# Population Structure of *Padina boryana* Thivy (Dictyotales, Heterokontophyta) in Two Locations in Phuket Province in Southern Thailand

Bongkot Wichachucherd

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Ecology (International Program)

Prince of Songkla University

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| **Author** | Miss Bongkot Wichachucherd |
| **Major Program** | Ecology (International Program) |

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**Major Advisor**

............................................
(Asst. Prof. Dr. Anchana Prathep)

**Co-advisor**

............................................
(Prof. Dr. Larry B. Liddle)

**Examining Committee**

............................................Chairperson
(Assoc. Prof. Pimpan Tansakul)

............................................Committee
(Asst. Prof. Dr. Anchana Prathep)

............................................Committee
(Prof. Dr. Larry B. Liddle)

............................................Committee
(Prof. Dr. Khanjanapaj Lewmanomont)

**The Graduate School, Prince of Songkla University, has approved this thesis as partial fulfillment of the requirements for the Master of Science Degree in Ecology (International Program)**

............................................
(Assoc. Prof. Dr. Krerkchai Thongnoo)
Dean of Graduate School

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| **ชื่อวิทยานิพนธ์** | โครงสร้างประชากรของสาหร่ายชนิด *Padina boryana* Thivy บริเวณพื้นที่จังหวัดภูเก็ต ตอนใต้ของประเทศไทย |
| **ผู้เขียน** | นางสาวบงกช วิชาชูเชิด |
| **สาขาวิชา** | นิเวศวิทยา (นานาชาติ) |
| **ปีการศึกษา** | 2550 |

## บทคัดย่อ


สาหร่ายสกุล *Padina* มีการกระจายทั่วโลกในเขตร้อน และเขตกึ่งร้อน สาหร่าย *Padina* มีเบลดเป็นรูปพัด บริเวณปลายเบลดขอบจะม้วน และมีลายของแถวขนและเซลล์สืบพันธุ์ สลับอยู่บนเบลด *Padina* จะยึดเกาะพื้นที่ที่มีลักษณะแข็งและ บางช่วงเวลาก็สามารถเจริญบนพื้นทรายได้ การที่สาหร่ายสกุลนี้มีการกระจายได้ดีและหนาแน่นในหลายพื้นที่ จึงเป็นที่มาของคำถามที่ว่า ทำไม *Padina* จึงมีการเพิ่มจำนวนประชากรได้ดี และปัจจัยใดที่ส่งผล ต่อการสืบพันธุ์ของสาหร่าย สมมติฐานในการศึกษาได้รวมเอารูปแบบการเจริญ การสร้างเซลล์สืบพันธุ์และการลงเกาะในธรรมชาติ มาอธิบายโครงสร้างประชากรของ *Padina boryana* Thivy ของสองบริเวณที่เลือกทำการศึกษา คือ อุทยานแห่งชาติสิรินาท และอ่าวตังเข็น โดยพิจารณาเรื่องรูปแบบการกระจายและจำนวนของทัลลัสในแต่ละระยะในวงจรชีวิต ลักษณะการเจริญ การเจริญพันธุ์ การตาย และการลงเกาะใหม่ โดยทั้งสองบริเวณที่ศึกษาใช้วิธีการศึกษาเหมือนกัน โดยเก็บตัวอย่างจำนวน 30 ทัลลัสทุกๆระยะ 20 เมตร โดยพื้นที่การแพร่กระจายของ *P. boryana* ตัวอย่างที่ได้นำมาวัดหาค่าการเจริญเติบโต และความสามารถในการสืบพันธุ์ โดยแต่ละทัลลัสจะวัดความสูง ความกว้าง ระยะการเจริญพันธุ์ นับจำนวนเซลล์สืบพันธุ์ที่สร้างและที่ปล่อยแล้ว นำข้อมูลที่ได้ในส่วนนี้จากทั้งสองบริเวณมาเปรียบเทียบ และได้ทำการศึกษาการลงเกาะใหม่ของ *P. boryana* ในพื้นที่ภาคสนาม นำข้อมูลที่ได้ของทั้งสองบริเวณที่ศึกษามาเปรียบความเหมือน และความแตกต่างของสองประชากร โดยเริ่มการศึกษาตั้งแต่ เดือนกันยายน 2548 และเสร็จสิ้นการเก็บตัวอย่างในเดือนสิงหาคม 2549 ประชากรของ *P. boryana* ทั้งสองประชากรที่ศึกษา มีรูปแบบการเจริญเหมือนกัน ในเรื่องระยะการดำรงชีพ และรูปแบบการกระจายของประชากร (population distribution) ปัจจัยพื้นฐานที่ส่งผลสำคัญต่อการเจริญ และการลงเกาะของ *Padina* คือ ความแรงของกระแสคลื่น และปริมาณตะกอน พบว่าการที่ *Padina* มีความสามารถในการสร้างและปล่อยเซลล์สืบพันธุ์ได้ตลอดทั้งปีรวมถึงความสามารถในการลงเกาะสูง ทำให้เพิ่มประชากรใหม่ได้มาก จึงพบประชากร *Padina* จำนวนมากในธรรมชาติ

**Thesis title** Population Structure of *Padina boryana* Thivy (Dictyotales, Heterokontophyta) in Two Locations in Phuket Province in Southern Thailand

**Author** Miss Bongkot Wichachucherd

**Major Program** Ecology (International Program)

**Academic Year** 2007

## ABSTRACT

The genus *Padina*, a brown alga in the phylum Heterokontophyta (Class Phaeophyceae), has a worldwide distribution in tropical and subtropical climate zones. All species of *Padina* have a fan-shaped blade, an infurled apical row of meristematic cells and a filamentous or felty holdfast. *Padina* attaches to rock, dead coral or any solid substrate and may be partially or wholly buried in sand periodically. Reproductive sori are also formed in concentric bands gradating in maturity from the apex to the base of the blade. They alternate in some species with rows of reproductive cell and rows of sterile hairs. Because of the broad distribution of this genus, we posed the question: How does *Padina* increase the number of individuals and what factors support its reproduction? The purpose of this project is to study the population structure of *Padina boryana* Thivy in two locations in Phuket province. The hypothesis includes the idea that characteristic patterns of growth, reproduction and recruitment in the natural habitats will determine the distribution of particular phases of the life history, the numbers of each phase and the annual cycle of maturation, death and then recruitment of new individuals. The two populations at the contrasting habitats of Sirinart National Park and Tang Khen, show similarities and differences over the year of study. Thirty samples have been collected at 20 meter intervals from the shoreline in the intertidal zones. The length, radius, maturity phase, quantity of reproductive cells and quantity of released reproductive cells were recorded for each individual. Specimens were put into size classes defined by length and radius. The frequencies of these classes were calculated. The maturity phase is categorized according to a maturity index. The recruitment study was carried out on hard substrata *in situ*. The research was started in September 2005 and finished in August 2006. The two population of *P. boryana* are the show with respect to life phases and distribution. The important factors which influence the growth of *Padina* and its recruitment are wave action and sedimentation. The high number of reproductive spores throughout the year and other recruitment mechanisms promoted the successful establishment of *Padina* populations on the shore.

# ACKNOWLEDGEMENTS

I would like to express my gratitude to Associate Professor Sunthorn Sotthibandhu, Associate Professor Chutamas Satasuk, Assistant Professor Anchana Prathep and Professor Larry B. Liddle for giving me inspiration and suggestions during the course of this work.

I am also greatly indebted to the team from the Seaweed and Seagrass Research Unit, Prince of Songkla University, Hat Yai, for helping me in the field work.

The financial support from the TRF/BIOTEC Special program for Biodiversity Research and Training grant BRT T_349005 made this thesis possible. This work was partially funded by Graduate School, Prince of Songkla University, Hat Yai, Songkhla.

Bongkot Wichachucherd

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# CHAPTER 1

# INTRODUCTION

Seaweeds are a diverse group of marine macro-algae. They are usually attached to a solid substrate and are referred to as benthic in habit. They are diverse in size, morphology and color and fall naturally into several divisions or phyla based on biochemical and cellular features. Seaweeds may be small filaments (1 mm), encrusting or upright calcified blades, broad foliose blades or large complex organisms called kelp (> 25 m long). They may survive and even thrive in stressful environments such as at the edges of reefs, in crashing waves, in the dim subtidal zone (220 m. deep) and in the intertidal zone. The intertidal zone, especially in the tropics has many stressful aspects which impinge on organisms and challenge their survival. High light intensities, high temperatures and desiccation (Campbell *et al.*, 1998) are especially important. Therefore the intertidal zone is an interesting habitat in which to study the populations of seaweed that can survive and distribute their populations abundantly.

The genus *Padina*, a brown alga in the Phylum Heterokontophyta, Class Phaeophyceae and Order Dictyotales (Lee, 1999), has a worldwide distribution in tropical and subtropical climate zones. *Padina boryana* Thivy is one of the most common species along the coasts of Thailand. This species was recognized as part of the record for Thailand in 1984 by Lewmanomont (1984). *P. boryana* can form extensive communities in intertidal and subtidal zones. It attaches to hard substrate and may periodically be partially or wholly buried in sand. The characteristic fan-shaped thalli, which grow from an apical cell row meristem, have periodic reproductive sori containing a homogeneously dense arc of reproductive cells. *Padina*, like all other genera in the order Dictyotales, shows an alternation of isomorphic generations type of life history with three possible vegetatively-identical thallus types: a sporophyte and two gametophytes (male and female). There are many species of *Padina* in Thailand. Nine have been described and recorded by Maneerat (1974); Pengseng (1992) and Lewmanomont and Ogawa (1995). They are *P. australis* Hauck, *P. durvillaei* Bory de Saint-Vincent, *P. boryana* Thivy (synonym *P. tenuis* Bory), *P. commersonii* Bory de Saint-Vincent), *P. tetrastromatica* Hauck, *P. pavonica* Linnaeus (synonym *P. pavonia*), *P. gymnospora* (Kutzing), *P. distromatica* Hauck, *P. minor* Yamada, and *P. japonica* Yamada

In the intertidal zone, many biological and physical factors affect the growth of seaweeds. Nutrient concentration (Schaffelke, 1999; Ichiki *et al.*, 2000; Kuffner and Paul, 2001; Szmant, 2002; Lapointe *et al.*, 2004; Palomo *et al.*, 2004; Roberson and Coyer, 2004), light intensity (Hansen, 1977; De Ruyter Van Steveninck and Breeman, 1987; Flores-Moya *et al.*, 1996; Ateweberhan, 2006; Plouguerné *et al.*, 2006), wave action (Payri, 1984; De Ruyter Van Steveninck and Breeman, 1987; Prathep *et al.*, 2006), temperature (Creed *et al.*, 1998; Hwang *et al.*, 2004), substrate type (Quartino *et al.*, 2001; Diez *et al.*, 2003) and herbivory (Lewis *et al.*, 1987; Steneck and Dethier, 1994; Van Alstyne *et al.*, 2001) are all important. These factors are known to influence distribution (Campbell *et al.*, 1998) and are known to be limiting factors for growth, reproduction, dispersal and settlement (Graham, 2002).

*Padina* spp. are dominant along the intertidal rocky shores of Phuket Province (Prathep, 2005; Thongroy *et al.*, 2007) and also in the shallow subtidal zone in

Talibong, Trang (Prathep and Tantiprapas, 2006) and in Samui, Surat Thani (Mayakun and Prathep, 2005). In Phuket, it is especially easily observed at Sirinart National Park and Tang Khen Bay. Many factors contribute to the survival, growth and development of *P. boryana*, however, the patterns of the physical and biological factors that regulate the populations have not been studied. In other words, the specific parameters which allow *P. boryana* to survive the stressful conditions of the tropical intertidal zone are not fully understood. The purpose of this study is to investigate the patterns of the complex processes of recruitment, growth and reproduction of *P. boryana*. Since it grows rapidly and forms reproductive cells throughout the year (Prathep, 2005), *P. boryana* is a good model subject to study year round in order to establish its reproductive potential and understand how it is fulfilled. The hypothesis of this study is that characteristic patterns of growth, reproduction and recruitment determine the population structure of *P. boryana* in the natural habitats. The differences and similarities of the two sites help establish the true basis of the controls on this species.

## Review of literature

### The characteristics of the genus *Padina*

Classification of *Padina* following Lee (1999).

Kingdom Protista

Division (Phylum) Heterokontophyta

Class Phaeophyceae

Order Dictyotales

Family Dictyotaceae

Genus *Padina* Adanson

Species *Padina boryana* Thivy

*Padina* is an unusual example of a brown alga in that it is calcified. Calcification in seaweeds is more common in green and red algae (Kraft *et al.*, 2004). *Padina boryana* thalli are erect, flattened, fan-shaped and parenchymatous (Figure 1). They attach by a rhizoidal holdfast. In submerged plants, the "fan" is often curved into a funnel shape and is composed of tufts of many overlapping lobes. Concentric lines, formed by hairs or hair scars, mark the frond. Reproductive sori of sporangia or oogonia appear as aggregations of minute dark spots also in concentric rows on the lower surface. Antheridia are colorless and low relief. The upper surface is always encrusted with calcareous substance. In *P. boryana*, plants are a greenish brown color. The blades are 2 cells thick throughout the thallus. The reproductive structures, sporangia, oogonia and antheridia, appear in alternate bands between the lines of hairs (Maneerat, 1974;

Geraldino, 2004). In the absence of reproductive structures it is not possible to determine the species of a *Padina* specimen.

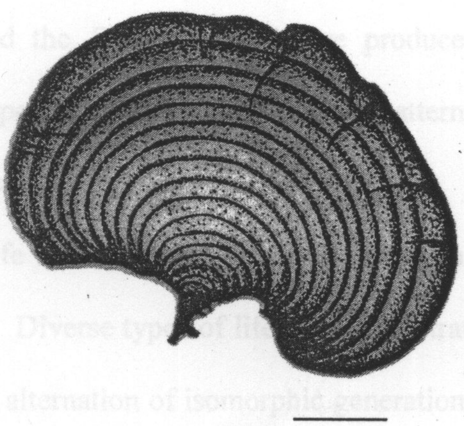



Figure 1. The whole thallus of *Padina boryana* Thivy

**Diversity of *Padina* in Thailand**

Many investigations of algae in Thailand have emphasized their diversity by describing the species (Maneerat, 1974; Pengseng, 1992; Lewmanomont and Ogawa, 1995). From these reports, nine species of *Padina* have been recorded from Thailand as mentioned above. Identification of *Padina* species has been problematical because of synonyms, that is, one species has been given many names by different authors who have collected them from different places. Also, some species do not have sufficiently detailed descriptions (Wynne and De Clerck, 1999).

**Growth and reproduction of *Padina* species**

*Padina* fronds have an infurled apical cell row. Both upright fronds and a prostrate stage called the *Dictyerpa* stage are produced. It is therefore vegetatively dimorphic. *Padina* species have variable growth patterns and reproduction also varies during the annual cycle.

The life history of any organism is its basic strategy for survival of the population in nature. Diverse types of life history or strategy are expressed amongst the algae. *Padina* has an alternation of isomorphic generations type of life history (Figure 2) involving a diploid sporophyte (a spore-producing phase) and haploid gametophytes (gamete-producing phases), characteristic of all members of the Dictyotales. The life cycle is of the isomorphic diplohaplontic type.

The sporophyte produces large haploid aplanospores (tetraspores) by meiosis from tetrasporangia which develop from epidermal cells and are clumped together in sori. The naked tetraspores are released by gelatinization of the apex of the sporangium, and soon after liberation, secrete a cellulose wall and develop into identical-looking monoecious or dioecious gametophytes (Lee, 1999) (Figure 2). *P. boryana* is dioecious (Maneerat, 1974; Geraldino, 2004).

Sporangia, oogonia and antheridia are formed in concentric rows of sori on the blade surface. Tetrasporangial sori appear to the naked eyes as dark spots forming dark rows on the upper blade. Fertile female gametophytes and sporophytes are difficult to distinguish from each other in surface view because sporangial and oogonial sori are rather similar in size and color. They can be distinguished by the cell size and the morphology of the sori (Figure 3-4). In *P. boryana* as in *Dictyopteris undalata*, sporangia at maturity are usually bigger in diameter than oogonia (Tanaka, 1998). Mature oogonia are more spherical or slightly ovoid and ca. 78 x 50 µm. diameter (Garreta *et al.*, 2007). Moreover, the fertile female gametophyte shows a light band on the upper surface of the blade and the oogonia are packed into wave-like sori. Antheridial sori are distinguished macroscopically from tetrasporangial and female sori by their whitish color and may be confused with sterile thalli. Sporophytes, female and male gametophytes appear similar and cannot be distinguished from each other when they are sterile. Sexual maturity in male gametophytes is more difficult to determine because antheridia and the small motile sperm are much less conspicuous than oogonia and eggs. However, antheridia are always seen prior to the release of eggs by females.

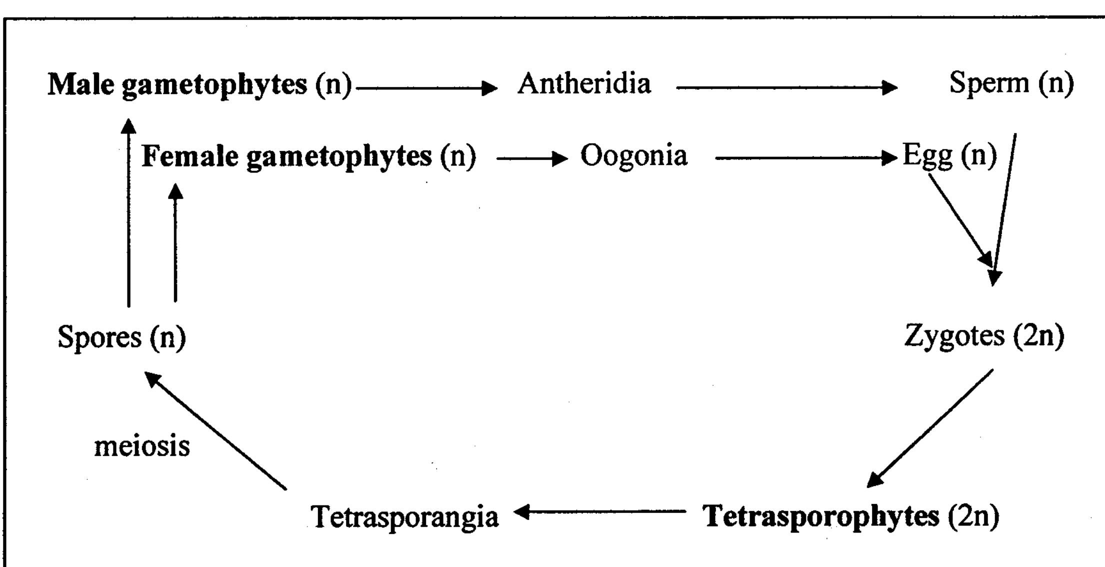



Figure 2. Diagram of the life cycle of *Padina boryana* Thivy (modified from Lee, 1999).

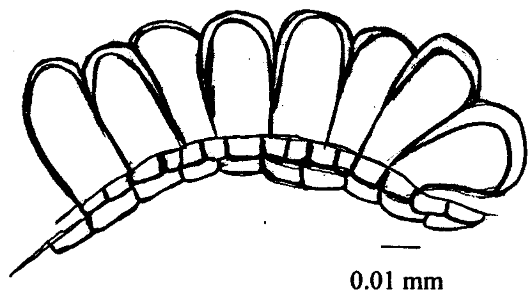



Figure 3. The longitudinal cross-section of *Padina boryana* (X400) showing the oogonia packed on the blade.

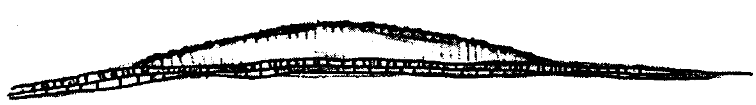



Figure 4. The longitudinal cross-section of *Padina boryana* (X100) showing the reproductive sori of antheridia.

**Recruitment**

Recruitment is of fundamental importance to population structure because it is the foundation upon which all subsequent interactions within the population take place. When recruitment fails, the new individuals do not have the opportunity to survive and that establishes the population structure. According to Woodin *et al.* (1995) there are two types of process that determine the recruitment success of organisms. First, the number of reproductive cells that reach a site and are retained is of primary importance and second, mortality during or after settlement.

**Environmental factors**

Many biological and physical factors influence *Padina* populations in nature. There is a paucity of relevant research reports on the subject. The Garreta *et al.* (2007) study of fertile gametophytes of *P. pavonica* revealed that the most important factor is the water temperature at the time of the early development of gametophytes. At higher temperatures, the gametophytes tend to be dioecious, while lower water temperatures apparently increase the ratio of monoecism.

The effects of salinity, pH and temperature on the spores and sporelings of *P. tetrastomatica* Hauck have all been studied (Subbaraju *et al.*, 1982). The alga showed tolerance to salinities between 27 and 32‰. At salinities <17.9‰ and >32.1‰ no spores survived. Temperatures between 23-28 °C and pH 8.0-8.5 were shown to be optimal for growth. The results of these studies will be compared with the observations made during this project.

Benthic algae have several life-history stages that may respond differently to environmental pressures. Algal propagules (spores and zygotes in the case of *Padina*) are released into the water column and dispersed. After they settle and attach they become part of the microscopic benthic community. The impacts of herbivory and nutrients cannot be assumed to be uniform, but will vary depending on the species, the life history stage or demographic factors (Diaz-Pulido and McCook, 2003). For example, growth and density of *Sargassum fissifolium* was affected by herbivore grazing while *Lobophora variegata* does not show any signs of grazing damage (Diaz-Pulido and McCook, 2003) even though they are part of the same community. The growth form of *L. variegata* is similar to the early post recruitment stage of *Padina* sp. However, its small fan-shaped thallus is prostrate and part of the under story and grows at greater depths on coral substrate. Moreover, *Padina* accumulates calcium on the blade which is reported to resist herbivores (Hay, 1985). Some publications report that one of the major causes of increased macroalgal abundance is high nutrient levels in the seawater. Schaffelke (1999) reported that the net photosynthetic rate was also higher and indicated that the growth would be expected to be faster. Algal fecundity would be higher due to its positive correlation with size (Nordemar *et al.*, 2007).

## Hypothesis

The characteristic patterns of growth, reproduction and recruitment determine the population structure of *Padina boryana* Thivy in the natural habitats. Differences in these patterns would also explain variations at two different intertidal sites.

## Objectives

1. To monitor the population structure of *P. boryana* in two locations in Phuket.
2. To study the relationship between growth and maturity and to describe the optimal growth and reproductive potentials.
3. To investigate the reproductive cycle and define the time of production of new individuals.
4. To investigate the potential recruitment on the hard substratum.
5. To determine the factors to which the differences in growth, reproduction and recruitment at the two study sites can be attributed.

**Research Questions**

An experiment was designed to address the following questions:

1. Do populations of *P. boryana* show the same population structure at two study sites?
2. Does growth of *P. boryana* relate to its reproduction?
3. When does *P. boryana* show the gametophyte and sporophyte life stages and when does it produce the reproductive cells?
4. How does it recruit on the hard substratum in nature?
5. What are the factors that can trigger the differences between two *Padina* populations at Koh Phuket?

# CHAPTER 2

# MATERIALS AND METHODS

## Study sites

This study was carried out at two field sites in Phuket Island/Province (7°45' - 8°15'N 98°15' - 98°40'E) (Figure 5): Sirinart National Park (SNP) and Tang Khen Bay (TKB). SNP is located at the northwest side of Phuket and TKB on Cape Panwa on the southeast side. The sites are both in the intertidal zones. The environmental factors such as desiccation, light intensity, prevailing winds, amount of sedimentation and nutrient concentration that might influence the *Padina* population, were determined. In addition, during the monsoon the strong winds from the southwest hit the SNP site directly and are less forceful at TKB, on the more protected side of Phuket Island. The average rainfall showed the dry season in November-April (average rainfall 91.33±26.7 $mm^3$) and rainy season in May-October (average rainfall 325.93±22.77 $mm^3$) (http://www.tmd.go.th/province_stat.php?StationNumber=48565).

*P. boryana* is abundant at both sites attached to hard substrates such as dead coral and rocks (Figure 6). It occurs from 0-120 m from the shore at SNP and from 140-260 m at TKB. The exposure time during low tide of both populations is essentially the same.

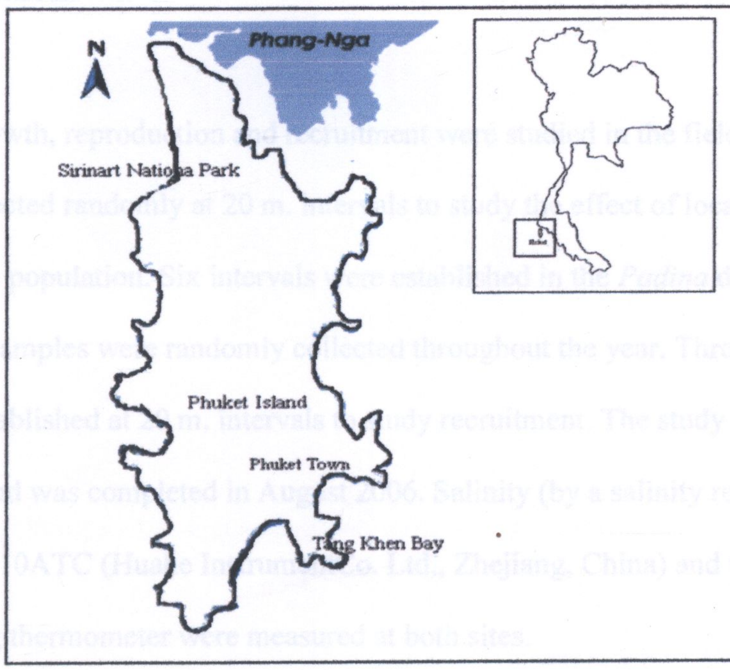



**Figure 5. Map of Phuket showing the two study locations; Sirinart National Park and Tang Khen Bay.**

**Figure 6. Populations of *Padina boryana* Thivy from study sites; SNP (left) and TKB (right).**

**Materials and Methods**

Growth, reproduction and recruitment were studied in the field. Thirty samples were collected randomly at 20 m. intervals to study the effect of location in the littoral zone on the population. Six intervals were established in the *Padina* distribution area (Figure 10). Samples were randomly collected throughout the year. Three permanent plots were also established at 20 m. intervals to study recruitment. The study began in September 2005 and was completed in August 2006. Salinity (by a salinity refractometer model XHO RHS-10ATC (Huake InstrumentCo. Ltd., Zhejiang, China) and water and air temperatures using thermometer were measured at both sites.

**1. Growth study**

The surface area of the fan-shaped thallus was calculated for the growth study. Samples were collected from the 6 shore levels. The radius (r) and length (l) were measured (Figure 7) for insertion in the following equation.

$$\text{Surface area} = \pi r l$$

To compare the population structure between two sites, all samples were grouped into size classes according to frequency of surface area. The histograms of the two study sites were compared.

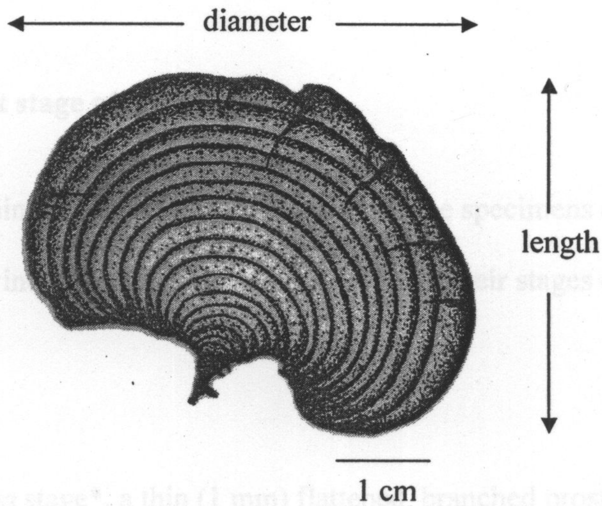



Figure 7. The whole thallus of *P. boryana* showing the length and diameter measurements.

## 2. Reproduction study

The samples were investigated separately at different shore levels as described above. Sporophytes, male and female gametophytes were determined. The portion of the sporangium sorus was 0.1-0.2 mm wide; the oogonial sorus was 0.8-0.13 mm wide and antheridial sorus was 0.8-0.1 mm wide on the blade. The sporophyte showed the sporangial size was bigger than the oogonial. They can be distinguished by their color and the reproductive line. In addition the oogonia are packed into a wave-like sorus on the blade while the sporangial sori are arranged more smoothly on the upper surface of the blade. The antheridia were difficult to detect by the naked eye. They are colorless and must be carefully observed under the compound microscope. The number of sporophytes, the number of reproductive rows, the quantity of spores and the quantity of released spores were monitored.

**2.1 The development stage of *P. boryana***

Preliminary observations indicated that the specimens could be conveniently divided into 5 different phases according to their stages of development and reproduction.

Phase 1: the *Dictyerpa* stage*, a thin (1 mm) flattened, branched prostrate stage.

Phase 2: juvenile: thalli with small blades, no lobes, no reproductive sorus.

Phase 3: early mature adult: thalli with a single reproductive sorus (the sporangium size 0.04 mm).

Phase 4: mature adult: thalli with more than one reproductive sori (the sporangium size mostly 0.08-0.1 mm).

Phase 5: late mature thalli: the spores, eggs and sperm already released from the reproductive sori (the sporangium size mostly 0.08-0.1 mm).

*The *Dictyerpa* stage, considered to be a perennating thallus, and because of its finer, prostrate habit, avoids both the abiotic and biotic factors that would affect the characteristic fan-shaped thallus of *Padina*.

Each plant was observed under the microscope to identify and categorize it according to the above five phases and also as to whether it was a sporophyte, female gametophyte or male gametophyte. The percentages of maturity phase and life history stage were recorded. Percentage of maturity was calculated by the number of mature thalli multiplied by 100 and then divided into the total number of thalli as the following:

$$\% \text{ Maturity} = \frac{\text{Amount of thallus (phase 3-5)} \times 100}{\text{Total}}$$

## 2.2 Calculation of number of spore

Preliminary observations showed that each sporangial sorus has a different pattern as described below according to 5 types. The sori are basically uniform with very small variations in the number of sporagia per area. Therefore, the number of each type of reproductive row for each thallus could be calculated by counting the number of sporangia in a random sample of 1 cm of the sorus (Figure 9). The average number of sporangia for each reproductive row was calculated based on the 1 cm area for each of the 30 thalli (Table 1). This number was multiplied by the length of the entire sorus and that indicates the total number of spores in each row in any particular spore arrangement. The condition of sporangial sori was put into 5 categories (Figure 8):

Type 1: a loose arrangement of small sporangium size (0.04-0.07 mm).

Type 2: a dense arrangement of small sporangium size (0.04-0.07 mm).

Type 3: a dense arrangement of mixed sporangium size (0.04-0.1 mm).

Type 4: a loose arrangement of big sporangium size (0.08-0.1 mm).

Type 5: a dense arrangement of big sporangium size (0.08-0.1 mm).

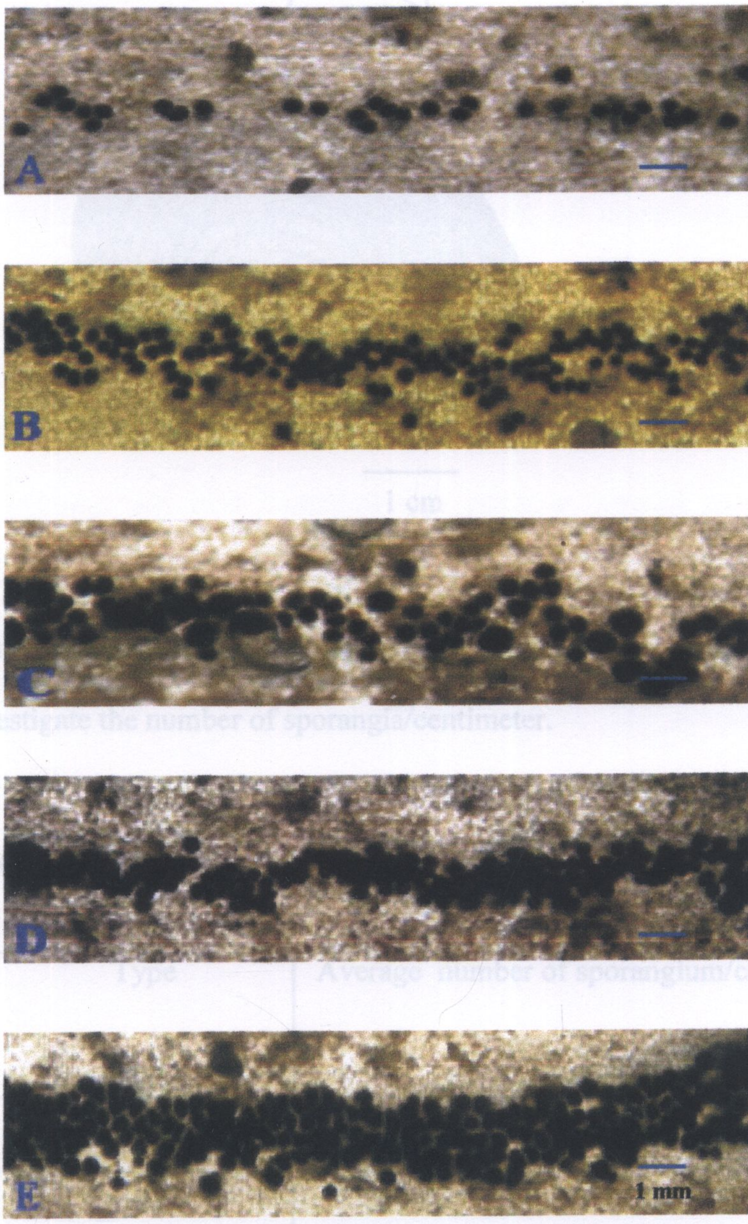



Figure 8. Sporangium arrangement on the surface of the blade (X40); A: type 1, B: type 2, C: type 3. D: type 4, E: type 5.

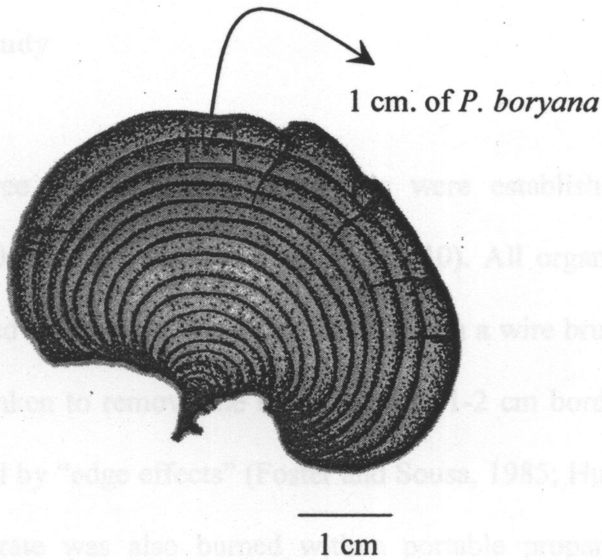



Figure 9. A one centimeter length of *P. boryana* reproductive line was randomly selected to investigate the number of sporangia/centimeter.

Table 1. The average number of each type of sporangium arrangement.

| Type | Average number of sporangium/cm (mean±SE) |
|---|---|
| 1 | 88±7 |
| 2 | 124±7 |
| 3 | 93±5 |
| 4 | 101±4 |
| 5 | 152±9 |

**3. Recruitment study**

Three 0.25 $m^2$ permanent plots were established randomly on hard substrata every 20 m in the *Padina* zone (Figure 10). All organisms in the permanent plots were removed and the substrate was scraped with a wire brush in the first month of study. Care was taken to remove the biota within a 1-2 cm border to avoid the bias of recruitment caused by "edge effects" (Foster and Sousa, 1985; Hutchinson and Williams, 2001). The substrate was also burned with a portable propane torch to sterilize it completely (Murray and Littler, 1978; Hutchinson and Williams, 2001). The number of new individuals was the basis for the data for this study. The percentage cover of *Padina* represented recruitment success by the quadrat method. The permanent plots were photographed to document the changes in the population.

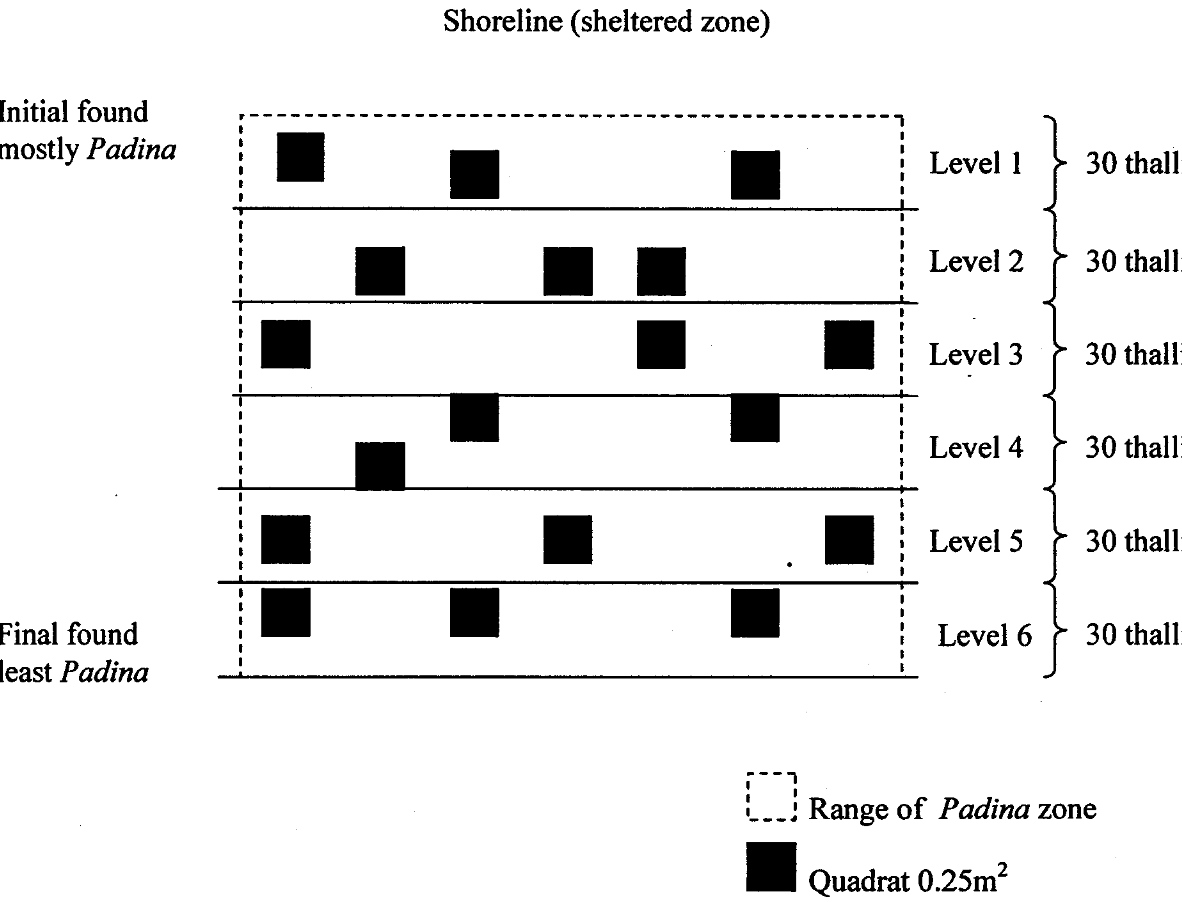



Figure 10. System of collection to assess the population distribution, reproduction and recruitment of *P. boryana*.

**Statistical analyses**

To compare the *Padina* population distribution at the 2 sites (TKB VS SNP), surface areas of 180 plants were measured and grouped into frequency size class distributions each month. The Kolmogonov-Smirnov test was employed to determine the differences of size distribution between sites and among months.

To compare the differences in average surface area, the number of produced and released spores, percentage of reproduction, percentage of sporophytes and percentage of gametophytes and percentage cover of *P. boryana* among shore levels (6 levels), among months (12 months) and between shores (2 shores). The data did not meet the assumptions of the parametric test even if they were transformed. Statistical results were presented based on non-parametric analyses (Stepwise Mann-Whitney U).

Spearman Rank Correlation Coefficient was employed to test the effects of physical factors such as air temperature, water temperature and salinity on average surface area, the number of produced and released spores, percentage of reproduction, percentage of maturity, percentage of sporophytes and gametophytes and percentage cover of *P. boryana*. Moreover, correlation between surface area and number of spores was also tested. All data were analyzed using SPSS for windows version 11.0. (Dytham, 1999; Monparwongsanon, 2003).

## CHAPTER 3

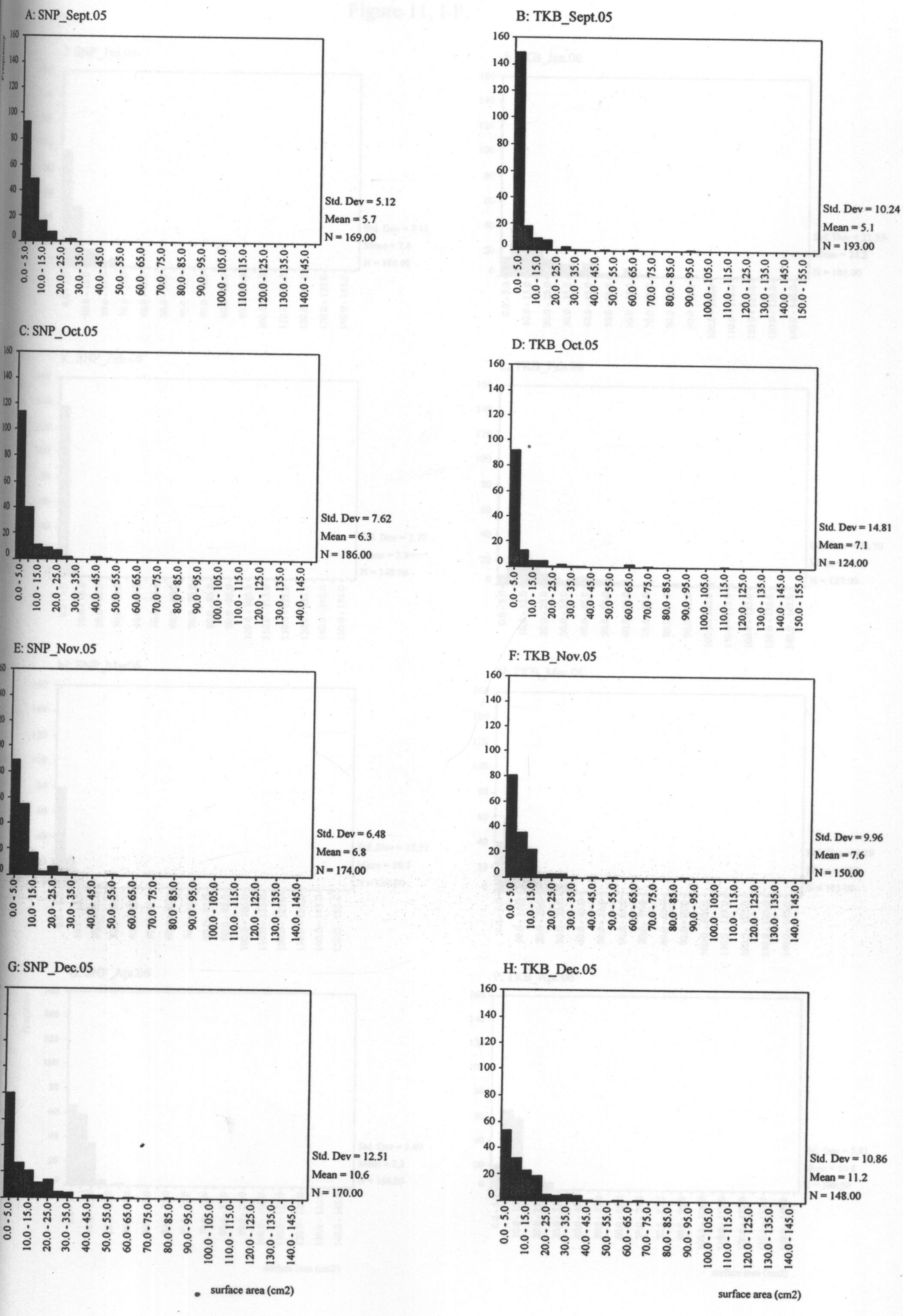
## RESULTS

### Size structure and reproductive potential

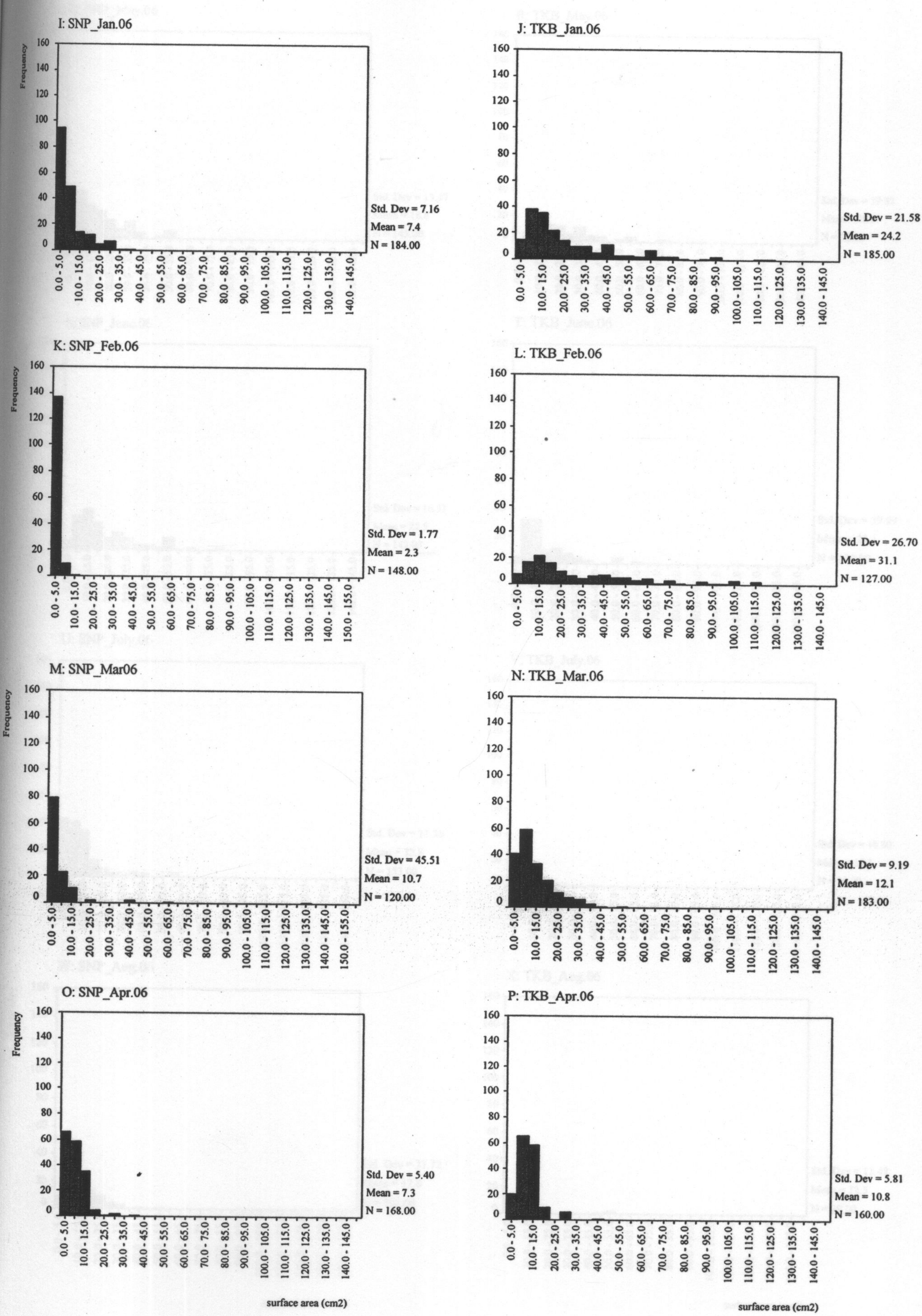
*Padina* populations were dynamic throughout the year (Figures 11A-X). The surface area distributions were skewed to the left, with many small individuals and few large ones in every month. The range of the surface area at SNP was from 2.3 to 22.5 $cm^2$ (Table 2). They showed the largest surface area in June 2006 (Figure 11S) and the smallest in February 2006 (Figure 11K). The range of the mean surface area was from 5.1 to 31.1 $cm^2$ at TKB (Table 2). At TKB the largest surface area was in February 2006 (Figure 11L) and the smallest in September 2006 (Figure 10B). The mean surface area of specimens varied from one month to another and they also varied between sites (Table 3). The range of mean of surface area was wider at TKB than at SNP.

*P. boryana* released spores throughout the year (Figure 12, Table 4). The number of released spores also varied at both sites. The number of released spores varied throughout the year at both sites and was significantly different between the two sites (Table 4, $P<0.05$). The average number of released spores was higher at SNP than TKB. There were two peaks of spores released, first in November 2005(Table 4; n=172, 1533.50±351.82 spores), and second in May 2006 (Table 4; n=145, 8069.21±1456.75 spores) through August 2006 at SNP. At TKB the average number of released spores occurred in February (Table 4; n=120, 9522.11±9522.11 spores) and started again in July 2006 (Table 4; n=34, 4399.10±4399.10 spore) through August 2006.

# Figure 11, A-H.


A: SNP_Sept.05
Std. Dev = 5.12
Mean = 5.7
N = 169.00
B: TKB_Sept.05
Std. Dev = 10.24
Mean = 5.1
N = 193.00
C: SNP_Oct.05
Std. Dev = 7.62
Mean = 6.3
N = 186.00
D: TKB_Oct.05
Std. Dev = 14.81
Mean = 7.1
N = 124.00
E: SNP_Nov.05
Std. Dev = 6.48
Mean = 6.8
N = 174.00
F: TKB_Nov.05
Std. Dev = 9.96
Mean = 7.6
N = 150.00
G: SNP_Dec.05
Std. Dev = 12.51
Mean = 10.6
N = 170.00
H: TKB_Dec.05
Std. Dev = 10.86
Mean = 11.2
N = 148.00
surface area (cm2)
surface area (cm2)

# Figure 11, I-P.



I: SNP_Jan.06
Std. Dev = 7.16
Mean = 7.4
N = 184.00
J: TKB_Jan.06
Std. Dev = 21.58
Mean = 24.2
N = 185.00
K: SNP_Feb.06
Std. Dev = 1.77
Mean = 2.3
N = 148.00
L: TKB_Feb.06
Std. Dev = 26.70
Mean = 31.1
N = 127.00
M: SNP_Mar06
Std. Dev = 45.51
Mean = 10.7
N = 120.00
N: TKB_Mar.06
Std. Dev = 9.19
Mean = 12.1
N = 183.00
O: SNP_Apr.06
Std. Dev = 5.40
Mean = 7.3
N = 168.00
P: TKB_Apr.06
Std. Dev = 5.81
Mean = 10.8
N = 160.00
Frequency
surface area (cm2)

Figure 11, Q-X.

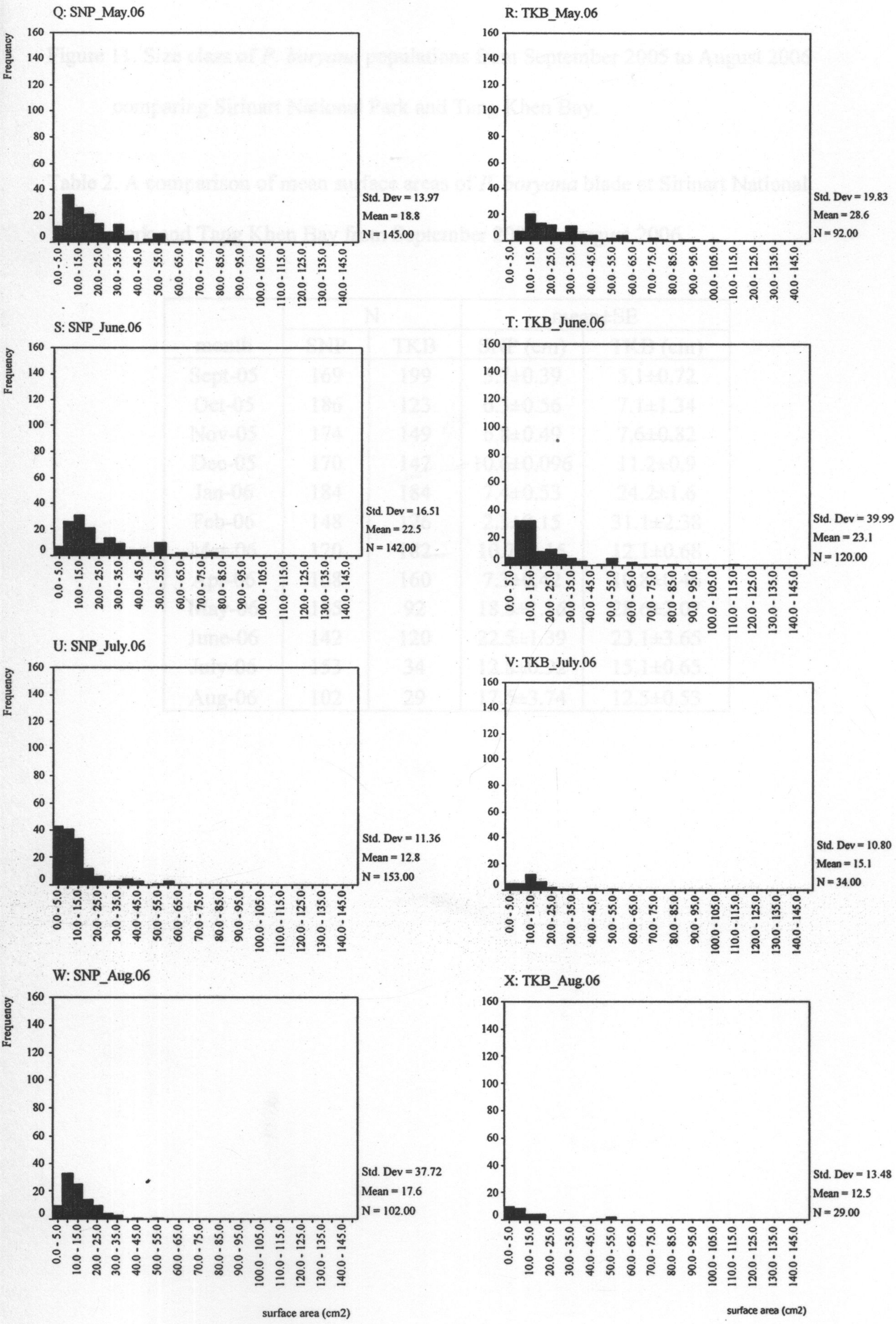

Q: SNP_May.06
Std. Dev = 13.97
Mean = 18.8
N = 145.00
R: TKB_May.06
Std. Dev = 19.83
Mean = 28.6
N = 92.00
S: SNP_June.06
Std. Dev = 16.51
Mean = 22.5
N = 142.00
T: TKB_June.06
Std. Dev = 39.99
Mean = 23.1
N = 120.00
U: SNP_July.06
Std. Dev = 11.36
Mean = 12.8
N = 153.00
V: TKB_July.06
Std. Dev = 10.80
Mean = 15.1
N = 34.00
W: SNP_Aug.06
Std. Dev = 37.72
Mean = 17.6
N = 102.00
X: TKB_Aug.06
Std. Dev = 13.48
Mean = 12.5
N = 29.00
Frequency
surface area (cm2)

Figure 11. Size class of *P. boryana* populations from September 2005 to August 2006 comparing Sirinart National Park and Tang Khen Bay.

Table 2. A comparison of mean surface areas of *P. boryana* blade at Sirinart National Park and Tang Khen Bay from September 2005 to August 2006.

| | N | | mean±SE | |
|---|---|---|---|---|
| month | SNP | TKB | SNP (cm) | TKB (cm) |
| Sept-05 | 169 | 199 | 5.7±0.39 | 5.1±0.72 |
| Oct-05 | 186 | 123 | 6.3±0.56 | 7.1±1.34 |
| Nov-05 | 174 | 149 | 6.8±0.49. | 7.6±0.82 |
| Dec-05 | 170 | 147 | 10.6±0.096 | 11.2±0.9 |
| Jan-06 | 184 | 184 | 7.4±0.53 | 24.2±1.6 |
| Feb-06 | 148 | 126 | 2.3±0.15 | 31.1±2.38 |
| Mar-06 | 120 | 182 | 10.7±4.15 | 12.1±0.68 |
| Apr-06 | 168 | 160 | 7.3±0.42 | 10.8±0.46 |
| May-06 | 145 | 92 | 18.8±1.16 | 28.6±2.07 |
| June-06 | 142 | 120 | 22.5±1.39 | 23.1±3.65 |
| July-06 | 153 | 34 | 12.8±0.92 | 15.1±0.65 |
| Aug-06 | 102 | 29 | 17.6±3.74 | 12.5±0.53 |

Table 3. A comparison of size class distribution at Sirinart National Park and Tang Khen Bay from September 2005 to August 2006; otherwise, **P*< 0.05, ** *P*< 0.01, *** *P*<0.001; ns = not significant.

| month | N | | $X^2$ | *P* |
|---|---|---|---|---|
| | SNP | TKB | | |
| Sept-05 | 169 | 199 | 3.321 | <0.001*** |
| Oct-05 | 186 | 123 | 1.264 | 0.082 ns |
| Nov-05 | 174 | 149 | 0.682 | 0.741 ns |
| Dec-05 | 170 | 147 | 1.472 | 0.026* |
| Jan-06 | 184 | 184 | 5.161 | <0.001*** |
| Feb-06 | 148 | 126 | 7.316 | <0.001*** |
| Mar-06 | 120 | 182 | 4.171 | <0.001*** |
| Apr-06 | 168 | 160 | 7.115 | <0.001*** |
| May-06 | 145 | 92 | 4.498 | <0.001*** |
| June-06 | 142 | 120 | 1.931 | 0.053 ns |
| July-06 | 153 | 34 | 11.49 | <0.001*** |
| Aug-06 | 102 | 29 | 13.409 | <0.001*** |

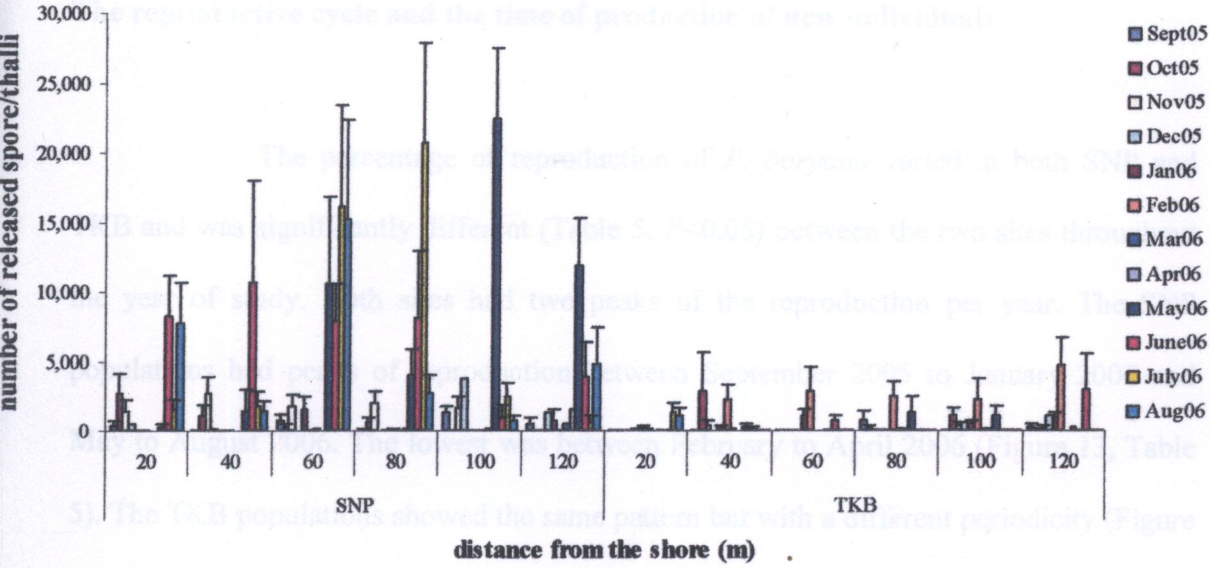



**Figure 12. Comparison of the average number of released spores/thalli from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.**

**Table 4. The average number of released spores at Sirinart National Park and Tang Khen Bay from September 2005 to August 2006; otherwise, *$P$<0.05, ** $P$<0.01, *** $P$<0.001; ns = not significant.**

| month | N | | mean±SE | | $X^2$ | $P$ |
|---|---|---|---|---|---|---|
| | SNP | TKB | SNP (spores) | TKB (spores) | | |
| Sept-05 | 161 | 188 | 459.23±146.20 | 510.77±404.61 | 2.362 | 0.018* |
| Oct-05 | 185 | 121 | 775.80±298.51 | 2,717.43±1,853.30 | 0.155 | 0.877 ns |
| Nov-05 | 172 | 148 | 1,533.50±351.82 | 516.49±269.42 | 3.265 | 0.001** |
| Dec-05 | 167 | 141 | 861.94±332.45 | 1,397.17±532.04 | 1.935 | 0.053 ns |
| Jan-06 | 184 | 174 | 367.79±206.57 | 1,675.71±494.53 | 3.637 | <0.001*** |
| Feb-06 | 148 | 120 | 6.82±5.62 | 9,522.11±2,245.58 | 6.735 | <0.001*** |
| Mar-06 | 120 | 178 | 124.57±93.05 | 244.78±111.03 | 0.645 | 0.519 ns |
| Apr-06 | 313 | 160 | 3,897.25±715.92 | 386.79±131.08 | 2.125 | 0.034* |
| May-06 | 145 | 92 | 8,069.21±1,456.75 | 2,217.74±1,221.68 | 4.372 | <0.001*** |
| June-06 | 142 | 120 | 6,092.80±1,506.24 | 1,543.9±824.73 | 3.921 | <0.001*** |
| July-06 | 153 | 34 | 6,303.18±1,628.21 | 4,399.06±2,618.45 | 1.822 | 0.068 ns |
| Aug-06 | 104 | 29 | 3,840.52±875.95 | 4,400.48±2,119.39 | 0.572 | 0.567 ns |

**The reproductive cycle and the time of production of new individuals**

The percentage of reproduction of *P. boryana* varied at both SNP and TKB and was significantly different (Table 5, $P<0.05$) between the two sites throughout the year of study. Both sites had two peaks of the reproduction per year. The SNP populations had peaks of reproduction between September 2005 to January 2006 and May to August 2006. The lowest was between February to April 2006 (Figure 13, Table 5). The TKB populations showed the same pattern but with a different periodicity (Figure 13, Table 5). For example, those populations peaked from December 2005 to February 2006 and May to June 2006. They were not significantly different among months ($P>0.05$).

Moreover, both sites showed the same percentages of the various life phases. Sporophytes showed the highest percentage throughout the year. There were, in fact, only a few female gametophytes in some months (Figure 13, Table 6). The percentage of male gametophytes was even lower and were observed only 3 times in the year: May (2.46%) to June (0.69%) to July (0.69%) 2006 in SNP, and April (2.24%) to May (4.44%) to June (8.3%) 2006 in TKB (Figure 13, Table 6).

*P. boryana* can be reproductive throughout the year. The percentage of maturation stages 3-5 was calculated to assess the reproductive potential of the populations and was found to be significantly different between months and sites (Figure 14, Table 7, $P<0.05$). Reproductive potential is a function of the number of spores and gametes produced. However, since the sporophyte generation was overwhelmingly dominant at both SNP and TKB, the data reflect the reproductive potential based on spore production. The data showed the same trend as the percentage of reproduction. Likewise, the peak of maturity was in September 2005 by 40.91±7.35% and May 2006 by 72.87±9.09% at SNP, and February 2006 by 34.28±3.62% and May 2006 by 59.18±10.49% at TKB (Table 7). Both sites showed significantly different peaks (Table 7, $P<0.05$). The percentage of maturation was higher in the end of the year at both sites. Statistical analysis supported the significant difference between months at the two sites in the January to February and July to August periods. However, it was greater at SNP than at TKB during the two peaks period and less from January to April 2006.

The averages of number of spores (Figure 15, Table 8) at SNP were greater than at TKB throughout the year. However, *P. boryana* showed the same phenomenon of producing more spores from May to August before the plants died. The number of spores varied throughout the year and showed significant differences (Table 8, $P<0.05$) between levels (distance from the shore) at both sites.

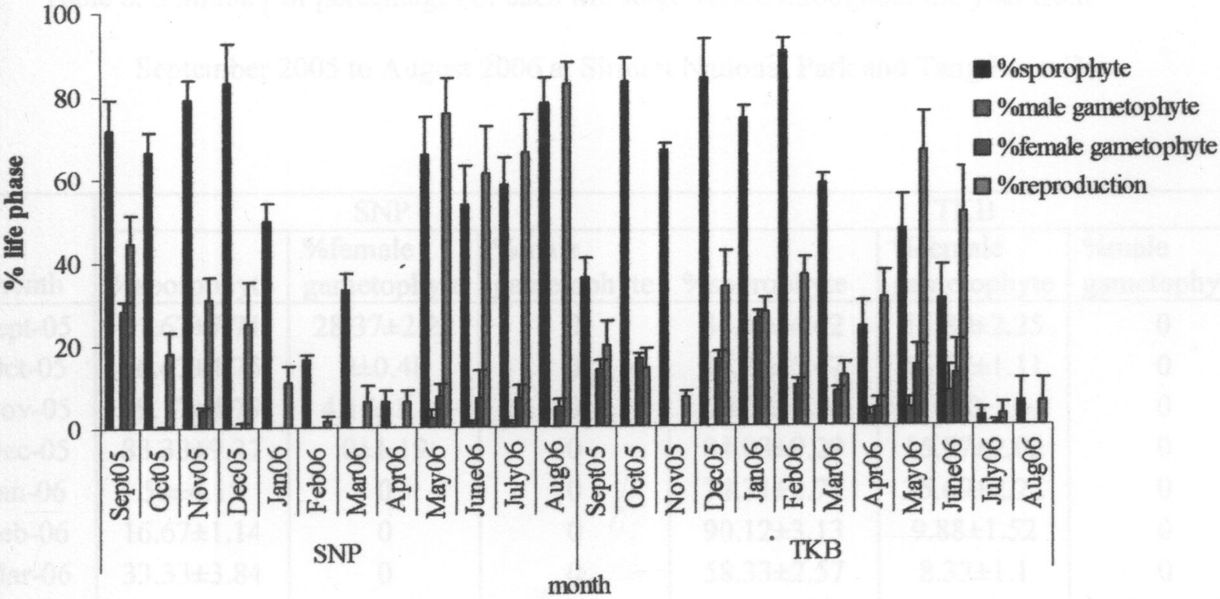



**Figure 13. Comparison of percentages of life phases of *P. boryana* from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.**

**Table 5. The average percentage of reproductive stages at Sirinart National Park and Tang Khen Bay; otherwise, *$P< 0.05$, ** $P< 0.01$, *** $P<0.001$; ns = not significant.**

| month | mean ±SE | | $X^2$ | $P$ |
|---|---|---|---|---|
| | SNP | TKB | | |
| Sept-05 | 44.64±6.59 | 19.60±5.97 | 2.082 | 0.037* |
| Oct-05 | 18.05±4.93 | 13.96±5.04 | 0.481 | 0.63 ns |
| Nov-05 | 30.92±5.49 | 7.09±1.56 | 2.722 | 0.006** |
| Dec-05 | 25.24±9.96 | 33.55±8.80 | 0.961 | 0.337 ns |
| Jan-06 | 10.90±4.15 | 27.39±3.70 | 2.491 | 0.013* |
| Feb-06 | 1.67±1.13 | 36.66±4.02 | 2.934 | 0.003** |
| Mar-06 | 6.43±3.84 | 11.98±3.14 | 1,292 | 0.196 ns |
| Apr-06 | 6.11±3.03 | 30.81±6.95 | 2.58 | 0.01** |
| May-06 | 75.50±8.70 | 66.29±9.56 | 0.561 | 0.575 ns |
| June-06 | 61.30±11.08 | 51.31±11.07 | 0.48 | 0.631 ns |
| July-06 | 66.33±8.92 | 2.78±2.78 | 2.989 | 0.003** |
| Aug-06 | 82.65±5.30 | 5.75±5.75 | 2.989 | 0.003** |

Table 6. Summary of percentages of each life stage varied throughout the year from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.

| | SNP | | | TKB | | |
|---|---|---|---|---|---|---|
| month | %sporophyte | %female gametophyte | %male gametophyte | %sporophyte | %female gametophyte | %male gametophyte |
| Sept-05 | 71.63±7.71 | 28.37±2.22 | 0 | 36.11±4.62 | 13.89±2.25 | 0 |
| Oct-05 | 66.67±4.75 | 0±0.48 | 0 | 83.33±5.47 | 16.67±1.11 | 0 |
| Nov-05 | 79.17±4.79 | 4.17±1.11 | 0 | 66.67±1.56 | 0 | 0 |
| Dec-05 | 83.33±9.37 | 0±1.19 | 0 | 84.03±9.29 | 15.97±2.02 | 0 |
| Jan-06 | 50±4.15 | 0 | 0 | 74.31±2.77 | 25.69±2.22 | 0 |
| Feb-06 | 16.67±1.14 | 0 | 0 | 90.12±3.13 | 9.88±1.52 | 0 |
| Mar-06 | 33.33±3.84 | 0 | 0 | 58.33±2.57 | 8.33±1.1 | 0 |
| Apr-06 | 6.11±3.03 | 0 | 0 | 24.1±5.95 | 4.46±2.05 | 2.24±1.65 |
| May-06 | 65.73±9.16 | 7.31±3.44 | 2.46±1.7 | 47.31±8.37 | 14.54±4.88 | 4.44±2.38 |
| June-06 | 53.66±9.39 | 6.94±6.94 | 0.69±0.69 | 30.59±8.32 | 12.42±8.39 | 8.3±6.17 |
| July-06 | 58.43±6.68 | 7.2±2.99 | 0.69±0.69 | 2.22±2.22 | 0.56±0.56 | 0 |
| Aug-06 | 78.02±6.38 | 4.62±2.1 | 0 | 5.75±5.75 | 0 | 0 |

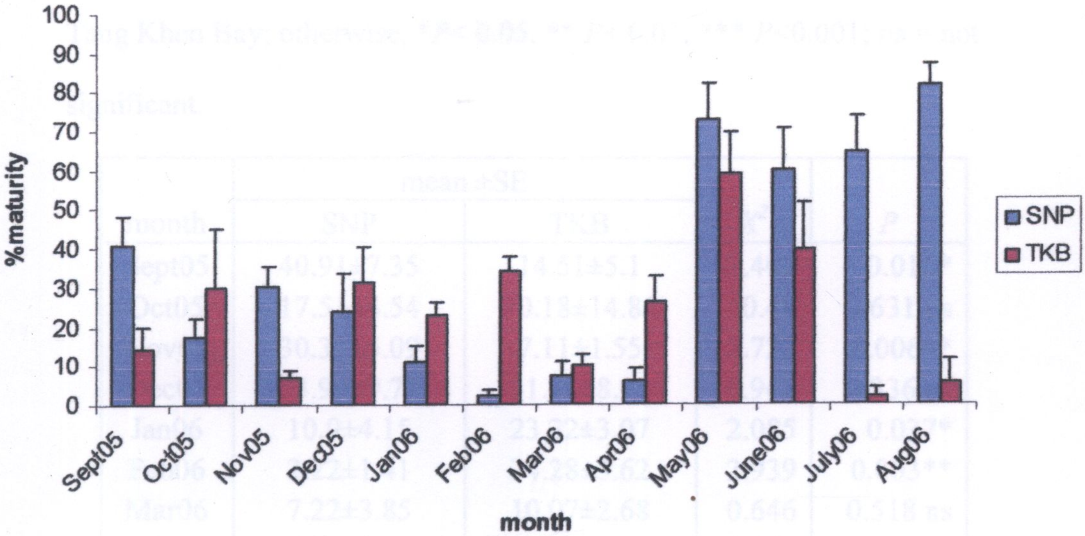



**Figure 14. Comparison of the percentages of mature (stages 3-5) thalli from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.**

Table 7. The average of percentage of maturation stages at Sirinart national Park and Tang Khen Bay; otherwise, *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; ns = not significant.

| month | mean ±SE | | $X^2$ | $P$ |
|---|---|---|---|---|
| | SNP | TKB | | |
| Sept05 | 40.91±7.35 | 14.51±5.1 | 2.402 | 0.016* |
| Oct05 | 17.51±4.54 | 30.18±14.86 | 0.48 | 0.631 ns |
| Nov05 | 30.33±5.09 | 7.11±1.55 | 2.722 | 0.006** |
| Dec05 | 23.99±9.71 | 31.56±8.98 | 0.962 | 0.336 ns |
| Jan06 | 10.9±4.15 | 23.22±3.07 | 2.085 | 0.037* |
| Feb06 | 2.22±1.41 | 34.28±3.62 | 2.939 | 0.003** |
| Mar06 | 7.22±3.85 | 10.07±2.68 | 0.646 | 0.518 ns |
| Apr06 | 6.11±3.03 | 26.12±6.78 | 2.096 | 0.036* |
| May06 | 72.87±9.09 | 59.18±10.49 | 0.961 | 0.337 ns |
| June06 | 60.12±10.48 | 39.66±12.02 | 1.043 | 0.297 ns |
| July06 | 64.59±8.98 | 2±2.3 | 2.989 | 0.003** |
| Aug06 | 81.54±5.66 | 5.75±5.75 | 2.989 | 0.003** |

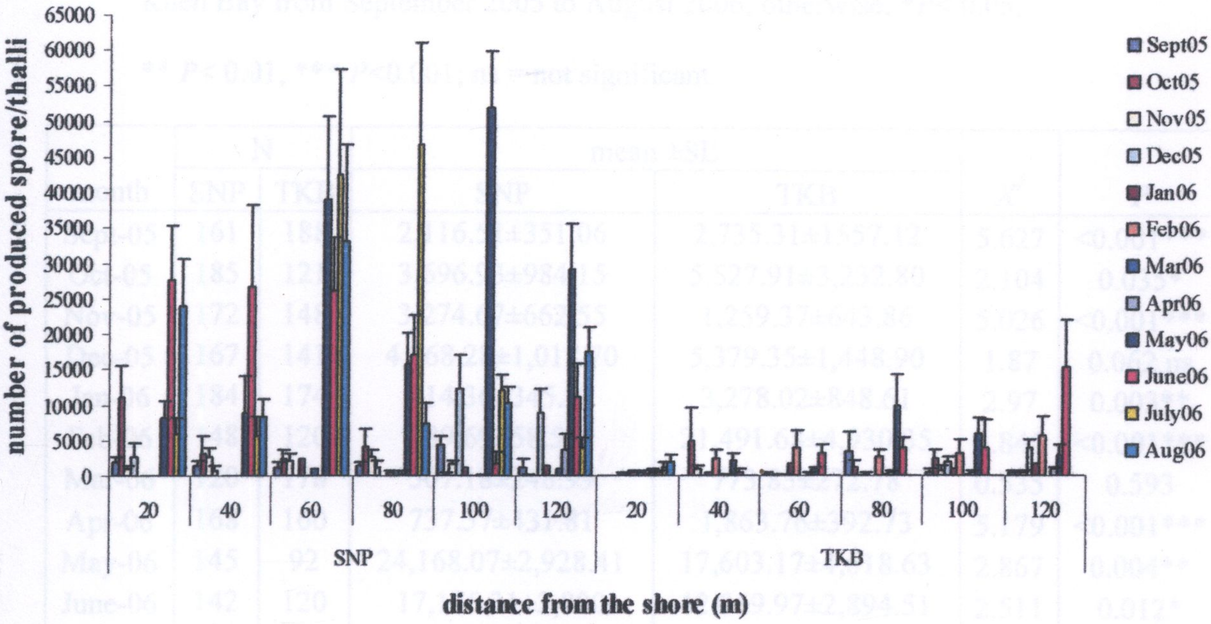



Figure 15. Comparison of the average number of spores/thalli from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.

Table 8. The average number of spores produced at Sirinart National Park and Tang Khen Bay from September 2005 to August 2006; otherwise, *$P< 0.05$, ** $P< 0.01$, *** $P<0.001$; ns = not significant.

| month | N | | mean ±SE | | $X^2$ | $P$ |
|---|---|---|---|---|---|---|
| | SNP | TKB | SNP | TKB | | |
| Sept-05 | 161 | 188 | 2,116.51±351.06 | 2,735.31±1557.12 | 5.627 | <0.001*** |
| Oct-05 | 185 | 121 | 3,696.93±984.15 | 5,527.91±3,232.80 | 2.104 | 0.035* |
| Nov-05 | 172 | 148 | 3,274.67±662.55 | 1,259.37±643.86 | 5.026 | <0.001*** |
| Dec-05 | 167 | 141 | 4,068.28±1,017.70 | 5,379.35±1,448.90 | 1.87 | 0.062 ns |
| Jan-06 | 184 | 174 | 914.36±345.37 | 3,278.02±848.61 | 2.97 | 0.003** |
| Feb-06 | 148 | 120 | 89.69±58.56 | 21,491.68±4,930.35 | 6.845 | <0.001*** |
| Mar-06 | 120 | 178 | 507.18±248.99 | 773.83±272.78 | 0.535 | 0.593 |
| Apr-06 | 168 | 160 | 737.57±431.81 | 1,863.76±392.73 | 5.179 | <0.001*** |
| May-06 | 145 | 92 | 24,168.07±2,928.41 | 17,603.17±4,618.63 | 2.867 | 0.004** |
| June-06 | 142 | 120 | 17,175.31±2,800 | 12,069.97±2,894.51 | 2.511 | 0.012* |
| July-06 | 153 | 34 | 17,659.22±3,358.72 | 4,488.47±2,658.53 | 4.817 | <0.001*** |
| Aug-06 | 102 | 29 | 14,724.92±1,818.80 | 8,205.52±3,681.07 | 4.086 | <0.001*** |

**Recruitment study**

Algal recruitment in this study followed a typical successional pattern. In the early stages filamentous green algae were dominant followed by taxa with more complex morphologies. After clearing the permanent plots, filamentous green and red algae appeared as the pioneer species. After that *Gelidium* spp., *Gracilaria* spp., *Turbinaria ornata*, followed. The green algae, *Ulva*, *Boodlea* and *Chlorodesmis*, were observed at both sites. Filamentous red algae such as *Champia*, *Gelidium*, and *Ceramium* were observed at SNP and crustose algae were also abundant at TKB. The prostrate thalli of *Padina*, *Dictyerpa*, grew in the plots after 1 month. The percentages of filamentous algae were high at both sites and they grew throughout the year (Table 9-10). In addition, the filamentous algae were higher in the lower intertidal, 61-120 m. from shoreline than in the upper zone, while *Padina* was found in higher numbers on the upper shore. Some plots were covered by the sediment at both sites.

New individuals of *Padina* were first noticed in October 2005, a month after the substrates were cleared. The prostrate *Dictyerpa* stage appeared first and was observed throughout the year at both sites. The foliose stage of *Padina* were first observed in the plots in November 2005. The foliose blade can develop from the *Dictyerpa* stage and form a canopy throughout the year. When the growth of *Padina* in the plot was at its peak in the May 2005 (Table 11-12; n=6±3.46, height=5.33±0.41cm. at 41-60 m. at SNP, n=9.33±5.21, height=4.29±0.39 cm. at 61-80 m. at TKB), *P. boryana* showed the highest percentage cover and also its greatest height in May and June 2005. After that, the blade was torn due to the tissue lost and the thalli became soft and easily damaged by water movement. *Padina* started to die off in June 2005. New individuals were recruited in the area in October 2005. In this study, *Padina* was mostly absent in the last two months, July and August 2006, at both sites.

The recruitment of *Padina* on the monitoring plots changed throughout the year (Figure 16-17). There were significant differences in percentage cover between TKB and SNP from December 2005 to June 2006 (Table 11, $P<0.05$). A higher percentage cover of both the *Dictyerpa* stage and foliose blades was found at TKB at all distances from the shore and during all months. The percentage cover of *Padina* was greater than 40% at TKB, and less than 40% at SNP.

There was no clear pattern of *Padina* recruitment and growth at SNP. For example, there was no recruitment at all in some plots. Higher recruitment occurred in the zone nearest to the shore throughout the year. There was significantly higher recruitment at the 0-20 meter level ($P<0.05$). However, there were no significant differences in percentage cover among other shore levels. At 101-120 meters, there was no recruitment of *Padina* at all throughout the study, also sediment approximately 0.5 mm thick, was observed. The highest percentage cover of *Padina* was found at the uppermost shore levels during March and June 2006 at 76.67%±14.53% and 75%±17.56% respectively. Most of percentages cover of *Padina* were the *Dictyerpa* stage in March 2006 with only a few foliose thalli 1 cm. in height (Table 11-12; n=10). Foliose thalli showed the highest percentage cover in June 2006 with an average height of 4.18±0.37 cm. at the upper level (Table 11-12; n=15±1.53). *Padina* started to die off after the peak month then the percentage cover decreased. The percentage cover of *Padina* was 23.33%±12.02% in June and 33.33%±24.04% in August (at the 0-20 m.), however, some of the foliose thalli were still in the plots (Table 11-12).

The percentage cover at TKB (Figure 17) revealed the dynamics of recruitment in the area. The percentage cover varied depending on the distance from the shore. There was higher recruitment at all shore levels at TKB resulting in the percentage cover being more than 40%, except at the 81-100 meters where there was no recruitment. There were significant differences ($P<0.05$) between the early period of the study and the later, November 2005-May 2006 and June 2006-August 2006. Early in the study a large canopy was formed, whereas at the end of the study the populations disappeared due to senescence. The growth and development cycle was dynamic at TKB. The highest percentage cover of *Padina* was reached in May (Table 11-12; n=9.33±5.21, 4.29±0.39 cm. at the 61-80 m.). Then it started to drop in June 2006 and the foliose thalli disappeared in August 2006, the last month of this study. In the permanent plots, the *Dictyerpa* stage thalli were observed throughout the year. This caused the percentage cover to be high after the peak of growth in January to February 2006 by almost 100% even though there were no foliose thalli in the plots.

The data of measurement of surface area and number of released spores support an understanding of the recruitment of *P. boryana* in the manipulated permanent plots. The percentage covers were high after the peak of releasing spores, another source of recruitment. Foliose thalli were visible within one month of spore release.

Physico-chemical parameters such as salinity, seawater and air temperature were subjected to correlation tests. The ranges of the physical parameters at both sites were only slightly different. The range of the average seawater temperature was 26°C-34°C at SNP and 25°C-38°C at TKB (Figure 18). The range of the average air temperature was 24°C-31°C at SNP and 23°C-37°C at TKB (Figure 19). The range of the average salinity was 24-34 ppt at SNP and 20-35 ppt at TKB (Figure 20). However, at SNP, there was a correlation between air temperature and surface area (Table 13, Figure 21; $r$ = -0.24). At TKB, there were significant correlations between air temperature and average percentage of female gametophytes (Table 13, Figure 22; $r$ = 0.237), water temperature and average percentage of female gametophytes (Table 13, Figure 23; $r$ = 0.334). Moreover, there were correlations between salinity and average percentage of male gametophytes (Table 13, Figure 24; $r$ = 0.235), average percentage of sporophytes (Table 13, Figure 25; $r$ = 0.235), average percentage of mature sporophytes (Table 13, Figure 26; $r$ = 0.339), average percentage of reproduction (Table 13, Figure 27; $r$ = 0.348), the average number of produced spores (Table 13, Figure 28; $r$ = 0.43), the average number of released spores (Table 13, Figure 29; $r$ = 0.253), and average surface area (Table 13, Figure 30; $r$ = 0.507).

Table 9. A comparison of the percentage of filamentous greens, filamentous reds and *P. boryana* at all levels in the permanent plots at Sirinart National Park from October 2005 to August 2006.

| | % filamentous green | | | | | | % filamentous red | | | | | | *Padina* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper (m.) | | Middle (m.) | | Lower (m.) | | Upper (m.) | | Middle (m.) | | Lower (m.) | | Upper (m.) | | Middle (m.) | | Lower (m.) | |
| month | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 |
| Oct-05 | 40±20 | 63.33±8.82 | 5±2.89 | 40±25.17 | 66.67±8.82 | 100 | 0 | 0 | 13.33±6.67 | 3.33±3.33 | 0 | 0 | 36.67±13.33 | 36.67±8.82 | 1.67±1.67 | 0 | 33.33±8.81 | 0 |
| Nov-05 | 33.33±16.67 | 50 | 55±27.54 | 66.67±8.82 | 60±10 | 91.67±1.67 | 0 | 0 | 11.67±6.01 | 20±11.55 | 23.33±14.53 | 6.67±3.33 | 33.33±16.67 | 52±0.58 | 0 | 0 | 16.67±16.67 | 0 |
| Dec-05 | 50 | 20±20 | 35±15 | 0 | 50 | 66.67±8.82 | 50 | 0 | 58.33±8.33 | 0 | 50 | 30 | 0 | 0 | 6.67±6.67 | 0 | 0 | 0 |
| Jan-06 | 60±30 | 46.67±23.33 | 85±7.64 | 0 | 75.33±7.97 | 3.33±3.33 | 1.67±1.67 | 20±10 | 13.33±8.33 | 0 | 21.67±8.33 | 3.33±3.33 | 3.33±3.33 | 0 | 1.67±1.67 | 0 | 0 | 0 |
| Feb-06 | 76.67±14.53 | 46.67±23.33 | 88.33±9.28 | 100 | 75.33±7.97 | 3.33±3.33 | 0 | 20±10 | 11.67±9.28 | 0 | 22.33±7.67 | 3.33±3.33 | 16.67±16.67 | 0 | 0 | 0 | 0 | 0 |
| Mar-06 | 23.33±14.53 | 66.67±3.33 | 88.33±9.28 | 100 | 78.67±6.33 | 3.33±3.34 | 0 | 20±10 | 11.67±9.28 | 0 | 22.33±7.67 | 3.33±3.33 | 76.67±14.53 | 0 | 0 | 0 | 0 | 0 |
| Apr-06 | 36.67±18.56 | 66.67±3.33 | 20±20 | 60 | 66.67±11.67 | 3.33±3.35 | 16.67±16.67 | 31.67±1.67 | 43.33±6.67 | 0 | 23.33±14.53 | 3.33±3.33 | 40±5.78 | 0 | 6.67±3.33 | 13.33±13.33 | 5±2.29 | 0 |
| May-06 | 23.33±13.02 | 6.67±6.67 | 63.33±6.67 | 5±5 | 28.33±10.14 | 60±5.77 | 8.33±8.33 | 0 | 16.67±16.67 | 13.33±13.33 | 55±15 | 0 | 56.67±12.02 | 23.33±14.53 | 20±10 | 13.33±13.33 | 10±5 | 0 |
| June-06 | 0 | 0 | 0 | 50 | 83.33±16.67 | 60±5.77 | 15±12.58 | 0 | 0 | 50 | 0 | 0 | 75±17.56 | 0 | 10±5.77 | 0 | 16.67±16.67 | 0 |
| July-06 | 36.67±19.22 | 0 | 0 | 50 | 100 | 100 | 15±15 | 0 | 0 | 50 | 0 | 0 | 23.33±12.02 | 3.33±3.33 | 11.67±6.01 | 0 | 0 | 0 |
| Aug-06 | 33.33±20.28 | 33.33±33.33 | 100 | 50 | 100 | 100 | 15±15 | 0 | 0 | 50 | 0 | 0 | 33.33±24.04 | 3.33±3.33 | 13.33±6.67 | 0 | 0 | 0 |

Table 10. A comparison of the percentage of filamentous greens, filamentous reds and *P. boryana* at all levels in the permanent plots at Tang Khen Bay from October 2005 to August 2006.

| | % filamentous green | | | | | | % filamentous red | | | | | | % *Padina* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper (m.) | | Middle (m.) | | Lower (m.) | | Upper (m.) | | Middle (m.) | | Lower (m.) | | Upper (m.) | | Middle (m.) | | Lower (m.) | |
| month | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | [illegible] |
| Oct-05 | 100 | 95±2.89 | 80±5.77 | 46.67±23.33 | 36.67±6.67 | 93.33±1.67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5±2.89 | 20±10 | 20±17.32 | 0 | 6.67±2.89 |
| Nov-05 | 6.67±1.67 | 88.33±9.28 | 30±30 | 0 | 20±10 | 83.33±4.41 | 6.67±6.67 | 0 | 0 | 0 | 0 | 0 | 10±5.77 | 11.67±9.28 | 13.33±2.89 | 53.33±46.19 | 26.67±5.77 | 16.67±7.64 |
| Dec-05 | 28.33±9.28 | 51.67±4.41 | 15±5.20 | 10±2.89 | 33.33±11.67 | 20.83±7.95 | 8.33±6.01 | 0 | 0 | 0 | 0 | 6.67±6.67 | 28.33±16.41 | 43.33±3.33 | 65±18.03 | 53.33±42.52 | 20±34.64 | 56.67±5.77 |
| Jan-06 | 35±2.89 | 90 | 1.33±0.67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23.33±8.33 | 33.33±12.02 | 98.67±1.15 | 66.67±57.74 | 0 | 100 |
| Feb-06 | 85±5 | 0 | 1.33±0.68 | 0 | 78.33±7.33 | 13.33±8.82 | 0 | 0 | 0 | 0 | 0 | 0 | 11.67±6.01 | 81±10.54 | 98.67±0.06 | 66.67±33.33 | 0 | 30 |
| Mar-06 | 58.33±24.21 | 38.33±20.48 | 31.67±7.26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.67±6.01 | 45±24.66 | 64.33±8.09 | 66.67±33.33 | 0 | 43.33±6.67 |
| Apr-06 | 46.67±8.82 | 21.67±13.02 | 25±12.58 | 13.33±6.67 | 0 | 26.67±3.33 | 0 | 0 | 0 | 0 | 0 | 6.67±6.67 | 24.67±13.48 | 48.33±21.67 | 66.67±8.82 | 53.33±26.67 | 0 | 66.67±8.82 |
| May-06 | 30±22.55 | 90 | 0 | 60±10 | 56.67±6.67 | 26.67±3.33 | 0 | 0 | 0 | 0 | 42.67±6.36 | 6.67±6.67 | 63.33±21.67 | 36.67±26.67 | 80±20 | 26.67±14.53 | 0.67±0.67 | 66.67±8.82 |
| June-06 | 20±5.77 | 46.67±8.82 | 46.67±27.28 | 46.67±24.04 | 100 | 26.67±3.33 | 10±10 | 0 | 0 | 0 | 0 | 6.67±6.67 | 70±15.28 | 40±5.77 | 53.33±27.28 | 20±11.55 | 0.67±0.67 | 66.67±8.82 |
| July-06 | 15±2.89 | 0 | 65±15 | 65±15 | 56.67±28.48 | 0 | 5±5 | 0 | 33.33±16.67 | 33.33±16.67 | 0 | 0 | 80±5.77 | 61.67±14.24 | 0 | 0 | 0 | 0 |
| Aug-06 | 0.67±0.67 | 20±15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99.33±0.67 | 50.33±25.69 | 0 | 0 | 0 | 0 |

Table 11. The average percentage of *P. boryana* recruitment at all shore levels at Sirinart National Park and Tang Khen Bay from October 2005 to August 2006; otherwise, *$P< 0.05$, **$P< 0.01$, ***$P<0.001$; ns=not significant.

| | SNP | | | | | | TKB | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper (m.) | | Middle (m.) | | Lower (m.) | | Upper (m.) | | Middle (m.) | | Lower (m.) | | | |
| month | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | $X^2$ | *P* |
| • Oct-05 | 36.67±13.33 | 36.67±8.82 | 1.67±1.67 | 0 | 33.33±8.81 | 0 | 0 | 5±2.89 | 20±10 | 20±17.32 | 0 | 6.67±2.89 | 0.914 | 0.361 ns |
| Nov-05 | 33.33±16.67 | 52±0.58 | 0 | 0 | 16.67±16.67 | 0 | 10±5.77 | 11.67±9.28 | 13.33±2.89 | 53.33±46.19 | 26.67±5.77 | 16.67±7.64 | 1.299 | 0.194 ns |
| Dec-05 | 0 | 0 | 6.67±6.67 | 0 | 0 | 0 | 28.33±16.41 | 43.33±3.33 | 65±18.03 | 53.33±42.52 | 20±34.64 | 56.67±5.77 | 4.822 | <0.001*** |
| Jan-06 | 3.33±3.33 | 0 | 1.67±1.67 | 0 | 0 | 0 | 23.33±8.33 | 33.33±12.02 | 98.67±1.15 | 66.67±57.74 | 0 | 100 | 4.235 | <0.001*** |
| Feb-06 | 16.67±16.67 | 0 | 0 | 0 | 0 | 0 | 11.67±6.01 | 81±10.54 | 98.67±0.06 | 66.67±33.33 | 0 | 30 | 3.946 | <0.001*** |
| Mar-06 | 76.67±14.53 | 0 | 0 | 0 | 0 | 0 | 11.67±6.01 | 45±24.66 | 64.33±8.09 | 66.67±33.33 | 0 | 43.33±6.67 | 2.62 | 0.009** |
| Apr-06 | 40±5.78 | 0 | 6.67±3.33 | 13.33±13.33 | 5±2.29 | 0 | 24.67±13.48 | 48.33±21.67 | 66.67±8.82 | 53.33±26.67 | 0 | 66.67±8.82 | 2.96 | 0.003** |
| May-06 | 56.67±12.02 | 23.33±14.53 | 20±10 | 13.33±13.33 | 10±5 | 0 | 63.33±21.67 | 36.67±26.67 | 80±20 | 26.67±14.53 | 0.67±0.67 | 66.67±8.82 | 2.114 | 0.034* |
| June-06 | 75±17.56 | 0 | 10±5.77 | 0 | 16.67±16.67 | 0 | 70±15.28 | 40±5.77 | 53.33±27.28 | 20±11.55 | 0.67±0.67 | 66.67±8.82 | 2.421 | 0.015* |
| July-06 | 23.33±12.02 | 3.33±3.33 | 11.67±6.01 | 0 | 0 | 0 | 80±5.77 | 61.67±14.24 | 0 | 0 | 0 | 0 | 0.931 | 0.352 ns |
| Aug-06 | 33.33±24.04 | 3.33±3.33 | 13.33±6.67 | 0 | 0 | 0 | 99.33±0.67 | 50.33±25.69 | 0 | 0 | 0 | 0 | 0.698 | 0.485 ns |

Table 12. The average length (cm.) of *P. boryana* in the permanent plots at Sirinart National Park and Tang Khen Bay from October 2005 to August 2006; D: *Dictyerpa* stage found.

| | SNP | | | | | | TKB | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper (m.) | | Middle (m.) | | Lower (m.) | | Upper (m.) | | Middle (m.) | | Lower (m.) | |
| month | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 |
| Oct-05 | 1 | D | D | D | D | D | 0 | 0.5 | 0 | 2 | 0.95±.14 | 0 |
| Nov-05 | D | D | D | D | 0.5 | 0 | 0.85±0.05 | 1 | 1.07±0.02 | 1.77±0.07 | 0.5 | 2.09±0.22 |
| Dec-05 | D | D | 1.5 | D | D | 0 | 0.82±0.05 | 0.61±0.04 | 1±0.05 | 1.56±0.1 | 0 | 3.32±0.17 |
| Jan-06 | 0.5 | D | D | D | D | 0 | 1.07±0.06 | 0.68±0.08 | 1.32±0.11 | 1.82±0.14 | 0 | 2.9±0.14 |
| Feb-06 | 0.5 | D | D | D | D | 0 | 1 | 1 | 1.33±0.12 | 1.82±0.14 | 0 | 0.5 |
| Mar-06 | 1 | D | D | D | D | 0 | 1 | 1.67±0.4 | 1.02±0.26 | 1.9±0.2 | 0 | 2.54±0.13 |
| Apr-06 | 0.95±0.06 | D | 1.44±0.22 | D | 0.89±0.11 | 0 | 1.31±0.08 | 1.35±0.1 | 1.22±0.08 | 1.82±0.13 | 0 | 2.79±0.17 |
| May-06 | 2.167±0.18 | 0.50 | 5.33±0.41 | 0.50 | 0.96±0.13 | 0 | 2.79±0.19 | 1.66±0.15 | 1.88±0.29 | 4.29±0.39 | 0 | 2.79±0.17 |
| June-06 | 4.18±0.37 | D | 4.2±1.55 | D | 1 | 0 | 1.8±0.1 | 1.11±0.09 | 1.83±0.14 | 1.55±0.58 | 0 | 2.79±0.17 |
| July-06 | 2.90±0.33 | 4±.58 | 4.67±1.33 | D | 0 | 0 | 3.23±0.11 | 1.53±0.1 | 0 | 0 | 0 | 0 |
| Aug-06 | 5.33±0.3 | 4±0.58 | 4.75±0.67 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

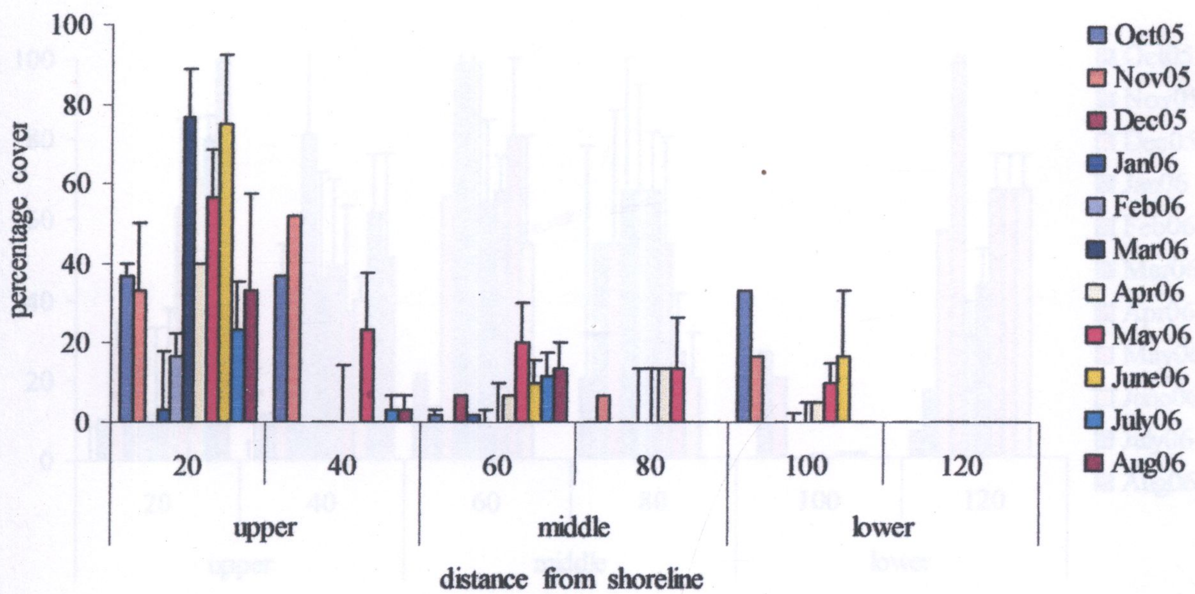



Figure 16. Percentages cover of *P. boryana* from October 2005 to August 2006 at Sirinart National Park.

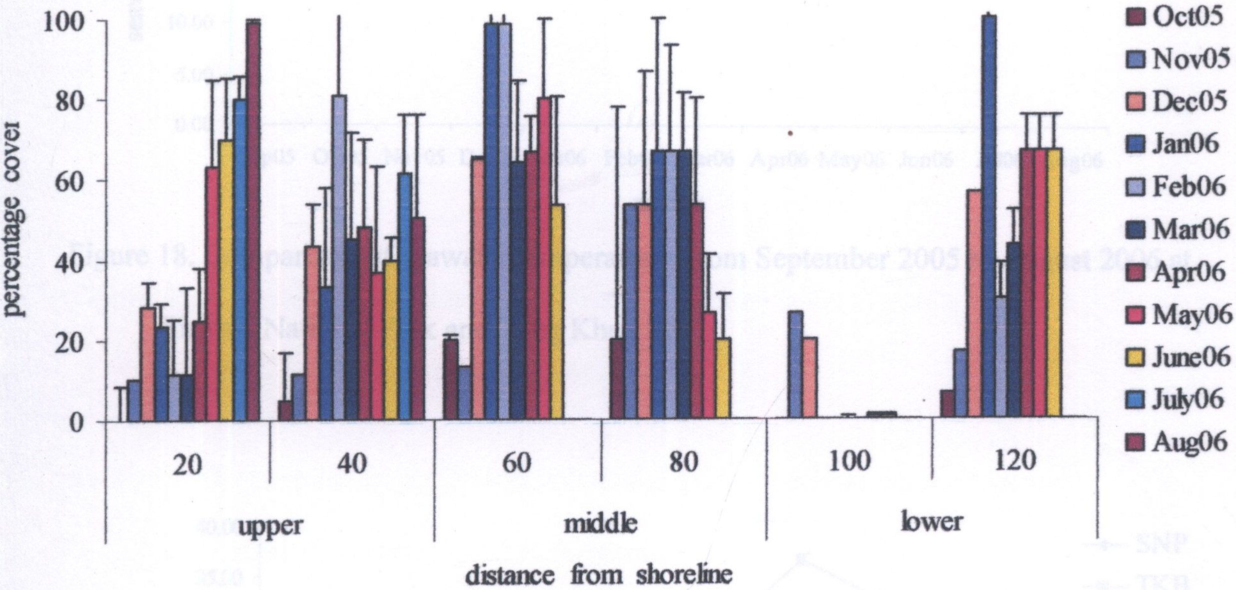



**Figure 17. Percentages cover of *P. boryana* from October 2005 to August 2006 at Tang Khen Bay.**

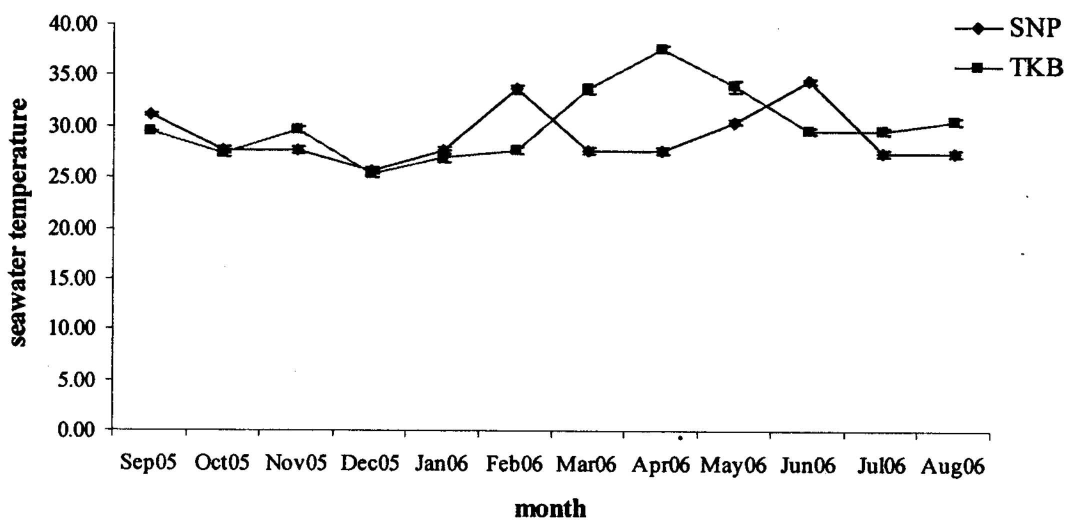



Figure 18. Comparison of seawater temperatures from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.

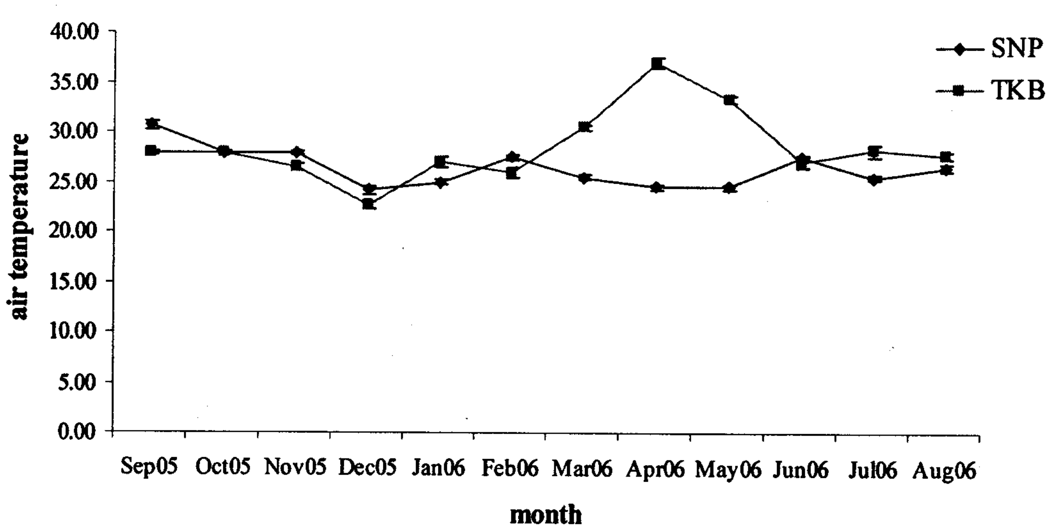



Figure 19. Comparison of air temperatures from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.

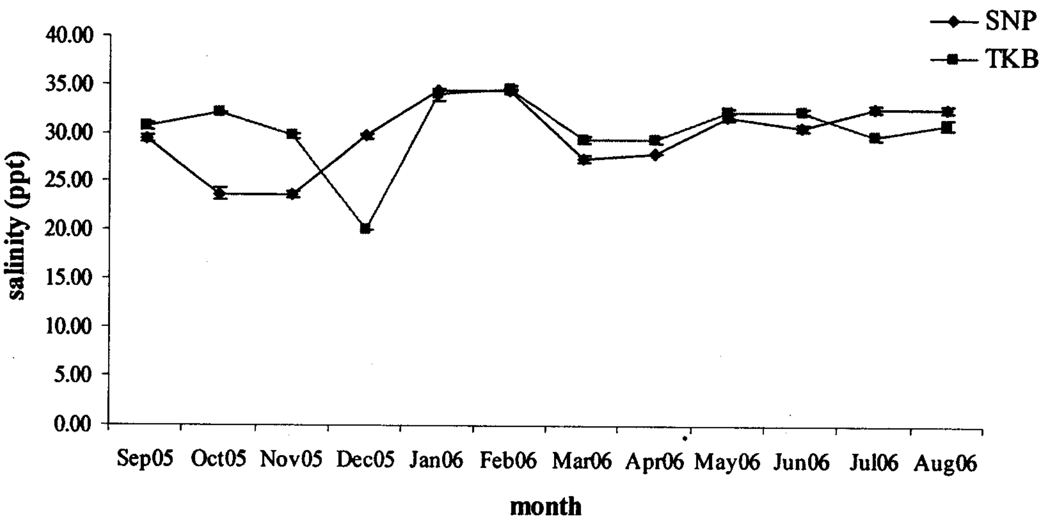



Figure 20. Comparison of salinity (ppt) from September 2005 to August 2006 at Sirinart National Park and Tang Khen Bay.

Table 13. The correlation coefficient value of physico-chemical parameters and biological characteristics of *P. boryana*.

| Biological parameters | SNP | | | TKB | | |
|---|---|---|---|---|---|---|
| | Temperature | | Salinity | Temperature | | Salinity |
| | Air | Water | | Air | Water | |
| Surface area | -0.24 | -0.117 | 0.158 | -0.091 | -0.028 | 0.507 |
| %female gametophyte | -0.128 | 0.12 | 0.114 | 0.237 | 0.334 | 0.13 |
| %male gametophyte | -0.006 | -0.089 | 0.114 | 0.111 | 0.047 | 0.235 |
| %sporophyte | 0.094 | -0.085 | 0.143 | -0.102 | -0.072 | 0.302 |
| %mature sporophyte | 0.088 | -0.072 | 0.147 | -0.086 | -0.109 | 0.339 |
| %reproduction | 0.084 | -0.065 | 0.145 | -0.063 | -0.029 | 0.348 |
| Number of spore produced | -0.008 | -0.035 | 0.062 | -0.137 | -0.088 | 0.43 |
| Number of spore released | 0.018 | 0.13 | -205 | 0.227 | -0.22 | 0.253 |
| %cover of *Padina* | 0.115 | 0.13 | -0.205 | -0.052 | 0.018 | 0.083 |

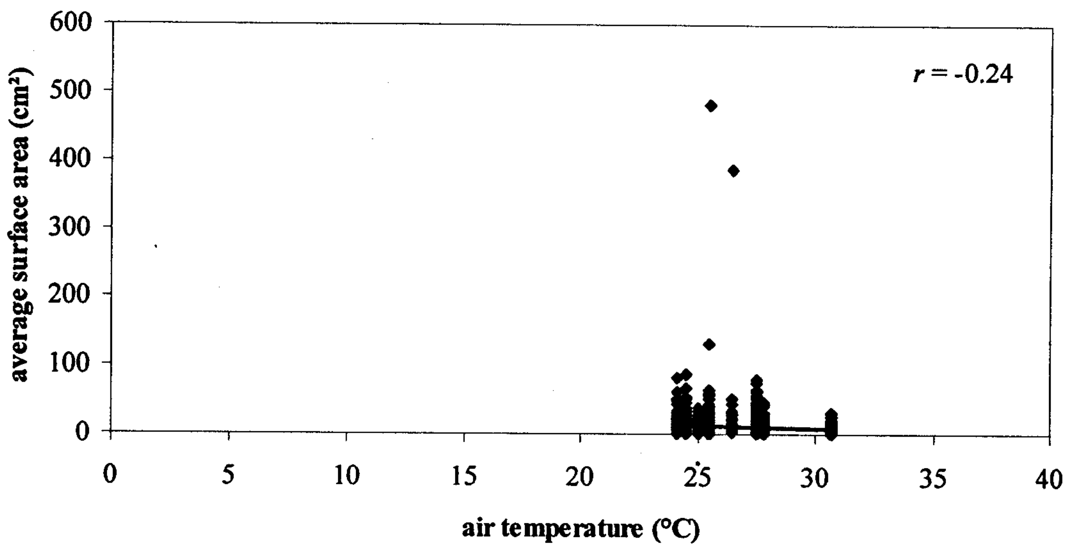



Figure 21. The correlation of average surface areas and air temperature from September 2005 to August 2006 at Sirinart National Park.

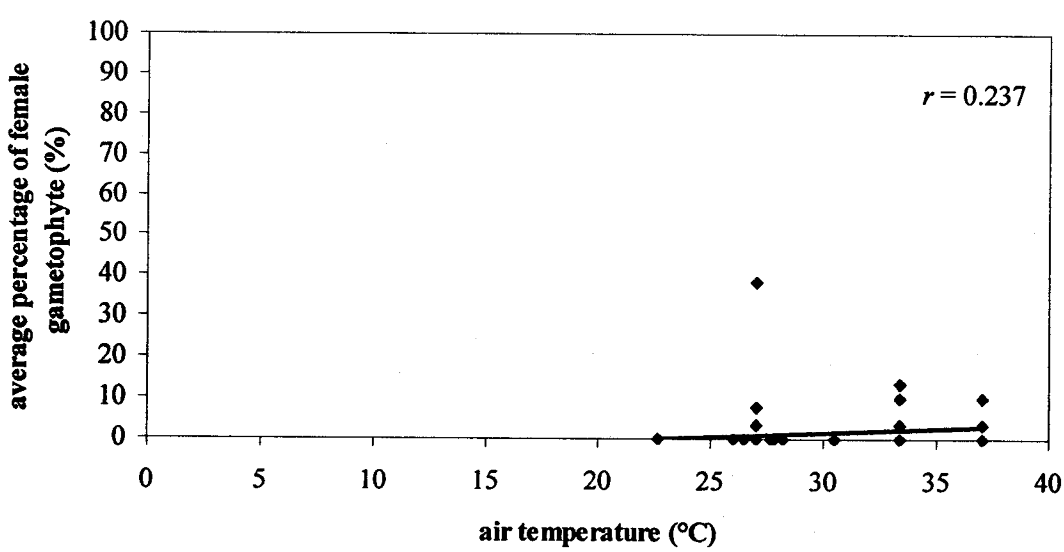



Figure 22. The correlation of average percentages of female gametophytes and air temperature from September 2005 to August 2006 at Tang Khen Bay.

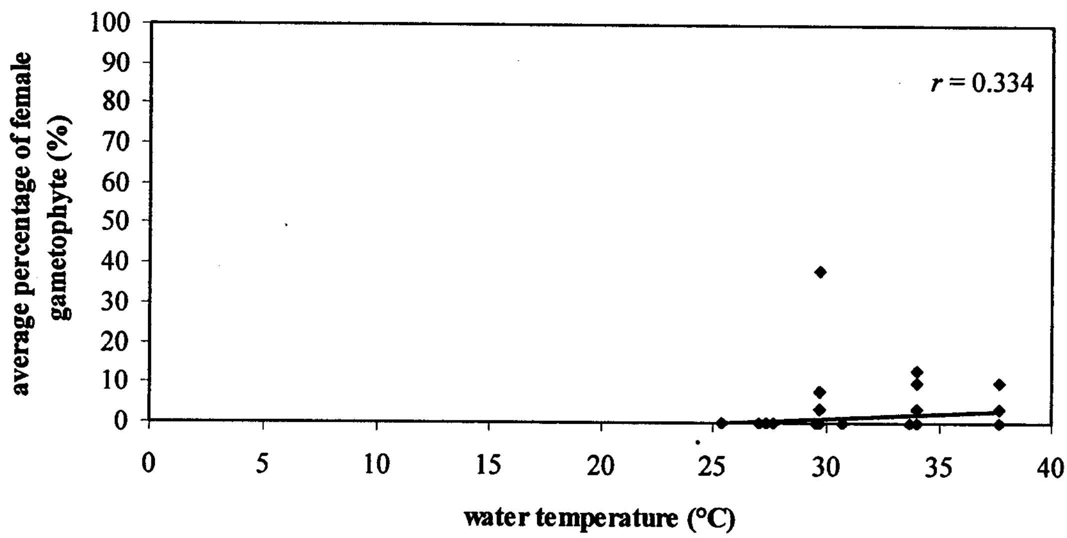



Figure 23. The correlation of average percentages of female gametophytes and water temperature from September 2005 to August 2006 at Tang Khen Bay.

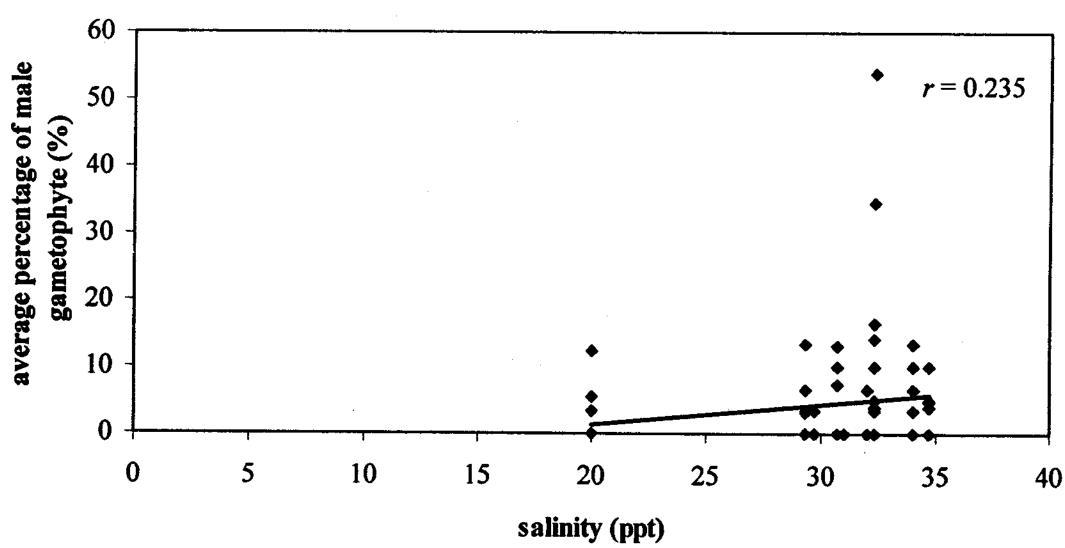



Figure 24. The correlation of average percentages of male gametophytes and salinity from September 2005 to August 2006 at Tang Khen Bay.

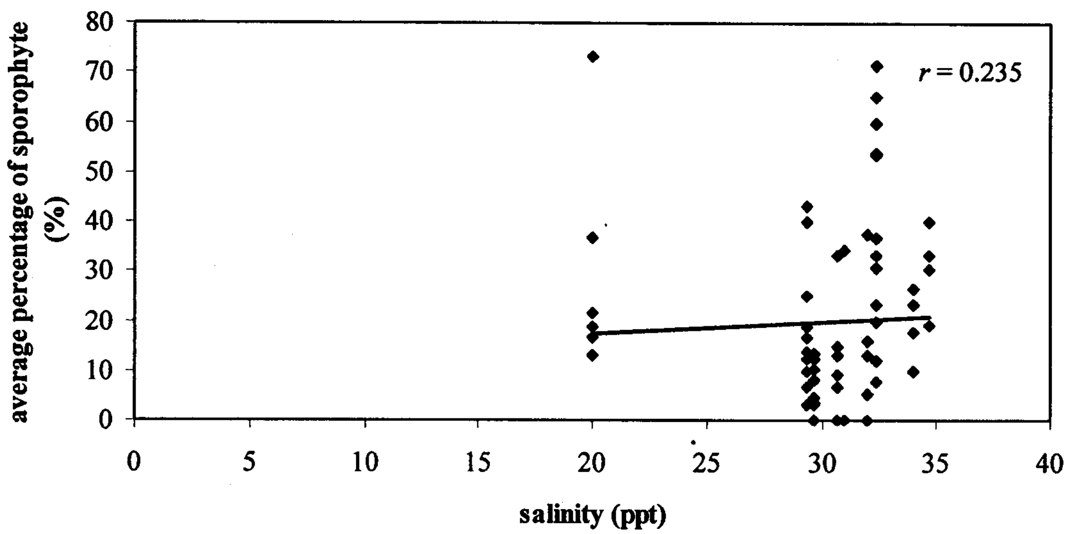



Figure 25. The correlation of average percentages of sporophytes and salinity from September 2005 to August 2006 at Tang Khen Bay.

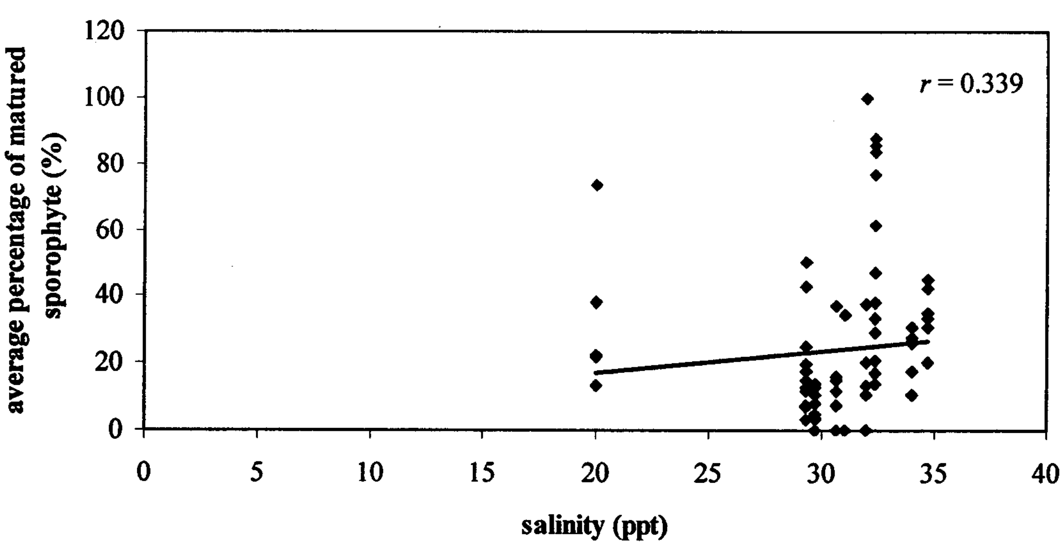



Figure 26. The correlation of average percentages of mature sporophytes and salinity from September 2005 to August 2006 at Tang Khen Bay.

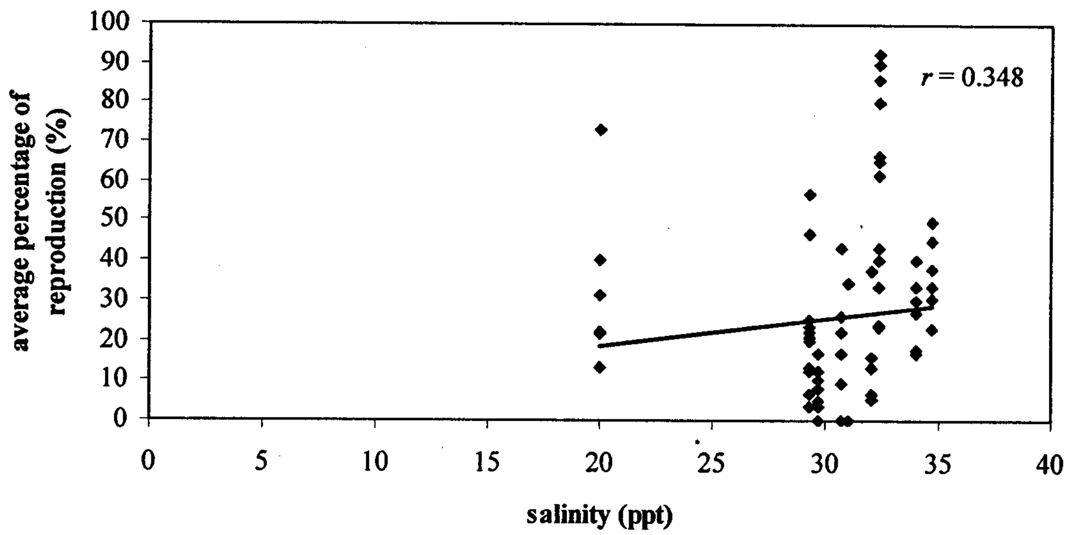



Figure 27. The correlation of average percentages of reproduction and salinity from September 2005 to August 2006 at Tang Khen Bay.

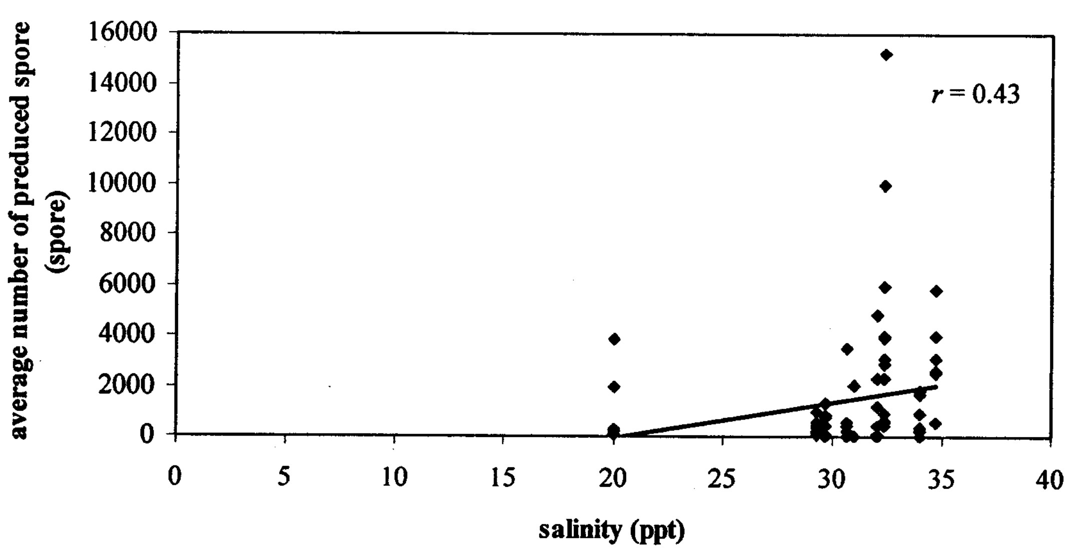



Figure 28. The correlation of average numbers of spores produced and salinity from Septejmber 2005 to August 2006 at Tang Khen Bay.

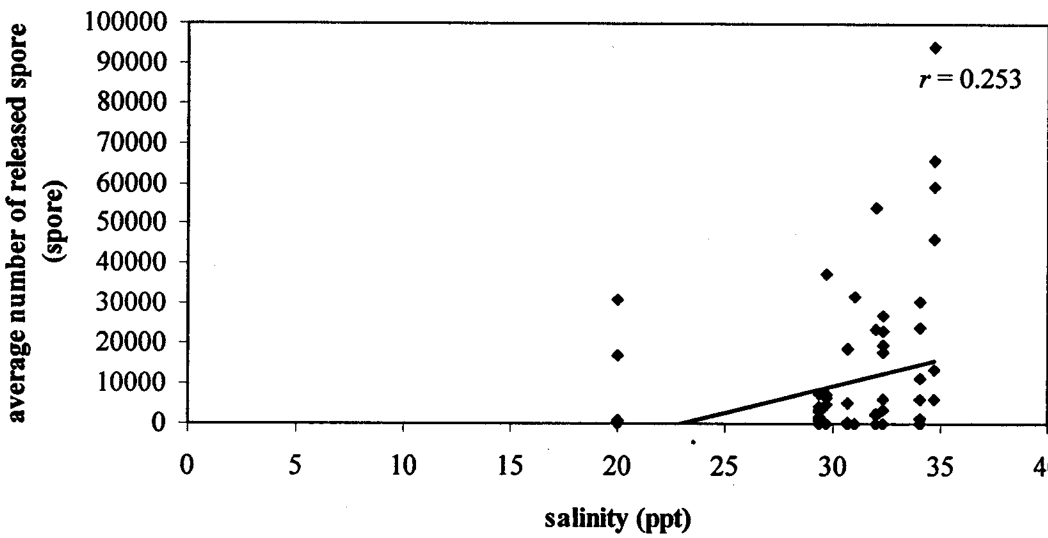



Figure 29. The correlation of average numbers of spores released and salinity from September 2005 to August 2006 at Tang Khen Bay.

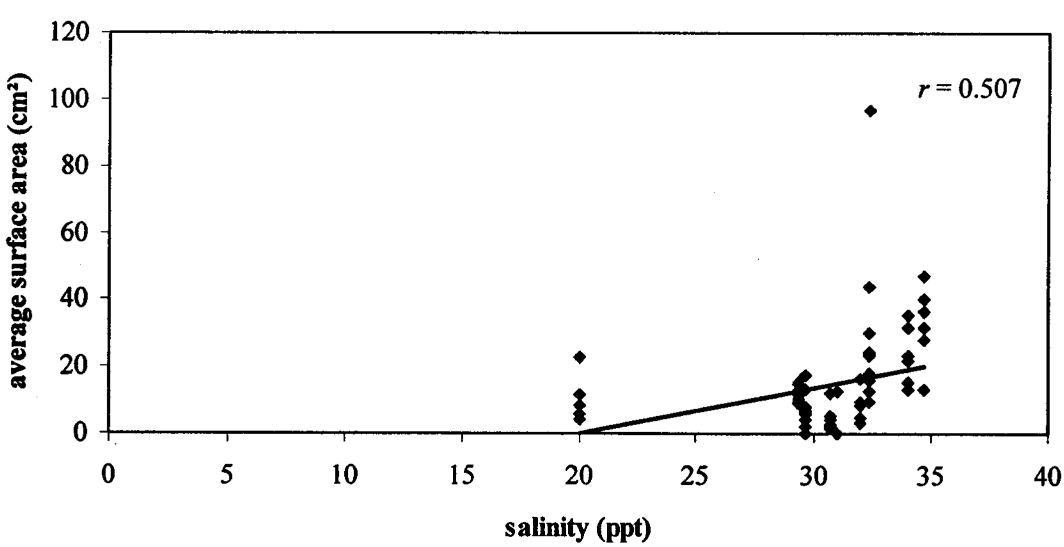



Figure 30. The correlation of average surface area and salinity from September 2005 to August 2006 at Tang Khen Bay.

# CHAPTER 4

# DISCUSSION

## Life phase of *P. boryana*

The percentage of reproduction was inferred by the percentage of sporophytes throughout the year because sporophytes were dominant in the study sites. Many investigators have indicated that sporophytes were dominant and that the gametophytes were rarely found both in intertidal and subtidal zones (Fagerberg and Dawes, 1973; Liddle, 1975; Lewis *et al.*, 1987). *Dictyota* species, also in the Dictyotales group, follow the same pattern (Hwang *et al.*, 2004)

Considering that *Padina* exhibits an isomorphic diplohaplontic life history (Lee, 1999) with an obligatory alternation between haploid gametophytes and diploid sporophytes, a dominance of sporophytes throughout the year is puzzling. It is possible that sporophytes may be able to produce new sporophytes asexually without going through the gametophyte phase (Allender, 1977) and not exhibit a full life cycle. This capacity of sporophyte self-generation appears to promote survival by increasing the number of individual plants of the population efficiently, thus *P. boryana* would become dominant on the shore.

The theory suggests that isomorphic phases are ecologically equivalent (i.e. have equal per capita mortality and fecundity rates) in contrast to the marine macroalgae that exhibit an alternation of heteromorphic generations in which one generation is more tolerant to unfavorable environmental conditions (Carney and Edwards, 2006) than the other. For example different herbivores might graze on the different morphologies. The ratio of the two phases in dioecious, haploid-diploid life cycle of many marine algae should be √2 gametophytes: 1 sporophyte (~60% haploids and 40% diploids) is expected at equilibrium (Thornber and Gaines, 2004; reviewed by Thornber, 2006). This perdition arises because of the cost of sex; every diploid individual can produce haploid offspring, whereas only haploid female gametophytes can produce diploid offspring. Although, many seaweeds do not follow that ratio, they do show that the demographic ratios between phases vary widely due to the differences of ecological response between two phases (Luxoro and Santelices, 1989; Scrosati *et al.*, 1994; reviewed by Thornber and Gaines, 2003; Carney and Edwards, 2006).

A low percentage of female gametophytes were found throughout the year but male gametophytes were found only in May, June and July at SNP and April and May and June at TKB. It appears that male gametophytes have high survival rates in the dry season and also a high success of fertilization since only a small number of gametophytes were found during this season. As reviewed by Thronber (2006), it appears that the advantages of diploid living include the ability to mask mutation and adapt more quickly to environmental variation. Further investigation on life phase, sex ratio and developmental timing of sporophytes and gametophytes would allow us to understand better this important aspect of algal life histories as well as the strategy for survival of *P. boryana*.

**Population structure, reproductive potential and recruitment of *P. boryana***

The structure of populations that determine birth and death processes are sensitive to changes in their environments. Population changes depend both on the variations in the environment and the life span of the organism. The fundamental model of population dynamics is the normal distribution model, the bell-shape curve. In addition, populations are regulated to stabilize below the equilibrium level or carrying capacity level (Neal, 2004). The stabilizing factor involves the numbers of individuals in the population or is density dependent. In addition, when the population is above equilibrium level, it tends to decrease in numbers and when it is below equilibrium level, it tends to increase (Maurer and Taper, 2002; Saller and Bredeweg, 2003).

Two populations of *P. boryana* at SNP and TKB showed a similar population distribution pattern, however they do not fit the normal distribution pattern. They have right tail shaped curve, dominated by the smaller thalli and only a few large ones throughout the year. Similar patterns are found in other brown seaweeds such as *Sargassum muticum* (Yendo) Fensholt (Arenas and Fernåndez, 2000), *Turbinaria triquetra* (J. Agardh) Kützing (Ateweberhan *et al.*, 2005) and *Sargassum lapazeanum* (Rivera and Scrosati, 2006) all members of the order Fucales. The data has suggested that new individuals developed continuously throughout the year providing new smaller thalli. The *Dictyerpa* stage of *Padina* was frequently observed in all plots in this study except those covered by the sediment. This filamentous stage developed into a visible blade size 0.5-1 cm. in 1 month. Such new thalli could develop throughout the year since *Dictyerpa* was always found in the experiment plots.

New recruits of *P. boryana* were found throughout the year at both sites in the experiment plots. However, recruitment was higher at TKB, a sheltered shore, where the average percentage cover was more than 40%. Lower wave action could allow a higher concentration of spores to settle whereas higher wave action diluted and washed away the new recruits of spores at SNP, a more exposed habitat (Gordon and Brawley, 2004). Another primary effect of wave action is the physical destruction of thalli and tearing the organisms from the substrates (Zacharias and Roff, 2001). This may explain that at the lower shore *P. boryana* recruited less than those on the upper shore, where there is less exposure to wave action.

Wave motion would be stressful for growth of *P. boryana* due to the size of thallus which was smaller at SNP than at TKB. *Padina* is one of few genera that can tolerate exposure during the low tide. The wave action, therefore, could cause it to have a reduced thallus size at SNP. The smaller size survives higher water action and has a decreased risk of being broken or torn (De Ruyter Van Steveninck and Breeman, 1987). Generally, many species of algae have to adapt themselves in response to water flow or wave exposure for survival. Reduced size (Kitzes and Denny, 2005), stronger holdfast and more flexible thalli (Denny and Roberson, 2002) are examples of such adaptations.

At both sites, *P. boryana* could not recruit on the permanent plots covered by sediment. Mayakun (2006) studied sediment accumulation between shore levels and showed that there were significant differences in grain size and amount of sediment between shallower and deeper zones at SNP. Sediment accumulates in the rainy season because the rainfall washes sediment downward the substrate. There were also greater sedimentation at SNP than at TKB. Sediment can therefore be considered a limiting factor for recruitment at both sites. Sediment has been shown by other researchers to inhibit or prevent the attachment and survival of macroalgal spores (Eriksson and Johansson, 2003; Isæus *et al.*, 2004; Schiel *et al.*, 2006). The scouring of sediment from moving water can affect early post-settlement stages (Eriksson and Johansson, 2003, Vadas *et al.*, 1992). Sediment can also affect growth indirectly by shading and inhibiting photosynthesis (Grant, 2000; Zacharias and Roff, 2001; Chapman and Fletcher, 2002). Likewise sediment itself is not a suitable substrate for propagule settlement. *P. boryana* might attach on the sediment temporarily but it could not attach on the hard substrata beneath the sediment.

The recruitment study provides an understanding of algal succession, a process that includes *P. boryana*, at two contrasting sites on the same island. As on many shores, filamentous algae, known as *r*-species. were the first colonizers, (Lubchenco, 1983; Gårdmark *et al.*, 2003, Mayakun, 2006). They were established quickly on the cleared plots and became dominant in the area. They are small fast-growing thalli. Also in less than 1 month, *Dictyerpa*, the creeping filamentous stage of *P. boryana*, occupied the same space along with the filamentous green and red algae. New juvenile fan-shaped thalli were evident in only 2 months. At around the same time the filamentous algal populations decreased and the new *P. boryana* thalli soon dominated the experimental plots. The rapid succession of *P. boryana* shows that it competes well with the other algae.

The ability of *P. boryana* to recruit rapidly is also reflected in the success of spore recruitment. The results showed that they produce spores throughout the year, providing a high reproductive potential. Even on the small thalli of *P. boryana* 1.06±0.25

$cm^2$, the spores were already observed. The numbers of released spores, with a maximum of fewer than 10,000 spores/ thallus is much less than the fucoid algal zygotes (Maggs and Callow, 2002). Fucoid algae produced approximately $10^9$ zygotes/thallus. Therefore, *P. boryana* has a very high success of spore recruitment since they produce relatively few in number. Liddle (personal communication) reports that, in culture, germination of spores is 100%. This fecundity helps explain the success of *P. boryana* in the stressful intertidal environment.

The factors that affect spore release also help us understand the distribution of *P. boryana*. Greater numbers of spores were released during the shift of seasons, from rainy to dry and also from dry to rainy season. The acute changes in the environmental conditions can trigger a greater number of spores released as reported in many studies (De Ruyter Van Steveninck and Breeman, 1987; Flores-Moya *et al.*, 1996; Yoshida *et al.*, 2001; Ateweberhan *et al.*, 2005). Such factors also influence the 2 populations of *P. boryana* in this study. Even if the plants were senescent the last crop of new spores would be the recruits that maintain the population. The new recruitment and die off cycle was less than 6 months long. Therefore *P. boryana* is highly dynamic and coordinated with broad annual changes. The successful recruitment and adaptation of the basic life history to the critical environmental factors helps explain the distribution patterns of *Padina boryana* throughout the year at two locations on Phuket Island.

# CHAPTER 5

## CONCLUSIONS

The successful survival of *P. boryana* was supported by:

1. The year round reproductive cells formation, especially spores.
2. Successful recruitment, the primary process.
3. The *Dictyerpa* stage which maintain the number of individuals from which the foliose stage can develop.

Some questions remain that require further investigation to answer.

1. What is the relationship between growth and reproductive potential? That is why can the smaller surface area produce more spores than the larger?
2. Why are sporophytes dominant?

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http://www.tmd.go.th/province_stat.php?StationNumber=48565 [October 29, 2006]

# APPENDIX

Appendix 1. Summary of Kolmogorov-Smirnov tests for population distribution between months within Sirinart National Park from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | ns | ns | 0.001** | ns | <0.001*** | 0.006** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Oct-05 | | 0.002** | 0.002** | 0.021* | <0.001*** | ns | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Nov-05 | | | 0.002** | ns | <0.001*** | <0.001*** | ns | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Dec-05 | | | | 0.027* | <0.001*** | <0.001*** | 0.001** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Jan-06 | | | | | 0.001** | <0.001*** | 0.011* | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Feb-06 | | | | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Mar-06 | | | | | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Apr-06 | | | | | | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| May-06 | | | | | | | | | ns | <0.001*** | ns |
| June-06 | | | | | | | | | | <0.001*** | <0.001*** |
| July-06 | | | | | | | | | | | ns |

Appendix 2. Summary of Kolmogorov-Smirnov tests for population distribution between months within Tang Khen Bay from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | 0.02* | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Oct-05 | | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Nov-05 | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | 0.015* |
| Dec-05 | | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | ns |
| Jan-06 | | | | | ns | <0.001*** | <0.001*** | <0.001*** | ns | 0.038* | 0.001** |
| Feb-06 | | | | | | <0.001*** | <0.001*** | ns | 0.004** | 0.006** | <0.001*** |
| Mar-06 | | | | | | | 0.012* | <0.001*** | <0.001*** | 0.028* | ns |
| Apr-06 | | | | | | | | <0.001*** | <0.001*** | 0.018* | ns |
| May-06 | | | | | | | | | <0.001*** | <0.001*** | <0.001*** |
| June-06 | | | | | | | | | | ns | 0.016* |
| July-06 | | | | | | | | | | | ns |

Appendix 3. Summary of Mann-Whitney U tests for average number of released spore between months within Sirinart National Park from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | ns | ns | ns | 0.003** | 0.001** | 0.005** | 0.005** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Oct-05 | | ns | ns | 0.003** | 0.001** | 0.006** | 0.005** | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Nov-05 | | | ns | <0.001*** | <0.001*** | <0.001*** | <0.001*** | <0.001*** | 0.027* | 0.017** | 0.002** |
| Dec-05 | | | | 0.026* | 0.011** | 0.032* | 0.04* | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Jan-06 | | | | | ns | ns | ns | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Feb-06 | | | | | | ns | ns | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Mar-06 | | | | | | | ns | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| Apr-06 | | | | | | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** |
| May-06 | | | | | | | | | ns | ns | ns |
| June-06 | | | | | | | | | | ns | ns |
| July-06 | | | | | | | | | | | ns |

Appendix 4. Summary of Mann-Whitney U tests for average number of released spore between months within Tang Khen Bay from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | 0.044* | ns | 0.001** | 0.003** | <0.001*** | ns | ns | ns | ns | ns | <0.001*** |
| Oct-05 | | ns | ns | ns | <0.001*** | 0.02* | ns | ns | ns | ns | 0.021* |
| Nov-05 | | | 0.003** | 0.01* | <0.001*** | ns | ns | ns | ns | ns | <0.001*** |
| Dec-05 | | | | ns | 0.001** | <0.001*** | ns | ns | 0.036* | ns | ns |
| Jan-06 | | | | | <0.001*** | 0.001** | ns | ns | ns | ns | ns |
| Feb-06 | | | | | | <0.001*** | <0.001*** | <0.001*** | <0.001*** | 0.021* | ns |
| Mar-06 | | | | | | | ns | ns | ns | ns | <0.001*** |
| Apr-06 | | | | | | | | ns | ns | ns | 0.004** |
| May-06 | | | | | | | | | ns | ns | 0.01** |
| June-06 | | | | | | | | | | ns | 0.003** |
| July-06 | | | | | | | | | | | ns |

Appendix 5. Summary of Mann-Whitney U tests for percentage of reproduction between months within Sirinart National Park from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | 0.016* | ns | ns | 0.006** | 0.003** | 0.006** | 0.004** | 0.025* | ns | ns | 0.004** |
| Oct-05 | | ns | ns | ns | 0.006** | ns | ns | 0.004** | 0.016** | 0.004** | 0.004** |
| Nov-05 | | | ns | ns | 0.003** | 0.01** | 0.01** | 0.006** | ns | ns | 0.004** |
| Dec-05 | | | | ns | ns | ns | ns | 0.01** | ns | 0.045** | 0.004** |
| Jan-06 | | | | | ns | ns | ns | 0.004** | 0.008** | 0.004** | 0.004** |
| Feb-06 | | | | | | ns | ns | 0.003** | 0.003** | 0.003** | 0.003** |
| Mar-06 | | | | | | | ns | 0.004** | 0.006** | 0.004** | 0.004** |
| Apr-06 | | | | | | | | 0.004** | 0.005** | 0.004** | 0.004** |
| May-06 | | | | | | | | | ns | ns | ns |
| June-06 | | | | | | | | | | ns | ns |
| July-06 | | | | | | | | | | | ns |

Appendix 6. Summary of Mann-Whitney U tests for percentage of reproduction between months within Tang Khen Bay from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | ns | ns | ns | ns | ns | ns | ns | 0.008** | 0.037* | 0.026* | ns |
| Oct-05 | | ns | ns | ns | ns | ns | ns | 0.006** | 0.01** | 0.031* | 0.031* |
| Nov-05 | | | 0.004** | 0.004** | 0.004** | ns | 0.005** | 0.004** | 0.004** | 0.046* | 0.046* |
| Dec-05 | | | | ns | ns | 0.025* | ns | 0.025* | ns | 0.005** | 0.02* |
| Jan-06 | | | | | ns | 0.025* | ns | 0.008** | ns | 0.004** | 0.031* |
| Feb-06 | | | | | | 0.004** | ns | 0.045* | ns | 0.003** | 0.013* |
| Mar-06 | | | | | | | 0.025* | 0.004** | 0.004** | 0.02* | 0.046* |
| Apr-06 | | | | | | | | 0.025* | ns | 0.005** | 0.02* |
| May-06 | | | | | | | | | ns | 0.003** | 0.005** |
| June-06 | | | | | | | | | | 0.003** | 0.008** |
| July-06 | | | | | | | | | | | ns |

Appendix 7. Summary of Mann-Whitney U tests for percentage of maturity between months within Sirinart National Park from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | 0.016* | ns | ns | 0.006** | 0.003** | 0.006** | 0.004** | 0.025* | ns | ns | 0.004** |
| Oct-05 | | ns | ns | ns | 0.009** | ns | ns | 0.004** | 0.016** | 0.004** | 0.004** |
| Nov-05 | | | ns | ns | 0.003** | 0.01* | 0.01* | 0.006** | 0.037* | 0.006** | 0.004** |
| Dec-05 | | | | ns | 0.02* | ns | ns | 0.01* | 0.025* | 0.055* | 0.004** |
| Jan-06 | | | | | ns | ns | ns | 0.004** | 0.008** | 0.004** | 0.004** |
| Feb-06 | | | | | | ns | ns | 0.003** | 0.003** | 0.003** | 0.003** |
| Mar-06 | | | | | | | ns | 0.004** | 0.006** | 0.004** | 0.004** |
| Apr-06 | | | | | | | | 0.004** | 0.005** | 0.004** | 0.004** |
| May-06 | | | | | | | | | ns | ns | ns |
| June-06 | | | | | | | | | | ns | ns |
| July-06 | | | | | | | | | | | ns |

Appendix 8. Summary of Mann-Whitney U tests for percentage of maturation between months within Tang Khen Bay from September 2005 to August 2006; otherwise, * $P$<0.5, **$P$<0.01, ***$P$<0.001; ns = not significant.

| month | Oct-05 | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sept-05 | ns | ns | ns | ns | 0.025* | ns | ns | 0.01** | 0.037* | 0.033* | ns |
| Oct-05 | | ns | ns | ns | ns | ns | ns | ns | ns | 0.033* | 0.049* |
| Nov-05 | | | 0.004** | 0.006** | 0.004** | ns | 0.008** | 0.004** | 0.004** | 0.046* | 0.046* |
| Dec-05 | | | | ns | ns | 0.01** | ns | 0.037* | ns | 0.005** | 0.02* |
| Jan-06 | | | | | 0.037* | 0.016* | ns | 0.006** | ns | 0.005** | 0.046* |
| Feb-06 | | | | | | ns | ns | ns | ns | 0.003** | 0.013* |
| Mar-06 | | | | | | | ns | 0.004** | 0.025* | 0.02* | 0.046* |
| Apr-06 | | | | | | | | 0.037* | ns | 0.008** | 0.02* |
| May-06 | | | | | | | | | ns | 0.003** | 0.008** |
| June-06 | | | | | | | | | | 0.005** | 0.013* |
| July-06 | | | | | | | | | | | ns |

Appendix 9. Summary of Mann-Whitney U tests for percentage of recruitment between months within Sirinart National Park from October 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oct-05 | ns | 0.001** | 0.003** | 0.002** | ns | ns | ns | ns | ns | ns |
| Nov-05 | | 0.007** | 0.014* | 0.008** | ns | ns | ns | ns | ns | ns |
| Dec-05 | | | ns | ns | ns | 0.009** | <0.001*** | 0.033* | ns | ns |
| Jan-06 | | | | ns | ns | 0.018* | 0.001** | ns | ns | ns |
| Feb-06 | | | | | ns | 0.013* | 0.001** | 0.042* | ns | ns |
| Mar-06 | | | | | | ns | 0.037* | ns | ns | ns |
| Apr-06 | | | | | | | ns | ns | ns | ns |
| May-06 | | | | | | | | ns | 0.03* | ns |
| June-06 | | | | | | | | | ns | ns |
| July-06 | | | | | | | | | | ns |

Appendix 10. Summary of Mann-Whitney U tests for percentage of recruitment between months within Tang Khen Bay from September 2005 to August 2006; otherwise, * $P<0.5$, ** $P<0.01$, *** $P<0.001$; ns = not significant.

| month | Nov-05 | Dec-05 | Jan-06 | Feb-06 | Mar-06 | Apr-06 | May-06 | June-06 | July-06 | Aug-06 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oct-05 | 0.027* | <0.001*** | 0.003** | 0.009** | 0.024* | 0.005** | 0.002** | 0.003** | ns | ns |
| Nov-05 | | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Dec-05 | | | ns | ns | ns | ns | ns | ns | 0.029* | 0.032* |
| Jan-06 | | | | ns | ns | ns | ns | ns | 0.008** | 0.014* |
| Feb-06 | | | | | ns | ns | ns | ns | 0.025* | ns |
| Mar-06 | | | | | | ns | ns | ns | ns | ns |
| Apr-06 | | | | | | | ns | ns | 0.05* | ns |
| May-06 | | | | | | | | ns | 0.021* | 0.035* |
| June-06 | | | | | | | | | ns | ns |
| July-06 | | | | | | | | | | ns |

Appendix 11. Comparison of the total rainfall between Sirinart National Park and Tang Khen Bay from September 2005 to August 2006 (http://www.tmd.go.th/province_stat.php?StationNumber=48565).

| month | Total rainfall ($mm^3$) | |
|---|---|---|
| | SNP | TKB |
| Sept-05 | 349.5 | 263.5 |
| Oct-05 | 412 | 226.7 |
| Nov-05 | 297 | 239 |
| Dec-05 | 98.1 | 102.8 |
| Jan-06 | 15.9 | 20.5 |
| Feb-06 | 3 | 9.1 |
| Mar-06 | 128.3 | 185.8 |
| Apr-06 | 90.8 | no data |
| May-06 | 286.6 | 242 |
| June-06 | 381.9 | 297 |
| July-06 | 186.7 | 213.7 |
| Aug-06 | 252.4 | 168.8 |

# VITAE

**Name** Miss Bongkot Wichachucherd

**Student ID** 4722028

**Educational Attainment**

| Degree | Name of Institution | Year of Graduation |
|---|---|---|
| B. Sc. (Biology) | Prince of Songkla University | 2004 |

**Scholarship Awards during Enrolment**

- TRF/BIOTEC Spatial program for Biodiversity Research and Training grant BRT T_349005
- Funding of Graduate School, Prince of Songkla University, Hat Yai, Songkhla.

**List of Publication and Proceeding**

- Prathep, A., Wichachucherd, B. and Thongroy, P. (2007). Spatial and temporal variations in density and thallus morphology of *Turbinaria ornata* in Thailand. Aquatic Botany 86(2), 132-138.
- Wichachucherd, B., Liddle, L. B. and Prathep, A., Population, recruitment and succession of a brown alga, *Padina boryana*, at an exposed shore of Sirinart National Park and sheltered area of Tang Khen Bay, Phuket Province, Thailand. (In preparation)

- Wichachucherd, B., Liddle, L. B. and Prathep, A., Spatial and temporal variation of haploid and diploid in marine alga *Padina boryana* Thivy at intertidal zone, Phuket province, Thailand. (In preparation)