Testing Two Large-Mesh Sea Urchin Diver Catch Bags

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Summary

Diver catch bags with mesh sizes of approximately 1½-inch and 2-inches square were tested to see whether they retained, or allowed the escape of small sea urchins, as compared with a small mesh (¼-inch square) control bag. The escapement of sub-legal sized urchins (less than 53 mm test diameter) varied from 8% to 26% for the larger (2-inch) mesh bag. Escapement from the 1½-inch mesh bag was not measured directly, but appears to have been similar. Escapement of legal-sized urchins from the 2-inch mesh bag varied from 0% to 5%. The experiment was conducted at a site with few legal sized urchins, and the urchins present were long-spined.

Background

The Maine commercial fishery for the green sea urchin (*Strongylocentrotus droebachiensis*) is managed, in part, by a legal minimum size limit of $2^1/_{16}$ inches (52.4mm) for the urchin test (shell), excluding spines. Culling (throwing back legally undersized) urchins once they are aboard the fishing vessel is allowed. A 5% tolerance is allowed, that is, harvesters may keep 5% undersized urchins by count. About 80% of the fishery is a dive (SCUBA) fishery; the other 20% are harvested by drags (Hunter et al, 2002).

Although many divers are size-selective while harvesting on bottom, others rely on a culler on their vessel to throw back substantial numbers of small urchins. Non-selective harvesting is referred to as "bailing" by the industry. It is not clear how many divers "bail", but there is certainly a range of selectivity among divers, from those who cull entirely on bottom to those who rely extensively on the culler at the surface.

Several divers have suggested that using large-mesh bags for their catches would allow smaller urchins to be released from the bags onto the urchin bed (sea floor) during fishing, rather than from the vessel. This could reduce both culling time and effort and culling mortality. The mortality of urchins culled on the vessel is not known, but could be significant, because of time spent out of the water, air temperature extremes (Robinson and MacIntyre, 1995), handling damage, and culling over deep water far from the original bed.

The mesh sizes of standard, commercially available and commonly used diver catch bags vary, but are generally less than ½-inch square (see Photos 1 & 2). Here we define "large" mesh to mean anything larger than that used in these standard bags.

Because net mesh is bought, sold and regulated in Maine using inches rather than metric units, we will use inches when describing mesh measurements here.

Purpose and Scope

The first task of most gear selectivity studies is to determine the size distribution of the fish that are retained (caught) by the gear, as compared with the size distribution of all the fish that encounter the gear. The difference between these distributions represents those fish that escape the gear.

There has been extensive research on the selectivity of mesh used in the cod ends of trawls or Danish seines (e.g. Pope et al, 1975, and Smolowitz, 1983.) In general, the size of the animals in the catch of a large mesh is compared with the catch of a smaller mesh (control) under similar conditions, and a selectivity curve is developed to describe this relationship.

It is not easy to predict the ability of an oval or dome-shaped animal to escape through a square mesh of a given size. It is further complicated by the presence, on Maine's green sea urchins, of spines that can vary in length from 1 to 25 mm and more.

For diver catch bags, the escapees may be made up of both sub-legal, and legal-sized individuals. It is desirable to choose gear that will maximize the number of sub-legal escapees while minimizing the number of legal escapees. Pinpointing this optimum mesh size was beyond the scope of this small, preliminary project. Our purpose here was only to determine whether escapement was possible, and, if so, suggest a direction for further testing. There was some initial doubt on the part of both researchers and commercial harvesters as to whether small urchins would escape a large-mesh bag, or stick together like "Velcro" and remain clumped inside no matter how large the mesh. Time and budget, and our doubts about the outcome, limited our experiment to two sizes of mesh only. We chose one which we knew was too small to allow the escapement of legal urchins, and a larger one which we had heard would, thus hopefully bracketing the range that would include the optimum-mesh bag.

In this study, we tested the two mesh sizes (approximately 1½-inch and 2-inches square) to determine:

- whether they allowed any small urchins to escape
- whether the 2" mesh allowed more small urchins to escape than the 1½" mesh
- whether the 2" mesh allowed any legal sized urchins to escape, and
- whether the control cover used on the 2" bag caused any "masking" of the 2" bag's selectivity. It is possible that the cover might interfere with the escape of urchins from the inner bag.

Procedures

Choosing the bags to test

Several urchin harvesters have been using large mesh and swear by it, and four of them loaned their bags for this project. We chose to test the one bag that was in the best condition, and seemed to have the most "normal" and reproducible construction. (See Photos 9, 10, and 11 for photos of the bags that were loaned but not used in this study.) We refer to this as bag "A". This bag was constructed of stiff black nylon mesh that measured approximately 1½ inches from the beginning of one knot to the beginning of an adjacent knot ("square" mesh measurement). See Figure 1 for net measuring nomenclature. This report will refer to square mesh measurements only, although inner stretch mesh measurements were also made.

Using simple geometry, and also some spineless urchin shells, it was shown that it would be physically impossible for a legal-sized ($2^{1}/_{16}$" or 52.4mm without spines) urchin to escape through the 1½-inch mesh of this bag (see Photos 3 & 4).

After further discussions with harvesters, we found a bag at a local dive shop that has been used by urchin and quahog divers, but was reported to have mesh openings so large that legal urchins would escape. This bag was purchased for the study. It is made of approximately 2" square green polypropylene mesh (Photos 5 & 6). We referred to it as bag "B". It is apparent in Photo 6 that a legal-sized urchin could escape from this bag easily if it had no spines.

A third bag was chosen as a control, that is, a small-mesh bag that would allow no escapement of harvestable-sized urchins. For this, it was decided to use a ¼"-square knotless nylon mesh cover built around the 2" bag (Photos 7 & 8). The cover would serve two functions:

1. To catch the urchins, if any, that escaped the larger mesh bag, thus providing a direct measure of escapement.
2. The catch of the cover and the inner bag together would provide the control, that is, a sample of all the urchins harvested.

We referred to this as bag "C".

Measuring the bag meshes

Although the International Council for the Exploration of the Sea (ICES) has developed standards for net mesh measuring techniques and equipment, they were not used here. For this reason we are calling our measurements strictly "approximate".

The square mesh distance (see Figure 1) for each bag was determined by measuring the distance from the beginning of one knot to the beginning of a knot 10 meshes away using a ruler and dividing by 10. This was repeated for several different locations in the bag, and in both directions, and an average was calculated. The mesh was stretched by applying as much pressure as the author could without hurting herself while holding both the netting and the ruler. This resulted in an approximate square mesh measurement for bag A of 1.50 inches and for bag B (and inner C) of 2.10 inches.

Inner stretch mesh measurements for bag A were also made using a gauge provided by the Maine Marine Patrol. This gauge (used in Maine to enforce shrimp mesh regulations) consists of a graduated wedge that is inserted into the mesh while a constant force is applied using a spring in the handle. Measurements were made in several parts of the bag and averaged. The approximate inner stretch mesh measurement for bag A was 2.40 inches. There was no gauge available for the B bag, which lies between Maine's shrimp and groundfish legal mesh sizes, but was estimated using a ruler to be about 3.5 inches.

Choosing the test site:

Since this experiment was to be performed during the 2002 DMR annual urchin dive survey, it was necessary to find an experimental site somewhere along the survey track. We were limited to the last leg of the track, because we did not have the test bags ready earlier. Luckily, Prof. Larry Harris (UNH) was able to recommend a site in Eastport, Maine that met most of the requirements below:

1. The site should have urchins in a good range of sizes, both legal and sub-legal.
2. There should be enough urchins to fill at least 9 bags, and enough legals so that the site might be fished commercially.

3. Urchins of different sizes should be arranged evenly, not in single-size patches. (This goal is somewhat unrealistic.)
4. The site should be on the survey track..
5. The urchins should be of poor roe quality and of no commercial value, so that a useful commercial site would not be damaged by our experiment. In all other respects, the site should mimic a commercial site.

Test procedures:

On July 11, 2002, our two survey divers, one of whom is also a commercial urchin diver, collected the test catches, using the three bags (A, B, C) described above. They were instructed to "bail", that is, to harvest all urchins regardless of size, except to avoid patches that appeared to have no legal-sized urchins at all, as a commercial harvester would.

We considered using one diver only, but we had two available which allowed us to complete the experiment more quickly. We were also interested in whether there would be any noticeable difference between divers. Since they had both received the same instructions, we didn't expect there would be any difference. Ideally, each diver should have tested each bag several times (replicates), allowing us to properly test for between-diver differences, but this would have increased the size of the experiment beyond our time constraints. Instead, each of the 3 bags was tested 3 times, for a total of 9 bagfuls, alternating divers to ensure that each diver used each bag at least once, and that each bag was used at the beginning, middle, and end of the experiment:

	Diver and Bag	
Dive	Robert	Jim
1.	C	A
2.	B	C
3.	A	B
4.	C	A
5.	(video)	B

Robert did four test dives, and Jim did five. During the fifth dive, Robert videotaped Jim using the B bag.

After each dive, the catches were brought to the vessel waiting at the surface, and dumped into separate labeled baskets. The catches from the inner (large mesh) and outer (small control mesh) C bags were separated. Staff on the vessel were instructed to handle the bags very carefully, so that no further escapement could occur because of shaking or jostling on the vessel.

All urchin diameters were measured to the nearest millimeter using calipers. Collecting the urchins took the divers less than an hour. Measuring the urchins took 7 staff on the vessel the next 4½ hours. All urchins were thrown back overboard as soon as they were measured, at or near the test site.

The divers and other staff were asked to make a general evaluation of the length of the spines of the urchins as either "short", "average", or "long".

Results

The experimental site was an urchin “barren”, that is, there was no algal cover. There was agreement among all staff that the urchins were “long-spined”, which is often cited by commercial divers as an indication of poor food availability and poor roe content.

A total of 5,325 urchins were captured and measured. 93% of these were sub-legal-sized (<53mm). Diameter-frequency histograms for each test of each bag are presented in Figure 2. All the urchins from the 3 replicates of each bag were pooled and the pooled diameter-frequencies are presented in Figure 3. The pooled diameter-frequencies are also listed in Table 1, with summary statistics at the bottom.

There were some urchins in the small mesh outer covers for each of the three bag C tests that must have escaped from the inner bag (Photo 12). They accounted for 8%, 15%, and 26% of the sub-legal-sized urchins that entered the bag. That is, 8%, 15%, and 26% of the sub-legal-sized urchins that were harvested into the 2" bag escaped into the cover. Two out of a total of 94 legal-sized urchins also escaped the inner C bags. For the three tests of this bag, these represented 5%, 0%, and 5% escapement of legal-sized animals. The average size of all the escaped urchins in the C bag covers was 28.37 mm (about 1⅛ inches).

A one-factor analysis of variance and a Student-Newman-Keuls multiple range test (Zar, 1999) were performed on the pooled data to determine whether there were significant differences in mean urchin diameter among the different bag types. The results are presented in Table 2. They show that:

1. There was a highly significant difference in the average size of urchins among the four treatments (A, B, C inner bag, and Control (C inner + cover)). $F= 35.8$, $p<<0.0001$.
2. The urchins in the inner C bag were significantly larger than the urchins in the control (C and cover together). The urchins in the B and A bags were also significantly larger than those in the control.
3. The sizes of the urchins in the B bag were not significantly different from the inner C bag. This suggests that the control cover used over the C bag did not mask, or interfere with its ability to allow escapement.
4. The urchins in the A bag were significantly larger than those in B or C, but see below.

Visual inspection of the diameter-frequency graphs in Figure 2 suggested that the divers, Robert and Jim, were not equally selective in their fishing. It appears that Jim consistently selected slightly larger urchins than Robert. A one-factor analysis of variance was performed on data pooled for each diver, using just the B and inner C bags. These were the 2" bags, which were tested by each diver 3 times. For these catches, the average urchin diameter for Jim was 40.9mm, for Robert, 35.3mm. This was a highly significant difference ($F=268.5$, $p<<0.0001$). See Table 3.

The data for each diver were pooled and presented in Figure 4. Visual inspection of Figures 2 and 4 also suggests that Robert filled the bags fuller than Jim did. The C bag that was filled the most had the best escapement.

Since we had not expected the urchins retained by bag A (1½") to be larger than those retained by bags B and C (2") (outcome #4 above), we wondered whether the difference between divers had created this apparent effect. So we pooled the data from just Jim's two A tests and compared them with his two tests of bag B. We chose Jim because he had tested the A and B bags twice each, whereas Robert had only used them once each. The results of a one-factor analysis of variance are in Table 4. They show that the mean urchin diameter in Jim's A bags was 39.59 mm and his B bags was 40.09 mm, and that these were not significantly different ($F=1.3332$, $p<0.2484$).

A selectivity curve was calculated for the 2" bag using the pooled data from the C tests and the methods described by DeAlteris (2000) for a covered cod end (see Figure 5). The 50% retention size, that is, the estimated size of an urchin at which 50% will be retained in the bag was calculated to be 17mm (about ⅔ of an inch).

A selectivity curve for the A bag (Figure 6) was calculated as the ratio of the number of urchins in each size category in the pooled A bags divided by the number in the pooled controls (C inner + cover) and multiplied by 100. The many values greater than 100 illustrate an apparent difference in fishing power between the A bag and the control, probably because of a difference in the size of the bags and therefore the amount they can hold. No attempt was made to correct for this difference, although Pope et al (1975) and Beverton and Holt (1957) describe this phenomenon in trawl data and a method to correct for it.

Discussion

<u>Factors affecting escapement</u>

Photo # 12 clearly demonstrates that urchins did escape from the 2" mesh bag. This escapement varied from 8% to 26% of the sub-legal catch in the 3 trials where it was measured directly with the covered bag. Several factors could account for this variation:

1) Selectivity of the diver
2) Variation in urchin sizes at the test locations
3) Fullness of the bag (amount meshes are stretched open)
4) Shaking and jostling
5) Presence of seaweed
6) Differences in spine lengths

It seems logical that the more full the bag, the wider open the mesh will be stretched and the greater escapement will be. It also seems reasonable that escapement will be high if the average size of the urchins entering the bag is small, either because of low diver selectivity or variation in the sizes of the urchins at the test site. Robert tended to fill his bags more fully than Jim and to select urchins that were smaller than Jim's. It was the third test of the C bag, done by Robert, that was the most full, and had the highest level of encounter with urchins less than 1-inch in diameter (Figure 2-C) and had the highest (26%) escapement.

It is less clear why Jim's one C bag, which was the least full and had the lowest percentage of small urchins entering, had the second best escapement (15%). Perhaps escapement occurs early and late in the collection process. Perhaps small urchins can escape early, when they are being put into an empty bag and there are no other urchins blocking the way, and then later, when the bag becomes full and the meshes are stretched further open there may be a second opportunity for escape. However, it may be futile to speculate based on data from so few trials.

It is also interesting that Jim's one C bag was also the one that had no escapement of legal-sized urchins, even though it had many more legals than Robert's (55 in Jim's, versus 20 and 19 in Robert's two trials). Expressed as a percentage of all the urchins entering the bag, it is even more surprising – 17% legals in Jim's vs 3% and 2% in Robert's. We can only speculate that the lack of escapement of legals from Jim's bag was due to its being so much less full than Robert's – it contained only 228 urchins while Robert's had 529 and 738. Although Robert's urchins were somewhat smaller than Jim's, it is still likely that Robert's bags were much more full, with the meshes stretched more fully open, especially in his last trial.

It should be noted that most of the urchins that escaped the C bags were less than 1½ inches in diameter (Figure 3). Only 8% of the urchins in the 1½ to 2- inch size range (38-52mm) that entered the bags escaped, while 27% of those less than 1½ inches, 48% of those less than 1 inch (< 25mm), and 80% of those less than ½ inch (< 13mm) escaped.

Conclusions and Recommendations

Although this experiment was complicated by unexpected differences between divers, it still convincingly demonstrated that small urchins will escape from a large-mesh bag, with varying success. Some factors influencing escapement are listed above.

Our results might have been much different if the urchins had shorter spines, as would be expected in a commercial catch. Shorter-spined urchins would certainly have had a higher rate of escapement. Because of this, the 2¨ bag might allow significant escapement of short-spined legal-sized urchins, especially if it were filled fully. (One diver with whom we spoke, who uses this bag, does not feel this is a significant problem.)

On the other hand, it is likely that a commercial site would have more algal cover than our experimental site, and algae entering the catch bags might plug them up and reduce escapement. (We simulated such a plug, shown in Photo #13.)

To resolve these questions, it would be useful to repeat this experiment at a commercial site, using one diver only.

It has also been suggested that the large-mesh bags are much more likely to snag on protruding rocks and ledges while being used on the bottom. This study did not attempt to evaluate the extent of this problem. One diver with whom we spoke, who uses the large polypropylene mesh, did not feel it was a serious problem. He felt that using polypropylene, which floats, reduced the incidence of snags. Polypropylene is buoyant in sea water, while nylon sinks (Terry Stockwell, DMR, personal communication, and Hayes et al, 1996).

We do not know how many divers are “bailing”, that is, being non-size-selective while harvesting. We also do not know how many small urchins survive the culling process, and therefore, cannot evaluate the destruction caused by non-selective fishing. Because of this, it is difficult to enumerate the advantages of using large-mesh catch bags.

Use of the large-mesh bags would clearly benefit the diver who “bails”. In this study, it was the smallest urchins that were most likely to escape, and a diver who is already highly size-selective might see little benefit from switching to large-mesh bags.

However, the divers with whom we spoke who use large-mesh catch bags are convinced that their catches are cleaner and require much less culling. They also mentioned lower by-catch of other organisms, such as seaweed, periwinkles, and sand lances. Before this experiment was conducted, it was difficult to say whether these cleaner catches were the result of the large-mesh bags, or caused by conservation-minded harvesters who were being more selective anyway. We conclude now that it was probably a combination of both.

Pending further study, we recommend that divers interested in reducing their reliance on their culler, or in protecting small urchins and their habitat, try using a mesh sized between the two tested here, that is, about 1¾ inches square.

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Copies of this report, and the videotape made during the last trial of the 2" bag, are available at the DMR Fishermen’s Library, PO Box 8, W. Boothbay Harbor, ME 04575.

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Appendix 1 – Tables

Diameter in mm	All A (1½¨sq)	All B (2¨sq)	All C (2¨sq) inner bag	All C covers (¼¨)	Control (C inner+covers)	All Pooled
10	0	0	0	1	1	1
11	0	3	0	2	2	5
12	0	0	1	1	2	2
13	2	2	2	0	2	6
14	3	8	1	1	2	13
15	2	10	2	6	8	20
16	1	6	4	6	10	17
17	7	5	12	2	14	26
18	9	9	7	10	17	35
19	15	7	11	11	22	44
20	15	25	20	14	34	74
21	24	26	23	23	46	96
22	22	23	25	20	45	90
23	21	19	20	22	42	82
24	36	41	26	21	47	124
25	42	39	38	17	55	136
26	39	30	34	17	51	120
27	38	35	39	20	59	132
28	32	33	38	13	51	116
29	39	38	47	12	59	136
30	58	42	52	10	62	162
31	50	54	59	11	70	174
32	54	47	48	5	53	154
33	37	32	47	11	58	127
34	47	68	53	12	65	180
35	65	53	60	7	67	185
36	56	62	61	11	72	190
37	62	54	52	5	57	173
38	54	33	41	7	48	135
39	42	50	61	8	69	161
40	90	64	54	8	62	216
41	66	41	68	8	76	183
42	69	60	65	7	72	201
43	60	40	55	7	62	162
44	53	46	55	1	56	155
45	80	65	52	2	54	199
46	48	62	48	5	53	163
47	62	50	54	2	56	168
48	50	33	21	1	22	105
49	41	37	51	1	52	130
50	52	50	30	1	31	133

Table 1. Diameter-frequencies (number of urchins) by type of bag.

Diameter in mm	All A (1½¨sq)	All B (2¨sq)	All C (2¨sq) inner bag	All C covers (¼¨)	Control (C inner+covers)	All Pooled
51	44	39	26	0	26	109
52	51	32	29	1	30	113
53	38	21	21	0	21	80
54	30	15	22	0	22	67
55	30	17	12	0	12	59
56	14	15	14	2	16	45
57	19	10	11	0	11	40
58	8	4	4	0	4	16
59	7	3	5	0	5	15
60	14	9	0	0	0	23
61	9	3	1	0	1	13
62	3	2	1	0	1	6
63	4	0	0	0	0	4
64	1	1	1	0	1	3
65	0	0	0	0	0	0
66	1	0	0	0	0	1
Summary						
Total urchins	1,816	1,573	1,584	352	1,936	5,325
Mean diam. mm.	39.25	37.74	37.52	28.37	35.85	37.57
Median diam.	40	38	38	27	36	38
Std. deviation	10.22	10.26	9.62	8.50	10.11	10.27
Maximum diam.	66	64	64	48	64	64
Minimum diam.	13	13	12	10	10	10
No. of sub-legal	1,638	1,473	1,492	350	1,842	4,953
No. of legal (53+)	178	100	92	2	94	372
% <½ inch	0.0	0.2	0.1	1.1	0.3	0.2
% < 1 inch	8.6	11.7	9.7	39.8	15.2	11.9
% < 1½ inch	42.7	49.0	49.4	82.7	55.4	49.2
% sub-legal	90.2	93.6	94.2	99.4	95.1	93.0
% legal	9.8	6.4	5.8	0.6	4.9	7.0
% of sub-legals retained			81.0			
% of legals retained			97.9			

Table 1 continued. Diameter-frequencies (number of urchins) by type of bag, with summary statistics.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A	1,816	71,272	39.2467	104.4317
B	1,573	59,361	37.7374	105.2599
C (inner bag)	1,584	59,427	37.5170	92.6264
Control (C inner+cover)	1,936	69,414	35.8543	101.3193

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10851.12	3	3617.04	35.7975	5.99E-23	2.606193
Within Groups	697692.51	6,905	101.04			
Total	708543.63	6,908	102.57			

~~**SNK Test**~~

Treatment	~~Control~~	~~C (inner)~~	~~B~~	~~A~~
Ranks of means	1	2	3	4
Means	35.85	37.52	37.74	39.25
Sums	69,414	59,427	59,361	71,272
n	1,936	1,584	1,573	1,816

					α=0.05	α=0.01	α=0.001	
~~Comparison~~	~~Difference~~	~~SE~~	~~q~~	~~p~~	~~table q~~	~~table q~~	~~table q~~	~~Conclusion~~
4 vs 1	3.3924	0.2339	14.50	4	3.633	4.403	5.309	A diff from Cntrl
4 vs 2	1.7297	0.2462	7.03	3	3.314	4.120	5.063	A diff from C
4 vs 3	1.5093	0.2467	6.12	2	2.772	3.643	4.654	A diff from B
3 vs 1	1.8831	0.2431	7.75	3	3.314	4.120	5.063	B diff from Cntrl
3 vs 2	0.2204	0.2549	0.86	2	2.772	3.643	4.654	B not diff from C
2 vs 1	1.6627	0.2426	6.85	2	2.772	3.643	4.654	C diff from Cntrl

Results	~~A~~	B	C	~~Cntrl~~

Table 2. Single-factor analysis of variance and SNK multiple range test for differences in mean urchin diameter among the four treatments (A, B, C inner, and Control). A= 1½¨sq mesh, B= 2¨sq mesh alone, C inner= 2¨sq mesh, and Control= C inner+¼¨sq mesh cover.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
All B and C inner Jim	1,304	53,394	40.9463	85.8436
All B and C inner Robert	1,853	65,394	35.2909	94.9245

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	24479.984	1	24479.984	268.49697	5.61E-58	3.844406
Within Groups	287654.46	3,155	91.17			
Total	312134.44	3,156				

t-Test: Two-Sample Assuming Unequal Variances

	All B and C inner Jim	All B and C inner Robert
Mean	40.9463	35.2909
Variance	85.8436	94.9245
Observations	1,304	1,853
Hypothesized Mean Difference	0	
df	2,889	
t Stat	16.529698	
P(T<=t) one-tail	5.126E-59	
t Critical one-tail	1.6453805	
P(T<=t) two-tail	1.025E-58	
t Critical two-tail	1.9607842	

Table 3. Single-factor analysis of variance and t-test for differences in mean urchin diameter between the two divers for bags B and C (inner) pooled.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
A Jim only	1,020	40,377	39.5853	108.3804
B Jim only	1,021	40,928	40.0862	83.6808

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	128.02	1	128.02	1.3332	0.2484	3.8460
Within Groups	195793.99	2,039	96.02			
Total	195922.01	2,040				

t-Test: Two-Sample Assuming Unequal Variances

	A Jim only	B Jim only
Mean	39.5853	40.0862
Variance	108.3804	83.6808
Observations	1,020	1,021
Hypothesized Mean	0	
df	2,005	
t Stat	-1.1546	
P(T<=t) one-tail	0.1242	
t Critical one-tail	1.6456	
P(T<=t) two-tail	0.2484	
t Critical two-tail	1.9611	

Table 4. Single-factor analysis of variance and t-test for differences in mean urchin diameter between bags A and B, Jim's tests only, pooled.

Appendix 2 - Figures

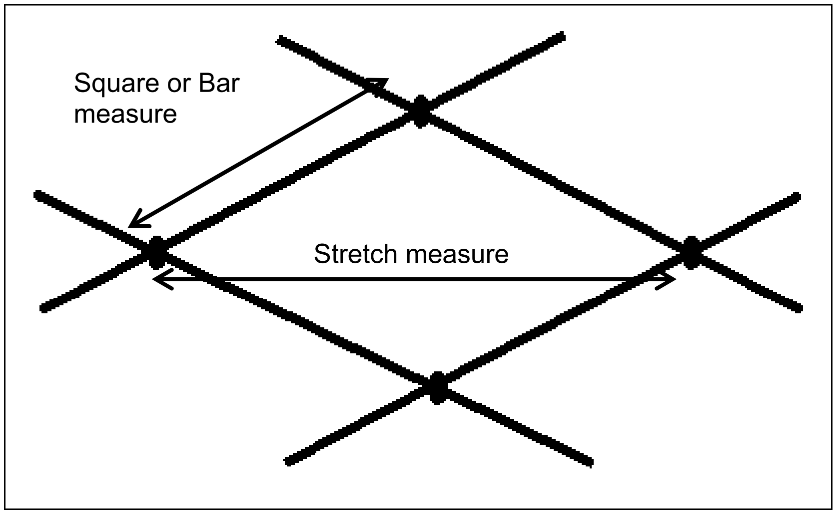


Figure 1. Mesh measuring nomenclature. “Square” or “bar” measures refer to the distance from the beginning of one knot to the beginning of an adjacent knot. “Stretch” measure refers to the distance from the beginning of one knot to the beginning of an opposite knot when the opening between these knots is stretched (Haynes et al, 1996). The “square” measure will be half the “stretch” measure. Pope et al (1975) also refer to an “opening of mesh”, which is the distance <u>inside</u> the mesh between two opposite knots when the opening is stretched. It is this inner stretch measure that is measured directly by mesh-measuring gauges.

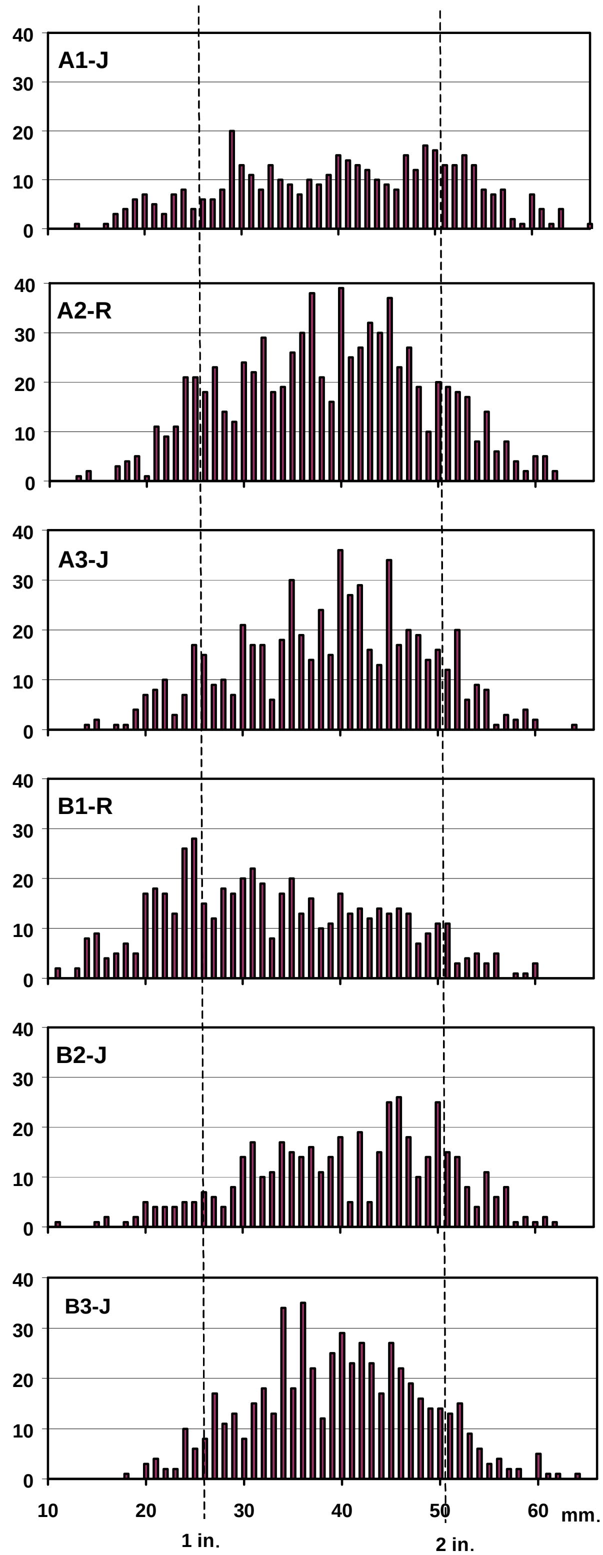


Figure 2, A-B. Diameter-frequency distributions for all A and B bag collections. Y-axis is numbers of urchins. X-axis is urchin diameter in millimeters, dotted lines in inches. J=Jim, R=Robert.

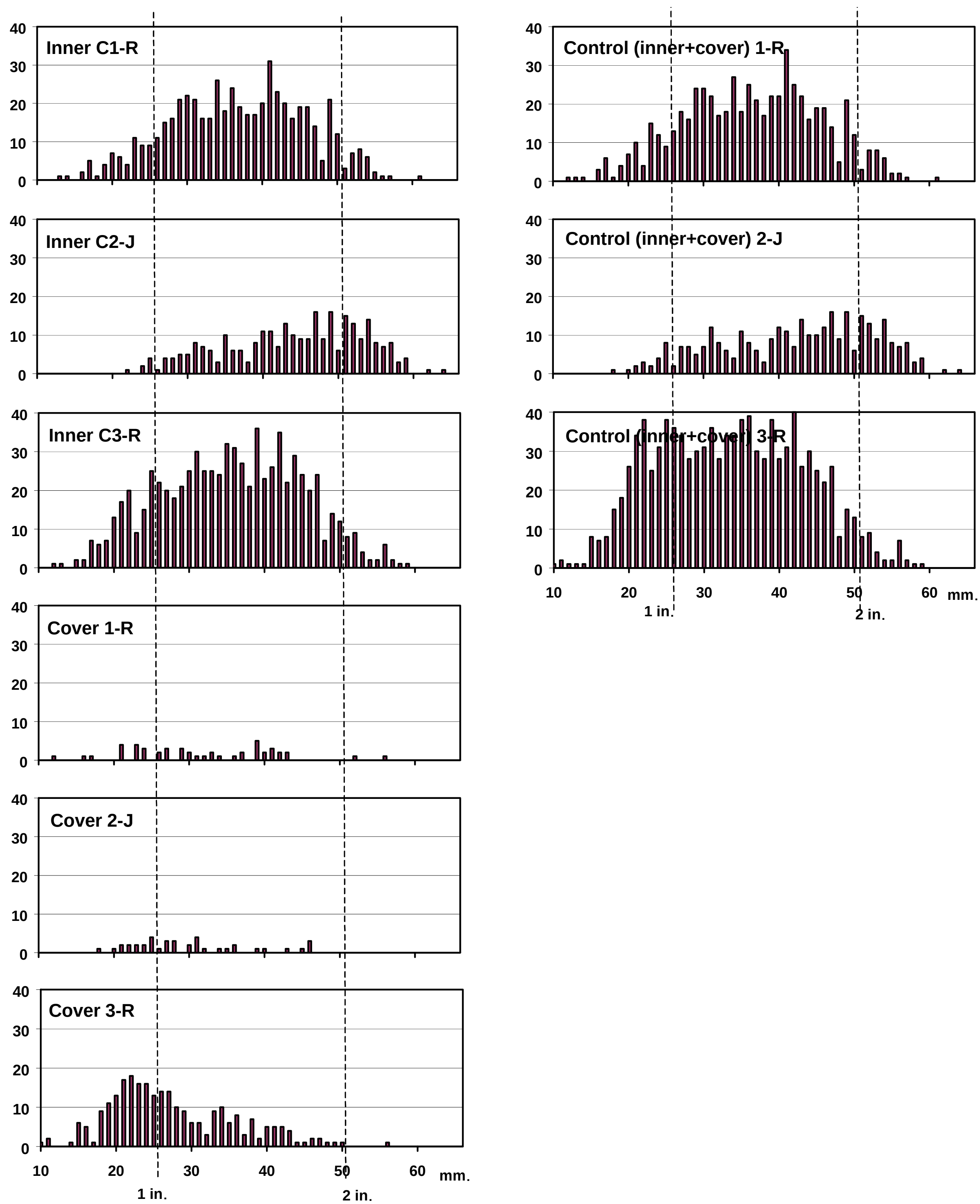


Figure 2 continued - C. Diameter-frequency distributions for all C bag collections. Y-axis is numbers of urchins. X-axis is urchin diameter in millimeters, dotted lines in inches. Divers J=Jim, R=Robert.

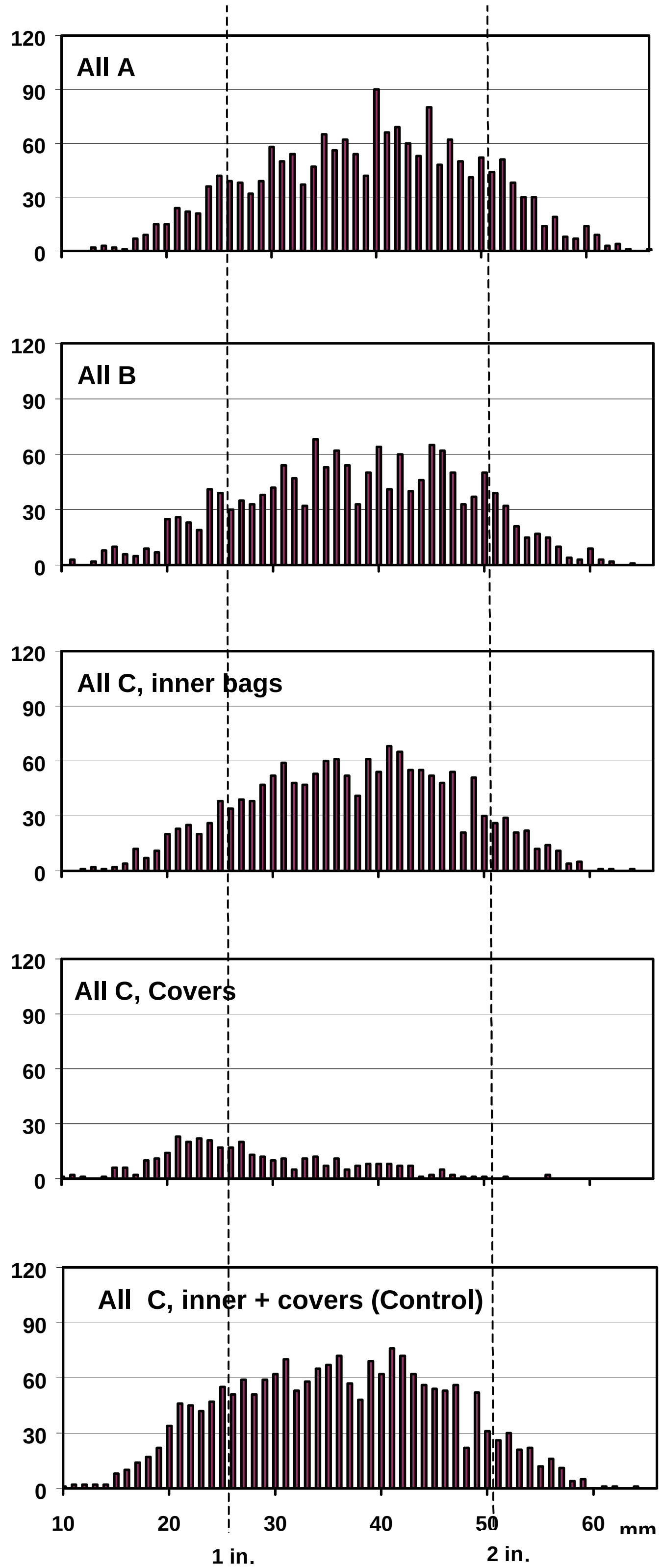


Figure 3. Pooled diameter-frequency distributions. Y-axis is numbers of urchins. X-axis is urchin diameter in millimeters, dotted lines in inches.

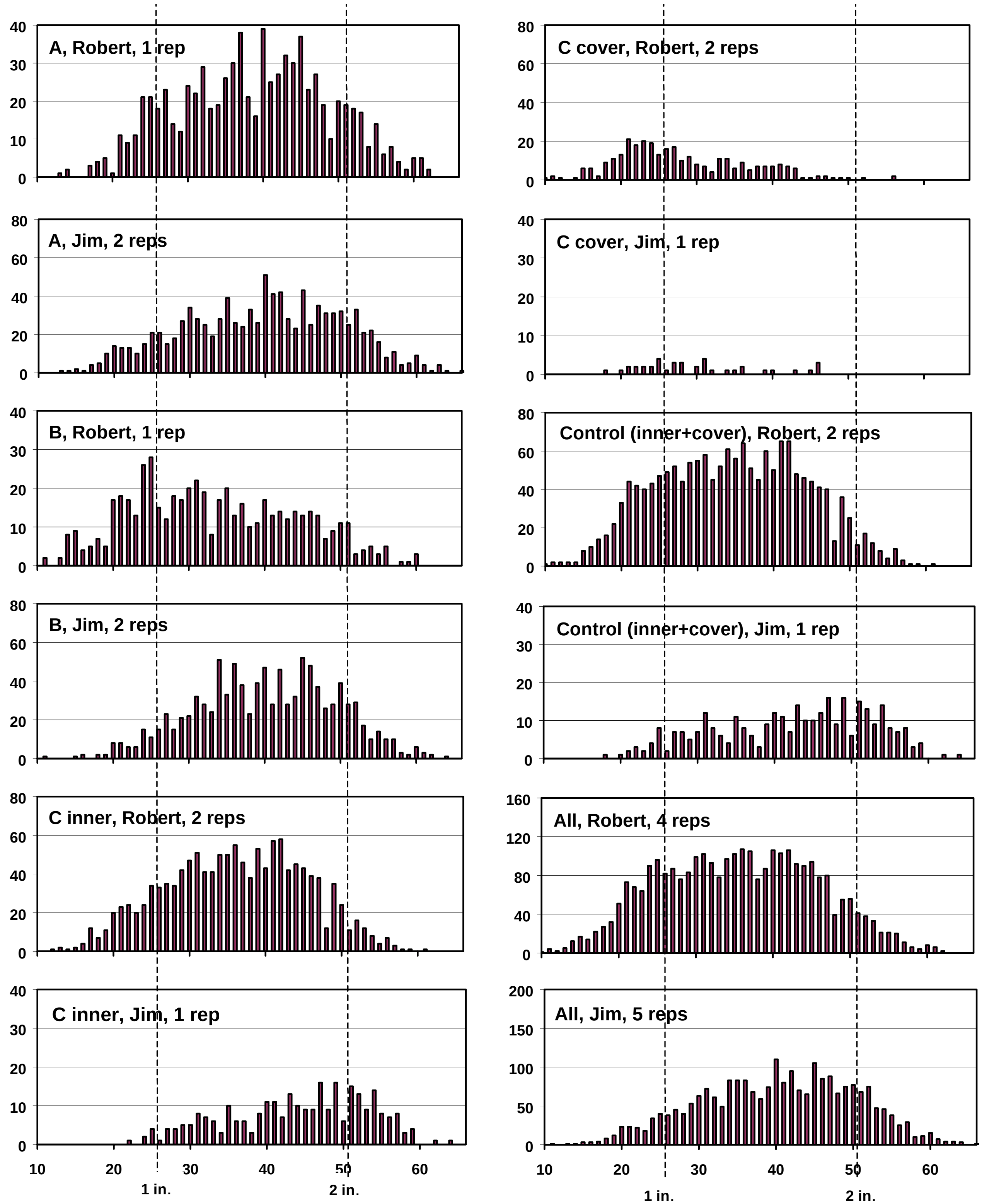
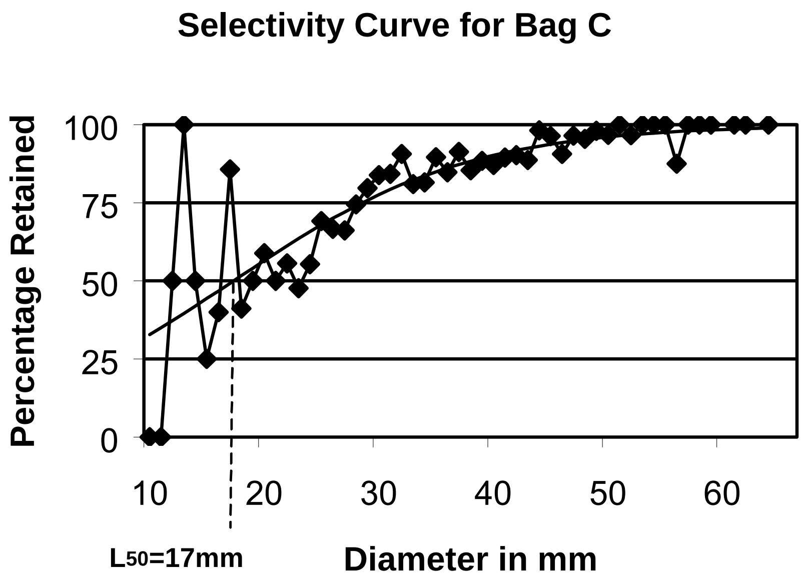
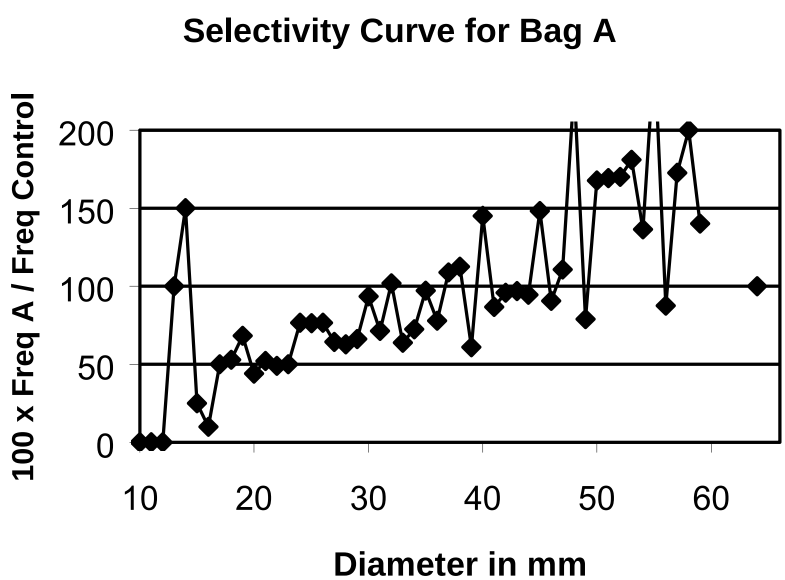


Figure 4. Diameter-frequency distributions, pooled by diver for each type of bag. Y-axis is numbers of urchins. Y-axis maximum has been scaled for the number of replicates (40 max for 1 rep, 80 for 2 reps, etc) so that the graphs may be compared visually. X-axis is urchin diameter in millimeters, dotted lines in inches.





Figures 5 and 6. Selectivity curves for Bags C and A.

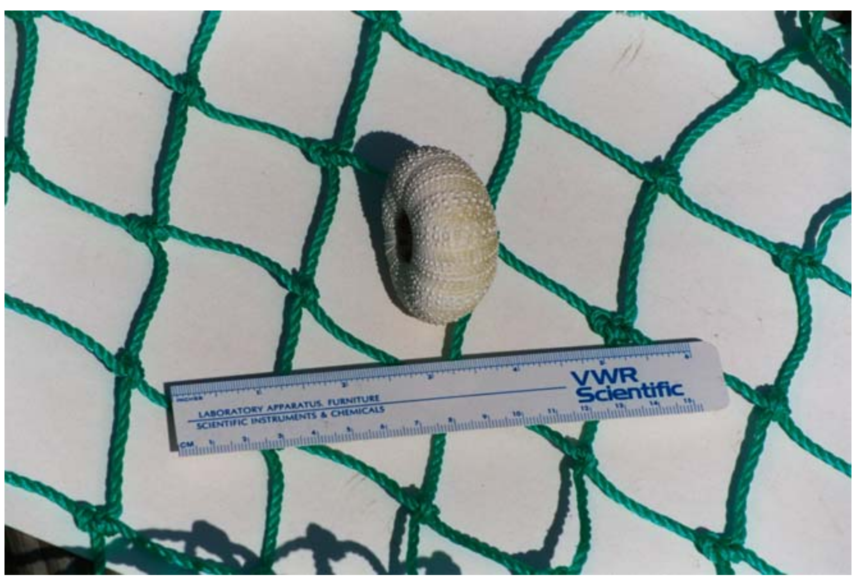
C's shows the frequency of urchins of each size in the inner 2-inch mesh bags pooled for the 3 trials, divided by the number in the control (inner+cover) pooled, x 100.

A's shows the frequency of urchins of each size in the A (1½-inch) bags pooled, divided by the number in the controls pooled, x 100.

Appendix 3 – Photos

Photos 1 and 2. A standard, commercially available diver catch bag, with a $2^{1}/_{16}$-inch urchin shell and a 6-inch ruler for reference. *Photos by Margaret Hunter*.

Photos 3 & 4. Bag A, approximately 1½-inch square mesh, with a $2^{1}/_{16}$-inch urchin shell and a 6-inch ruler for reference. *Photos by Margaret Hunter.*



Photos 5 & 6. Bag B, approximately 2-inch square mesh, with a $2^{1}/_{16}$-inch urchin shell and a 6-inch ruler for reference. *Photos by Margaret Hunter.*

Photos 7 & 8. C or "control" bag, with an inner bag of approximately 2-inch square mesh and an outer cover of approximately ¼-inch square mesh, with a $2^{1}/_{16}$-inch urchin shell and a 6-inch ruler for reference. *Photos by Margaret Hunter*.

Photos 9, 10, and 11. Other large-mesh bags used by commercial urchin divers but not used in this experiment, with a $2^{1}/_{16}$-inch urchin shell and a 6-inch ruler for reference. *Photos by Margaret Hunter.*

Photo 12. Bag C-3, showing that 26% of the sub-legal sized urchins escaped the inner 2-inch mesh bag and were trapped in the outer smaller mesh cover. This was the best case of 3 tests.
Photo by Kerry Lyons.

Photo 13. Bag B, partially filled, with sea urchins and rockweed. *Photo by Kerry Lyons.*