.83	11.58	11:08	11:20	12	59	30	37	1.23	284.89
17	54	41.695	130	51.638	8.66	11.28	11:13	11:18	5	59	30	0	0.00	0.00
18	54	15.072	130	49.627	0.73	6.07	10:50	11:05	15	57	29	44	1.52	245.74
21	54	16.608	130	52.485	-1.31	4.33	11:52	12:21	29	59	30	221	7.37	860.26
26	54	16.827	130	51.500	-0.82	6.40	14:22	14:42	20	59	30	120	4.00	567.94
27	54	14.557	130	47.981	6.83	9.60	12:43	12:51	8	61	31	0	0.00	0.00
28	54	15.047	130	48.131	5.43	5.73	13:27	13:30	3	51	26	8	0.31	46.90
30	54	17.065	130	51.695	7.53	9.33	12:32	12:44	12	51	26	21	0.81	190.45
32	54	15.852	130	50.351	6.10	7.62	16:28	16:39	11	59	30	17	0.57	94.98
33	54	14.939	130	52.762	5.58	9.63	13:23	13:46	23	59	30	125	4.17	399.69
36	54	16.453	130	49.755	0.70	5.39	16:15	16:25	10	61	31	68	2.19	279.30
38	54	16.141	130	52.525	12.34	15.36	10:43	10:51	8	59	30	19	0.63	181.03
40	54	15.485	130	48.886	-0.94	4.08	12:10	12:44	34	59	30	201	6.70	949.01
42	54	16.629	130	51.403	4.69	8.93	15:45	15:58	13	59	30	41	1.37	306.76
43	54	17.035	130	51.733	7.68	10.30	12:57	13:18	21	59	30	70	2.33	489.51
44	54	15.211	130	49.010	1.31	10.88	16:16	16:31	15	59	30	35	1.17	224.50
45	54	15.914	130	52.168	2.38	5.46	14:14	14:26	12	59	30	60	2.00	183.71
46	54	15.263	130	49.393	3.99	7.41	11:17	11:24	7	59	30	47	1.57	298.80
47	54	16.621	130	50.046	1.74	7.07	17:31	17:54	23	59	30	134	4.47	675.21
48	54	16.574	130	50.072	2.23	4.79	16:54	17:14	20	59	30	102	3.40	489.52
50	54	14.999	130	51.648	6.07	9.08	12:35	12:45	10	59	30	29	0.97	232.83

Table 1. continued

Transect	Latitude (N)		Longitude (W)		Depth (m) chart datum		Time		Total Time (minutes)	Transect Length(m)	Number Quadrats	Number RSU Counted	Population Density (RSU/m^2)	Biomass Density (g/m^2)
					Minimum	Maximum	Start	End						
51	54	15.040	130	48.453	4.15	7.47	13:04	13:15	11	59	30	25	0.83	227.36
52	54	15.997	130	49.553	5.24	8.47	14:49	15:02	13	43	22	48	2.18	584.95
53	54	16.478	130	49.992	5.24	7.19	16:27	16:47	20	59	30	100	3.33	508.42
54	54	14.621	130	51.528	2.41	7.38	11:29	11:49	20	59	30	118	3.93	583.54
57	54	15.636	130	49.104	3.54	7.50	14:00	14:10	10	55	28	14	0.50	157.47
60	54	15.942	130	52.394	8.11	11.77	10:17	10:30	13	59	30	76	2.53	534.28
62	54	16.849	130	51.663	1.58	5.91	15:16	15:29	13	55	28	101	3.61	420.81
64	54	16.044	130	50.232	0.21	7.22	18:11	18:24	13	59	30	73	2.43	421.17
66	54	15.138	130	48.319	7.62	8.75	15:45	15:54	9	59	30	28	0.93	282.78
67	54	14.826	130	51.607	-0.12	7.68	10:55	11:03	8	19	10	12	1.20	199.25
68	54	15.834	130	52.200	2.26	5.73	15:38	16:05	27	59	30	213	7.10	601.23
69	54	14.603	130	51.883	-0.40	7.38	10:14	10:40	26	41	21	128	6.10	817.31
72	54	16.359	130	52.530	8.32	11.89	11:27	11:39	12	59	30	23	0.77	181.31
74	54	16.332	130	49.651	-0.52	1.58	15:35	16:01	26	59	30	196	6.53	877.35
75	54	13.886	130	47.999	-0.30	4.72	11:55	12:46	51	53	27	130	4.81	767.03
78	54	16.776	130	52.427	3.51	11.49	12:37	12:57	20	53	27	132	4.89	686.93
79	54	14.591	130	51.713	0.24	0.64	12:17	12:22	5	61	31	0	0.00	0.00
80	54	15.558	130	49.140	6.19	8.05	13:42	13:52	10	59	30	18	0.60	167.34
81	54	15.337	130	49.310	6.43	7.80	11:38	11:50	12	49	25	54	2.16	379.74
82	54	16.069	130	49.084	4.33	5.33	14:23	14:37	14	59	30	31	1.03	202.72
84	54	14.082	130	48.727	2.74	11.49	10:10	10:34	24	53	27	114	4.22	713.20
88	54	16.296	130	49.170	7.80	8.20	15:16	15:21	5	61	31	0	0.00	0.00
89	54	14.304	130	48.462	1.10	6.22	14:42	14:57	15	59	30	52	1.73	417.45
90	54	15.084	130	48.290	1.52	4.45	15:19	15:36	17	59	30	65	2.17	440.90
92	54	52.767	130	52.767	3.96	9.60	12:56	13:08	12	29	15	54	3.60	304.54
94	54	15.161	130	51.608	2.35	15.15	10:16	10:44	28	37	19	162	8.53	1462.66
95	54	16.012	130	52.271	12.98	14.17	10:04	10:09	5	59	30	5	0.17	51.97
98	54	14.844	130	52.501	5.18	8.99	12:05	12:19	14	57	29	70	2.41	399.84
100	54	13.756	130	47.670	4.42	7.68	10:44	11:13	29	59	30	157	5.23	619.70

Table 2. Number of quadrats by substrate category and primary substrate class for the 2007 Tree Nob Red Sea Urchin survey.

Substrate Category	Primary Substrate Class	Quadrat Count
1-Hard	1-Bedrock Smooth	945
	2-Bedrock Crevices	0
	3- Boulder	102
	Total	**1047**
2-Moderate	4-Cobble	64
	5-Gravel	135
	11-Shell, Whole	10
	Total	**209**
3-Soft	6-Pea Gravel	22
	7-Sand	410
	10-Shell, Crushed	30
	0-Mud	0
	9-Wood	0
	Total	**462**
	Overall Total	**1718**

Table 3. Summary of Red Sea Urchin count, mean density (number/m2) (SE in brackets), quadrat count, average substrate category and percent algae coverage, by depth range (chart datum) for the 2007 Tree Nob Red Sea Urchin survey. Substrate category: 1 = hard (rocky); 2 = moderate (cobble/gravel); 3 = soft (sandy). Canopy = tall, shading, surface-reaching algae. Understory = 30cm to 2m in height. Turf = 5cm to 30cm in height. Encrusting = species forming a thin, crustose layer on rocks.

Depth Range (m)	Number of RSU: Total	Number of RSU: Density/m^2(SE)	Number of Quadrats	Mean Substrate Category	Mean Percent Cover by Algae: Canopy	Understory	Turf	Encrusting
<0.0	210	2.38 (0.75)	88	1.27	8.18	33.18	15.80	40.45
0.0-<2.5	1572	6.00 (0.52)	262	1.38	1.72	14.58	4.50	68.97
2.5<5.0	1206	3.60 (0.23)	335	1.25	0.66	2.00	1.13	74.42
5.0<7.5	913	2.04 (0.12)	448	1.66	0.00	0.87	0.09	55.02
7.5<10.0	463	1.12 (0.09)	413	1.97	0.00	1.77	2.08	37.63
10.0<12.5	151	1.37 (0.23)	110	2.18	0.00	0.00	0.00	29.73
≥12.5	32	0.52 (0.20)	62	2.68	0.00	0.00	0.00	5.48
All	**4547**	**2.65 (0.30)**	**1718**	**1.66**	**0.81**	**4.97**	**2.24**	**52.60**

Table 4a. Population and biomass density estimates for three size classes of Red Sea Urchins from the 2007 Tree Nob Red Sea Urchin survey for individual sites and all sites combined.

Urchin Size	Site	Number of Transects (n)	Population Density (RSU/m^2) Lower Confidence Bounds		Population Density (RSU/m^2) Estimated Value	Population Density (RSU/m^2) Upper Confidence Bounds		Population Density (RSU/m^2) Estimated Standard Error	Biomass Density (g/m^2) Lower Confidence Bounds		Biomass Density (g/m^2) Estimated Value	Biomass Density (g/m^2) Upper Confidence Bounds		Biomass Density (g/m^2) Estimated Standard Error
			95%	90%		90%	95%		95%	90%		90%	95%	
All	1	5	1.346	1.665	3.112	4.651	4.795	0.661	477	581	1094	1515	1567	208
	2	25	1.479	1.555	2.080	2.815	2.972	0.365	610	641	805	1033	1072	113
	3	31	2.255	2.381	3.076	4.074	4.232	0.491	731	761	946	1196	1228	125
	Combined	61	2.079	2.159	2.657	3.145	3.288	0.299	739	761	901	1029	1058	80
Legal Size (≥90 mm TD)	1	5	0.678	0.891	1.743	2.395	2.518	0.342	372	451	943	1259	1293	178
	2	25	0.926	0.989	1.349	1.663	1.742	0.197	496	521	692	829	861	89
	3	31	1.073	1.134	1.494	1.757	1.813	0.182	510	539	701	823	854	84
	Combined	61	1.144	1.174	1.454	1.615	1.659	0.130	572	588	718	796	814	61
Commercially Targetted Size (90-140 mm TD)	1	5	0.559	0.747	1.659	2.292	2.421	0.349	238	371	857	1162	1210	180
	2	25	0.907	0.952	1.309	1.629	1.731	0.199	460	480	646	779	814	87
	3	31	1.042	1.105	1.470	1.735	1.796	0.185	480	506	674	787	819	83
	Combined	61	1.112	1.153	1.418	1.583	1.632	0.129	535	552	678	745	767	58

Table 4b. Analysis of variance (ANOVA) corresponding to the estimated densities and corresponding sum of squares (SS) and mean of squares (MS) for the treatment effects, the mean of squares for the error and the ratio between the two mean of squares (F-value). For the purpose of the ANOVAs each transect is weighted equally. There are different numbers of transects at each site, giving unbalanced data.

Urchin Size	Site	Number of Transects (n)	Population Density (RSU/m^2)					Biomass Density (g/m^2)				
			SS (Treatment)	MS (Treatment)	MS (Error)	F-value	p-value	SS (Treatment)	MS (Treatment)	MS (Error)	F-value	p-value
All	1	5	1.034	7.410	0.213	34.768	0.000	0.185	0.240	0.017	14.331	0.000
	2	25	8.344					0.231				
	3	31	5.442					0.063				
	Total	61	14.820					0.479				
Legal Size (≥90 mm TD)	1	5	0.419	0.371	0.042	8.750	0.000	0.253	0.139	0.009	14.772	0.000
	2	25	0.274					0.017				
	3	31	0.050					0.009				
	Total	61	0.743					0.279				
Commercially Targetted Size (90-140 mm TD)	1	5	0.290	0.336	0.044	7.719	0.001	0.160	0.093	0.009	10.080	0.000
	2	25	0.297					0.026				
	3	31	0.085					0.000				
	Total	61	0.672					0.186				

Table 5. Number of Red Sea Urchins measured and percent of urchins ≤50mm test diameter (TD) and ≥90mm TD for 2007 Tree Nob Red Sea Urchin survey. R_T = percent of all urchins that were ≤50mm TD. R_S = percent of sublegal urchins (TD<90mm) that were ≤50mm TD.

Test Diameter (mm)			Numbers Measured				Percent of Total Urchins Measured		
							≤50 mm TD		≥90 mm TD
Mean	Minimum	Maximum	Total	≤50 mm TD	≥90 mm TD	90-140mm TD	R_T	R_S	
91.1	8	164	4439	298	2451	2391	6.7	15	55.2

Table 6a. Estimated mean, lower and upper 90% confidence bounds (LCB, UCB) of Red Sea Urchin biomass density and maximum sustainable yield for all sites combined for the 2007 Tree Nob Red Sea Urchin survey using the submerged reef method.

Spatial Biomass Density(t/km^2)						Surveyed	Bc Biomass (t)						MSY (t) 0.2 M Bc (where M=0.10)					
TD≥90mm			TD 90-140mm			Area	TD≥90mm			TD 90-140mm			TD≥90mm			TD 90-140mm		
Mean	LCB	UCB	Mean	LCB	UCB	(km^2)	Mean	LCB	UCB	Mean	LCB	UCB	Mean	LCB	UCB	Mean	LCB	UCB
718	588	796	678	552	745	10.85	7791	6376	8638	7353	5988	8081	156	128	173	147	120	162

Table 6b. Estimated mean, lower and upper 90% confidence bounds (LCB, UCB) of Red Sea Urchin biomass density and maximum sustainable yield by site for the 2007 Tree Nob Red Sea Urchin survey using the submerged reef method.

Site	Spatial Biomass Density(t/km^2)						Surveyed	Bc Biomass (t)						MSY (t) 0.2 M Bc (where M=0.10)					
	TD≥90mm			TD 90-140mm			Area	TD≥90mm			TD 90-140mm			TD≥90mm			TD 90-140mm		
	Mean	LCB	UCB	Mean	LCB	UCB	(km^2)	Mean	LCB	UCB	Mean	LCB	UCB	Mean	LCB	UCB	Mean	LCB	UCB
1	943	451	1259	857	371	1162	1.17	1100	527	1469	1000	433	1356	22	11	29	20	9	27
2	692	521	829	646	480	779	4.28	2961	2227	3547	2762	2053	3334	59	45	71	55	41	67
3	701	539	823	674	506	787	5.41	3789	2916	4451	3642	2735	4255	76	58	89	73	55	85
						Total:	**10.85**	**7850**	**5670**	**9467**	**7404**	**5221**	**8945**	**157**	**114**	**189**	**148**	**105**	**179**

Table 6c. Estimated mean, lower and upper 90% confidence bounds (LCB, UCB) of Red Sea Urchin biomass density and maximum sustainable yield for the Tree Nob Group using the existing shoreline method.

Linear Biomass Density (t/km)						RSU Habitat	Bc Biomass (t)						MSY (t) 0.2 M Bc (where M=0.10)					
TD≥90mm			TD 90-140mm			Shoreline	TD≥90mm			TD 90-140mm			TD≥90mm			TD 90-140mm		
Mean	LCB	UCB	Mean	LCB	UCB	Length (km)	Mean	LCB	UCB	Mean	LCB	UCB	Mean	LCB	UCB	Mean	LCB	UCB
36	28	52	29	22	43	32.77	1168	907	1704	961	736	1395	23	18	34	19	15	28

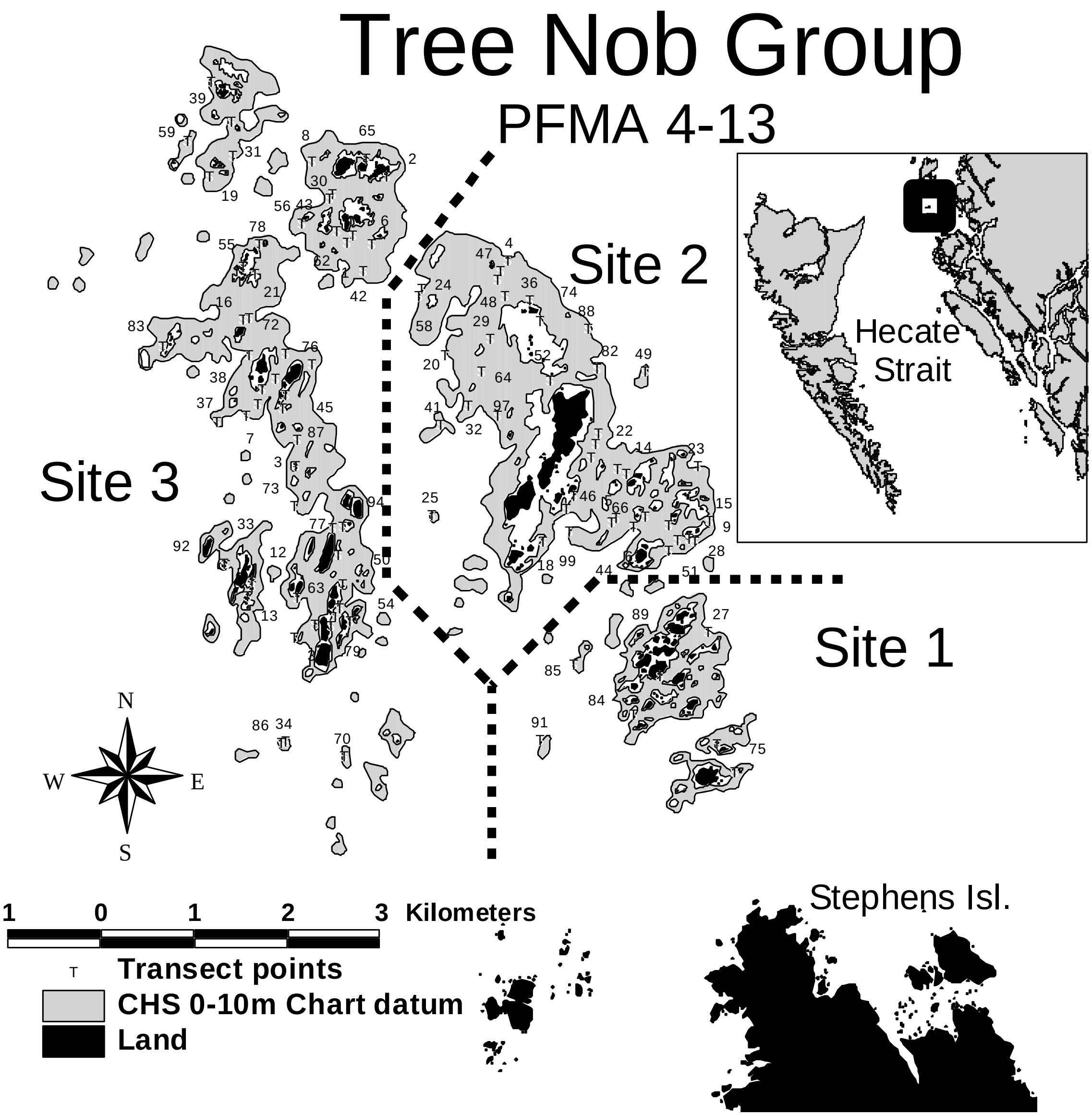

Figure 1. Map of survey area and transect locations (with transect number) for the Red Sea Urchin stock assessment survey conducted in the Tree Nob Group (2007). Dashed lines indicate site boundaries. Survey locale marked by black box on inset.

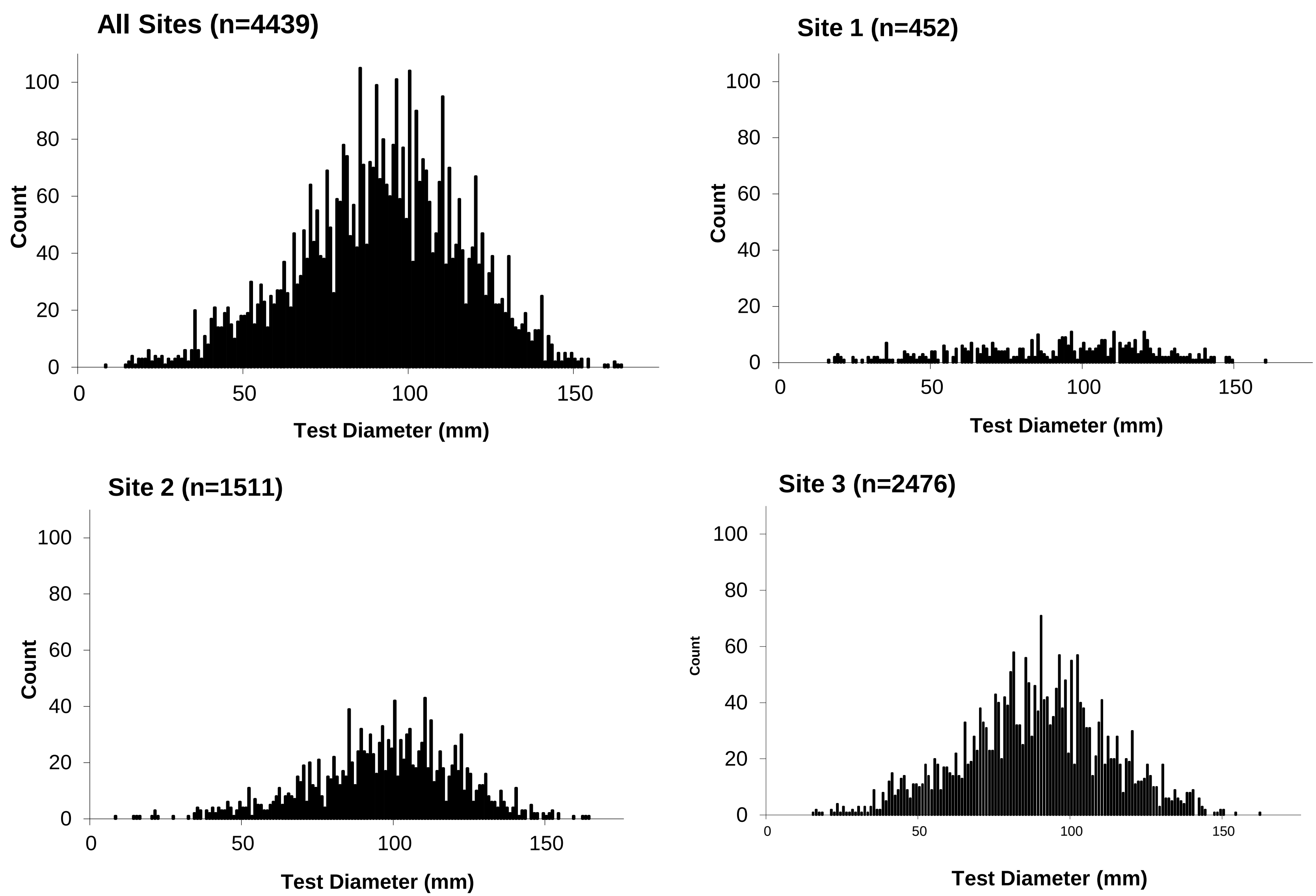

Figure 2. Size frequency distribution of RSU (n= number of red sea urchins measured) during 2007 Tree Nob Red Sea Urchin survey for all sites combined and for each of Sites 1, 2 and 3.