2006

Small Scale Distribution of the Sand Dollars Mellita tenuis and Encope spp. (Echinodermata)

James P. Swigart
University of South Florida

Follow this and additional works at: http://scholarcommons.usf.edu/etd
Part of the American Studies Commons

Scholar Commons Citation
http://scholarcommons.usf.edu/etd/3930

This Thesis is brought to you for free and open access by the Graduate School at Scholar Commons. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Scholar Commons. For more information, please contact scholarcommons@usf.edu.
Small Scale Distribution of the Sand Dollars *Mellita tenuis* and *Encope spp.*

(Echinodermata)

by

James P. Swigart

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science
Department of Biology
College of Arts and Sciences
University of South Florida

Major Professor: John Lawrence, Ph.D.
Susan Bell, Ph.D.
Ron Sarno, Ph.D.

Date of Approval:
July 19, 2006

Keywords: nonrandom, aggregation, density, nearest neighbor, percent organic content

© Copyright 2006 , James P. Swigart
Acknowledgements

I would like to thank my major professor Dr. John Lawrence. His guidance made completing graduate school possible and our many conversations have challenged me to think intuitively. I would like to thank my committee members Dr. Susan Bell and Dr. Ron Sarno for providing suggestions with regards to both my research and class work.

Thank you to those of you took time to sit on the ocean bottom with me: Susan Hilber, Janessa Cobb, Jennifer Rhora, Brian Badgley, and Dave Karlen. Thank you to Bill Dent and Ben Meister for their assistance and SCUBA instruction. Thank you to Captain Tom Worle and the rest of the crew of the R/V Bellows for making each research trip comfortable and Florida Institute of Oceanography for providing ship time through a grant to Dr. Lawrence.

Thank you to my family for encouraging me to be a marine biologist, even while landlocked in Central Illinois. Thank you to my wife Linsay for putting up with the long hours and spending your weekends with me in the lab when I knew you would rather be elsewhere.
# Table of Contents

List of Tables iii

List of Figures iv

Abstract v

Introduction 1

Materials and Methods 9

- Distribution Index 9
- Percent Organic Content 10
- Correlation Analysis 11
- Sites 11
  - Captiva Island – Observational (March 18, 2005) 11
  - Egmont Key – Observational (March 19, and September 18, 2005) 13
  - Fort De Soto, Mullet Key – Observational (May 21, and September 10, 2005) 13
  - Fort De Soto, Mullet Key - Experimental (July 10, 2005) 14
- Statistics 18
  - Density – Fort De Soto 18
  - Distribution - Fort De Soto, Mullet Key 18
  - Percent Organic Content 19
  - Captiva Island 19
  - Fort De Soto 19
  - Correlation 20

Results 21

- Density - Fort De Soto 21
- Percent Organic Content 21
  - Captiva Island 21
  - Egmont Key 21
  - Fort De Soto 23
- Distribution 26
  - Captiva Island and Egmont Key 26
  - Fort De Soto 26
- Correlation of Nearest Neighbor and Percent Organic Content 28


Captiva Island 28
Egmont Key 29
Fort De Soto 29

Discussion 34
Percent Organic Content 34
Captiva Island and Egmont Key 35
Fort De Soto 36
Distribution and Correlation 36
Captiva Island 37
Egmont Key 38
Fort De Soto 39

Conclusion 43

References 44
List of Tables

Table 1. Density comparisons of *Mellita tenuis* at Fort De Soto, 2005 22
Table 2. Mean percent organic content of sediment at Fort De Soto by month, 2005 24
Table 3. Comparison of percent organic content of the sediment at Fort De Soto, 2005 24
Table 4. Nearest neighbor indices (R) for Captiva Island and Egmont Key 24
Table 5. Distribution of plots for all sampling periods at Fort De Soto Park, 2005 30
Table 6. Correlation analysis of nearest neighbor index and percent organic content of the sediment for Fort De Soto, 2005 30
List of Figures

Figure 1. Location of study sites ................................................. 12
Figure 2. PVC 1m² quadrat used at Fort De Soto site .................. 16
Figure 3. Study design of Captiva Island site ......................... 15
Figure 4. Study design of Fort De Soto site ......................... 15
Figure 5. Sediment enriched with fish food flakes at Fort De Soto, July 2005 17
Figure 6. Experimental aggregation of Mellita tenuis at Fort De Soto, July 2005 17
Figure 7. Variation in grain size frequency (%) distribution for all sites in 2005 22
Figure 8. Nearest neighbor index (R) for Captiva Island site, March 2005 25
Figure 9. Nearest neighbor index (R) for Egmont Key site grouped by month in 2005 27
Figure 10. Spatial distribution frequency of Mellita tenuis at Fort De Soto 27
Figure 11. Egmont Key correlation of nearest neighbor index (R) and percent organic content of the sediment in 2005 31
Figure 12. Correlation analysis of nearest neighbor index (R) and percent organic content for Mellita tenuis, May 2005 at Fort De Soto 32
Figure 13. Correlation analysis of nearest neighbor index (R) and percent organic content for Mellita tenuis for July 2005 at Fort De Soto 32
Figure 14. Correlation analysis of nearest neighbor index (R) and percent organic content for Mellita tenuis for September 2005 at Fort De Soto 33
Small Scale Distribution of the Sand Dollars *Mellita tenuis* and *Encope spp.*  
(Echinodermata)  

James P. Swigart  

ABSTRACT  

Small scale distributions of *Mellita tenuis* and *Encope spp.* were quantified at Fort De Soto Park on Mullet Key, off Egmont Key and off Captiva Island, Florida during 2005. Off Captiva Island, *Encope spp.* were aggregated in 33.3% of plots in March. Off Egmont Key, *M. tenuis* were aggregated in 100% of plots in March but in no plots in September. At Fort De Soto Park, *M. tenuis* were aggregated in 37.5% of plots in May 12.5% in July and 50.0% in September. Sand dollars in 6.3% of the plots in September at Fort De Soto had a uniform distribution. Individuals in all other plots at all sites had random distributions. At Fort De Soto, each plot was revisited a few hours after the initial observation; 37.5% of plots had a different distribution at the second observation.  

Percent organic content of the smallest sediment grains (<105 µm) was not correlated with sand dollar distribution, except off Egmont Key. There was a significant negative correlation between nearest neighbor index and percent organic content. *Mellita tenuis* do aggregate on occasion. The cause of aggregation is not known. If localized differences in percent organic content of the sediment influence distribution, then homogeneity in the percent organic content of the sediment, as found in the majority of plots, would suggest random distribution of sand dollars.
Introduction

Nature is sometimes seen as a sum of random and unpredictable events. However, nature only appears entirely random to the casual observer. When care is taken to record natural events, patterns often emerge and can be predicted. When an organism is studied, it may respond to patterns of abiotic events as well as the influences of other organisms (Krebs 1994).

The distribution of a population is one factor of the natural history that may appear random until looked at closely. Wind-dispersed plants are expected to have a random distribution. Neither the adult plant nor the seed can control where the wind will deposit the seed. Since the presence of one seed would not affect the probability of another seed landing in the same area, it is considered a random distribution. However, even though deposition might be random, not all habitats are suitable for germination. If there is a good patch of soil, more seeds could be expected to germinate and grow successfully. This would increase the likelihood that another plant of the same species would be found in the area and thus have an aggregated distribution (Pielou 1960).

Spatial scale is important when looking at distributions. Population studies overlook changes in habitat at smaller scales that have distinct influences on an individual’s behavior (Underwood et al. 2004, Chapman 2000, Siegel 2005, Commoto et al. 2006). Adult *Semibalanus cariosus* barnacles have a regular population at a small scale. As they filter water, they remove recruits which prevent them from settling nearby
(Navarrete and Wieters 2000). This lack of recruitment maintains the spacing between adults. If the barnacles had been examined at a larger scale, they would have appeared to be an aggregation and the method by which adults interfere with recruitment might have gone unrecognized.

Understanding small scale interactions are important for making predictions about organisms’ distributions. Predator-prey relationships, interspecific and intraspecific competition for resources, and reproduction are all strong pressures that drive behavior and an organism’s distribution pattern. Typically an individual is subject to all the pressures in varying degrees. The balance of these pressures is often referred to as finding the ideal-free distribution (Kacelnik et al. 1992). The ideal free distribution gives individuals the greatest chance of surviving and reproducing while minimizing costs. The ideal-free distribution is relevant for a specific set of selective pressures. If one of the selective pressures changes, then the ideal-free distribution will change as well. Understanding the distribution can give insight into the selective pressures that are influencing the study organism at that time.

There are three broad categories in spatial distribution: random, regular (or uniform), and aggregated. If individuals have a random distribution, the presence of an individual does not affect the probability that another individual will be found adjacent to it (Pielou 1960). Random distributions are often the null hypothesis when distribution studies are conducted because random distributions imply that individuals are not influencing each other and are not being influenced by some external stimuli.

If individuals have a regular distribution, the presence of an individual decreases the probability that another individual will be found adjacent to it (Pielou 1960).
Individuals with this type of distribution are sometimes referred to as dispersed (see: Underwood et al. 2004). These individuals increase survivorship or reproductive success by distancing themselves from others. A regular distribution would reduce intraspecific competition for food if the food was spread evenly. A regular distribution may also provide some relief from predation if the density is low, forcing the predator to spend more time searching for its prey (Nachman 2006). The larvae of the barnacle *Eliminius modestus* settle in a regular pattern on artificial substrate in a controlled laboratory setting (Crisp 1961). The larvae maintain a spacing of approximately 2mm in all directions. Crisp believed that by settling at a regular distance, the barnacles have room to grow, but there is not space for other species to settle. This distribution pattern increases survivability while reducing interspecific competition. It also allows the barnacles to be close enough to increase reproductive success.

If individuals have an aggregated distribution, then the presence of an individual increases the probability that another individual will be found adjacent to it (Pielou 1960). Sea urchins may increase reproductive success by spawning within an aggregation (Bauer 1976, Lamare and Stewart 1998, McCarthy and Young 2002, Pennington 1985, Young et al. 1992). An aggregated distribution would increase intraspecific competition for food, but it is possible that the food supply in that area is abundant enough to overcome the extra competition. Sea urchins utilize a similar strategy. Sea urchins respond to chemical cues released by damaged plants. If a sea urchin begins feeding, other sea urchins move towards the food supply (Dean et al. 1984, Vadas et al. 1986). Moving towards a detected food source, even if other sea urchins are
there, provides greater benefits to the urchins than wandering the barrens searching for food.

Sand dollars are common throughout the Gulf of Mexico and the Caribbean (Ghiold and Hoffman 1986). One common sand dollar in the Tampa Bay region is *Mellita tenuis* Clark 1940. *Encope michelini* and *Encope aberrans* are common in the Gulf of Mexico. Sand dollars are typically found in sandy substrates, on the surface or buried just below the surface (Hyman 1955).

*Mellita tenuis* has adult densities of 2 to 17 individuals·m\(^{-2}\) at Fort DeSoto, FL (Lane and Lawrence 1980). Densities have been observed where *M. tenuis (=quinquiesperforata)* were literally lying on top of each other (Salsman and Tolbert 1965). Size and maturity may have an effect on density as 731 juveniles·m\(^{-2}\) was recorded by Lane and Lawrence (1980). Along with high densities, sand dollars have been noted as having patchy or aggregated distributions on a variety of scales (Dexter 1977, Ebert and Dexter 1975, Pomory et al. 1995, Steimie 1990), though rarely has the type of distribution been examined. Lane and Lawrence (1980) and Merrill and Hobson (1970) determined that *M. tenuis* and *D. excentricus* respectively had binomially aggregated populations. The population of *D. excentricus* was clearly aggregated as the sand dollars were piled on top of each other and overlapping. The sand dollar *Laganum depressum* (Saunders 1986) was found to be patchy in distribution at a scale of 100m\(^{2}\).

Aggregated distributions are common in natural systems (Sokal and Rohlf 1981, Krebs 1989). Reproduction and predation avoidance have been considered as causes for other echinoderm aggregations. Vadas and Elner (2003) used cues of predators and conspecifics to determine that predation does not cause aggregation in the sea urchins
*Lytechinus variegatus* or *Tripneustes ventricosus*. Aggregation is less likely to be beneficial to sand dollars as predator avoidance. Unlike sea urchins, sand dollars do not have protective spines that they can intertwine with other individuals to reduce their exposed edge.

Several species of sea urchins aggregate during spawning (Bauer 1976, Lamare and Stewart 1998, McCarthy and Young 2002, Pennington 1985, Young et al. 1992). Sand dollars and sea urchins do reproduce similarly so sand dollars may also aggregate during the spawning season. This study will not be conducted during spawning season so reproduction will not be an influence.

Other proposed factors affecting distributions of sand dollars include nutritive content of the substrate, substrate particle size, and hydrodynamics (Pomory et al. 1995). Sand dollars are sediment feeders and ingest the sand as they move over or through it (Bell and Frey 1969, Findlay and White 1983). Diatoms, algae, chitin fragments and other organic particles, as well as inorganic material, are typically found in the gut of sand dollars (Bell and Frey 1969, O’Neill 1978). There is some debate as to whether sand dollars actively select food particles. Telford et al. (1985) found that the proportion of diatoms in the gut contents was greater than in the sediment. Timko (1976), however, determined that sand dollars were nonselective in food particles collected.

The sediment in a populated area is likely to heterogeneous at a small scale (Tokeshi 1999). Organic carbon can be expected to be deposited non-uniformly (Garrigue 1998) and other organic particles will be moved by currents and turbidity (James 2000). Sea urchins aggregate when food is abundant (Scheibling and Hamm 1991). Telford et al. (1985) found that enriching sediment with diatoms initiated feeding
behavior in *Mellita isometra* (=*quienquiesperforata*). Smith (1981) found no difference in the percent organic material inside and outside of the beds of *D. excentricus*.

However, *D. excentricus* can suspension feed and remove nutrients from particles in the water instead of the sand (Merrill and Hopson 1970, O’Neill 1978). More aggregated distributions of sediment feeding sand dollars might occur in areas of high nutritive quality.

Substrate size also may affect distribution of *Mellita* species. Since the grains are physically lifted, they must be small enough to be manipulated (Telford et al. 1985). If the particles are too small, sand dollars may have a difficult time burying or sifting through the sediment (Bell and Frey 1969). Sand dollars also have to be able to move on or just beneath the sand in order to have an adequate food supply. *Mellita tenuis* typically prefer particle sizes from 63 µm to 0.5 mm in size in a lab setting (Pomory et al. 1995). Habitat is not expected to be homogeneous at all scales (Tokeshi 1999). Smaller particles will be carried more by swifter moving water than larger particles. In areas where hydrodynamics are low, small particles might collect in higher proportions. These areas might offer different habitats for sand dollars and cause aggregations to develop if the surrounding areas are less suitable.

Living in the subtidal, sand dollars themselves are also subject to hydrodynamics. Even though sand dollars typically live in the subtidal region, the water is not completely calm and the sand dollar could be lifted by the waves. Once the sand dollar is lifted, it might be tumbled in the current to an area where the turbulence is not as strong. Lane and Lawrence (1980) hypothesized this explained patchiness in distribution of *M. tenuis* (=*quinquiesperforata*). Lunules may play an important role in reducing lift by providing
openings for pressure underneath the sand dollar to be released (Telford et al. 1981). Another method by juvenile Mellita spp. and D. excentricus to avoid displacement is the presence of weight belts (Chia 1973, Mooi and Chen 1996). Juveniles ingest sand that is stored in the diverticulum. The sand may act to add weight to the sand dollar until it reaches a size sufficiently large as to not be moved by the current. Mellita tenuis has strategies to counteract hydrodynamics (lunules, test shape, and weight belts) so water movement should not be a factor causing distribution changes.

If distribution results from behavior, then mobility must be present at some stage of life. Planktonic larvae of some marine invertebrates move in the water column to ensure that settlement occurs on acceptable substrate (Mora and Sale 2002). Small scale distribution could be determined upon settlement by more larvae choosing to settle on nutrient rich substrate. Caldwell (1972) demonstrated that larvae of M. quinquisperforata choose to settle on substrates with high organic content. That the final distribution is determined at settlement is unlikely, however, as sand dollars are mobile and the nutritive quality of the substrate should decrease with more individuals feeding upon it (Hyman 1955, Bell and Frey 1969).

Sand dollars have been known to have a regular distribution. The sand dollar Dendraster excentricus arranges itself in the sand so that the majority of its test is vertical in the water column allowing it to filter feed. The sand dollars maintain a uniform spacing that ensures that the sand dollars do not have the hydrodynamics surrounding them disrupted (Merrill and Hobson 1970). This provides a steady stream of water and nutrients flowing over them. The sand dollars in this study, however, do not filter feed and so are not expected to have a regular distribution.
While the distribution should not be regular, it still may be non-random. The distributions of sand dollars have been described as aggregated or patchy at a large scale (Lane and Lawrence 1980, Merrill and Hobson 1970, Saunders 1986). Under right conditions, an aggregated distribution will be found at a small scale. Of the factors examined so far, only food availability in the sediment is relevant to the site and specimens. The sediment in a populated area is likely to heterogeneous at a small scale (Tokeshi 1999). I hypothesize that sand dollars (*Encope* spp. and *Mellita tenuis*) have a non-random, aggregated distribution at a small scale. I hypothesize that aggregation is correlated with nutrient level within the sediment.
Materials and Methods

Distribution Index

Distributions of sand dollars have been quantified to a degree. Merrill and Hobson (1970) and Lane and Lawrence (1980) used binomial distribution analysis to demonstrate that sand dollars aggregated. One benefit of binomial distribution analysis (and Poisson) is that it can be measured with densities, which are collected in many studies. Density estimates are common for many reasons. First, they are a measurement that is easily scalable and easily compared with other studies. Second, densities are relatively simple to obtain compared with other measurements.

Unfortunately, with binomial distribution analysis (and Poisson), it is difficult to determine if distribution varies within the population (Sokal and Rohlf 1981, Krebs 1989). For this reason, the Clark and Evans’ (1954) nearest neighbor test is better. The nearest neighbor test uses distances between neighbors to calculate spatial distribution patterns. Benefits of this analysis are that measurements are density independent and significance can be determined for each sample (Clark and Evans 1954, Krebs 1989). Significance among samples can be determined using ANOVA to look at distribution variation within the population (Sokal and Rohlf 1981). This nearest neighbor method is typically used in terrestrial studies (Goodall 1952, Crisp, 1961, Krebs 1989, Whitney and Krebs 1975, Sinclair 1977). It has been used in small scale marine systems with barnacles, 1 cm² plot (Crisp 1961), the sea urchin Styllocidaris lineata, 20 m² sections of
larger transects (Young et al. 1992), polychaetes, 0.01 m² (Tokeshi 1995), and the sand dollar *Laganum depressum*, 1 m² plot (Saunders 1986).

The distribution of the sand dollars was measured using Clark and Evans’ (1954) nearest neighbor test (\(R = r_A r_E^{-1}\)) as shown in Krebs (1989). When necessary, the Donnely (1978) edge correction was used as shown in Krebs (1989). Potential values range from 0 to ~ 2.12. A value of 1 represents a random distribution. Values below 1 suggest aggregation while values above 1 suggest uniform or regular distributions. Z scores were used to demonstrate significant difference from random distribution. The null hypothesis was that the distribution of sand dollars within the individual plot did not differ significantly from random.

**Percent Organic Content**

Three samples of approximately 100g of sediment were collected from within the area for analysis of particle size distribution and organic content. Sediment samples were dried and sorted by size using a U.S. standard sieve series. Grains less than 105 µm were ashed to measure the percent organic content. Grains less than 105 µm are typically found in the gut of sand dollars. The grains in the gut of the sand dollar appear to be crushed; it is not known what the original size of those grains were (Hilber S, pers comm.). The food of the sand dollars (algae, diatoms, chitin) (Bell and Frey 1969, O’Neill 1978) are also less than 105 µm. Grains of less than 105 µm give the best indication of what sand dollars are known to consume and allow for greater sensitivity than ashing the entire sediment (Lane 1977). The percent organic content of these three samples was averaged to obtain a mean for the plot. To test if organic content varied between plots, the plots were compared using z-scores.
Correlation Analysis

Correlations between percent organic content and spatial distribution index were measured for all three sites each time the site was visited as well as pooled data when appropriate. The Spearman correlation was used as sample sizes were small and the data were not normally distributed. The null hypothesis was that there are no correlations between percent organic and nearest neighbor indices.

Sites

Captiva Island – Observational (March 18, 2005)

The site is located at 26.54°N 82.48°W (Fig. 1), approximately 20 km west of Captiva Island, Florida at a depth of 20m. *Encope michelini* was the predominant sand dollar found, but *Encope aberrans* was also found here. The two species are very similar in general morphology but differences in food grooves occur (Phelan 1972). As no attempt was made at determining species *in situ*, all sand dollars at this site will be referred to as *Encope*. Divers used a 3.1m cord to draw a 30m² circle in the sand at a random location (Fig. 2). The area encircled was then searched for sand dollars. If 7 sand dollars were not found (the minimum number required for analysis), another circle was drawn immediately adjacent to the previous circle. If 7 or more sand dollars were found, the distances between sand dollars were measured. A sand dollar was selected and the distance to other sand dollars was measured with only the shortest distance being recorded. This identified the nearest
Fig. 1 Location of study sites. White circle (see insert) designates Fort De Soto site (27° 37’ 22” N 82° 44’ 15” W). Black circle marks the Egmont Key site (26.58°N 82.83°W). The star marks the Captiva Island site (26.54°N 82.48°W)
neighbor of the first sand dollar. The nearest neighbor of each sand dollar within the circle was found, even if its nearest neighbor was outside the circle.

Egmont Key – Observational (March 19, and September 18, 2005)

The site is located at 26.58°N 82.83°W (Fig. 1), approximately 7 km west of Egmont Key, Florida at a depth of 6m. *Mellita tenuis* is the predominant sand dollar at this location. *Encope spp.* are present, but not abundant and did not occur in the study plots. In September, all sand dollars were dead. The individuals appeared to be recently dead as they were grey, not bleached and the tests were intact. They were buried under approximately one centimeter of sand and were not moved by the current. It is likely that they were in the same positions as when they died.

The procedure was identical to that at the Captiva Island site except that divers used a 0.75m cord to draw a 1.75m² area circle in the sand instead of a 3.1m cord (Fig. 2). The sizes of the study areas were determined from previous density measurements at the sites. The areas used were appropriate for finding 10 individuals based on the previous measurements (Lawrence JM, pers. comm.).

Fort De Soto, Mullet Key – Observational (May 21, and September 10, 2005)

The study site was at 27° 37’ 22” N 82° 44’ 15” W, about 75m off Mullet Key, Florida (Fig. 1). The study site was halfway between Fort De Soto and North Beach on the gulf side in about 1.5 m water, just inshore of a sand bar. *Mellita tenuis* is the predominate sand dollar at this location. Only one live *Encope michelini* was found during the three months of observation. No *Encope spp.* was in any study plots. The site was accessed by SCUBA using two teams of divers. A PVC 1m² quadrat was divided into 0.01m² squares (Fig. 4). The quadrat was laid on the sand and its corners were
marked with flagged stakes so that the same site could be revisited. Each 0.01m² square was checked for the presence of sand dollars. The location of each sand dollar was recorded. Three squares were randomly selected and an approximately 100g sediment sample was collected from each of those squares (Fig. 3). This process was repeated and 8 plots were observed before divers had to surface. There were two groups of four contiguous quadrats. The two groups were parallel to each other as well as the shore.

A few hours later, the 1m² plots were visited again and the location of sand dollars was recorded. Another 3 sediment samples were collected from 3 random squares. Squares from the previous observation were not excluded. Each plot was observed again for a total of 16 observations. The shallow depth of this site allowed divers to complete more observations in a more complete manner and also to revisit the same plots to allow temporal analysis.

Fort De Soto, Mullet Key - Experimental (July 10, 2005)
The same study site was used and the first set of observations was obtained in the same manner as in the May and September with the following exceptions. After sediment was collected, all sand dollars in the quadrat were collected. There were two groups of four quadrats along a transect line. The four quadrats were 5m from each other. The two groups were approximately 5m apart, parallel to each other and the shore.

After all 8 plots were observed, 0.1m³ of sand, enriched with 200g of crushed goldfish food flakes, was added and spread evenly on four plots, the first and last of each group (Fig. 5). Within each group of the four plots parallel to the shore, one plot had enriched sand and all of the sand dollars within that plot were piled in the center, one had
Fig. 2 Study design of Captiva Island site. A 3.1m line (cord) was used to draw a 30m² circle in the sand. The circle was searched for sand dollars and if found, nearest neighbor measurements were taken. Three sediment samples (black circles) were taken equidistant from each other. When completed, another 30m² was drawn adjacent to the first and the process repeated. The study design for the Egmont Key site was the same except a 0.75m line was used to draw a 1.5m² circle.

Fig. 3 Study design of Fort De Soto site. A plot was created using a 1 m² PVC quadrate divided into 100 squares (Fig 4). The location of sand dollars was mapped using the grid. Three Sediment samples were taken from each plot at randomly determine squares. Eight plots were laid out per dive and there were two dives per month for a total of 16 plots per month. The map of sand dollar locations was used to determine nearest neighbor measurements.
Fig. 4 PVC 1m² quadrat used at Fort De Soto site. The quadrat had a 10x10 grid of 0.01m² squares. The corners of each were marked with flagging tape to increase visibility.
Fig 5 Sediment enriched with fish food flakes at Fort De Soto, July 2005. Fish food is darker and greenish on the lighter sediment. Photo is approximately 30cm wide.

Fig 6 Experimental aggregation of *Mellita tenuis* at Fort De Soto, July 2005. Sand dollars are approximately 60 mm wide.
unaltered sand and all of the sand dollars within that plot were piled in the center (Fig. 6), one had enriched sand and no sand dollars, and the last plot had unaltered sand and had no sand dollars. Five hours later, the quadrats were visited again and the location of sand dollars was recorded. Another 3 sediment samples were collected from 3 random points in the quadrat.

Statistics

Density – Fort De Soto

Densities were collected at each plot and used to determine if density changed among months. A non-parametric ANOVA test was used because sample sizes were small (n = 16 per month, n = 3 for October). The Kruskal-Wallis test was used with a posteriori Mann-Whitney tests to differentiate between months. The null hypothesis was that the densities for the different months were not significantly different.

Distribution - Fort De Soto, Mullet Key

The distribution of the sand dollars was measured using Clark and Evans’ (1954) nearest neighbor test with the Donnely (1978) edge correction as shown in Krebs (1989). The edge correction was necessary because the location of the sand dollars was mapped onto a grid and the measurements were taken from the grid. Individuals were not recorded if they were outside of the quadrat.

For each month, the second eight observations were taken at the same location as the first eight observations. The Wilcoxon signed-rank test was used to test for differences between the first eight observations and the second eight observations. The null hypothesis was that there was no difference between the first eight observations and the second eight observations. To determine if the distribution varied by month, the
variance was tested using Kruskal-Wallis. The null hypothesis was that the distribution does not vary among months. A one-way ANOVA was desired, but the data were not normally distributed (Shapiro-Wilk W = 0.81 df = 47 p <0.0001, null hypothesis was that the data were normal). Because the data was not normally distributed, a non-parametric was used. A X² was used to test if the number of plots with aggregated distributions was significantly different a random population. Data from all three months were included (n = 48). The null hypothesis was that the number of aggregated plots for each month did not differ from 0.

***Percent Organic Content***

Captiva Island

Formaldehyde has the possibility to induce error into percent organic measurements. To test for error, six sediment samples were collected from Ft. De Soto. Three of the samples had five percent formaldehyde added while three were controls. They were ashed and a Wilcoxon signed-rank test was used to test for differences between the two groups.

Fort De Soto

The organic content of the sediment was manipulated in July. For that month, organic content of the four plots that had fish food flakes added were compared both before and after addition. A Wilcoxon Signed-rank test was used. The null hypothesis was that the fish food flakes did not cause a detectable difference in organic content. The months were compared using Kruskal-Wallis. The null hypothesis was that there was greater variance within the month than among the months. Mann-Whitney tests were used a posteriori to determine where the significant differences were.
Correlation

Correlations between percent organic content and distribution were measured for all three sites for each observation and for pooled data when appropriate. Spearman correlations were used as sample sizes were small and the data were not normal. The null hypothesis was that there were no correlations between percent organic content and nearest neighbor indices.
Results

Density - Fort De Soto

In May the density of *M. tenuis* was 16.19 ±4.89 individuals·m⁻². In July, it decreased to 12 ±3.85 individuals·m⁻². For September, the density increased to 20.25 ±6.56 individuals·m⁻². In October, the density was 18.33 ±3.21 individuals·m⁻².

The null hypothesis that there was no variance among months was rejected ($X^2 = 18.07$ df = 3 $p < 0.001$). There was more variance among groups than within groups.

The results of the Mann-Whitney tests are shown in Table 1. The density of July was always significantly different, though the density of other months did not show significant differences. Density in July was lower than in all other months.

Percent Organic Content

Captiva Island

Adding formaldehyde did not change the organic content of the sand ($X^2 = 0.049$ df = 1 $p > 0.824$) in March, 2005. The sediment had a mean percent organic content of 4.60 ±0.75. None of the plots had a significant z-score indicating that the sediment of the plots is not significantly different from the other plots. The sediment was homogenous with regards to percent organic content and grain size frequency (Fig. 7).

Egmont Key

In March 2005, the sediment had a mean percent organic content of 1.51 ±0.37. The sediment had a mean percent organic content of 1.13 ±0.06 in September. None of
Table 1 Density comparisons of *Mellita tenuis* at Fort De Soto, 2005. * denotes significant p values. All tests had df = 2. The density of July was significantly different from that of all other months.

<table>
<thead>
<tr>
<th>Months Compared</th>
<th>Mann-Whitney X²</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-July</td>
<td>7.4331</td>
<td>*0.0064</td>
</tr>
<tr>
<td>May-September</td>
<td>3.5827</td>
<td>0.0584</td>
</tr>
<tr>
<td>May-October</td>
<td>2.3188</td>
<td>0.1278</td>
</tr>
<tr>
<td>July-September</td>
<td>13.4216</td>
<td>*0.0002</td>
</tr>
<tr>
<td>July-October</td>
<td>5.3137</td>
<td>*0.0212</td>
</tr>
<tr>
<td>September-October</td>
<td>0.2019</td>
<td>0.6532</td>
</tr>
</tbody>
</table>

Fig 7 Variation in grain size frequency (%) distribution for all sites in 2005.
the plots had a significant z-score indicating that the sediment of the plots is not significantly different from the other plots within each month. The sediment was homogenous with regards to percent organic content.

The percent organic content in March was compared with that in September using a Kruskal-Wallis test. The sediment samples from the two months were significantly different ($X^2 = 4.5$ df = 1 $p = 0.034$). The sediment in March had a higher percent organic content than the sediment in September.

Fort De Soto

Descriptive statistics for each month are given in Table 2. Of the 48 different plots (16 per month · 3 months), only 1 (in September) had a significant z-score. In May, the mean percent organic content was 1.33 ±0.17. In July, the mean percent organic was 1.15150 (±0.13). In September, it was 0.93 ±0.11. In July, the plots that had the organic content manipulated did not show a significant difference ($T = 3$, df = 3 $p > 0.30$). The null hypothesis is accepted that adding fish food flakes did not have a discernable effect on percent organic content. The Kruskal-Wallis test showed a significant variance among months ($X^2 = 28.99$, df = 2 $p < 0.0001$). Post-hoc Mann-Whitney tests show that the percent organic content for each month is significantly different from each other month (Table 3). The sediment in May had the highest percent organic content while the sediment in September had the lowest percent organic content.
Table 2 Mean percent organic content of sediment at Fort De Soto by month, 2005. (n = 16)

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean percent organic content</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>1.33 ± 0.17</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>1.15 ± 0.13</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>0.93 ± 0.11</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Comparison of percent organic content of the sediment at Fort De Soto, 2005. * denotes significance. All tests had df = 2. All months had percent organic content of the sediment that was significantly different from each other month.

<table>
<thead>
<tr>
<th>Months Compared</th>
<th>Mann-Whitney X²</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>May – July</td>
<td>8.0984</td>
<td>* 0.0044</td>
</tr>
<tr>
<td>May – September</td>
<td>21.1420</td>
<td>* &lt; 0.0001</td>
</tr>
<tr>
<td>July – September</td>
<td>15.3636</td>
<td>* &lt; 0.0001</td>
</tr>
</tbody>
</table>

Table 4 Nearest neighbor indices (R) for Captiva Island and Egmont Key. ¹ denotes presence of *Encope spp.* ² denotes presence of *Mellita tenuis.* * denotes significant aggregation.

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>R</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captiva Island ¹</td>
<td>March 18, 2005</td>
<td>0.55</td>
<td>2.42</td>
<td>* &lt;0.05</td>
</tr>
<tr>
<td>Captiva Island ¹</td>
<td>March 18, 2005</td>
<td>1.07</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Captiva Island ¹</td>
<td>March 18, 2005</td>
<td>0.94</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>March 19, 2005</td>
<td>0.42</td>
<td>3.31</td>
<td>* &lt;0.01</td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>March 19, 2005</td>
<td>0.24</td>
<td>4.59</td>
<td>* &lt;0.01</td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>March 19, 2005</td>
<td>0.31</td>
<td>5.1</td>
<td>* &lt;0.01</td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>March 19, 2005</td>
<td>0.27</td>
<td>4.86</td>
<td>* &lt;0.01</td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>September 19, 2005</td>
<td>0.91</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>September 19, 2005</td>
<td>0.91</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Egmont Key ²</td>
<td>September 19, 2005</td>
<td>0.87</td>
<td>0.63</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 8 Nearest neighbor index (R) for Captiva Island site, March 2005. Distributions of *Encope spp.* were measured in three plots. * denotes significant aggregation at $\alpha = 0.05$. 

*
Distribution

Captiva Island and Egmont Key

At the Captiva Island site on March 18, 3 plots had sufficient numbers of *Encope* for distribution measurements. Of these three, one plot had an aggregated distribution of *Encope* (Fig 8, Table 4). On March 19 at Egmont Key, 4 plots of *M. tenuis* had sufficient numbers of sand dollars for distribution measurements (Fig. 9, Table 3). *Mellita tenuis* was significantly aggregated at the 0.01 level in all of these plots.

In September 18, 3 plots had sufficient numbers of *M. tenuis* for distribution measurements (Table 3). All sand dollars were dead. None of those plots had significant z-scores. The individuals were not aggregated.

There were significant differences between the distributions of each month at Egmont Key. Distributions in March had significantly lower R values than in September ($X^2 = 4.5$ df = 1 $p = 0.03$).

Fort De Soto

Aggregated distribution of *M. tenuis* occurred in 16 of the 48 plots. The percentage of plots with aggregated sand dollars varied with month (Fig. 10). In May, 37.5% (N = 16) of the plots had significantly aggregated sand dollars ($p < 0.05$). In July, 12.5% (N = 16) of plots had significantly aggregated sand dollars ($p < 0.05$). In September, 50% (N = 16) of the plots had significantly aggregated sand dollars and the sand dollars in one plot (6.25% of the plots) had a regular distribution ($p < 0.05$). The Kruskal-Wallis test indicates that there are no differences in distribution pattern between months ($X^2 2.84$ df = 2 $p = 0.24$). There is more variation of nearest neighbor indices within months than among months.
Fig. 9 Nearest neighbor index (R) for Egmont Key site grouped by month in 2005. Each bar represents one plot of 10 m². Only *Mellita tenuis* was evaluated at this site. * denotes significant aggregation at 0.01

Fig. 10 Spatial distribution frequency of *Mellita tenuis* at Fort De Soto
The nearest neighbor indices of the first observation of a month were compared with the second observation of the month. The Wilcoxon signed-rank tests indicate that there were no differences (May: \( T = 15 \), July: \( T = 12 \), September: \( T = 13 \), \( N \) for all months = 8 \( p > 0.10 \)). There are more plots with aggregated distributions than expected by chance (\( X^2 = 6.5 \) df = 2 \( p < 0.05 \)).

Since the sand dollars were manipulated before the second measurements in July, a Kruskal-Wallis non-parametric ANOVA was used to see if there were significant differences among the three months for the first observation only. The results indicate the differences are not significant (\( X^2 = 1.81 \), df = 2, \( p = 0.41 \)).

At the first observation in July, all eight plots contained randomly distributed sand dollars. At the second observation in July, two plots had aggregated individuals and six had randomly distributed individuals. Sand dollars in two of the eight plots changed distributions from the first to the second observation. Sand dollars in seven of the eight plots changed distributions from how they were placed experimentally. Of the four plots that contained experimentally aggregated individuals, only one contained an aggregated distribution five hours later. This plot did not have fish food added to the sediment. The other three contained random distributions. Of the plots from which sand dollars had been removed, one had aggregated individuals. That plot had fish food added to the sediment (Table 5).

*Correlation of Nearest Neighbor and Percent Organic Content*

Captiva Island

In March, there was not a significant correlation (\( r_s = -0.5 \), \( n = 3 \) \( p > 0.6667 \)) between nearest neighbor index (\( R \)) and percent organic content of the sediment.
Egmont Key

In March and September, there was not significant correlations ($r_s = -0.6$, $n = 4$, $p > 0.40$; $r_s = -0.5$, $n = 3$, $p > 0.67$) between nearest neighbor index ($R$) and percent organic content of the sediment. For both months at Egmont Key, a significant negative correlation ($r_s = -0.82$, $n = 7$, $p < 0.02$) is found (Fig 11). As percent organic content increases, the nearest neighbor index decreases.

Fort De Soto

The Spearman correlation tests failed to reject the null hypothesis for any observation (Table 6). The nearest neighbor index is not correlated with percent organic content for any month (Figs 12-14). When the observations from all three months were pooled, there was still not a significant correlation between nearest neighbor index and percent organic content ($r_s = -0.17$, $n = 48$, $p = 0.25$). There was not a significant relationship between percent organic content and nearest neighbor index at Fort De Soto.
Table 5 Distribution of plots for all sampling periods at Fort De Soto Park, 2005. Only *Mellita tenuis* was evaluated at this site. A = aggregated, R = random, U = regular or uniform. The same plots were visited in observation 1 and observation 2. For July, 1 indicates plots that had sand dollars experimentally aggregated, 2 indicates plots that had all sand dollars removed. 3 indicate plots that were enriched with fish food flakes.

<table>
<thead>
<tr>
<th>Plot #</th>
<th>May Obs 1</th>
<th>May Obs 2</th>
<th>Change</th>
<th>July Obs 1</th>
<th>July Obs 2</th>
<th>Change</th>
<th>Sept Obs 1</th>
<th>Sept Obs 2</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R</td>
<td>R</td>
<td></td>
<td>R</td>
<td>R</td>
<td>R^1,3</td>
<td>A</td>
<td>R</td>
<td>A - R</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>R</td>
<td>A - R</td>
<td>R</td>
<td>A</td>
<td>R - A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>A</td>
<td></td>
<td>R</td>
<td>R</td>
<td>R^2,3</td>
<td>A</td>
<td>R</td>
<td>A - R</td>
</tr>
<tr>
<td>4</td>
<td>R</td>
<td>A</td>
<td>R - A</td>
<td>R</td>
<td>R</td>
<td>R^2,3</td>
<td>A</td>
<td>R</td>
<td>A - R</td>
</tr>
<tr>
<td>5</td>
<td>R</td>
<td>R</td>
<td></td>
<td>R</td>
<td>R</td>
<td>R^1,3</td>
<td>U</td>
<td>R</td>
<td>U - R</td>
</tr>
<tr>
<td>6</td>
<td>A</td>
<td>A</td>
<td></td>
<td>R</td>
<td>R</td>
<td>R^2</td>
<td>R</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>R</td>
<td>R</td>
<td></td>
<td>R</td>
<td>R</td>
<td>R^1</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>R</td>
<td>R</td>
<td></td>
<td>R</td>
<td>A</td>
<td>A^2,3</td>
<td>R - A</td>
<td>R</td>
<td>A - A</td>
</tr>
</tbody>
</table>

Table 6 Correlation analysis of nearest neighbor index and percent organic content of the sediment for Fort De Soto, 2005. Only *Mellita tenuis* was evaluated at this site. Spearman Correlation ($r_s$) indicates that neither month has a significant correlation linking Nearest Neighbor index and percent organic content of the sediment.

<table>
<thead>
<tr>
<th>Month</th>
<th>$r_s$</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>-0.43529</td>
<td>0.092</td>
</tr>
<tr>
<td>July</td>
<td>-0.21176</td>
<td>0.4311</td>
</tr>
<tr>
<td>September</td>
<td>-0.37353</td>
<td>0.1541</td>
</tr>
</tbody>
</table>
Fig 11 Egmont Key correlation of nearest neighbor index (R) and percent organic content of the sediment in 2005. There is a significant negative correlation ($r_s = -0.82 \ p < 0.02$) between percent organic content and nearest neighbor index of *Mellita tenuis* for 2005. Trend line added with Microsoft Excel ($y = -0.7x + 1.7369$).
Fig. 12  Correlation analysis of nearest neighbor index (R) and percent organic content for *Mellita tenuis*, May 2005 at Fort De Soto. Relation between nearest neighbor index and percent organic content of the sediment. There is no significant correlation.

Fig. 13  Correlation analysis of nearest neighbor index (R) and percent organic content for *Mellita tenuis* for July 2005 at Fort De Soto. Relation between nearest neighbor index and percent organic content of the sediment. There is no significant correlation.
Fig. 14 Correlation analysis of nearest neighbor index (R) and percent organic content for *Mellita tenuis* for September 2005 at Fort De Soto. Relation between nearest neighbor index and percent organic content of the sediment. There is no significant correlation.
Discussion

Sand dollars have often been noted as having clumped distributions (Dexter 1977, Ebert and Dexter 1975, Pomory et al. 1995, Steimie 1990). This evidence is often anecdotal or applies to large scale descriptions using Poisson distribution measurements obtained from densities (Merrill and Hobson 1970, Lane and Lawrence 1980). The purpose of this study was to quantify the distribution of sand dollars at a small scale. The Clark and Evans’ (1954) nearest neighbor test allows measurements to be taken at the desired scale. It was hypothesized that sand dollars would have aggregated distributions and that the distributions would be correlated with percent organic content. One basis for these hypotheses is that the sediment is variable and that the sand dollars are capable of cueing on that variation. Since it had been noted that aggregations occur, it was believed that variation in percent organic content would be associated with variation in spatial distribution.

Percent Organic Content

Organic material (diatoms, algae, and chitin fragments) is typically found in the gut of sand dollars and is believed to be the primary food source (Bell and Frey 1969, O’Neill 1978). As with most habitats, areas occupied by sand dollars are not expected to be completely homogeneous. Microhabitats may have large influences on distribution (Scheibling 1982, Underwood et al. 1991). It was expected that variability in percent organic content of the sediment might cause variability in distribution as well. To test
this, it was important to ascertain if significant variation of percent organic content did exist in the sediment. It did not.

However, percent organic content may not be the best indicator of food stimuli. The percent organic content of the sediment typically ranged from 1% to 1.5% dry weight. Because the percentage is so low, it is difficult to discern differences that may exist in the sediment. This may also explain why enriching the sediment with fish food did not have a significant effect on percent organic content. Even though the fish food flakes were still visible in the sand during the second observation, the 200g of fish food would not have a great effect on 0.1m$^3$ of sand. If sand dollars are able to sense the presence of food sources as mentioned in Telford et al. (1985), then they must be able to detect small quantities of food in large amounts of nonnutritive sediment.

The fish food itself may not be an appropriate food source. While it does provide organic material, it may not provide the correct stimulus. Sea urchins aggregate around damaged algae (Dean et al. 1984, Vadas et al. 1986). The plant material itself was not the stimulus for the aggregation, but the chemical cues release by the damaged algae. Processed fish food may lack the chemical stimulus that attracts sand dollars or initiates feeding behaviors. A natural food source that might contain necessary chemical stimuli may provide different results.

Captiva Island and Egmont Key

The size of the study area at Captiva Island may not be appropriate determining fine differences in percent organic content. However, an area that large was necessary to locate enough *Encope* to perform the nearest neighbor test. In contrast to Captiva Island, the sediment was homogenous and there were no apparent depressions. Lane and
Lawrence (1980) hypothesized that depressions provided areas for particles to settle out of the water column and that sand dollars might aggregate in these areas.

Fort De Soto

For each month, the percent organic content did not vary significantly among the plots. Variation within the plots of each month was low suggesting that the mean percent organic content is representative of the entire plot. The sediment appeared homogenous. No obvious depressions were found and the sediment had the same frequency of particle sizes.

The surf was strong during all three sampling periods. The water was constantly moving and changing directions. Any organic source would likely be dispersed by the wave action. Visibility was low (1 m) during all months. The constant resuspension of fine particles into the water could homogenize the organic content of the area. Since only the smallest grain sizes were used to measure percent organic content, the fine particles in the water could prevent any localized collection of organic content.

Distribution and Correlation

This study of *M. tenuis* and *Encope spp.* examined populations of sand dollars at a small scale. Populations of *M. tenuis* were studied at 10m$^2$ (Egmont Key) and 1m$^2$ (Fort De Soto) while *Encope spp.* were studied 30m$^2$ (Captiva Island) scale. It was expected that aggregation distributions would be found that supported the observations of others (Dexter 1977, Ebert and Dexter 1975, Saunders 1986 Pomory et al. 1995, Steimie 1990).

Microhabitats may have large influences on distribution (Scheibling 1982, Underwood et al. 1991). This possibility was tested with correlation coefficients. Correlations do not establish that the treatment was the cause of the effect, but it can
allow conclusions and predictions. It was hypothesized that sand dollars would have aggregated distributions and that these distributions would be correlated with food availability. The more food present, the more aggregation should occur. If food was abundant, there would less intraspecific competition and more individuals could share an area close to each other. Because of how the nearest neighbor index (R) is calculated (aggregation having a low index and regular distributions have a high index), a negative correlation between nearest neighbor index (R) and percent organic content would support my hypothesis. A low R should be correlated with a high percent organic content.

Captiva Island

If aggregation is caused by a behavioral stimulus, the lack of aggregation would suggest that this stimulus is not present. While the percent organic content is high at Captiva Island, no plot had significantly higher content than the others. This lack of variation among may prevent aggregation. The sediment appeared uniform in other ways as well. The sediment was flat with no apparent dips or furrows except small ripples that would not have altered the hydrodynamics. The sediment had a uniform grain size. If aggregation requires variation in the substrate, then Captiva Island site is not a suitable study area for observing aggregated distributions. However, the site does not give evidence to refute the hypothesis. Randomly distributed individuals would be expected in areas with no heterogeneity in the sediment and Captiva Island provides this type of site.
Egmont Key

There were differences in distribution of *M. tenuis* between March and September. Individuals were aggregated in all four plots in March but were not aggregated in any of three plots in September. This study site provides a unique look at distribution not only because percent organic content was significantly different, but also because the characteristics of the population changed drastically from March to September.

In September, all individuals at the Egmont Key site were dead, possibly from a red tide outbreak in the area. They appeared to have died recently as the spines had been lost and the pigment was faded, but the tests were intact without epibionts. Dislocation of dead individuals could result only from currents. However, the sand dollars were buried about one centimeter below the surface of the sediment. There was a strong current during September, but the sand dollars were not moved by it. Sand dollars set on the surface did not move with the current, though the sand did begin to cover the sand dollars. It is likely that the individuals were in the same location as when they died. All three plots contained randomly distributed individuals.

As with Captiva Island, since there was no significant variation among plots within a month for percent organic content, there cannot be a significant correlation. When the two months are observed, though, a significant negative correlation exists between nearest neighbor indices and percent organic content. The mean percent organic content was higher in March and all the plots had aggregated distributions (low R values). In September, the mean percent organic content was lower and all of the plots had random distributions (mid-range R values). This suggests that the distribution of *M.*
*Mellita tenuis* is influenced by percent organic content. Since the percent organic content is a measure of food supply, it can be concluded that sand dollars tend to aggregate when food is abundantly available.

This does not completely support my hypothesis, however. Since there was no significant variation among plots of the same month, all plots had to be pooled. The conclusions refer to the population instead of the small-scale distribution of subsets within the population. For inferences to be made about the influence of percent organic content on small-scale distributions, not only does there need to be significant variation among plots for percent organic content, but also for distributions as well. Unless a correlation can be found within a single month, the conclusions are limited to the population scale.

Some caution does need to be used when looking at causes of the random distribution for the sand dollars during September. The sediment samples are indicative of the conditions at the time of the sampling and not at the time of death for the sand dollars. It is also possible that the stress placed on the sand dollars before death was sufficient to alter their behavior and therefore foraging for food may have been of less importance. It is possible that the percent organic content of the sediment could have changed after the sand dollars died.

Fort De Soto

*Mellita tenuis* aggregate. The number of plots in which *Mellita tenuis* were aggregated is greater than expected by chance. Distributions change, suggesting distribution is fluid. The lack of significant differences in R values between the first and
second observation each month suggests population distribution is not changing, but that the small-scale distribution of sand dollars is changing.

Why would the distribution change within a few hours? If sand dollars were consuming food, then the change in food availability may elicit a response. However, percent organic content did not significantly change. This indicates that food availability is not changing. The sand dollars were disturbed during the observation as they had to be uncovered to accurately record their position and measure distances between them. However, the response of the sand dollars to being uncovered was to rebury and stop moving. If they stopped moving, distribution would not change. If the sand dollars did move later as a response to the handling, a trend in movement should have been present as all sand dollars were disturbed in the same fashion. Yet, there is no pattern in the change of distributions. The behavior of the sand dollars may be more complex or the proper stimuli may not be evident at this time. In either case, the explanation for the change in distribution is not known.

The distributions that occurred in July are particularly interesting. During the first observation, all eight plots contained sand dollars with a random distribution. This is a major contrast to the distributions found in May and September. However, after experimental manipulation, seven of the eight plots had a change in distribution. The individuals in three plots changed from an experimentally aggregated distribution to a random distribution. The individuals in another three plots changed from an experimentally regular distribution to a random distribution. The individuals in the seventh plot changed from a regular distribution to an aggregated distribution.
This second observation allows consideration about stimuli affecting distribution. All of the plots that had sand dollars removed were recolonized after five hours. It is possible sand dollars moved into these areas because no other sand dollars were present. This could be accomplished through random movement. When sand dollars move, net movement should decrease when they come into contact with another sand dollar. This may not be a behavioral response but result from the fact that the sand dollar would have to alter direction and move around the contacted individual. If there are no sand dollars in the plot, there is less chance that something will impede movement. This lack of impediment could give the impression that sand dollars were dispersing into vacant areas as seen by this experiment.

A similar explanation could be given for the apparent dispersal from experimental aggregation of individuals in three other plots. The individuals could be moving randomly, but those moving in a direction away from the center would not have sand dollars impeding their movement and would appear to be dispersing. Unfortunately, only the beginning and end distributions are known.

There was not a correlation between percent organic content and nearest neighbor indices among months. Like Egmont Key, there were significant differences between percent organic contents for each month. However, there were not significant differences in nearest neighbor indices (R) among months. Without variation, a correlation cannot be calculated. Even when only the first observation of each month was examined, there were not significant differences in nearest neighbor indices (R) among months. This is interesting as none of the plots in July were non-random during the first observation. Despite that the number of aggregated distributions appears to change between months,
the underlying nearest neighbor indices (R) were variable enough that significant changes were not found.

Because of how the nearest neighbor index (R) is calculated (aggregation having a low index and regular distributions have a high index), a negative correlation between nearest neighbor index (R) and percent organic content would support my hypothesis. The lack of correlation does not necessarily give evidence against my hypothesis. The percent organic content was not significantly variable at most sites. Without significant variation, the correlation coefficient becomes statistically useless.

From an intuitive standpoint, the lack of variability in percent organic content can lead to random distributions. If the sediment is homogenous, then there is no benefit to being in one area versus another. There is no reason to move closer to another individual, as this would increase competition. However, avoiding other sand dollars would also limit feeding by making areas unsuitable solely because of their proximity to another sand dollar. It would also make it difficult for the sand dollar to feed because its mobility would be limited by other sand dollars and it would soon deplete its food supply. Random distributions reduce intraspecific competition from aggregations, but are less restricting in foraging than regular distributions. The majority of the plots contained individuals with a random distribution and it may be because the sediment was homogenous.
Conclusions

It was hypothesized that sand dollars (*Encope* spp. and *Mellita tenuis*) would have a non-random, aggregated distribution. This occurs only occasionally. However, it still more occurs more often than would be expected by chance, especially for *M. tenuis*. More data are needed to evaluate *Encope* spp. populations. *Mellita tenuis* appears to have aggregated distributions both at the population and small-scale level. Small scale distribution patterns change frequently.

It was also hypothesized that aggregation would be correlated with food content. In general, sand dollars did not aggregate based on percent organic content of the sand. Only at Egmont Key did *M. tenuis* show a significant negative correlation. Since *Mellita tenuis* were dead at Egmont Key during September, conclusions must be made with caution. The lack of variation in the percent organic content of the sediment may lead to random distributions.

It is possible that both species of sand dollars could alter their distributions in response to localized availability of food. On a larger time scale, percent organic content does not appear be a strong factor in determining distributions of *Mellita tenuis*. Percent organic content did change from month to month at Fort De Soto, but the distribution frequency of *M. tenuis* did not.
References Cited


Google Earth 3.0.0762 (2005) Google Inc. earth.google.com


Pier PM, Grant RE (1965) Echinoid distribution and habits, Key Largo Coral Reef Preserve, Florida. Smithsonian Miscellaneous Collections 149(6):54-55.


