



## **Deep Sea Holothuroid Responses to Nutrient Fluctuations**

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### **ABSTRACT**

Technology has allowed for long-term abyssal time series studies to be conducted at Station M, 220 km off the central coast of California. The deep sea community is reliant upon surface primary production and large detrital events. This project was to determine changes in size distribution, density, and biomass of holothuroid species using ROV video transects over a six year sampling period. The goal was to determine if these changes were in relation to increases in nutrients (particulate organic carbon) on the seafloor. The results of this study did see changes in these factors and is addressed on an individual species level. Overall, it seems that biomass does increase with the addition of nutrients to the seafloor, but it is unclear as to how fast and how long these species are able to capitalize on the additional nutrients.

## INTRODUCTION

The ocean covers over two-thirds of the Earth's surface. Deep sea habitats comprise ninety percent of that ocean realm. Despite the vast amount of deep sea habitat, relatively little is known about the processes and the organisms that inhabit them. Until recently, traditional methods of trawling were often the only way information was gathered about deep sea communities (Gage and Tyler 1999). Although this gave information as to the diversity of some organisms on the seafloor, it was not usually successful in capturing small organisms which are a large component of the deep sea community (Theil 1975, Hessler and Sanders 1967, Grassle and Maciolek 1992). Also, trawling did not shed adequate light as to organism distribution or relative abundance along the seafloor and the factors that drive populations.

Advances in technology have allowed scientists to start filling gaps in knowledge regarding the deep sea. More recently, studies have shown the deep sea to be dependent on photosynthetic processes in the surface waters (Rowe 1971, Johnson et al. 2007, Smith et al. 2008, Ruhl et al. 2008). For decades, scientists have been able to estimate the amount of primary production at the surface waters using satellite imagery (Esaias et al. 1986, Brown et al. 1985, Kuster 2004), but it was difficult to determine how much of this food was reaching the ocean floor. Studies began to determine how much marine snow and detritus from surface waters reached the deep sea (Thiel et al. 1989, Smith et al. 1998). Soon it was determined that levels of marine snow alone were not enough to meet the demands of the deep sea community and that large scale detrital aggregates supplemented the marine snow (Kaufman and Smith 1997, Smith et al. 1998, Shaw et al. 1998).

The advent of remotely operated vehicles (ROVs) began as military endeavors to aid in the retrieval of torpedoes, but quickly spread to use in industries and science. An ROV is a robot that is controlled remotely by a pilot on board a ship. The ROV is tethered via a fiber optic cable that records video imagery, positional data, and other information and sends it back to the ship. This technology allows scientists to observe organisms and habitats *in situ*. The added benefit of having transects recorded with the ROV is that it can later be analyzed to obtain a great deal of information about organisms, their behaviors, and associations.

In 1989, an abyssal time series project was started at a site (Station M) off the coast of central California. This project combines the use of sediment traps, cameras, and ROV technologies to measure particulate organic matter that is sinking to the sea floor and how it affected the communities of the deep. Ruhl (2007) addressed the abundance and size distribution of epibenthic megafauna at Station M, finding changes in both abundance and size over time with a focus on echinoderms. Echinoderms, especially holothuroids, have become a secondary focus at the Station M site due to their response to fluxes in organic matter and their role in the redistribution of nutrients (Kaufman and Smith 1997, Ruhl and Smith 2004).

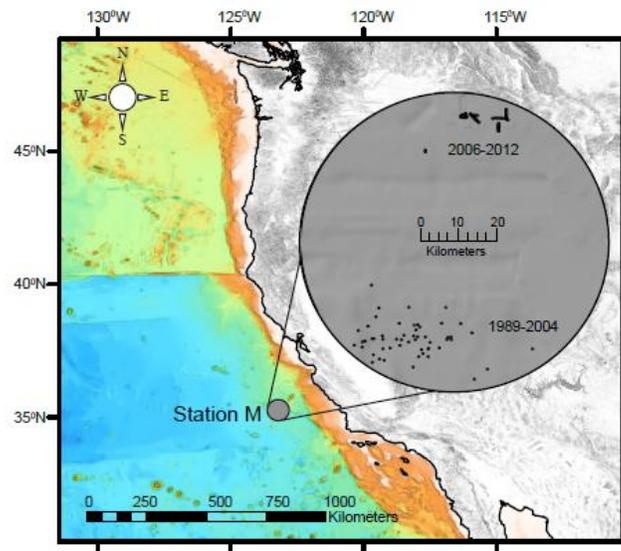
The objective of this project was to collect a comprehensive size distribution of all holothuroids at the Station M site from 2006 to 2012. Due to three large nutrient influxes that settled on the seafloor in the form of phytodetritus and salp debris, changes in size distribution were carefully monitored. This is in some ways a continuation of a portion of Henry Ruhl's 2007 abundance and size distribution study. In addition to size distribution of holothuroids, biomass was estimated for eight of the thirteen species using data from similar species based on length measurements (Ruhl, unpublished). Information gathered in this study is intended to add to the broader knowledge of how holothuroid populations are shifting as nutrient availabilities change. This study is important in determining what might happen to these populations as climate change alters the amount of CO<sub>2</sub> being absorbed into the ocean, and thus primary production in surface waters.

## **MATERIALS AND METHODS**

### **STUDY SITE AND IMAGERY COLLECTION**

The Station M study site is located approximately 220 kilometers off the central California Coast with an average depth of 4,100 meters (Figure 1). The overall habitat is characterized by silty clays and minimal topography. This is a representative site for deep sea or abyssal habitats. The location also allows for measurements to be made for the interannual changes in particulate organic matter on the seafloor due to the unique

California upwelling system. The longevity of sampling at this site provides insight as to communities and populations shift over time.



**Figure 1:** Map of the Station M study site. Inset map represents transects taken via camera sled and ROV.

During the six year sampling period, two remotely operated vehicles (ROVs) were launched off the *R/V Western Flyer*. The ROV *Tiberon* and ROV *Doc Ricketts* collected multiple video transects at the Station M study site (Table 1). Both ROVs were fitted with high definition cameras with zoom and tilt functions. The video collected for the transects was oriented at a forward-oblique angle with a coverage of approximately 1 meter square width. Mounted lasers were used as a reference of 29 centimeters. This allows for estimation of both organisms and field of view. A total of 13,540 meters<sup>2</sup> of transect video imagery was taken. of which 11,120 meters<sup>2</sup> was annotated for this project.

**Table 1.** Summary table of transects taken collected a six year sampling period and the functional length of the transect as designated by the annotations made to date.

<b>Sampling Period</b>	<b>Dives</b>	<b>ROV</b>	<b>Overall Transect Length (meters)</b>	<b>Annotated Transect Length (meters)</b>
Dec 2006	1067	<i>Tiberon</i>	1120	1120
Feb 2007	1077, 1080	<i>Tiberon</i>	220	220
June 2007	1094	<i>Tiberon</i>	80	80
Sept 2007	1141, 1143	<i>Tiberon</i>	420	420
Feb 2009	8	<i>Doc Ricketts</i>	1560	1560
May 2011	230, 231, 232	<i>Doc Ricketts</i>	4500	3500
Nov 2011	321, 323, 324	<i>Doc Ricketts</i>	2640	2140
June 2012	403	<i>Doc Ricketts</i>	400	400
Nov 2012	442, 443	<i>Doc Ricketts</i>	2600	1680

## VIDEO ANNOTATIONS

Each holothuroid on transect was assessed and measured using the MBARI proprietary annotation system VARS. Holothuroids were recorded to their lowest taxonomic level possible. If the species was unable to be deciphered to the thirteen commonly observed species, it was marked, but not included in quantitative measurements. To minimize distortions in the measured length, each organism was aligned in the same plane as the sizing lasers (Figure 2). A framegrab of the organism was taken and the VARS distance tool was then used to measure the reference lasers and the holothuroid. The measurements for the organism were made from the anterior to the posterior end, excluding feeding tentacles. The *Peniagone* spp. have an angle of inflection at the anterior end, so measurements began in the middle of the dorsal papillae ridge to the posterior end. These are based on previous studies (Ruhl 2007). This measurement output was later translated from pixel length to a size measurement in centimeters using a script and the knowledge that the sizing lasers are 29 centimeters apart.



**Figure 2:** A framegrab taken with a *Elpidia sp. nov* center aligned within the plane of the lasers. The lasers and the organism are then measured using VARS distance tool.

## BIOMASS CONVERSIONS

Biomass was estimated through the use of mass equations based on length supplied by Henry Ruhl (unpublished) to obtain an estimate of how biomass was changing at Station M over time. These measurements were taken from holothuroids in the Atlantic Ocean. Some of the biomass equations were for the same species while others were determined by using a proxy species similar in size and body morphology. The equations were determined by species or a proxy species or genus similar in size and body shape. For example, some of the undefined *Peniagone* species (*P. sp. nov.*, *P. sp. 1*, *P. sp. 2*) all used the same equation for *Peniagone spp.* to determine biomass. All

**Table 2.** Table showing the equation used to estimate biomass (in grams) for holothuroid species at Station M.

Station M Species	Species or Proxy used for Equation	Equation for mass (grams)
<i>Elpidia sp. nov</i>	<i>Deima sp.</i>	$0.0027[\text{length (mm)}]^{2.2564}$
<i>Oneirophanta mutabilis complex</i>	<i>Oneirophanta mutabilis</i>	$0.0004[\text{length (mm)}]^{2.5082}$
<i>Peniagone gracilis</i>	<i>Peniagone gracilis</i>	$0.002[\text{length (mm)}]^{1.7974}$
<i>Peniagone papillata</i>	<i>Peniagone spp.</i>	$0.0015[\text{length (mm)}]^{1.9989}$
<i>Peniagone sp. 1</i>	<i>Peniagone spp.</i>	$0.0015[\text{length (mm)}]^{1.9990}$
<i>Peniagone sp. 2</i>	<i>Peniagone spp.</i>	$0.0015[\text{length (mm)}]^{1.9991}$
<i>Peniagone sp. nov</i>	<i>Peniagone spp.</i>	$0.0015[\text{length (mm)}]^{1.9992}$
<i>Peniagone vitrea</i>	<i>Peniagone vitrea</i>	$0.0008[\text{length (mm)}]^{1.9366}$
<i>Psychropotes longicauda</i>	<i>Psychropotes longicauda</i>	$0.0002[\text{length (mm)}]^{2.6518}$
<i>Scotoplanes globosa</i>	<i>Scotoplanes globosa</i>	$0.0256[\text{length (mm)}]^{1.6211}$

equations can be seen in Table 2. It is also important to note that length measurements needed to be in millimeters to be entered into the biomass equations

## STANDARDIZATION OF MEASUREMENTS

Being able to compare both length and biomass measurements across species and time periods was very important to this study. Length measurements and biomass were standardized by percentage per time period. This allows for population demographics to be comparable despite differences in both transect length and sample size.

## RESULTS

### SIZE DISTRIBUTION AND ABUNDANCE

The overall size distribution was assessed for all thirteen species observed at Station M during this six year sampling period. The size ranges and average sizes for each species can be seen in Table 3. The largest holothuroid size distribution was *Paelopatides confundens*, spanning over 20 cm with a range from 4.03 cm to 24.12 cm. However, more than half of the observed individuals measured under the average of 8.84 cm. The smallest size distribution was observed in *Peniagone sp. 1*. The difference in size of *Peniagone sp.1* spanned less than 5 cm from 1.53cm to 6.48. The size distributions of each species were also examined by sampling period to determine changes over time. The resulting graphs for each species at each time period can be seen in Appendix A. There were two distinct groups of holothuroids: those that remained in relatively small numbers throughout

**Table 3.** The total sample size, distribution and average size for each of the thirteen observed holothuroid species at Station M.

Species	Sample size	Size Distribution (cm)	Average Size (cm)
<i>Abyssocucumis abyssorum</i>	15	4.74 - 13.35	9.47
<i>Elpidia sp. nov</i>	3, 348	0.55 - 5.38	4.87
<i>Oneirophanta mutabilis complex</i>	9	7.12 - 14.48	10.75
<i>Paelopatides confundens</i>	19	4.03 - 24.12	8.84
<i>Peniagone gracilis</i>	585	1.40 - 8.09	3.59
<i>Peniagone papillata</i>	212	2.44 - 20.56	7.72
<i>Peniagone sp. 1</i>	257	1.53 - 6.48	3.89
<i>Peniagone sp. 2</i>	49	1.82 - 12.40	4.81
<i>Peniagone sp. nov</i>	3,089	1.47 - 16.47	7.1
<i>Peniagone vitrea</i>	802	1.50 - 12.37	4.44
<i>Psychropotes longicauda</i>	5	3.83 - 13.11	6.18
<i>Scotoplanes globosa</i>	625	1.63 - 15.02	5.96
<i>Synallactidae</i>	27	3.65 - 17.52	11.88

all sampling periods and those that changed significantly throughout the sampling periods. The following are designated as having relatively low sample sizes and little change over time regardless of the fluctuation in particulate organic matter. *Abyssocucumis abyssorum* was not observed on transects until the November 2011 sampling period with a density of 0.001 m<sup>-2</sup>. The density ranged just from 0.001 to 0.003 m<sup>-2</sup> from that sampling period to November 2012 (Figure A.1). There were no individuals under 4 cm observed. The *Oneirophanta mutabilis complex* was not observed in six of the nine sampling periods. The most individuals (n=7) were observed in February 2009 with a density of 0.004 m<sup>-2</sup>. All individuals observed were above 7 cm in size (Figure A.2). *Paelopatides confundens* was observed in November 2011 and the subsequent sampling periods. The density in November 2011 was 0.004 m<sup>-2</sup> and shifted to 0.005 m<sup>-2</sup> in the following sampling periods. Although most individuals measured under 8 cm, the largest seen was 24.12 cm (Figure A.3). *Psychropotes longicauda* had the fewest observations of all the species detected at 5. A single large individual (13.11 cm) was observed in June 2012. The next sampling period (November 2012) was comprised of smaller individuals ranging from approximately 3 cm to 6 cm (Figure A.4). The density remained the same at 0.002 meter<sup>-2</sup> during both sampling periods. The last species that did not have a notable change in size distribution and population was *Synallactidae sp.* This species was observed from February 2009 to

**Table 4.** The summary statistics of the 5 species of holothuroids that did not have significant changes in size distribution or abundance during the nine sampling periods. Sample size, minimum size, maximum size, size range and average size at each time period is depicted.

		<i>Abyssocucumis abyssorum</i>	<i>Oneirophanta mutabilis complex</i>	<i>Paelopatides confundens</i>	<i>Psychropotes longicauda</i>	<i>Synallactidae</i>
December 2006	Sample Size (n)	0	0	0	0	0
	Minimum Size (cm)	--	--	--	--	--
	Maximum Size (cm)	--	--	--	--	--
	Size Range	--	--	--	--	--
	Average Size (cm)	--	--	--	--	--
February 2007	Sample Size (n)	0	0	0	0	0
	Minimum Size (cm)	--	--	--	--	--
	Maximum Size (cm)	--	--	--	--	--
	Size Range	--	--	--	--	--
	Average Size (cm)	--	--	--	--	--
June 2007	Sample Size (n)	0	0	0	0	0
	Minimum Size (cm)	--	--	--	--	--
	Maximum Size (cm)	--	--	--	--	--
	Size Range	--	--	--	--	--
	Average Size (cm)	--	--	--	--	--
September 2007	Sample Size (n)	0	0	0	0	0
	Minimum Size (cm)	--	--	--	--	--
	Maximum Size (cm)	--	--	--	--	--
	Size Range	--	--	--	--	--
	Average Size (cm)	--	--	--	--	--
February 2009	Sample Size (n)	0	7	0	0	6
	Minimum Size (cm)	--	7.11	--	--	9.27
	Maximum Size (cm)	--	13.04	--	--	15.67
	Size Range	--	5.92	--	--	6.40
	Average Size (cm)	--	10.55	--	--	13.25
May 2011	Sample Size (n)	0	1	0	0	11
	Minimum Size (cm)	--	--	--	--	6.61
	Maximum Size (cm)	--	--	--	--	17.21
	Size Range	--	0	--	--	10.61
	Average Size (cm)	--	14.48	--	--	12.85
November 2011	Sample Size (n)	3	0	8	0	1
	Minimum Size (cm)	7.46	--	4.03	--	--
	Maximum Size (cm)	8.97	--	12.42	--	--
	Size Range	1.50	--	8.39	--	0
	Average Size (cm)	8.35	--	7.22	--	11.82
June 2012	Sample Size (n)	6	1	2	1	2
	Minimum Size (cm)	4.73	--	11.28	--	8.79
	Maximum Size (cm)	13.35	--	19.23	--	13.54
	Size Range	8.61	0	7.96	0	4.75
	Average Size (cm)	9.63	8.45	15.25	13.11	11.17
November 2012	Sample Size (n)	6	0	9	4	7
	Minimum Size (cm)	6.40	--	4.07	3.83	3.65
	Maximum Size (cm)	12.26	--	24.12	5.58	17.52
	Size Range	5.86	--	20.05	1.75	13.88
	Average Size (cm)	9.86	--	8.86	4.45	9.40

final sampling period in November 2012 where smaller individuals appeared in the size distribution (Figure A.5). Summary statistics for these five species can be seen in Table 4.

The remaining species observed in this study presented marked changes in the size distribution and abundance of individuals over the nine sampling periods (Table 5). *Elpidia sp. nov* was present in relatively low numbers in December 2006, February 2007, and February 2009 (0.003, 0.060, 0.015 m<sup>-2</sup> respectively). Most individuals during these time periods ranged from 1 cm to 2 cm in size. There was an increase in the density of *Elpidia* to 0.203 m<sup>-2</sup> during the May 2011 sampling period. Most of the 709 individuals observed were 1 cm to 2 cm in length, but the size distribution ranged from 0.55 cm to 4.83 cm. During the next sampling period, the density increased again to 0.472 m<sup>-2</sup> and the size distribution curve shifted. The most common size range for this sampling period was 2 to 3 cm. This size distribution and density remained the same for the June 2012 sampling period. The final November 2012 sampling period almost doubled in density from the previous sampling period with 0.084 m<sup>-2</sup> with a standard and well defined bell curve (Figure A.6).

*Peniagone gracilis* was first observed in the May 2011 sampling period with a 0.121 per meter<sup>2</sup> density. The size range during this time period was 1.40 to 8.09 cm. During this time period 45% of the individuals observed were in the 2 to 3 cm range (Figure A.7). The density then oscillated from 0.033 m<sup>-2</sup> to 0.115 m<sup>-2</sup> over the next three time periods. The changes in density coincided with contraction and expansion of the size distribution. The smaller density sampling periods (November 2011, November 2012) had smaller range of sizes. Conversely, the time period with a larger density (June 2012) has a larger size range of individuals.

*Peniagone papillata* was the only species to be seen in all of the sampling periods. The density only varied by 0.032 m<sup>-2</sup> between the highest and lowest time periods. The lowest density was during the September 2007 and the February 2009 sample periods at 0.002m<sup>-2</sup>. The highest density occurred in May 2011 (0.034m<sup>-2</sup>) which proved to have the widest size distribution as well with a spread of 17.76 cm (Figure A.8). This wide size distribution continues into the November 2011 sampling period. As time

**Table 5.** The summary statistics of the 8 species of holothuroids that measured changes in size distribution or abundance during the nine sampling periods. Sample size, minimum size, maximum size, size range and average size at each time period is depicted.

		<i>Elpidia</i> <i>sp. nov.</i>	<i>Peniagone</i> <i>gracilis</i>	<i>Peniagone</i> <i>papillata</i>	<i>Peniagone</i> <i>sp. 1</i>	<i>Peniagone</i> <i>sp. 2</i>	<i>Peniagone</i> <i>sp. nov.</i>	<i>Peniagone</i> <i>vitrea</i>	<i>Scotoplanes</i> <i>globosa</i>
December 2006	Sample Size (n)	3	0	3	0	0	0	2	0
	Minimum Size (cm)	1.44	--	4.14	--	--	--	7.07	--
	Maximum Size (cm)	4.51	--	6.42	--	--	--	7.82	--
	Size Range	3.07	--	2.28	--	--	--	0.76	--
	Average Size (cm)	2.60	--	5.30	--	--	--	7.45	--
February 2007	Sample Size (n)	15	0	3	0	0	1	1	0
	Minimum Size (cm)	0.78	--	4.84	--	--	--	--	--
	Maximum Size (cm)	2.65	--	6.15	--	--	--	--	--
	Size Range	1.87	--	1.31	--	--	0	0	--
	Average Size (cm)	1.47	--	5.72	--	--	3.96	8.18	--
June 2007	Sample Size (n)	0	0	1	0	0	1	0	0
	Minimum Size (cm)	--	--	--	--	--	--	--	--
	Maximum Size (cm)	--	--	--	--	--	--	--	--
	Size Range	--	--	0	--	--	0	--	--
	Average Size (cm)	--	--	4.60	--	--	3.99	--	--
September 2007	Sample Size (n)	0	0	1	0	0	0	0	0
	Minimum Size (cm)	--	--	--	--	--	--	--	--
	Maximum Size (cm)	--	--	--	--	--	--	--	--
	Size Range	--	--	0	--	--	--	--	--
	Average Size (cm)	--	--	8.57	--	--	--	--	--
February 2009	Sample Size (n)	23	0	3	0	0	2	23	0
	Minimum Size (cm)	0.95	--	7.17	--	--	3.58	1.50	--
	Maximum Size (cm)	3.28	--	12.82	--	--	3.82	11.40	--
	Size Range	2.33	--	5.66	--	--	0.24	9.90	--
	Average Size (cm)	1.68	--	10.18	--	--	3.70	3.28	--
May 2011	Sample Size (n)	709	422	114	0	7	1813	430	169
	Minimum Size (cm)	0.55	1.40	2.80	--	2.48	2.41	1.91	1.63
	Maximum Size (cm)	4.83	8.09	20.56	--	12.40	16.47	12.37	13.60
	Size Range	4.28	6.70	17.76	--	9.92	14.07	10.46	11.97
	Average Size (cm)	1.69	3.74	9.51	--	7.70	8.48	4.88	8.12
November 2011	Sample Size (n)	1011	71	63	0	14	416	96	95
	Minimum Size (cm)	0.85	1.95	2.44	--	1.92	2.53	2.24	1.90
	Maximum Size (cm)	4.61	4.08	14.41	--	10.13	12.02	8.91	12.88
	Size Range	3.76	2.13	11.97	--	8.21	9.49	6.67	10.98
	Average Size (cm)	2.63	3.09	5.26	--	4.77	5.61	5.26	5.77
June 2012	Sample Size (n)	183	46	8	0	2	173	32	50
	Minimum Size (cm)	1.09	2.34	5.57	--	5.49	2.24	2.76	2.12
	Maximum Size (cm)	5.14	6.61	9.65	--	5.61	11.28	6.73	14.66
	Size Range	4.05	4.27	4.08	--	0.12	9.05	3.97	12.53
	Average Size (cm)	2.87	4.10	7.26	--	5.55	6.10	4.54	7.81
November 2012	Sample Size (n)	1404	46	16	257	26	683	218	311
	Minimum Size (cm)	0.98	1.70	2.79	1.53	1.82	1.47	1.78	1.65
	Maximum Size (cm)	5.38	3.62	9.89	6.48	8.40	10.38	6.07	15.02
	Size Range	4.40	1.92	7.10	4.95	6.58	8.91	4.29	13.37
	Average Size (cm)	2.99	2.39	5.41	3.89	4.00	4.64	3.26	4.54

progressed, the size distribution became smaller in range and shifted towards smaller individuals.

*Peniagone sp. 1* has a distribution unlike any others in this study. This species was not seen even a single time until the November 2012 time period. The individuals that were observed had an average size of 3.89 cm (Table 5) while most ranged between 4 and 7 cm (Figure A.9). There were no individuals observed under 1.53cm and few observed under 3 cm. This density bloom of  $0.153\text{m}^{-2}$  did occur after an nutrient influx in June and September of 2012 although it is unknown if their appearance is in direct relation to the influx.

The next species to show changes in population and size distribution is *Peniagone sp. 2*. It was first observed in the May 2011 sampling period with a wide size range with individuals ranging from 2.48 cm to 12.40 cm. Individuals were observed for all size classes within this range. The wide distribution continues into the November 2011 sampling period as well. The individuals observed in the June 2012 sample period had a significantly different size range, with all individuals measuring close to the 5.5 cm average. These three time periods measured densities that were relatively the same ( $0.002\text{ m}^{-2}$ ,  $0.007\text{ m}^{-2}$ ,  $0.005\text{ m}^{-2}$  chronologically). The last sampling period marked a difference in both density and size range (Table 5). The size distribution shifted towards that of smaller individuals with the average being 4.00 cm (Figure A.10). The density during this time period also increased to  $0.015\text{ m}^{-2}$ .

*Peniagone sp. nov.*, one of the two most prevalent species observed along with *Elpidia sp. nov.*, was observed in small numbers prior to May 2011. In May 2011, the density increased from  $0.001\text{ m}^{-2}$  in the previous sampling period to  $0.518\text{ m}^{-2}$ . There was also a wide size distribution (range of 14.07 cm) with all sizes represented. There was a standard distribution curve during this time period (Figure A.11). The distribution shifts to be dominated by smaller individuals in the November 2011 sampling period. Most individuals were measured in the 4 cm to 6 cm range and the density lowers to  $0.194\text{ m}^{-2}$ . The larger size distribution and standard distribution curve returned in the June 2012 sampling period. Once again, this coincided with a higher density of  $0.433\text{ m}^{-2}$ . The final sampling period measured both smaller individuals and a smaller size distribution.

*Peniagone vitrea* was a species that was observed in all but two of the sampling periods. Despite it being present in both December 2006 and February 2007, larger numbers of individuals were not seen until February 2009 (density = 0.015 m<sup>-2</sup>). During this time, 87% of individuals were under 5 cm. The size distribution increased in May 2011 to have a range from 1.91 cm to 12.37 cm. The distribution curve was left shifted towards smaller individuals. The density was higher at 0.123 m<sup>-2</sup> during this time period as well. The November 2011 sampling period found the size distribution curve to be more in line with a standard normal curve. Although the highest density (0.130 m<sup>-2</sup>) was calculated for November 2012, the size distribution was limited to smaller individuals.

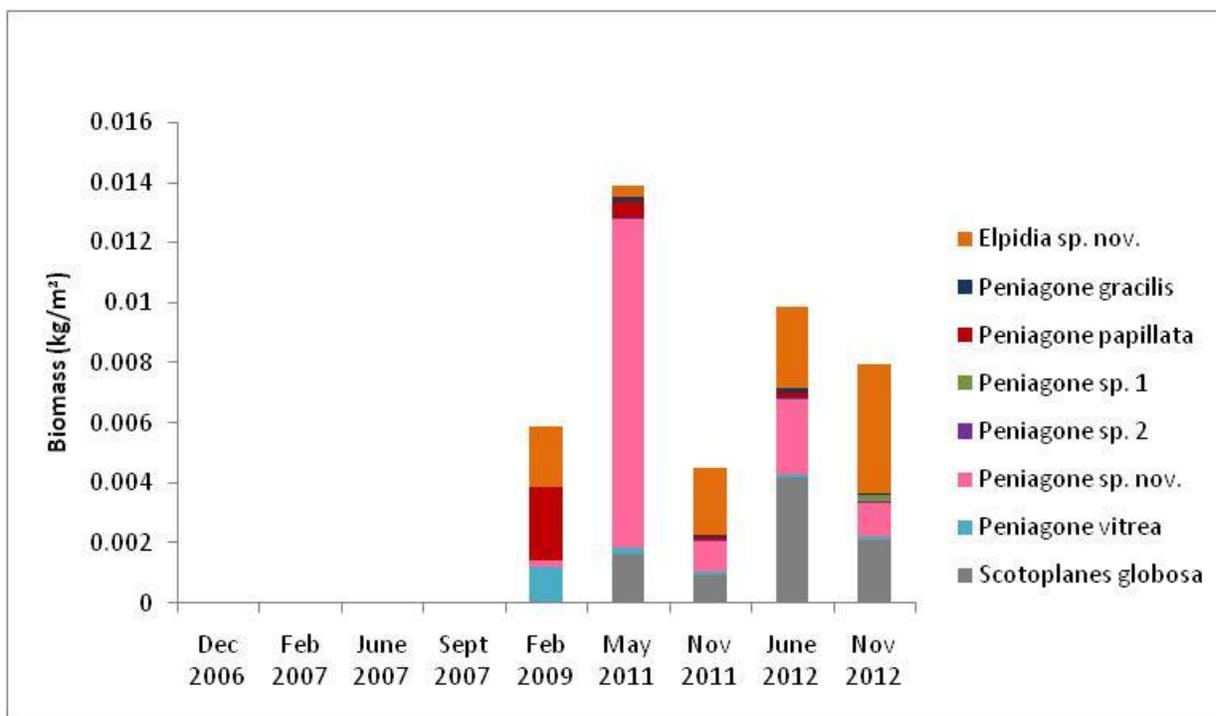
The last species that had a change in both size distribution and density is *Scotoplanes globosa*. This species was not observed until the May 2011 sampling period. The individuals had a wide size range distribution from 1.63 cm to 13.60 cm. The distribution was an even bi-modal with peaks at 5 cm and 10 cm (Figure A.13). The distribution remained bi-modal although it was not an even bi-modal distribution in November 2011. There was a large peak with 41% of the observations peaking around the 2 cm to 3 cm range. The much smaller peak was 13% at 11 cm bin. The density increased from 0.044 m<sup>-2</sup> in November 2011 to 0.125 m<sup>-2</sup> in June 2012. The size distribution once again became an even bi-modal distribution. The pattern of an uneven bi-modal size distribution returned in the November 2012 sampling period.

## BIOMASS

The biomass was calculated using conversion equations provided by Henry Ruhl. This was intended to be able to compare the relative biomass between time periods at Station M. It was decided the species that had large changes in size distribution and density would be used for biomass calculations. The three most prevalent species also had the highest biomass. The *Peniagone sp. nov.* had the highest overall biomass for the combined time periods with 0.015 kg/m<sup>2</sup>. It's biomass peaked in May of 2011. The next highest contributor to overall biomass came from *Elpidia sp. nov.* The overall biomass measured at approximately 0.012 kg/m<sup>2</sup> with a peak in November 2012. *Scotoplanes*

*globosa* was the third highest in terms of overall biomass, peaking in June 2012. These three species all had a peak in a different sampling period time frame.

The overall biomass (Figure 3) was determined for the sampling periods to detect changes over time in the response of the holothuroid deep sea community. The biomass during the 2006 and 2007 sampling periods was negligible. February 2009 was the first sampling period to have a bloom in holothuroids, thus a notable measure of biomass. The three most common species during this time period were *Elpidia sp. nov.*, *Peniagone papillata*, and *Peniagone vitrea*. The largest calculated biomass period occurred in May 2011 and was mostly due to a population bloom of *Peniagone sp. nov.* After a decrease in total biomass in November 2011, the biomass increased once again with the major contributors being *Elpidia sp. nov.*, *Peniagone sp. nov.*, and *Scotoplanes globosa*.



**Figure 3.** The total biomass for all species at each time period.

## DISCUSSION

The size distribution and density of deep sea holothurians has changed over time for some of the species at Station M while others have remained in consistent low densities. It is difficult to attribute all of the increases in both size distribution and biomass to the nutrient influx. This is especially true for the increased biomass observed in both February 2009 and May 2011. This is, in part, due to the unavailability of sampling between September 2007 and February 2009. It is unknown if there were other environmental conditions attributing to the increased community size. The same is true for the time period between the February 2009 and May 2011 sampling periods.

Assuming the increased communities and biomass was attributed to the influx of nutrients in June and September 2009, then the observed species had varying responses. The differences in response by each species lends to the idea of niche partitioning even in a group of organisms that are so similar. Studies have shown that the morphology of the terminal disc and tentacle stalk of the buccal feeding tentacles allow for each species to access a different aspect of the nutrients reaching the seafloor (Hudsen et al. 2003, Roberts and Moore 1997). Furthermore, lipid analysis has shown only certain chlorophyll pigments may be taken in by a holothuroid species, leaving other chlorophyll nutrients in the excrement for other organisms (Neto et al. 2006). The uptake of particular pigments may influence the rate at which the holothuroid grows and reproduces.

The reproduction and growth rate of these species is also an important factor in both size distribution and biomass. Organisms such as *Peniagone sp. nov.* and *Scotoplanes globosa* may be able to capitalize quickly on large nutrient influxes and reproduce quickly. In May 2011, the bi-modal distribution of *S. globosa* suggests there are two distinct cohorts meaning reproduction has occurred in at least one cycle. The response of this nature is also dependent upon the amount of time the species spends in a larval state and the recruitment of the species. Unfortunately, there is little known about the larval stages of deep sea holothuroids.

Although species such as *Scotoplanes globosa* and *Peniagone gracilis* were not observed on transects until May 2011, *Peniagone sp.1* seemed to have a more abrupt

appearance at Station M. It is possible that this species immigrated into the area after the June 2012 nutrient influx. Multiple individuals were observed swimming just above the benthos and in the water column during the November 2012 sampling period. Some holothuroid species have been found to have chemosensory receptors in their buccal tentacles which allow them to detect nutrients in the sediment and surrounding waters (Bouland et al 1982, VanderSpeigel et al. 1998).

The increase in biomass during June 2012 suggests the influx of salp detritus impacted the growth and population of the holothuroids at Station M. Macrofauna such as holothuroids play a large role in the mechanical breakdown of organic detritus (Darnell 1967, Fenchel 1970, Tenore et al. 1984). As the salp detritus is broken down, the holothuroids are able to grow larger and reproduce. The smaller biomass in the next sampling period (November 2012) may be lower to unsustainable population levels as the salp detritus is taken up by organisms.

## **CONCLUSIONS/RECOMMENDATIONS**

This project has documented the changes in size distribution, density, and biomass for deep sea holothuroids at Station M. It appears that increases in density and size distribution coincided with increased nutrients into the system. The lack of certainty to the Feb 2009 and May 2011 population blooms is difficult to attribute to the food pulse observed in June and September of 2007 due to lack of intermediate sampling. Perhaps, the June 2012 and subsequent sampling periods will provide us more information as to how long a nutrient pulse can sustain large amounts of holothuroids. Additional time series data must be attained to determine if changes are a cyclic pattern or if it is response to larger concerns such as climate change.

## **ACKNOWLEDGEMENTS**

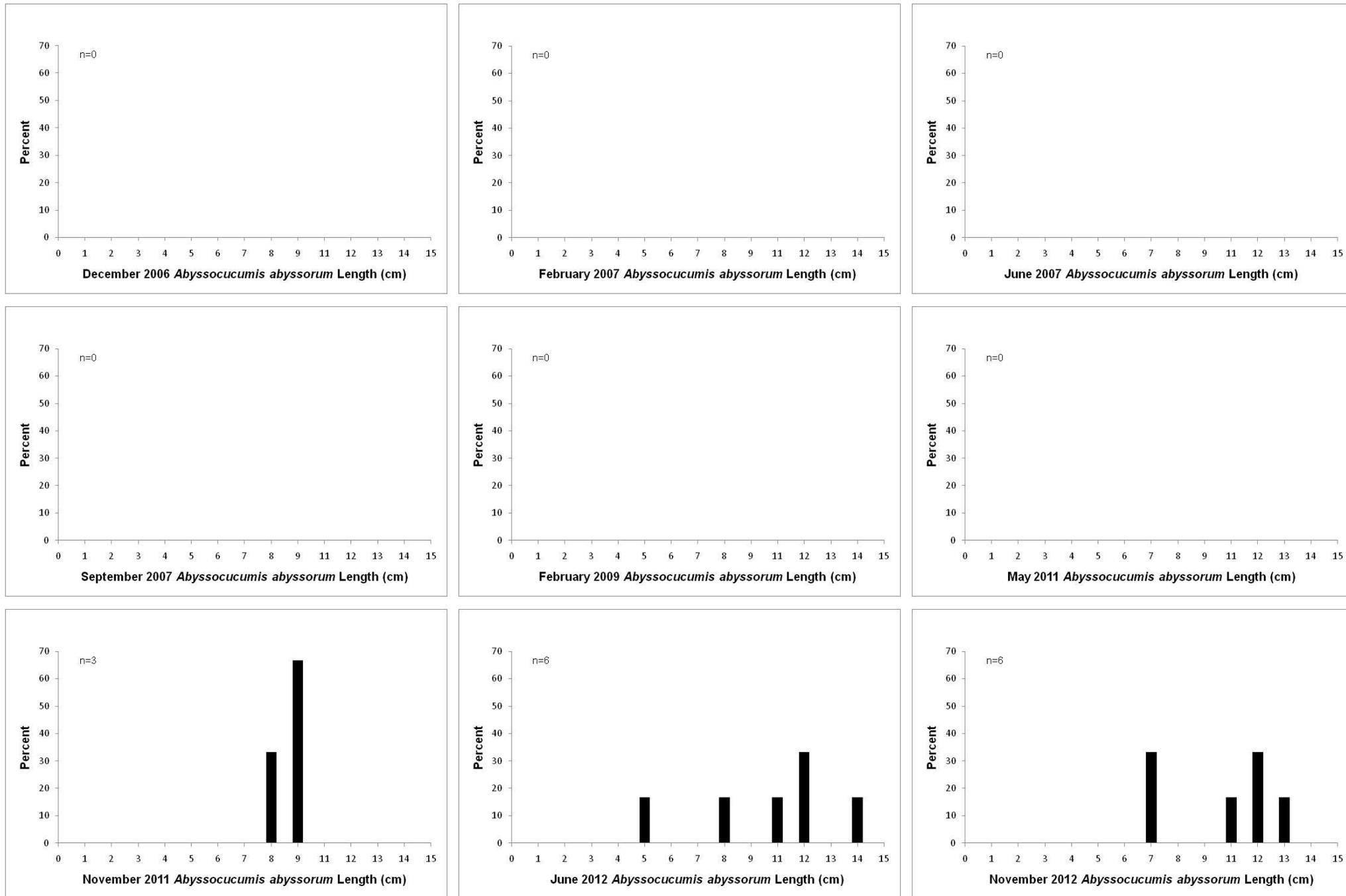
I would like to thank my mentor, Dr. Ken Smith, for giving me the opportunity to intern with the Pelagic-Benthic Coupling Lab. I would also like to Linda Kuhnz who has been a wealth of knowledge for both video annotation and holothuroids. There is no doubt that I would not have been able to accomplish as much as I have in the ten weeks I have been here without her help. Christine Huffard helped me gain my sense of perspective when addressing all the hundreds of graphs I created and reigned me in when I got a little over zealous. My experience at MBARI would also not have been possible without George Matsumoto who packs in an amazing experience for all the interns in their short time at MBARI.

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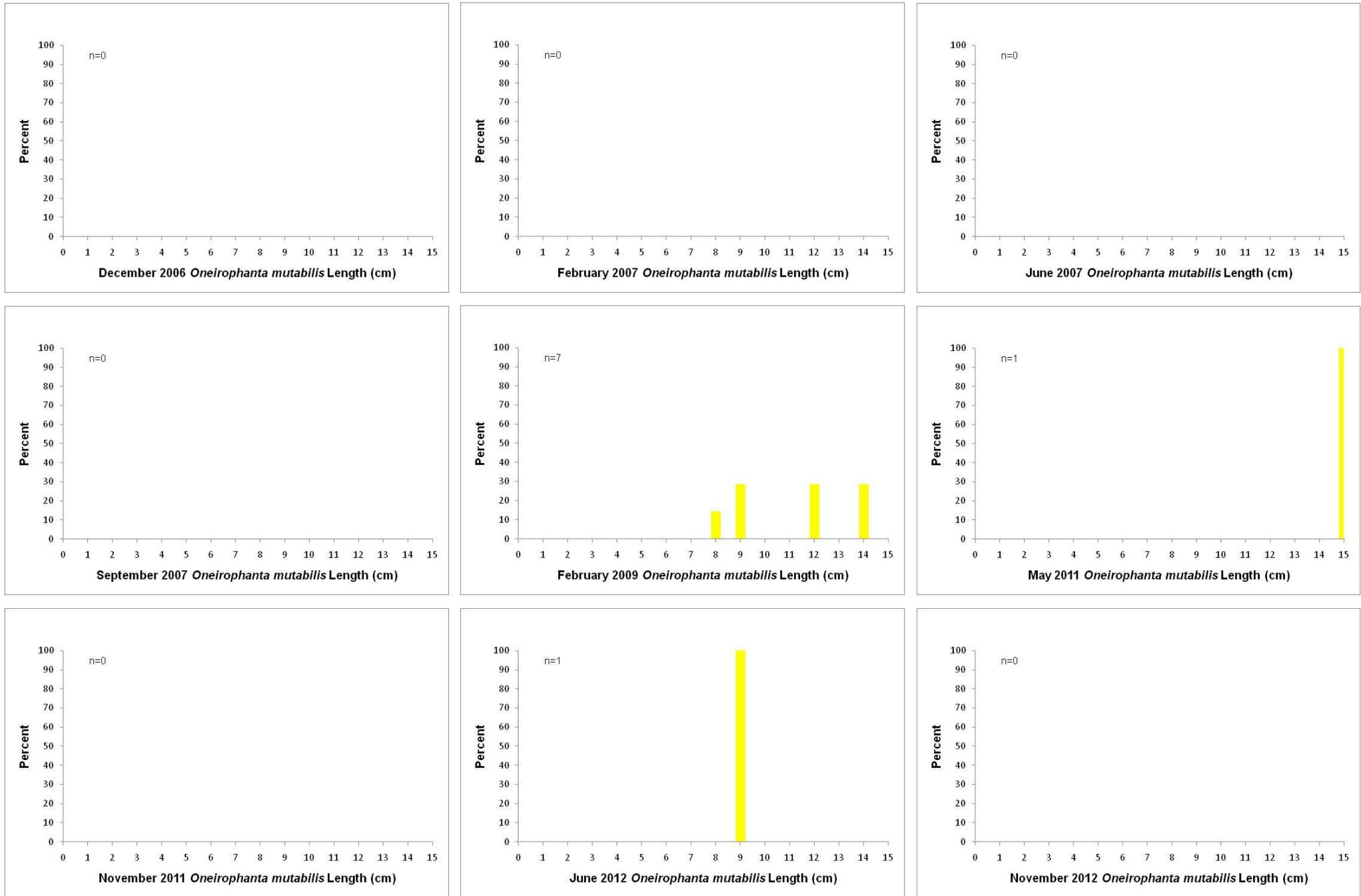
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**Appendix A.** The size distributions of all holothuroid species observed at Station M, for each sampling period.



**Figure A.1:** Size distribution for holothuroid species *Abyssocucumis abyssorum* for all 9 sampling periods.



**Figure A.2:** Size distribution for the holothuroid species *Oneirophanta mutabilis* complex for all 9 sampling periods.

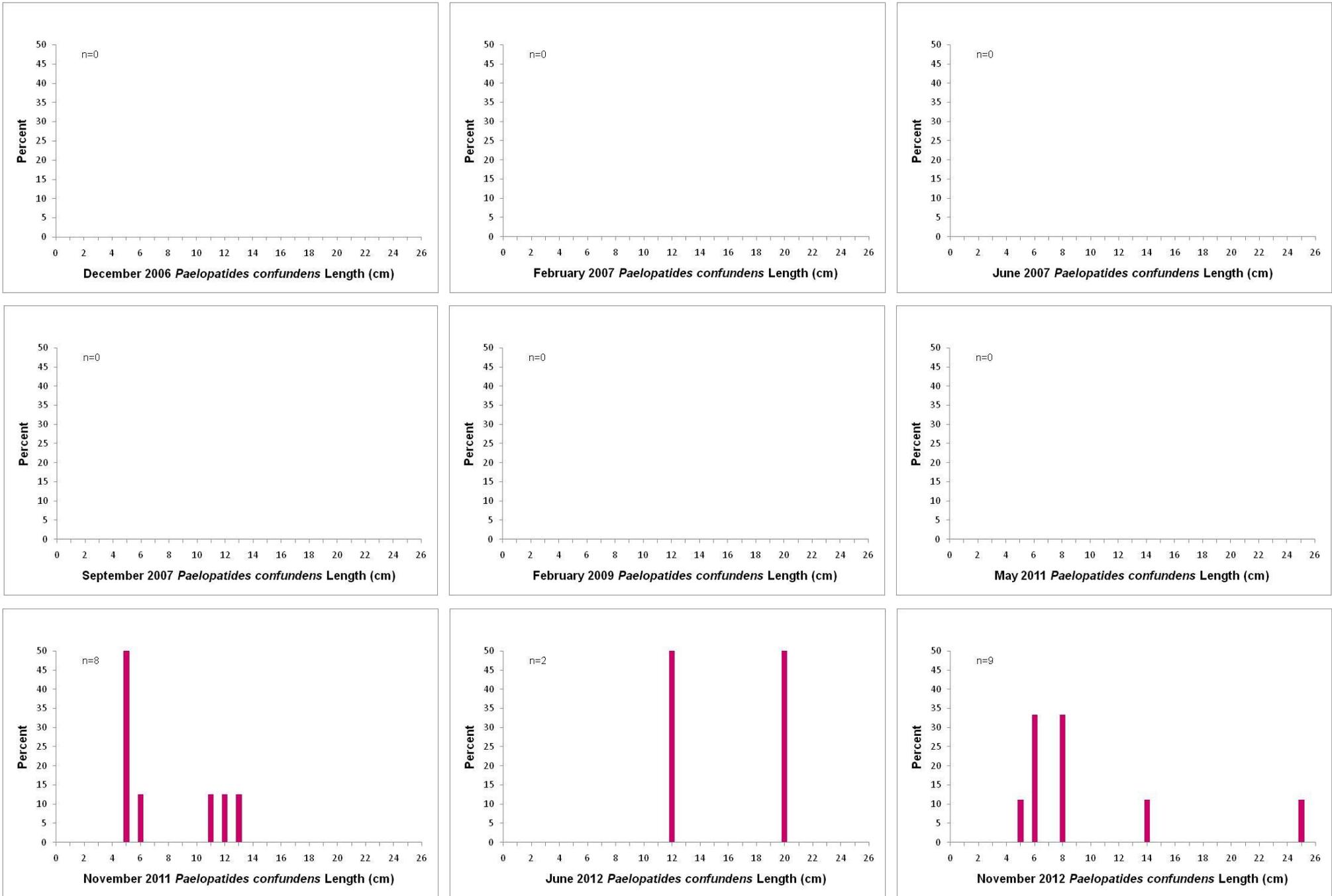


Figure A.3: Size distribution for holothuroid species *Paelopatides confundens* for all 9 sampling periods.

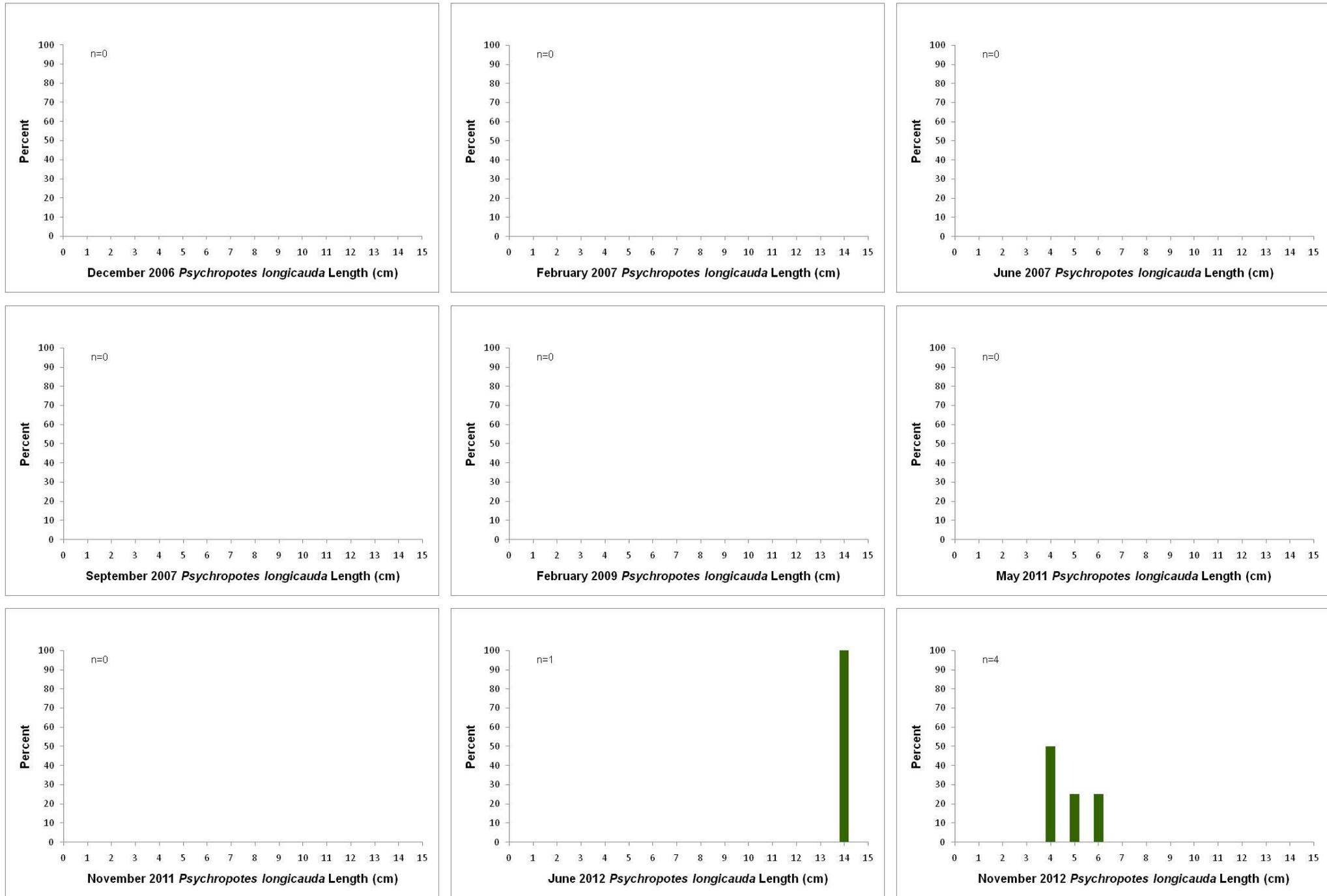


Figure A.4: Size distribution for holothuroid species *Psychropotes longicauda* for all 9 sampling periods.

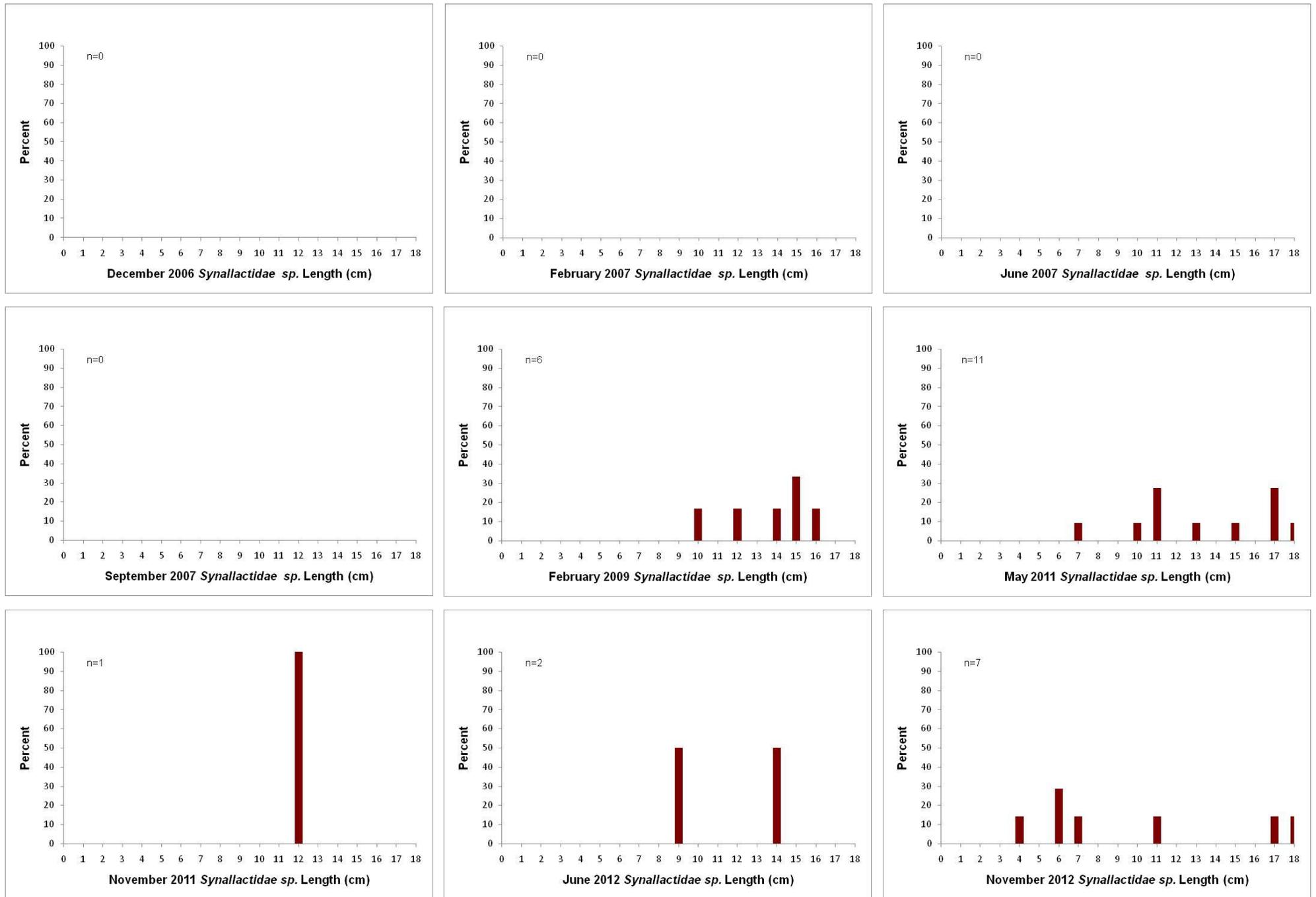


Figure A.5: Size distribution for holothuroid species *Synallactidae sp.* for all 9 sampling periods.

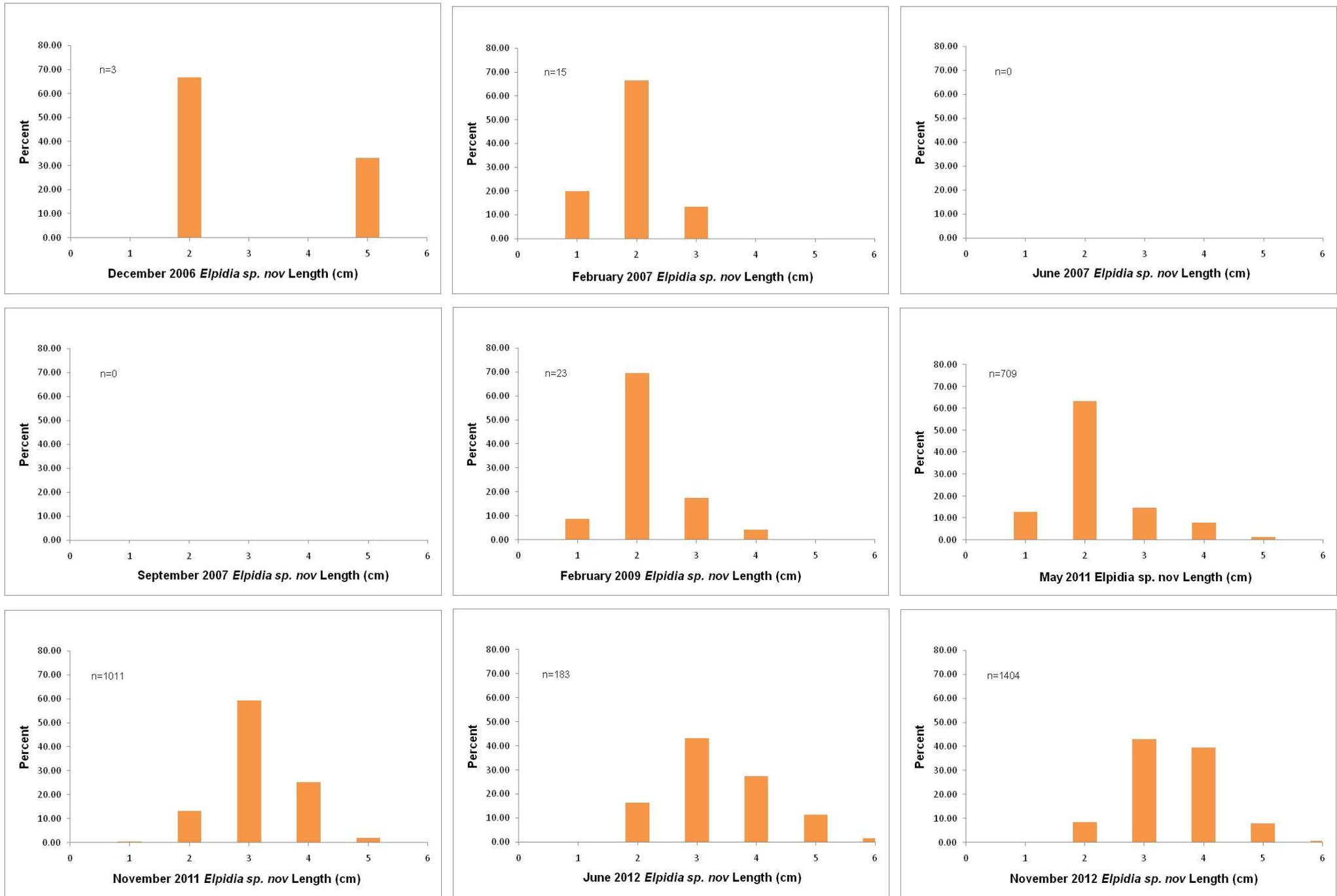


Figure A.6: Size distribution for holothuroid species *Elpidia sp. nov.* for all 9 sampling periods.

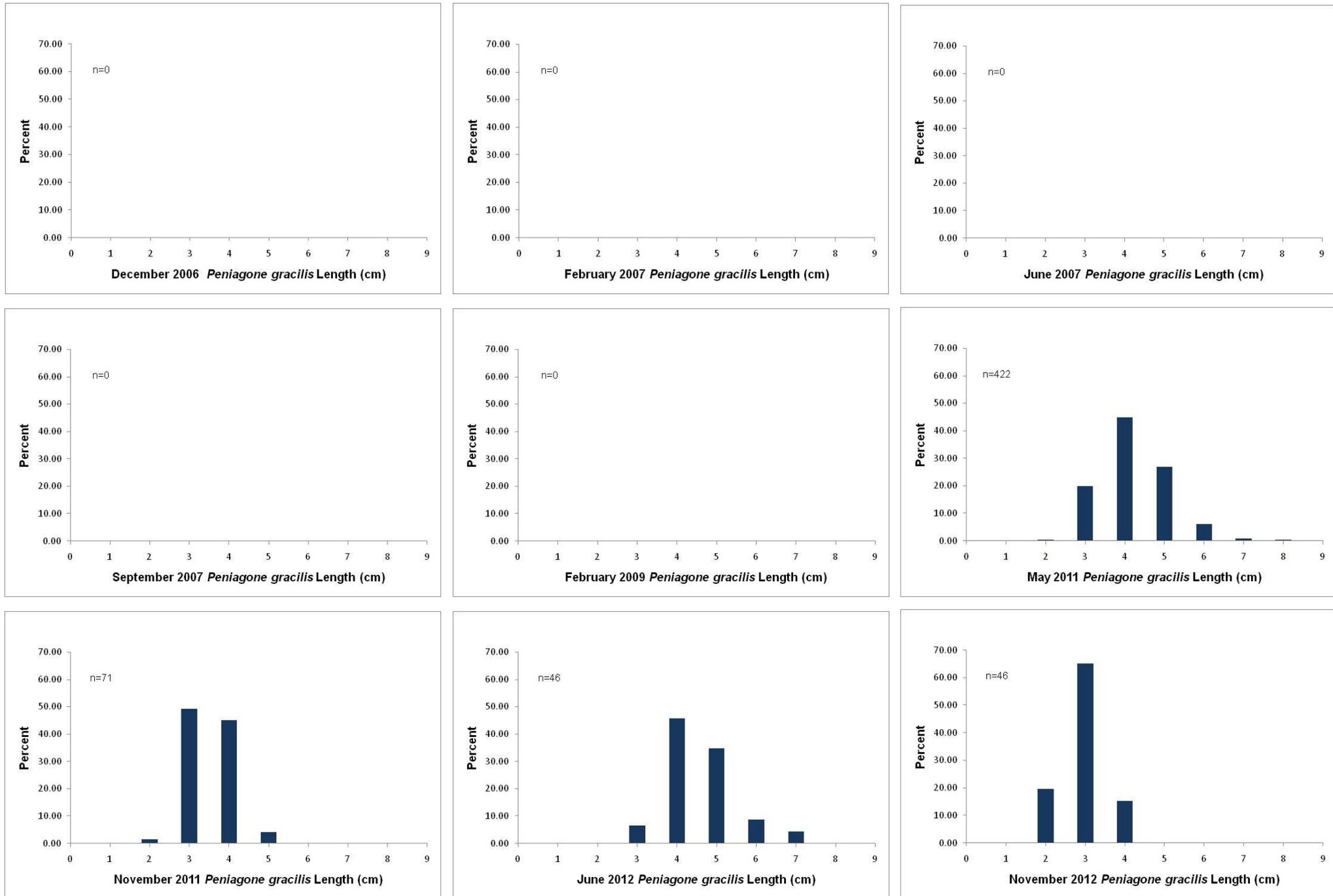


Figure A.7: Size distribution for holothuroid species *Peniagone gracilis* for all 9 sampling periods.

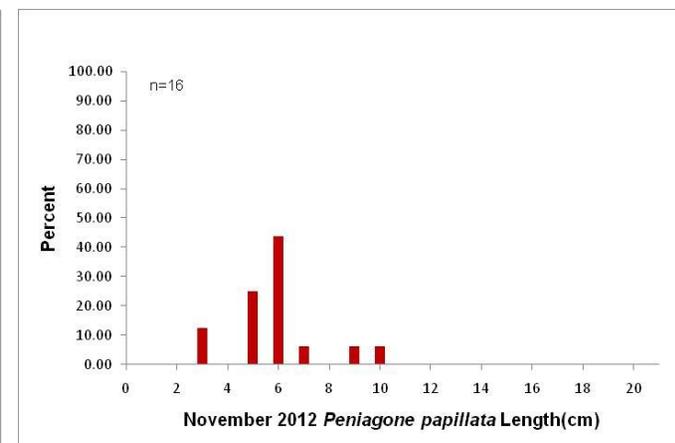
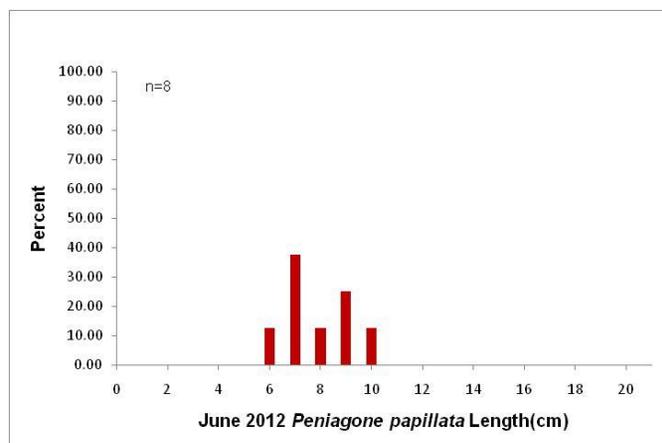
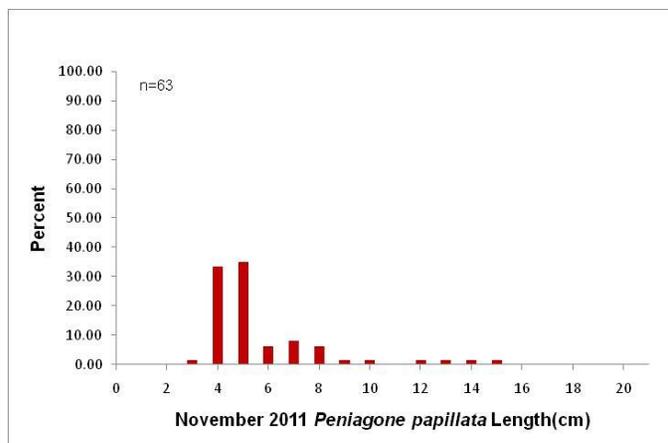
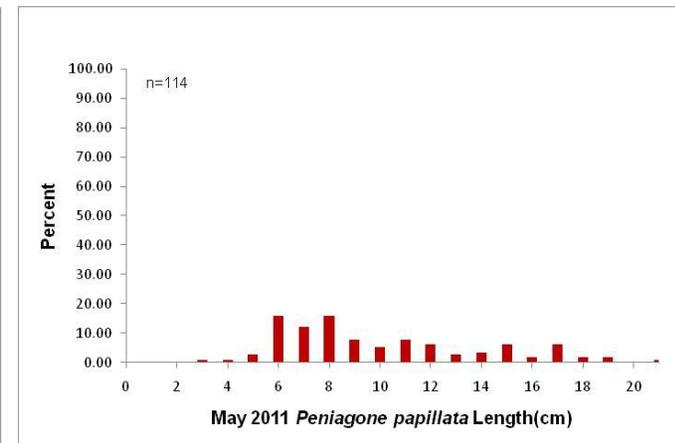
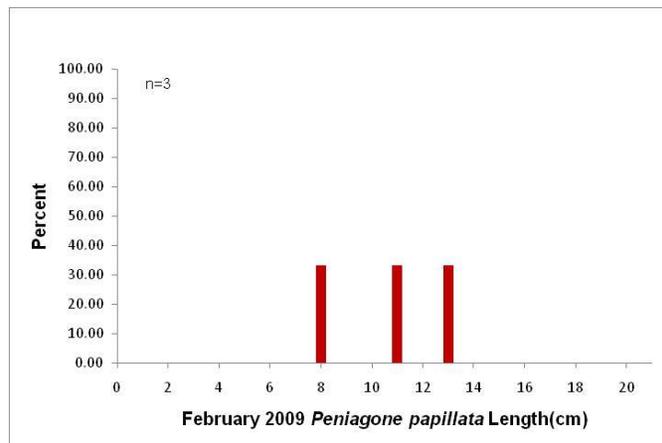
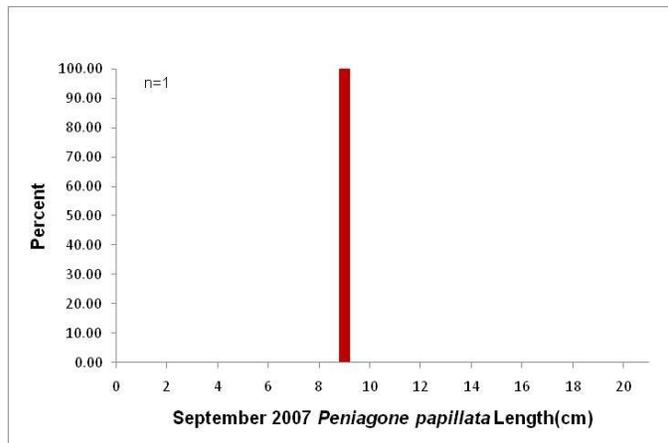
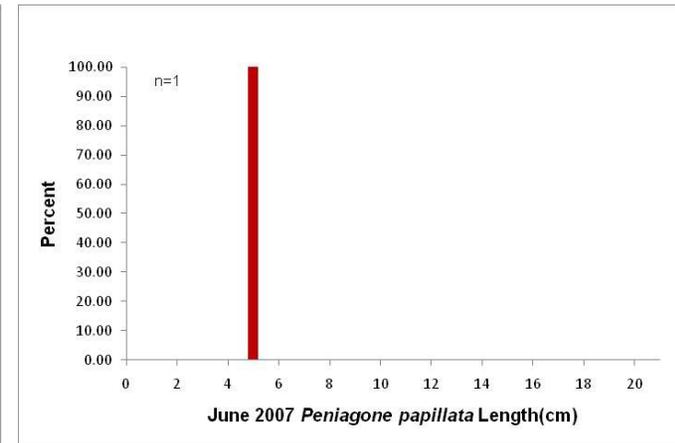
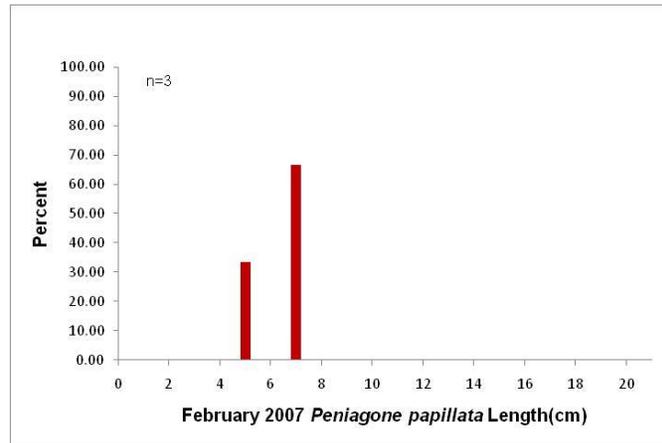
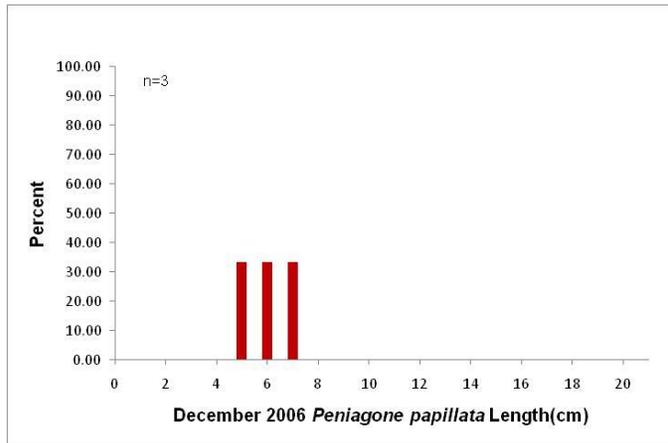
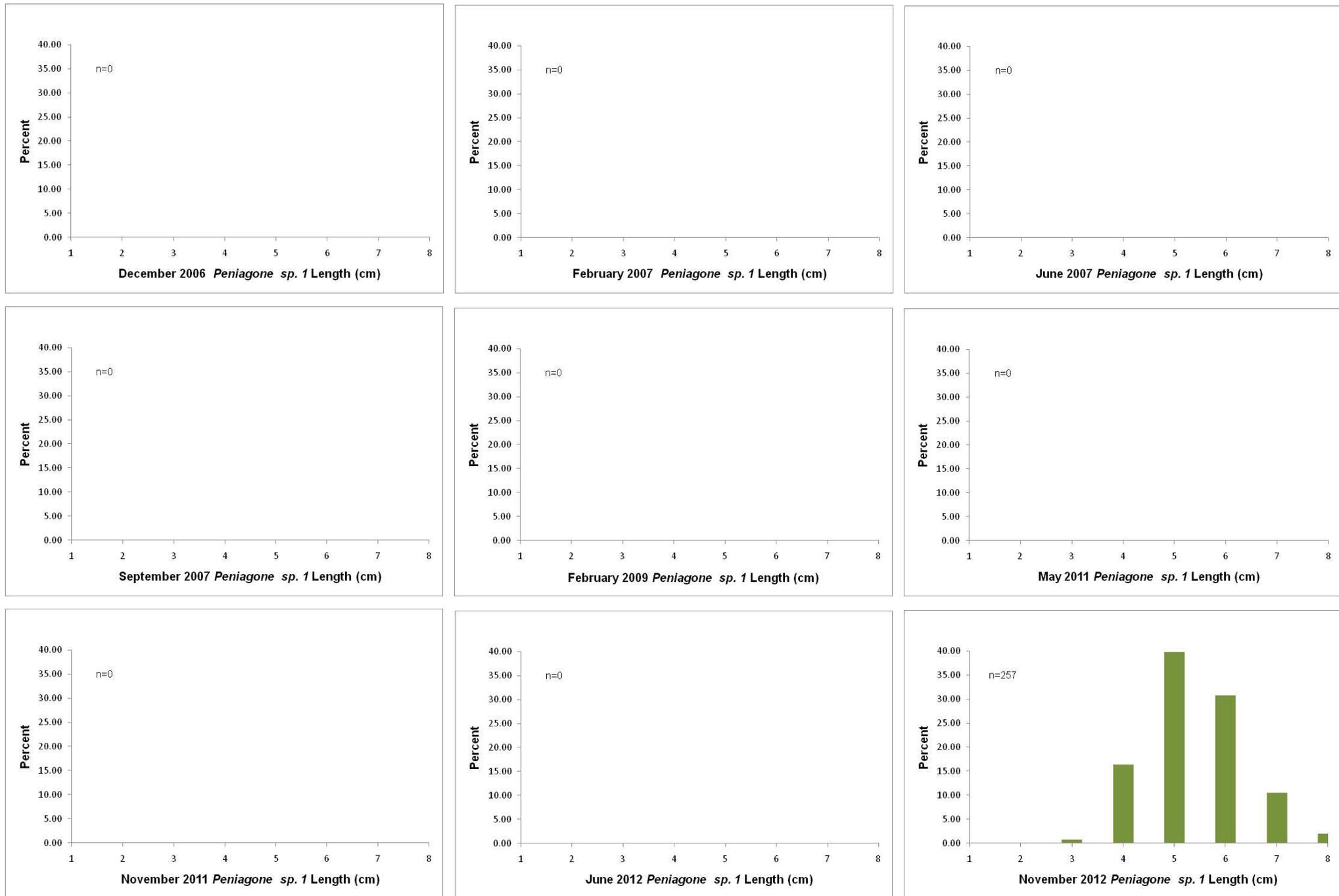


Figure A.8: Size distribution for holothuroid species *Peniagone papillata* for all 9 sampling periods.



**Figure A.9:** Size distribution for holothuroid species *Peniagone sp. 1* for all 9 sampling periods.

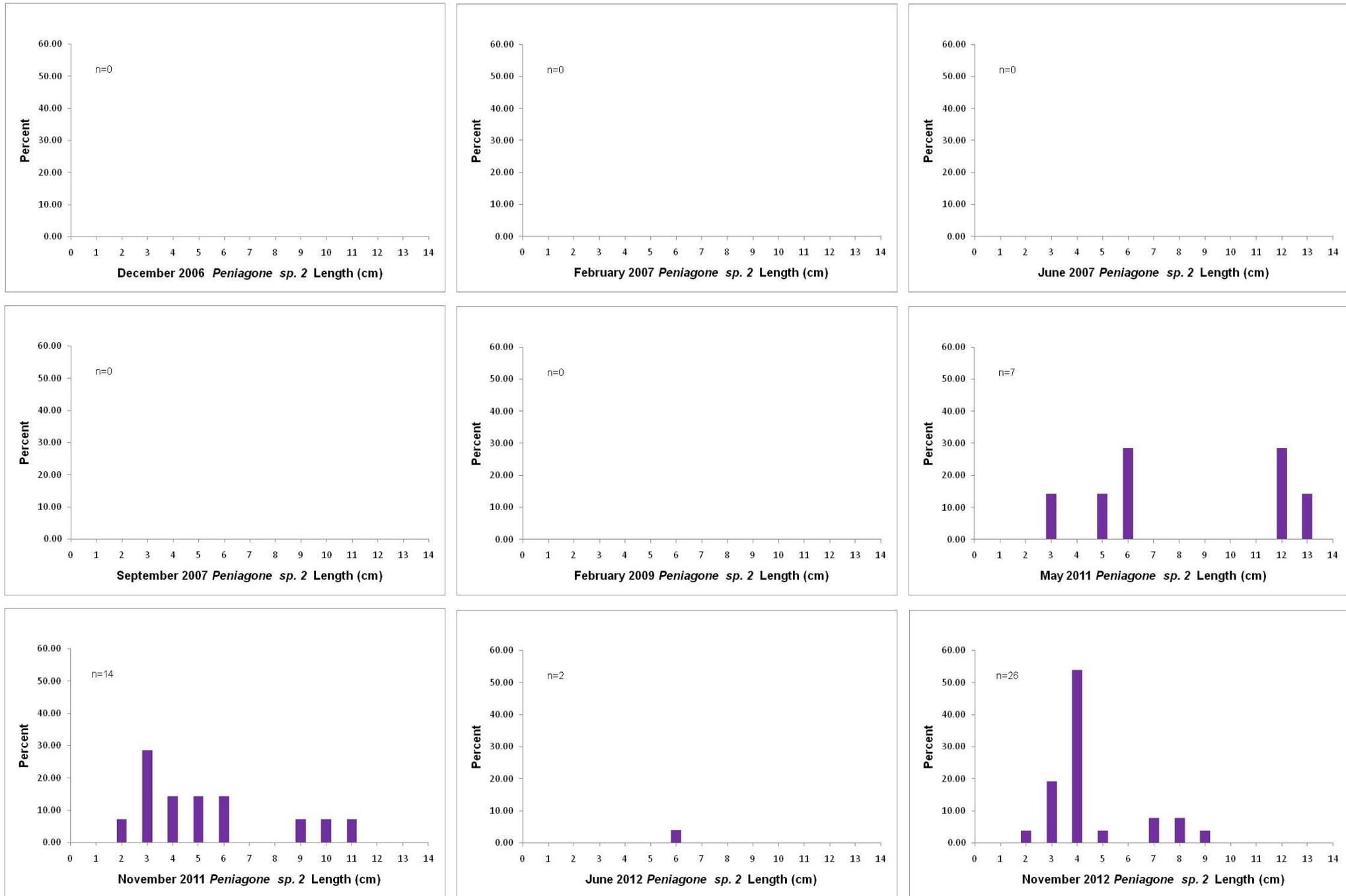


Figure A.10: Size distribution for holothuroid species *Peniagone sp. 2* for all 9 sampling periods.

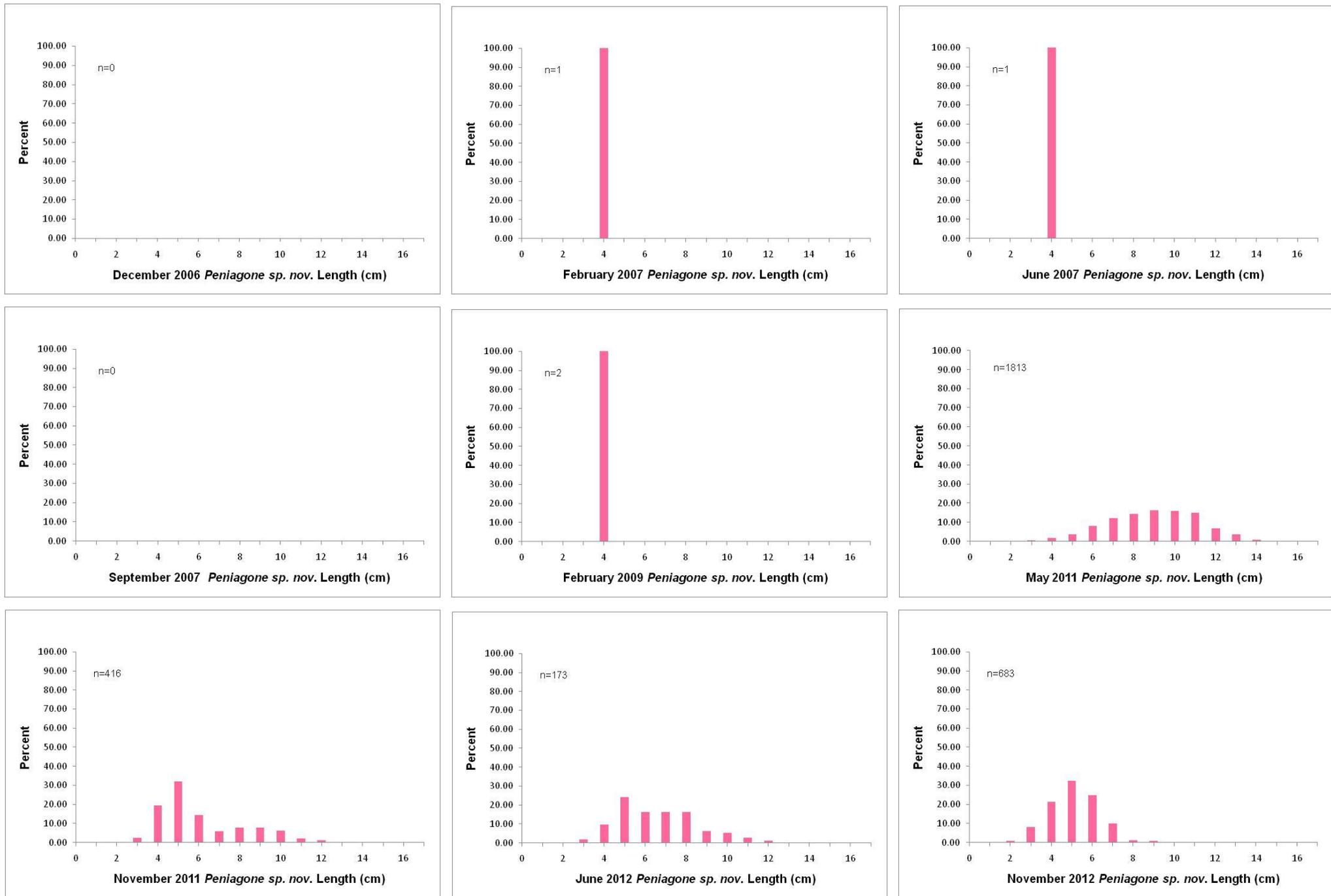


Figure A.11: Size distribution for holothuroid species *Peniagone sp. nov.* for all 9 sampling periods.

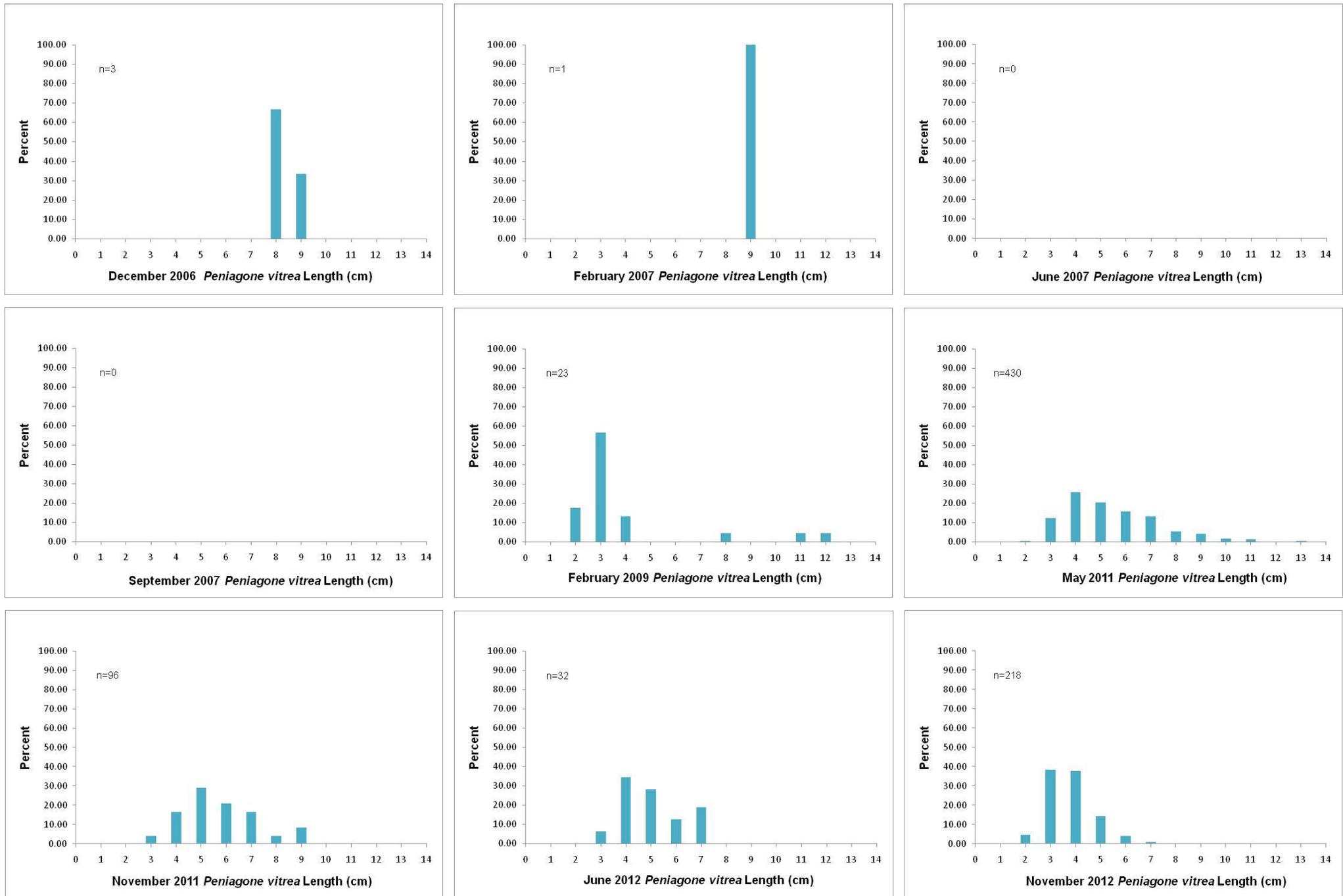


Figure A.12: Size distribution for holothuroid species *Peniagone vitrea* for all 9 sampling periods.

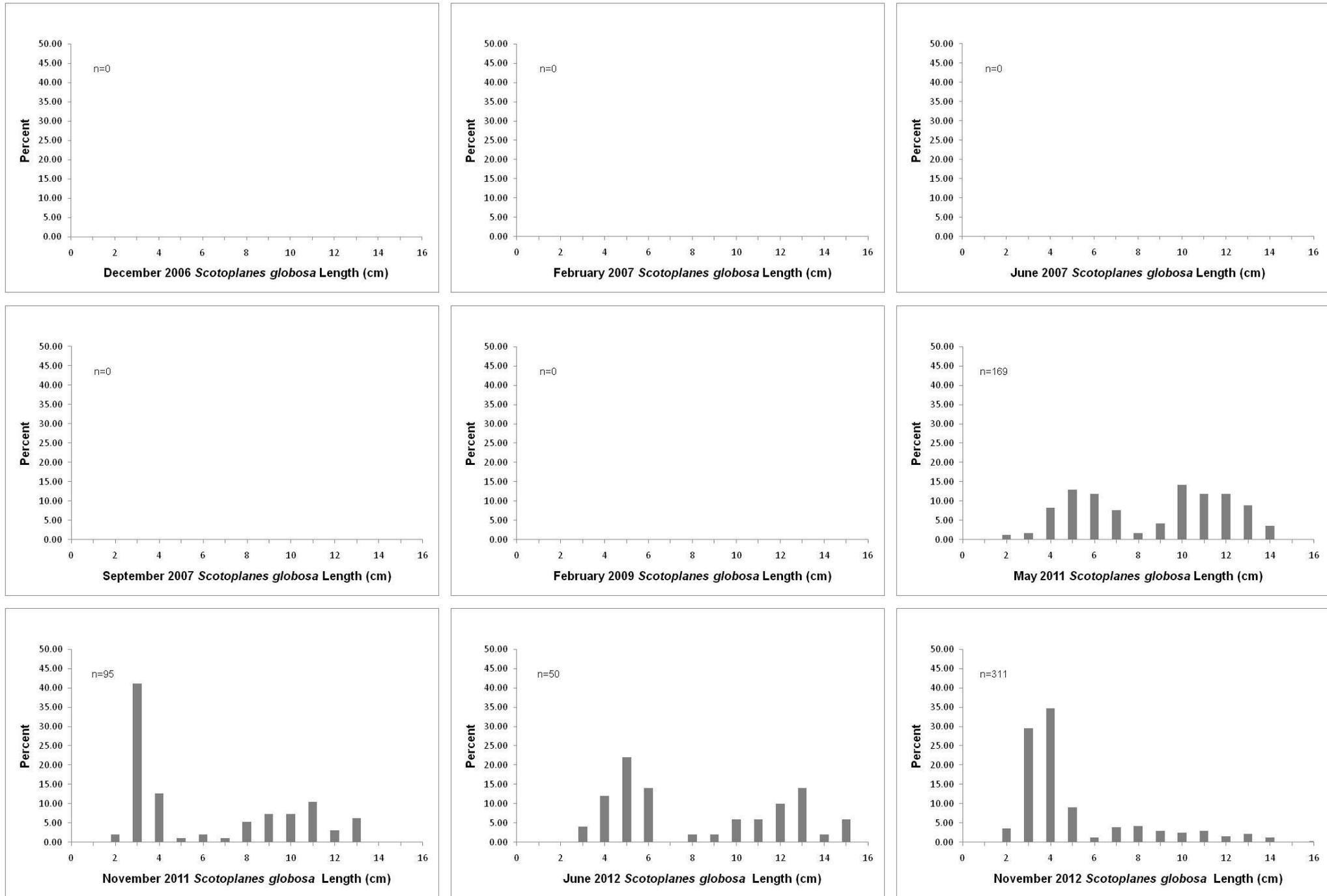


Figure A.13: Size distribution for holothuroid species *Scotoplanes globosa* for all 9 sampling periods.