BIOEROSION BY A SEA URCHIN, DIADEMA SETOSUM, IN A CORAL COMMUNITY AT KHANG KHAO ISLAND, INNER GULF OF THAILAND

NISIT RUENGSAWANG

A THESIS PRESENTED TO RAMKHAMHAENG UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE
(BIOLOGY)
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การกร่อนทางชีวภาพโดยเม่นทะเลชนิด *Diadema setosum* ในกลุ่มปะการังเกาะค้างคาว บริเวณอ่าวไทยตอนใน

นิสิต เรืองสว่าง

วิทยานิพนธ์เสนอต่อมหาวิทยาลัยรามคำแหง
เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญา
วิทยาศาสตรมหาบัณฑิตสาขาชีววิทยา
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Thesis Title	Bioerosion by a Sea Urchin, *Diadema setosum*, in a Coral Community at Khang Khao Island, Inner Gulf of Thailand	
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ABSTRACT

Thesis Title : Bioerosion by a Sea Urchin, *Diadema setosum*, in a Coral Community at Khang Khao Island, Inner Gulf of Thailand

Student's Name : Mr. Nisit Ruengsawang

Degree Sought : Master of Science

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Bioerosion caused by sea urchin is an important factor affecting coral reef growth and development. Although *Diadema setosum* is a dominant species in coral communities in the Inner Gulf of Thailand, there is no study on bioerosion by this sea urchin in coral communities in the Gulf of Thailand. The aims of the present study are to estimate bioerosion rates by *D. setosum* in coral communities at Khang Khao Island, Inner Gulf of Thailand by Acidification method and to examine distribution patterns and population changes of this sea urchin by using random quadrats in February, June and November 1998. The results show that distribution patterns and population densities of *D. setosum* during the study periods were in the same trend. The highest population density was found in the shallowest zone, followed by the coral zone and the deepest zone, respectively. Population densities were in the range of 0.4-11.8 individuals/m^2. Bioerosion rates were in the range of 0.34-1.43 g $CaCO_3$/individuals/day or 1.64-5.5 Kg $CaCO_3/m^2$/year. The highest bioerosion rates were found in the shallowest zones due to mainly high population density. The first severe coral bleaching event in the Gulf of Thailand during April-May 1998 was a factor resulted in increasing of population densities of *D. setosum* and consequently enhancing bioerosion rates during that period. In conclusion, bioerosion rates by *D. setosum* obtained from the present study were in the same range of those reported by previous workers from several localities.

บทคัดย่อ

ชื่อเรื่องวิทยานิพนธ์ : การกร่อนทางชีวภาพโดยเม่นทะเลชนิด *Diadema setosum* ในกลุ่มปะการังเกาะค้างคาว บริเวณอ่าวไทยตอนใน

ชื่อผู้เขียน : นายนิสิต เรืองสว่าง

ชื่อปริญญา : วิทยาศาสตรมหาบัณฑิต

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2. ผู้ช่วยศาสตราจารย์ ดร. สุทัศน์ สุบินประเสริฐ

การกร่อนทางชีวภาพโดยสาเหตุจากเม่นทะเลเป็นปัจจัยหนึ่งที่มีบทบาทสำคัญต่อกระบวนการสร้างและพัฒนาแนวปะการัง เม่นทะเลชนิด *Diadema setosum* เป็นสิ่งมีชีวิตชนิดเด่นที่สามารถพบได้ทั่วไปในกลุ่มปะการังบริเวณอ่าวไทยตอนใน แต่ไม่มีข้อมูลการศึกษาถึงผลกระทบของเม่นทะเลชนิดนี้ต่อกลุ่มปะการังในอ่าวไทย การศึกษานี้มีวัตถุประสงค์เพื่อวิเคราะห์อัตราการกร่อนทางชีวภาพโดยเม่นทะเล *D. setosum* ของกลุ่มปะการังเกาะค้างคาว บริเวณอ่าวไทยตอนใน โดยใช้วิธี Acidification method ตลอดจนศึกษารูปแบบการแพร่กระจายและการเปลี่ยนแปลงประชากรของเม่นทะเล *D. setosum* โดยใช้วิธีการสุ่ม quadrat ในช่วงเดือนกุมภาพันธ์ มิถุนายน และพฤศจิกายน 2541

ผลการศึกษาพบว่ารูปแบบการแพร่กระจายและความหนาแน่นของเม่นทะเล *D. setosum* ตลอดช่วงระยะเวลาที่ศึกษามีแนวโน้มที่เหมือนกัน โดยในบริเวณเขตที่ตื้นจะพบเม่นทะเล *D. setosum* แพร่กระจายอยู่หนาแน่นกว่าบริเวณเขตปะการังและเขตที่ลึกตามลำดับ โดยมีค่าอยู่ในช่วงระหว่าง 0.4-11.8 ตัว/ตารางเมตร อัตราการกร่อนของปะการังตลอดช่วงระยะเวลาที่ศึกษามีค่าอยู่ในช่วงระหว่าง 0.34-1.43 กรัมหินปูน/ตัว/วัน ซึ่งเมื่อคำนวณหาอัตราการกร่อนต่อพื้นที่พบว่ามีค่าอยู่ในช่วงระหว่าง 1.64-5.5 กิโลกรัม

หินปูน/ตารางเมตร/ปี บริเวณเขตที่ตื้นจะมีอัตราการกร่อนมากที่สุดโดยมีความหนาแน่นของเม่นทะเลเป็นปัจจัยที่สำคัญ

ปรากฏการณ์ปะการังฟอกขาวที่เกิดขึ้นอย่างรุนแรงเป็นครั้งแรกในอ่าวไทย ในช่วงเดือนเมษายน-พฤษภาคม 2541 เป็นปัจจัยหนึ่งที่มีผลต่อการเพิ่มขึ้นของประชากรเม่นทะเล *D. setosum* และเป็นเหตุให้อัตราการกร่อนทางชีวภาพของปะการังในช่วงเวลาดังกล่าวมีค่าสูง ผลการศึกษาในครั้งนี้สรุปว่าอัตราการกร่อนทางชีวภาพโดยเม่นทะเลชนิด *D. setosum* มีค่าอยู่ในระดับเดียวกันกับผลการศึกษาที่ผ่านมาในหลายบริเวณของโลก

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Nisit Ruengsawang

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CHAPTER 1

INTRODUCTION

Coral reefs are among the most biologically important ecosystems on our planet and one of the excellent resources for human especially the fisheries. Unfortunately, the natural disturbances and the effects of human activities have been affecting coral reefs at different levels which were depending on the intensity, space and timing of the event. The agents of coral reef destruction are biological, physical and chemical which are intimately related (Hutchings 1986, 239). The roles of biological destruction on coral reefs were recognized and were reported to be very important in coral reef ecosystem. Many of the organisms in coral reefs can encourage reef growth and destroy reef framework. Therefore, the results of interactions between construction and destruction of coral reefs can decide the fate of the reef structure (Glynn 1988, 153; Bak 1990, 267).

The various activities of the reef organisms that cause coral and coralline algal erosion are collectively termed bioerosion (Neumann 1966, 92). Several workers clearly show that bioerosion is one of the important factors controlling reef growth (Hein and Risk 1975, 134; Hudson 1977, 495; MacGeachy 1977, 481; Glynn et al. 1979, 47; Scoffin et al. 1980, 504; Risk et al. 1995, 79; Bruggemann et al. 1996, 59; Mokady et al. 1996, 367). Bioeroders, a variety of organisms that erode and weaken the calcareous skeletons of reef-building species, always encounter in coral reef ecosystem such as sea urchins, fishes, polychaetes, bivalves, sponges, etc. which can be classified as external and internal bioeroders depending on their location on calcareous substrata (Glynn 1997, 69).

Sea urchins graze on attached plants, encrusting organisms, sessile organisms and detritus but in some areas they also attack live corals (Glynn et al. 1979, 47; Bak 1994, 99). The hardness of sea urchin's jaw apparatus, Aristotle's lantern, is an efficient tool for grazing, biting and scarping that is a major factor in the success of echinoid in feeding on such a variety of material, taking advantage of whatever is available (Birkeland 1989, 28). Several species in the following genera graze large amount of reef rock while feeding and excavating burrows: *Diadema, Echinometra, Echinothrix, Echinostrephas* and *Eucidaris*. The results from previous studies of biological destruction of reefs obviously show that bioerosion by sea urchin is very important on hard reef substrata (Hunter 1977, 108; Scoffin et al. 1980, 504; Trudgill et al. 1987, 97; Glynn 1988, 130; Bak 1990, 271; Mokady et al. 1996, 372).

In the Inner Gulf of Thailand, black long-spined sea urchin, *Diadema setosum* is a common and conspicuous echinoid in coral communities. However, the effects of this sea urchin on coral community have not been reported. The coral communities at Khang Khao Island have always been subjects to experimentation and investigation by many researchers more than decade (Kamura and Choonhabandit 1986, 175-193; Sakai et al. 1986, 27-74; Tsuchiya et al. 1986, 75-96; Yamazato and Yeemin 1986, 163-174; Moordee 1987; Ruengsawang and Yeemin 1998, 215-220). The results revealed that *D. setosum* is a dominant echinoid species throughout over decade in this area and can effect benthic community structure and the processes of coral reef development. Therefore, the present study concentrates on the bioerosion by *D. setosum*, one of factors controlling reefs development, in coral communities at Khang Khao Island, Chonburi Province.

Objectives

The major objectives of this study are as the following:

1. To quantify bioerosion rates by a sea urchin, *Diadema setosum*, on coral communities of Khang Khao Island, in the Inner Gulf of Thailand.

2. To investigate distribution patterns and population changes of a sea urchin, *D. setosum*.

3. To apply the finding as fundamental data for management of living resources in coral communities.

Hypothesis

D. setosum affects to the process of coral reef development at Khang Khao Island, in the Inner Gulf of Thailand due to the high bioerosion rate when compared with the previous reports on bioerosion rates in other areas of the world.

Scope of Research

This research concentrates on the bioerosion rates by a sea urchin, *D. setosum*, on coral communities at Khang Khao Island, in the Inner Gulf of Thailand. In addition, distribution patterns and population changes of this urchin that is the dominant species in coral communities in the Gulf of Thailand were also determined.

CHAPTER 2

LITERATURE REVIEW

The coral reef structure is the results of the interaction between reef growth and reef destruction. The agents of reef destruction are biological, physical and chemical that are intimately related. Biological agents of reef destruction normally weaken the substrate and make it vulnerable to physical and chemical erosions. Similarly, damages caused by physical or chemical erosions encourage bioerosion (Hutchings 1986, 239; 1983, 113).

The activities of many organisms associated with coral reefs that caused coral and coralline algal erosion are collectively termed bioerosion (Neumann 1966, 92). During the past three decades, bioerosion has been recognized as one of the important factors and processes controlling reef growth and reef development (Bak 1994, 99; Glynn 1997, 68; Sammarco 1996, 144). Bioeroders, organisms that graze, scrape, bore, or otherwise excavate into calcareous substrate to either access prey or create a dwelling, can be divided into external and internal bioeroders which are normally associated with coral reefs. External bioeroders are usually present and visible on reef substrate such as sea urchins, fishes, chitons, limpets, and hermit crabs. Internal bioeroders are organisms which live within calcareous skeletons such as algae, sponges, bivalves, sipunculans, and polychaetes (Glynn 1997, 69; Wood 1999, 259). Bioeroders break down reef substrate in a variety of processes that can be classified as grazing, boring, and etching (Hutchings 1986, 239).

Previous studies have been recognized that sea urchins are the major grazer and the important bioeroder in coral reef ecosystem (Hunter 1977, 106; Sammarco 1980, 246; Scoffin et al. 1980, 494; Glynn 1988, 130; Bak 1990, 267; Mokady et al. 1996, 367). Grazing by sea urchin affects the distribution, abundance and species composition of marine invertebrates as well as marine plants (Benayahu and Loya 1977, 388; Glynn et al. 1979, 47; 1990, 365; Hatcher 1983, 169; Mukai and Nojima 1985, 185; Sammarco 1985, 392; Liddell and Ohlhorst 1986, 271; Andrew and Underwood 1993, 89; Coyer et al. 1993. 35; Benedetti-Cecchi and Cinelli 1995, 203). They graze live or dead coral substrata, encrusting coralline algae, filamentous or tufted algae growing on reef substrate for available food.

Sea urchins that are commonly reported as important species in bioerosion are *Diadema antillarum*, *D. setosum*, *D. savignyi*, *Echinometra lucauter*, *E. mathaei*, *Eucidaris thouarsii*, *Echinotrix calamaris*, *E. diadema* and *Echinostrephus molaris* (Hunter 1977, 108; Stearn and Scoffin 1977, 475; Glynn et al. 1979, 48; 1988, 131; Russo 1980, 100; Scoffin et al. 1980, 494; Bak 1990, 271; Mokady et al. 1996, 367). Reported bioerosion rates by sea urchin are in the ranges of 3-9 kg $CaCO_3.m^{-2}.y^{-1}$ depending on population density, species and intensity of grazing (Mokady et al. 1996, 367). Many authors have used different methods for estimating bioerosion rates such as acidification of total gut contents (weight difference) (Stearn and Scoffin 1977, 475; Scoffin et al. 1980, 495), ash-free dry weight of total gut content (Bak 1990, 269) and acidification of excreted fecal pellets (CO_2 pressure measurement) (Mokady et al. 1996, 368).

Several investigators concluded that many factors implicate the controlling of sea urchin population. Predation is frequently reported as the important factor controlling density of sea urchins. McClanahan and Muthiga (1989, 91) described the difference in predation rates between heavily fished and unfished reefs. Clearly, fishing pressure leads to a reduction in predations which allow *Echinometra mathaei* to increase its density. After the 1982-1983 El Nino event, Glynn (1988, 135) reported that populations of *Diadema maxicanum* in Panama increased dramatically from 3 individuals.m^{-2} before 1983 to 80 individuals.m^{-2} due to high recruitment. Similarly, population densities of *Eucidaris thouarsii* in the Galapagos Island increased from 5 to 30 individuals.m^{-2} from before to after 1983 due to redistribution. However, larval supply, disease related mass mortality, post-metamorphic survivorship and food abundance have also implicated in controlling sea urchin population (Heck and Valentine 1995, 206).

Glynn (1997, 85) classified the bioerosion increasing under a variety of circumstance according to conditions causing coral tissue death and conditions that provide a growth advantage to bioeroder compare with calcifying species's population. In general, any condition that causes coral tissue death will enhance probability of invasion by grazers and borers. Therefore, any natural or anthropogenic disturbance that causes the loss of live coral tissue will ultimately increase the risk of bioeroder invasion and higher rates on limestone loss.

Diadema setosum, a black long-spined sea urchin, is the widespread and conspicuous echinoid in the tropical region. Tsuchiya et al. (1986, 88) studied on distribution of subtidal macrobenthic animals around Khang Khao and Thai Ta Mun Islands. They found that *D. setosum* was extremely abundant and may play an important role in organization process of the subtidal community. Ruengsawang and Yeemin (1998, 215) resurveyed the distribution and abundance of *D. setosum* in coral communities of Khan Khao Island and concluded that *D. setosum* is a dominant species in this area throughout thirteen years. The high densities of *D. setosum* may affect benthic communities, and construction and development of coral reefs by the grazing process.

A case study of bioerosion in Thailand, Moordee (1987) studied bioerosion on *Porites lutea* by some infaunal animals at Ko Khang Khao, Chon Buri Province. The results show that the most important bioeroders on *P. lutea* in the shallow zone were the polychaetes while in the deep zone were the bivalves. However, the bioerosion on coral blocks were mostly affected by both polychaetes and sipunculids. In addition, the boring destruction efficiency was found to be depend on several factors such as density of borers, certain environmental factors enhancing survival rate of the coral borers, succession of various groups of borers and the spawning season of the borers.

The knowledge of the role of sea urchins on coral reef ecosystems is well known but only few available data concerning bioerosion processes on coral communities in Thailand have been reported. Therefore, the study on bioerosion by *D. setosum* in coral communities at Khang Khao Island is one of the fundamental subjects of coral reef development and management in Thailand.

The Study Site

Khang Khao Island is located in the Inner Gulf of Thailand (latitude 13° $06'$ $24''$N to 13° $07'$ $0''$N and longitude 100° $48'$ $45''$E to 100° $49'$ $0''$ E) which is one of the small islands around Sichang Island. This island is approximately 60 and 40 kilometers from the Chao Phraya and Bang Pakong river-mount, respectively, so this area is effected by the runoff during rainy season and its shape is roughly triangular with about 1 km. long and 0.7 km. width. Coral communities are always found around this island and the massive coral, *Porites lutea*, is the most dominant species. Distribution and abundance of hermatypic corals and macrobenthic animals have been described by Sakai et al. (1986, 32-60) and Tsuchiya et al. (1986, 77-84), respectively. For this study, three stations of Khang Khao Island were selected to solve the major objectives (Figure 1). All stations are influenced by the differentiation of monsoon. Station N is on the north coast of the island which is directly effected by Northeast monsoon during October - February. Station E is on the east coast of the island which is effected by Southwest monsoon during May - September and Southeast monsoon or Southeast trade during February - April. Station W is on the west coast of the island which is also effected by Southwest monsoon. The station descriptions are as following;

Station N: divided into 3 zones as;

N-S the shallowest zone

N-C the coral zone

N-D the deepest zone

Station E: divided into 3 zones as;

E-S the shallowest zone

E-C the coral zone

E-D the deepest zone

Station W: divided into 2 zones as;

W-S the shallowest zone

W-D the deepest zone

In the case of station W, only two zones were recognized because the coral zone was narrow and overlapped with the shallowest zone.

Field Experiments

Measurement of Environmental Factors

1. Temperature

Seawater temperature was detected in each station during February, June, and November 1998 by using a thermometer at a few centimeters below the seawater surface.

2. Salinity

Water sample at a few centimeters below the seawater surface in each station was measured salinity by using a refractometer during February, June, and November 1998.

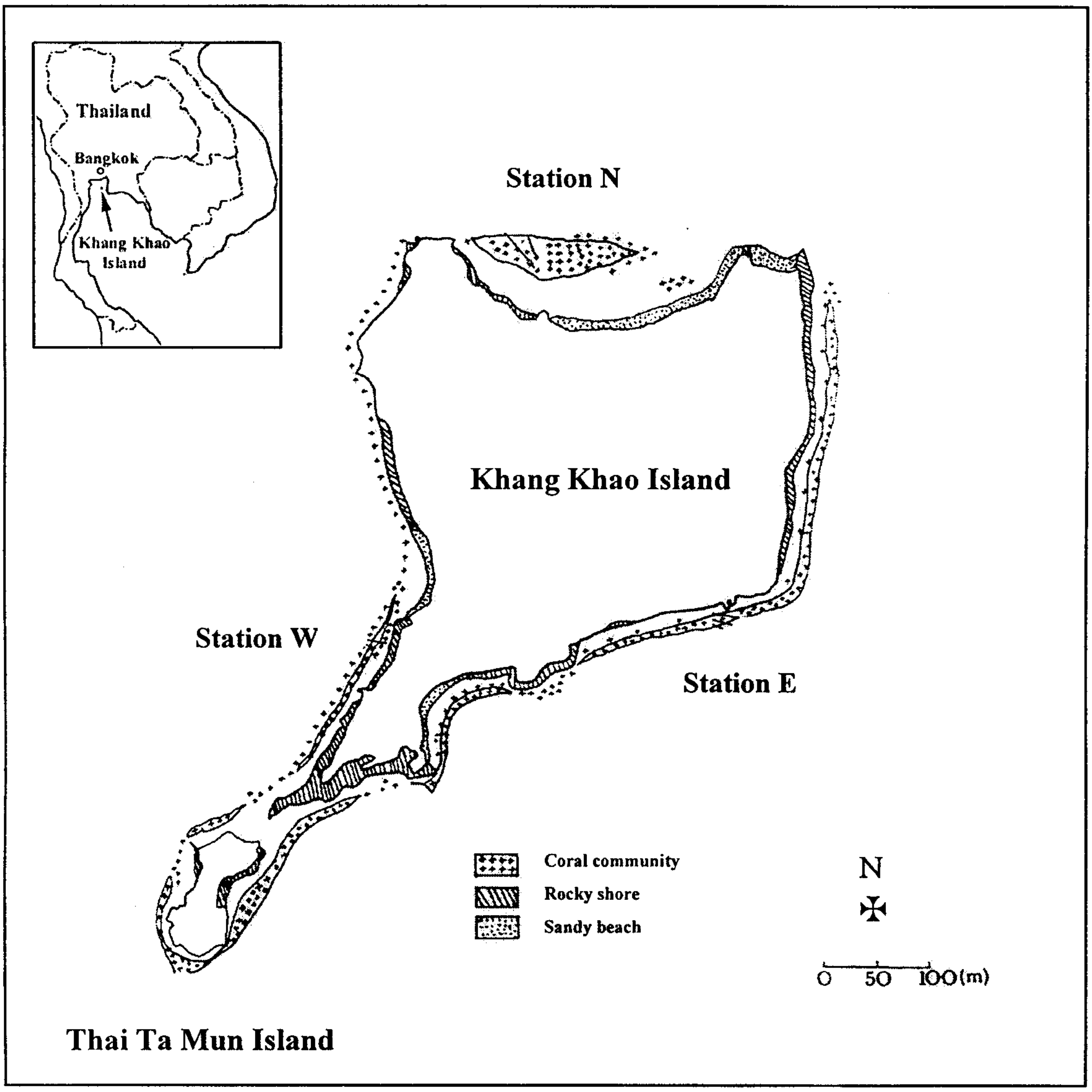


Figure 1 Map of Khang Khao Island Showing the Study Sites

Population Density

Population densities of *D. setosum* on coral communities of Khang Khao Island were determined in February, June, and November 1998. Thirty random 1x1 m quadrats were thoroughly searched in each station and the number of *D. setosum* in these quadrats were recorded (Figure 2, 3). The finding is used to assess density fluctuations of *D. setosum* in space and time during the present study.

Size-Class Frequency Distribution

Size distributions of *D. setosum* were performed in February, June, and November 1998 at 3 stations (N, E and W) of coral communities at Khang Khao Island. In each station, certain individuals of *D. setosum* were randomly collected by SCUBA diving during daylight. Sea urchin samples were preserved in 10% formalin with seawater and transferred to the laboratory. For size-class analyses, test diameter without spines of all samples were measured with vernier calipers to the nearest millimeters (Figure 4). Finally, size-class histograms were constructed to compare the differentiation of size distribution of *D. setosum* in space and time.

Estimation of the Bioerosion Rates

After size distribution analysis, all samples of *D. setosum* were used to assess the quantity of $CaCO_3$ in gut contents. First, physical parameters of samples were measured, i.e., diameter and height of test and Aristotle's lantern by vernier calipers to the nearest millimeter. Body and gonad wet weights were also determined by analytical balance. Then samples were dissected and removed the whole of fecal pellets and gut content (Figure 5, 6). After dissection, fecal pellets and gut content were inspected and urchin spine was removed (Figure 7).

To estimate the bioerosion rates, I pre-weighed a dry clean ceramic crucible and added the sample in the crucible. Then I determine the weight of the crucible and the sample to the nearest milligram by using an analytical balance and oven dry at $105^{o}C$ for 24 hours (until the sample no longer lose weight). Tongs were used for removing the crucible from the oven and placed it in a desiccator containing silica gels, and allowed the sample and crucible to cool at room temperature and weighed.

Then I placed the crucible in a muffle furnace at $550^{o}C$ for 5 hours to destroy the organic matter (If black charcoal deposits are still visible, then continue ashing). The temperature did not exceed $550^{o}C$ because the $CaCO_3$ would be converted to CaO_2, thus resulting in a biased ash-free dry weight. After the furnace has been allowed to cool for several hours, I remove the crucible containing the ashed samples and cooled them at room temperature in a desiccator and then weighed (Wa).

As the refractory complex organic compounds are not destroyed, $CaCO_3$ in the sample was estimated by acidification method. Hydrochloric acid (HCl) was used as the chemical agent to digest the $CaCO_3$. The ashed sample in crucible was mixed with 20 ml. of 20% HCl, the result of this reaction created CO_2 gas (to test the complete reaction, see the bubble gases if it disappeared, it has been completely reacted). Then the solution was carefully removed and the remaining was dried, and weighed (Wc). The amount of total $CaCO_3$ in sample was calculated as the difference between the weight of the crucible with ash (Wa) and the weight of the crucible and the remaining after acid digestion (Wc):

$$\text{Weight of the total } CaCO_3 \text{ in sample} = Wa - Wc$$

Finally, the finding data were used to test the relationships between the physical parameters by correlation analysis.

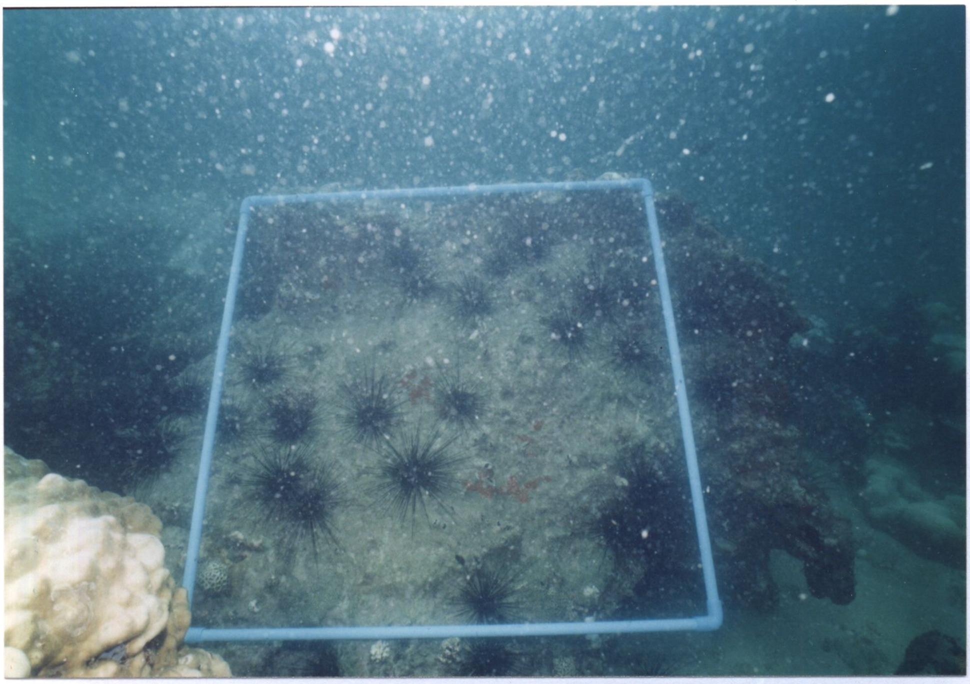


Figure 2 Random Quadrat was Used to Determine the Population Density of *D. setosum*.

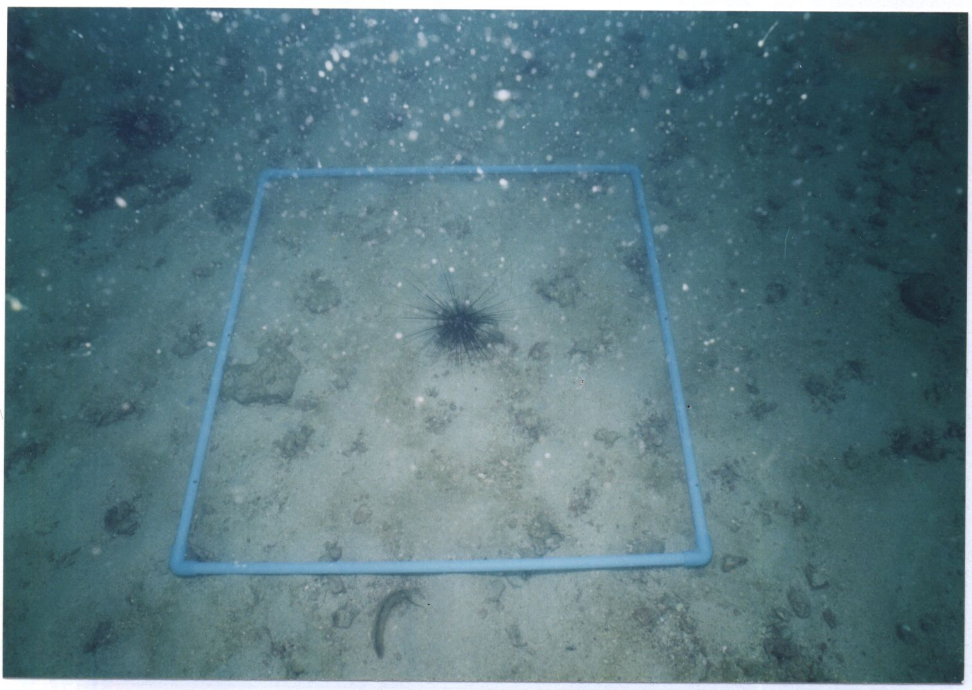


Figure 3 Random Quadrat in the Deepest Zone of Station E.

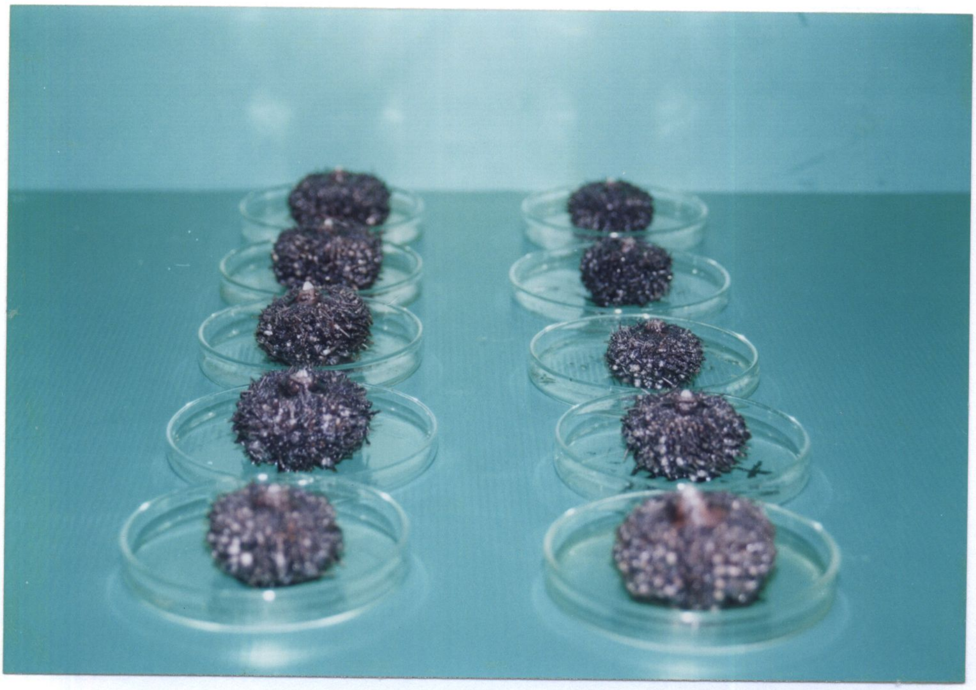


Figure 4 Test Diameter of Sea Urchins were Measured with Vernier Calipers to the Nearest Millimeters.

Figure 5 Sea Urchin Sample was Dissected and Removed the Whole of Fecal Pellets and Gut Content.

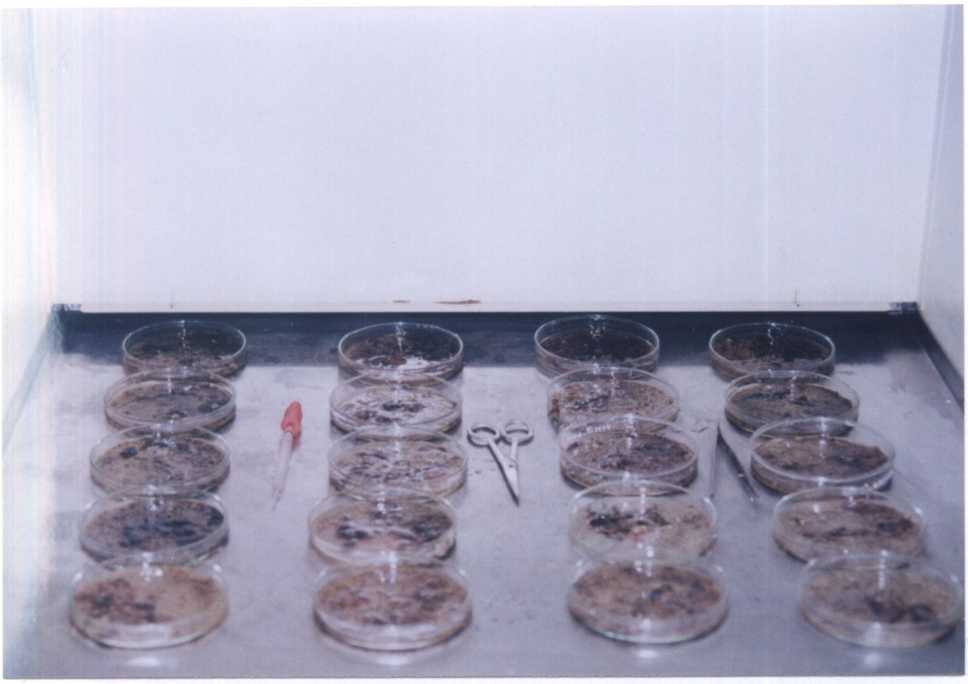


Figure 6 After Dissection, Each Sample was Placed in the Dish with Label.

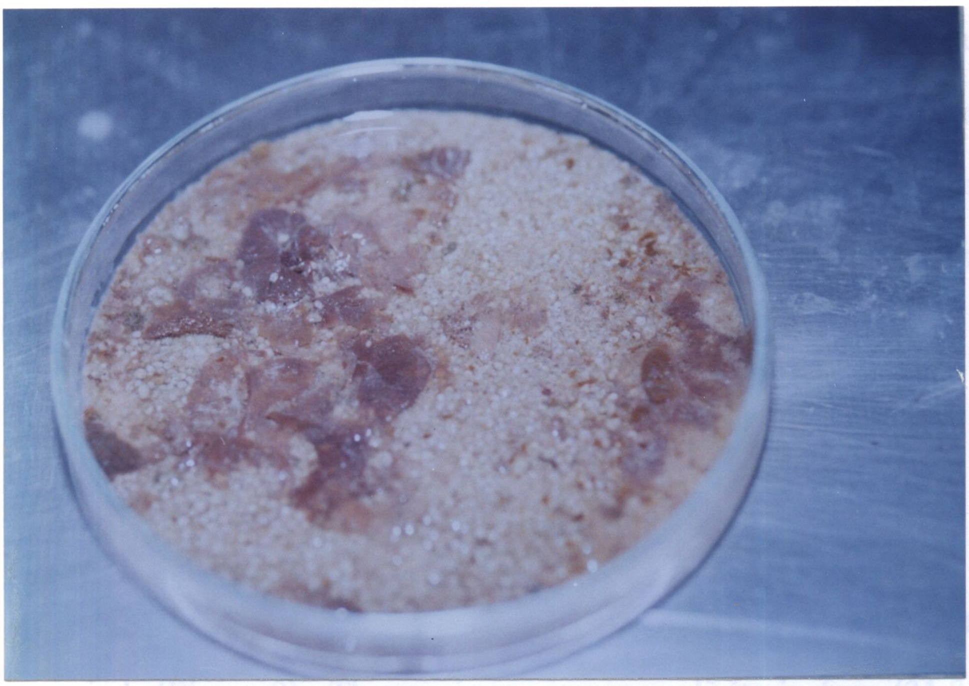


Figure 7 Fecal Pellets and Gut Content were Inspected and Urchin Spines were Removed. Then the Sample was Quantified Amount of $CaCO_3$ by Acidification Methods.

CHAPTER 3

RESULTS

Environmental Factors

Temperature

The results in Figure 8 show that the seawater temperature was slightly difference in each station . However, the average temperature in June 1998 ($30.33^{\circ}C$) was higher than other periods due to during the summer. Moreover, the first severe event of occurrence of coral bleaching in the Gulf of Thailand in April-May, 1998 was clearly showed that the temperature was increased. The data are corresponding with the NOAA (National Oceanic and Atmospheric Administration) report (Figure 10, 11).

Salinity

The salinity was also slightly difference in each station during the study periods (Figure 9). The maximum average salinity in June (31.83 ppt.) was likely due to the high temperature than other periods.

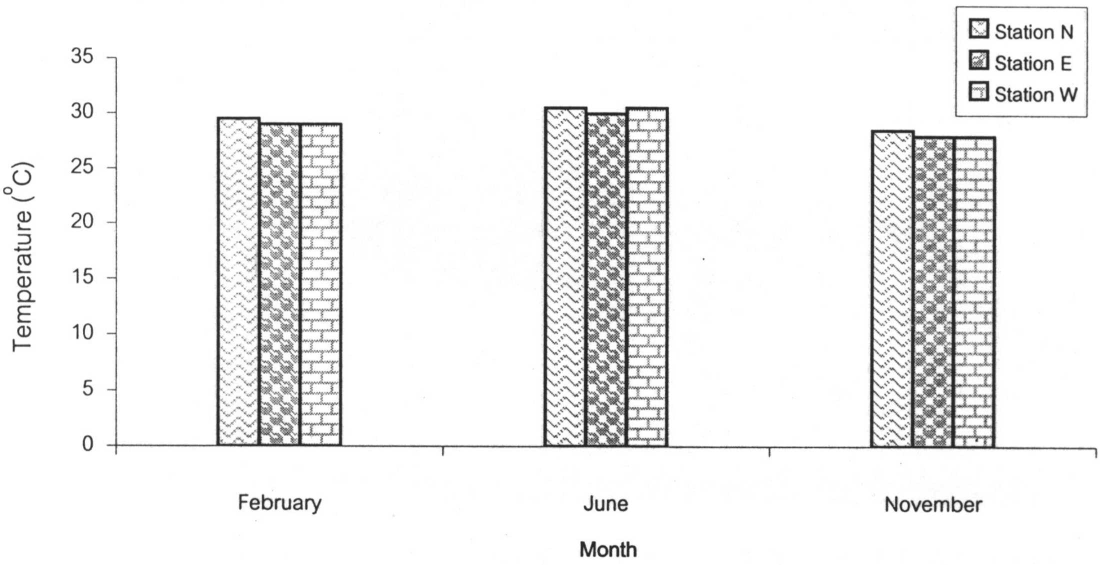


Figure 8 Seawater Temperature in February, June, and November, 1998

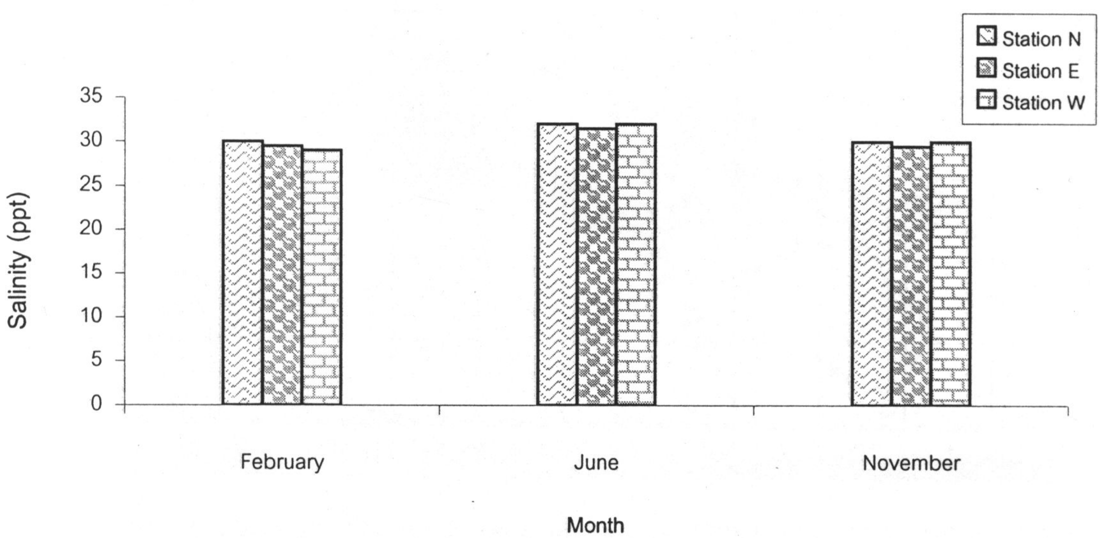


Figure 9 Salinity of Seawater in February, June, and November, 1998

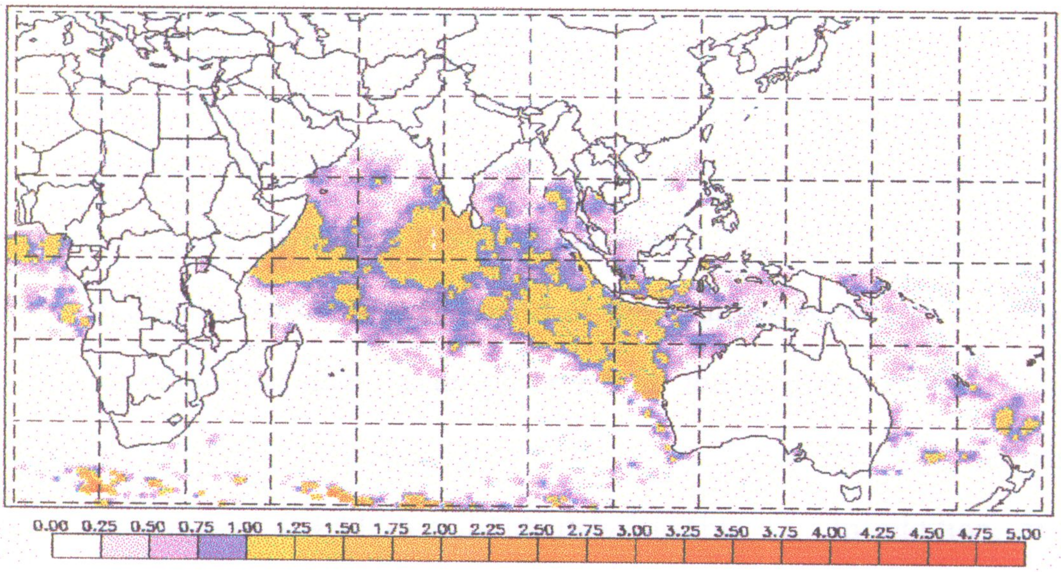


Figure 10 Report of Seawater Surface Temperature in April, 1998 from NOAA (A Color Table is the Degree of Temperature (^{o}C) that Exceed the Maximum Monthly Climatology in Each Region.)

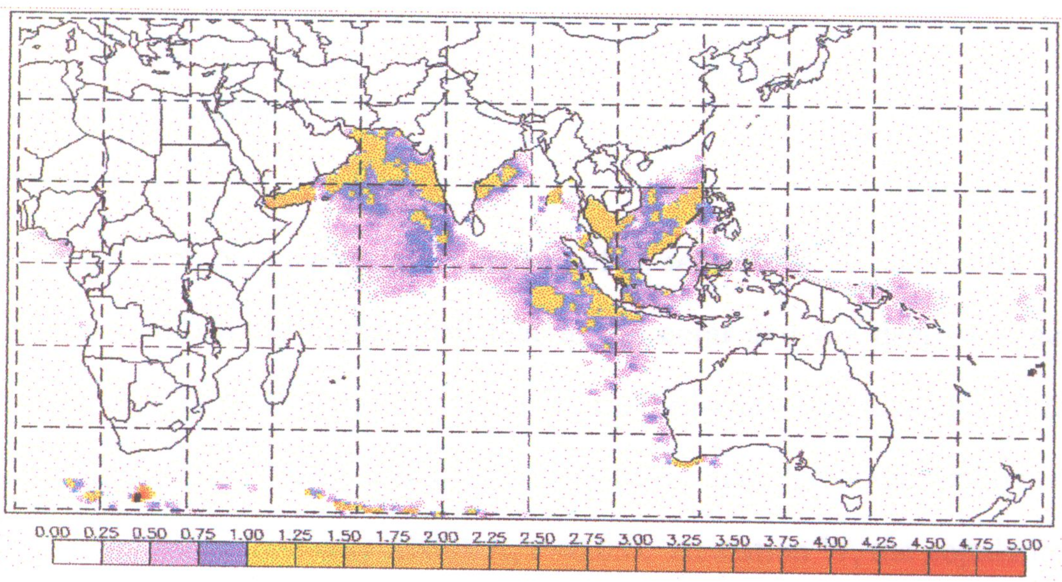


Figure 11 Report of Seawater Surface Temperature in May, 1998 from NOAA (A Color Table is the Degree of Temperature (^{o}C) that Exceed the Maximum Monthly Climatology in Each Region.)

Distribution Pattern and Population Density

Distribution patterns of *Diadema setosum* at station N, E and W in February, June and November, 1998 were in similar trends (Figure 12). The highest population densities were found at the shallowest zones while the lowest population densities were observed at the deepest zones. The population densities of *D. setosum* in all study sites during the study periods were in the range of 0.4-11.76 individuals/m^2 (Table 1). In addition, two species of sea urchins, *Temnopleurus toreumaticus* and *Toxopneustes pileolus*, were also found especially at the deepest zones but in low densities.

Spatial and Temporal Changes in Population Density

February 1998

At station N, the population density of *D. setosum* in the shallowest zone was significantly higher than that in the coral and the deepest zones (one-way ANOVA, $P<0.05$). At station E, the population density of *D. setosum* in the deepest zone was significantly lower than that in the shallowest and the coral zones (one-way ANOVA, $P<0.05$). At station W, the population density of *D. setosum* in the shallowest zone was significantly higher than that in the deepest zone. Population densities of *D. setosum* in the shallowest zones of all studied stations were not different (one-way ANOVA, $P>0.05$). However, the population density of *D. setosum* in the deepest zone of station E was significantly lower than that of station N and W (one-way ANOVA,

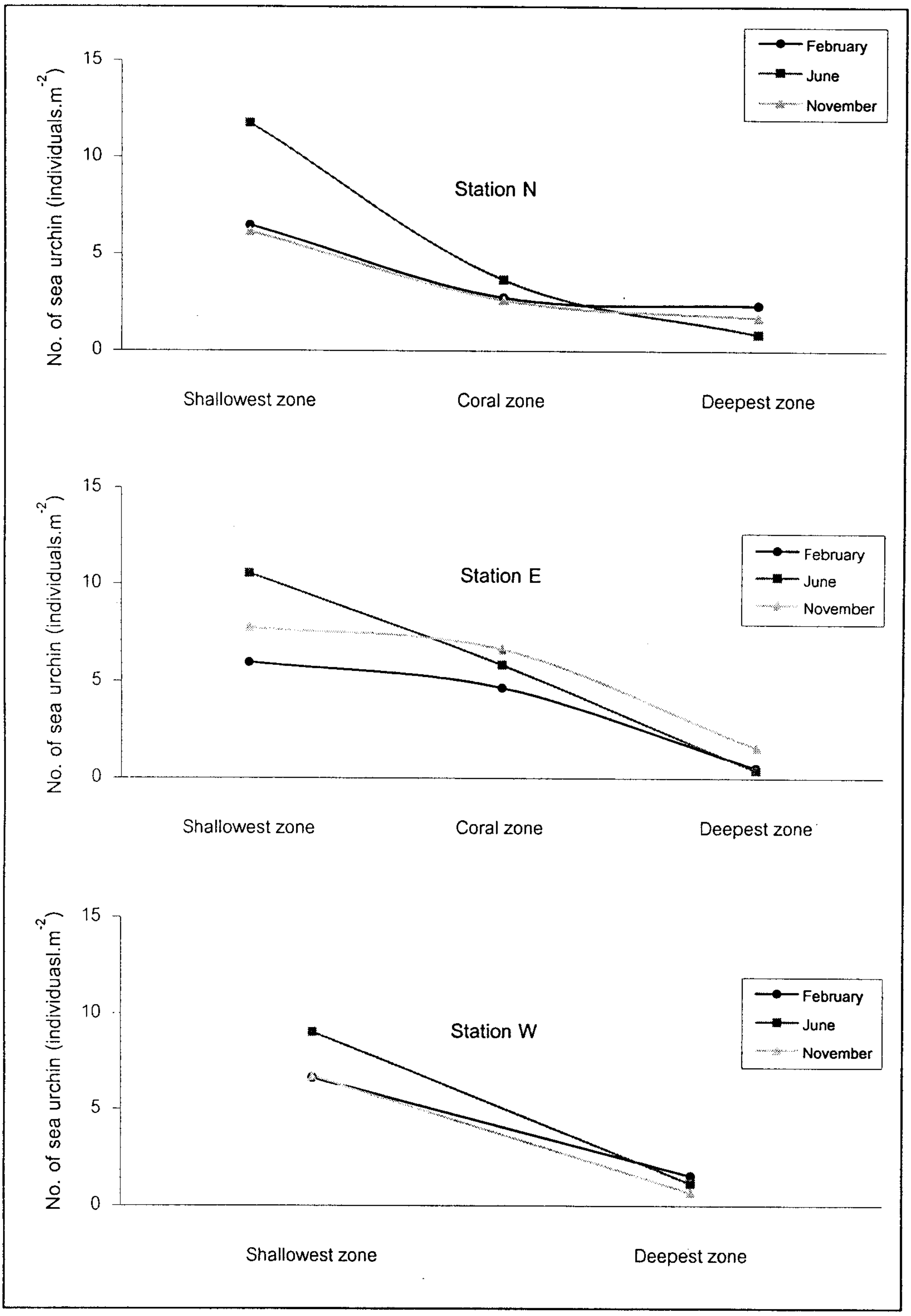


Figure 12 Distribution Patterns of *D. setosum* at Station N, E and W of Khang Khao Island in February, June and November 1998.

Table 1 Mean Population Density of *Diadema setosum* at Station N, E and W in the Three Sampling Periods.

Month	Population Density (Mean ± S.D.)							
	Station N			Station E			Station W	
	Shallowest zone	**Coral zone**	**Deepest zone**	**Shallowest zone**	**Coral zone**	**Deepest zone**	**Shallowest zone**	**Deepest zone**
February 1998	6.5 ± 5.51 n = 30	2.76 ± 1.97 n = 30	2.36 ± 2.39 n = 30	5.96 ± 4.69 n = 30	4.66 ± 2.8 n = 30	0.53 ± 0.89 n = 30	6.63 ± 3.63 n = 30	1.53 ± 1.73 n = 30
June 1998	11.76 ± 13.15 n = 30	3.66 ± 2.36 n = 30	0.86 ± 1.4 n = 30	10.53 ± 6.88 n = 30	5.83 ± 5.04 n = 30	0.4 ± 0.62 n = 30	9.03 ± 4.35 n = 30	1.133 n = 30
November 1998	6.16 ± 6.37 n = 30	2.633 ± 1.95 n = 30	1.73 ± 1.61 n = 30	7.76 ± 4.51 n = 30	6.63 ± 3.04 n = 30	1.6 ± 2.19 n = 30	6.7 ± 4.0 n = 30	0.66 ± 0.84 n = 30

P<0.05, Figure 13).

June 1998

Population densities of *D. setosum* in each zone of the three stations were significantly different (one-way ANOVA, P<0.05, t-test, P<0.01). The population densities in the shallowest zones were higher than those in the coral and the deepest zones (Figure 14). The comparison of population density of *D. setosum* in the same zones among studied stations clearly show that the population densities in the shallowest zone and the deepest zone were not statistically different (one-way ANOVA, P<0.05, Figure 14).

November 1998

Population densities of *D. setosum* in each zones of station N and W were significantly different (one-way ANOVA, P<0.05, t-test, P<0.01). The population densities in the shallowest zones were the highest. However, the population density in the deepest zone of station E was significantly lower than other zones (one-way ANOVA, P<0.05, Figure 15). The comparison of population density of *D. setosum* in the same zones among studied stations clearly show that the population densities in the shallowest zones were not statistically different (one-way ANOVA, P>0.05). However, the population density of *D. setosum* in the deepest zone of station W was significantly lower than that of station N and E (one-way ANOVA, P<0.05, Figure 15).

Comparison of Population Density of *D. setosum* in the same Zones of Station N, E and W During the Study Periods

Station N

The population densities of *D. setosum* in the shallowest and the coral zones were not statistically different (one-way ANOVA, P>0.05). However, the population density of *D. setosum* in the deepest zone in June, 1998 was significantly lower than that in February and November (one-way ANOVA, P <0.05, Figure 16).

Station E

The population density of *D. setosum* in the shallowest zone in June, 1998 was significantly higher than that in February, 1998 (one-way ANOVA, P<0.05). The population density in the coral zone in November, 1998 was significantly higher than that in February, 1998 (one-way ANOVA, P<0.05). The population density in the deepest zone in November was significantly higher than that in February and June, 1998 (one-way ANOVA, P<0.05, Figure 17).

Station W

The population density of *D. setosum* in the shallowest zone in June, 1998 was significantly higher than that in February and November, 1998 (one-way ANOVA, $P<0.05$). However, there were no statistically difference of population densities between the study periods in the deepest zone (one-way ANOVA, $P<0.05$, Figure 18).

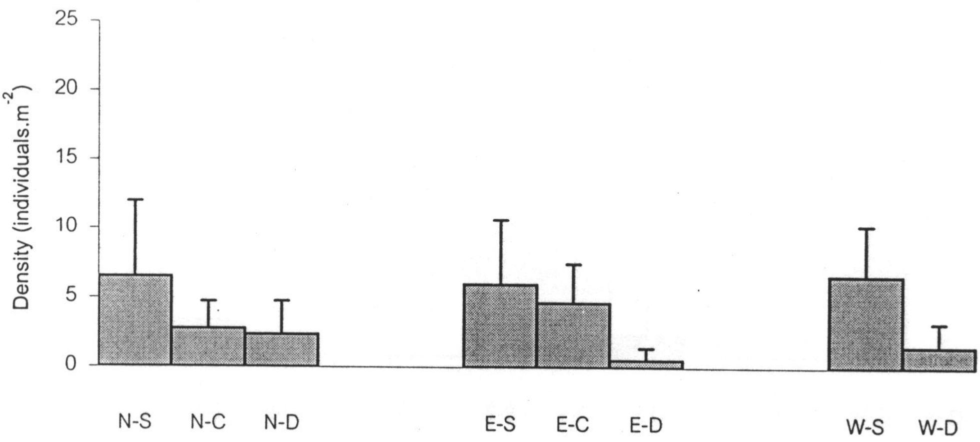
The Test Diameter and Size-Class Distribution of *D. setusum*

The test diameters and sizes-class distributions of *D. setosum* at station N, E and W in February, June and November, 1998 were shown as the following;

The Test Diameter of *D. setosum*

February 1998

At station N, test diameter of *D. setosum* in the shallowest zone was significantly higher than the deepest zone (one-way ANOVA, $P<0.05$). At station E, test diameters of *D. setosum* in all zones were significantly different (one-way ANOVA, $P<0.05$). The test diameter of *D. setoum* in the shallowest zone was higher than those in the coral and the deepest zones (Figure 19). However, the test diameter of *D. setosum* in each zone of station W was no statistically difference (t-test, $P>0.01$). The comparison of test diameter in the

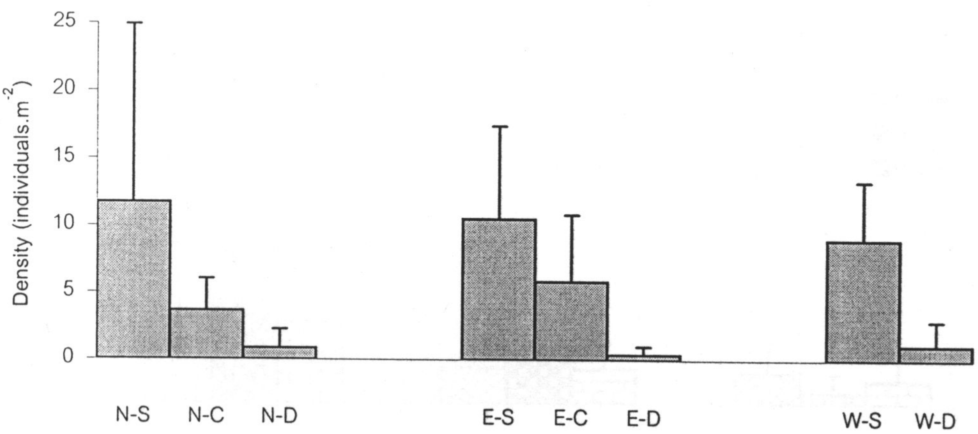


N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 13 Population Density of *D. setosum* at Station N, E and W in February, 1998

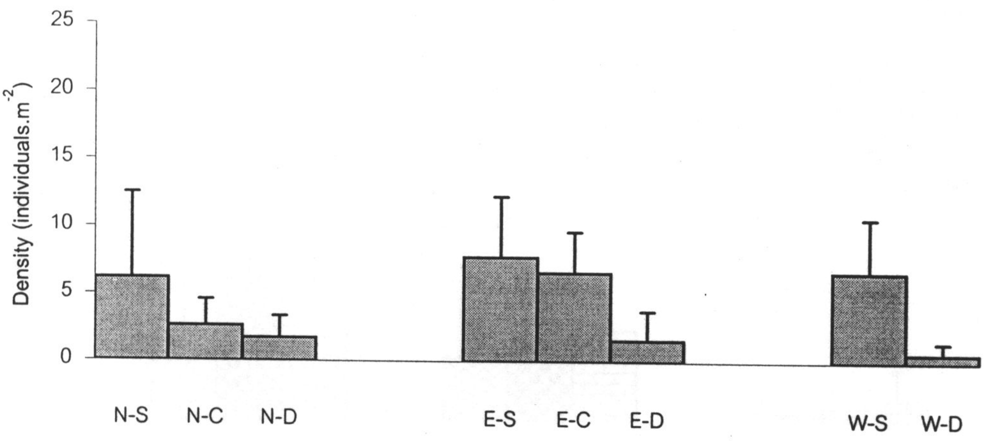


N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 14 Population Density of *D. setosum* at Station N, E and W in June, 1998



N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 15 Population Density of *D. setosum* at Station N, E and W in November, 1998

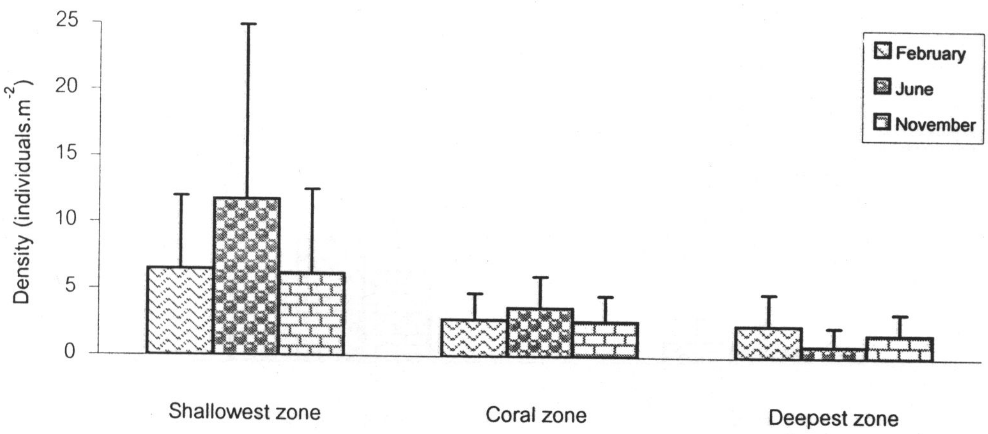


Figure 16 Comparison of Population Density of *D. setosum* in Different Stydy Periods at Station N.

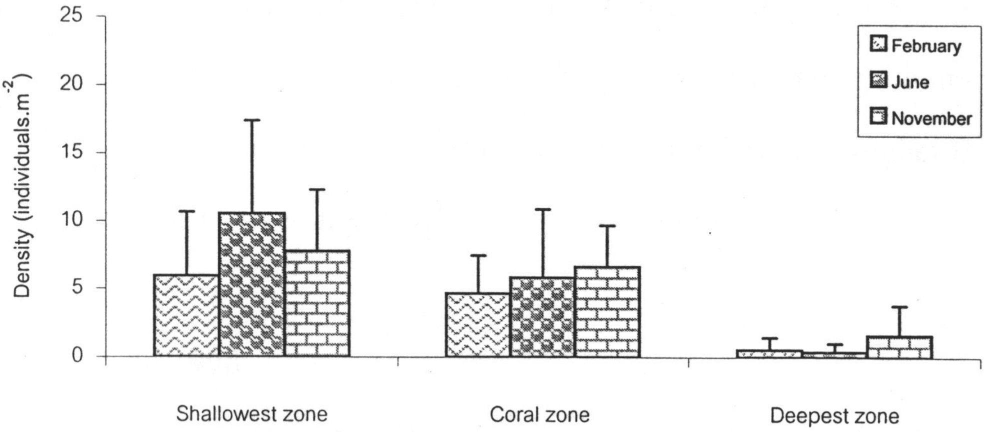


Figure 17 Comparison of Population Density of *D. setosum* in Different Stydy Periods at Station E.

Figure 18 Comparison of Population Density of *D. setosum* in Different Stydy Periods at Station W.

same zones among the studied station clearly show that the test diameter of *D. setosum* in the shallowest zone of station E was significantly higher than that of station N (one-way ANOVA, P<0.05). However, the test diameter of *D. setosum* in the deepest zone of station W was significantly higher than that of station N and E (one-way ANOVA, P<0.05, Figure 19).

June 1998

The test diameter of *D. setosum* in the deepest zone of station N was significantly lower than that in the shallowest and the coral zones (one-way ANOVA, P<0.05). However, the test diameters of *D. setosum* in the deepest zones of station E and W were higher than other zones (one-way ANOVA, P <0.05, t-test, P<0.01, Figure 20). The comparisons of test diameter in the same zones among the studied station clearly show that the test diameters of *D. setosum* in the shallowest zones were not statistically different (one-way ANOVA, P<0.05). However, the test diameter of *D. setosum* in the deepest zone of station N was significantly lower than that of station E and W (one-way ANOVA, P<0.05, Figure 20).

November 1998

The test diameter of *D. setosum* in the shallowest zones of station N and E were significantly higher than that in the coral and the deepest zones (one-way ANOVA, P<0.05). However, the test diameter of *D. setosum* in the shallowest and the deepest zone of station W were not statistically different (t-test, P<0.01, Figure 21). The comparisons of test diameter in the same zones among the studied stations clearly show that the test diameters of *D. setosum* in the shallowest zones were not statistically different. However, the test diameter of *D. setosum* in the deepest zone of station W was significantly higher than that of station E and N (one-way ANOVA, P<0.05, Figure 21).

Comparison of Test Diameter of *D. setosum* in the Same Zone of Station N, E and W During the Study Periods

Station N

The test diameter of *D. setosum* in all zones in February, June and November, 1998 were not significantly different (one-way ANOVA, P <0.05, Figure 22).

Station E

The test diameter of *D. setosum* in the shallowest and the coral zones were significantly higher in February, 1998 than that of June and November, 1998. However, the test diameter of *D. setosum* in the deepest zone was significantly higher in June, 1998 than other periods (one-way ANOVA, P <0.05, Figure 23).

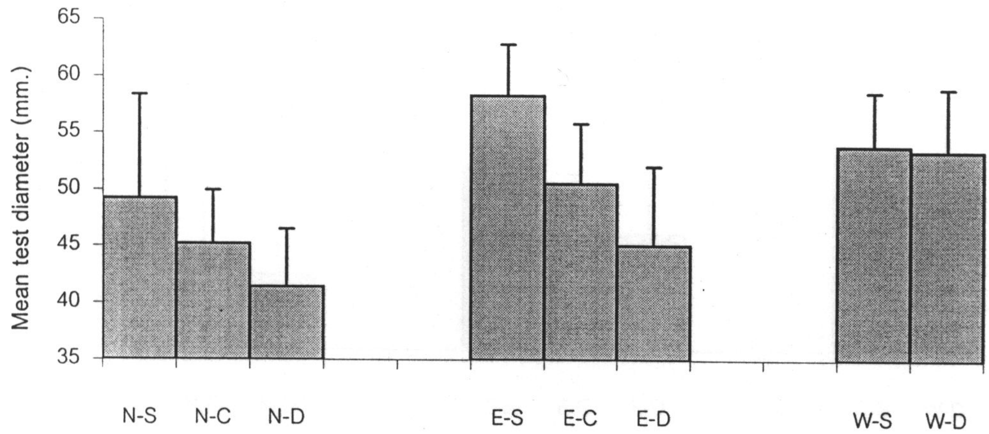
Station W

In June 1998, the test diameter of *D. setosum* in the shallowest zone was significantly lower than February and November, 1998. However, the test diameter of *D. setosum* in the deepest zone in November, 1998 was significantly lower than February, 1998 (one-way ANOVA, $P<0.05$, Figure 24).

The mean test diameters of *D. setosum* in the study sites during the study periods were in the range of 37.95-58.30 mm. (Table 2).

Size-Class Distribution of *D. setosum*

After size-class histograms in all stations of the sampling periods were constructed. The size-class distribution data at station N and W clearly shown that the small sizes of *D. setosum* were present in June, 1998 (test diameter 20-25 mm. and 25-30 mm.). It seems to be that the recruitment of *D. setosum* in this period was higher than that of February and November, 1998 (Figure 25, 27). However, the size-class distributions at station E did not show obvious pattern (Figure 26). Figure 28 shows the size-class distribution at station N, E and W, for all pooled data. The recruitment of *D. setosum* in June, 1998 was obviously higher than that in February and November, 1998.

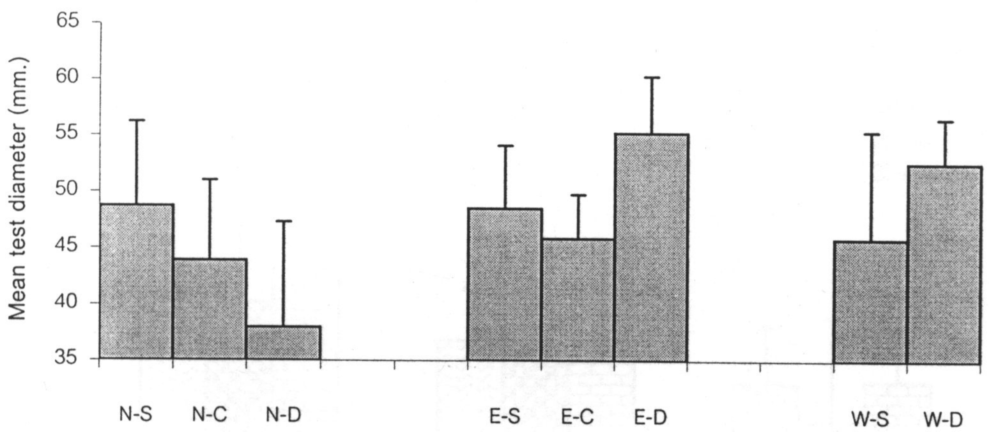


N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 19 Mean Test diameter of *D. setosum* at Station N, E and W in February, 1998.

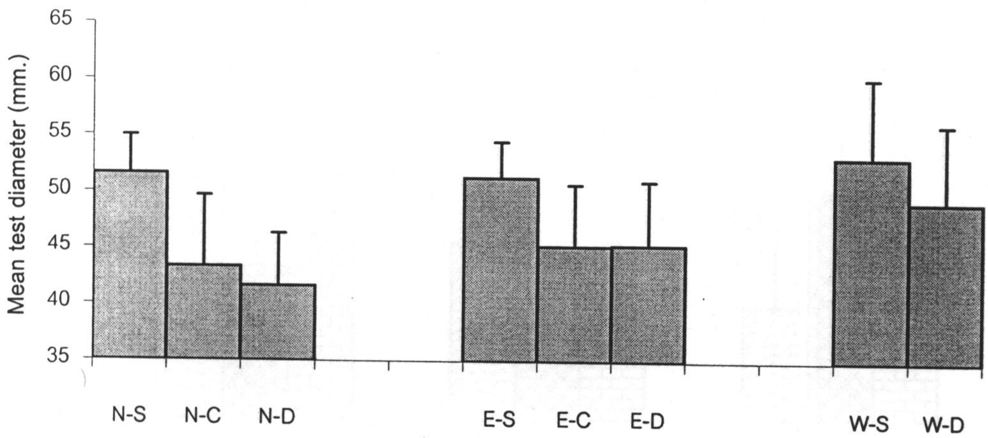


N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 20 Mean Test diameter of *D. setosum* at Station N, E and W in June, 1998.



N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 21 Mean Test diameter of *D. setosum* at Station N, E and W in November, 1998.

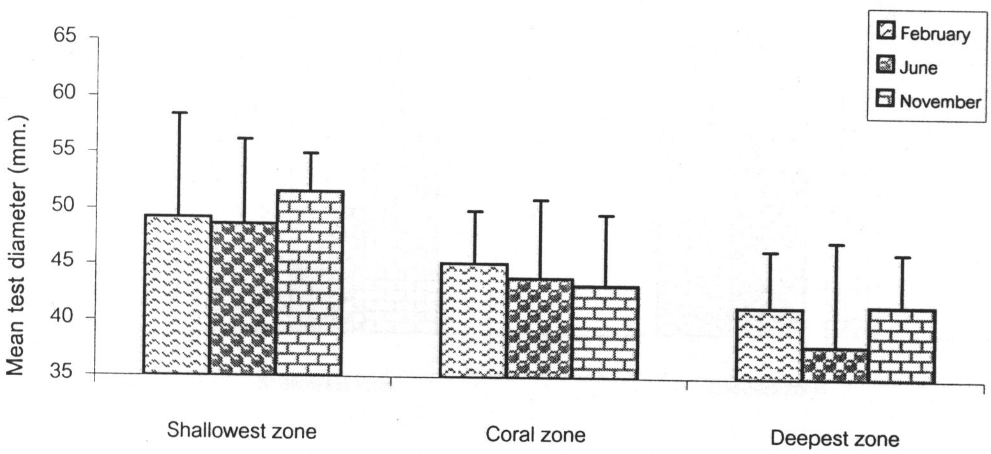


Figure 22 Comparison of Mean Test Diameter of *D. setosum* in Different Study Periods at Station N.

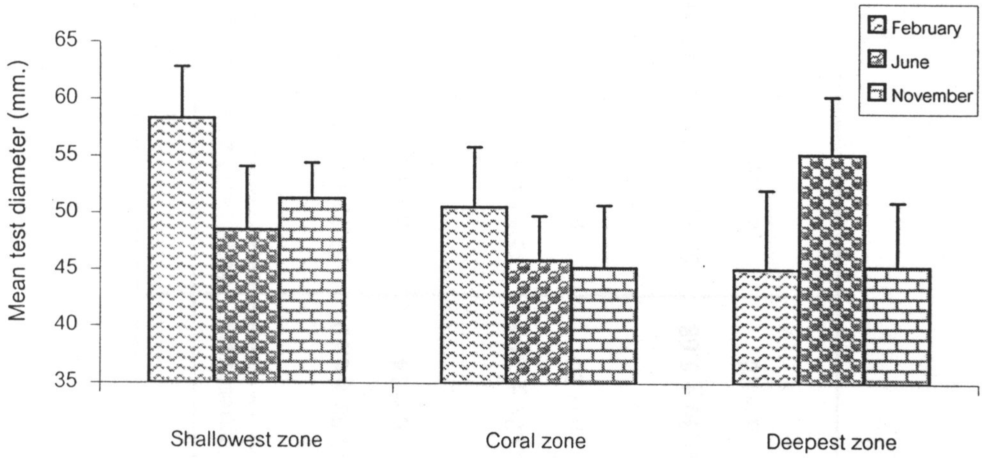


Figure 23 Comparison of Mean Test Diameter of *D. setosum* in Different Study Periods at Station E.

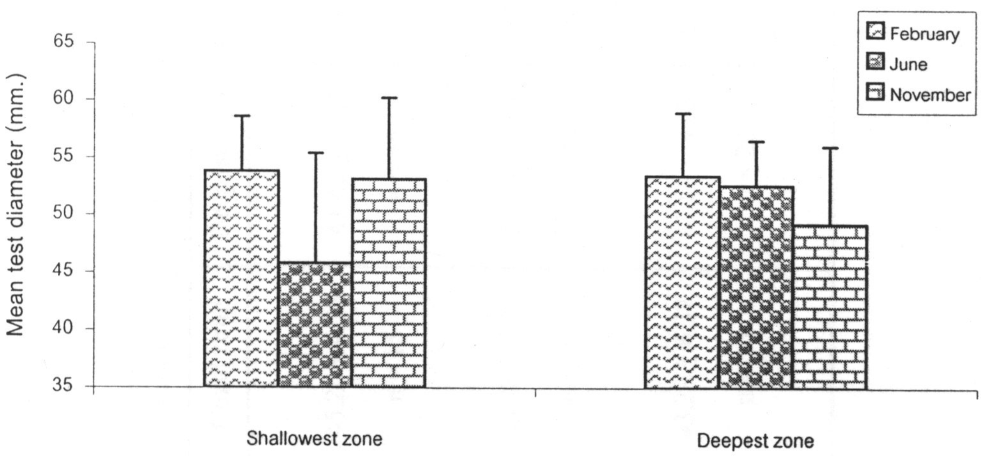


Figure 24 Comparison of Mean Test Diameter of *D. setosum* in Different Study Periods at Station W.

Table 2 Mean Test Diameter of *D. setosum* at Station N, E and W in the Different Sampling Periods.

Month	Mean test diameter of *D. setosum* (mm.) ± S.D.							
	Station N			Station E			Station W	
	Shallowest zone	Coral zone	Deepest zone	Shallowest zone	Coral zone	Deepest zone	Shallowest zone	Deepest zone
February 1998	49.23 ± 9.14 n = 13	45.20 ± 4.75 n = 15	41.42 ± 5.07 n = 15	58.30 ± 4.52 n = 13	50.54 ± 5.30 n = 15	45.08 ± 6.99 n = 14	53.83 ± 4.77 n = 15	53.43 ± 5.53 n = 15
June 1998	48.68 ± 7.50 n = 20	43.92 ± 7.08 n = 20	37.95 ± 9.34 n = 20	48.51 ± 5.59 n = 20	45.86 ± 3.89 n = 20	55.24 ± 5.05 n = 20	45.83 ± 9.57 n = 20	52.58 ± 3.96 n = 19
November 1998	51.60 ± 3.36 n = 20	43.29 ± 6.37 n = 20	41.59 ± 4.69 n = 20	51.29 ± 3.16 n = 20	45.21 ± 5.51 n = 20	45.30 ± 5.68 n = 20	53.12 ± 7.08 n = 20	49.23 ± 6.83 n = 20

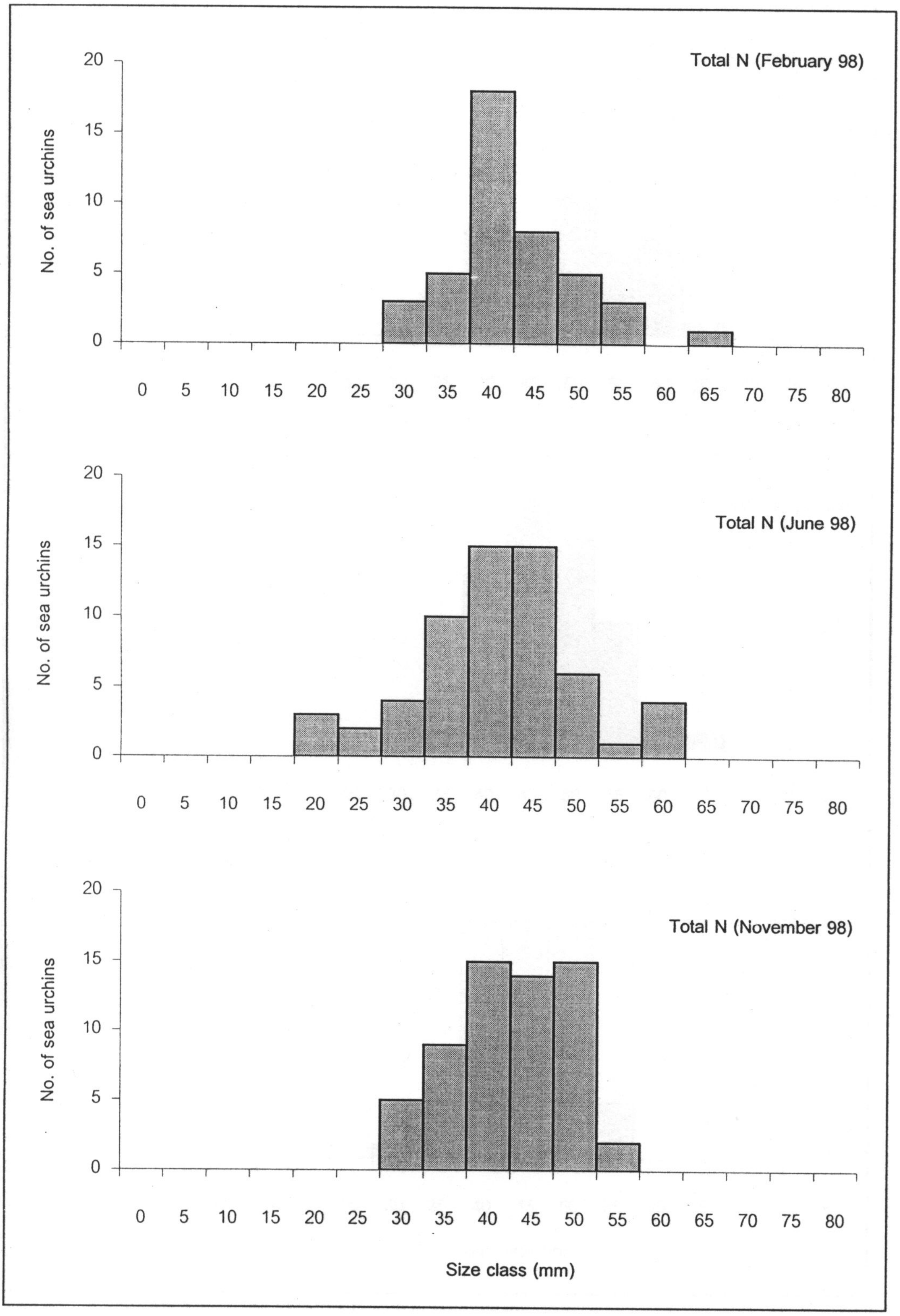


Figure 25 Size-Class Distribution of *D. setosum* at Station N in February, June and November 1998

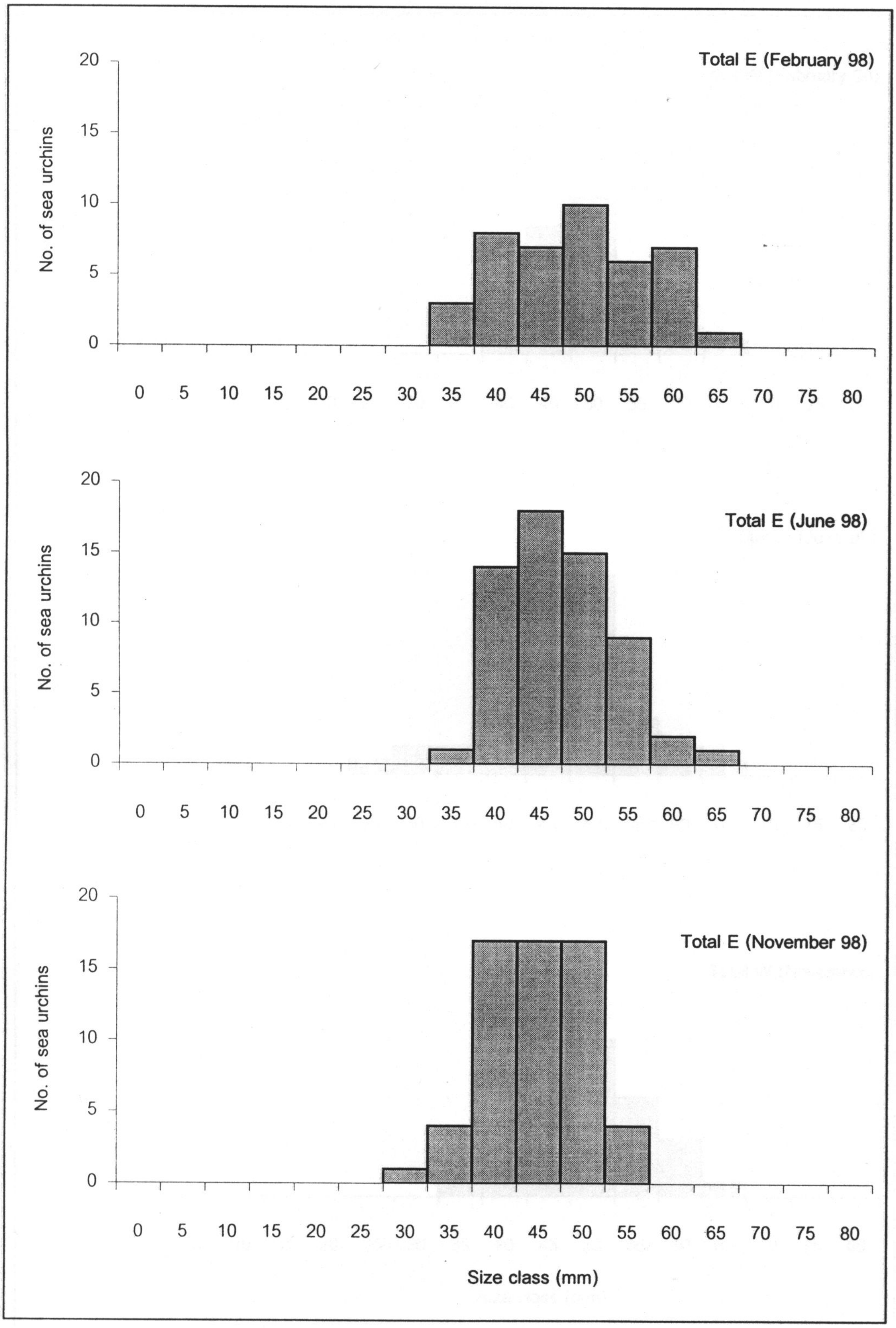


Figure 26 Size-Class Distribution of *D. setosum* at Station E in February, June and November, 1998

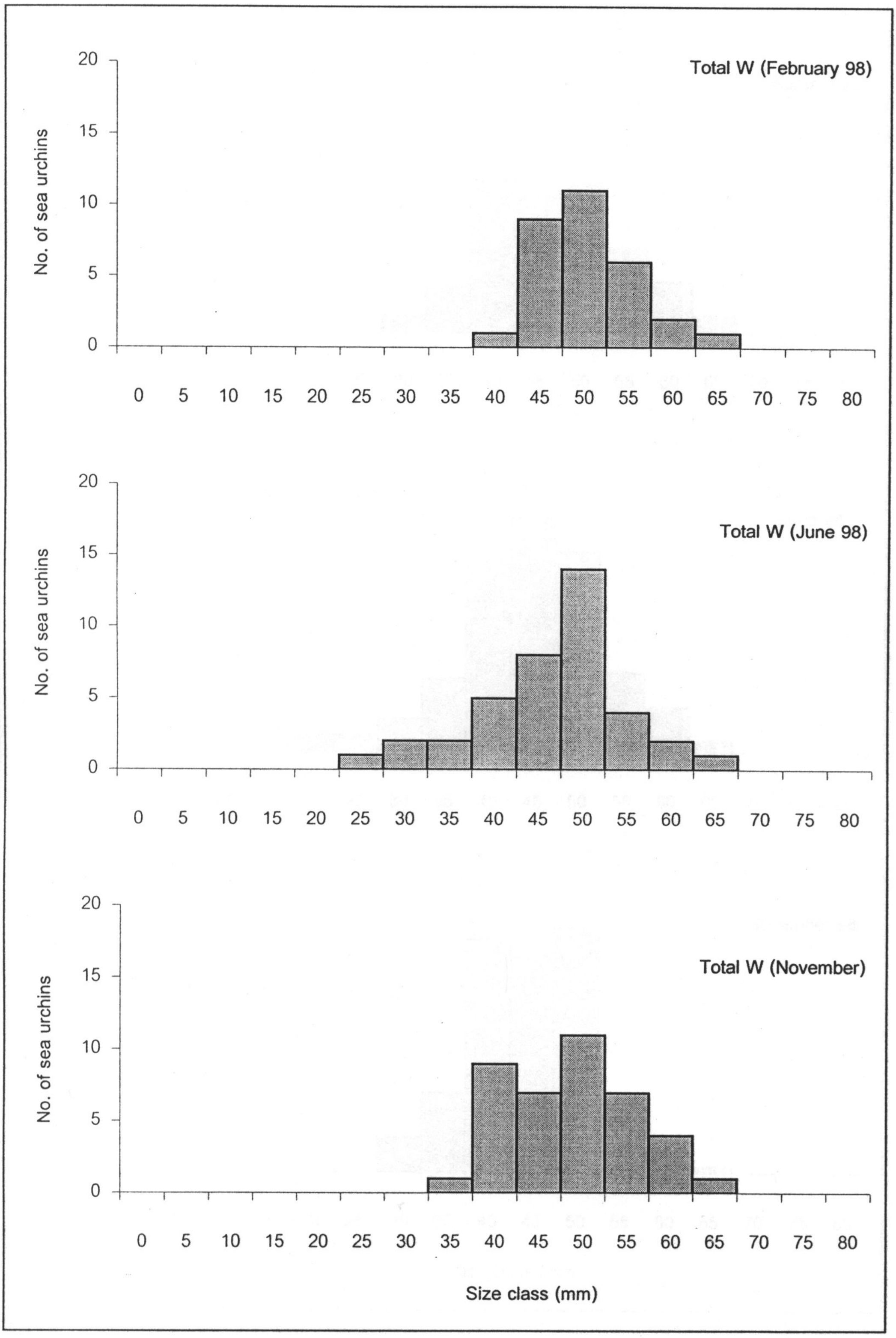


Figure 27 Size-Class Distribution of *D. setosum* at Station W in February, June and November 1998

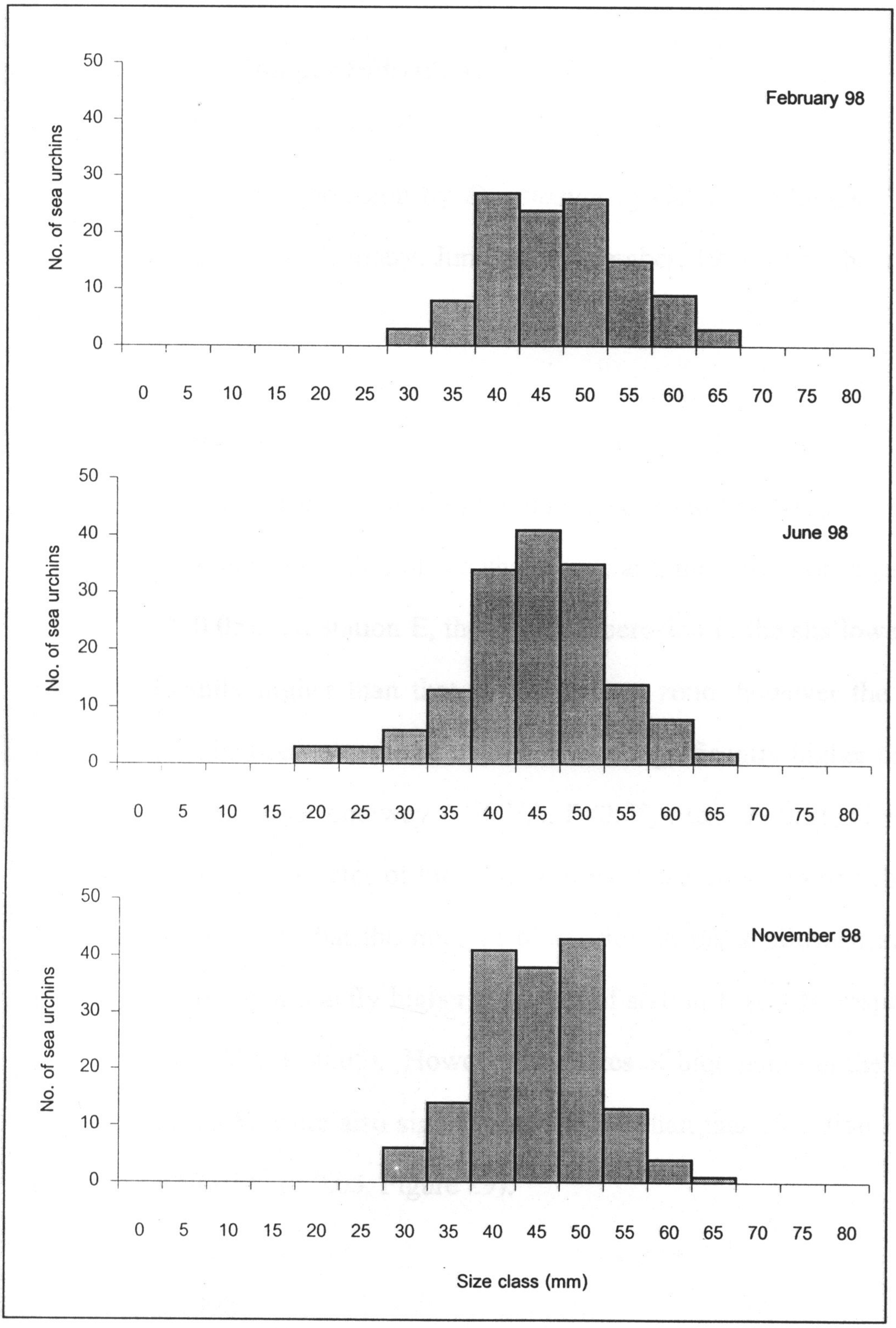


Figure 28 Size-Class Distribution of *D. setosum* at Khang Khao Island (pooled data) in February, June and November, 1998.

Rates of Bioerosion per Individual

The rates of bioerosion by *D. setosum* (g $CaCO_3$. individual^{-1}. d^{-1}) at station N, E and W in February, June and November, 1998 were shown as the following;

February 1998

At station N, the rate of bioerosion in the deepest zone was significantly higher than that of the shallowest and the coral zones (one-way ANOVA, P<0.05). At station E, the rate of bioerosion in the shallowest zone was significantly higher than that in the deepest zone, however the rate of bioerosion in the deepest zone at station W was significantly higher than that of the shallowest zone (one-way ANOVA, P<0.05, t-test, P<0.01, Figure 29). The comparison of the rates of bioerosion in the same zones among the study stations clearly show that the rates of bioerosion in the shallowest zones of station W were significantly higher than that of station E and N, respectively (one-way ANOVA, P<0.05). However, the rates of bioerosion in the deepest zones of station W were also significantly higher than that of station N and E (one-way ANOVA, P<0.05, Figure 29).

June 1998

The rates of bioerosion in each zone of station N were not significantly different (one-way ANOVA, P>0.05). At station E, the rates of bioerosion in the shallowest zone was significantly higher than that of the coral zone (one-way ANOVA, P<0.05). However, the rate of bioerosion in the deepest zone of station W was significantly higher than that of the shallowest zone (t-test, P <0.01, Figure 30). The comparisons of the rates of bioerosion in the same zones among the study stations clearly show that the rate of bioerosion in the shallowest zone of station E was significantly higher than that of station N and W, respectively (one-way ANOVA, P<0.05). However, the rates of bioerosion in the deepest zone of station W was significantly higher than that of station N (one-way ANOVA, P<0.05, Figure 30).

November 1998

At station N, the rate of bioerosion in the shallowest zone was significantly higher than that of the deepest and the coral zones (one-way ANOVA, P<0.05). However, the rate of bioerosion in each zone of station E and W were not statistically different (one-way ANOVA, P<0.05, t-test, P <0.01, Figure 31). The comparisons of the rate of bioerosion in the same zones among the study stations clearly show that the rate of bioerosion in the shallow zone of station N was significantly higher than that of station E and W, respectively (one-way ANOVA, P<0.05). However, the rates of bioerosion in the deepest zones were not statistically different (one-way ANOVA, P<0.05, Figure 31).

Comparison of the Rate of Bioerosion by *D. setosum* in the Same Zones of Station N, E and W During Different Study Periods

Station N

The rates of bioerosion in the shallowest and coral zones in February, 1998 were significantly lower than those of June and November, 1998. However, the rates of bioerosion in the deepest zones were not significantly different (one-way ANOVA, $P<0.05$, Figure 32).

Station E

The rates of bioerosion in the shallowest in June, 1998 were significantly higher than those of November and February, respectively. However, the rates of bioerosion in the coral and the deepest zones were significantly lower in February, 1998 than other periods (one-way ANOVA, $P<0.05$, Figure 33).

Station W

The rates of bioerosion in the shallowest in February, 1998 were significantly higher than that of November, 1998. However, the rates of bioerosion in the deepest zones in November, 1998 were significantly lower than other periods (one-way ANOVA, $P<0.05$, Figure 34).

The rates of bioerosion by *D. setosum* in all study sites during the study periods were in the range of 0.34-1.43 g $CaCO_3$. individual^{-1}. d^{-1} (Table 3).

To test the difference in bioerosion rates on different size class, the mean bioerosion rate of *D. setosum* in each size class was compared. The results seem to show that the amount of $CaCO_3$ is related to size of sea urchin (Figure 35). In June 1998, the mean bioerosion rates in each size class seem to be higher than those in February and November.

According to the analysis of feces composition, the organic matter was 15.09% and the inorganic matter was 84.91%. For the inorganic matter, it composed of sand 35.52% and $CaCO_3$ 49.4% (Figure 36). $CaCO_3$ was the highest percent of feces composition in all the study periods (Figure 37).

The Total Rates of Bioerosion by *D. setosum*

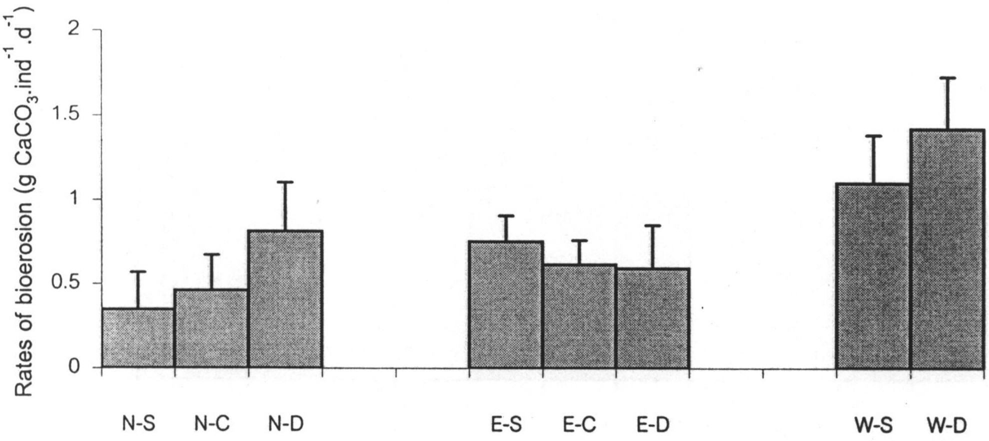
The total rates of bioerosion by *D. setosum* in all zones during the study periods of station N, E and W were calculated by multiplying the average of $CaCO_3$ per individual by the population density. The figures of this study were in the range 0.31-15.07 g $CaCO_3$. individual^{-1}. d^{-1} (Figure 38). The finding clearly showed that the total bioerosion rates in the shallowest zones were higher than that in the coral and the deepest zones. In June 1998, the total bioerosion rates in the shallowest and the coral zones were obviously higher than those in February and November, 1998. Clearly, the total bioerosion rates are depending on the population density.

The Correlation Coefficient between all Parameters

The relationships between $CaCO_3$ in gut content, test diameter, test height, Aristotle's lantern diameter, Aristotle's lantern height, body weight, gonad weight and fecal dry weight of *D. setosum* were established (Table 4). They revealed that test diameter, test height, Aristotle's lantern diameter, Aristotle's lantern height and body weight were highly correlation. However, fecal dry weight was medium correlation, but gonad weight was no relation with all parameters.

Comparison of the Amount of Fecal Dry Weight in Gut Content of *D. setosum* in the Different Times.

The results in Figure 39 show that the amount of fecal dry weight in gut content of *D. setosum* (size class 40 mm.) at the shallowest zone, the coral zone and the deepest zone of station A in the different times (6.00, 12.00, 18.00, 24.00) were not statistically different (H = 3.77, H = 4.30, H = 1.03, df = 3, respectively). Due to the amount of $CaCO_3$ in gut content was related to the fecal dry weight, thus the amount of $CaCO_3$ was also not different between the sampling times.

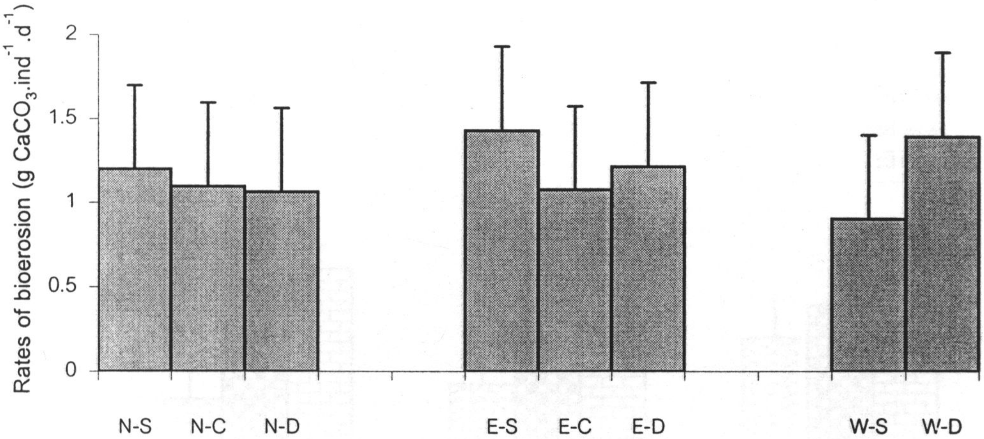


N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 29 Rates of Bioerosion per Individual of *D. setosum* at Station N, E and W in February, 1998

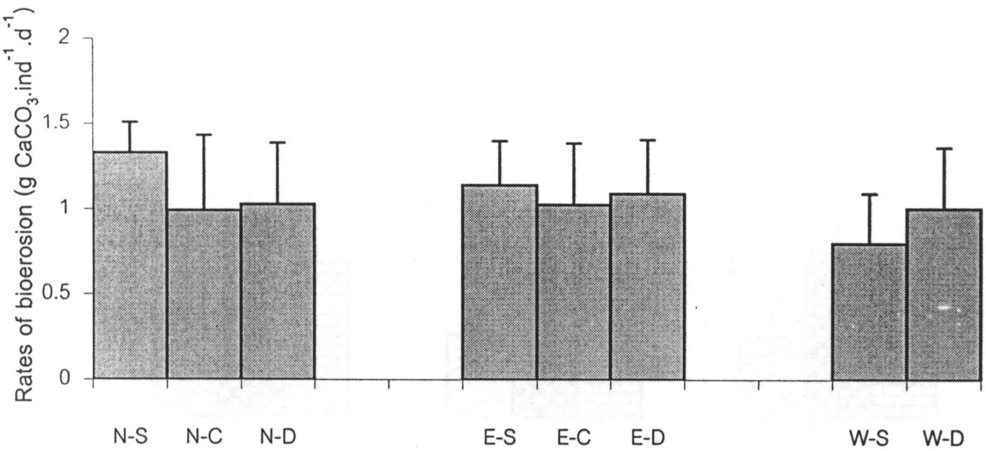


N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 30 Rates of Bioerosion per Individual of *D. setosum* at Station N, E and W in June, 1998.



N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 31 Rates of Bioerosion per Individual of *D. setosum* at Station N, E and W in November, 1998.

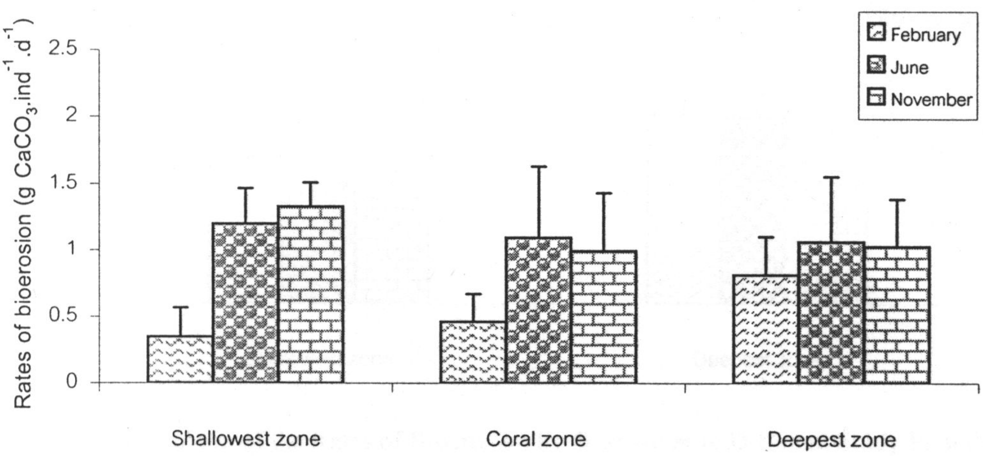


Figure 32 Comparison of the Rates of Bioerosion by *D. setosum* in Different Study Periods at Station N.

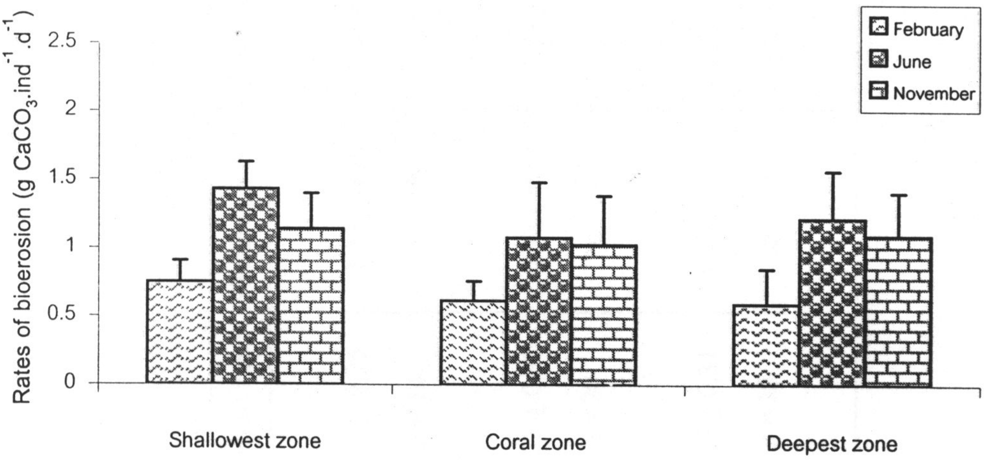


Figure 33 **Comparison of the Rates of Bioerosion by *D. setosum* in Different Study Periods at Station E.**

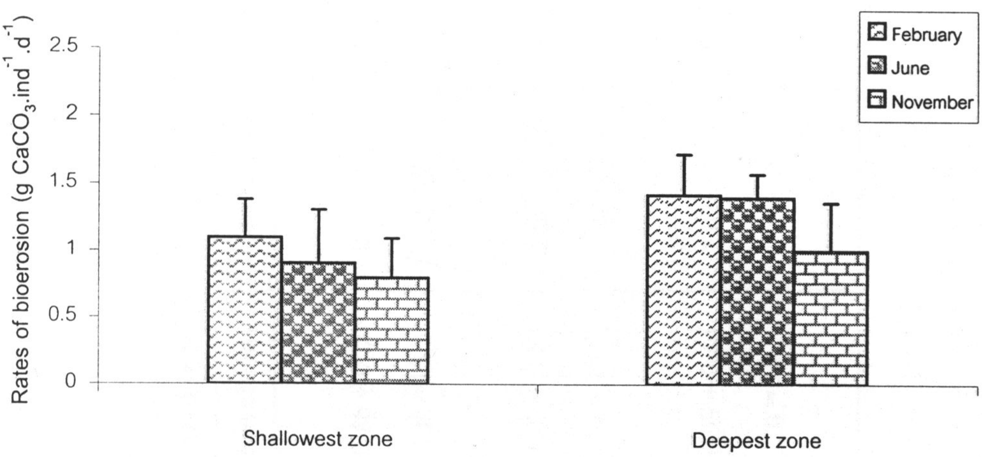


Figure 34 **Comparison of the Rates of Bioerosion by *D. setosum* in Different Study Periods at Station W.**

Table 3 The Rates of Bioerosion by *D. setosum* (g $CaCO_3$. Individual^{-1}. d^{-1}) at Station N, E and W in the Different Sampling Periods.

	Rates of bioerosion (g $CaCO_3$. individual^{-1} . d^{-1})							
Month	Station N			Station E			Station W	
	Shallowest zone	Coral zone	Deepest zone	Shallowest zone	Coral zone	Deepest zone	Shallowest zone	Deepest zone
February 1998	0.34 ± 0.21 n = 13	0.46 ± 0.20 n = 15	0.81 ± 0.28 n = 15	0.75 ± 0.15 n = 13	0.61 ± 0.14 n = 15	0.59 ± 0.25 n = 14	1.09 ± 0.28 n = 15	1.41 ± 0.30 n = 15
June 1998	1.197 ± 0.26 n = 20	1.09 ± 0.53 n = 20	1.06 ± 0.49 n = 20	1.43 ± 0.19 n = 20	1.07 ± 0.40 n = 18	1.21 ± 0.35 n = 20	0.90 ± 0.39 n = 20	1.39 ± 0.17 n = 19
November 1998	1.32 ± 0.18 n = 20	0.99 ± 0.44 n = 20	1.02 ± 0.36 n = 20	1.13 ± 0.26 n = 20	1.02 ± 0.35 n = 20	1.09 ± 0.31 n = 20	0.79 ± 0.29 n = 20	1.00 ± 0.35 n = 20

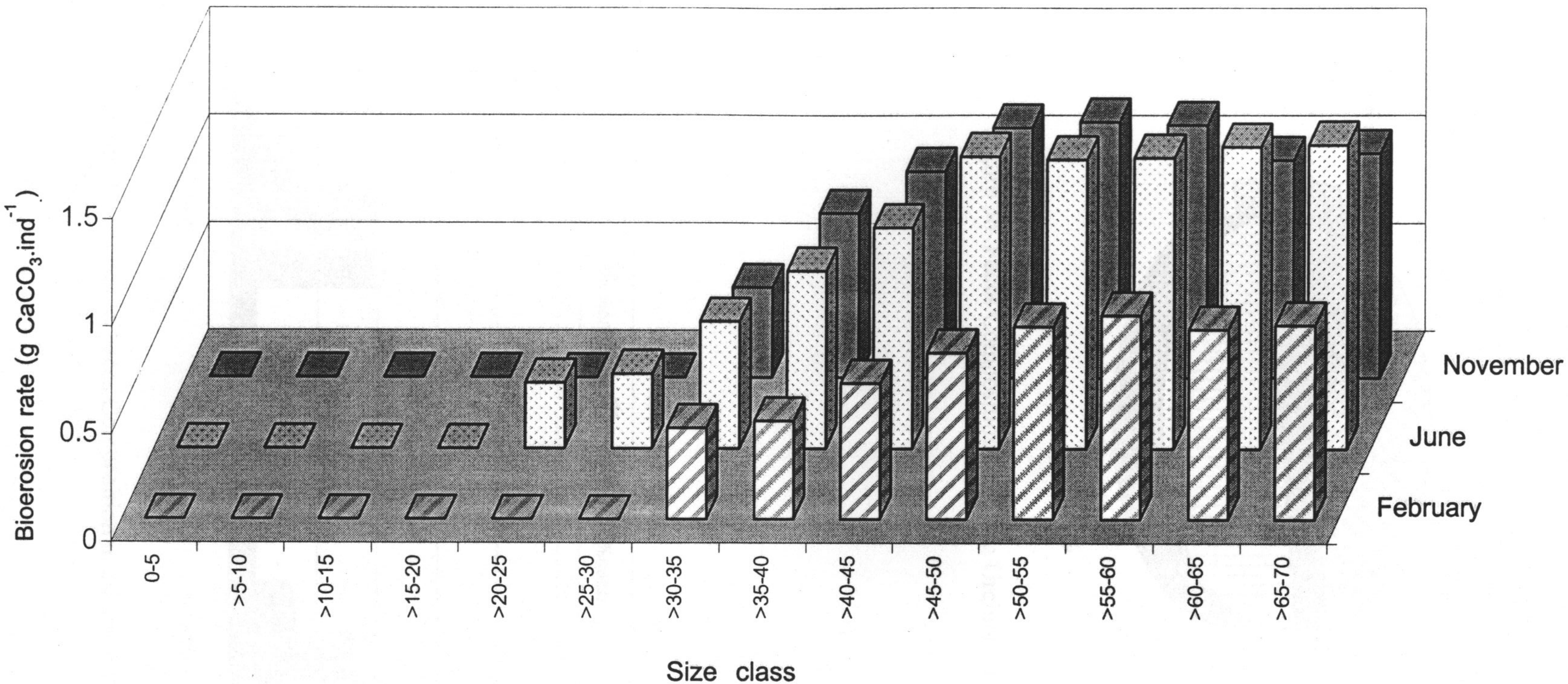


Figure 35 Bioerosion Rates by *D. setosum* According to Size Class in Feburary, June, and November, 1998

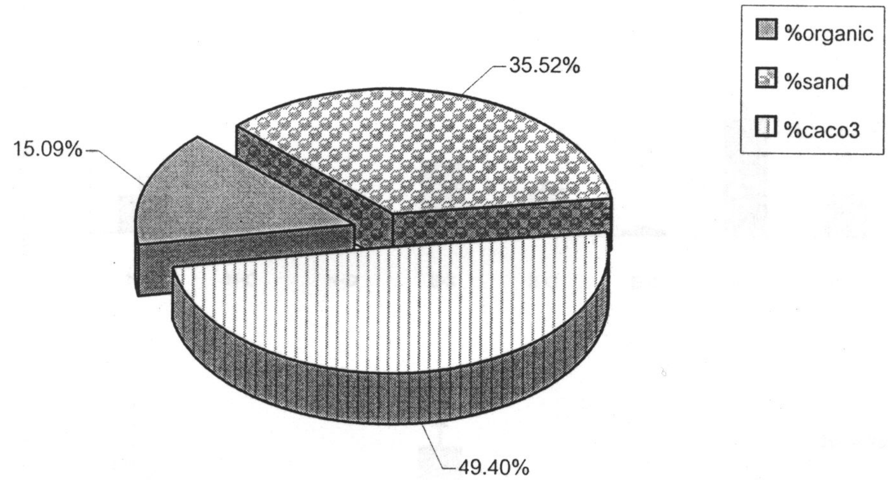


Figure 36 Feces Composition in all Sea Urchins Samples.

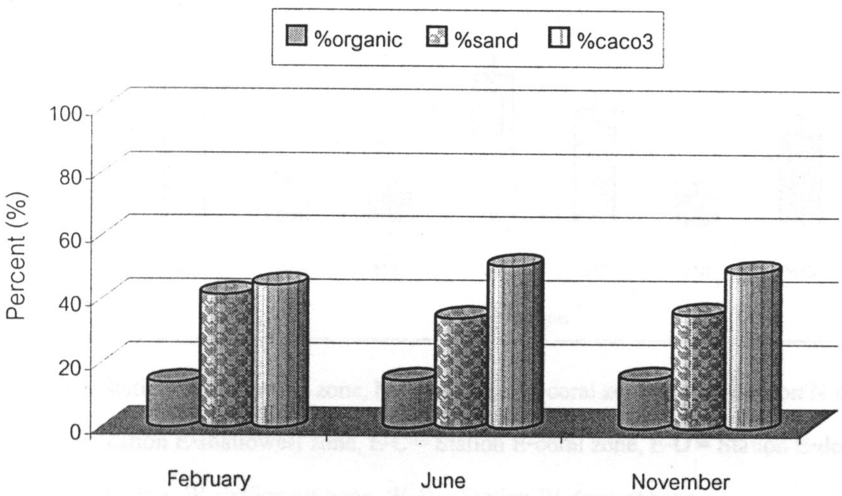
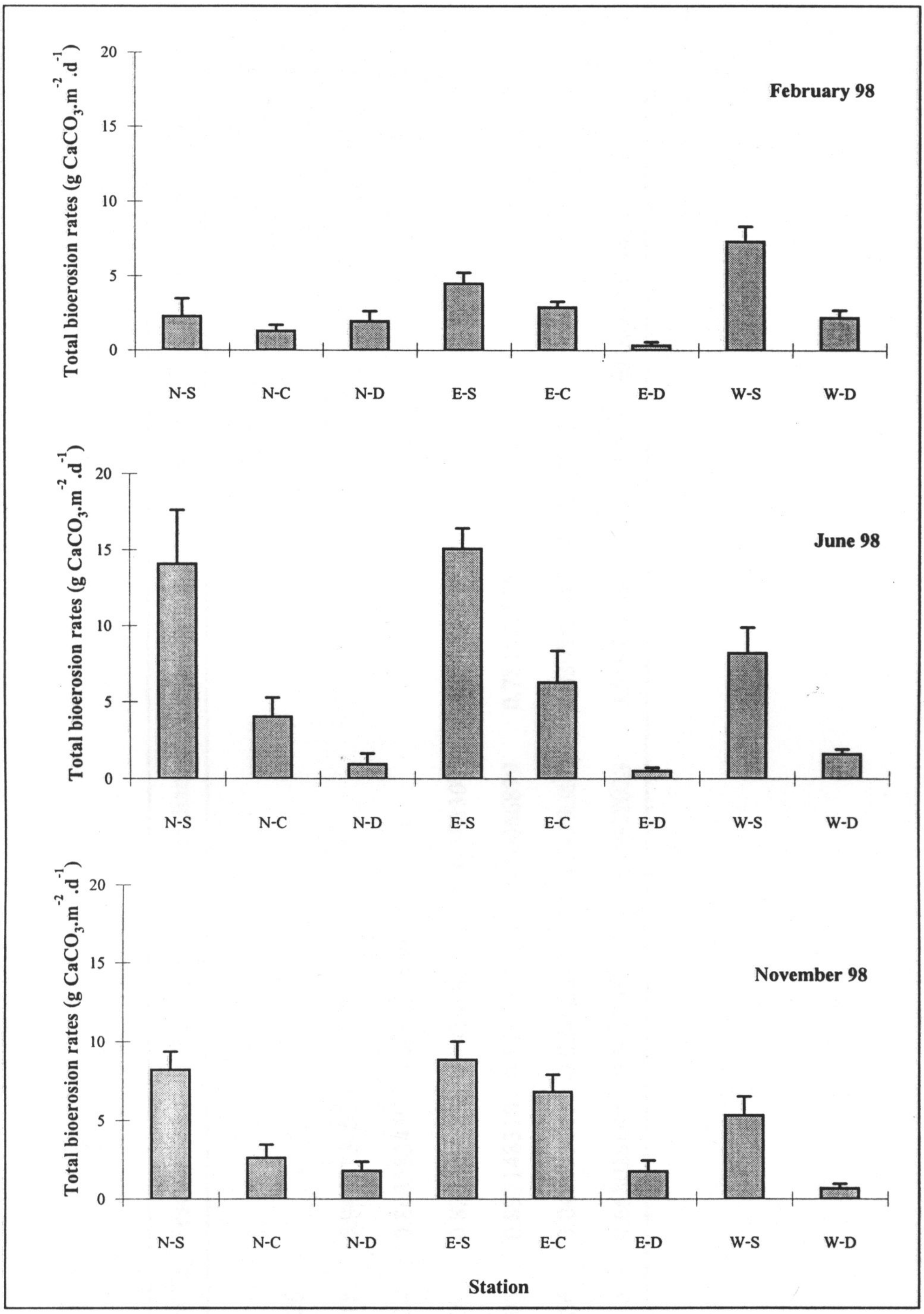


Figure 37 Percent of Feces Composition in all the Study Periods.



N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

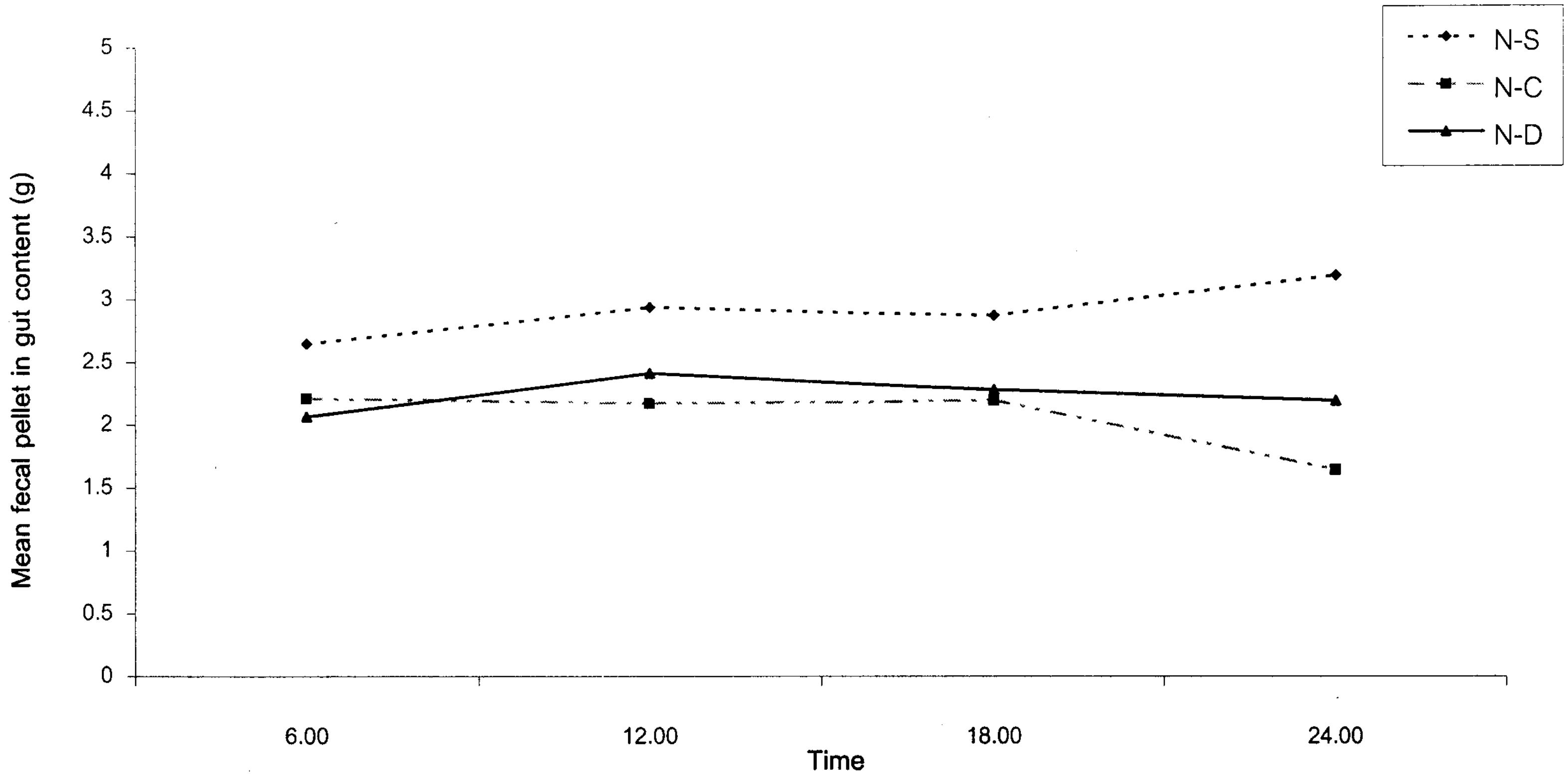
E-S = Station E-shallowest zone, E-C = Station E-coral zone, E-D = Station E-deepest zone

W-S = Station W-shallowest zone, W-D = Station W-deepest zone

Figure 38 Total Bioerosion Rates by *D.setosum* in all Study Sites at Khang Khao Island During Febuary, June and November 1998.

Table 4 Correlation Matrix between all Parameters.

	Amount of $CaCO_3$	Test diameter	Test high	Aristotle diameter	Aristotle high	Body weight	Gonad weight	Dry weight
Amount of $CaCO_3$	1							
Test diameter	0.530925326	1						
Test high	0.510831518	0.946873455	1					
Aristotle diameter	0.538927384	0.863583439	0.868028806	1				
Aristotle high	0.50723986	0.827309023	0.841498372	0.921883079	1			
Body weight	0.517135493	0.897148318	0.876544398	0.80066879	0.781571805	1		
Gonad weight	0.069840166	0.040593641	0.054666475	0.054390839	0.030882645	0.022543834	1	
Dry weight	0.669429475	0.668029645	0.621766577	0.60812028	0.559741764	0.744070401	-0.003448588	1



N-S = Station N-shallowest zone, N-C = Station N-coral zone, N-D = Station N-deepest zone

Figure 39 Mean of the Amount of Fecall Pellet (dry weight) in Gut Content of *D. setosum* in the Different Time at Station A

Status of Coral Communities at Khang Khao Island

After the severe coral bleaching event in the Gulf of Thailand during April-May 1998, recovery patterns of stony corals were in various degrees. Most of the dominant coral species, *Porites lutea*, recovered. Only a few colonies of *P. lutea* showed partial colony mortality or completely died (Figure 40). However, the branching corals, *Acropora* spp. which assemblaged on sandy bottoms exhibited high rates of mortality (Figure 41) or high partial colony mortality (Figure 42). Subsequently, filamentous algae mainly covered on dead coral colonies and provided available food sources for *D. setosum* (Figure 43-44). Population densities of *D. setosum* increased after the coral bleaching phenomenon. The sea urchins always grouped in the dead coral patches (Figure 45). The highest population density of *D. setosum* was found in the shallowest zone, followed by the coral zone (Figure 46-47). According to the field observations, numbers of small sea urchins were increasing (Figure 48).

Deterioration of coral colonies caused by *D. setosum* was obviously found in all study sites at different degrees of degradation (Figure 49-51). Based on the study on coral community changes, coral degradation caused by *D. setosum* remarkably increased after the coral bleaching event (Figure 52-55).

Figure 40 *Porites lutea* is the Most Dominant Coral Species in the Coral Communities at Khang Khao Island.

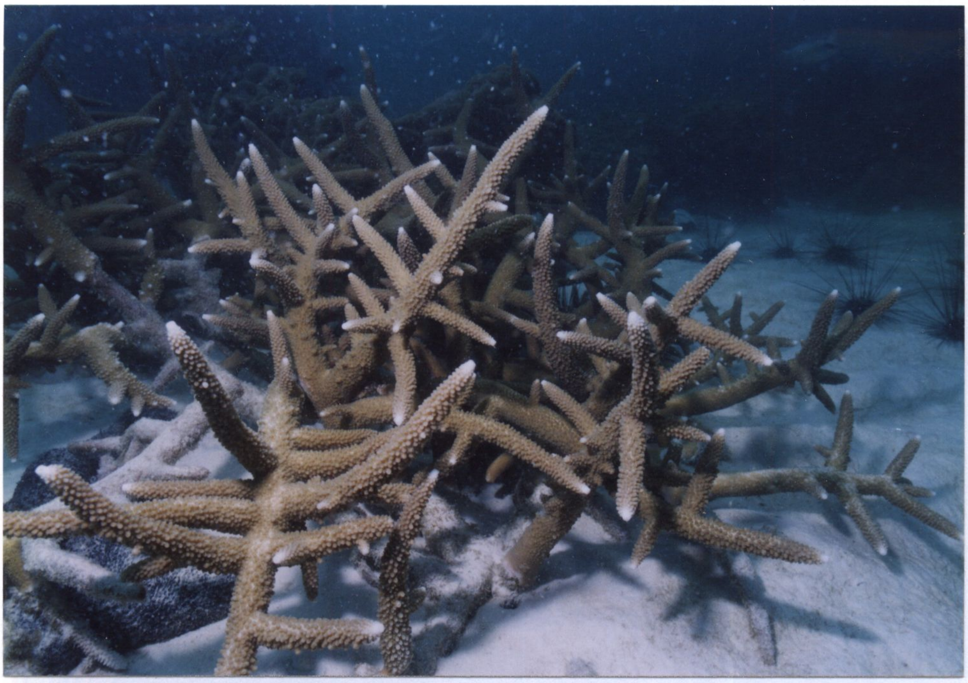


Figure 41 A Branching Coral, *Acropora* sp., on Sandy Bottom of Khang Khao Island.

Figure 42 Activities of *D. setosum* on the Assemblage of Dead *Acropora* sp.

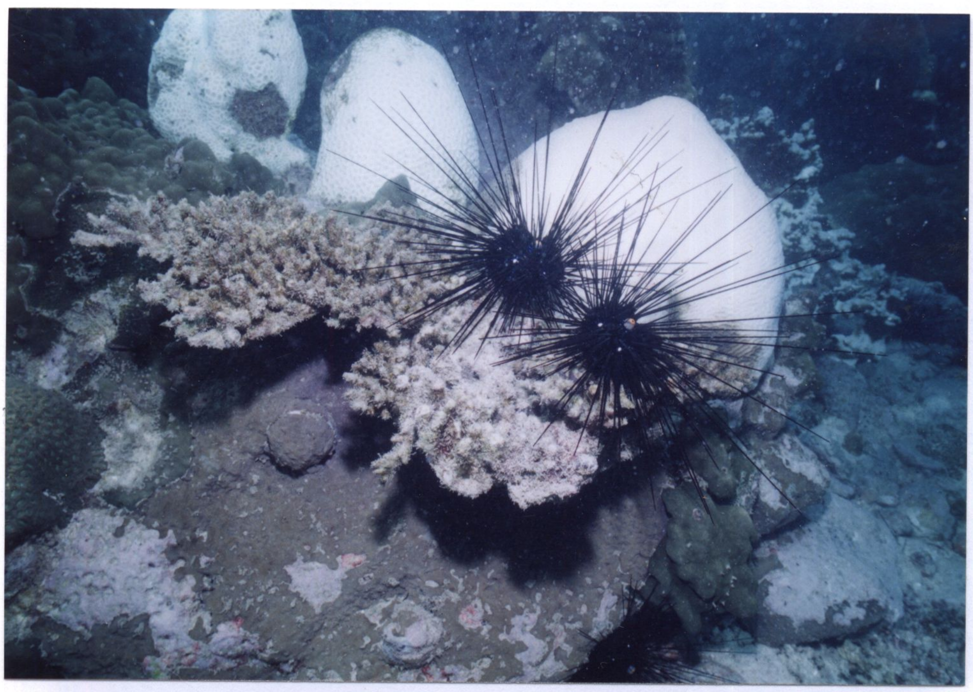


Figure 43 Dead Colony of *Acropora* sp. was Covered by Filamentous Algae after the Coral Bleaching Phenomenon.

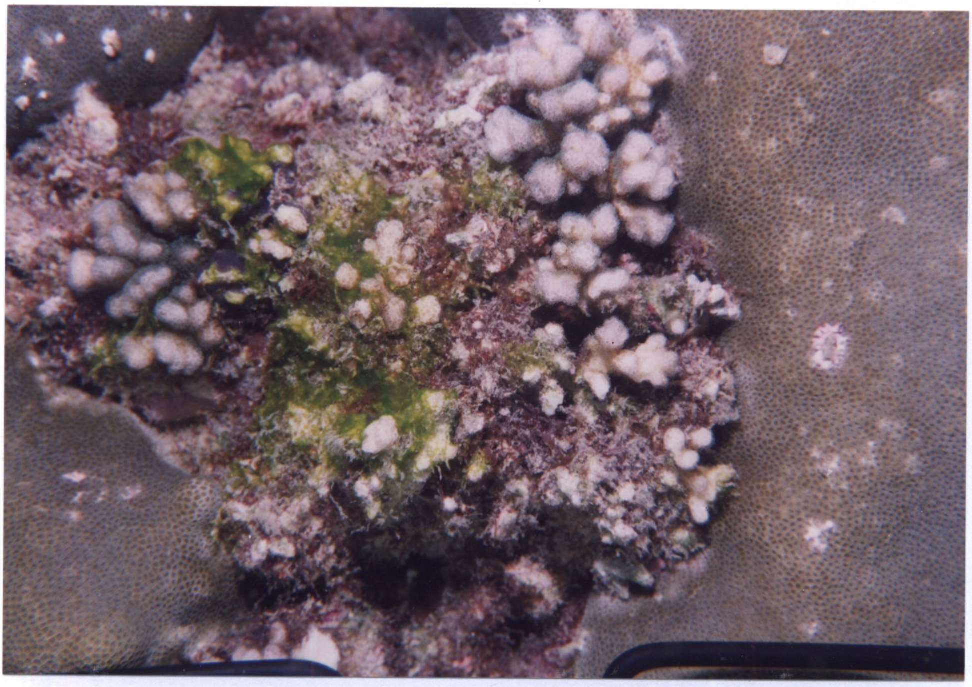


Figure 44 Filamentous Algae is Available Food Resource for *D. setosum*.

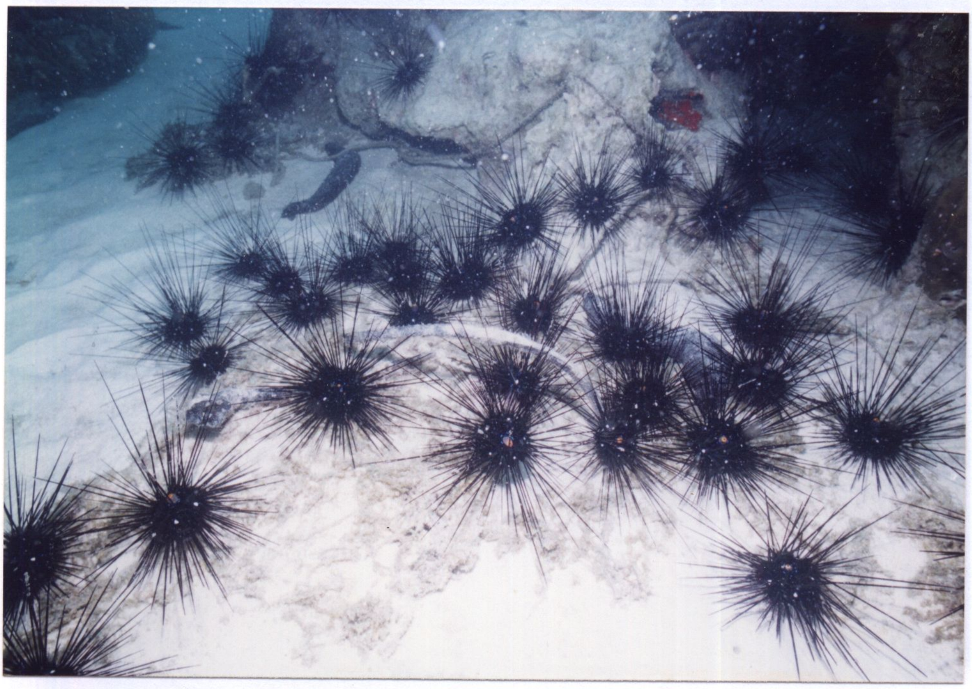


Figure 45 Aggregation of *D. setosum* in the Coral Zone of Station N.

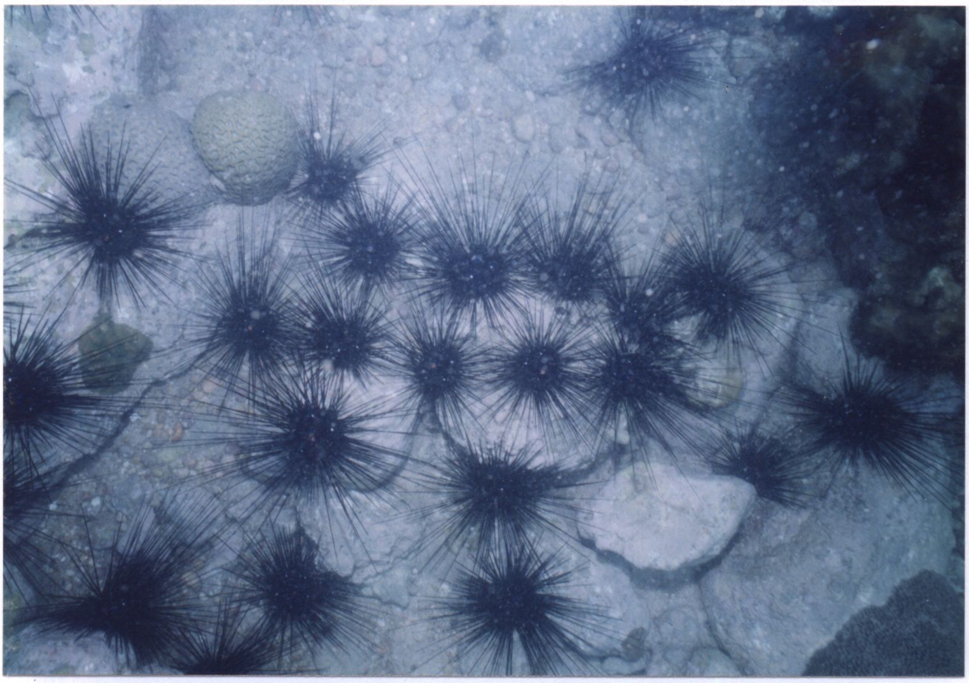


Figure 46 Density of *D. setosum* in the Shallowest Zone was the Highest Compared to Other Zones.

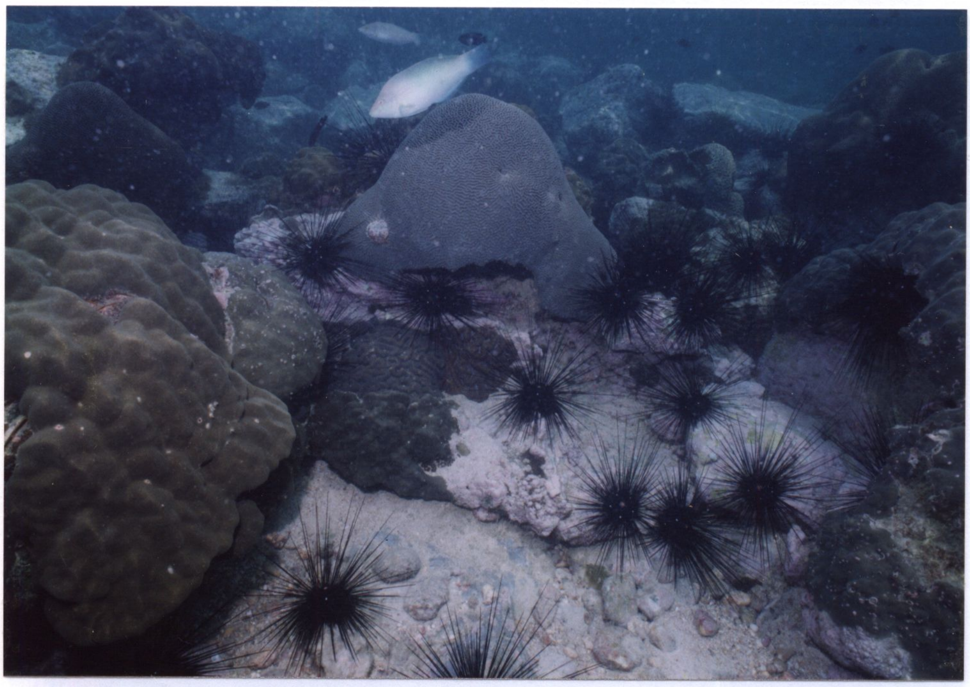


Figure 47 *D. setosum* in the Coral Zone of Station E

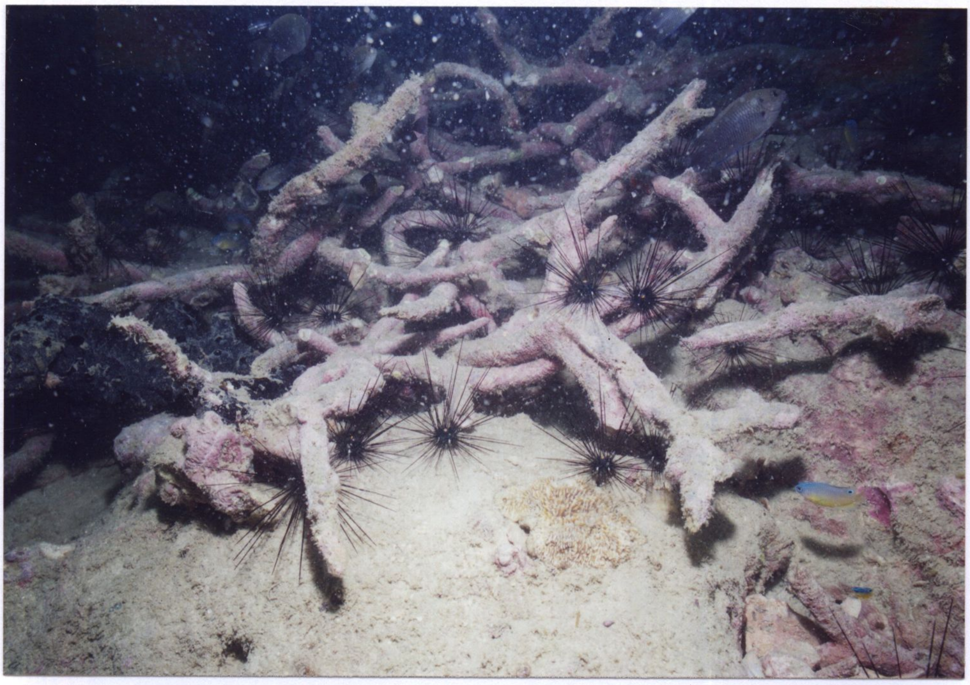


Figure 48 Recruitment of *D. setosum* Seems to be Increasing after the Event of Coral Bleaching.

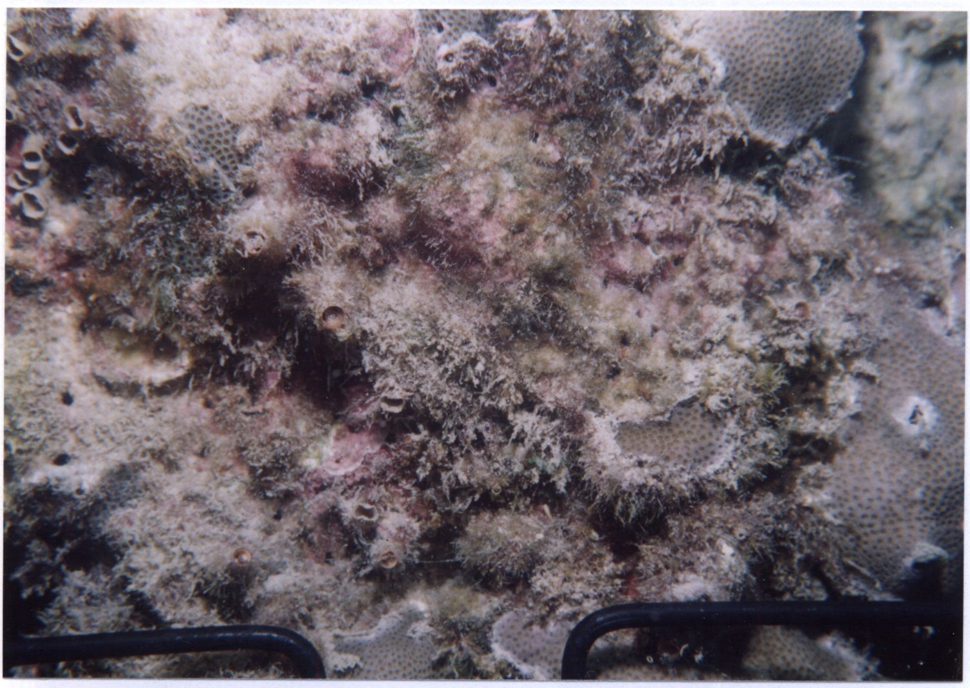


Figure 49 Grazing Scars on *Porites lutea.*

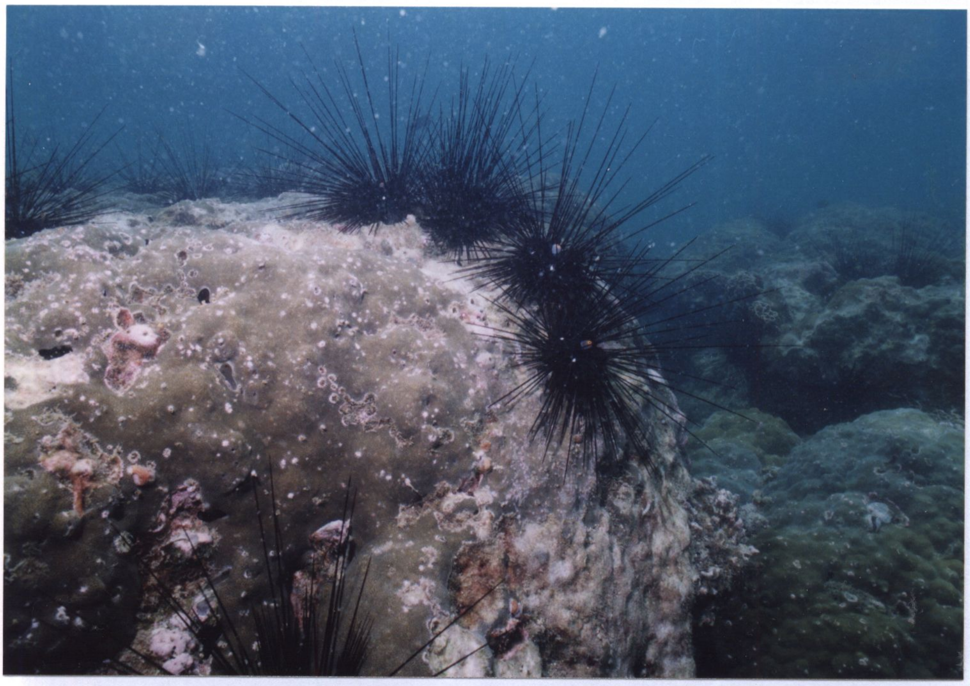


Figure 50 Grazing Activities of *D. setosum* on *Porites lutea* at the Coral Zone of Station E.

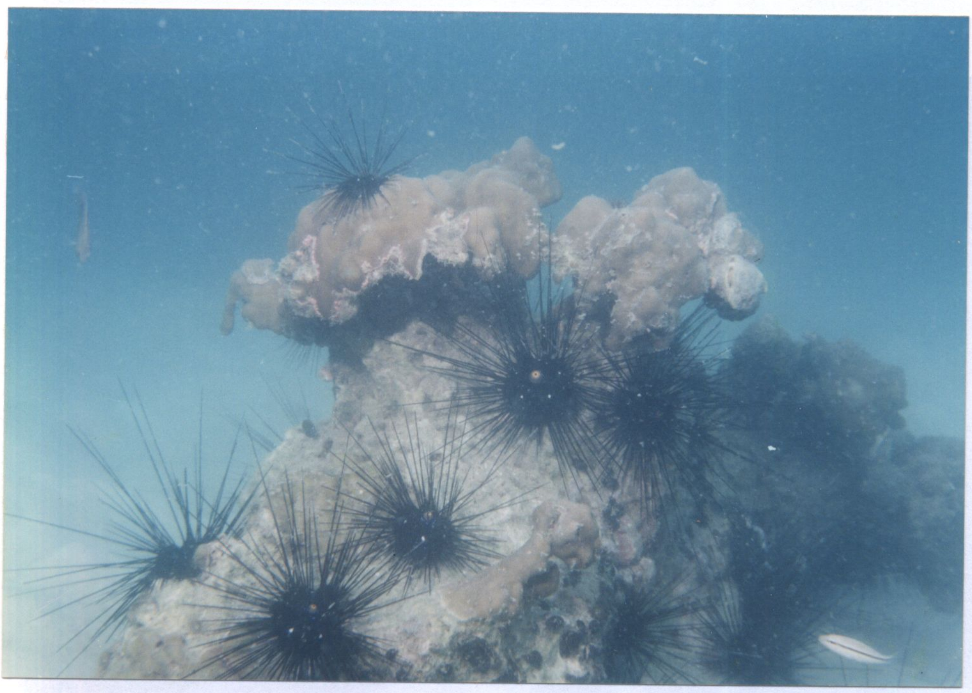


Figure 51 The Effect of *D. setosum* on *Porites lutea*

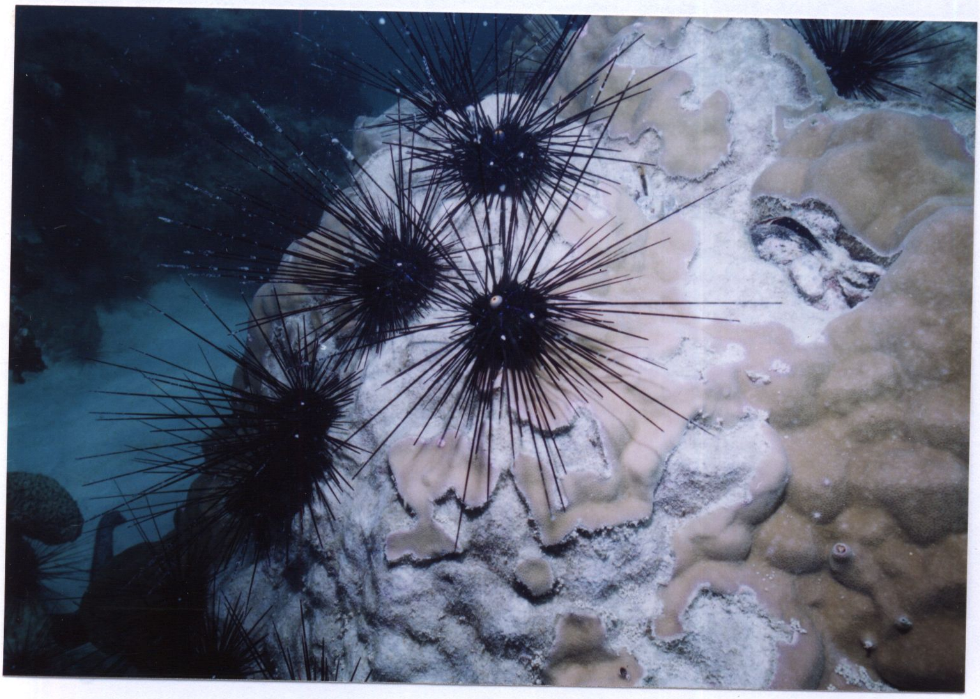


Figure 52 Bioerosion by *D. setosum* Weakens the Coral and Makes it Vulnerable to Physical and Chemical Erosion.

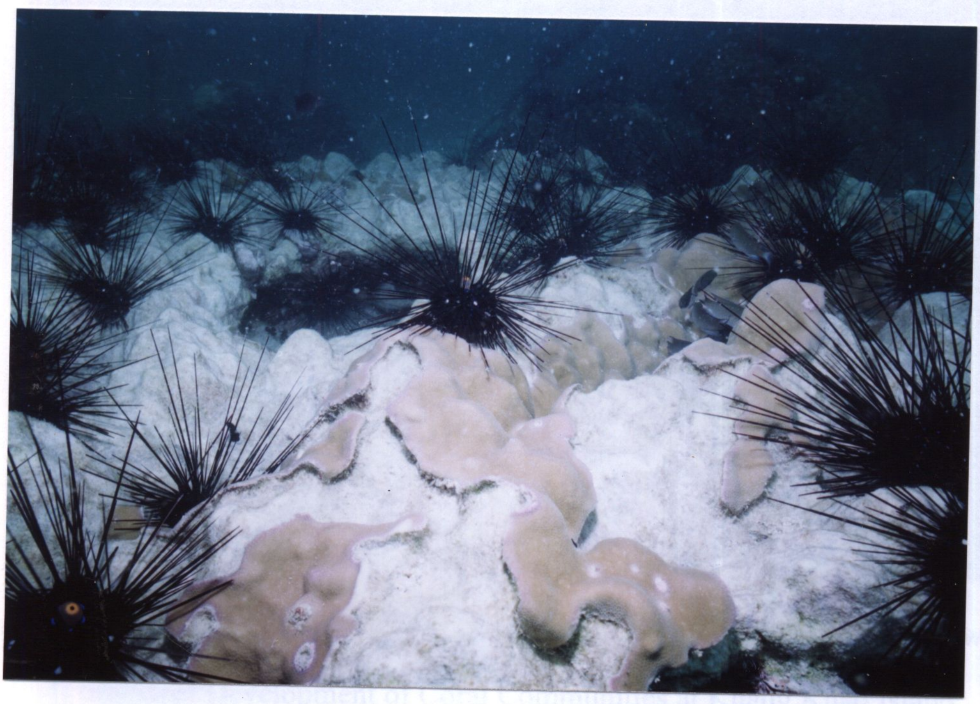


Figure 53 High Density of *D. setosum* Enhances the Bioerosion Rates.

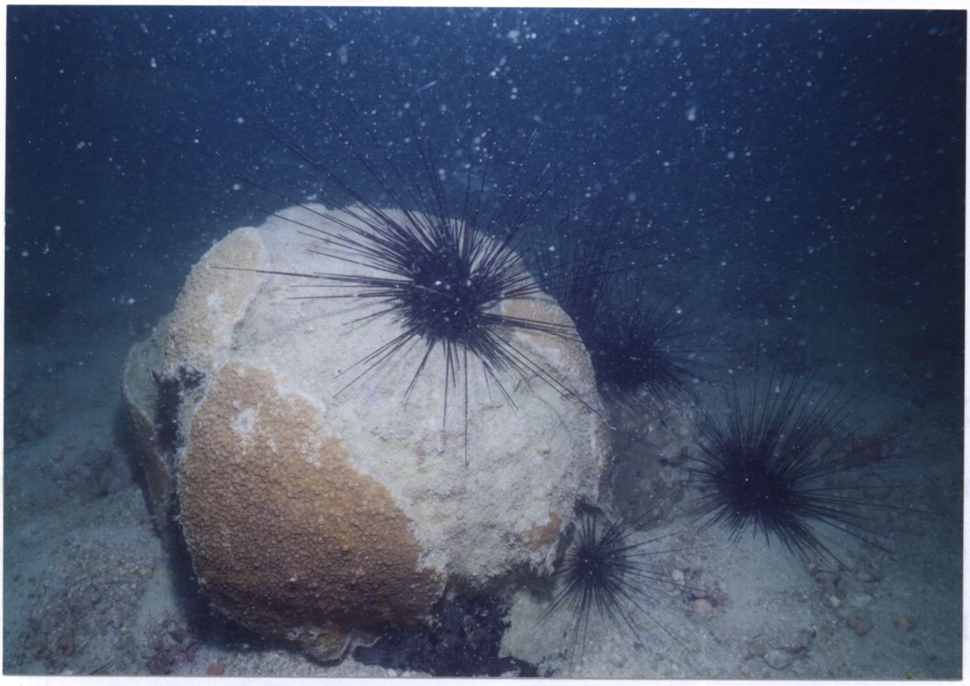


Figure 54 *D. setosum* Grazes on Dead Part of Massive Coral.

Figure 55 Bioerosion by *D. setosum* is One of the Factors Controlling Reef Growth and Reef Development of Coral Communities at Khang Khao Island.

CHAPTER 4

DISCUSSIONS

The distribution pattern and population density of *D. setosum* at Khang Khao Island clearly showed the similar trends. The high densities of *D. setosum* were always found in the shallowest zones and decreased in the coral and deepest zones, respectively. Consequently, the results implied that population density of *D. setosum* generally increases with depth. Previous studies reported that population densities of *D. setosum* were in the range of 4-38 inds.m^{-2} and 12-28 inds.m^{-2} at the intertidal and subtidal areas, respectively (Tsuchiya and Lirdwitayapasit 1986, 22; Tsuchiya et al. 1986, 88). For this study, maximum mean density of *D. setosum* was 11.76 inds.m^{-2} which overlaps in the range of the previous studied. However, measurement methods were different. The present study used random quadrat for determining the population density of *D. setosum* while the previous studies used belt transect method. Nevertheless, *D. setosum* in coral communities at Khang Khao Island is exclusively a dominant echinoid species in this area throughout thirteen years (Ruengsawang and Yeemin 1998, 219).

During April-May 1998, the first severe coral bleaching phenomenon occurred in the Gulf of Thailand. Mean population density of *D. setosum* in the shallowest zones of Khang Khao Island appear to be increasing which probably depends on many factors. After coral bleaching, filamentous algae obviously grew on many substrates such as rock, boulder, dead corals, dead parts of live coral colonies and live corals which are valuable food resources of *D. setosum*. The recruitment rate of *D. setosum* after the event of coral bleaching seems to increase. The results of size-class distribution indicated that the small sizes of *D. setosum* were clearly observed in June 1998 than that in February and November 1998.

Several investigators suggested that increasing of sea urchin population is caused by predator reductions such as Balistidae (triggerfishes) and low competitive pressure by herbivorous fishes due to overfishing (Glynn et al. 1979, 48; Hay 1984, 451; McClanahan and Muthiga 1989, 91; McClanahan and Shafir 1990, 368; McClanahan et al. 1994, 253; Watson and Ormond 1994, 127). In case of Khang Khao Island, the previous studied clearly showed that four families of herbivorous fishes such as Scaridae, Acanthuridae, Siganidae and Kyphosidae were absent while Pomacentidae was the dominant herbivorous fishes (Menasveta et al. 1986, 116). However, it seems to be that competition between herbivorous fishes and *D. setosum* was much lower pressure. In addition, *D. setosum* around this area obviously showed that it normally displayed activities both during day and night times (unpublished data). This evidence supported that predation pressure on *D. setosum* in this area was comparatively low.

In this study, bioerosion by *D. setosum* was calculated from the total $CaCO_3$ in gut contents for estimating daily erosion. This method appears that most of substrates broken free by grazing process are not ingested and cannot be measured in the field experiments. Therefore, the rates of bioerosion from this study may be underestimated. This is the first study on bioerosion by

D. setosum in Thai waters. Therefore, this available data provide opportunity to compare with the reports of the other workers from elsewhere. Bioerosion rates in the present study are in the range of 0.34-1.43 g $CaCO_3$/individual/m^2 and the mean bioerosion rate is 0.99 g $CaCO_3$/individual/day which is higher than the previous reports (Scoffin et al. 1980, 475; Glynn 1988, 147; Bak 1990, 267; Mokady et al. 1996, 370). However, certain reports show the higher rates of bioerosion compared to this study (Hunter 1977, 108; Stearn and Scoffin 1977, 475; Bak 1990, 267) (Table 5). The comparison of rate of bioerosion of the same sea urchin species shows that the figure of this study was higher than that of the previous study from Mokaday (1996, 370). However, it should be kept in mind that the methods for estimating bioerosion rates were different.

Population density of *D. setosum* varied in space and time. The highest bioerosion rate, 15.07 $g.m^{-2}.d^{-1}$, in June 1998 confirmed that bioerosion rate depended on sea urchin density. This bioerosion rate is higher than that reported by Bak (1990, 267). Reported rates of bioerosion by sea urchin usually are in the range of 3-9 kg $CaCO_3/m^2$/year while bioerosion rates for this study are in the range of 1.64-5.5 kg $CaCO_3/m^2$/year and overlap the former reports.

Moordee (1987, 96) reported that the average maximum bioerosion rate by borers was in the range of 67.98-214.74 g $CaCO_3/m^2$/year. However, this study clearly shows that bioerosion rate by *D. setosum* is in the range of 1,658.8-5,500.5 g $CaCO_3/m^2$/year which is much higher than that caused by the borers. These results agree with Moordee (1987, 136) who indicated that *D. setosum* was an efficient bioeroder at Khang Khao Island.

Table 5 Comparison of Bioerosion by Sea Urchins.

Species	**Bioerosion rates (g $CaCO_3$. $ind^{-1}.d^{-1}$)**	**Locality**	**Reference**
Diadema setosum	0.99	Khang Khao Island	**This study**
	0.31	Eilat	Mokady et al. 1996
Diadema mexicanum	0.19	Ulva Island	Glynn 1988
Diadema savignvi	1.92	Moorea	Bak 1990
Diadema antillarum	1.07	Barbados	Stearn and Scoffin 1977
	1.16	Barbados	Hunter 1977
	0.63	Barbados	Scoffin et al. 1980
Echinometra mathaei	0.12	Moorea	Bak 1990
	0.12	Eilat	Mokady et al. 1996

The most important aim of bioerosion study is to find out the balance between construction and destruction forces which is the result decided the fate of coral reef. On certain reefs, the calcium carbonate budget has been reported (Scoffin et al. 1980, 475-508; Bak 1990, 267-272; Le Campion-Alsumard et al. 1993, 685; Conand et al. 1997, 953-958; Pari et al. 1998, 128). Unfortunately, more data of rates of reef growth and reef destruction in coral communities at Khang Khao Island are required in order to calculate the calcium carbonate budget. However, Sudara et al. (1991, 108) reported that average growth of *Porites lutea*, the most dominant coral species at Khang Khao Island, was approximately 9 $mm.y^{-1}$ which was significantly correlated with the amount of suspended solid but not with sedimentation rate. Therefore, the bioerosion rates caused by *D. setosum* at Khang Khao Island is considerably important for regarding coral reef development in this coral community. It is possible that bioerosion rates are higher than accretion rates of $CaCO_3$.

Many others have discussed the relationship between bioerosion rate and size of sea urchin. Bak (1990, 271; 1994, 101) and Conand et al. (1997, 954) concluded that size of sea urchin was related with $CaCO_3$ in gut content. However, Mokady et al. (1996, 371) pointed out that sea urchins of different size classes, or of different species may have profoundly different gut contents, but their gut turn over rates may vary just as much. Therefore, sea urchins having larger gut contents do not necessarily ingest more food and $CaCO_3$ per unit time. His study on gut turn over rates of sea urchins such as *Echinometra mathaei* and *Diadema setosum* revealed that *E. mathaei*, smaller size than *D. setosum*, displayed the faster turn over rate.

Timing and duration of the experiments are also very important factor for estimating bioerosion rates. Several investigators carried out their experiments during very early in the morning for avoiding interruptions of urchin activities. They assumed that sea urchins feed during the night and inactive during the day. Calculation of daily bioerosion was based on the assumption that defecation rate is constant throughout day and night. The experiments on defecation rates of different species of sea urchins by Mokady et al. (1996, 369) showed very constant rate of defecation. This result supports the assumption of a constant rate of defecation of sea urchins. For this study, the rate of defecation rates of *D. setosum* also seems to be constant rates during twelvc hours of the experiment (unpublished data). Consequently, these results contradict a suggestion that nocturnally feeding echinoids might have higher defecation rates at night.

Several factors affecting the enhancement of bioerosion rates are interesting aspects of this study. Evidently, rates of bioerosion during and after the event of coral bleaching are higher than prior to the coral bleaching event. This evidence suggests that primary disturbances to coral community lead to continue and intensify reef perturbation (Hutchings 1986, 246; Glynn 1988, 130; Hallock 1988, 279; Sammarco 1990, 154; Kiene and Hutchings 1994, 97; Eakin 1996, 117; Reaka-Kudla et al. 1996, 106; This study).

The intensity of bioerosion by *D. setosum* in this area is markedly increasing due to high population density. In my opinion, it is impossible for the removing sea urchins from this area since the change of species composition may lead to another problems. Therefore, the natural management is the suitable way that may need long period of times to solve this problem.

Finally, future study on the calcium carbonate budgets of coral communities at Khang Khao Island is very important for providing basic information to understand the coral reef development in this area. Furthermore, the long-term monitoring on the change of species composition that inhabits in this area is also the most important complementary information on the process of reef development.

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