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Ágrip

Útbreiðsla og stofnstærð ígulkersins skollakopps *(Strongylocentrotus droebachiensis)* var könnuð í september 2015 og október 2016 á aðalveiðisvæði í sunnanverðan Breiðafirði (suður af línu 65°10´N og austur af línu 22°40´W). Heildarstærð veiðisvæðis var áætlað 9.7 km^2 og fundust ígulker í töluverðu magni á sjö undirsvæðum innan þess. Til rannsóknanna var notaður ígulkeraplógur og neðansjávarmyndavél. Meðalveiðihæfni plógsins var metin, 29%, út frá samanburði á fjölda ígulkera/m^2 á botnmyndum áður en veiði hófst og í afla frá sama svæði á sama tíma. Heildarstofnstærð svæðisins var áætluð 2.700 tonn og meðalfjöldi á öllu svæðinu 3.5 ígulker/m^2. Stærðarsamsetning stofnsins var skoðuð, en meðalstærð (þvermál) var mismunandi eftir svæðum, 48 - 67 mm. Á öllum svæðum til samans var meðalstærðin 59.3 mm. Stærðardreifing á svæðunum var svipuð, en lang flest keranna voru í stærðaflokki 55-60 mm. Stærðar-þyngdarsambönd voru aðeins mismunandi á milli svæða, þyngst dýr miðað við stærð fundust á því svæði þar sem framleiðnin var mest. Nýtingarhlutfall úr afla var metið og var mismunandi eftir stöðvum og svæðum. Meðalnýting svæðanna var frá 38-70% en fyrir öll svæðin til samans var 55%. Nítján botndýrategundir voru greindar af botnmyndum frá fjórum svæðum og voru mismuandi tegundir ríkjandi. Slöngustjarna fannst í lang mestu magni en aðeins á einu svæði, hörpudiskur var ríkjandi á öðru og skollakoppur á tveimur af 4 svæðum.

Abstract

A dredge survey was conducted in September 2015 and April 2016 to provide the first assessment of sea urchin resources in southern Breiðafjörður (south of line 65°10´N and east of line 22°40´W) at 8 – 60 m depth. The whole area investigated was 9.7 km^2. Sea urchins were patchy distributed in significant concentration in seven (I-VII) small subareas within the *investigated area. The efficiency of the dredge was assessed in the investigation by comparing species diversity and abundance from bottom photographs before dredging and in the catch from the same site. The standing stock for the whole area was about 2.700 tonnes using the mean efficiency (29%) for the dredge used. The average density in all areas combined after correction of the dredge efficiency was 3.5 individuals/m^2. Information on population structure was provided. The mean shell size was significantly different between areas in 10 out of 15 area combinations ($p < 0.05$) (Kolmogorov-Smirnov) and the most frequent size class was 55 – 60 mm. The size (diameter) –weight relationship differed between areas and and the greatest relative wet weight for similar sized urchins was observed were higest productivity has probably taken place. The utilization coefficient differed greatly between catches. The mean coefficient for all areas combined was 55%, ranging from 38 – 70 % between areas. Nineteen different invertebrate species were identified from bottomphotographs from four areas investigated. The dominating species differed, where brittle star (Ophiuroidea) dominated in Area I, Chlamys islandica (the Iceland scallop) in area II and the green sea urchin (Strongylocentrotus droebachiensis) in area VI and VII.*

Lykilorð: *ígulker, skollakoppur, stofnstærðarmat, stærðarsamsetning, veiðhæfni, nýtingarhlutfall.*

Undirskrift verkefnisstjóra:	**Undirskrift forstöðumanns sviðs:**

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Introduction

Most sea urchin fisheries are found in the temperate regions of the world and only few genera are harvested. The harvested product is the gonad of both sexes (roe) and the longest tradition for consumption is in Asia, Polynesia, Mediterranean and Chile. Japan is the biggest market, consuming 80 – 90% of the global supply, about 50.000 tonnes. Chile, New Zealand and Philippines have a domestic market but the European market, consuming 3000 – 3500 tonnes yearly, is mainly in Italy, France and Spain (Stefánsson et al. 2017). The world´s production of sea urchins peaked in 1995 but since then it has declined and now Chile stands for more than half of the production. The world production of sea urchins in 2014 was 76.500 tonnes (FAO 2016). In the northern hemisphere, the genus *Strongyloentrotus* accounts for most of the harvest and mainly two species are fished, i.e *S. franciscanus* and *S. droebachiensis*. In Icelandic waters, there are two exploitable species of sea urchins i.e the green sea urchin (*S. droebachiensis)*, which is the only targeted species, and the edible sea urchin (*Echinus esculentus)* (Figure 1).

Figure 1. The green sea urchin (*Strongylocentrotus droebachiensis*) on the left and the common sea urchin (Echinus esculentus) to the right.

Mynd 1*. Ígulkerin grænígull t.v. og marígull t.h. eru algengust ígulkera á grunnsævi hér við land. - Ljósm./Photo: Karl Gunnarsson.*

Sea urchin are dioecious and store nutrients in their gonads year around prior to the production of the gametes. The roe serves thus both for reproduction (eggs and sperm) and as a nutrient store in intra-gonadal storage cells (nutritive phagocytes). Therefore, gonad condition of sea urchins can be used to estimate the nutrition state and the quality of the habitat (Murillo-Navarri & Jimenez-Guirado 2012). Body indices can vary throughout the year due to fluctuations in the environment and it has been shown that gonads grow during the cold winter (Byrne 1990). The size and quality of the gonad varies both as a function of the reproductive cycle and the availability and type of food. The time of harvesting is determined based on the quantity and quality of the roe. The market demands roe filling >10% but when that is reached the quality can be variable and is unacceptable when too soft or when eggs and sperm begin to be formed just before spawning.

In Iceland harvesting of sea urchins started in 1983 by divers but this was not economically feasible and stopped in 1989. In 1993 the fishing started again with increasing demand from the Asian markets, primarily Japan. Since then sea urchins have only been harvested by dredging in Icelandic waters as it is considered to be the best solution for the Icelandic fisheries because of the weather, cost and efficiency. In the beginning, two types of modified dredges were used. Since 2005 a new version of modified scallop dredge has been used, a kind of a ski dredge (Figure 2). The selectivity and efficiency of the dredge is unknown, but the efficiency of scallop dredges varies from 2 – 85% (Navarte et al. 2011). The landings peaked in 1994 when 1.500 tonnes were landed. After that the fishery declined extremely and stopped 1997. In 2005 exploitation of the stock started again and now only in Breiðafjörður west Iceland. Since 2007 the annual landings have been about 150 tonnes until 2014 when it started to increase, reaching 350 tonnes in 2017. Since 2007, the catch per unit effort (CPUE) has been steady, ranging from 365 – 478 kg/hour fished (Anon 2018). The main fishery has always been in a small area of the southern part of Breiðafjörður and focused on small hot spots. Iceland is the largest supplier of wild caught sea urchin in Europe based on harvest figures. However, unlicensed and illegal fishing is carried out in various European countries, making the harvest difficult to estimate. Most of the sea urchins landed in Iceland are shipped alive to a market in France, and in 2015, a total of 96% were exported to France (Statistic Iceland 2016).

Figure 2. A commercial sea urchin dredge.
Mynd 2. *Ígulkeraplógur um borð í Fjólu. Ljósm./Photo:Guðrún Þórarinsdóttir.*

The geographical distribution of green sea urchin around Iceland is very patchy. It is commonly associated with laminarian kelp which it feeds on. Current information on distribution, quality and size of the stock around Iceland is limited and no estimates of biomass, trends in relative abundance or assessments of sustainable yield exist. No fishery-independent survey has been carried out and the only data (location, landed catch, fishing effort) available have been from the fishery. However, some investigations on densities (ind./m^2) distribution and population structures in small areas off Iceland have been carried out (Einarsson 1993, Ásbjörnsson 2011) and the distribution of the fishery in the 1993 – 1997 (Einarsson 1994). The main objective of the present study was to examine the stock size and distribution in the main fishing area in Breiðafjörður, population structure, utilization in catches and dredge efficiency.

Methods

The study area

Surveys were conducted to assess the sea urchin stock in southern Breiðafjörður (south of line 65°10´N and east of line 22°40´W) (Figure 3) at depth of 8 – 60 m from 13th – 18th of September 2015 and 11th – 13th of April 2016. The surveys were carried out on a commercial sea urchin fishing vessel (Fjóla SH 7) (Figure 4) using a commercial dredge, measuring 250 cm in width and with mesh size of the bag beeing 100 mm (Figure 2).

Distribution, density/abundance and dredge efficiency

In order to determine the distribution and biomass/abundances, an area swept method was used, as each catch was weighed and the distance covered by the dredge was caluclated. The total catch weight was divided by the size of the area covered in each tow to give abundance in kg/m^2. Biomass estimates in a given area were calculated from the mean biomass in that area multiplied by the total size of the area. The density (ind./m^2) was calculated by dividing the mean wet weight of the individuals in an area into the abundance (kg/m^2) of the area.

In September 2015 photographs were taken at 22 sites within four of the seven investigated areas (I, II, VI, and VII) (Figure 3) by an underwater photocamera (Figure 5). At each site, photographs were taken at several locations and a total of 160 photos were captured. Later on, the sea urchins from the photos were counted, as well as other bottom species which were identified and counted to estimate the diversity on the bottom. The dominating species in each area was identifed. The density (no/m^2) of sea urchins from the photos and the results from the dredge survey (no/m^2) from the same area at the same time were compared and the dredge efficiency assessed as percent of dredged individuals of what was observed from the photographs.

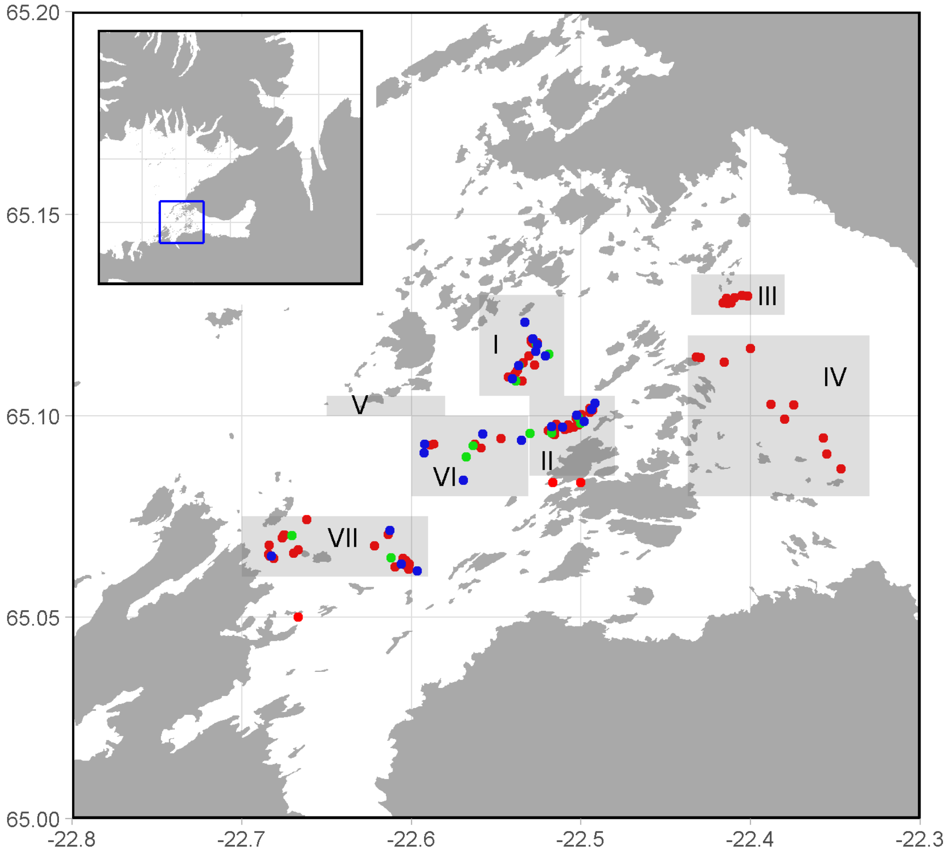

Figure 3. A map of the seven fishing subareas (shaded) investigated in Breiðafjörður. The red and the green dots denote the stations in September 2015 and April 2016 respectively, but the blue are photo stations from September 2015.

***Mynd 3**. Kort af rannsóknarsvæðum í Breiðafirði. Rauðu punktarnir eru mælingastöðvar í september 2015, grænu frá apríl 2016 og bláu eru myndatökustöðvar frá september 2015.*

Figure 4. The sea urchin fishing boat Fjola SH7 (2070).

Mynd 4. *Ígulkerabáturinn Fjóla SH7 frá Stykkishólmi. Ljósm./Photo: Guðrún Þórarinsdóttir.*

Figure 5 An underwater photocamera.

Mynd 5. Neðansjávarmyndavél. Ljósm./Photo: Guðrún Þórarinsdóttir.

Population structure and utilitation coefficent

From the catches in September 2015 a subsample of approximately 20 kg was taken at several sites within six areas investigated (Figure 6) and brought to the laboratory for investigation of population sturcture. The size of the sea urchins (diamater and height) was measured to the nearest 0.1 mm and the total wet weight of each individal was assessed to the nearest 0.1 g. Analysis of variance (ANOVA) was used to compare the mean length for the six areas investigated. Length frequency distributions for each sample was established with 5 mm size classes as well as for the whole population. To analyse whether the length distributions from all six areas differed i.e if each area contained individuals from a population with a specific distribution, a Kolmogorov-Smirnov test was used and applied to all 15 possible area combinations. The relationship between size (diameter) and wet weight was also investigated for the six aeras and for the whole population combined using the equation:

$$W = a L^{b}$$

where, W= wet weight (gr); L: total size (mm); a = intercept and b slope. Both a and b were estimated using a linear regression analysis and to obtain linearity, the equation was log-transformed:

$$LogW=Log\ a + b\ logL$$

Also, regression slopes were compared between areas with a analysis of covariance with the area as a categorial variable.

In September 2015, samples were taken from five of the fishing areas investigated but in April 2016, samples were taken from three areas, as well as one outside (13) (Figure 6) where live urchins, by-catch and mud/sand were sorted out and weighed. The fraction of live green sea urchins from the sample was weighed and the utilization coefficient (percentage whole wet weight of sea urchins from the whole wet weight of the catch) estimated for each station and a mean for each area. The fraction of roes as a percentage of the wet weight of the urchins was determined.

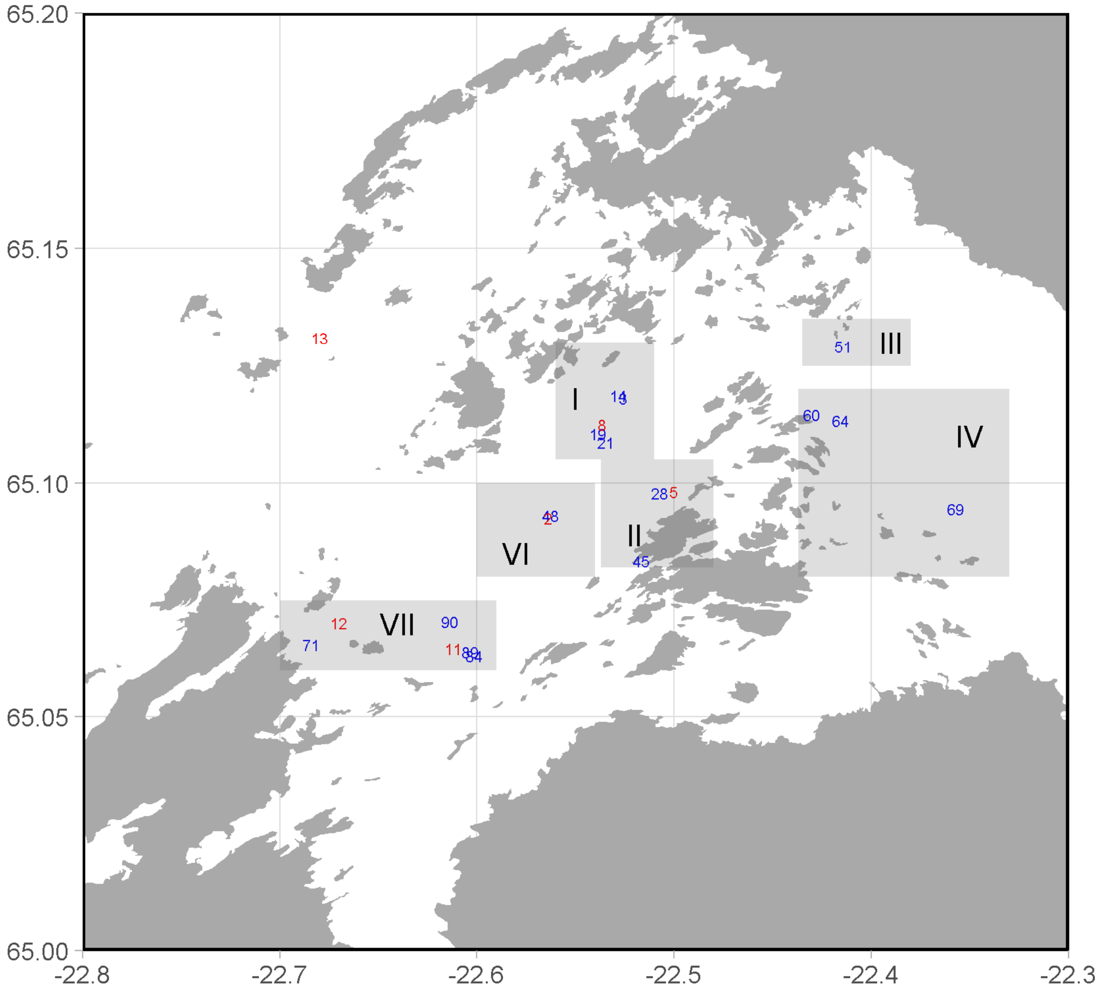

Figure 6. Map of sampling stations in Breiðafjörður for population structure (diameter/height/weight), by-catch and utilitation coefficient in catches in september 2015 (blue sample numbers) and by-catch and utilitaztion coefficients in April 2016 (red sample numbers).

Mynd 6*. Kort af sýnatökustöðvum í Breiðafirði, til mælinga á stærð og vigt, meðafla og nýtingarhlutfalli í september 2015 (blá stöðvanúmer) og meðafla og nýtingarhlutfalli í april 2016 (rauð stöðvanúmer).*

Results

Distribution, abundance, density, biomass and efficiency of the dredge

The whole area investigated measured 9.7 km^2 and contained seven smaller harvesting areas that differed in size and depth. Sea urchins were widely distributed and found at all stations sampled (91) at 8 – 60 m depth. The estimated mean abundance, assessed by the area swept method, ranged from 0.04 – 0.12 kg/m^2 and the density from 0.5 – 2.0 ind./m^2 giving that the dredge was 100% efficient. Further investigation on the dredge efficiency showed that the mean efficiency was 29%, giving the standing stock for all areas combined 2.700 tonnes. The mean abundance (kg/m^2), range, mean density and standing stock for each of the seven areas are summarised in Table 1. In this Table, the data are corrected for the 29% efficiency of the dredge.

After correcting the density for the efficiency of the dredge (29%), the maximum density in all areas investigated was observed in areas III and IV, i.e 5.1 and 6.9 ind/m^2 respectively. These two areas have the lowest mean depth (11 m) and were of a moderate size (1.4 and 2.7 km^2) giving the maximum biomass in the areas. In area III, gravel bottom and kelp beds were observed. The mean roe yield differed greatly between these areas, 12% and 2.1% in area III and IV respectively, (Table 2).

Area I and II were relatively small, 0.7 and 0.3 km^2 respectively. The mean depth was 33 m and the bottom covered with gravel and drifting kelp was observed. The average density was 3.1 and 3.4 ind/m^2, and the mean roe yield high, 11.5 and 13%, in area I and II, respectively (Table 2).

Area VI was the biggest (3.4 km^2) and the bottom was muddy. This area had the lowest density (1.7 ind. m^{-2}) and a low row yield (4.5%) (Table 2). The depth varied greatly between the stations investigated in this area. The density in area VII (0.4 km^2), with mean depth of 19 m, was rather low, or 2.1 ind/m^2. The bottom was gravel and rocky and kelp was observed.

The abundance/density in area V was not measured in this study but results from previous fishing surveys were used. The size of the area was still measured and the mean abundance from surveys converted to density which was 3.4 ind/m^2.

Table 1. Estimated mean abundance and range (kg/m^2), density (no/m^2) and total standing stock/biomass (wet weight t) for green sea urchin at 8 – 60 m depth. The abundance, density and biomass is corrected with the efficiency of the dredge which was calculated as 29%.

***Tafla 1**. Meðal lífmassi og dreifing (kg/m^2), fjöldi/m^2 og stofnstærð (tonn) ígulkera á 8 – 60 m dýpi. Tekið er tillit til veiðhæfni plógsins sem var áætluð 29%.*

Area no	Location	No. of samples	Depth range (m)	Area km^2	Abundance kg/m^2	Range kg/m^2	Denstiy no/m^2	Biomass (mt)
I	**N - Breidasund**	21	28-55 mean=35 m	0.7	0.28	0.14-0.69	3.1	196
II	**S-Breidasund**	28	18-60 mean=32 m	0.3	0.28	0.14-0.52	3.4	84
III	**Within Rastar**	14	8-14 mean=11 m	1.4	0.41	0.07-0.72	5.1	574
IV	**Within Rastar**	7	8-13 mean=11 m	2.7	0.31	0.14-0.48	6.9	837
V	**Breidasund***	0		0.8	*0.28		*3.4	*224
VI	**Breidasund**	2	14-55	3.4	0.14	0.07-0.21	1.7	476
VII	**E-Seley**	19	14-33 mean=19 m	0.4	0.24	0.07-0.38	2.1	96
	All areas	91	8-60	9.7	0.28	0.24-0.72	3.5	2716

**The abundance in area was estimated from previous fishing surveys but the size of the area was measured in the study.*

Population structure and roe yield

In the six areas where sea urchins were measured (Figure 6), no individuals < 17 mm in diameter were observed. Significant difference in mean size was observed for the six areas investigated (ANOVA, F_5=32.73, $p < 0.05$). The mean size in the different areas ranged from 48.1 – 67.0 mm (Figure 7, Table 2). The lowest mean was observed in the biggest area (IV) (48.1 mm and 45.7 g) with the lowest roe yield (Table 2). The highest mean on the other hand, was observed in one of the smallest area (VII) (67 mm and 113.1 g), with the highest roe yield. (Figure 7, Table 2). In four (I, II, III, VI) out of six areas > 50% of the urchins were in the size classes 51 – 65 mm (Figure 7).

When all size frequency distributions were compared, ten out of fifteen combinations were significantly different from one another ($p<0.05$) (Figure 7, Table 3). When all areas were combined, the pooled size distribution showed approximately unimodal pattern dominated by individuals between 40 and 70 mm with the mean size of 59.3 mm (Figure 8).

Table 2. A summary of populations structure and roe yield, data for green sea urchins in six areas in southwestern Breidafjördur in September 2015.

Tafla 2. *Niðurstöður stærðarmælinga ígulkera (þvermál, hæð, votvigt) frá sex svæðum í Breiðafirði í September 2015.*

Area	Location	Station	Depth	Diameter (mm)			Height (mm)			Wet weight (g)			Roe
no	(size)	number	m	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	%
I	**N -Breidasund**	3	34	64.4	8.2	28.1-83.3	38.7	4.7	19.8-47.9	98.3	31.2	9.7-159.0	13
	(0,7 km^2)	14	32	65.7	10.1	40.5-81.5	37.5	6.1	21.6-45.5	107.5	41.7	20.8-180.1	
		19	41	58.5	6.7	42.5-72.3	34.4	4.4	27-45.8	76.5	26.0	39.1-141.1	10
		21	28	58.1	5.9	48.4-70.5	34.5	3.9	28-41	77.6	23.8	39.3-136	
	All samples n	**n=161**		**61.2**	**8.0**	**28.1-83.3**	**36.3**	**5.0**	**19.8-47.9**	**90,0**	**31.7**	**9.7-180.1**	
II	**S-Breidasund**	28	25	62.5	9.8	35-75	37.4	5.6	23-49.3	91.7	32.8	17.2-163.7	13.5
	(0.3 km^2)	48	53	56.4	8.2	42.5-73.3	34.9	5.6	26-57.1	72.4	30.0	33.5-152.2	12.5
	All samples	**n=81**		**59.1**	**9.4**	**35-75**	**36**	**5.7**	**23-57.1**	**81**	**32.6**	**17.2-163.7**	
III	**Within Rastar**	51	11	57.4	8.7	30.5-78	35	4.5	20-42.5	73.6	29.1	10.3-150.7	10.5
	(1.4 km^2)	60	11	59.5	8.7	33.5-78	35.5	6.0	20-46.5	81.3	34.5	13.5-153.1	14
	All samples	**n=81**		**58.6**	**8.7**	**30.5-78**	**35.3**	**5.4**	**20-46.5**	**78**	**32.3**	**10.3-153.1**	
IV	**Within Rastar**	64	10	54.8	9.1	30-68.5	31.1	5.2	17-38.5	62.9	23.7	10.4-104	3.8
	(2.7 km^2)	69	11	41.3	7.0	17-52	23.5	5.0	11-39	28.0	11.6	2.4-59.2	0.4
	All samples	**n=71**		**48.1**	**10.6**	**17-68.5**	**27.4**	**6.3**	**11-39**	**45.7**	**25.6**	**2.4-104**	
VI	**Breiðasund**	45	56	57.6	8.6	37-71	35.5	5.0	22.5-46	80	30.5	21.2-151	4.5
	(3.4 km^2)	90	55	60.6	8.6	35.5-79.5	35.2	5.7	21-44	90.5	36.0	17.6-155.7	4.5
	All samples	***n=70***		***58.9***	***8.6***	***35.5-79.5***	***35.2***	***5.3***	***21-46***	***84.6***	***32.7***	***17.6-155.7***	
VII	**E-Seley**	71	18	66.9	7.8	46-81	37.9	4.18	29-46	101.8	32.2	35.8-173.4	10.5
	(0.4 km^2)	84	22	66.2	13.6	29-85.4	39.1	7.9	16-58	124.5	53.6	9.0-216.1	17.5
		89	14	69.8	7.6	59.5-82	37.8	5.0	30-46	125.7	40.8	78-195.7	
	All samples	***n=74***		***67.0***	***10.8***	***29-85.4***	***38.2***	***6.4***	***16-58***	***113.1***	***45.5***	***9-216.1***	
All areas pooled		***n=538***		***59.3***	***10.5***	***17-85.4***	***35.0***	***6.4***	***11-58***	***82.9***	***37.9***	***2.4-216.1***	

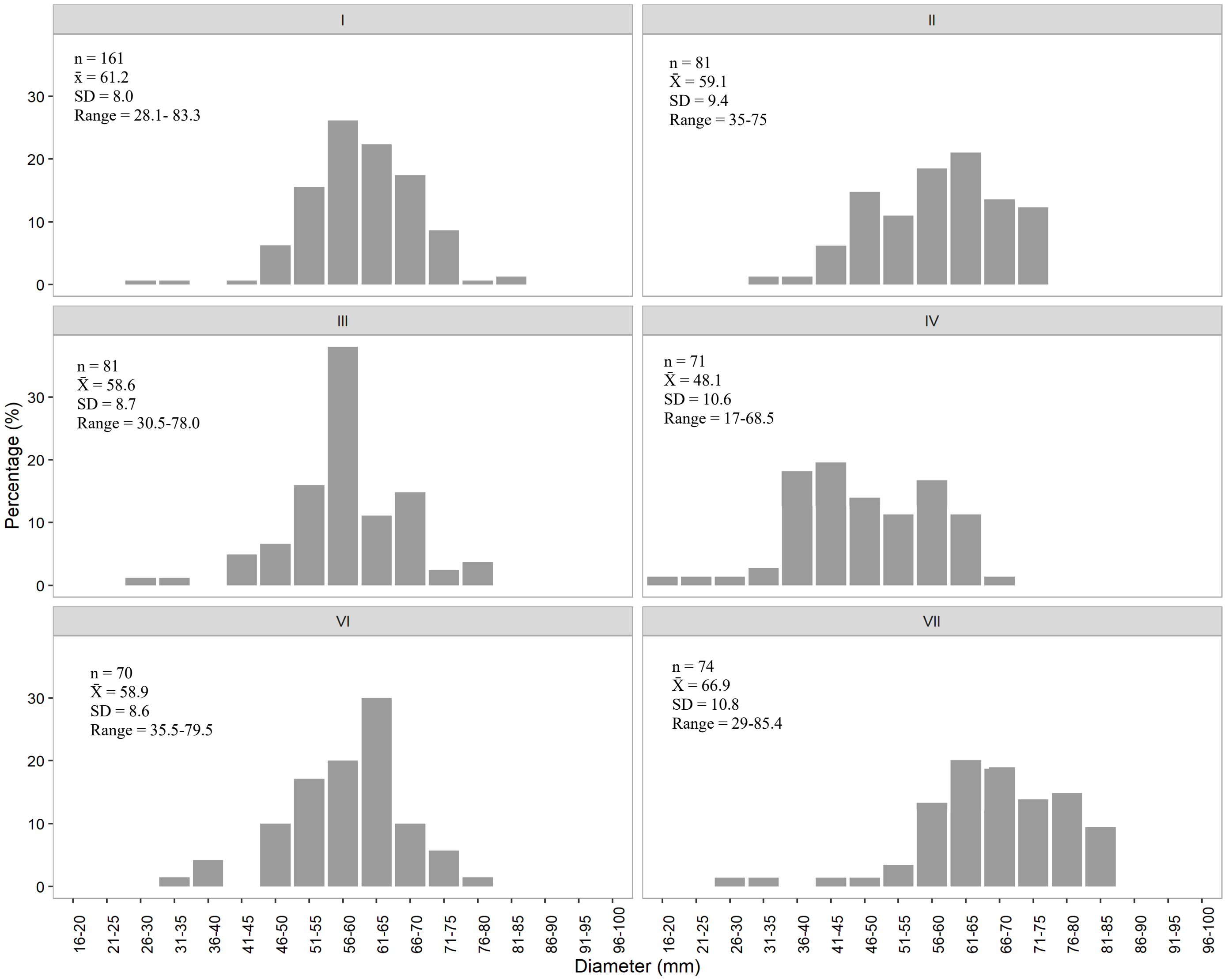

Figure 7. Size (diameter) frequency distribution for 5 mm size classes of green sea urchin in six areas in Breiðafjörður.

***Mynd 7**. Stærðardreifing (þvermál) ígulkera frá sex rannsóknarsvæðum í Breiðafirði.*

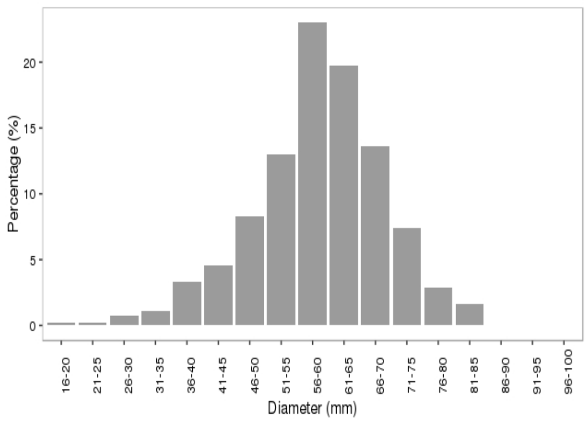

Figure 8. Size (diameter) frequency distribution for 5 mm size classes of green sea urchin for all areas combined.

***Mynd 8**. Stærðardreifing (þvermál) ígulkera frá öllum rannsóknarsvæðum í Breiðafirði.*

Table 3. Size frequency distributions; Results from Kolmogorov-Smirnov test from all areas. The probability represents the p-value.

***Tafla 3**. Stærðar-þyngdarsambönd: Niðurstöður úr Kolmogorov-Smirnov prófi frá öllum svæðum.*

Area	Probability
I-II	0.107
I-III	0.019*
I-IV	$1.05e^{-12}$*
I-VI	0.413
I-VII	$1.38e^{-4}$*
II-III	0.247
II-IV	$2,45e^{-06}$*
II-VI	0.834
II-VII	$2.78e^{-4}$*
III-IV	$2.41e^{-08}$*
III-VI	0.285
III-VII	$3.32e^{-07}$*
IV-VI	$5.77e^{-07}$*
IV-VII	$1.85e^{-13}$*
VI-VII	$2.540e^{-05}$*

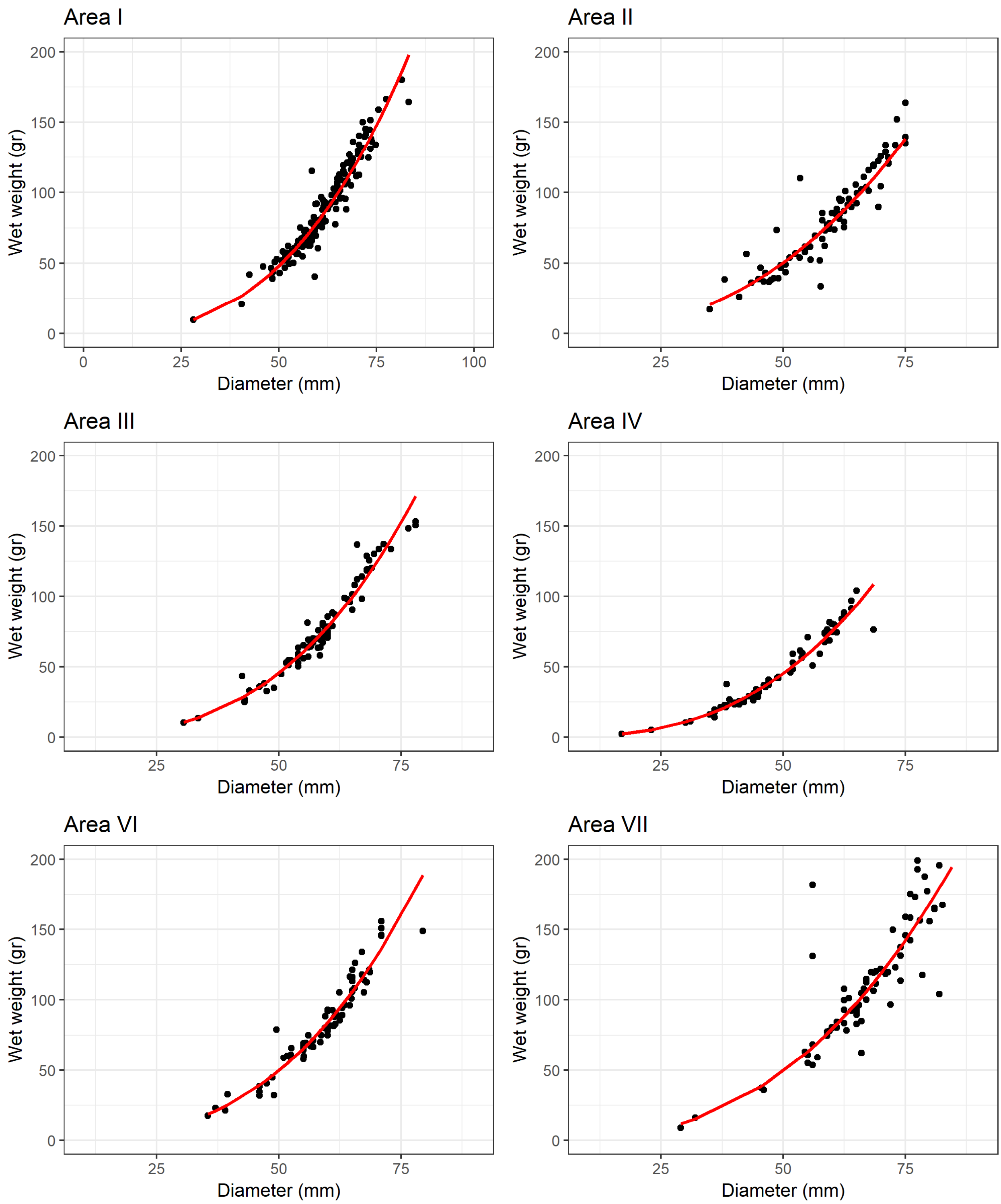

Figure 9. Estimated size (diameter) wet weight relationship for green sea urchin from six areas investigated.

***Mynd 9**. Stærðar- þyngdarsambönd ígulkera frá sex mismunandi rannsóknarsvæðum.*

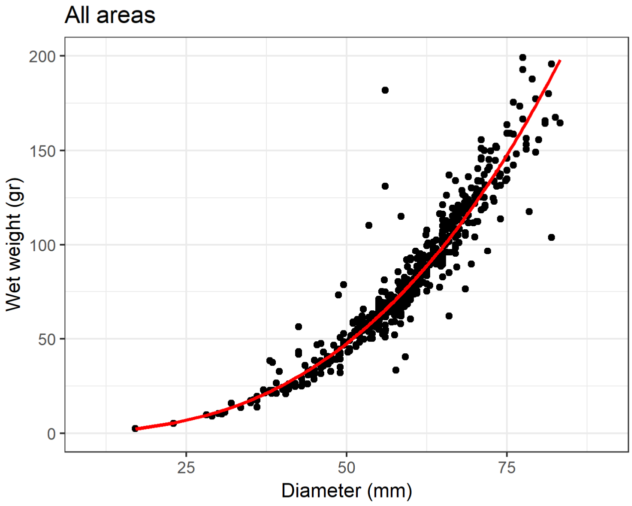

Figure 10. Estimated size-wet weight relationship for green sea urchin from all areas.

Mynd 10*. Stærðar- og þyngdarsambönd ígulkera frá öllum svæðum.*

Table 4. Regression parameters of the length-weight relationship of green sea urchins from six areas in southwestern Breiðafjörður in September 2015.

Tafla 4*. Aðhvarfsstuðlar lengdar- og þyngdarsambanda ígulkera frá sex svæðum í Breiðafirði í september 2015.*

	Logarithmic regression	Exponential form of the equation				
Area	(Log W = Log a + Log L)	a	b	W	r^2	p
I	y = -6.98 + 2.77x	0.0009	2.77	$0.0009*L^{(2.77)}$	0.92	< 0.05*
II	y = -5.81 + 2.48x	0.0029	2.48	$0.0029*L^{(2.48)}$	0.85	< 0.05*
III	y = -7.83 + 2.97x	0.0004	2.97	$0.0009*L^{(2.97)}$	0.95	< 0.05*
IV	y = -7.08 + 2.78x	0.0008	2.78	$0.0009*L^{(2.78)}$	0.97	< 0.05*
VI	y = -7.33 +2.87x	0.0006	2.87	$0.0009*L^{(2.87)}$	0.93	< 0.05*
VII	y = -6.34 + 2.61x	0.0017	2.61	$0.0009*L^{(2.61)}$	0.85	< 0.05*

There was a significant correlation between shell length and total body weight in all six areas ($P < 0.05$) (Figure 9, Table 4). The greatest relative wet weight and the greatest estimated slope (b) was found in area III indicating that urchin from this area usually contained more meat per unit shell size (diameter) for the range of sizes considered. This relationship was lowest in area II (Table 4). The interaction of slopes was significant (ANCOVA, $F_5 = 5.18$, $p = 0.0001$) between logarithmic values of size (diameter) and total body weight between all six areas, i.e the slopes across groups are significantly different (Table 4).

In four (I, II, III, VII) out of six areas where roe yield was investigated in September 2015 (Figure 6), the quality was satisfying for the market (>10%), ranging from 10 – 17.5%. In the two biggest areas the yield was only 3.8 – 4.5% (Table 2).

Catch utilization and by-catch

The utilization coefficient (a percentage of green sea urchin whole wet weight of the whole catch weight), which was estimated in September 2015 and April 2016 differed between stations, ranging from 11 – 98% (Table 5). The mean coefficient between areas ranged from 38 – 70% with the maximum utilization and the highest mean coefficient observed in September at station 64 at 10 m depth (Table 5). At this station the catch was relatively clean, with almost no by-catch but the roe yield was only 3.8% (Table 2). The lowest utilization was observed at station 89 at 19 m depth. The lowest mean was observed in area VII (40.5%) in September where the range of depth was wide (Table 5). The roe yield of the urchins at the only two stations measured was 10.5 and 17.5% but the catch was mostly gravel and dead shells. In April, the highest utilization, both in a single station (64%) and the mean (63.5%) was in Area VII (Table 5), where the catch was clean (no by-catch) (Figure 11) but roe yield was not measured.

In the same way, the by-catch in a catch differed between stations and areas. In both September and April, the percentage of by-catch was highest in area II, i.e 29 and 44% respectively in these months (Table 5).

Figure 11. A catch with low (left) and high (right) utilization coefficient.

Mynd 11*. Afli með lágu (vinstri) og háu (hægri) nýtingarhlutfalli. Ljósm./Photo: Guðrún Þórarinsdóttir.*

Table 5. Utilization coefficient of sea urchin (%), by-catch (kg/%) and mud (kg/%) from each station in September 2015 and April 2016.

Tafla 5. *Nýtingarhlutfall ígulkera úr afla (%), meðafli (kg/%) og botnefni (kg/%) í september 2015 og april 2016.*

Area	Samples (no)	Depth (m)	Total weight of sample (kg)	Sea urchin (kg) (%)	By-catch kg (%)	Mud/sand kg (%)	Mean uti. in an area (%)
Sep-15							
II	28	25	14.2	5.6 (40)	4.1 (29)	4.5 (32)	
	45	56	22.7	10.5 (46)	3.4 (15)	8.8 (39)	43
III	51	11	12	7.2 (60)	2.2 (18)	2.7 (22)	
	60	11	14	10 (71)	0.3 (2)	3.6 (26)	65.5
IV	64	10	7.6	7.5 (98)	0.9 (12)	0	
	69	11	5.2	2.3 (42)	0.2 (4)	2.7 (52)	70
VI	48	56	15.5	9.2 (60)	4.1 (26)	2.2 (14)	60
VII	71	18	14.7	8.5 (58)	3.4 (23)	2.8 (19)	
	84	22	14.6	3.4 (23)	2.9 (20)	8.4 (57)	
	89	19	9.3	1 (11)	0.1 (1)	8.2 (88)	40.5
	90	55	15.7	11 (70)	0.8 (5)	3.9 (25)	
Apr-16							
I	8	38	15.2	5.8 (38)	1.2 (21)	8.2 (54)	38
II	5	36	14.5	6.2 (43)	2.7 (44)	5.6 (39)	
	11	22	14.2	7.5 (53)	1.1 (15)	5.6 (39)	48
VII	2	50	10.7	6.8 (64)	2 (29)	1.9 (18)	
	12	16	9.2	5.8 (63)	1.1 (19)	2.3 (25)	63.5
Outside	13	26	5	3.3 (66)	1 (30)	0.9 (18)	62

Efficiency of the dredge and bottom species observed from photographs

The mean number of sea urchins counted from the bottom photographs (Figure 12) within an area, range and the mean number caught by the dredge as well as the efficiency of the dredge is shown in Table 6. The highest mean density (6.5 ind/m^2) from photos as well as the smallest catch was in area VI at 55 m depth, resulting in the lowest efficiency (8%). The efficiency was highest (60%) in area VII at 20 m depth, where the lowest density was observed from the photos (1 ind/m^2). The mean density of sea urchins for all areas combined was 3.9 ind/m^2 and the mean efficiency of the dredge 29%, ranging from 8 – 60 % between areas.

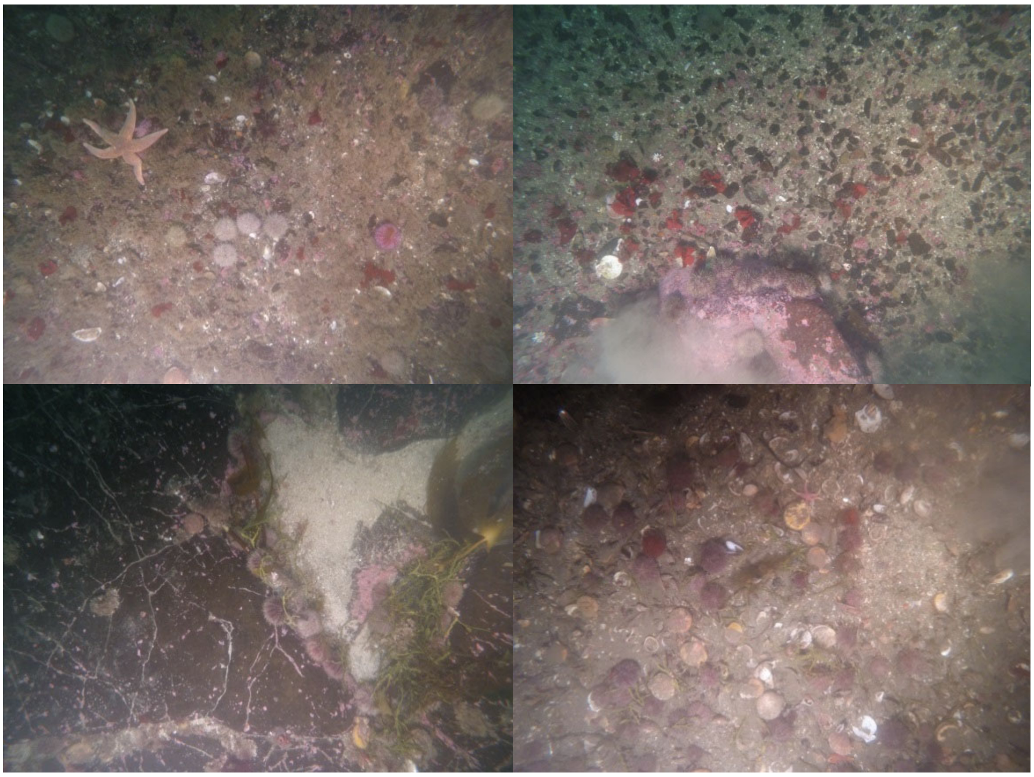

Figure 12. Bottom photographs showing sea urchin from different types of seabed in Breiðafjörður, Iceland.

***Mynd 12**. Botnmyndir af ígulkerum frá mismunandi botngerðum í Breiðafirði. Ljósm./Photo: Hafrannsóknastofnun.*

Table 6. Mean number of urchins/m^2 from photos, range, percentage of photos without urchins, mean number of urchins/m^2 from catch and efficiency of the dredge.

***Tafla 6**. Meðalfjöldi ígulkera/m^2 talinn af bonmyndum, dreifing, hlutfall mynda án ígulkera, meðalfjöldi/m^2 úr afla og veiðihæfni plógsins.*

Area	No. of stations	No. of photos	Mean no/m^2 Photos	Range no/m^2	% zero photos	Mean no/m^2 Dredge	Efficiency of dredge
I	7	54	2.4	1,3-3,8	2	0.9	32
II	5	45	5.8	2,9-8,6	7	1	17
VI	5	31	6.5	3,9-13,7	10	0.5	8
VII	3	30	1.0	1,2-2,0	70	0.6	60
All areas	20	160	3.9	1,2-13,7	18	0.8	29

From the bottom photographs, 19 different invertebrate species were identified (Table 7). Area I had the highest species diversity (16 species) where brittle star (*Ophiuroidea)* dominated. The Iceland scallop (*Chlamys islandica*) dominated in area II and the green sea urchin *(Strongylocentrotus droebachiensis*) in areas VI and VII.

Table 7. Species and mean no/m^2 identified from bottom photographs in four different fishing areas for sea urchin in Breiðafjörður.

Tafla 7. *Tegundir og meðalfjöldi/m^2 talinn af botnmyndum frá 4 mismunandi veiðisvæðum í Breiðafirði.*

Species	Area I	Area II	Aarea VI	Area VII
Strongylocentrotus droebachiensis	2.4±0.6	5.8 ± 1.9	6.5 ± 2.3	1 ± 0.92
Echinus esculentus	0.19± 0.26	0.76 ± 0.84	1.36 ± 2.0	0.08 ± 0.16
Clamys islandica	10.6 ± 15.3	10.89 ± 21.66	4.21 ± 2.54	0.50 ± 0.63
Modiola modiolus	5.81 ± 5.16	5.52 ± 5.96	3.39 ± 2.92	1.14 ± 0.64
Cardium ciliatum	0.04 ± 0.09	0	0.04 ± 0.08	0
Astartidae	0.9 ± 1.04	1.66 ± 1.80	1.63 ± 1.13	0.92 ± 0.46
Arctica islandica	0	0	0	0.04 ± 0.09
Serripes groenlandicus	0.016± 0.04	0	0	0
Buccinum undatum	3.05 ± 2.25	0.60 ± 0.44	0.92 ± 0.77	0.16 ± 0.13
Hyas araneus	0.14 ± 0.18	0.10 ± 0.06	0.10 ± 0.12	0.18 ± 0.29
Cancer irroratus	0	0	0	0.0 2± 0.03
Paguroidea	0.27 ± 0.27	0.02 ± 0.04	0.02 ± 0.04	0.03 ± 0.04
Ophiuroidea	29.4 ± 77.7	0	0	0
Solaster endeca	0.07 ± 0.17	0	0	0
Crossaster pappasus	0.55 ± 0.53	0.25 ± 0.31	0.09 ± 0.14	0.10 ± 0.16
Asterias rubens	0.93 ± 1.15	0.55 ± 0.51	0.05 ± 0.08	0.10 ± 0.05
Henricia sp.	0.75 ± 0.80	0.41 ± 0.62	0.56 ± 0.48	0.21 ± 0.23
Ascidacea	0.11 ± 0.03	0	0	0
Cuccumaria frondosa	0	0	0	0.02 ± 0.03

Discussions

Distribution, density, biomass and dredge efficiency

The total green sea urchin stock investigated in the fishing area in Breiðafjörður was estimated to be around 2.700 tonnes. The distribution of the urchins was patchy in seven sub-areas observed differing in size and density of the urchins. Most of the tows (88%) were taken at 8 – 35 m depth and the most common bottom type was sand and gravel, although rocky substrata was also observed.

In Icelandic waters the green sea urchin is most common in the shallow subtidal zone at depts above 50 m but have been observed down to 600 m depth (Botndýragrunnur 2018). Generally, it occurs on a rocky bed but is also found on gravel and sandy bottoms (Filbee-Dexter and Scheibling 2012) especially where there are strong currents and good food supply (Himmelman 1986, Scheibling & Raymond 1990). Upper depth limits vary with season and wave action that can dislodge the urchins or limit their change to graze on macroalgae. On sedimentary bottoms urchins rely on drift algae and are more sparsely distributed (Filbee-Dexter and Scheibling 2012). In the present study the maximum density (5.1 and 6.9 ind/m^2) was observed at 11 m depth (area III and IV). However, the roe yield differed greatly between these areas (12% and 2.1%, respectively). Area III consisted of gravel bottom and kelp which might indicate a higher food supply but nutrition influences growth and reproduction (Minor & Scheibling 1997). Area IV had the highest density observed and the lowest roe yield. At high densities, grazing increases and food availability can become limiting, resulting in reduced growth and reproduction (Keats et al. 1984). The same goes for the areas with the lowest density (area VI = 1.7 ind/m^2 and area VII = 2.1 ind/m^2) at various depths. The roe yield differed greatly (4.5% and 14% respectively) and the bottom substrate was dissimilar. Area VI consisted of a muddy substrate, but area VII was rocky with gravel and kelp. Himmelman (1986) suggested that the density of green sea urchins decreased with depth to about 20 – 30 m, which in many areas correspond to the distribution of kelp. Sea urchin mainly feed on kelp but are also known for feeding on various bottom species, dead animals and even on lime algae scraping from rocks (Himmelman and Steel 1971, Briscoe and Sebens 1988). In this study, the greatest distribution was observed at lower depths and the highest roe yield found where kelp was observed. At greater depths, drifting algae (Kelly et al. 2012) and detrital kelp (Filbee-Dexter and Scheibling 2014) can supply food enough for sea urchin in the area.

Up until now, information on the status of the green sea urchin stock in Iceland has been limited, as no stock assessments have been carried out before. However, densities and population structures have been investigated at several locations by diver sampling. The results have shown patchy distribution, either low densities or high with grate range at the same locations at different time (Einarsson 1991, Ásbjörnsson 2011, Hjörleifsson et al. 1995).

Dredges have been used in the Icelandic sea urchin fishery since 1992 when a scallop dredge was converted to an urchin dredge. The efficiency of these urchin dredges has been unknown until now. In the present study the number of sea urchins seen on bottom photographs were compared to the number that was fished in the dredge at the same site just after photographing (indirect method). The mean efficiency of the dredge for all areas combined was estimated to be 29%. The efficiency differed between all areas and were dependant on depth, highest at the lowest depth. Efficiency and selectivity of dredges are influenced by numerous factors such as their design, on operational factors i.e. towing speed, the ratio of warp length versus water depth, duration of the tow, and on environmental factors such as depth, current speed and bottom type. It can be estimated by comparing the abundance, size and biomass of urchins in the dredge catch with those remaining in tracks after dredging (direct method) (Caddy 1968, Caddy 1971, Medcof and Caddy 1971, Mason et al. 1979) or with that of un-dredged sediments (indirect method) (Fifas 1991). Efficiency and selectivity can also be assessed by repeatedly fishing the same area until the target species is markedly reduced (DeLury 1947). Capture efficiency for dredges has been estimated for several bottom-dwelling commercial bivalves, primarily scallops with different methods giving different efficiency from 1 – 40% depending on investigations (Caddy 1968, Mason et al. 1979, Fifas and Berthou 1999, Beukers-Stewart et al. 2001).

As a follow of the present study the the Icelandic fishery is now managed by a maximum allowable catch, which is set for a certain area where the biomass has been estimated (Anon 2018). Before that no advice was given for the fishery and the only avaliable information about the stock was from log-books.

Population structure

The mean size and size distribution of the sea urchin differed slightly between areas. The range in the sampling was 17 – 85 mm and the mean size for the whole population was 60 mm. The greatest mean size, weight and roe yield was observed in area VII at 20 m depth, which is a low-density area. The lowest mean size, weight and roe yield was in an area IV at 11 m depth, which had high density. Increased density is known to negatively affect growth of sea urchins (Levitan 1988, James et al. 2017), as competition for food and habitat increases.

The market demands urchins of 45-55 mm minimal size and in Canada (British Colombia), the harvestable size (55mm) is reached at the age of 4 years (Munk 1992). The sampling method may influence the size distribution. Using dredges, as in the present study, can increase the mean size due to size selectivity of the dredge. Market demands of urchin (45-55 mm) may thus influence the size distribution, as the gear selects for a preferable size. However, in the present study, few small urchins were both noted on the bottom photographs investigated and in the catch, thus presumably not a result of ineffective sampling of the smallest size groups. Sampling by divers should give the most accurate results as all size classes are collected. This has been done for several fjords in Iceland (Einarsson 1991, Ásbjörnsson 2011) where the mean size was slightly different from those obtained by dredging (Einarsson 1987). Urchins have also been sampled by traps (Magnúsdóttir et al. 2013) but the size distribution from traps may not be precise as the biggest individuals move faster and reach the trap before others (Dumont et al. 2006, Lauzon-Guay et al. 2006). However, habitat may also influence as greater movement has been observed in habitats away from kelp forrests than inside. However, starving is not considered to affect movement (Dumont et al. 2006).

In the present study, the estimated length-weight relationship measured in September was significant in all areas. There was also a significant relationship between all slopes. The greatest relative wet weight and the greatest estimated slope (b) was found in area III (mean depth 11 m) indicating that urchin from this area usually contained more meat per unit shell size (diameter) for the range of sizes considered. This relationship was lowest in area II (mean depth 32 m) which might indicate a poorer environmental condition. Environmental factors, such as food supply, salinity, temperature and density as well can have enormous influence on growth for the green sea urchin and when food is plentiful, the growth can be fast even though the density is high (Levitan 1988).

A length-weight relationship provides information on growth patterns and growth of animals. The relationship differs between species according to their body shape and within a species according to the condition of individuals (Cone 1989). During development, sea urchins pass through stages in their life history that are defined by different size-weight relationship. Season (energy supply and spawning) is very important when it comes to physical condition of urchins as the roe yield makes up the highest percentage of the weight.

The age structure of green sea urchins in Iceland is unknown as they have never been aged. Different populations have been found to differ in age. In northern Greenland, urchins have been found to have a lifespan of 45 years (Blicher et al. 2007). In the north-west Atlantic (Bay of Fundy) the maximum age was determined 20 – 25 years (Robinson and McIntyre 1997) but off the coast of Maine they have been aged more than 50 years old (Russell et al. 1998).

Catch utilization and by-catch

The mean utilization coefficient differed between areas as well as within areas. The highest utilization observed from a single catch was in September at 10 m depth (area IV). At this station the catch was clean, very little by-catch and no mud or sand. Here, the density of urchin was highest, but the roe yield measured lowest indicating competition for food in the area. The lowest utilization in a catch was in area VII at 19 m depth. There, the density of urchins was low and the mud and sand content was high. Species were also identified and counted from bottom photographs taken from four areas (I, II, VI, VII) just before dredging. Nineteen species were identified, and the highest diversity, 16 species, was observed in area I. There, the dominating species was Ophiuroidea (brittle star), followed by Iceland scallop and horse mussel.

Conclusions

Results from the present study indicate a significant concentration of green sea urchin patchy distributed in seven small subareas within the main fishing area in Breiðafjörður. The abundance/density differed between subareas and was related to depth and food supply. The mean efficiency for the dredge used was assessed to be was 29%, ranging from 8-60% depending on bottom dype and depth. The mean size (diameter) of the urchin differed between areas and most frequent size class was 55-60 mm. The size (diameter) –weight relationship differed as well and the greatest relative wet weight for similar sized urchins was observed were higest productivity has taken place. The utilization coefficient differed greatly between catches, was highest where the density of urchins was highest but the roe yield lowest, indicating starvation of the urchins.

Recomenndations

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