Human Impact on Rotifera Communities of Coastal Peat Swamps in Phuket Province, Southern Thailand

Supenya Chittapun

Doctor of Philosophy Thesis in Biology

Prince of Songkla University

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Author	Supenya Chittapun
Major Program	Biology

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ชื่อวิทยานิพนธ์ อิทธิพลของมนุษย์ต่อสังคมโรติเฟอร์ในเขตพื้นที่ป่าพรุบริเวณชายฝั่งจังหวัดภูเก็ต ภาคใต้ของประเทศไทย

ผู้เขียน นางสาว สุเปญญา จิตตพันธ์

สาขาวิชา ชีววิทยา

ปีการศึกษา 2546

บทคัดย่อ

ตรวจสอบผลของการรบกวนที่เกิดขึ้นจากมนุษย์ต่อความหลากหลายทางชีวภาพในเขตพื้นที่ป่าพรุบริเวณชายฝั่งจังหวัดภูเก็ต 5 แห่งคือ พรุไม้ขาว พรุจูด พรุจิก พรุเจ๊ะสัน และพรุสระบัว ระหว่างเดือนพฤศจิกายน 2542 ถึงเดือนกุมภาพันธ์ 2544 โดยเก็บตัวอย่างเชิงคุณภาพทุกเดือนด้วยถุงลากแพลงก์ตอนขนาดตา 26 ไมโครเมตร พร้อมทั้งวัดปัจจัยสิ่งแวดล้อมบางประการ ประเมินความหลากหลายทางชีวภาพในพื้นที่ป่าพรุโดยใช้โรติเฟอร์ในกลุ่ม Monogononta และวิเคราะห์หาปัจจัยที่มีผลต่อสังคมโรติเฟอร์

พบโรติเฟอร์ทั้งสิ้น 133 ชนิด จากโรติเฟอร์ที่พบทั้งหมด *Dicranophoroides* sp. เป็นชนิดที่รายงานเป็นครั้งแรกในเขตออเรียลทัล และ *Harringia rousseleti* เพิ่งรายงานเป็นครั้งแรกในประเทศไทย นอกจากนี้พบว่า Chao2 เป็น nonparametric estimator ที่มีความลำเอียงน้อยที่สุดในการคำนวณหาจำนวนชนิดของโรติเฟอร์ในพื้นที่ป่าพรุทั้ง 5 แห่ง โดยพื้นที่ที่มีจำนวนชนิดของโรติเฟอร์มากที่สุดคือ พรุเจ๊ะสัน (137 ชนิด) รองลงมาคือ พรุจิก (93ชนิด) พรุไม้ขาว (81ชนิด) พรุจูด (73 ชนิด) และพรุสระบัว (56 ชนิด) ตามลำดับ จากค่าดัชนีความหลากหลายของ Simpson พบว่าพรุจิกมีความหลากหลายมากที่สุด (5.889) รองลงมาคือ พรุเจ๊ะสัน (3.444) พรุจูด (3.115) พรุสระบัว (2.960) และพรุไม้ขาว (2.883) ตามลำดับ พิจารณาความแตกต่างขององค์ประกอบของโรติเฟอร์เปรียบเทียบกับพรุจิกซึ่งเป็นพรุดั้งเดิม พบว่าพรุสระบัวซึ่งเป็นพรุที่มีสารอาหารสูง มีองค์ประกอบของโรติเฟอร์แตกต่างมากที่สุด (66%) รองลงมาคือ พรุไม้ขาว (55%) และพรุจูด (54%) ซึ่งมีสภาพเป็นน้ำกร่อย และพรุเจ๊ะสัน (39%) ซึ่งเปลี่ยนสภาพเป็นอ่างเก็บน้ำ ตามลำดับ จากผลการศึกษาชี้ให้เห็นว่า พื้นที่ป่าพรุดั้งเดิมมีความหลากหลายของโรติเฟอร์มากกว่าพื้นที่ป่าพรุที่ถูกรบกวน และกิจกรรมของมนุษย์โดยรอบพื้นที่ป่าพรุส่งผลให้มีการเปลี่ยนแปลงองค์ประกอบชนิดของโรติเฟอร์

ตรวจสอบปัจจัยที่มีผลต่อสังคมโรติเฟอร์โดยใช้การวิเคราะห์แบบหลายตัวแปร พบว่าความเค็ม และค่าการนำไฟฟ้า เป็นปัจจัยสำคัญที่มีผลต่อสังคมโรติเฟอร์ รองลงมาได้แก่ ความหนาแน่นของพืชน้ำ ปริมาณคลอโรฟิลล์เอ ความขุ่นของน้ำ และปริมาณไนเตรต ตามลำดับ จากผล

การศึกษาชี้ให้เห็นว่า การปล่อยน้ำเสียจากการเพาะเลี้ยงสัตว์น้ำวัยอ่อน ส่งผลให้โรติเฟอร์ในพื้นที่ป่าพรุมีความหลากหลายลดลง และมีการเปลี่ยนแปลงองค์ประกอบชนิดอย่างเห็นได้ชัด

นอกจากนี้เพื่อทดสอบความสามารถในการฟื้นคืนของสังคมโรติเฟอร์หลังการถูกรบกวน ได้ทดลองทดสอบความสามารถในการฟักของไข่โรติเฟอร์ซึ่งอยู่ในระยะพัก พบว่าระยะเวลาส่งผลให้ความสามารถในการอยู่รอดของไข่ระยะพักลดลงอย่างมาก ในขณะที่สภาวะที่ใช้เก็บรักษาไข่ระยะพักจะมีผลหลังจากเก็บรักษาไข่ระยะพักไว้เป็นเวลา 6 เดือน การค้นพบครั้งนี้แสดงให้เห็นว่าไข่ระยะพักมีอายุขัย เพราะฉะนั้นความสามารถในการฟื้นคืนของสังคมโรติเฟอร์จากไข่ระยะพักในบริเวณที่ถูกรบกวน จะมีประสิทธิภาพก็ต่อเมื่อ การฟื้นฟูนั้นกระทำอย่างรวดเร็วในระยะเวลาอันสั้นหลังจากถูกรบกวน

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Abstract

Human activities influencing the biodiversity were examined at five coastal peat swamps (Mai-Khao, Jood, Jik, Jae-Son and Sra-Boua) in Phuket province during November 1999 to February 2001. Qualitative samples were taken on a monthly basis using a 26 μm plankton net, and some environmental parameters were measured. The biodiversity of the peat swamps as indicated by Rotifera in class Monogononta was assessed, and the important variables resulting rotifer communities were investigated.

A total of 133 rotifer species was identified. Of these, *Dicranophoroides* sp. was a new record to the Oriental region and *Harringia rousseleti* was new to Thailand. In addition, Chao2 was examined as the least bias nonparametric estimator for estimating species richness in the five peat swamps. The highest species richness was found in Jae-Son (137 species), followed by Jik (93 species), Mai-Khao (81 species), Jood (73 species) and Sra-Boua (56 species), respectively. Moreover, Simpson diversity index showed that Jik (5.889) was the great diverse area, followed by Jae-Son (3.444), Jood (3.115), Sra-Boua (2.960) and Mai-Khao (2.883), respectively. With regard to complementarity using Jik, a pristine peat swamp, as a reference, biotic distinctness was found to be highest at Sra-Boua (66%), a eutrophic

area, followed by Mai-Khao (55%) and Jood (54%), brackish peat swamps and Jae-Son (39%), a reservoir peat swamp, respectively. These results indicated that the pristine swamps contained higher rotifer diversity than the disturbed areas, and human activities around the peat swamps have exerted their influence on rotifer communities by alterating the species composition.

Additionally, multivariate analysis revealed that the most significant variables influencing different rotifer assemblage in the five peat swamps were salinity and conductivity, followed by the degree of coverage of macrophyte, Chlorophyll a, turbidity and nitrate, respectively. This result suggested that discharged seawater from aquaculture had strong impact on the rotifer diversity decreasing and species composition alteration.

Besides, in order to assess the recovery potential of rotifer communities after disturbance, an experimental study on rotifer hatching was performed. The experiment indicated that exposure time had a strong impact on the viability of resting eggs, whereas the effect of exposure conditions appeared only after six months. The finding demonstrated that resting eggs have life span. Therefore, the recovery of rotifer communities from sediment egg banks in disturbed peat swamps can only be effectively attained when restoration is implemented within a relatively short period after perturbation.

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I would like to express my deep appreciation to my advisor, Associate Professor Dr. Pornsilp Pholpunthin for his guidance, valuable advice and his human touch which have made my Ph.D. study the most rewarding experience. My sincere gratitude also goes to my co-advisors, Dr. Hendrik Segers for his worthy advice on tackling the riddles of my research questions and his valuable suggestion that has helped validate my findings and Associate Professor Dr. La-orsri Sanoamuang who has pioneered research on rotifers in Thailand. External examiners, Associate Professor Dr. Soawapa Angsupanich and Professor Ladda Wongrat, were so insightful in reflecting certain shortcomings in the collection and interpretation of field data which led to the revision of some parts of my dissertation.

I would also like to extend my sincere gratitude to Assistant Professor Dr. Sunthorn Sotthibandhu for sharpening my brain and enhancing my aptitude, Associate Professor Dr. Chutamas Pholpunthin and Assistant Professor Dr. Kitichate Sridith for their guidance, understanding and support. My thankfulness also goes to all lecturers in Biology Department for their kind cooperation in various ways.

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I am extremely thankful to the TRF/BIOTEC Special Program for Biodiversity Research and Training grant (BRT541051) for its financial support in the sample collections over my master's period during 1998 – 1999 and the Royal Golden Jubilee Ph.D. program No. 4.B.PS/42 Fund for supporting my Ph.D. research between 1999 - 2002.

Finally, I wish to thank my parents, my relatives and Mr. Chate Sirichote for their love and care and incessant encouragement throughout my life.

Supenya Chittapun

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List of Abbreviations

al	=	alula
c.	=	calculated
°C	=	degree Celsius
CCA	=	Canonical Correspondence Analysis
cm	=	centimeter
d	=	Berger-Parker dominance index
D	=	Simpson diversity index
DCA	=	Detrend Correspondence Analysis
DO	=	Dissolved Oxygen
E	=	Simpson's equitability
et al.	=	Et. Ali (Latin), and others
fu	=	fulcrum
g	=	gram
H	=	Shannon Wiener index
J	=	Shannon Wiener' equitability
kg	=	kilogram
km^2	=	square kilometer
µm	=	micrometer
m^2	=	square meter
ma	=	manubrium

List of Abbreviations (continued)

$mg.l^{-1}$	=	milligram per liter
$mS.cm^{-1}$	=	milli Siemens per centimeter
NTUs	=	Nephelometric Turbidity Units
OECD	=	Organization for Economic Co-operation and Development
p.	=	page
ppt	=	part per thousand
ra	=	ramus
SPSS	=	Statistical Package for Social Science
TWINSPAN	=	Two-Way Indicator Species Analysis
un	=	uncus

1. INTRODUCTION

Literature review

1.1 Peat swamp

1.1.1 What is a peat swamp?

Peat swamp is a particular type of wetland, which is an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes and forces the biota to exhibit adaptations to tolerate flooding. Using sets of plant and animal associations, wetlands can be classified into six basic types, one of which is peat swamp (Keddy, 2000). Peat swamps can be distinguished from other wetland habitats by an accumulation of organic matter called peat. Peat is formed when decomposition fails to keep pace with the production of organic matter. This is a result of water logging, a lack of oxygen or nutrients, high acidity or low temperature (Finlayson and Moser, 1991). Because of the high level of material decomposition, freshwater in the peat swamp is characterized by its acidity and by being brownish in color. The vegetation of tropical peat swamps is dominated by evergreen trees rooted in deep peat (Phengklai *et al.*, 1989). In primary peat swamps, the vegetation is composed of numerous plant species. In contrast to this, the majority of vegetation consists of *Melaleuca* sp., as secondary vegetation type in degenerated peat swamps.

1.1.2 The formation of peat swamp

A possible hypothesis for the development of coastal peat swamps in southern Thailand is that they are initiated by continuous strong winds and waves causing the formation of a raised sandy beach, at short distance from the coastline. During a long period the raised sandy beach would enlarge, extend, and become higher, until it came to converge with the seashore, forming a large shallow inland sea. In the absence of an outlet to the sea, the inland laguna would become a freshwater lake due to the heavy rainfall in the area. The annual native plants, which are adapted to such conditions, would proliferate causing the gradual filling of the lake over a long period of time. Then the pioneer perennial species would follow into the area. Decomposition of plant biomass is a relatively slow process in such a biotope, due to the high content of sodium sulphide in the water preventing the developing of bacteria. The accumulation of organic matter results in a peat layer of varying thickness. The process to form such peat swamps takes thousands of years (Phengklai *et al.*, 1989).

1.1.3 What are the importances of peat swamps?

Peat swamps play several vital functions in the ecosystem. One of the most important roles is flood control. Peat swamps act as sponges, storing and slowly releasing rainfall and run-off, which result in the reduction of flood peaks. In addition, their vegetation is essential in helping the stabilization of banks and shores, counteracting forces of erosion and sea level rise. Moreover, peat swamps play a key role in ground water recharge and discharge. They also act as a filter for certain kinds of waste and soluble contaminants. These processes are important for controlling storm water run-off, for replenishing supplies of water for human consumption and also in maintaining the flow of ground water. An environment rich in peat swamps

remaining; these are To-daeng in Narathiwas province and Jik in Phuket province. The main causes of peat swamp destruction in Thailand are transformation and invasion. These factors result in area reduction and lead to complete disappearance of some peat swamp areas.
(see:http://www.wildlifefund.or.th/07_Habitats/03_peatswam_forest/peatswam_forest 00.html and http://www.zyworld.com/NAKARIN/HTMLbirdhabitat.htm#peat)

1.2 Rotifera

1.2.1 What are rotifers?

Rotifers are a cosmopolitan zooplankton group belonging to the Phylum Rotifera, which is composed of more than 2,000 species (Nogrady *et al.*, 1993). This Phylum is typically characterized by an unsegmented, pseudocoelomate, primary bilateral symmetrical body, and a complete digestive system (Nogrady *et al.*, 1993; Miller and Harley, 1996). The members are probably derived evolutionarily from ancestral acoelic turbellarians and related to the gnathostomulids (Starkweather, 1987; Ruttner-Kolisko, 1974 quoted by Segers, 1995-1996).

Rotifers in general can be distinguished from other zooplankton by two unique features: the presence of a corona and a mastax (Nogrady *et al.*, 1993) (Figure 1.1). The corona is an annular band of cilia of the apical hypodermis, which surrounds the apical field. The cilia serve for locomotion and for directing food towards the mouth. The mastax is a muscular organ in the pharynx working for selection, catching and processing of food (Starkweather, 1987; Nogrady *et al.*, 1993; Segers, 1995-1996; Solomon *et al.*, 2002). It consists of a number of hard elements called trophi (Figure1.2). The trophi is the most important morphological feature used in the classification and identification of monogonont rotifers to species level (Segers, 1995-1996).

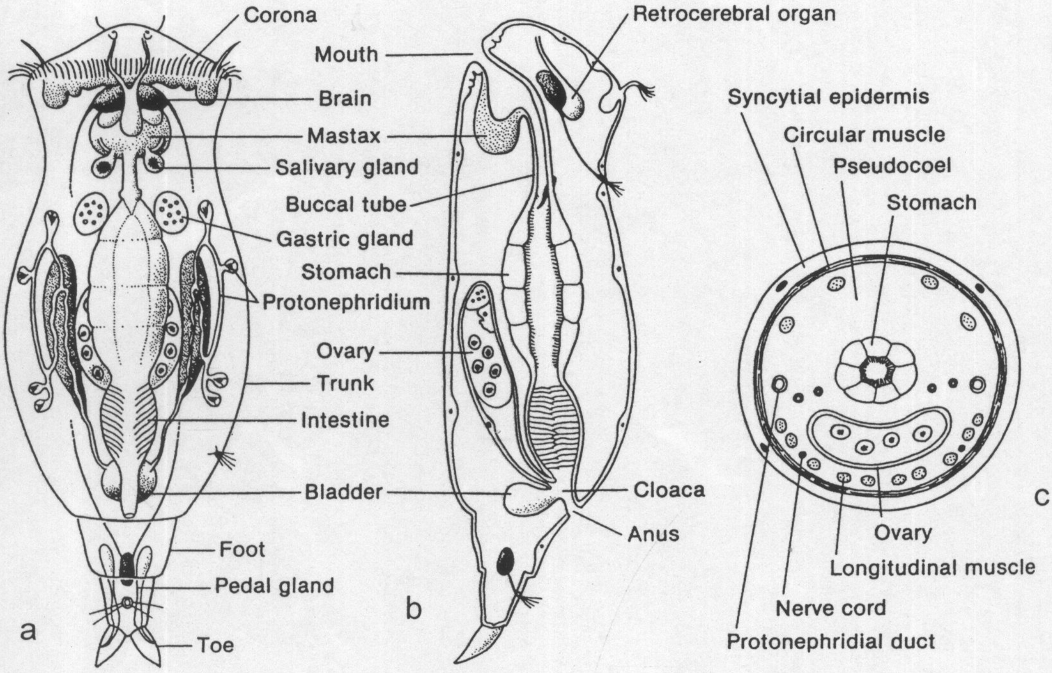

Figure 1.1 Rotifer anatomy; a: Dorsal view, b: Lateral view and c: Cross section (Ruppert and Barnes, 1994, p. 308).

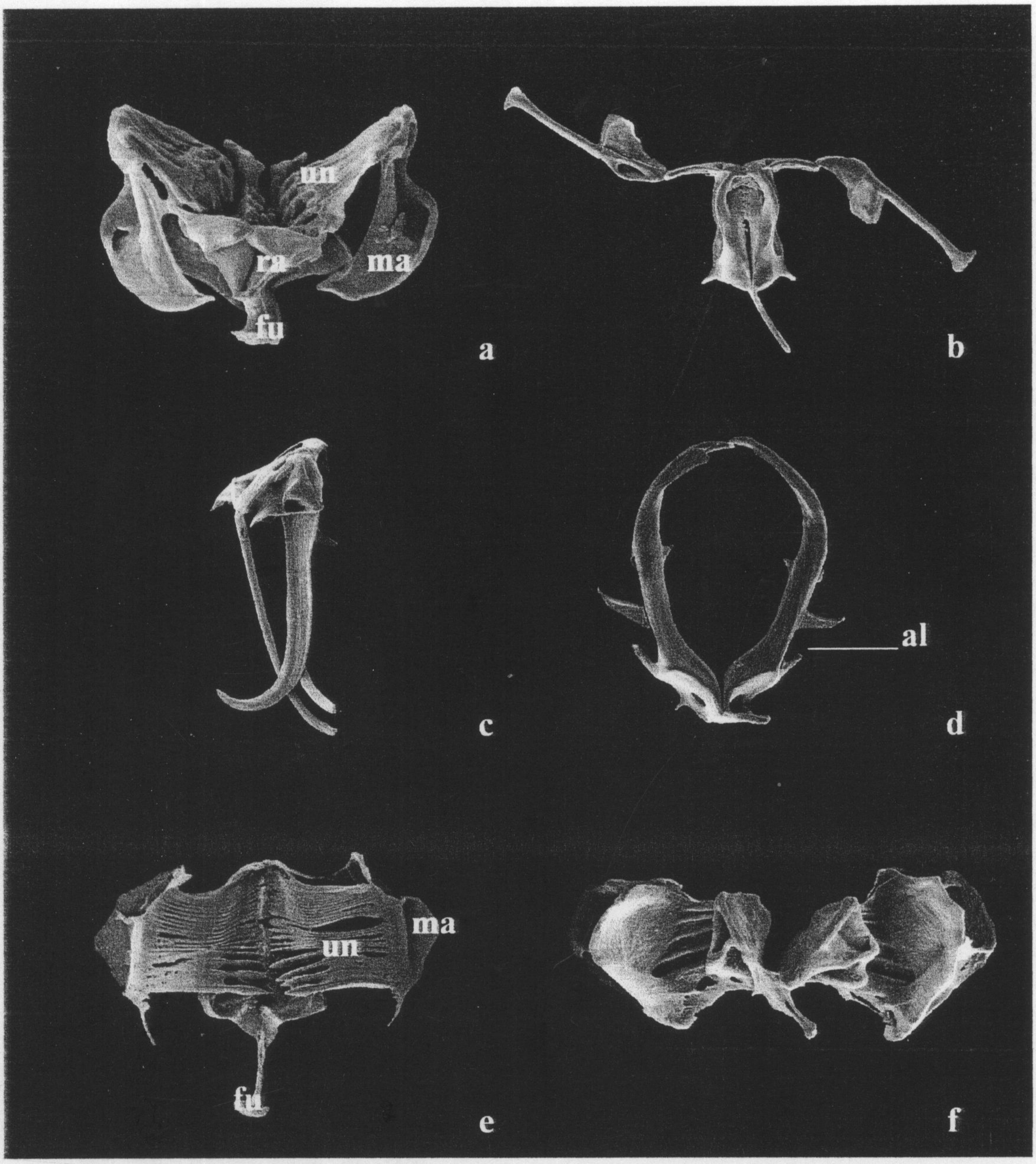

Figure 1.2 Some major types of trophi; a: Malleate trophi of *Brachionus*; b: Forcipate trophi of *Dicranophorus*; c: Virgate trophi of *Trichocerca*; d: Incudate trophi of *Asplanchna*; e and f: Malleoramate trophi of *Filinia* and *Hexathra*, respectively (fu: fulcrum, ra: ramus, ma: manubrium, un: uncus, al: alula).

The Phylum Rotifera can be divided into three classes, Pararotatoria, Bdelloidea and Monogononta (Segers, 2002). This research work focused only on the Monogononta Rotifera, the largest group of Rotifera containing more than 1,600 species (Segers, 2002).

The three classes of rotifers reproduce by three different mechanisms. The class Pararotatoria reproduces exclusively bisexually; gametogenesis occurs by meiosis, with the production of two polar bodies. In Bdelloidea, on the other hand, no males have ever been observed and reproduction is exclusively by asexual parthenogenesis. This involves two equational divisions producing two polar bodies. Monogonont rotifers reproduce both by parthenogensis and by sexual reproduction called heterogony (Figure 1.3) (Wallace and Snell, 1991; Nogrady *et al.*, 1993).

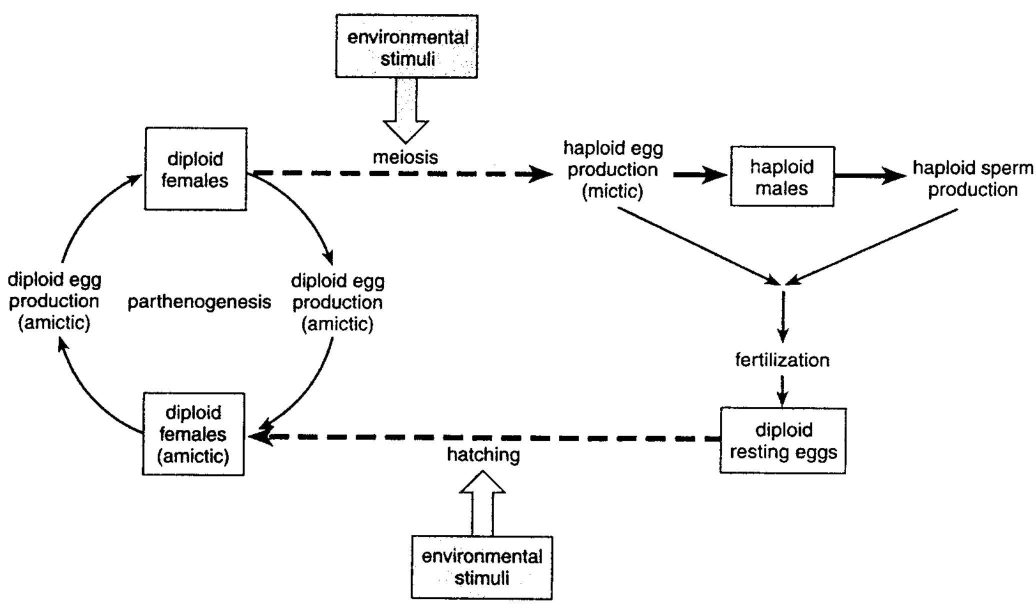

Figure 1.3 The life cycle of monogonont rotifers (Pechenik, 2000, p. 196).

Reproduction in Monogononta rotifers is dominated by asexual parthenogenesis; amictic females produce diploid eggs, which develop into amictic females. Sexual reproduction is triggered by the occurrence of adverse conditions or as a result of specific environmental cues. Amictic females will produce mictic females giving haploid eggs. Unfertilized hapolid eggs will develop into males producing sperm. When haploid eggs are fertilized, these will develop into thick-shelled eggs, called resting eggs. These eggs will accumulate in the sediment and are able to survive through periods of adverse conditions. When favorable conditions return, they hatch as amictic female, which will start reproducing parthenogenetically (Wallace and Snell, 1991).

Resting eggs (diapause form) are the product of sexual reproduction, which is cued by variety of stimuli that are directly or indirectly predictive of environmental deterioration. As favorable conditions return or as a result of specific cues, they develop and hatch to reestablish their population again. These dormant forms represent a biodiversity bank as the eggs survive through adverse environmental conditions, preserve species diversity and provide a reliable colonization source when conditions improve. The biodiversity bank assures genetic continuity through periods of environmental adversity. It means that resting eggs represent a bank, like the seed pool of plants, from which recolonization of the environment can occur at a later time (Pourriot and Snell, 1983; Ricci, 2001).

The duration of the period of dormancy is different not only among species but also among clones of the same species. The emergent rotifers can be observed within a few hours or after several months of incubation. These phenomena depend on environmental conditions. Two hatching patterns can be observed. First, the eggs hatch individually at more or less regular intervals over an extended period of time. This pattern could be adaptive in environments where conditions that are favorable for population growth occur unpredictably. This strategy spends more in wasted hatching. The alternative pattern is synchronous hatching of large numbers of eggs over a short period of time, in response to some environmental cues. An advantage of this pattern is that no wasted hatching under unsuitable environmental conditions will occur, therefore this pattern could be adaptive to predictable environments (Pourriot and Snell, 1983).

1.2.2 What are the roles of rotifers?

Rotifers can be found in freshwater, brackish water and saline water of both aquatic and semi-aquatic habitats, however they are predominantly freshwater inhabitants. Because rotifers are the most diverse group of freshwater metazoan, and a diverse component of freshwater ecosystems, they play a major role in most types of such habitats. Fundamentally, as a primary consumer of phytoplankton, rotifers convert energy and matter to organisms in higher trophic levels. In addition, as a result of their high reproductive capacity and high feeding rates, rotifers play a pivotal part in energy flow and nutrient cycling. Since they are small in size (0.006-1.00 mm), highly nutritious (proteins 58 - 72%, lipids 21.31% of their dry mass) and easily produced in mass quantity (reaching to 50,000 and 500,000 individuals/liter), rotifers are suitable as food for first period of exogenous feeding aquatic animal larvae (Lubzens *et al*, 1993). Additionally, because of their widespread occurrence and range of environmental preference, rotifers can be used as bioindicators of the trophic state of water bodies (Mäemets, A., 1983; Pontin, 1993; Marneffe *et al.*, 1998; Duggan *et al.*, 2001). Recently, rotifers, especially *Brachionus calyciflorus* and *B. plicatilis*, have been employed as test organisms for toxicological studies as a consequence of their cosmopolitan distribution, their short generation time and their use in ealily mass culture (Wallace and Snell, 1991; Janssen *et al.*, 1993; Ferrando *et al.*, 1993; Fernández-Casalderrey *et al.*, 1993; Nogrady and Rowe, 1993). These aspects of rotifers render them particularly interesting as study organism.

1.2.3 A study of Rotifera in Thailand

The study of Rotifera in Thailand has intensified recently. As with most investigations on specific taxonomic groups, most studies so far focused on taxonomy using samples collected form various freshwater habitats such as lakes, reservoirs, canals, rivers, roadside canals and rice fields (Koste, 1975; Boonsom, 1984; Segers and Sanoamuang, 1994; Sanoamuang *et al.*, 1995; Sanoamuang, 1996; Pholpunthin, 1997; Segers and Pholpunthin, 1997; Sanoamuang and Segers, 1997; Pholpunthin and Chittapun, 1998; Sanoamuang, 1998; Sanoamuang and Savatenalinton, 1999; Sanoamuang and Savatenalinton, 2001). However, special habitat types such as peat swamps have been overlooked in the initial studies. Peat swamps are very special. They take thousands of years to form, and are characterized by their brownish and acid water (Phengklai *et al.*, 1989). Recently, interest in the rotifer fauna of peat swamp areas has increased (Chittapun *et al.*, 1999; Chittapun *et al.*, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002; Chittapun *et al.*, 2003). Up to date, 154 rotifer species have been recorded from eight peat swamps in southern Thailand. This number contains many species that had not been documented from Thailand or neighboring countries before. In addition, six species were new to science: *Colurella sanoamuangae* Chittapun, Pholpunthin and Segers, *C. psammophila* Segers and Chittapun, *Encentrum pornsilpi* Segers and Chittapun and *Lepadella desmeti* Segers and Chittapun from Mai-khao peat swamp, Phuket province; *Keratella taksinensis* Chittapun, Pholpunthin and Segers from To-Daeng peat swamp, Narathiwas province and *Lecane kunthuleensis* Chittapun, Pholpunthin and Segers from Kun-Thu-Lee peat swamp, Suratthanee province. This result suggests that peat swamp ecosystems have a special rotifer fauna, possibly as a result of their long history and unique ecological characteristics. Therefore, more attention should be paid to the conservation of such areas for the future.

Research questions

As a result of anthropogenic activities in peat swamps, some areas have been transformed by construction such as reservoirs and airport construction, to the extent that some have completely disappeared. Therefore, in order to reveal the effect of human activities on biodiversity in peat swamp areas, this work was initiated by the study of the impact of human activities in peat swamp areas by using monogononta rotifers as a test group. This study was performed by investigating the species composition of Rotifera from five coastal peat swamps in Phuket province, Southern Thailand. Then, in order to assess the influence of anthropogenic factors on the freshwater community, a multivariate analysis was performed on rotifer communities and the environmental variables affecting these, using data collected in these five peat swamps. In addition, to evaluate the capacity of freshwater communities to restore after perturbation, the recruitment capacity of resident rotifers was investigated by performing experiments on the hatching of resting eggs present in the sediment.

Hypothesis

Human activities will decrease the diversity of coastal peat swamp ecosystems, as indicated by Rotifera Monogononta.

Objectives

This research consists of four parts, which have all been conducted to obtain knowledge on the following aspects of the rotifer fauna:

Part 1: Taxonomy and biogeography of coastal peat swamp Rotifera

The results of previous studies of the rotifer fauna of peat swamp habitats suggests that these are a special habitat type containing a highly diverse rotifer taxocoenosis. Therefore, to contribute to the information on peat swamp rotifers in Thailand, this research is primarily aimed to further document the rotifer species diversity of five coastal peat swamps in Phuket province, southern Thailand.

Part 2: Rotifer diversity in coastal peat swamps

Our research aims at investigating quantitative aspects of rotifer diversity in different types of peat swamp. The objective of this part is to analyze different aspects of rotifer biodiversity: actual species richness in each area, some diversity indices and complementarity, in the five peat swamps.

Part 3: Ecology of coastal peat swamp Rotifera

Considering the scarcity of knowledge on rotifer ecology in tropical regions, and the unique characteristics of peat swamp areas promoting a diverse rotifer fauna, a detailed study of rotifer ecology is called for. To contribute to the knowledge of ecology of Rotifera in Thailand, this study will attempt to identify the important environmental variables and understand how they act on rotifer communities in coastal peat swamps. In addition, human activities take place in some peat swamps, which may result in profound effects such as salinisation, transformation and agricultural pollution. In order to monitor changes in environmental conditions and understand how these activities affect the rotifer communities in peat swamps, this research also intends to investigate anthropogenic effects on the composition of the rotifer fauna.

Part 4: Recruitment of rotifer resting egg bank

Rotifers have resting eggs that enable them to survive through periods of adverse conditions. This implies that rotifer communities have the ability to recover, by hatching of resting eggs, after restoration of habitats disturbed by human activities. To investigate the capability of recovery in disturbed peat swamps, the viability of the resting egg bank in the sediment of a disturbed peat swamp was tested.

2. STUDY AREAS

2.1 The study areas

There were more than 640,000 km^2 of peat swamp areas in Thailand. Most of them distribute in southern and some in eastern Thailand. In the past, there were 647,071.95 km^2 scattering in Narathiwas, Suratthanee, Trang, Nakornsrithammarat, Pattanee,Yala, Songkla, Phattalung, Chumporn, Phuket and Krabi provinces. The biggest Thai peat swamp was in Narathiwas (453,360 km^2), but, due to the anthropogenic disturbances, this area had been decreased to 80,000 km^2 in 1985 and 16,000 km^2 in 1991. This showed high average rate of peat land decreasing at 9,600 km^2 per year. Another well known Thai peat land is Ban-Mai-Khao peat swamp in Phuket province, which is now greatly breaking down and is being destroyed by several anthropogenic activities. Therefore, in order to investigate the effect of disturbances on the biodiversity in peat swamps, this research was carried out in Ban-Mai-Khao peat swamp.

(see:http://www.wildlifefund.or.th/07_Habitats/03_peatswam_forest/peatswam_forest 00.html and http://www.zyworld.com/NAKARIN/HTMLbirdhabitat.htm#peat)

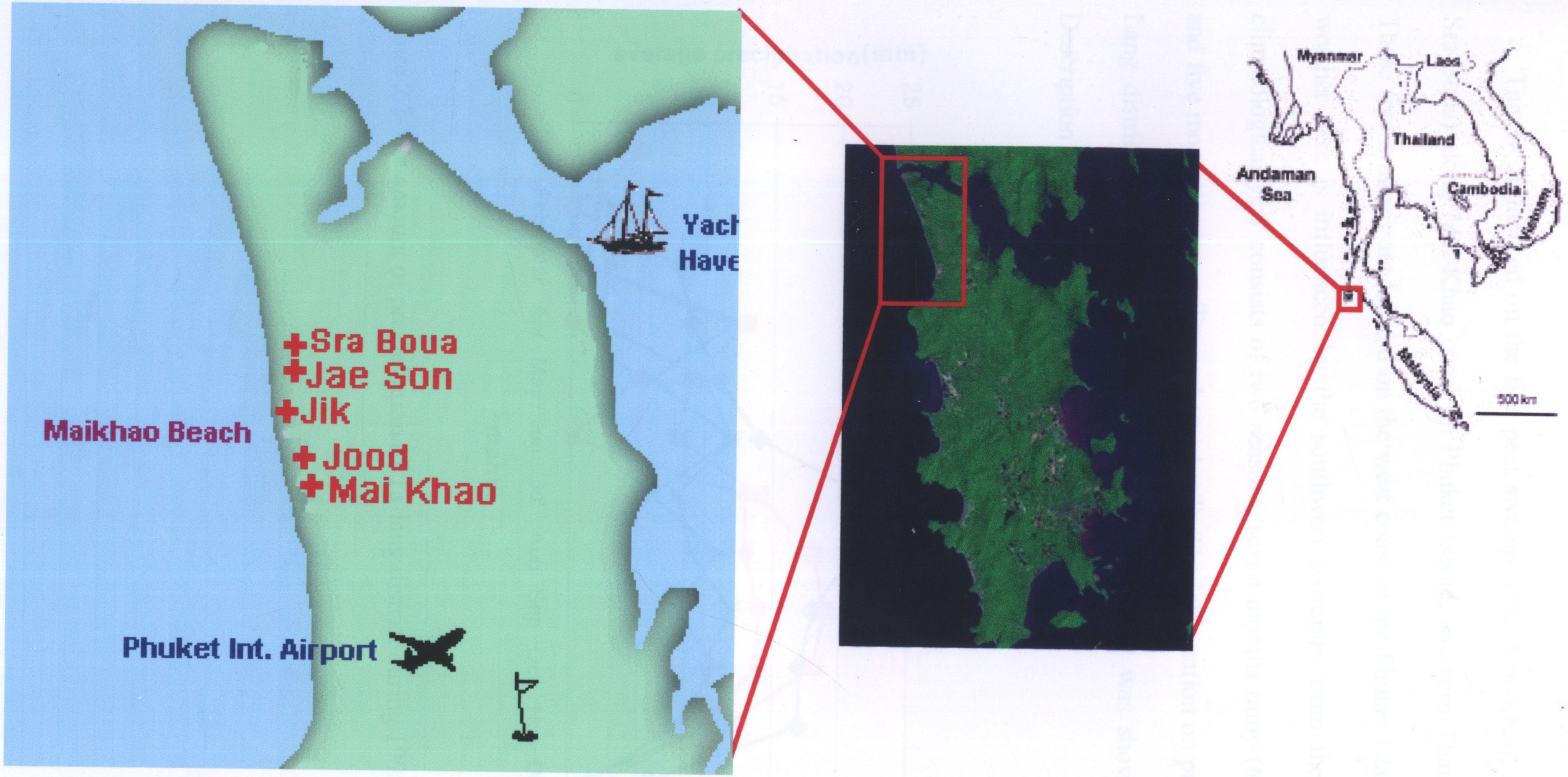

Figure 2.1 Map of Thailand showing the location of five coastal peat swamps (Mai-Khao, Jood, Jik, Jae-Son and Sra-Boua) along Mai-Khao beach on Phuket Island, southern Thailand.

This work focused on the five peat swamps (Jik, Mai-Khao, Jood, Jae-Son and Sra-Boua) along Mai-Khao coast on Phuket Island, southern Thailand (Figure 2.1). These five swamps are located on the west coast of the Phuket Island, Thailand. The weather here is influenced by the southwest monsoon from the India Ocean. A climatological year consists of two seasons, seven months rainy (May – November) and five months summer (December - April). The information on precipitation of Ta-Lang district of Phuket province during 1995 – 1999 was shown in Figure 2.2. Description of all peat swamps are following.

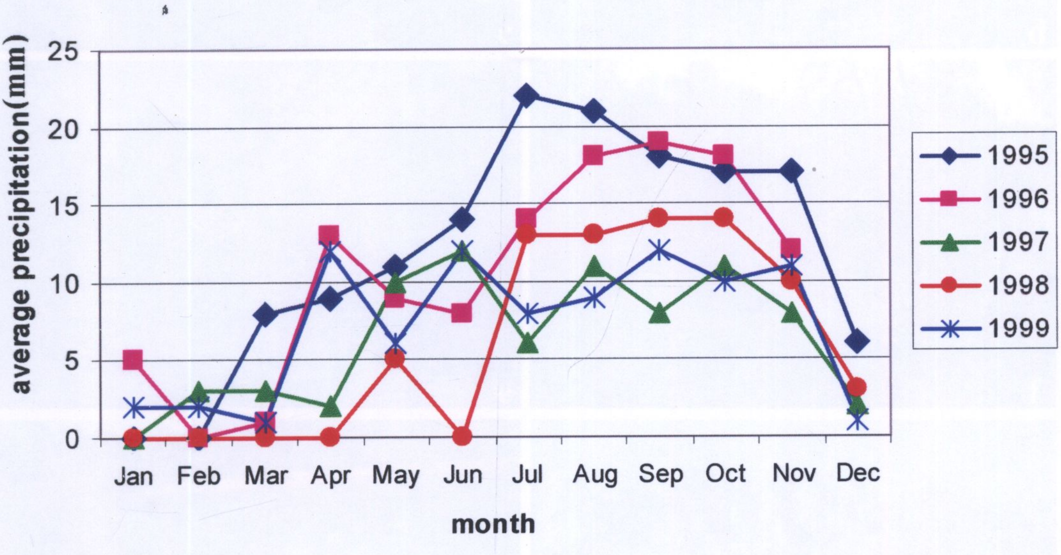

Figure 2.2 The amount of precipitation of Ta-lang district during 1995-2000.

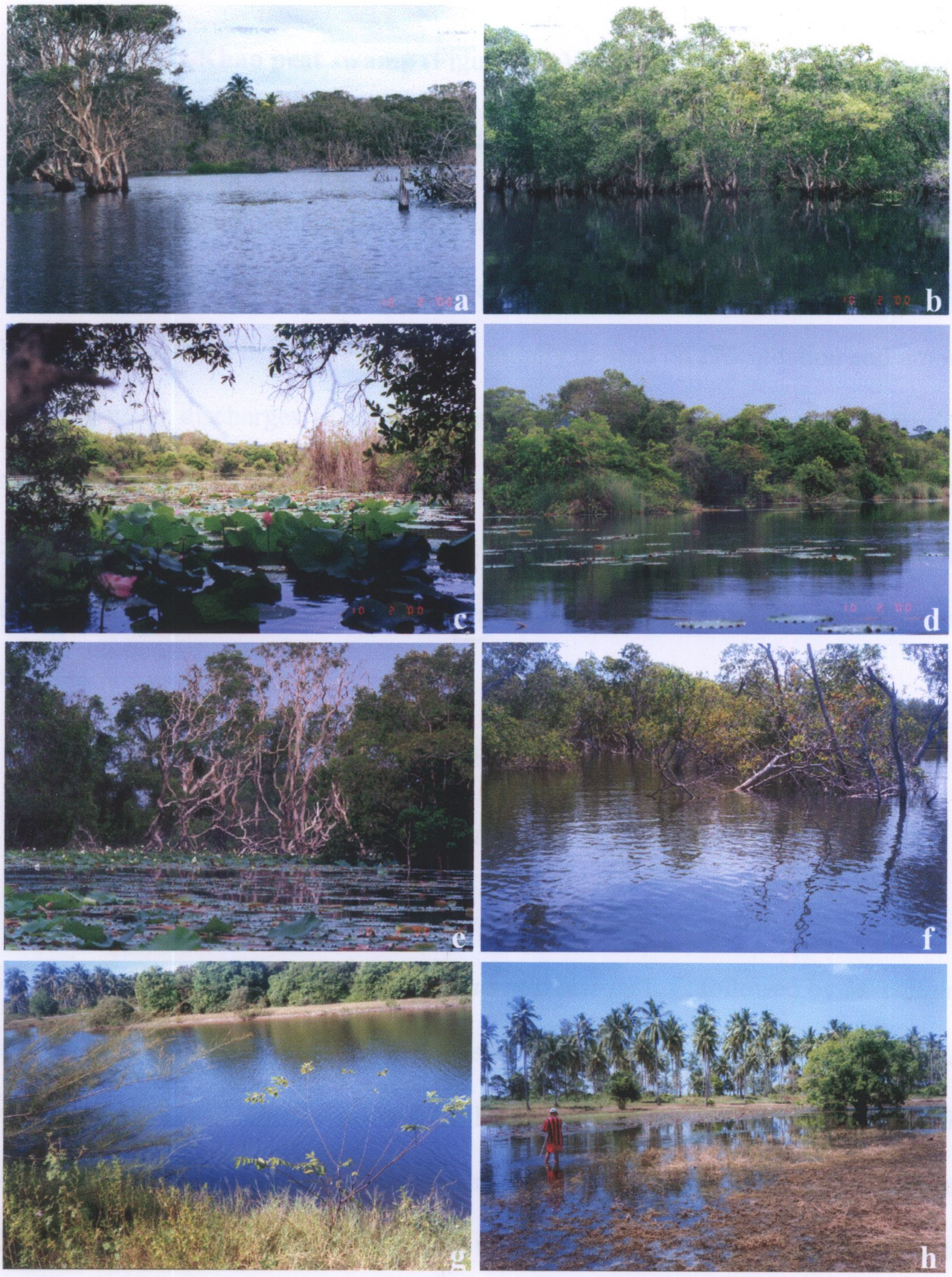

Figure 2.3 Coastal peat swamp areas along Mai-Khao beach in Phuket province, southern Thailand (a: Mai-Khao, b: Jood, c, d, e: Jik, f, g: Jae-son, h: Sra-Boua).

2.1.1 Mai-Khao peat swamp (Figure 2.3a)

Location: (8° 07.21′N - 8° 07.40′N, 98° 17.34′E - 98° 17.44′E)

This peat swamp has an area of 64 m^2. The dominant vegetation are *Melaleuca cajuputi* Powell followed by *Scolopia macrophylla* (Wright and Am.) Clos. Water was brownish in color. Acidity and salinity depend on precipitation and amount of saline water discharges from shrimp farms, which are located nearby. During the summer season, the water dried away especially at the edges, but still remained in the center of the swamp. Nowadays, there is a saline water effect on vegetation in this area and result as *M. cajuputi* Powell, *Nymphoides indicum* Kuntze and littoral grasses have disappeared.

2.1.2 Jood peat swamp (Figure 2.3b)

Location: (8° 07.65′N - 8° 07.75′N, 98° 18.21′E - 98° 18.29′E)

Another disturbanced peat swamp by shrimp farms has an area of 80 m^2 of land. The dominant vegetation was *Fucus microcarpa* L.f., followed by *M. cajuputi* and *S. macrophylla.* Some of the water is cover by *Eichhornia crassipes* Solms, *N. indicum* Kuntze and *Ottelia alismoides* Pers.. Acidity and salinity depend on the precipitation and the amount of saline water release from shrimp farms, as in Mai-Khao peat swamp. The open water area in this peat swamp fragments into small water bodies during the dry season.

2.1.3 Jik peat swamp (Figure 2.3c, 2.3d and 2.3 e)

Location: (8° 08.62′N - 8° 07.77′N, 98° 18.33′E - 98° 18.40′E)

This peat swamp is the largest pristine permanent peat swamp on Phuket Island, 123.2 m^2. Seventy percent of the area was occupied by 49 species of vegetation, which is dominated by *Alstonia pneumatophora* Baker ex Den Berger, followed by *M. cajuputi* Powell and thirty percent of the area is covered with water. The majority of the water body is covered by water lilies, *Utricularia aurea* Lour. and submerged grass in littoral zone. No disturbance from human activities here. In the past, Jik peat swamp had been proffered by the government to dredge for irrigation but the project was halted. Freshwater is acid and being brownish in color.

2.1.4 Jae-Son peat swamp (Figure 2.3f and 2.3g)

Location: (8° 09.28′N - 8° 09.70′N, 98° 18.08′E - 98° 18.24′E)

This peat swamp was modified to a 320 m^2 reservoir by dredging around, but holding 80 m^2 of some peat swamp vegetation and land at the center. The capacity of this reservoir is 669,130 m^3. The flora community in the central part is composed of *M. cajuputi* followed by *F. microcarpa, Syzygium zelanicum* (L.) DC. and *Rhodomyrtus tomentosa* (Aiton) Hassk.. Jae-Son is completely freshwater and no brownish in water. There were no floated or submerged plants in this area. In the dry season, the water may dry out and the groud may emerge.

2.1.5 Sra-Boua swamp (Figure 2.3h)

Location: (8° 09.87′N - 8° 09.94′N, 98° 17.87′E - 98° 17.88′E)

This swamp holds on 10 m^2. An observation of geographical and physical features of this area, Sra-Boua swamp could have been a peat swamp before, because its location was on the same line of other peat swamps. Then, this area was gradually changed and became shallower by time, through natural succession. Sra-Boua swamp was full of water lilies, *Nymphaea nouchali* Burm., and was enclosed by agricultural areas. Sra-Boua swamp was completely dried during the summer season. Unfortunately, this area was completely dried out during the sampling period, because of the construction of a hotel near by (since June, 1999).

2.2 Water qualities in the peat swamps

Table 2.1 shows some parameters, which were measured during sampling period from November 1999 to February 2001, from five peat swamps along Mai-Khao coast on Phuket Island. Temperature was not different among the areas. The highest dissovled oxygen value was noted from Sra-Boua (14 $mg.l^{-1}$), while the lowest value was noted in Mai-Khao (0.17 $mg.l^{-1}$) and Jood (0.2 $mg.l^{-1}$). The highest pH was recorded in Mai-Khao (9.21). Regarding salinity, the five peat swamps can be classified into two types: freshwater (Jik, Jae-Son and Sra-Boua) and brackish water (Mai-Khao and Jood). The salinity is positively related with conductivity, so high conductivity values were measured in Mai-Khao and Jood. Due to mass of filamentous algae, the highest turbidity was recorded from Sra-Boua. Besides, the highest phosphate and nitrate were recorded from Sra-Boua and result in high Chlorophyll a in this area.

2.3 Anthropogenic activities in the coastal peat swamps

According to the data on physical and chemical measurments in table 2.1, the five coastal peat swamps can be divided into four groups with respect to their disturbances. The first one is Jik peat swamp, which has little or no effect of human activities. The other three have an anthropogenic activity from salinasation in Mai-Khao and Jood peat swamps, transformation to reservoir in Jae-Son peat swamp and eutrophication in Sra-Boua peat swamp.

2.3.1 Aquaculture in Mai-Khao and Jood peat swamps

The information of water qualities information in Mai-Khao and Jood peat swamps, they had been recorded as freshwater habitats (Chittapun and Pholpunthin, 1999). Nowaday the aquaculture farms has been increased nearby extensively, result in increasing the amount of saline water being discharge into the peat swamp. Consequently, Mai-Khao and Jood peat swamps become brackish. This salinization result in dead vegetation and environmental changes, especially in water qualities (Table 2.1). Higher salinity brings about higher conductivity and alkalinity. Moreover, there are soluble inorganic from the residual of shrimp food releasing together with the saline water. This is a source of eutrophication, as a result in the widely length of dissolved oxygen and Chlorophyll a values.

Table 2.1 Some parameters from five peat swamps along Mai-Khao coast on Phuket Island, measuring during sampling period from November 1999 to February 2001

Peat swamps	Temperature (°C)	Dissolved Oxygen ($mg.l^{-1}$)	pH	Salinity (ppt)	Conductivity ($\times 10^{-2}$ $mS.\ cm^{-1}$)	Turbidity (NTU)	Nitrate ($\times 10^{-2}$ $mg.l^{-1}$)	Phosphate ($\times 10^{-2}$ $mg.l^{-1}$)	Chl *a* ($\times 10^{-2}$ $mg.l^{-1}$)
Jik	27.2 - 32.9	2.15 – 7.5	5.05 – 7.43	0	3.5 – 7.4	3 – 37	3.8 – 75	2.7 – 4	0.04 – 8.91
Mai-Khao	26.7 – 36.5	0.17 - 9	5.59 – 9.21	1.4 - 7.4	280 - 1300	4 – 151	4 – 100	2.2 – 5	0.14 – 18.4
Jood	26 – 37.7	0.2 – 12.76	5.41 – 7.81	0.9 – 5.1	192 – 920	1 – 63	0.5 – 260	0.2 – 0.5	0.48 – 15.9
Jae-Son	24.3 – 35.4	3.25 - 9	5.2 – 8.16	0	2.7 – 10.2	2 – 60	1.5 – 230	2.1 – 5.2	0 – 16.3
Sra-Boua	26.7 – 34.8	3.03 – 14	5.53 – 7.82	0 - 1	8.1 – 26.9	17 - 374	41 – 290	2.5 – 5.4	2.1 – 23.4

2.3.2 Transformation in Jae-Son peat swamp

Jae-Son peat swamp was modified into a reservoir by digging around a peat swamp resulting in a changed of environmental conditions and water qualities. Although there is the vegetation remaining in the central part, its structure is change and it is reduced in size. In addition, there are no brownish in color and acidity as the fundamental character of peat swamp (Table 2.1). As reservoir, there is high amount of run off water, which comes from many areas. This contaminated water, which can be observed by nitrate and phosphate values, sometimes lead to eutrophication, high chlorophyll a value.

2.3.3 Agriculture in Sra-Boua peat swamp

Sra-Boua peat swamp was surrounded by agricultural areas. Therefore, the swamp may contaminated by fertilizes and pesticides. In table 2.1, high value of nitrate and phosphate were measured at here. The amount of nitrate and phosphate provide an essential inorganic substance for rapidly growing filamentous algae, consequently high value of Chlorophyll a was measured. Moreover, the greenish water results in high dissolved oxygen and turbidity values. After the nutrient was exhausted and slightly light can penetrated, the algal start decreasing and dissolved oxygen was used in decomposition. Then, DO and turbidity were lower measured. According to the Organization for Economic Co-operation and Development (OECD) boundary values for trophic classificffation system, general biological and physical characteristics of eutrohpic areas are frequent occurrence of algal blooms, high relative quantity of green and blue-green algae (*Oscillatoria*), often shallow water body and poor water usage (Ryding and Rast, 1989). From this, Sra-Boua was identified as a eutrophic swamp.

3. RESULTS

The result chapter of this dissertation consists of four parts. The first part deals with the taxonomy and biogeography of the rotifer fauna from five coastal peat swamps on Phuket Island, southern Thailand. In this part, the rotifer fauna, mainly Monogononta, from Jik, Mai-Khao, Jood, Jae-Son and Sra-Boua were investigated and the biogeography of genus *Brachionus*, *Lecane* and *Trichocerca* were examined. In the second part, the biodiversity of the rotifer fauna of five peat swamp areas using qualitative data was analysed. The biodiversity of the rotifer fauna from the five peat swamps was assessed by exploring the observed species richness in each area, calculating several diversity indices and then comparing among them and comparing the complementarity among areas based on their rotifer composition. In the third part, anthropogenic factors affecting peat swamp rotifer communities were studied by classifying the five peat swamps based on rotifer communities and by identifying important environmental variables affecting the rotifer communities. Finally, the potential to restoration of rotifer communities was investigated. This study is a hatching experiment on the sediment egg bank. In this experiment, the sediment egg banks, which were exposed under different conditions and durations, were incubated to investigate to what extent the rotifer diversity is able to be reestablished both in terms of species number and specimens hatching.

PART 3.1 TAXONOMY AND BIOGEOGRAPHY OF ROTIFER FAUNA FROM FIVE COASTAL PEAT SWAMPS ON PHUKET ISLAND, SOUTHERN THAILAND

Introduction

Soon after studies on the rotifer fauna of peat swamps started being conducted in extensively (Chittapun *et al.*, 1999; Chittapun *et al.*, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002, Chittapun *et al.*, 2003), it became clear that the results were noticeable, and peat swamps were found to contain many extraordinary rotifer species. This is thought to be the result of the long history of rotifers and unique ecological characteristics of the habitats, making them valuable natural environments with a high conservation value. Among many peat swamp areas in Thailand, one of most interesting habitat type is that of coastal peat swamp. Such peat swamps are located parallel with the coastal line and at a distance of approximately 0.5 km from the beach. The water characteristics are, of course, close to those of other peat swamps; it is fresh, brownish and slightly acidic. One of the coastal peat swamp areas in Thailand is Phru Ban Mai-Khao in Phuket province. Presently, the area has been fragmented into several small swamps, due to natural succession and human activities. In order to extend our knowledge on a peat swamp rotifers , this research work was aimed to investigate rotifer species inhabiting five coastal peat swamps along Mai-Khao coast on Phuket Island, southern Thailand.

Materials and Methods

Samples were collected from five peat swamps, Mai-Khao, Jood, Jik, Jae-Son and Sra-Boua, along Mai-Khao coast (Figure 3.1.1). The sampling duration and the number of sites and samples varied in each area (Table 3.1.1). In order to obtain a representative overview of the composition of the rotifer fauna in each peat swamp, sample sites were selected to represent the local size and diversity of microhabitat types in each area. The more heterogeneous the swamp, the larger the number of samples collected.

Qualitative samples were collected on a monthly basis by approximately 10 m-long horizontal hauls using a 26 μm plankton net. The material was immediately preserved in 5% formaldehyde solution. On return in the laboratory, rotifers were sorted under an Olympus VM dissecting microscope. Then, they were identified and counted under an Olympus CH-2 compound microscope. Identification was mainly focussed on Monogononta species, with particular attention to the taxonomically less demanding loricate species. Some specimens were drawn, others were photographed and some SEM pictures were also taken.

Making slides for drawing and taking photographs was prepared by sorting animals from samples. Then, to clean, they were washed in distilled water for several times, and placed in a small drop of glycerine on slide. Next, they were covered by cover slide, and, finally, sealed slided border by transparent nailpolish. Animal drawing were done using an Olympus CH-2 compound microscope attached with camera lucida. Light microscopy photograph were taken under an

OlympusCX40RF2000 disecting microscope fitted with an Olympus DP11connected to personal computer (Chittapun *et al.,* 2003).

In addition, preparing specimens for scanning electron microscopy can be divided into two types: animal and trophi specimens. Animal preparation was started by placing the specimens on a nucleopore membrane, which was subsequently placed in a stainless steel case. Speciemens were dired by dehydration using graded ethanol, and subsequenctly critical-point drying. The dried speciemens were then mounted on a metal specimen stub (diameter 10mm, height 5 mm) using a double-sided adhesive tape. For the trophi preparation, animals were dissolved by sodiumhypochlorite on slide until the trophi were liberated. Then, the trophi were sucked by ultrafine tube and were washed several times by distilled water. Next, the trophi were placed on small circled slide, which was positioned on metal specimen stub using a double-sided adhesive tape and leave for air dry. Finally, the dried animall and trophi were coated with gold, and observed using a JEOL 5800LV scanning electron microscope (Chittapun and Pholpunthin, 1999).

Table 3.1.1 Sampling durations and number of sites and samples of five coastal peat swamps on Phuket Island

Peat swamp	Sampling duration	Number of sites	Total number of samples
Mai-Khao	November 99 - February 01	5	150
Jood	November 99 - February 01	3	94
Jik	May 00 - February 01	3	58
Jae-Son	November 99 - February 01	7	215
Sra-Boua	November 99 - May 00	2	22

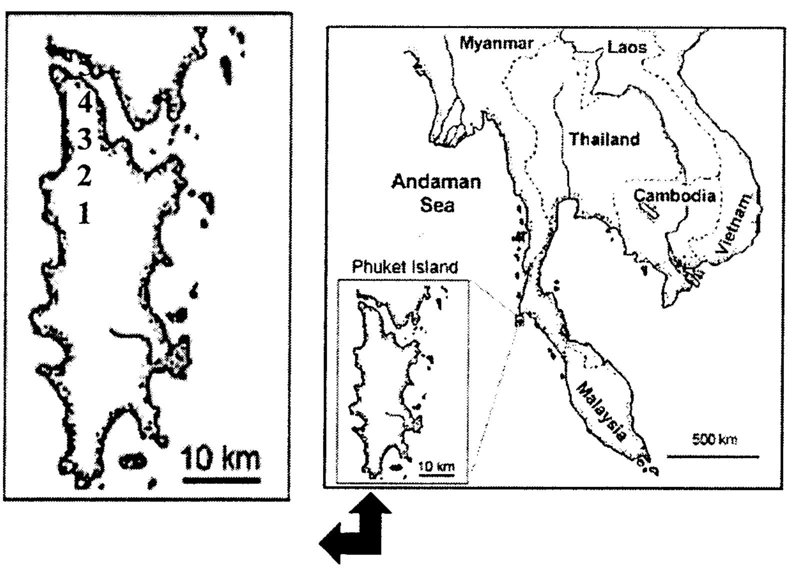

Figure 3.1.1 Map of Thailand showing the location of five coastal peat swamps in Phuket province (1: Mai-Khao, 2: Jood, 3: Jik, 4: Jae-Son and 5: Sra-Boua).

Results and Discussion

3.1.1 Species composition of Rotifera in five coastal peat swamps

One hundred and thirty two Monogonont and one Bdelloid species of rotifer (Table 3.1.2), distributed over 34 genera and 21 families, were identified from five peat swamps along Mai-Khao coast in Phuket province. Because this work focuse mainly on loricate species, result shows the most diverse rotifer genera are *Lecane* (30.82%), followed by *Lepadella* (12.03%) and *Trichocerca* (11.28%) (Figure 3.1.2). This result corresponds exactly with existing knowledge on the rotifer composition from all previously studied peat swamp areas (Chittapun *et al.*, 1999; Chittapun *et al.*, 2001 and Chittapun *et al.*, 2002). The result also concurs with reports that *Lecane* is the most diverse rotifer genus in the tropical region (Fernando, 1980; Segers and Dumont 1995; Segers, 1996).

Additionally, the composition of the peat swamp rotifer community agrees with the report from Thala-Noi, located in the south part of Thailand (Segers and Pholpunthin, 1996). In contrast to the results, many wetlands, located in north-east Thailand (e.g., Lake Kud-Thing in Nong Khai province: Sanoamuang *et al.*, 1995 and Sanoamuang and Savatenalinton, 2001), have been reported *Brachionus* as the second most diverse genus. In accordance with this, it is suggested that the composition of rotifer communities varies throughout Thailand, as a result of climatic and ecological differences. In the present study, the great diverse peat swamp is Jae-Son (100 species), followed by Jik (84 species), Jood (67 species), Mai-Khao (65 species) and Sra-Boua (48 species), respectively.

Table 3.1.2 List of rotifer fauna from five coastal peat swamps in Phuket province, southern Thailand (1 = Mai-Khao, 2 = Jood, 3 = Jik, 4 = Jae-Son, 5 = Sra-Boua, # = odd case and * = new record to Oriental region)

Anuraeopsis coelata (Beauchamp) 3,4,5
A. fissa (Gosse) 1,2,3,4,5
A. navicula (Rousselet) 1,2,3,4,5
Ascomorpha ovalis (Bergndal) 3,4
Asplanchana seiboides (Leydig) 3,4
Brachionus angularis Gosse 1,2,5
B. calyciflorus Pallas 2,5
B. dichotomus Shephard 2,3,4
B. donneri Brehm 3,4
B. falcatus Zacharias 1,3,4,5
B. forficula Wierzejski 3,4
B. lyratus Shephard 3
B. murphyi Sudzuki 4,5
B. quadridentatus Hermann 1,2,3,4,5
B. rotundiformis Tschugunoff 1,2
B. urceolaris (Müller) 1,2,3,4
Cephalodella forficula (Ehrenberg) 1,2,3,4,5
C. gibba (Ehrenberg) 1,2,3,4,5
C. innesi Myers 1,2,4
C. tenuior (Gosse) 1,4
Collotheca sp. 4
Colurella adriatica Ehrenberg 4
C. colurus (Ehrenberg) 1,3
C. obtusa (Gosse) 1,2,3,4
C. psammophila Segers and Chittapun 1
C. sanoamuangae Chittapun, Pholpunthin and Segers 1,2,3
C. sulcata (Stenroos) 3,4
C. tesselata (Glascott) 1,3,4
C. uncinata (Müller) 1,2,3,4,5
Conochilus natans Seligo 3,4
Dicranophorus epicharis Harring and Myers 1,2,3,4,5
#**Dicranophoroides sp.* 3
Dipleuchanis propatula (Gosse) 4
Dissotrocha aculeata (Ehrenberg) 4
Encentrum pornsilpi Segers and Chittapun 1,2,4
Euchanis dilatata Ehrenberg 2,3,4,5
Filinia longiseta (Ehrenberg) 2,3,5
F. opoliensis(Zacharias) 2,3,4
Floscularia conifera (Hudson) 1,2,3,4
Harringia rousseleti de Beauchamp 3
Hexathra mira (Hudson) 1,2,3,4
Keratella cochlearis (Gosse) 3,4
K. tropica (Apstein) 1,2,3,4,5

Lecane abanica Segers 1
L. acanthinula (Hauer) 1,2
L. aculeata (Jakubski) 1,2,3,4
L. arcula Harring 1,2,3,4,5
L. batillifer (Murray) 4
L. bifurca (Bryce) 1,2
L. bulla (Gosse) 1,2,3,4,5
L. closterocerca (Schmarda) 1,2,3,4,5
L. crepida Harring 2,4
L. curvicornis (Murray) 1,2,3,4,5
L. doryssa Harring 2,4
L. flexilis (Gosse) 2,4
L. furcata (Murray) 1,2,3,4,5
L. grandis (Murray) 1,2
L. haliclysta Harring and Myers 5
L. hamata (Stokes) 1,2,3,4,5
L. hastata (Murray) 1,2,3,4
L. hornemanni (Ehrenberg) 1,2,4
L. inermis (Bryce) 1,2,3,4,5
L. lateralis Sharma 4
L. leontina (Turner) 5
L. ludwigii (Eckstein) 1,4
L. luna (Müller) 1,2,4
L. lunaris (Ehrenberg) 1,3,4,5
L. monostyla (Daday) 1,2,3,4
L. obtusa (Murray) 1,2,3,4,5
L. palinacis Harring and Myers 3
L. pyriformis (Daday) 1,2,3,4,5
L. quadridentata (Ehrenberg) 3
L. rhenana Hauer 4
L. rhytida Harring and Myers 1,2,3,4
L. robertsonae Segers 3,4
L. segersi Sanoamuang 1,2,5
L. signifera (Jennings) 1,4,5
L. subtilis Harring and Myers 4
L. superaculeata Sanoamuang and Segers 5
L. tenuiseta Harring 1,2,3,4
L. thienemanni Hauer 4
L. undulata Hauer 1,2,3,4,5
L. unguitata (Fadeev) 1,3,4,5
L. ungulata (Gosse) 4
Lepadella acuminata (Ehrenberg) 1,2,3,4,5
L. apsicora Myers 2,4
L. apsida Harring 1,2,3
L. cyrtopus Harring 4

Table 3.1.2 (continued)

L. desmeti Segers and Chittapun 1,2,3,4
L. ehrenbergi (Perty) 3,4
L. eurysterna 1,2,3,4,5
L. latusinus (Hilgendorf) 3,4
L. minoruoides Koste and Robertson 3,4
L. monodactyla Berzins 3
L. ovalis (Müller) 3,4
L. patella (Müller) 1,2,3,4,5
L. rhomboides (Gosse) 1,2,3,4,5
L. triba Myers 3,4,5
L. triptera (Ehrenberg) 4
L. vandenbrandei Gillard 3,4
Macrochaetus collinsi (Gosse) 2,3,4
Monommata dentata Wulffert 1,2,3,4
M. grande Tessin 4
Mytilina ventralis (Ehrenberg) 1,3,4
Notommata saccigera Ehrenberg 1,2,3,4
N. copeus Ehrenberg 3
Plationus patulus (Müller) 2
Platyias quadricornis (Ehrenberg) 5
Polyarthra vulgaris Carlin 1,2,3,4,5
Proales sp. 1,2,3,4,5
Scaridium bostjani Daems and Dumont 3
S. longicaudum (Müller) 1,3,4
Squatinella mutica (Ehrenberg) 2,3,4
Syncheta sp. 3
Taphrocampa annulosa Gosse 2
Testudinella amphora Hauer 4
T. emarginula (Stenroos) 3,4,5
T. patina (Zacharias) 1,2,4,5
Trichocerca bidens (Lucks) 2,3,4
T. braziliensis Murray 1,2,4
T. capucina (Wierzejski and Zacharias) 3,4
T. chattoni (De Beauchamp) 3,4
T. flagellata Hauer 3
*T.*cf. *gracilis* (Tessin) 3,4
T. hollaerti De Smet 5
T. insulana (Hauer) 1,4
T. mus Hauer 5
T. pusilla (Jinnings) 1,2,3,4,5
T. ruttneri (Donner) 3,4
T. similis (Wieszejski) 2,3,4,5
T. tenuior (Gosse) 1,2,5
T. tigis (Müller) 4
T. weberi (Jinnings) 5

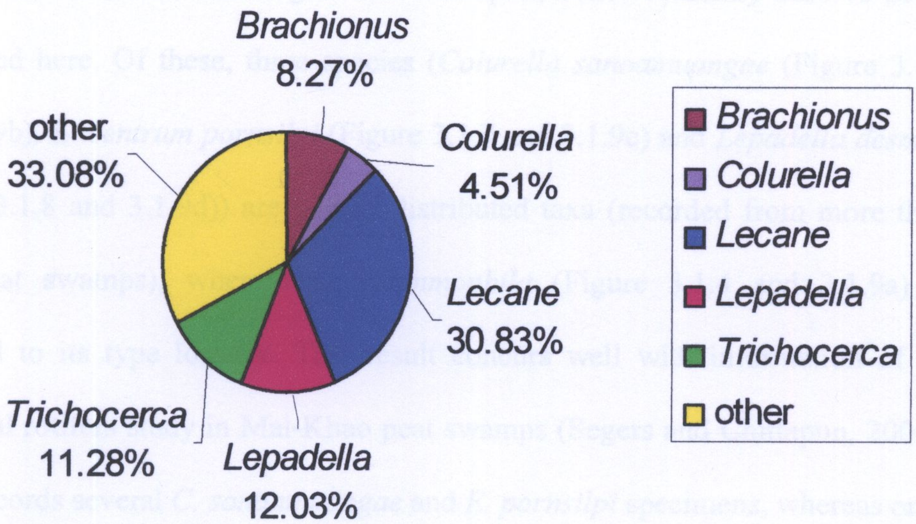

Figure 3.1.2 Percentages of the rotifer composition of five coastal peat swamps along Mai-Khao coast in Phuket province.

Of the 133 taxa on record, 23 species (17.29%) can be considered as common rotifer species, presenting in all areas and 34 species (25.56%) were only found in one area (Table 3.1.2). In addition, *Dicranophoroides* sp. (Figure 3.1.6) is a new record for the Oriental region, whereas *Harringia rousseleti* (Figure 3.19e) is new to Thailand. The first species, *Dicranophoroides* sp., is morphologically different from an extant species in the genus (see De Smet and Pourriot, 1997). Hence, although only a single specimen was found, it may represent a new species. *Harringia rousseleti*, on the other hand, is cosmopolitan, but rare (De Ridder and Segers, 1997). These records confirm that the peat swamp areas contain many remarkable rotifer species.

Four new species that have been described from Mai-Khao peat swamp (Chittapun *et al.*, 1999 and Segers and Chittapun, 2001) evidently deserve being mentioned here. Of these, three species (*Colurella sanoamuangae* (Figure 3.1.5 and 3.1.9b), *Encentrum pornsilpi* (Figure 3.1.7 and 3.1.9c) and *Lepadella desmeti* (Figure 3.1.8 and 3.1.9d)) are widely distributed taxa (recorded from more than three peat swamps), whereas *C. psammophila* (Figure 3.1.4 and 3.1.9a) is restricted to its type locality. This result concurs well with information of an interstitial rotifers study in Mai-Khao peat swamps (Segers and Chittapun, 2001), which records several *C. sanoamuangae* and *E. pornsilpi* specimens, whereas only few individuals of *C. psammophila*, could be reported. Although this paper reported that *L. desmeti* has a large distribution area, the number of specimens found was low (Segers and Chittapun, 2001). Up to date, two of the species mentioned, *E. pornsilpi* and *C. psammophila*, have never been recorded from elsewhere. Consequently, they are considered to be endemic to coastal peat swamps.

3.1.2 Zoogeography of genus *Brachionus*, *Lecane* and *Trichocerca* (Table 3.1.3 and Figure 3.1.3)

To date, 57 species of *Brachionus*, 177 *Lecane* and 67 *Trichocerca* are recognized worldwide (Segers *et al.*, 1994; Silva-Briano and Segers, 1993; Segers, 2003 - *Trichocerca*; Sanoamuang, 1996; Segers and Baribwegure, 1996; Zhuge and Koste, 1996a; Zhuge and Koste, 1996b; De Ridder and Segers, 1997; Sanoamuang and Segers, 1997; Segers, 1997; Segers and Mertens, 1997; Segers and Pourriot, 1997; Sudzuki and Xiang-fei, 1997; Youqin *et al.*, 1997;

Sanoamuang and Savatenalinton, 1999; Sanoamuang and Savatenalinton, 2001; Chittapun *et al.*, 2003). Of these, 11 (19.30%), 41 (23.16%) and 16 (22.39%) species respectively were recoded from the five peat swamps (Table 3.1.3 and Figure 3.1.3). Of *Brachionus*, four species (36.37%) are cosmopolitan, three (27.27%) are Tropicopolitan, two (18.18%) are Australasian, one (9.09%) is Oriental taxon and one (9.90%) is an Old world taxon (Pejler, 1977; Dumont, 1983; De Ridder and Segers, 1997). Of *Lecane*, most are widely distributed, cosmopolitan (34.15%) and Tropicopolitan taxa (43.90%). There is one Oriental and two Thai endemics (Segers, 1996; Segers, 2001). In addition, all *Trichocerca* species reported are widely distributed, except *T.*cf. *gracilis*, for which there are insufficient data and the identification of which is unconfirmed. Most of them are cosmopolitan taxa (46.67%), followed by tropicopolitan taxa and Pan(sub)tropical taxa (33.33% and 13.33%), respectively (Segers, 2003). The results indicate that while some *Brachionus* and *Lecane* are endemic to the Oriental region, there is no regional endemism in *Trichocerca.* This corresponds with the existing knowledge on biogeography of these three genera of rotifer fauna (Pejler, 1977; Dumont, 1983; Segers, 1996, 2003).

Table 3.1.3 Distribution of rotifers in genera *Brachionus*, *Lecane* and *Trichocerca* of the five coastal peat swamps

Brachionus (11 species – 19.30%)

Cosmopolitan taxa (4 species – 36.37%)

Brachionus angularis Gosse	*B. quadridentatus* Hermann
B. calyciflorus Pallas	*B. urceolaris* (Müller)

Tropicopolitan taxa (3 species – 27.27%)

B. donneri Brehm	*B. falcatus* Zacharias
B. rotundiformis Tschugunoff	

Australasian taxa (2 species – 18.18%)

B. lyratus Shephard	*B. dichotomus* Shephard

Oriental taxon (1 species – 9.09%)

B. murphyi Sudzuki

Old world taxon(1 species – 9.09%)

B. forficula Wierzejski

Lecane (41 species – 23.16%)

Cosmopolitan taxa (14 species – 34.15%)

Lecane bifurca (Bryce)	*L. ludwigii* (Eckstein)
L. bulla (Gosse)	*L. luna* (Müller)
L. closterocerca (Schmarda)	*L. lunaris* (Ehrenberg)
L. furcata (Murray)	*L. pyriformis* (Daday)
L. flexilis (Gosse)	*L. quadridentata* (Ehrenberg)
L. hamata (Stokes)	*L. ungulata* (Gosse)
L. inermis (Bryce)	*L. tenuiseta* Harring

Table 3.1.3 (continued)

Tropicopolitan taxa (18 species – 43.90%)

L. aculeata (Jakubski)	*L. leontina* (Turner)
L. arcula Harring	*L. monostyla* (Daday)
L. crepida Harring	*L. obtusa* (Murray)
L. curvicornis (Murray)	*L. palinacis* Harring and Myers
L. doryssa Harring	*L. rhenana* Hauer
L. grandis (Murray)	*L. rhytida* Harring and Myers
L. haliclysta Harring and Myers	*L. signifera* (Jennings)
L. hastata (Murray)	*L. subtilis* Harring and Myers
L. hornemanni (Ehrenberg)	*L. undulata* Hauer

Pantropical taxa (2 species – 4.88%)

L. robertsonae Segers	*L. thienemanni* Hauer

Eastern hemisphere taxa (5 species – 12.20%)

Widely distributed (1 species – 2.44%)

L. abanica Segers

Palaeotropical taxa (2 species – 4.88%)

L. lateralis Sharma	*L. unguitata* (Fadeev)

Oriental taxon (1 species – 2.44%)

L. acanthinula (Hauer)

Australasian taxon (1 species – 2.44%)

L. batillifer (Murray)

Endemic to Thailand (2 species – 4.88%)

L. segersi Sanoamuang	*L. superaculeata* Sanoamuang and Segers

Table 3.1.3 (continued)

Trichocerca (15 species – 22.39%)

Cosmopolitan taxa (7 species – 46.67%)

Trichocerca bidens (Lucks)	*T. tenuior* (Gosse)
T. capucina (Wierzejski and Zacharias)	*T. tigis* (Müller)
T. pusilla (Jinnings)	*T. weberi* (Jinnings)
T. similis (Wieszejski)	

Warm-water taxa (5 species – 33.33%)

T. braziliensis Murray	*T. flagellata*
T. chattoni (De Beauchamp)	*T. ruttneri* (Donner)
T. insulana (Hauer)	

Pan(sub)tropical taxa (2 species – 13.33%)

T. hollaerti De Smet	*T. mus* Hauer

Insufficient data (1 species – 6.67%)

T. cf. *gracilis* (Tessin)

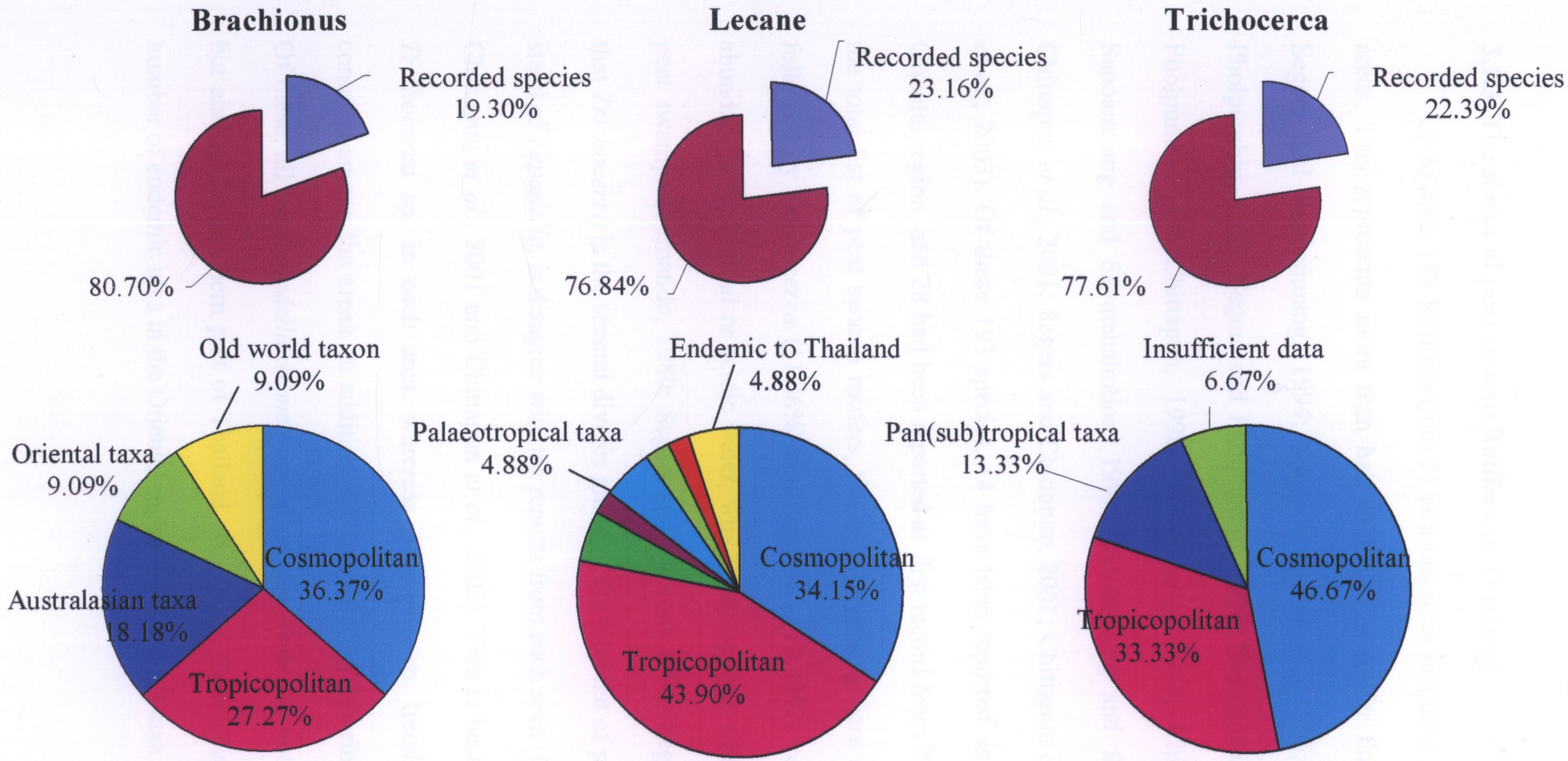

Figure 3.1.3 Proportional occurrence of distribution patterns in genera *Brachionus*, *Lecane* and *Trichocerca* of the five coastal peat swamps

3.1.3 The status of peat swamp Rotifera in Thailand

Up to date, 193 Rotifera from 21 families were recorded from nine peat swamp areas. This represents more than half of the Thai rotifer fauna (Boonsom, 1984; Segers and Sanoamuang, 1994; Sanoamuang *et al.*, 1995; Sanoamuang, 1996; Pholpunthin, 1997; Segers and Pholpunthin, 1997; Sanoamuang and Segers, 1997; Pholpunthin and Chittapun, 1998; Sanoamuang, 1998; Chittapun *et al.*, 1999; Sanoamuang and Savatenalintion, 1999; Sanoamuang and Savatenalintion, 2001; Chittapun *et al.*, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002; Chittapun *et al.*, 2003). Of these 193 species, 14 have been reported as first record from the Oriental region, and 28 had been reported as first record from Thailand. According to the total list of peat swamp rotifers, the most diverse genera are *Lecane* (30.21%), followed by *Trichocerca* (11.46%) and *Lepadella* (10.42%), respectively. *Lecane* is abundant in the littoral or acidic water, which corresponds with the characteristic of peat swamps (Fernando, 1980; Segers and Dumont 1995; Segers, 1996). However, that *Trichocerca* is the second diveres group of the total list of peat swamp rotifers, in stead of *Lepadella,* is disagree with the reports from each area (Chittapun *et al.*, 1999; Chittapun *et al.*, 2001 and Chittapun *et al.*, 2002). This is because there is different *Trichocerca* sp. in each area, whrereas *Lepadella* sp. trend to share species in common among the areas. In addition, six species were described as new to science. Of these, all but *Lepadella desmeti* are, at present, endemic not only to peat swamps but also to the southern part of Thailand. Moreover, these new species increase the number of endemic taxa in the Oriental region from 8 to 13 taxa (Segers, 2001).

3.1.4 Notes on selected taxa

3.1.4.1 ***Colurella psammophila*** Segers and Chittapun, 2001 (Figure 3.1.4 and 3.1.9a)

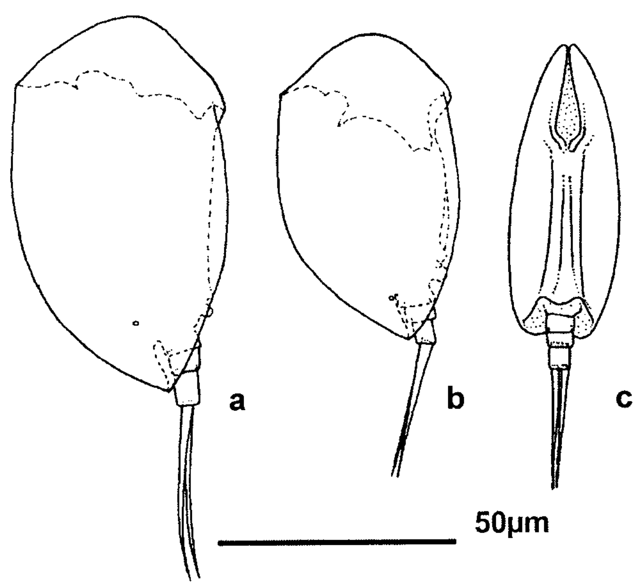

Figure 3.1.4 *Colurella psammophila* Segers and Chittapun, 2001 (a, b: lateral view, c: ventral view).

Description: Parthenogenetic female (male unknown): lorica laterally compressed, ventral sulcus shallow. Head aperture margins dorsally and ventrally straight, medially curved. Dorsal margin anteriorly straight, evenly curved from medially onwards. Minute openings to lateral antennas present postero-laterally. Head aperture with deep ventral and dorsal sinuses, dorsal foot aperture without dorsal notch, no lorica extensions lateral to the foot. Foot with three pseudosegments, the distal one approximately 1.5 times as long as the two proximal ones. A sensorial organ present mid-dorsally on the distal foot pseudosegment. Toes equal, straight to weakly curved.

Measurements: lorica length 65-81 μm, height 35-47 μm, width 23 μm. Second foot pseudosegment 5.2-5.7 μm, third foot pseudosegment 6.8-8.9 μm, toe length 30-38 μm (Segers and Chittapun, 2001)

3.1.4.2 ***C. sanoamuangae*** Chittapun, Pholpunthin and Segers, 1999 (Figure 3.1.5 and 3.1.9b)

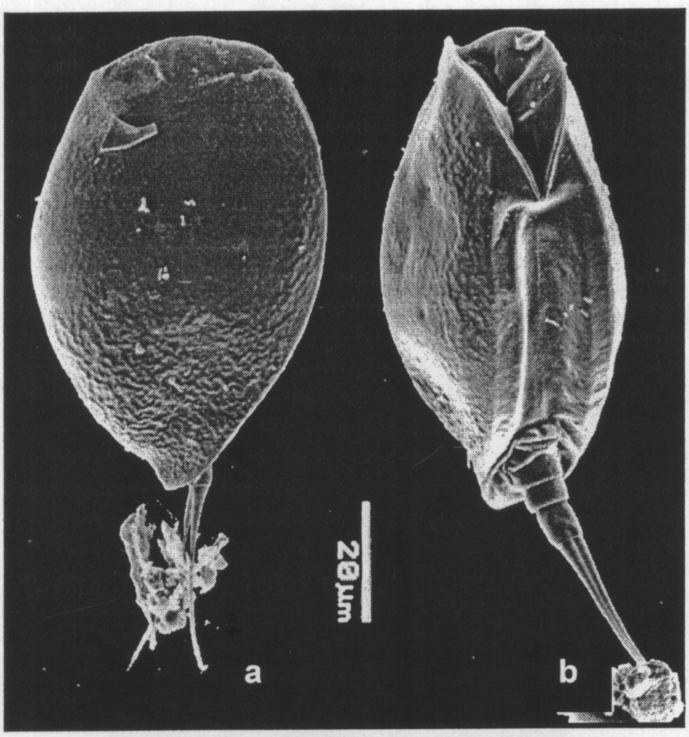

Figure 3.1.5 *Colurella sanoamuangae* Chittapun, Phonpunthin and Segers, 1999 (a: lateral view, b: ventral view).

Description: Parthenogenetic female: Body ellipsoidal in dorsal, oval in lateral vies. Lorica three times as long as wide, about one and a half time as high as wide. Head aperture margins rounded, with median concavity in lateral view; dorsally a small U-shaped sinus, ventrally a deep V-shaped sinus in anterior view. Dorsal and ventral margins smoothly curved. Posterior end of lorica with, in lateral view, slightly projecting, triangular tip; in ventral or dorsal view this projection is a small, tongue-shaped projection over the foot aperture. Ventral sulcus deep. Foot with three pseudosegments, the distal one about twice the length of the basal or median one. Toes relatively long, weakly curved ventrally, smoothly tapering to an acute point distally. Male unknown.

Measurments: Lorica length 98-102 μm, heigh 66-72 μm, last foot pseudosegment length 8-10 μm, toe length 44-48 μm (n=6) (Chittapun *et al.*, 1999)

3.1.4.3 *Dicranophoroides* sp. (Figure 3.1.6)

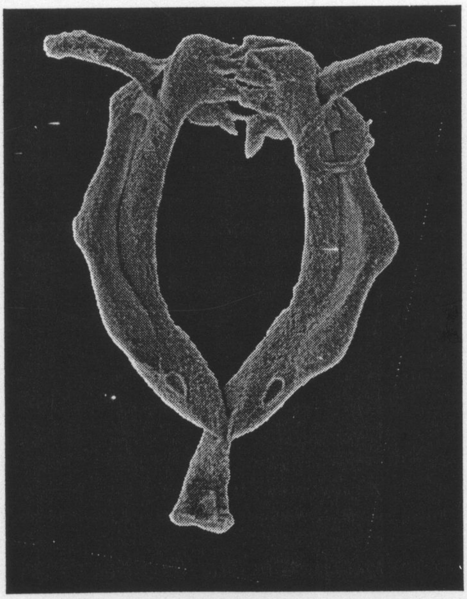

Figure 3.1.6 Ventral view of *Dicranophoroides* sp. trophi.

It is closely related to *D. caudatus*.

The species was found in a single specimen from Jik peat swamp. The external characteristics of the preserved specimen are similar to *Dicranophorus epicharis*. However, the trophi agrees well with genus *Dicranophoroides*, although not with any other documented species (De Smet, 1996). Therefore, it may be a new species.

Trophi forcipate, symmetrical. Rami: subbasal chambers terminating in square with curved angle expansion with 3 stout subapical teeth, projecting inwardly; inner margin without teeth; basal chamber lateral and lamellar, inwardly projecting teeth not projecting beyond apical teeth of subbasal chamber. Fulcrum short, c. ¼ ramus length, stout triangular, posterior strongly expanded. Unci with principle stout single toothed broadly expand before offset tips. Manubria ramus length, posterior expanded, curved.

Measurement: trophi 28.98 μm, ramus 23.57 μm, fulcrum 5.41 μm, uncus 12.74 μm

3.1.4.4 *Encentrum pornsilpi* Segers and Chittapun, 2001 (Figure 3.1.7 and 3.1.9c)

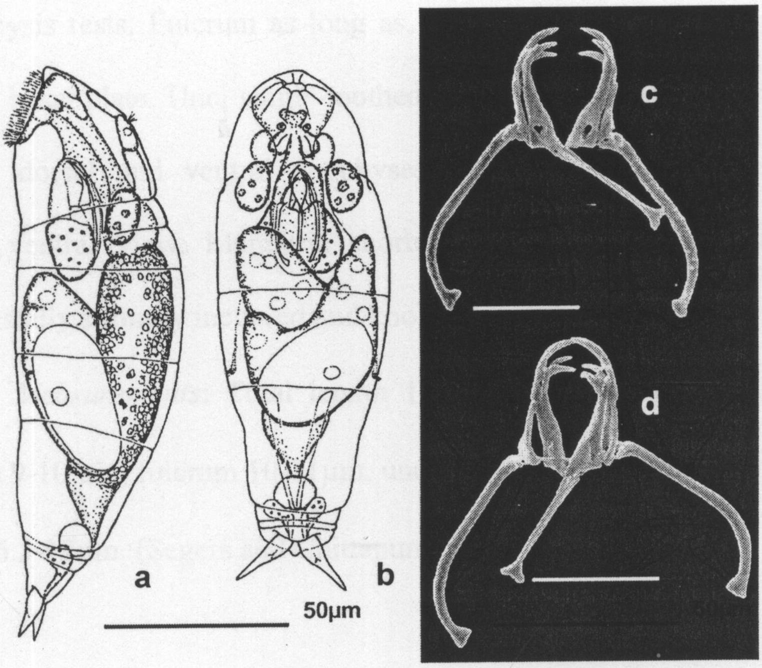

Figure 3.1.7 *Encentrum pornsilpi* Segers and Chittapun, 2001 (a: lateral view, b: ventral view, c: ventral view of trophi, d: dorsal view of trophi).

Description: Parthenogenetic female (male unknown): Body elongate, fusiform; cuticle soft, transparent. Head c. 1/3 total length. Rostrum small, short and rounded. Corona slightly oblique, no palps observed. Trunk with weak constrictions. Tail absent. Foot short, conical in lateral view. Toes short, c. 1/8-1/10 total length, bases swollen, slightly decurved ventrally, clearly separated and with papilla between toes. No eyespots, but with two light-refracting globules in the subcerebral glands. Salivary glands terminal. Proventriculus present. Gastric glands large, ovate. Pedal glands clubbed, foot-length. Trophi small, elongate, slender. Rami longer than wide, outer margin of rami slightly concave laterally, angular posteriorly. Each ramus terminally with single, incurved apical tooth, anterior to this tooth a preuncinal tooth set at right angle to axis; this tooth with a minute medial knob whereupon the ventral uncinal apophysis rests. Fulcrum as long as, or longer than the rami, posterior end with indented basal plate. Unci single-toothed, curved, long and slender. Tooth shaft length small, dorsal and ventral apophyses present. Intramallei long, elongate-triangular in ventral view. Manubria shorter than incus, a triangular expansion proximally, distally strongly incurved and knobbed.

Measurements: Total length 137-160 μm, toe 14-17μm, trophy 23-27μm. Ramus 9-10 μm, fulcrum 10-11μm, uncus 4.4-5.9 μm, intramalleus 5.2-5.5 μm, manubrium 16.3-17μm. (Segers and Chittapun, 2001)

3.1.4.5 ***Lepadella desmeti*** Segers and Chittapun, 2001 (Figure 3.1.8 and 3.1.9d)

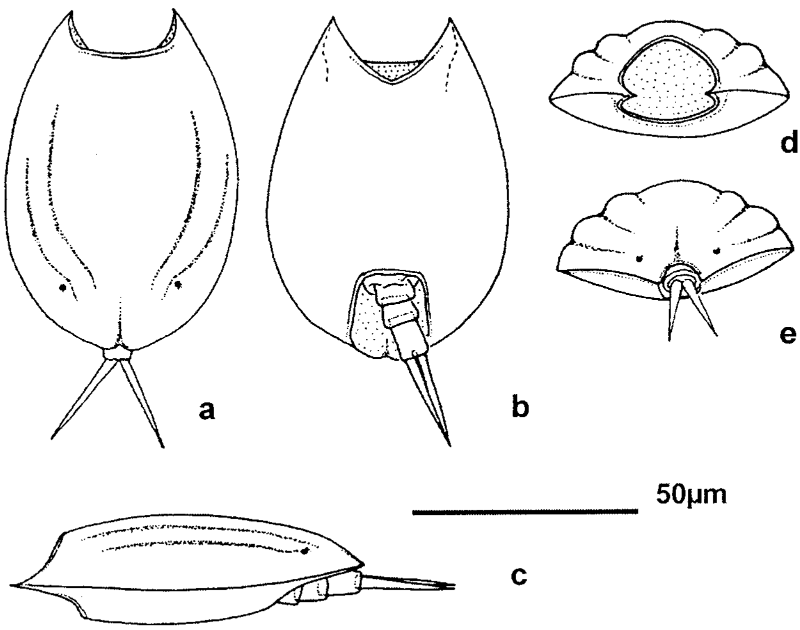

Figure 3.1.8 *Lepadella desmeti* Segers and Chittapun, 2001 (a: dorsal view, b: ventral view, c: lateral view, d: anterior view, e: posterior view).

Description: Parthenogenetic female (male unknown): Lorica stiff, relatively flat. Outline oval, with the greatest width in the posterior third, c. 1.5 times as long as wide. Dorsal plate convex, with two pairs of rounded longitudinal ridges, caudal end indented; a pair of openings to the lateral antenna present postero-laterally. Ventral plate weakly concave. Head aperture dorsally and ventrally concave, dorsally broadly U-shaped, ventrally deeper, V-shaped. No clear collar. Foot aperture squarish, longer than wide, lateral margins slightly diverging to posterior. Foot three pseudosegmented, two broad basal and one elongate and slender distal foot pseudosegment. Toes equal, straight (curved in the holotype, this probably an artefact), evenly narrowing to acutely pointed tips.

Measurements: Lorica length 72-78 μm (78), width 47-54 μm (48), head aperture width 21-25 μm (23), ventral sinus depth 15-18 μm (10), dorsal 6-10 μm (7), foot aperture width 14-17μm (13), length 16-20 μm (22), toe length 21-25 μm (22), second foot pseudosegment length 5-6 μm (5), third 9-12 μm (9). (Segers and Chittapun, 2001)

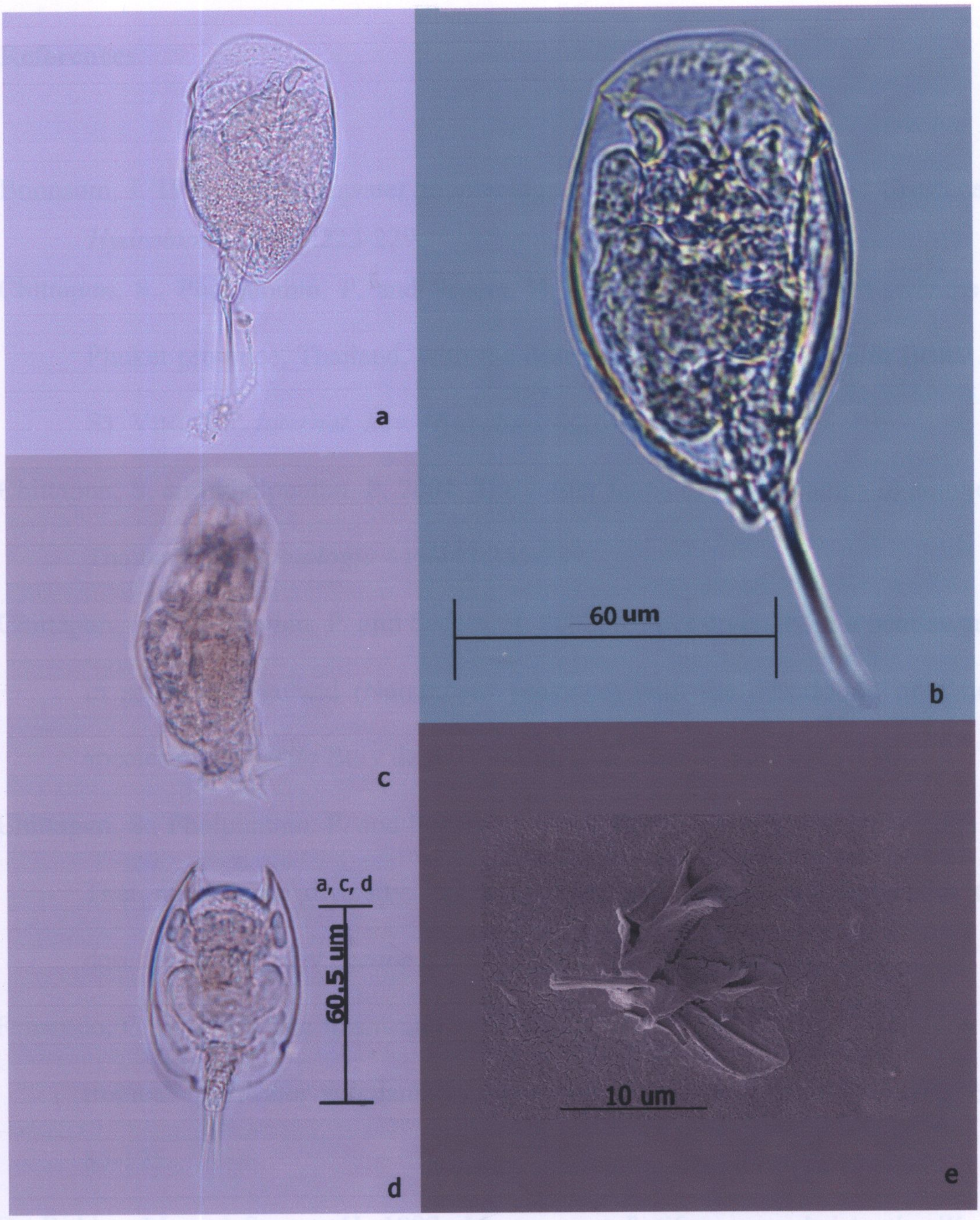

Figure 3.1.9 Microscopic pictures of rotifers; a: *Colurella psammophila,* b: *C. sanoamuangae,* c: *Encentrum pornsilpi*, d: *Lepadella desmeti,* e: *Harringia rousseleti.*

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PART 3.2 BIODIVERSITY OF ROTIFER FAUNA FROM FIVE COASTAL PEAT SWAMPS ALONG MAI-KHAO COAST ON PHUKET ISLAND, SOUTHERN THAILAND

Introduction

Biological diversity or biodiversity is a concept that covers of the total genetic diversity, species diversity and ecological diversity of an ecosystem (Southwood and Henderson, 2000; Kempton, 2002). It has relationship with ecosystem functioning, which has emerged as a major scientific issue today. Recently, experiments have shown that increasing species diversity frequently enhances ecosystem functioning (Henry *et al.,* 2001). In addition, the interest in biodiversity and ecosystem functioning has grown from concern, for example, the potential ecological consequences of the present and future loss of biodiversity caused by the increased impact of human activities on natural and managed ecosystem (Loreau, 2000; Kempton, 2002).

The urgent challenges of global climate change, massive habitat transformation, and the threat of widespread extinction have made extrapolation and prediction a crucial component of many research agendas (Colwell and Coddington, 1994). The magnitude and the urgency of the task of assessing global biodiversity require that I make the most of what I know through the use of estimation and extrapolation. Estimating biodiversity through extrapolation has been done on terrestrial, freshwater and marine habitats, but mostly on terrestrial and marine (Dumont and Segers, 1990; Colwell and Coddington, 1994; Hellmann and Fowler, 1999; Odegaard, 2000; Beger *et al.*, 2003; Foggo *et al.*, 2003; Thompson, Withers, 2003; Thompson *et al.*, 2003).

Rotifera is the most diverse taxon of primary freshwater Metazoa. As such, it should play a significant role in planning for the conservation and sustainable use of worldwide biodiversity (Colwell and Coddington, 1994). The term biodiversity or diversity has been employed in many rotifer studies. Most of the previous researches reported mainly species richness (Ferrari et al., 1989; Green, J. 1993; Galkovskaya and Molotkov, 2001; Oltra etal, 2001; Sharma and Sharma, 2001); some calculate diversity indices like the Shannon-Wiener index (Galkovskaya and Molotkov, 2001). Estimating biodiversity through extrapolation in particular, has only been done by Dumont and Segers (1996). They calculated the expected total species richness of zooplankton (Rotifera and Cladocera) from a number of habitats worldwide using the Chao1 estimator (see Colwell and Coddington, 1994).

The Chao1 estimator has been evaluated on seed bank data (Colwell and Coddington, 1994) and marine organisms (Foggo *et al.*, 2003). It was found to represent the most reliable choice of estimator. However, it has never been tested proved which, of several alternative estimators, performs best using rotifer data. I therefore , this research is aimed at doing this by using datasets from five coastal peat swamps as well as asses rotifer biodiversity in five areas.

A second aim of this chapter is to assess rotifer biodiversity in the coastal peat swamp areas by using methods of estimation and extrapolation. Colwell and Coddington (1994) explained that an approximate description of the pattern of biodiversity for a taxon along a gradient or among the phases of a mosaic can be broken down into two parts: measuring or estimating the *species richness* of species assemblages locally, and measuring or estimating the *complementarity-* the distinctness of dissimilarity- of these local inventories. In the present study I followed this approach by estimating species richness and complementarity through quantitative techniques. I also analyzed rotifer diversity by using non-parametric indices of diversity, which are wellknow and frequently used by many rotiferologists.

Materials and Methods

Field study

Qualitative samples were collected monthly from five peat swamps; Mai-Khao, Jood, Jik, Jae-Son and Sra-Boua, along Mai-Khao coast during November 1998 to February 2000 by using 26 μm mesh plankton net (see part 3.1). Animals were immediately preserved in 4% formaldehyde solution. Specimens were sorted under an Olympus VM dissecting microscope. Then they were identified to species level and counted under an Olympus CH-2 compound microscope. Counting was continued until no additional species were observed.

Data analysis

The data use in the statistical analysis composed of two types; qualitative and quantitative data. The qualitative data consisted of species list of Rotifera in each peat swamp. The quantitative data were numbers of specimens of rotifer species in each sample. Since illoricate rotifer species such as *Monommata, Notommata* and *Scaridium* are difficult to identify to species level, they were counted in terms of number of specimens per genus. The qualitative data were used to measure complementarity, while, the quantitative data were used to estimate species richness, and to calculate species diversity indices.

Estimating rotifer biodiversity through extrapolation: species richness and complementarity

Species richness

Species richness is the simplest way to describe community and regional diversity and forms the basis of many ecological models of community structure (Hellmann and Fowler, 1999; Odegaard, 2000; Gotelli and Colwell, 2001; Foggo *et al.*, 2003). Quantifying species richness is important, not only for basic comparisons among sites, but also for addressing the saturation of local communities colonized from regional source polls (Hellmann and Fowler, 1999; Cornell, 1999 quoted by Gotelli and Colwell, 2001; Foggo *et al.*, 2003; Ugland *et al.*, 2003). In addition, many ecological studies require accurate estimates of species richness for an area, especially in an environmental impact assessment (EIA) (Hellmann and Fowler, 1999; Thompson, *et al.*, 2003; Ugland *et al.*, 2003). However, complete inventories of species richness are costly, time consuming, and demand enormous resources in terms of taxonomic expertise (Foggo *et al.*, 2003).

Raw species richness counts or higher taxon counts can be valid for highly visible and well-studied taxa such as birds and plants, but a complete census of species in an area is rarely feasible (Colwell and Coddington, 1994; Kempton, 2002; Ugland *et al.*, 2003). In studying diverse taxonomic groups and many taxa inhabiting tropical habitats, in particular, stable total of species counts may never be reached. The problem is that as more individuals are sampled, more species will be recorded (Bunge and Ritzpatrick, 1993 quote Gotelli and Colwell, 2001, Kempton, 2002). To overcome these problems, the estimates of the total species richness of Rotifera from five coastal peat swamps using species richness estimators were calculated.

Numerous different techniques have been proposed to estimate total species richness from a limited number of samples. They can be categorized into 4 different groups: (1) extrapolations of species-area curves; (2) fitting of species-abundance distributions; (3) modeling species accumulation curves; (4) non-parametric techniques (Colwell and Coddington, 1994; Southwood and Henderson, 2000; Foggo *et al.*, 2003). This study decided to estimate the total species richness by using non-parametric techniques. There are five commonly used non-parametric approximations for species richness; Chao1, Chao2, First-order Jackknife, Second-order Jackknife and Bootstrap methods (Table 3.2.1) (Colwell and Coddington, 1994; Southwood and Henderson, 2000; Foggo *et al.*, 2003). In order to compare species richness of five peat swamps, which of these produced the most reliable estimation was firstly examined. Subsequently, this method was used to extrapolate the species richness of all localities and compare them.

To investigate which of the alternatives yielded the most reliable estimation, the curve of the mean cumulative number of species encountered in incrementally aggregated sample over 50 randomized permutations of the sample aggregation was plotted. Randomization was done by using EstimateS program (version 6, R. K. Colwell, http://viceroy.eeb.uconn.edu/estimates). The rationale behind this randomization is that it eliminates problems of area and sample heterogeneity (Cowell and Coddinton, 1994; Foggo *et al.*, 2003; Thompson and Withers, 2003; Thompson *et al.*, 2003; Ugland *et al.*, 2003). Then, the data set for use in the comparison of species richness estimators was selected following two criteria: it should be a large data set and the data should come from homogeneous area. This was the case for the data of Jae-Son, so the five estimators were compared by their performance on these data. After the five estimators were calculated, these values were plotted together with the observed species accumulation curve. A good estimator should provide the least biased estimates for small numbers of samples (Colwell and Coddington, 1994). The best estimator is, finally, used to calculate the expected species richness of each peat swamp, and this number was used to compare diversity in the different peat swamps.

Complementarity

When the fauna sampled at different localities were compared, the task can be approached by considering either the similarity or the distinctness of their species assemblages. The conventional approach had been to measure similarity. Recently, the term complementarity has been introduced by Vane-Wright *et al.* (1991) to measure the difference in the biota between potential reserves, and this concept has been used often in conservation concerns (Dumont and Segers, 1990; Colwell and Coddington, 1994; Southwood and Henderson, 2000).

The concept of complementarity is intended to cover distinctness in species composition over a broad spectrum of environmental scales, including small-scale ecological differences such as disturbances (Colwell and Coddington, 1994). Using the concept of complementarity, when appropriate and informative, allows us to see both local richness and biotic differences as positive components of biodiversity. (Biotic similarity is negatively related to overall biodiversity.) The choice of complementarity over its statistical equivalents, distinctness, dissimilarity or distance, is strictly a rheotorical preference to capture the sense that complementary faunas form parts of a whole (Colwell and Coddington, 1994).

In the present study, the complementarity of the faunas of the different peat swamp areas was measured by calculating the Marczewski-Steinhaus (M-S) distance (Table 3.2.2). The M-S distance is the simplest measure that captures the meaning of the complementarity of two sites. In addition, it is reported to be the most appropriate measure of complementarity (Colwell and Coddington, 1994; Southwood and Henderson, 2000).

Non-parametric indices of diversity

Species diversity, the taxonomic variety of living organisms, is one of the three principal levels of biological diversity (Kempton, 2002). There are numerous measures of, or ways to estimate diversity. One of the most frequently used group of measures are non-parametric indices of species diversity called diversity indices. The diversity indices have the advantage that they make no data assumptions. In addition, they can facilitate the ecological interpretation of vast data sets and can be considered a useful way to condense data. Moreover, people with little biological expertise can (or should) be able to understand these methods (Beisel *et al.*, 2003; Foggo *et al.*, 2003).

There are numerous non-parametric indices of species diversity (Magurran, 1988; Southwood and Henderson, 2000; Kempton, 2002), but the most commonly used ones, especially in rotifer researches, are the Berger-Parker dominance index (*d*), Shannon-Wiener diversity index (*H*) and its equitability (*J*), and Simpson's diversity index (*D*) and its evenness (*E*). These formulae are shown in

Table 3.2.2. These indices were performed on rotifer datasets from five peat swamps, then, comparison and discussion among them were carried out.

Berger-Parker dominance index (*d*)

The Berger-Parker dominance index is a simple index. Conceptually, it expresses the proportion of the total catch that is due to the most dominant species (Magurran, 1988; Southwood and Henderson, 2000). Therefore, this index is not influenced by species richness.

May (1975) concluded that the Berger-Parker dominance index seemed to characterize the distribution as well as any other index, and even better than most others. May also argued that this index is strongly influenced by the underlying relative species abundance distribution (Southwood and Henderson, 2000).

Shannon-Wiener diversity index (*H*)

The Shannon-Wiener diversity index is the most commonly use index to characterize species diversity in many ecological studies of organisms: rotifers (eg. Galkovskaya and Molotkov, 2001) and marine organism (eg. Foggo *et al.*, 2003). It measures the degree of uncertainty in a sampling event. That is, if the diversity is low, then the probability of picking a particular species is high. If the diversity is high, then it is difficult to predict the identity of a randomly picked individual (Southwood and Henderson, 2000). This index accounts for both abundance and evenness of the species present (Magurran, 1988; Mackenzie *et al.*, 1998). Its equitability can be calculated by dividing H by H_{max}. It varies between 0 and 1 with complete evenness.

Table 3.2.1 Used names, formulae, references and codes of estimate indices. S_{obs} = number of observed species, a = number of singletons, b = number of doubletons, L = number of species occurring in only one sample, M = number of species occurring exactly two samples, n = number of samples, p_i = proportion of the n that has species i present and q''_{ij} = proportion of the n bootstraps which hold both species i and j. For further details see Colwell and Coddington (1994) and Southwood and Henderson (2000)

No.	Usual name	Formulae	Reference	Code
1.	Chao1	$S_{obs} + (a^2/2b)$	Chao(1984)	S_1^*
	Variance of S_1^*	$var(S_1^*) = b\left[\frac{(a/b)^4}{4} + (a/b)^3 + \frac{(a/b)^2}{2}\right]$		
2.	Chao2	$S_{obs} + (L^2/2M)$	Chao(1987)	S_2^*
	Variance of S_2^*	$var(S_2^*) = M\left[\frac{(L/M)^4}{4} + (L/M)^3 + \frac{(L/M)^2}{2}\right]$		
3.	First-order Jackknife	$S_{obs} + L\left(\frac{n-1}{n}\right)$	Burnham & Overton's (1978,1979) Heltshe & Forrester (1983)	S_3^*
	Variance of S_3^*	$Var(S_3^*) = \frac{n-1}{n}\left(\sum_{o}^{S} j^2 f_j - \frac{L^2}{n}\right)$		
4.	Second-order Jackknife	$S_{obs} + \left[\frac{L(2n-3)}{n} - \frac{M(n-2)^2}{n(n-1)}\right]$	Smith & van Belle (1984)	S_4^*
	Variance of S_4^*	$Var(S_3) = S_{obs} + \sum_{j=1}^{S_{obs}} (1-p_j)^n$		
5.	Bootstrap	$S_{obs} + \sum_{i=1}^{S_{obs}} (1-p_i)^n$	Smith & van Belle (1984)	S_5^*
	Variance of S_5^*	$Var(S_5^*) = \sum (1-p_i)^n \left[1-(1-p_i)^n\right] + \sum\sum \{q''_{ij} - \left[(1-p_i)^n (1-p_i)^n\right]$		

Table 3.2.2 Used names, formulae, references and codes of complementarity and diversity indices. X_{ij} and X_{ik} = the presence-absence values for species in species lists j and k, S = number of taxa in the communities, N_{max} = the dominant species, N_T = the total catch, p_i = proportion contribution to sample total. For further details see Magurran (1988), Colwell and Coddington (1994) and Southwood and Henderson (2000)

No. Usual name	Formulae	Reference	Code
1. Marczewski-Steinhaus distance	$C_{jk} = C_{jk} = \frac{U_{jk}}{S_{jk}}$	Holgate (1969)	C_{jk}
	where $S_{jk} = S_j + S_k - V_{jk}$ and $U_{jk} = S_j + S_k - 2V_{jk}$	Pielou (1984)	
2. Berger-Parker dominance index	$\frac{N_{\max}}{N_T}$	Berger & Parker (1970)	d
3. Shannon-Wiener diversity index	$-\sum_{i=1}^{S} p_i \ln p_i$	Shannon & Weaver (1963)	H
4. Shannon-Wiener maximal index	$\frac{-\sum_{i=1}^{S} p_i \ln p_i}{\ln S}$	Shannon & Weaver (1963)	H_{max}
5. Shannon-Wiener's evenness	$\frac{H}{H_{\max}}$	Hurlbert (1971)	J
6. Simpson's diversity index	$\frac{1}{\sum_{i=1}^{S} p_i^2}$	Simpson (1949)	D
7. Simpson's maximal index	$\frac{1}{S}$	Simpson (1949)	D_{max}
8. Simpson's eveness	$\frac{D}{D_{\max}}$	Hurlbert (1971)	E

The Shannon-Wiener diversity index is relatively easy to calculate, but it is fairy sensitive to actual site differences. May (1975) concluded that the index is dominated by the abundant species and is an insensitive measure of the characteristics of the communities' distribution (Southwood and Henderson, 2000).

Simpson's diversity index (*D*)

The Simpson's diversity index is a measure of dominance. It also takes abundance and evenness of the species present into account. The formula describes the probability that any two individuals drawn at random from an infinitely large community belong to the same species (Magurran, 1988; Southwood and Henderson, 2000). Its evenness is computed by dividing D *by* D_{max}.

The Simpson diversity index, another regularly use index, is less sensitive to species richness, and is heavily weighted towards the most abundant species rather than that it provides a measure of species richness (Magurran, 1988; Southwood and Henderson, 2000). Generally, it is less sensitive than the Shannon-Wiener diversity index. Additionally, May (1975) argued that this index is strongly influenced, for value of $S_{obs} > 10$, by the underlying distribution (Magurran, 1988; Southwood and Henderson, 2000).

Although there are several ways to assess biodiversity including species richness as well as species diversity indices, no single approach can be entirely effective in integrating and describing community structure. This is because each biodiversity measurement possesses both advantages and disadvantages. Therefore, choosing a measure for biodiversity assessment should be considering (1) the kind of data analyzed, (2) the index properties wanted by users, sampling areas (Beisel et al., 2003; Ugland *et al.*, 2003) as well as the user's objectives. Moreover, the evaluation of the most appropriate estimator or index should be based on the consideration of their theoretical properties as against our knowledge of ecology or by testing them with field data for either their fit or their value in discrimination (Southwood and Henderson, 2000).

Results and Discussion

3.2.1 Species richness

3.2.1.1 Species accumulation curve

The species accumulation curves data from each peat swamps slightly creep up, when sample numbers is increased (Figure 3.2.1a and b). This implies that the five peat swamps contain diverse rotifer fauna, so that the curve cannot reach plateau at terminal. Therefore, to assess the rotifer species in these five areas, I use non-parametric estimator to calculate the expected rotifer species. The shape of the species accumulation curves is noticeably different for all five datasets (Figure 3.2.1). Only Jae-Son datasets trend to slowly creep up at approximately 30% of the total sampling effort in the species accumulation. From this study, therefore, Jae-Son species accumulation curve is the most appropriate data for identifying the least bias nonparametric estimator.

The shape of species accumulation curves is influenced by species richness, relative abundance and diversity (Thompson and Withers, 2003; Thompson *et al.*, 2003). Sites with a high proportion of relatively abundant species have a steep rising initial slope, an early plateau and provide an accurate estimate of species richness with lower sampling effort than where there is a higher proportion of rare species (Thompson *et al.*, 2003). Therefore, the exceptional dataset used to examine which of the non-parametric species richness estimator is the optimal one in this study is Jae-Son data.

3.2.1.2 The best estimator for coastal peat swamp rotifer fauna

The mean number of species calculated from five non-parametric estimators was plotted with the Jae-Son species accumulation curve (Figure 3.2.2). Then the coordinate boxes were drawn at 14 samples (the point at which the observed richness reaches approximately half (53 species) the observed richness) and 28 samples (twice this number) (Cowell and Coddington, 1994). The result shows Chao2 estimator clearly provide the least biased estimates for small numbers of samples, followed by Chao1, second-order Jackknife, first-order Jackknife and bootstrap method, respectively (Table 3.2.3). That Chao2 is the best estimator agrees well with the study on seed bank (Colwell and Coddington, 1994). But it is at variance with the woody plant study by Hellmann and Fowler (1999) and Foggo *et al.* (2003). They reported that the least bias estimator is the second-order Jackknife and Choa 1, respectively. However, different non-parametric species richness estimators estimate different species richness value and extrapolation to a total species count increases error, with certain models being more effective for different groups of organisms, or in different environments, or with different amounts of effort (Thompson *et al.*, 2003).

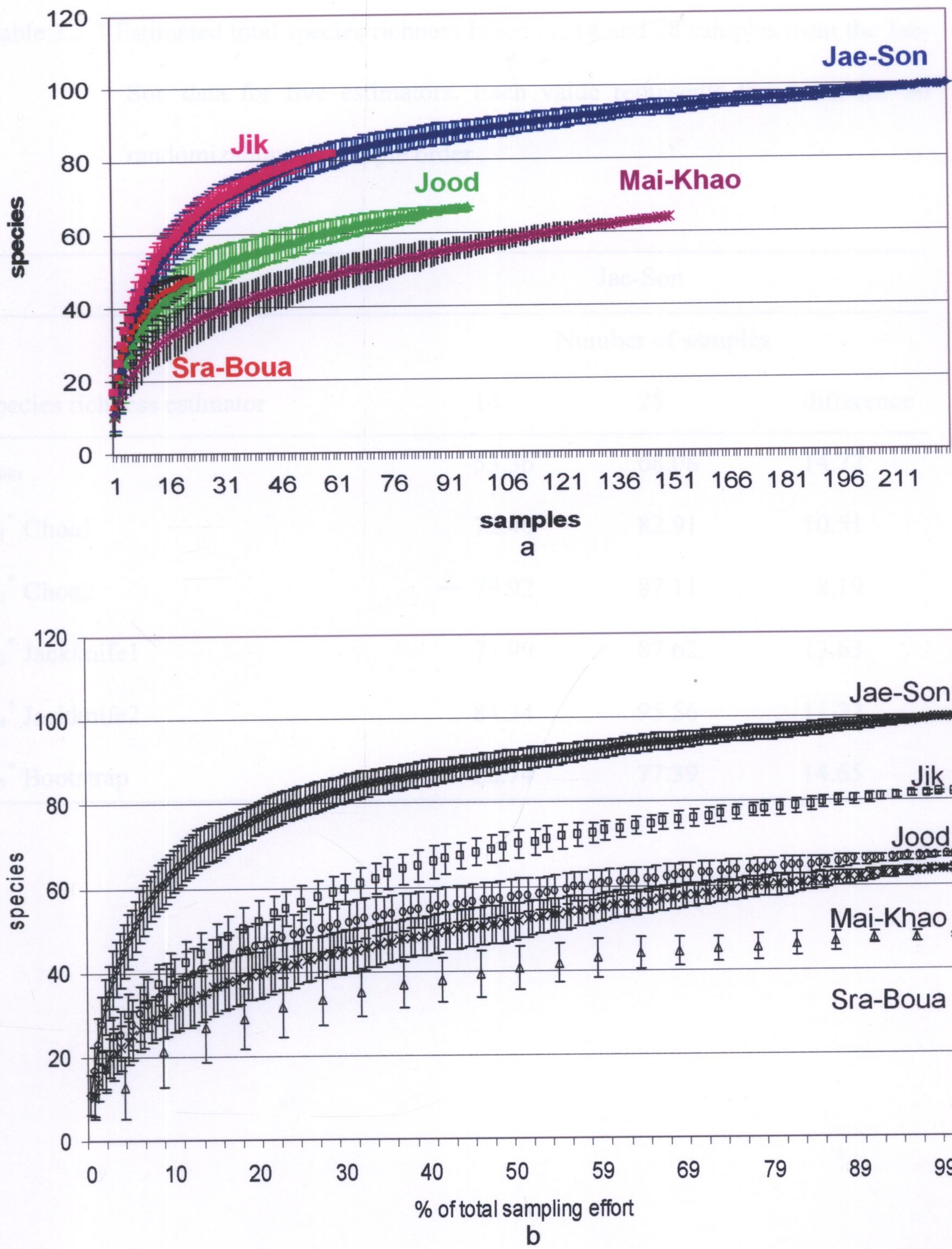

Figure 3.2.1 (a) Observed species accumulation curves of the five areas (±1SD); (b) Observed species accumulation curves (±1SD) of the percent of total sampling effort from five coastal peat swamps.

Table 3.2.3 Estimated total species richness based on 14 and 28 samples from the Jae-Son data for five estimators. Each value represents the mean for 50 randomizations of sample order

	Jae-Son		
	Number of samples		
species richness estimator	14	28	difference
S_{obs}	53.36	68.08	14.72
S_1^* Choa1	72.40	82.91	10.51
S_2^* Choa2	78.92	87.11	8.19
S_3^* Jackknife1	73.99	87.62	13.63
S_4^* Jackknife2	84.34	95.56	11.22
S_5^* Bootstrap	62.74	77.39	14.65

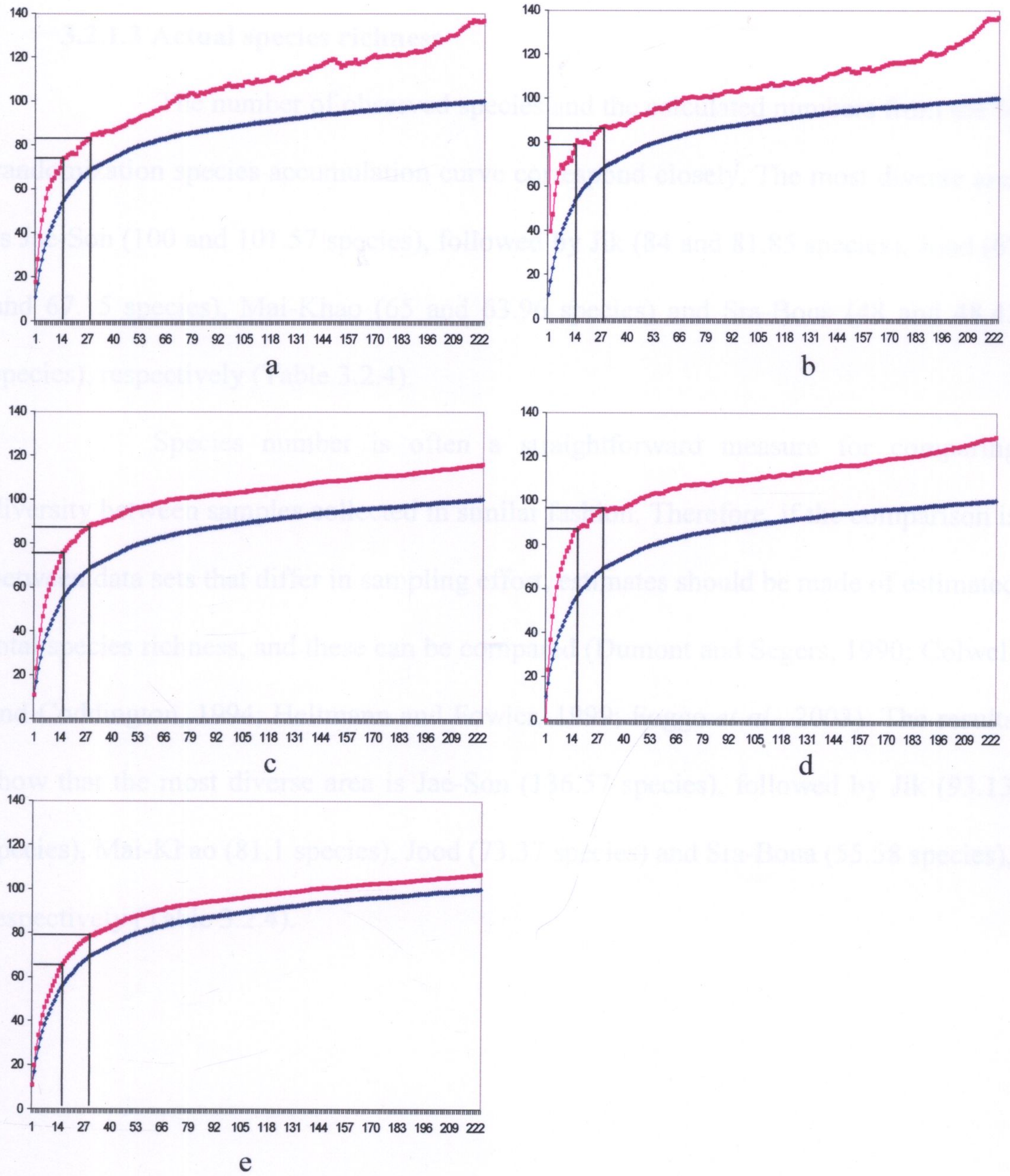

Figure 3.2.2 Performance of five non-parametric estimators of species richness for Jae-Son peat swamp. (a) S_1^*, Choa 1; (b) S_2^*, Choa 2; (c) S_3^*, First-order Jackknife; (d) S_4^*, Second-order Jackknife; (e) S_5^*, Bootstrap. The blue curve in each panel (the species accumulation curve) plots the observed number of species. The pink curve in each panel displays the estimated total species richness based on successively larger number of samples from the dataset. The estimates based on 14 and 28 samples are indicated by coordinate boxes to allow visual comparison the estimates based on small numbers of samples (see table 3.2.3).

3.2.1.3 Actual species richness

The number of observed species and the calculated numbers from the 50 randomization species accumulation curve correspond closely. The most diverse area is Jae-Son (100 and 101.57 species), followed by Jik (84 and 81.85 species), Jood (67 and 67.15 species), Mai-Khao (65 and 63.96 species) and Sra-Boua (48 and 48.43 species), respectively (Table 3.2.4).

Species number is often a straightforward measure for comparing diversity between samples collected in similar fashion. Therefore, if the comparison is between data sets that differ in sampling effort, estimates should be made of estimated total species richness, and these can be compared (Dumont and Segers, 1990; Colwell and Coddington, 1994; Hellmann and Fowler, 1999; Foggo *et al.*, 2003). The results show that the most diverse area is Jae-Son (136.57 species), followed by Jik (93.13 species), Mai-Khao (81.1 species), Jood (73.37 species) and Sra-Boua (55.58 species), respectively (Table 3.2.4).

Table 3.2.4 Total species richness from observation, calculated species richness from 50 randomization species accumulation curve and expected species richness from Chao2 estimator of five peat swamps

Areas	S_{obs}	calculated from species accumulation curve	Chao2
Jik	84	81.85	93.13
Jae-Son	100	101.57	136.57
Mai-Khao	65	63.96	81.10
Jood	67	67.15	73.37
Sra-Boua	48	48.43	55.58

3.2.2 Measures of complementarity

Complementarity, or biotic distinctness, of the five areas was analyzed and presented in Table 3.2.5. Using Jik, a pristine swamp, as a reference, the four disturbed areas show percentual distinctness ranging from 34-69%. The highest distinct rotifer fauna occurred in Sra-Boua (66%), a eutrophic area, followed by Mai-Khao (55%) and Jood (54%), two brackish peat swamps and Jae-Son (39%), a reservoir peat swamp, respectively. The number of species in common with Jik is highest in Jae-Son (70 species), followed by Jood (48 species), Mai-Khao (46 species) and Sra-Boua (33 species), respectively. The results appear to indicate that human activities result in changes in rotifer composition in the peat swamps. Anthropogenic activities, especially agriculture and aquaculture, caused more than fifty percent alteration of the species composition. This is because disturbances generally result in the opening up of niche spaces, or liberating of resources that can be exploited by new individuals (Begon *et al.,* 1998). Moreover, the anthropogenic perturbations influence the biotic properties of the environment in relation to that organism's specific tolerance limits, and the ability to reach the habitat (dispersal ability) (Putman, 1994). That a species disappears from a habitat results in a vacant niche. Subsequently, new species enter and colonizes the gap, and, when these are more tolerant, they may turn out to be become dominant (Mackenzie *et al.*, 1998). As a result of different species invading and disappearing, the species assembly changes.

Table 3.2.5 Richness (S_{obs}) and percentage complementarity of rotifer fauna among the five coastal peat swamps along Mai-Khao beach on Phuket island (Matrix entries: pairwise percentage complementarity (number of species in common))

	Jik	Jae-Son	Jood	Mai-Khao	Sra-Boua
richness	84	100	68	65	47
Jik	0				
Jae-Son	39(70)	0			
Jood	54(48)	51(55)	0		
Mai-Khao	55(46)	53(53)	34(33)	0	
Sra-Boua	66(33)	69(35)	60(33)	66(33)	0

Moreover, when the comparison was made amonth the four disturbed areas, the result reveals that their pair-wise complementarity is over fifty percent (Table 3.2.5). The modified Jae-Son reservoir presents 51-53% dissimilarity with the brackish areas (Mai-Khao and Jood) and 69% difference when compared to a eutrophic swamp, Sra-Boua. In addition, brackish swamps display 65-66% dissimilarity when compared to the eutrophic area. This illustrates that different anthropogenic activities result in different species assemblage alterations. The reason is because various human impacts lead to different environmental variables being changed and consequently, different species responding.

3.2.3 Species diversity indices and equitability

The species diversity of Rotifera in the five swamps was studied using three non-parametric indices and two measures of evenness: Berger-Parker dominance index (*d*), Shannon Wiener index (*H*) and Shannon Wiener' equitability (*J*) and Simpson diversity index (*D*) and Simpson's equitability (*E*). All result is shown in Table 3.2.6.

Table 3.2.6 Three commonly used diversity indices calculated for the five peat swamps. *d*: Berger-Parker dominance index; *H*: Shannon Wiener index; *J*: Shannon Wiener' equitability; *D*: Simpson diversity index; *E*: Simpson's equitability

Peat swamp areas	Species richness	*d*	*H*	*J*	*D*	*E*
Jik	84	0.283	1.842	0.513	5.889	0.164
Jae-Son	100	0.474	1.614	0.428	3.444	0.079
Sra-Boua	47	0.553	1.436	0.495	2.960	0.165
Jood	68	0.587	1.357	0.448	3.115	0.157
Mai-Khao	65	0.584	1.265	0.417	2.883	0.145

From table 3.2.6, the highest Berger-Parker dominance index value was calculated for the samples from Jood, followed by Mai-Khao, Sra-Boua, Jae-Son and Jik (0.587, 0.584, 0.553, 0.474 and 0.283), respectively. Since this index is calculated by using only the most dominant species divided by the total catch, a high value indicates presence of a single or some species that constitute a great proportion of the community. A community is said to have a high species diversity if many equally or nearly equally abundant species are present. Conversely, if a community is composed of a very few species, or if only a few species are abundant, then species diversity is low (Mackenzie *et al.*, 1998). Therefore, it can be suggested that rotifer communities in Jood, Mai-Khao, Sra-Boua and Jae-Son comprise of a few dominant species, while, Jik includes many equally abundant species. Species diversity, on the other hand, can be expected to reach a high value in Jik and decrease gradually in Jae-Son, Sra-Boua, Mai-Khao and Jood, respectively.

As for the other two indices, the maximum value of Shannon Weiner index (*H*) was calculated for the samples from Jik (1.842), followed by Jae-Son (1.614), Sra-Boua (1.436), Jood (1.357) and Mai-Khao (1.265), respectively, while, the maximum value for Simpson's diversity index (*D*) was obtained in Jik (5.889), followed by Jae-Son (3.444), Jood (3.115), Sra-Boua (2.960) and Mai-Khao (2.883), respectively. It should be considered that the Shannon Weiner index measures the degree of uncertainty in a sampling event. The higher the value of *H*, the greater is the uncertainly, or the probability that the next individuals chosen at random from a collection of species containing N individual will not belong to the same species as the previous one. In contrast, the lower the value of *H*, the greater the probability that the next individual encountered will be the same species as the previous one (Southwood and Henderson, 2000). This suggests that Jik peat swamp holds a more diverse rotifer fauna than any of the disturbed areas, Jae-Son, Sra-Boua, Jood and Mai-Khao. In accordance with Simpson' diversity index, Jik is the most diverse area, followed by Jae-Son, Jood, Sra-Boua and Mai-Khao, correspondingly. Hence, it can be concluded that all anthropogenic activities in the four peat swamps, including the discharged of saline water in Jood and Mai-Khao impact strongly on communities and result in low diversity.

Both the Shannon-Wiener and Simpson's diversity indices present the same trend in that the maximum values were calculated from undisturbed areas and the values are consistently lower in disturbed areas. However, there are differences between the values for some disturbed areas, especially regarding the sequence in order with decreasing diversity value. This is due to the properties of each index, as they all focus on different part characters. Simpson's diversity index trends to focuses on the single most dominant species, whereas the Shannon-Wiener diversity index considers all components of the species assemblage (Magurran, 1988; Southwood and Henderson, 2000). Consequently, the value of *H* is sensitive to differences in abundance of rare species, where *D* is sensitive to the relative abundance of the most abundant species only. In addition, Shannon-Wiever diversity index of diversity is not suited to comparison among sites because it is biased for small samples as in Sra-Boua whereas Simpson's diversity has the statistical accuracy for reliable comparison among communities using small samples (Thompson and Withers, 2003). Besides, the Shannon-Wiever diversity index is appropriate when you have a random sample of species abundances from a larger community or sub-community of interest. Such a sample may not contain representatives for each species in the entire community. However, species diversity measures have been suggested to be poor indicator of pollution and environmental changes (Hawthorne and Dauer, 1983 quoted Angsupanich and Kuwabara, 1999).

Shannon Wiener equitability and Simpson's evenness of rotifer communities in five peat swamps were calculated and are shown in table 3.2.5. The Shannon Wiener equitability values are quite similar, which the maximum value presents in the pristine Jik (0.513), followed by Sra-Boua (0.495), Jood (0.448), Jae-Son (0.428) and Mai-Khao (0.417), all disturbed areas. This result suggests that rotifer communities in the five areas have the same underlying distribution, similar moderate distribution. In contrast to *E,* the highest value displays in Sra-Boua (0.165), followed by Jik (0.164), Jood (0.157), Mai-Khao (0.145) and Jae-Son (0.079), respectively. This result indicates that rotifer assemblages in Jik, Sra-Boua, Jood and Mai-Khao have the same distribution, whereas Jae-Son contains a few abundant species. These two evenness measures do not display the same sensitivity, because the evenness depends on diversity index properties. The diversity of communities is a function of both species richness and abundance, which are differently emphasized in each formula and consequently result in different evenness value.

Choosing diversity indices to assess biodiversity depends on the ecological framework. If you would like to emphasize on spatial and temporal differences, you have to choose an index with a high sensitivity to rare species. In contrast, limnologist studying the variability of zooplankton community structure induced by environmental changes are perhaps more interested in measures with a high sensitivity to changes in abundances of dominant taxa (Beisel *et al.*, 2003). This study is aimed to assess biodiversity in peat swamp areas, which are different environmental conditions; as a result. Therefore, the work chooses to rely most on Simpson's diversity index and its evenness in our interpretation. Hence, the most diverse peat swamp in this study is Jik, followed by Jae-Son, Jood, Sra-Boua and Mai-Khao, respectively. Rotifer communities in Jik, Jood, Sra-Boua and Mai-Khao compose of equally nearly abundant species, whereas, the rotifer assemblage in Jae-Son contains a few dominant species.

Conclusion

The chao2 is the least bias estimator for rotifer community in peat swamps. It is used to obtain a total species richness to compare among sites. The most diverse area in term of species richness is Jae-Son, followed by Jik, Mai-Khao, Jood and Sra-Boua, respectively.

In term of species diversity index, Simpson' diversity index is applied to interpret the results in this study. The most diverse peat swamps is Jik, followed by Jae-Son, Jood, Sra-Boua, and Mai-Khao respectively. The eveness is high in Jik, Jood, Sra-Boua and Mai-Khao, while it is low in Jae-Son. That Jae-Son contains high species diversity but low community diversity is because it is the largest swamp in this study. But, although there are many rotifer species there, only a few species is dominant.This result in high species richness and low diversity in Jae-Son. Morover, the results indicate that a weakly diverse rotifer community comprising few dominant species is present in the disturbed areas, whereas, undisturbed areas contain many nearly equally abundant species and, consequently, a high diverse fauna.

The disturbed areas show species assemblages that differ markedly from the fauna in a pristine peat swamp. This indicates that all anthropogenic activities result in changes in composition of the rotifer fauna, and different human activities affect species composition in different ways. The most severe treat on the rotifer composition, in terms of reduction of species richness and change towards uneven community composition in peat swamp areas is the discharge of saline water from aquaculture farms.

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PART 3.3 MULTIVARIATE ANALYSIS OF ROTIFER COMMUNITIES IN FIVE COASTAL PEAT SWAMPS ON PHUKET ISLAND, SOUTHERN THAILAND

Introduction

Habitats provide a variety of resources to their occupants including food, shelter and mating sites. The availability of these resources can be affected, and potentially affected differentially, by habitat fragmentation, degradation and loss. Consequently, the patterns of resource availability in space and changes in these patterns through time, as a result of any of these processes, may affect patterns of distribution and abundance of species within and among habitat patches (Caley *et al.*, 2001).

The peat swamp areas, one of the most very important tropical ecosystems, play a significance role in the hydrologic cycle and act as a local climatic regulation (Ueda, *et al.*, 2000). They have been demonstrated to contain many remarkable rotifer species, which result from a long history and unique ecological characteristic (Chittapun *et al.*, 1999; Chittapun *et al.*, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002; Chittapun *et al.*, 2003; Chittapun *et al.*, part 1). Presently, as a consequence of an extremely extensive land-use, the peat swamps are severely disturbed resulting in habitat degradation and destruction. Obviously, Phru Ban Mai-Khao, a peat swamp along Mai-Khao coast, was fragmented into several small peat areas by natural succession and human activities. They are then, diversified by different disturbances and some are completely dried out. Fortunately, the pristine one still exists. So far, there are six remaining peat swamp areas and three kinds of anthropogenic disturbance taking place in these areas, in summary. According to anthropogenic disturbances, the noticeably activity is salinisation, discharged of saline water from nearby shrimp farms, affecting on macrophyte in Mai-Khao and Jood disappeared. Secondly, a transformation, Jae-Son peat swamp was digged peat land out and transformed to be a reservoir for irrigation. The last perturbation is in Sra-Boua peat swamp, where is enveloped by agricultural areas, as a result of fertilizer and pesticide contamination, which lead to eutrophication. These anthropogenic disturbances impact on habitat changes and degradation, which may effect on abundance and distribution of the organism living there.

Small bodied species inhabiting smaller habitat patches are likely to respond more rapidly to habitat fragmentation or degradation than larger-bodied species, because of their generally greater rates of mortality and reduced ages and sizes of maturity (Caley *et al.*, 2001). Rotifers, as small predominantly freshwater inhabitants, are the most diverse group in term of number and species diversity of freshwater metazoan. They play a significant role in freshwater ecosystem. Fundamentally, as a primary consumer of phytoplankton, rotifers convert energy and matter to organisms ranged in higher trophic levels. In addition, as a result of their high reproductivity and high feeding rates, rotifers play a pivotal part in energy flow and nutrient cycling. As their fundamental, rotifers are, therefore, choosing as a studied organism to examine the effect of anthropogenic factors on peat swamp areas.

The study of Rotifera in Thailand has been increasing significantly (Boonsom, 1984; Segers and Sanoamuang, 1994; Sanoamuang *et al.*, 1995; Sanoamuang, 1996; Pholpunthin, 1997; Segers and Pholpunthin, 1997; Sanoamuang and Segers, 1997;

Pholpunthin and Chittapun, 1998; Sanoamuang, 1998; Chittapun *et al.*, 1999; Sanoamuang and Savatenalintion, 1999; Chittapun *et al.*, 2001; Sanoamuang and Savatenalintion, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002; Chittapun *et al.*, 2003). However, all of them are focus mainly on taxonomy, whereas the other aspects have never been employed. In addition, the majority of the rotifer knowledge is based on temperate region; a few had been documented from in tropic zone (see Ricci, 2001). Hence, to establish a new facet of the rotifer study, ecology, in Thailand and to contribute to the tropical rotifer knowledge, this study was conducted. This study is to investigate the effect of anthropogenic factors on peat swamp areas by using rotifer communities as indicator.

There are several studies dealing with using rotifer as indicator. Since trophic state has been commonly found to be important in determining distribution of rotifer community, the most extensive knowledge is the studies intended to provide lists of rotifer species indicative of different trophic states based on qualitative and quantitative data (e.g. Mäemets, 1983; Berzins and Pejler, 1989; Duggan *et al.,* 2001). Recently, that the rotifer community composition and distribution can be also indicated by ecological conditions had been investigated (Segers and Dumont, 1993; Jersabek, 1995). However, no quantitative data has yet been elaborated. Therefore, this study is also aim to investigate the ecological importance on rotifer distribution among five peat swamps using multivariate approach performed on quantitative data.

Materails and Methods

The peat swamp rotifers were sampled monthly from November 1999 to February 2001 (see Chittapun *et al.*, manuscript 1) using a 26 μm mesh plankton net. Animals were immediately preserved in 4% formaldehyde solution. Specimens were sorted under an Olympus VM dissecting microscope, then, they were identified and counted under an Olympus CH-2 compound microscope. Counting continued at least for three times or until no additional species was observed. Since the specimens of *Monommata* sp. and *Scaridium* sp. are difficult to count and identify to species level, the data using in ecology analysis of these two species are the number of specimens in genus level.

During sampling, measurements of some physical and chemical parameters were done (see Table 1 in study area). Temperature, pH, salinity, conductivity and turbidity were measured using a HORIBA, U-10 multimeter. Dissolved oxygen, Chlorophyll *a* and phosphate were analyzed in laboratory followed Standard method for the examination of water and wastewater (1992). Nitrate was analyzed by Spectrophotometer version spectroquant NOVA 60 MERCK at Central Equipment Division, Faculty of Science, Prince of Songkla University, Hat Yai campus and data on precipitation in the study areas was obtained from the Meteorology Department of Thailand.

Data analysis

Rotifer communities

The rotifer species data were converted to relative abundance values. Then to homogeneity of variance, the relative abundance was transformed using log (n+1) transformation, which prevents the creation of undefined values due to zeros in the data set (McCune *et al.*, 2002). This data was used in cluster analysis, detrended correspondence analysis (DCA) and Two-Way Indicator Species Analysis (TWINSPAN). In addition, the rotifer communities data, which was excluded species comprising lower than 12% (31 species remain), was used in canonical correspondence analysis (CCA).

Environmental variables

Environmental data including temperature, pH, dissolved oxygen (DO), salinity, conductivity, turbidity, precipitation, nitrate, phosphate and Chlorophyll a, were used without transformation, because the value in each variable are small differences. Moreover, the qualitative data, habitat (pelagic or littoral), percent of macrophyte cover and type of macrophytes (emerge or submerge plant) were used in analysis as well. Then correlations between rotifer communities and environmental variables were performed to investigate the relationship between the factors and species distribution in CCA.

Statistical analysis

Several multivariate and traditional statistical techniques were used to analyze the peat swamp rotifer communities' data.

Classification of study areas based on rotifer communities

Cluster analysis and DCA were used to classify five coastal peat swamps into distinct group based on their rotifer communities' similarity. According to cluster analysis, Sorensen distance was selected for measuring percent similarity. While in DCA, samples and species were ordinated simultaneously. The samples were arranged by distinguishing reference samples from impaired samples with downweight rare species.

Environmental variables influence on Rotifer distribution

CCA was used to identify important variables influencing on rotifer communities. Two matrices were required in CCA. The main matrix contained abundance of rotifer species in set of sample units, while the second matrix held on environmental variables measured in the same sample units. Then, the ordination of samples and species was constrained by their relationships to environmental variables. The variables, which influence on rotifer distribution, were presented in term of vector on graph. During CCA process, row and column score were standardized by Hill's (1979) method, which has been argued that this scaling makes the resulting ordination more interpretable ecologically (Jongman et al. 1995). In addition, Monte Carlo test was run to test the null hypothesis on no relationship between metrics.

Community similarity

The species composition, species list, of Mai-Khao and Jood peat swamps were performed by using Sϕrensen index. This index was used to compare similarity of rotifer composition from the past, freshwater habitat and present, brackish water, in term of present-absence data. Sϕrensen index has been recommended to be the best index based on presence–absence data (Smith, 1986 quoting Southwood and Henderson, 2000).

$$\text{S}\phi\text{rensen (1984) } C_s = \frac{2a}{2a+b+c}$$

a = the number of species held in common

b = the number of species found at only one of the site one

c = the number of species found at only one of the site two

Classification of Rotifer taxa

TWINSPAN, a method of simultaneously classifying both species and sample units and producing two-way ordered tables was performed on the quantitative data, log abundant of rotifer communities. The 0, 0.5, 1. 1.5 and 2 cut level was defined.

Cluster analysis, DCA, CCA and TWINSPAN were employed in PC-ORD program version 3.02 (MjM Software Design, Gleneden Beach, Oregon, USA.).

Results and Discussion

3.3.1 The classification of five peat swamps based on rotifer communities

Cluster analysis of rotifer communities from five coastal peat swamp areas revealed four distinct groups at 80% similarity level; Mai-Khao+Jood, Jik, Jae-Son and Sra-Boua (Figure 3.3.1). Mai-Khao and Jood had the highest similarity in rotifer communities, 99.93% similarity level, and this group was obviously separated and greatly different from the other three areas. According to the other three, Jik showed 78.40% similarity to Jae-Son and they had 46.20% similarity to Sra-Boua. The result indicates that rotifer communities of Mai-Khao and Jood are exactly similar and their rotifer structure is significantly difference from Jik, Jae-Son and Sra-Boua. This concurs with the four different groups of peat swamps; pristine Jik, Jae-Son reservoir, polluted Sra-Boua and brackish Mai-Khao and Jood. Hence, it suggests that each disturbance has effect on rotifer communities.

```
                          Distance (Objective Function)

            .051             .198             .344             .491             .638
            |-------+--------+--------+--------+--------+--------+--------+--------+

                          Information remaining (%)

          100.000           75.000           50.000           25.000            .000
            |-------+--------+--------+--------+--------+--------+--------+--------+

Jik          ------------| 74.40%
                         |--------------------| 46.20%
Jae-Son      ------------|                    |-----------------------------|
                                              |                             |
Sra-Boua     ---------------------------------|                             | 0.11%
                                                                            |
Jood         | 99.93%                                                       |
             |--------------------------------------------------------------|
Mai-Khao     |
```

Figure 3.3.1 Cluster Analysis based on rotifer communities of five coastal peat swamps in Phuket province.

The DCA analysis of rotifer communities from the five areas appeared an ordination in species composition based on time, monthly samples (Figure 3.3.2). The first and second axis explained 62.2% and 27.3% of the variance of data respectively. Therefore 89.5% of data can be explained by this graph, which is good. The result shows that the reference samples ordinate together in a loose big group to the right hand site of center of axis1. While in the left hand site, the triangular points tended to patchy disperse. According to the big group in right hand size, it composed of reference samples of Mai-Khao and Jood, which were tightly overlap. Referring to the left hand site, they were categorized into three groups based on study sites. Sample positions of Jik and Jae-Son were ranked in closely group to the axis2 and they were separated out from each in vertical. In addition, most of Sra-Boua samples were positioned in the middle of axis, while a single was located in Jae-Son group. This DCA result agreed well with the cluster analysis outcome that rotifer communities in Mai-Khao and Jood were extremely similar and their composition was greatly different from the others.

Additionally, since each point represented monthly samples, these reference points implied the temporal composition of rotifer community. Therefore, the characteristic of point distribution suggested the fluctuation of rotifer communities in each area throughout sampling period. The more scatter the reference samples were plotted, the more fluctuation the rotifer communities were detected. Jik and Jae-Son spots appeared clumsy in ordination, whereas Mai-Khao, Jood and Sra-Boua showed more scatter. It can imply that rotifer community in Jik and Jae-Son were not much change in species composition as in the other three, especially in Sra-Boua.

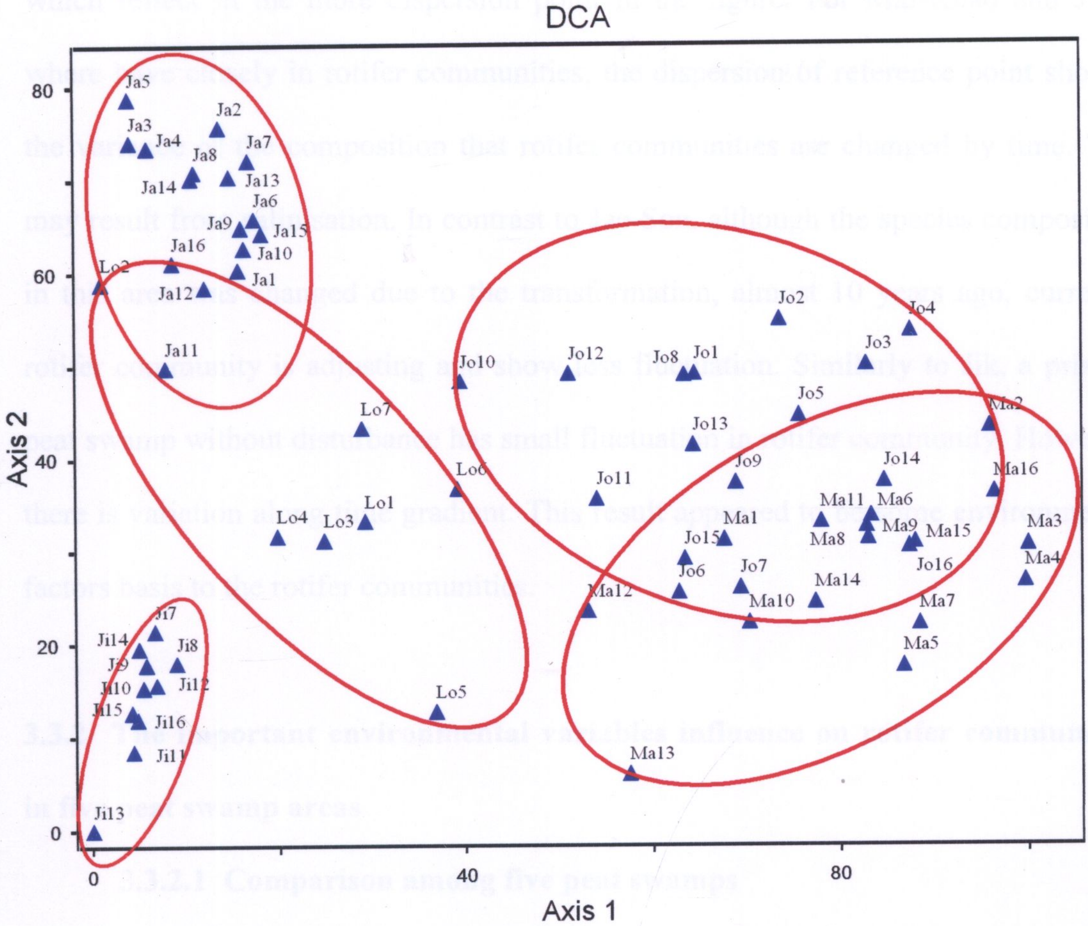


Figure 3.3.2 DCA ordination of rotifer community of monthly samples from five coastal peat swamps (number = sampling month, Ma = Mai-Khao, Jo = Jood, Ji = Jik, Ja = Jae-Son and Lo = Sra-Boua).

According to the three widely disperse references groups, Sra-Boua shows highly fluctuation due to more disturbances. Since this work started sampling at Sra-Boua, it was occupied by people nearby to harvest organism for food and there are many agricultural crop surrounding. Moreover after the third sampling, the building construction was took place. It was dug and replaced as a result in highly disturb, which reflect in the more dispersion point in the figure. For Mai-Khao and Jood, which reflect in the more dispersion point in the figure. For Mai-Khao and Jood, where have closely in rotifer communities, the dispersion of reference point showed the variance of the composition that rotifer communities are changed by time. This may result from salinisation. In contrast to Jae-Son, although the species composition in this area was changed due to the transformation, almost 10 years ago, currently rotifer community is adjusting and show less fluctuation. Similarly to Jik, a pristine peat swamp without disturbance has small fluctuation in rotifer community. However, there is variation along time gradient. This result appeared to be some environmental factors basis to the rotifer communities.

3.3.2 The important environmental variables influence on rotifer communities in five peat swamp areas

3.3.2.1 Comparison among five peat swamps

The abundance of thirty-one rotifer species in 274 sample units and thirteen environmental variables were performed CCA analysis. The iteration report showed that a stable solution was found for each of the first three axes. The tolerance level of .100000E-12 was achieved after 14, 60 and 25 relations for the first three axes, respectively. The total variance in rotifer composition among the five coastal peat swamps ("inertia") that could potentially be explained is 3.613. For the species data, most of the variation (15.4%) explained is in the first axis and 4.3% and 3.4% were further explained in axes 2 and 3 respectively. Pearson Correlation between species and environmental factors showed 0.943 and 0.696 explained by axes 1 and 2 respectively (Table 3.3.1).

Table 3.3.1 Axis summary statistics for CCA analysis of the five peat swamps

Number of canonical axes: 3

Total variance ("inertia") in the species data: 3.613

	Axis 1	Axis 2	Axis 3
Eigenvalue	.556	.155	.123
Variance in species data			
% of variance explained	15.4	4.3	3.4
Cumulative % explained	15.4	19.7	23.1
Pearson Correlation, Spp-Envt*	.943	.696	.630
Kendall (Rank) Corr., Spp-Envt	.691	.515	.380

From the thirteen original variables, the CCA identified two environmental variables explaining the variance in the rotifer data among the five peat swamps. Salinity and conductivity are ecological importance and contribute a correlated environment variable with differences in rotifer composition among areas. The important variables were presented in term of vectors (Figure 3.3.3 and 3.3.4). These ordination diagrams showed that the two vectors pointed out in the same direction. It means therefore these two variables have strongly correlation together, which showed r = 0.998 in the correlation. Additionally, the length of the vectors in Figure 3.3.3 and 3.3.4 represented their relative importance; thus salinity and conductivity were equally important water quality in rotifer distribution. Both salinity and conductivity have concord correlation (Pontin and Langley, 1993), because higher salinity results in higher ion discharge, which is measured in term of conductivity.

Moreover, they have strongly parallel relation to axis 1; .885 and .866 for conductivity and salinity, respectively (Table 3.3.2). Salinity has been proposed by many scientists that it is an important factor in aquatic system. Cause, the concentration of salts has relative to osmotic resistance to water uptake, which is conditioning in rotifer distribution (see eg. Miracle and Serra, 1989; Styling, 2002).

Table 3.3.2 Inter-set correlation for 11 variables of the CCA analysis in the five peat swamps (Temp = Temperature, Chl a = Chlorophyll a, NO_3^{2-} = Soluble Nitrate, PO_3^- = Soluble Phosphate, DO = Dissolved oxygen, Turb = Turbidity, Cond = Conductivity, Sal = Salinity, % cover = Percent of macrophyte covering and Preci = The monthly average precipitation)

		Correlations	
Variable s	Axis 1	Axis 2	Axis 3
1Temp	.125	-.165	-.073
2 Chl a	.308	.204	-.151
3 NO_3^{2-}	-.014	.090	.061
4 PO_3^-	.059	.091	-.142
5 DO	-.206	-.216	-.053
6 pH	.121	.125	.022
7 Turb	.189	.109	-.079
8 Cond	.885	-.195	-.063
9 Sal	.866	-.225	-.077
10 %cover	.044	.262	-.544
11 Preci	-.016	.283	.002

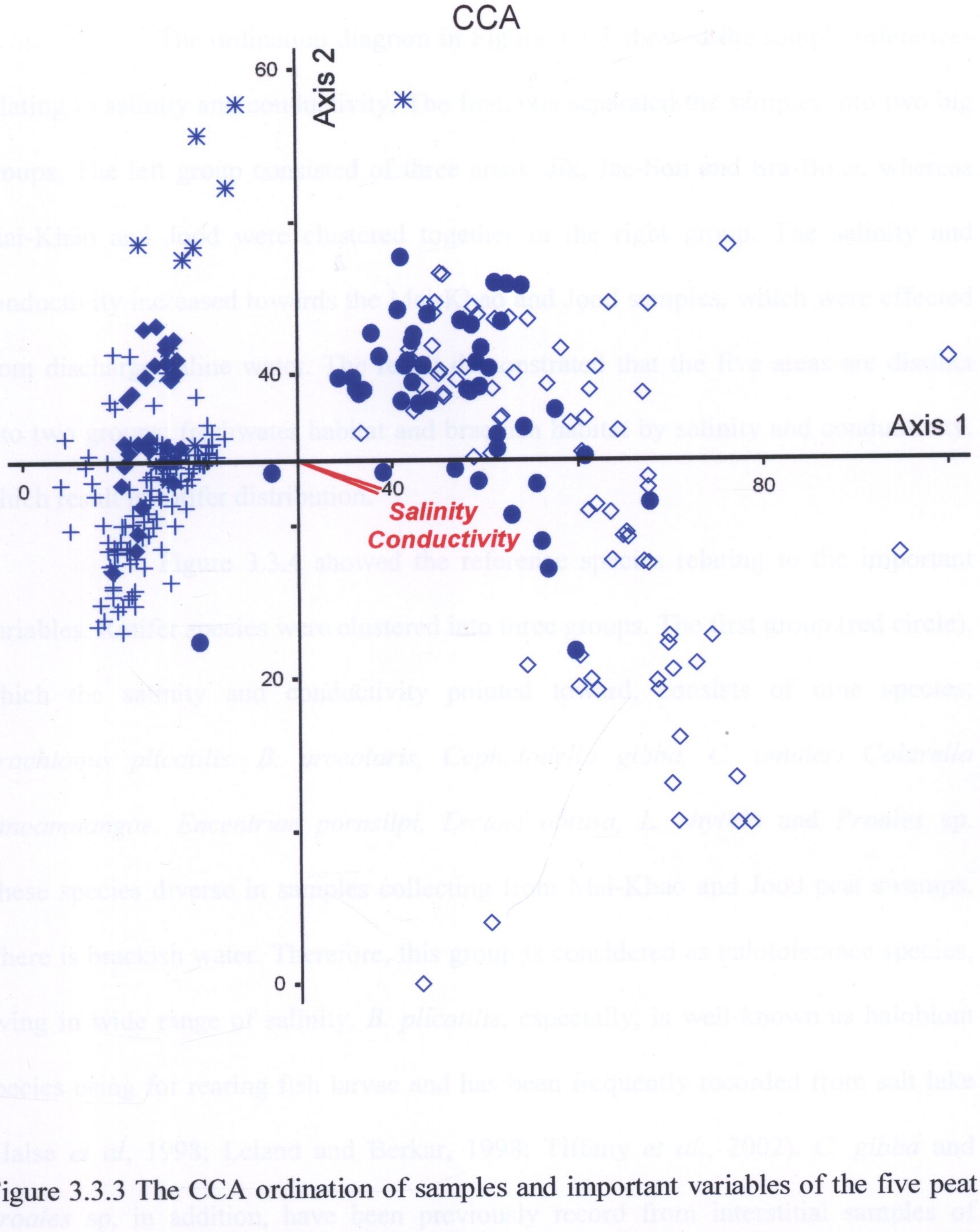


Figure 3.3.3 The CCA ordination of samples and important variables of the five peat swamps (◇ = Mai-Khao samples, ● = Jood samples, ◆ = Jik samples, + = Jae-Son samples and ✳ = Sra-Boua samples).

The ordination diagram in Figure 3.3.3 showed the sample references relating to salinity and conductivity. The first axis separated the samples into two big groups. The left group consisted of three areas; Jik, Jae-Son and Sra-Boua, whereas Mai-Khao and Jood were clustered together in the right group. The salinity and conductivity increased towards the Mai-Khao and Jood samples, which were effected from discharge saline water. The result demonstrated that the five areas are distinct into two groups; freshwater habitat and brackish habitat by salinity and conductivity, which result in rotifer distribution.

Figure 3.3.4 showed the reference species relating to the important variables. Rotifer species were clustered into three groups. The first group (red circle), which the salinity and conductivity pointed toward, consists of nine species; *Brachionus plicatilis, B. urceolaris, Cephalodella gibba, C. tenuier, Colurella sanoamuangae, Encentrum pornsilpi, Lecane obtusa, L. rhytida* and *Proales* sp. These species diverse in samples collecting from Mai-Khao and Jood peat swamps, where is brackish water. Therefore, this group is considered as halotolerance species, living in wide range of salinity. *B. plicatilis*, especially, is well-known as halobiont species using for rearing fish larvae and has been frequently recorded from salt lake (Halse *et al*, 1998; Leland and Berkar, 1998; Tiffany *et al.*, 2002). *C. gibba* and *Proales* sp, in addition, have been previously record from interstitial samples of saltwater beach (Turner, 1993).

Second group is in the green circle. This group composing of nineteen species; *Anureaopsis coelata, A. fissa, A. navicula, Ascomorpha ovalis, B. angularis, B. dichotomus, B. falcatus, B. forficula, B. quadridentatus, C. forficula, Filinia longiseta, Hexathra mira, Keratella cochealis, L. lunaris, Lepadella patella,* *Polyarthra vulgaris, Trichocerca capucina, T. pusilla* and *T. similis* is record mostly from freshwater samples. They can not distribute over saline water, so they are called halosensitive. *L. bulla*, *L. hamata* and *Testudinella patina*, finally, the blue group are ranged between the former two groups. Hence, these are a narrow salt tolerance group.

The results demonstrate that anthropogenic salinisation effect strongly on rotifer, which result in different rotifer communities in five peat swamps. Especially for Mai-Khao and Jood areas, these two swamps are completely altered from freshwater to be brackish water habitats. The replacement of the halosensitive biota with a holotolerant one represent overall biological responses to increased salinity (Williams, 2001). Hence, the rotifer communities in these two peat swamps may greatly changed from the past.

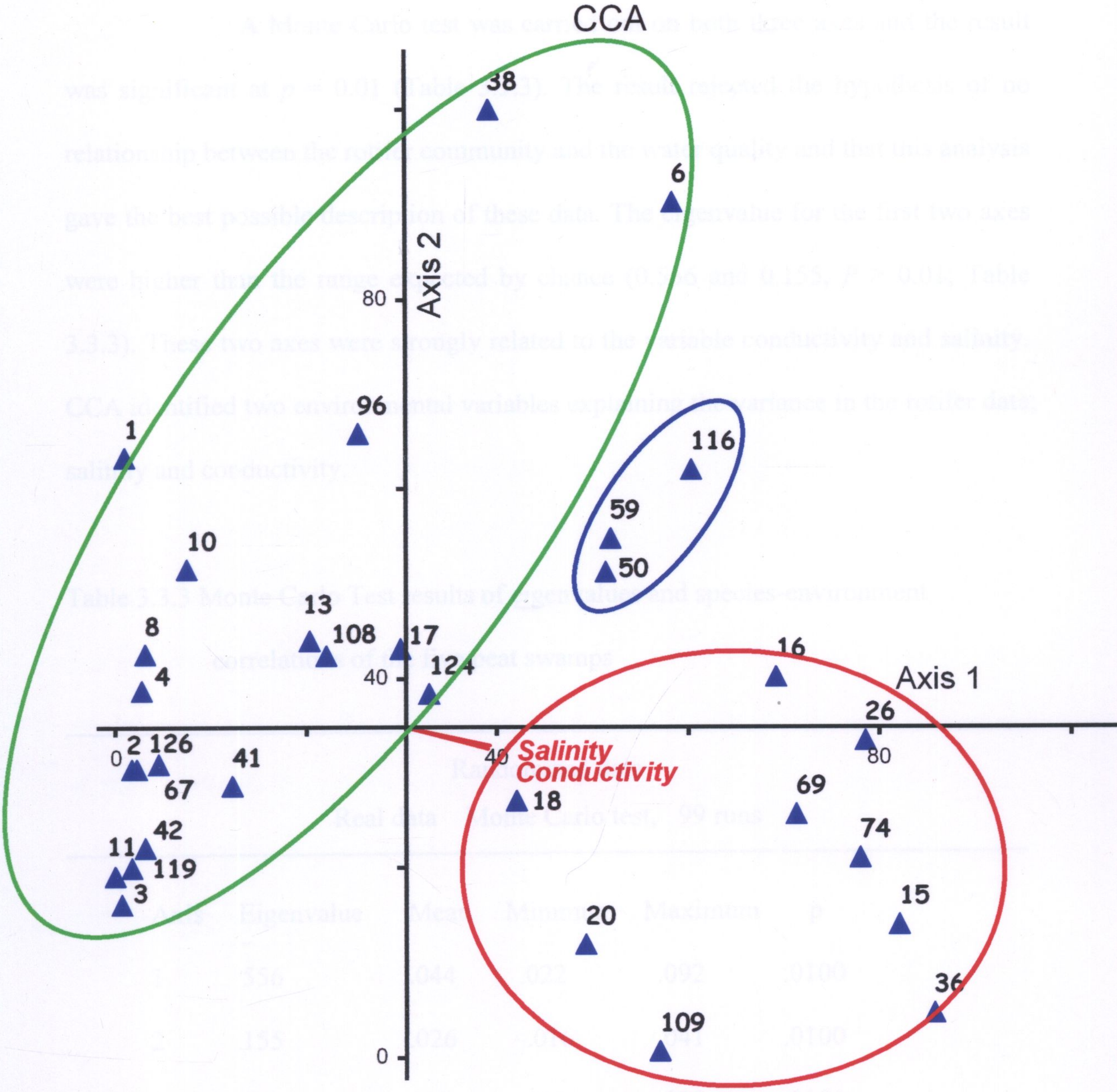


Figure 3.3.4 The CCA ordination of rotifer species and important variables of the five peat swamps, 1 *Anureaopsis coelata*,2 *A. fissa,* 3 *A. navicula,* 4 *Ascomorpha ovalis,* 6 *Brachionus angularis,* 8 *B. dichotomus,* 10 *B. falcatus,* 11 *B. forficula,* 13 *B. quadridentatus,* 15 *B. plicatilis,* 16 *B. urceolaris,* 17 *Cephalodella forficula,* 18 *C. gibba*, 20 *C. tenuier,* 26 *Colurella sanoamuangae,* 36 *Encentrum pornsilpi,* 38 *Filinia longiseta,* 41 *Hexathra mira,* 42 *Keratella cochealis*, 50 *Lecane bulla,* 59 *L. hamata,* 67 *L. lunaris,* 69 *L. obtuse,* 74 *L. rhytida,* 96 *Lepadella patella,* 108 *Polyarthra vulgaris,* 109 *Proales* sp., 116 *Testudinella patina,* 119 *Trichocerca capucina,* 124 *T. pusilla,* 126 *T. similes.*

A Monte Carlo test was carried out on both three axes and the result was significant at p = 0.01 (Table 3.3.3). The result rejected the hypothesis of no relationship between the rotifer community and the water quality and that this analysis gave the best possible description of these data. The eigenvalue for the first two axes were higher than the range expected by chance (0.556 and 0.155, $P > 0.01$; Table 3.3.3). These two axes were strongly related to the variable conductivity and salinity. CCA identified two environmental variables explaining the variance in the rotifer data; salinity and conductivity.

Table 3.3.3 Monte Carlo Test results of eigenvalues and species-environment correlations of the five peat swamps

	Real data	Randomized data Monte Carlo test, 99 runs			
Axis	Eigenvalue	Mean	Minimum	Maximum	p
1	.556	.044	.022	.092	.0100
2	.155	.026	.016	.041	.0100
3	.123	.019	.013	.029	.0100
Axis	Spp-Envt Corr.	Mean	Minimum	Maximum	p
1	.943	.321	.245	.435	.0100
2	.696	.316	.240	.458	.0100
3	.630	.312	.223	.399	.0100

3.3.2.2 Comparison among three freshwater peat swamps

Since anthropogenic salinisation shows strongly impact on rotifer distribution, the other variables from different disturbances are absent. It is not because there is no pressure but because the impacts are weaker comparison to salinity. Therefore, in order to investigate the future ecological variables, the CCA was performed on the rotifer communities from the three freshwater areas, excluding salinisation factors. The abundance of twenty-one rotifer species in 151 sample units and thirteen environmental variables were used in this analysis.

The tolerance level of .100000E-12 was achieved after 24, 13 and 301 iterations for the first three axes, respectively. The total variance in rotifer composition among the three coastal peat swamps ("inertia") that could potentially be explained is 2.121. 16.3% variation of species data is explained in the first axis and 8.2% and 3.9% were further explained in axes 2 and 3, respectively. Pearson Correlation between species and environmental factors showed 0.933, 0.696 and .803 explained by axes 1, 2 and 3, respectively (Table 3.3.4).

Table 3.3.4 Axis summary statistics for CCA analysis of the three peat swamps

Number of canonical axes: 3

Total variance ("inertia") in the species data: 2.121

	Axis 1	Axis 2	Axis 3
Eigenvalue	.347	.173	.082
Variance in species data			
% of variance explained	16.3	8.2	3.9
Cumulative % explained	16.3	24.5	28.4
Pearson Correlation, Spp-Envt*	.933	.722	.803
Kendall (Rank) Corr., Spp-Envt	.415	.490	.489

CCA analysis reveals five factors influencing on rotifer distribution among three freshwater peat swamps. These are Chlorophyll a, nitrate, turbidity, conductivity and percent cover of macrophyte (Figure 3.3.5 and 3.3.6). The strongest factor presenting by the longest vector is percent cover of macrophyte, followed by conductivity, Chlorophyll a, turbidity and nitrate, respectively. The ordination of reference samples and species positioning among principal environmental variables are presented in figure 3.3.5 and 3.3.6. In these graphs, conductivity, turbidity, Chlorophyll a and nitrate have strongly contrary correlation with axis 1 (-.819, -.779, -.607 and -.572, respectively), whereas percent cover of macrophyte is strongly contrary correlation with axis 2 (-.601) (Table 3.3.5).

Table 3.3.5 Inter-set correlation for 11 variables of the CCA analysis in the three peat swamps (Temp = Temperature, Chl a = Chlorophyll a, NO_3^{2-} = Soluble Nitrate, PO_3^- = Soluble Phosphate, DO = Dissolved oxygen, Turb = Turbidity, Cond = Conductivity, Sal = Salinity, % cover = Percent of macrophyte covering and Preci = the monthly average precipitation)

	Correlations		
Variables	Axis 1	Axis 2	Axis 3
1 Temp	.065	.044	.150
2 Chl a	-.607	-.224	-.273
3 NO_3^{2-}	-.572	.112	.337
4 PO_3^-	-.079	-.134	-.050
5 DO	.020	.102	-.062
6 pH	-.066	.005	.032
7 Turb	-.779	-.046	-.383
8 Cond	-.819	.224	.108
9 Sal	-.249	-.064	-.189
10 %cover	-.386	-.601	.150
11 Preci	.079	-.130	.135

Figure 3.3.5 shows the reference samples ranking along with the important variables. The plots of Jik and Jae-Son ranked in tight group, whereas Sra-Boua references placed in disperse along an axis 1. Taking into consideration on axis 1, the result indicates that a Sra-Boua peat swamp has high conductivity, turbidity, nitrate and Chlorophyll a comparison to Jik and Jae-Son. These variables exhibit characteristics of eutrophication, because nitrate is essential inorganic in phytoplankton growth, which can examine by measuring Chlorophyll a. Regarding to axis 2, subsequently, the ordination shows some sample sites in Jik and Sra-Boua peat swamp is covered by macrophyte, which show higher percent cover in Jik than Sra-Boua. Contrary to Jae-Son, most of its area is vacant from macrophyte, as well as, some samples from Jik, which also collecting from empty areas as well. The result denotes well the character of each habitat that Jik is a swamp dominated by littoral zone, where assemblage by emerged plant, even in water bodies is abundant by submerged macrophyte. In contrast to Jae-Son, as a reservoir there is no littoral zone anymore, most of area is limnetic zone. Sra-Boua, in addition, the habitat is varied by activities. Sometimes there was fulfilled with water lilies or macrophyte and some these plants were wiped out.

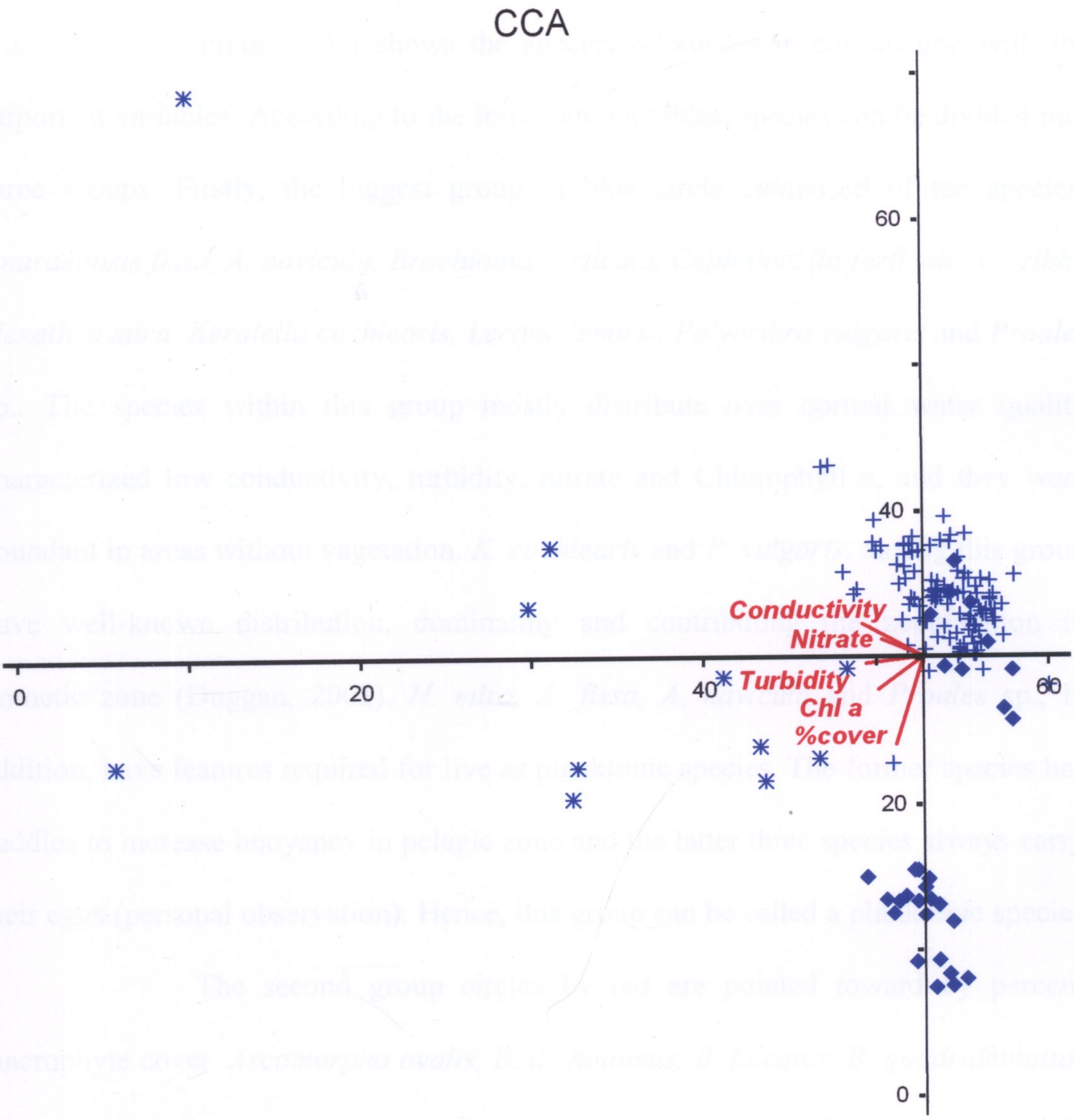


Figure 3.3.5 The CCA ordination of samples and important variables of the three peat swamps (◆ = Jik samples, + = Jae-Son samples and ✳ = Sra-Boua samples).

Figure 3.3.6 shows the species references in conjunction with the important variables. According to the important variables, species can be divided into three groups. Firstly, the biggest group in blue circle composed of ten species; *Anuraeopsis fissa, A. navicula, Brachionus forficula, Cephalodella forficula, C. gibba, Hexathra mira, Keratella cochlearis, Lecane lunaris, Polyarthra vulgaris* and *Proales* sp.. The species within this group mostly distribute over normal water quality characterized low conductivity, turbidity, nitrate and Chlorophyll a, and they were abundant in areas without vagetation. *K. cochlearis* and *P. vulgaris*, among this group, have well-known distribution, dominating and contributing the zooplankton in limnetic zone (Duggan, 2001). *H. mira, A. fissa, A. navicula* and *Proales* sp., in addition, have features required for live as planktonic species. The former species has paddles to increase buoyancy in pelagic zone and the latter three species always carry their eggs (personal observation). Hence, this group can be called a planktonic species.

The second group circles by red are pointed toward by percent macrophyte cover. *Ascomorpha ovalis, B. dichotomus, B. falcatus, B. quadridentatus, Lepadella patella, Trichocerca capucina, T. pusilla* and *T. similis* were recorded in high number from Jik samples, where they were abundant, when live associated with macrophyte. According to morphological feature of these members, most of them have particularly well developed foot regions (especially genus *Brachionus, Lepadella* and *Trichocerca*), which have been suggested as the morphological adaptation required for life in periphytic zone (see Duggan, 2001). Trichocercids, in addition, have been noted that prefer to live in periphytic environments (Pejler and Berzins, 1993). Additionally, *L. patella* and *T. similis* have been documented by Pennak (1966) as specie essentially restricted to vegetation; seldom found in open water (Duggan, 2001). Therefore, the member of this group can be called periphytic rotifers.

Finally, the group representing by the green circle, composes of three species, *A. coelata*, *B. angularis* and *Filinia longiseta.* These species distributed over eutrophication area, high conductivity, turbidity, nitrate and Chlorophyll a. However *A. coelata* and *F. longiseta* trend to live in area cover with macrophyte, whereas *B. angularis* disperse in empty area. This report on *B. angularis* and *F. longiseta* as eutrophic indator species corresponds well with the existing knowledge (Bērziņš and Pejler, 1987; Pontin and Langley, 1993). The result showing *F. longiseta* living associated with macrophyte, however, is contradict with the review of the ecology of periphytic rotifers by Duggan (2001) that it is chiefly limnetic species.

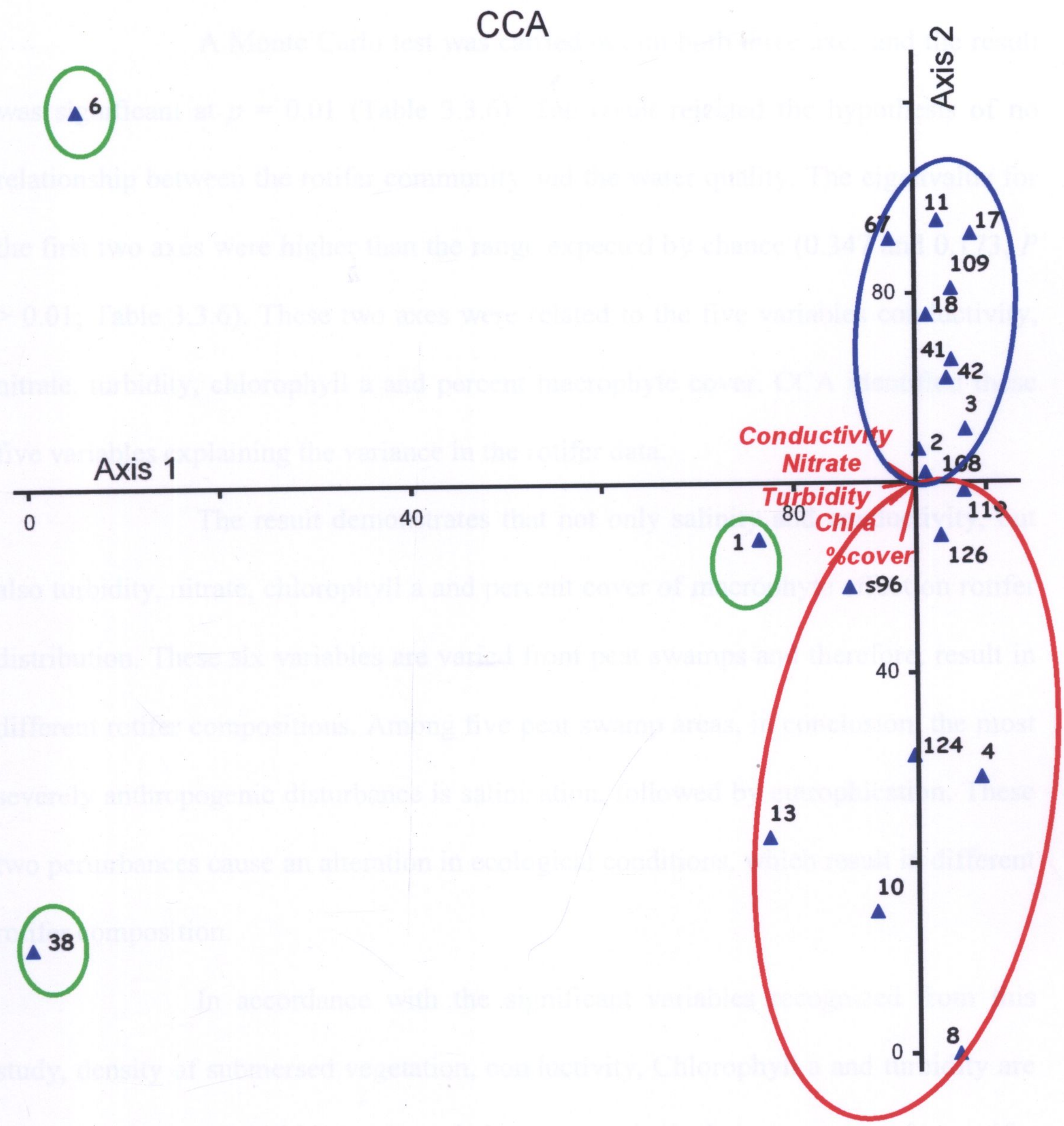


Figure 3.3.6 The CCA ordination of rotifer species and important variables of the three peat swamps, 1 *Anureaopsis coelata,* 2 *A. fissa,* 3 *A. navicula,* 4 *Ascomorpha ovalis,* 6 *Brachionus angularis,* 8 *B. dichotomus,* 10 *B. falcatus*, 11 *B. forficula,* 13 *B. quadridentatus,* 17 *Cephalodella forficula,* 18 *C. gibba,* 38 *Filinia longiseta,* 41 *Hexathra mira,* 42 *Keratella cochealis,* 67 *L. lunaris,* 96 *Lepadella patella,* 108 *Polyarthra vulgaris,* 109 *Proales* sp., 119 *Trichocerca capucina,* 124 *T. pusilla,* 126 *T. similis.*

A Monte Carlo test was carried out on both three axes and the result was significant at p = 0.01 (Table 3.3.6). The result rejected the hypothesis of no relationship between the rotifer community and the water quality. The eigenvalue for the first two axes were higher than the range expected by chance (0.347 and 0.173, $P > 0.01$; Table 3.3.6). These two axes were related to the five variables conductivity, nitrate, turbidity, chlorophyll a and percent macrophyte cover. CCA identified these five variables explaining the variance in the rotifer data.

The result demonstrates that not only salinity and conductivity, but also turbidity, nitrate, chlorophyll a and percent cover of macrophyte effect on rotifer distribution. These six variables are varied from peat swamps and therefore, result in different rotifer compositions. Among five peat swamp areas, in conclusion, the most severely anthropogenic disturbance is salinisation, followed by eutrophication. These two perturbances cause an alteration in ecological conditions, which result in different rotifer composition.

In accordance with the significant variables recognized from this study, density of submersed vegetation, conductivity, Chlorophyll a and turbidity are corresponding well with the knowledge on ecological importances for rotifer distribution in temperate region (Jersabek, 1995; Duggan *et al.*, 2001). Temperature, however, does not show any influence on rotifer in tropical region, although, it has been indicated as the environmental importance for temperate rotifer (Jersabek, 1995; Duggan *et al.*, 2001). This is because temperature shows a narrow fluctuated range in tropical region comparison to temperate zone.

Table 3.3.6 Monte Carlo Test results of eigenvalues and species-environment correlations ot the three peat swamps

	Real data	Randomized data Monte Carlo test, 99 runs			
Axis	Eigenvalue	Mean	Minimum	Maximum	p
1	.347	.052	.024	.148	.0100
2	.173	.028	.016	.064	.0100
3	.082	.019	.012	.034	.0100
Axis	Spp-Envt Corr.	Mean	Minimum	Maximum	p
1	.933	.426	.303	.824	.0100
2	.722	.369	.265	.512	.0100
3	.803	.350	.254	.509	.0100

3.3.3 The effect of salinisation on rotifer composition

Comparison of recently species composition in Mai-Khao and Jood peat swamps to the previously time was investigated using Sϕrensen index. The results reveal 68% and 63% dissimilarly respectively. This demonstrates that the anthropogenic salinisation in Mai-Khao and Jood resulted in greatly changing rotifer composition.

The changes in rotifer communities, as a function of elevated salinity, may have consequences with in peat swamps food web. As species drop out along disturbance gradients, there may be the potential of a reduced number of linkages in food webs which potentially reduce carbon transfer in aquatic ecosystems (Blinn and Bailey, 2001). Therefore, the reduction in rotifer composition in regions of high salinisation may have subtle consequence on food chain.

3.3.4 Classification of Rotifer taxa from five coastal peat swamps

The result is showed in figure 3.3.7.

3.3.4.1 Species indicator

The result reveals six indicator species. At first level (λ = 0.4418 at iteration 4), two freshwater indicator species; *Anuraeopsis fissa* and *Trichocerca similis* and three saline indicator species; *Brachionus plicatilis*, *B. urceolaris* and *Colurella sanoamuangae* are specified. In addition, *Hexathra mira*, a noneutrophication indicator species is indicated at second level (λ = 0.3410 at iteration 4).

3.3.4.2 Species groups

Based on cluster analysis and DCA, the samples were classified into four groups, Jik, Jae-Son, Sra-Boua and Mai-Khao+Jood. This result agrees with the classifatior of samples by TWINSPAN outcome (Figure 3.3.7). The samples in figure 3.3.7 were divided into four groups. The first group composes of seven samples only from Sra-Boua area. The second contains all Jik samples and one from Jea-Son. The third group is Jae-Son samples. Finally, the biggest group is dominated by Mai-Khao and Jood samples. Then, considering on species distribution among samples was examination.

TWINSPAN illustrates 100 rotifer taxa that can be categorized into five groups as following.

3.3.4.2.1 Taxon group a

The biggest group composes of fifty-five species, which mostly record only from freshwater samples and seldom from saline water. These are called freshwater species. This group, however, can be further separate into three smaller groups according to their appearent area. Firstly, the green box contains twelve common freshwater species, abundance in all freshwater habitats, but rare in saline water. Of these, two species, *A. fissa* and *T. similis* are identified as freshwater indicator species. The species in this group, consequently, can be called halo-sensitive species. The species in pink box, secondly, are mostly abundant only in Jik, a pristine peat swamp, whereas a few are recorded in Jae-Son and never been recorded from Sra-Boua. This set consists of twelve species. Of these, four are *Trichocercid,* two are *Lepadella,* two are *Brachonids* and one *Scaridium*. These species represent common characters of species associated with macrophyte. Hence, the pink group is considered as periphytic Rotifera, presenting in vegetative Jik swamp. Since Jik swamp show high number of periphytic rotifers, it imply that this pristine area contains highly diverse aquatic organism. The reason is because macrophytes provide food, shelter and mating site etc. for periphyton, complex communities. Finally, the biggest light blue group, the rotifer taxa in this group has restricted distribution over Jae-Son reservoir, while a few were record from Jik and Sra-Boua. Thus, they are the freshwater species, which desire neutral condition than harsh. In addition, most of the member is *Lecane* species, which mainly contribute a diverse of rotifer fauna of all habitats, as well as in peat swamps (see Chittapun *et al.*, 1999; Chittapun *et al.*, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002; Chittapun *et al.* (2003); Chittapun *et al.*, manuscript 1.). This is common species group.

3.3.4.2.2 Taxon group b

The member of this group is common species, which is distributed over all habitats. Of these, *P. vulgaris* and *T. pusilla* show highly annually abundance. In addition, this group is including *H. mira*, which has been indicated as noneutrophication indicator.

3.3.4.2.3 Taxon group c

This group holds on twenty-seven species. Most of this member is abundant over samples from Mai-Khao and Jood, where have strongly influences from anthropogenic salinisation. In addition, they are frequently found from saline areas, whereas a few recorded from freshwater bodies. However, this group can be further classified into two groups. The former is pink box including twelve species. Of these, three are recognized as saline indicator species. They are regularly presented over saline water bodies; a few were record from freshwater. Consequently, they are called as halospecies. The latter green group has more widely distribution than the former. Some taxa can be recorded from freshwater bodies, but in rarely and small number. They are the wide range distribution species. In addition, *B. angularis* and *T. tenuier* had been observed only over disturbance habitats, Sra-Boua, Mai-Khao and Jood peat swamps. Therefore, they can be indicator for disturbance, because they diverse in only disturbance habitat, but the result from TWINSPAN is not pointed out. However, *B. angularis* is a well documented eutrophic species.

Figure 3.3.7 TWINSPAN analysis on rotifer communities from five peat swamps.

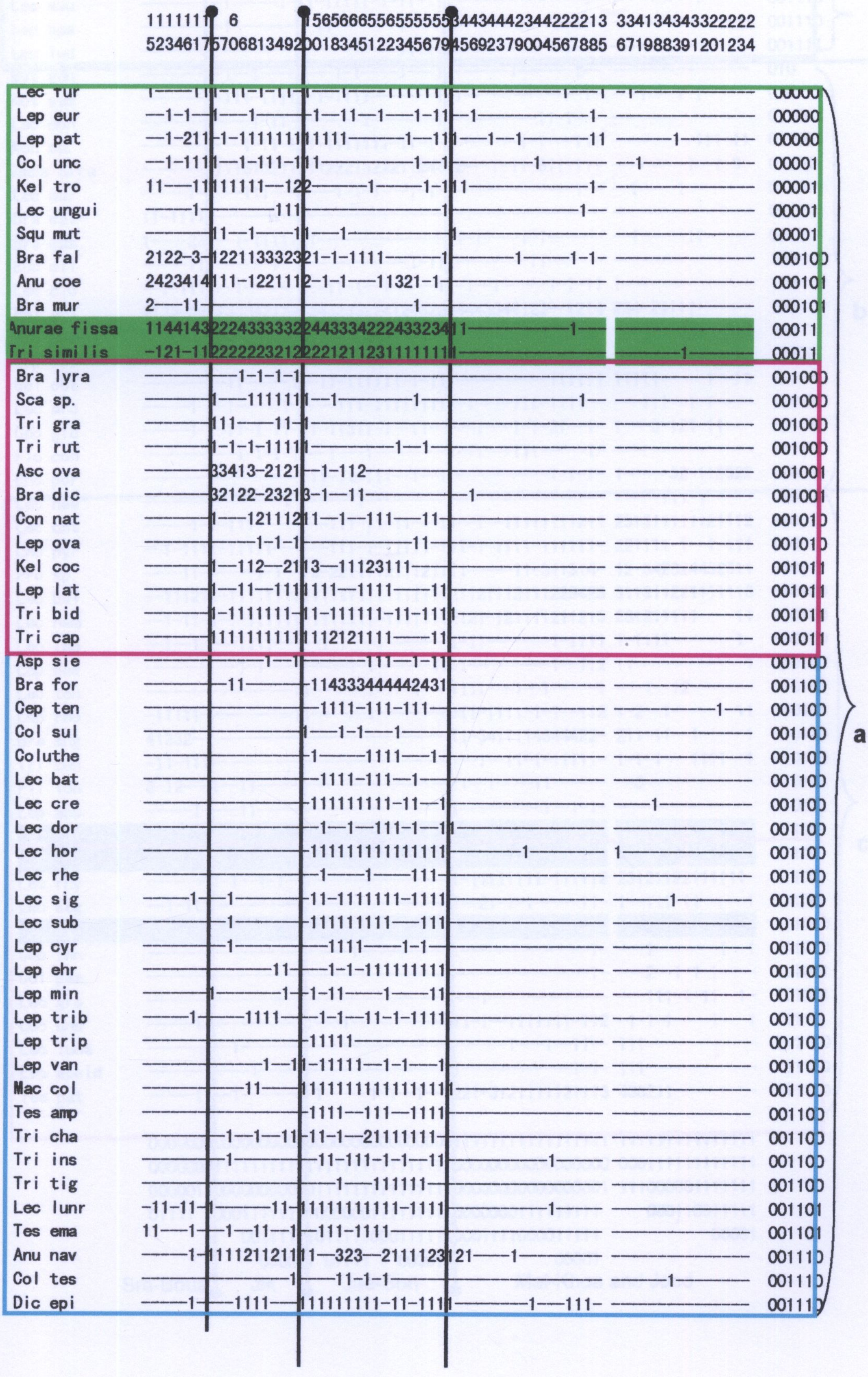
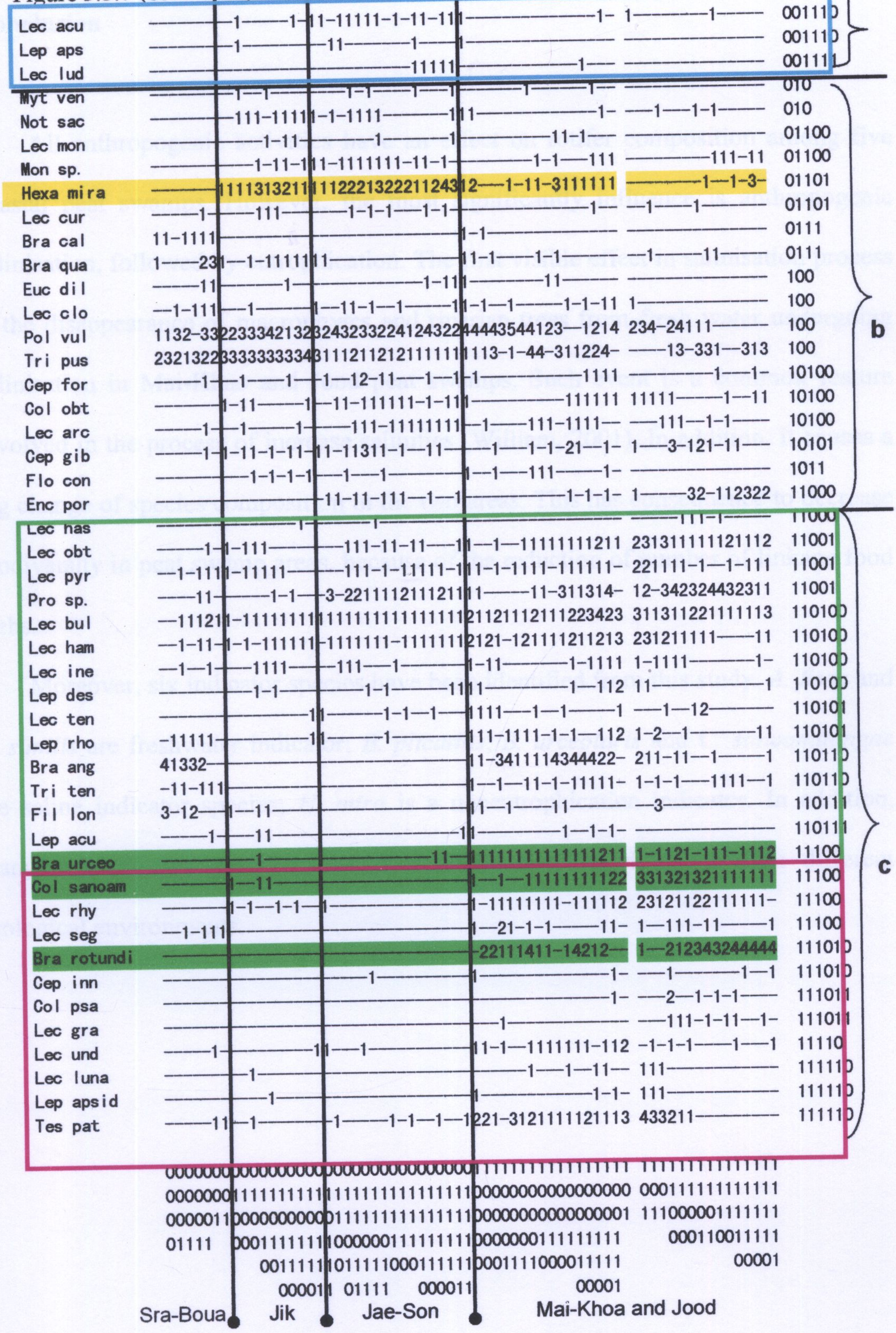


Figure 3.3.7 (continued)



Conclusion

All anthropogenic activities have an effect on rotifer composition among five coastal peat swamps. However, the most significantly influence is anthropogenic salinisation, followed by eutrophication. The first visible effect in salinisation process is the disappearance of macrophytes and riparian trees from fresh water undergoing salinisation in Mai-Khao and Jood peat swamps. Such event is a common feature involved in the process of increase salinities (William, 2001). In addition, it causes a big change of species composition in the two areas. This has consequence to decrease biodiversity in peat swamp areas, because of the reduction of number of linkage food webs.

Moreover, six indicator species have been identified from this study. *A. fissa* and *T. similis* are freshwater indicator; *B. plicatilis*, *B. urceolaris* and *C. sanoamuangae* are saline indicator species; *H. mira* is a noneutrophication indicator. In addition, many species have specific ecological distribution, which result from different ecological environments.

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Part 3.4 Restoration of Tropical Peat Swamp Rotifer Communities After Perturbation: An Experimental Study of Recovery of Rotifers from the Resting Egg Bank

Introduction

Presently, the most severe threat to the world's wetlands is posed by land uses that destroy or severely damage habitats (Finlayson and Moser, 1991). Human-induced pressures affect ecosystem functioning as well as biodiversity at all levels, from ecosystems to organisms. Whereas populations of some organisms are irreversibly affected, others may be able to recover from the effects of disturbances. This resilience results at least partly from their potential to survive periods of adverse conditions through resistant, dormant stages.

Monogonont Rotifera, being of prime ecological importance in freshwater ecosystems, has resting eggs or cysts as dormant stages (Gilbert, 1974). These are diapausing embryos produced by fertilized mictic females. Sexual reproduction is induced by a variety of cues including the occurrence of environmental changes associated with habitat deterioration. Hatching of these resting eggs generally occurs in coincidence of favorable conditions in the habitat, and results in the re-establishment of populations (Pourriot and Snell, 1983; Ricci, 2001). Resting eggs thus represent a biodiversity bank, as they can assure genetic continuity through periods of hazardous environmental conditions and offer a recolonization resource when favorable conditions return (Pourriot and Snell, 1983; Ricci, 2001).

So far, the majority of studies on rotifer resting eggs consist of investigations on resting egg production and hatching, often in relation to the use of rotifers as food source in aquaculture (Lubzens *et al.*, 1980; Pourriot *et al.*, 1980; Minkoff *et al.*, 1983; Serrano *et al.*, 1989; Lubzens *et al.*, 1993). There are few studies on resting eggs in natural rotifer populations. Ito (1958) and Nipkow (1961) were amongst the first to study incubation of rotifer resting eggs from sediments (May, 1987). Pourriot et al. (1984) and Gilbert and Wurdak (1978) compared the morphology of resting eggs of different taxa. May (1987) performed a quantitative study of rotifers hatching from sediments from Loch Leven, Scotland, and recorded species-specific effects of temperature on the emergence of rotifers, and showed that all pelagic rotifer species found in the lake could be hatched from the sediment egg bank. Langley *et al.* (2001) investigated the relative importance of recruitment from the resting egg bank versus passive dispersal in the recolonization of temporary ponds, and found that the former is by far the most important source. These studies clearly show the potential importance of resting egg banks in the restoration of rotifer communities after disturbance. However, there are several hiatuses remaining (see Ricci, 2001). For instance, no information is available on rotifer resting egg banks in tropical habitats, and little is known on any but pelagic rotifer taxa.

As for the diversity of tropical habitats, one of the most intriguing habitats is that of peat swamp forest. Previous studies on the diversity of Monogonont Rotifera in peat swamps suggest that this ecosystem has a diverse rotifer fauna, as a result of its long history and unique ecological characteristics (Chittapun *et al.*, 1999; Chittapun and Pholpunthin, 2001; Segers and Chittapun, 2001; Chittapun *et al.*, 2002; Chittapun *et al.*, 2003). Unfortunately, these habitats are seriously threatened by human activities such as agriculture (e.g., transformation to arable land, eutrophication) and aquaculture (e.g., salinization resulting from discharge of saltwater from shrimp farms). These activities constitute serious threats to the general biodiversity, and diversity of Rotifera Monogononta in particular, of these ecosystems in Thailand. In order to assess if, and to what extent rotifer communities can recover after restoration of these peat swamps, this work aimed to study the recruitment of rotifers from the sediment resting egg bank stored under different condition and duration of exposition.

Materials and Methods

Study area

Mai-Khao is one of the six remaining peat swamps located along Mai-Khao coast on Phuket Island, Southern Thailand (Figure 3.4.1). Historically, the different peat swamps in the area were connected, but they are now isolated and diversified ecologically due to different human activities in each fragment. Mai-Khao peat swamp has recently become brackish as it received discharged saltwater from nearby aquaculture farming. As a result, the once thriving macrophyte vegetation has disappeared, and the accumulated layer of peat is decomposing. Because of the decline of macrophytes, the sediment in its shallow areas is now exposed to direct sunlight during the dry season

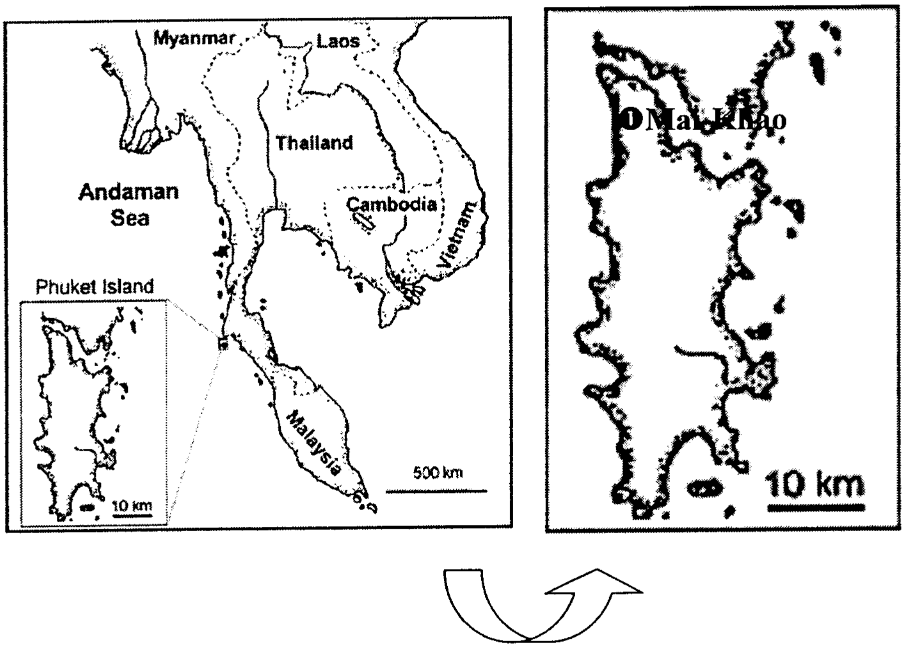

Figure 3.4.1 Map of Thailand showing the location of Mai-Khao peat swamps on Phuket Island, southern Thailand.

Sediment collection, treatment and incubation

Sediment including resting eggs was collected randomly from a dry area of Mai Khao peat swamp on 27 February 2000, yielding a total of approximately 5 kg of material. To avoid excessive differences among resting egg ages, only the top 1 cm of sediment was scraped off from the soil. The sediment was allowed to dry further under a paper cover for a month. Then, it was homogenized by removing large pieces of plant material, grinding and passing it through a 0.5 cm mesh sieve. The sediment was then divided in three equal parts, which were subjected to different treatments:

- Cold-Dark (CD): Sediment stored in an opaque box, and kept in a refrigerator (2-4°C). This condition was assumed to reflect the optimal condition to retain viability in the resting eggs.
- Ambient-Dark (AD): Sediment stored in an opaque box, under ambient temperature. Condition reflects that of resting eggs deep in the sediment.
- Ambient-Light (AL): Sediment stored in a translucent box, under ambient temperature. Condition reflects that of completely exposed resting eggs.

The sediment boxes in the "ambient" treatments were placed together in a water bath, in order to keep the temperature in the boxes similar, and placed under a clear roof in the culture laboratory (Figure 3.4.2a). Temperature varied in this treatment, ranging from 27 to 42 °C, but remained similar in both boxes. The duration of the treatments varied from 0 months (initial experiment), to 1, 2, 4, 6, 12, 18 and 24 months (Figure 3.4.3).

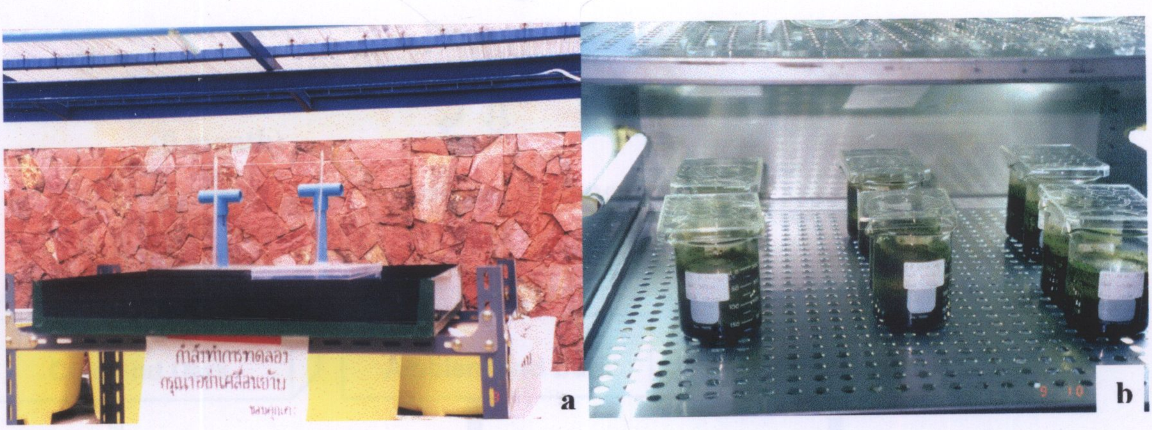

Figure 3.4.2 (a) The sediment stored in AD and AL condition and placed under clear roof in culture laboratory building; (b) The sediment placed in Jermaks incubation.

Hatching of rotifer resting eggs was tested by placing exactly 20g of sediment into 250 ml beakers, and adding 150 ml of distilled water. Each test was replicated four times. The beakers were placed in an incubator (Jermaks) at 28°C, with a 12h light – 12h dark light regime (Figure 3.4.2b). Every 4 days during 3 months, the water in these beakers was poured out in a different vial, and topped back to the same level in the original beaker. To collect and count the rotifers hatched during each 4-days interval, formalin was added to the collected water to a final concentration of about 5%. Rotifers were then sorted and counted under an Olympus VM dissecting microscope, and identified using an Olympus CH-2 compound microscope. As few individuals, and no additional species were found to hatch after 3 months in an initial test experiment, the observations were stopped after this period.

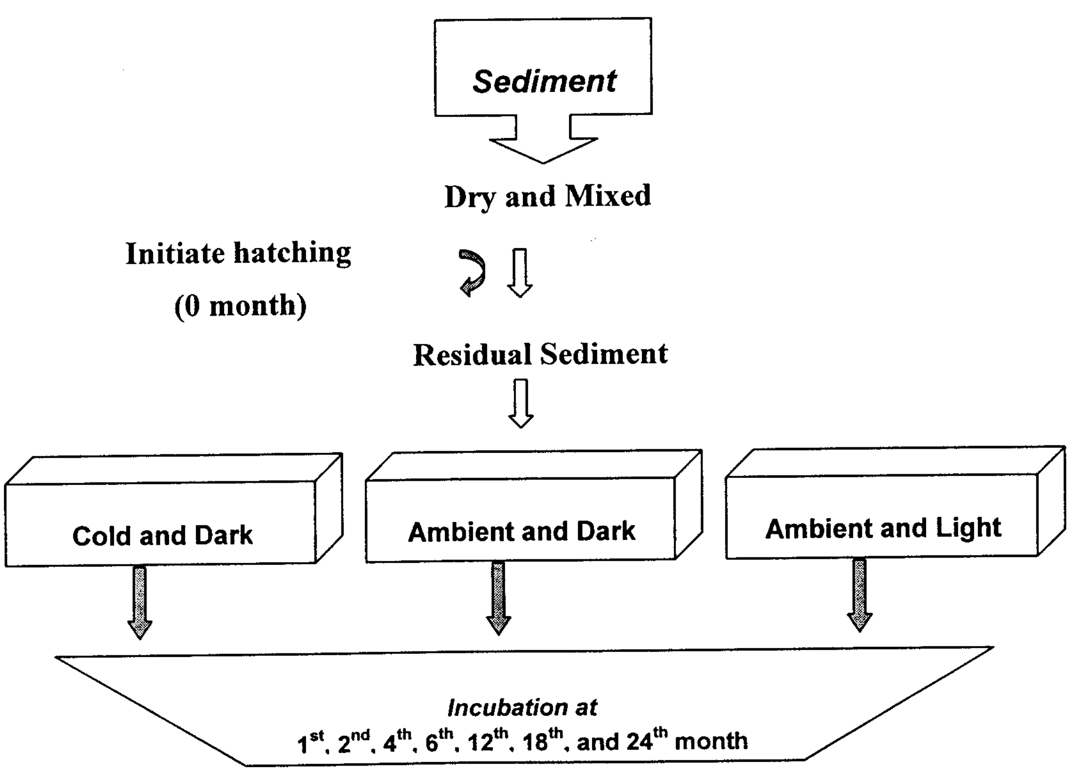

Figure 3.4.3 Process of study recreates capability of rotifer population.

Data Analysis

Data on emerging of rotifers after different exposure condition and durations was analyzed by applying Repeated Measures Analysis (SPSS statistical package for Window, Release 11.0.1). The analysis was performed on two different aspects of data: number of species emerging, and number of individual specimens hatching. To examine the combined effect of exposure condition and duration on the diversity of the rotifers hatching, each group of data was separated into two time periods. First, the data for a short-term effect was tested by analyzing results from two months intervals over a period of six months (0, 2, 4 and 6 months); second, long-term effects was also tested by analyzing results from six months intervals over a total period of 24 months (0, 6, 12, 18 and 24 months).

Results

3.4.1 Effects of treatment and exposure time

The effect of treatment and exposure time on rotifer hatching was analyzed by considering two aspects of diversity, viz. number of species and number of individuals.

3.4.1.1 Number of species

The number of species hatching from the sediment was affected significantly by exposure condition, both in the short- and the long term ($F = 4.97$ and 10.37, $p < 0.05$, df = 2). Significant effects of short- and long-term exposure within treatments were also present (F = 20.94 and 66.25, $p < 0.01$, df = 3 and 4, respectively). Both factors interacted significantly (short-term: $F = 4.60$, $p < 0.01$, df = 6; long-term: $F = 2.68$, $p < 0.01$, df = 8) (Table 3.4.1).

Table 3.4.1 Repeated measurement analysis of the short- and long-term effect of exposure conditions and duration on the number of species hatching

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Short term effect					
Duration	26.896	3	8.965	20.935	0.000
Exposure condition	2.260	2	1.130	4.969	0.035
Duration*Exposure condition	11.792	6	1.965	4.598	0.002
Long term effect					
Duration	206.100	4	71.304	66.246	0.000
Exposure condition	3.227	2	1.613	10.371	0.005
Duration*Exposure condition	16.700	8	1.965	2.684	0.020

Table 3.4.2 Rotifer species hatching from the sediment exposure in different conditions (# commonest species)

Species	**start**	**CD**	**AD**	**AL**
Brachionus plicatilis		+		
#B. urceolaris	+	+	+	+
Cephalodella gibba	+	+		
C. innersi		+		
Encentrum pornsilpi		+	+	
Floscularia conifera	+	+	+	
Hexathra mira				+
Lecane bifurca		+	+	+
#L. bulla	+	+	+	+
L. inermis		+	+	+
L. ludwigii		+	+	
#L. obtusa	+	+	+	+
L. tenuiseta	+	+	+	+
L. unguitata	+			
Lindia torulosa		+		
Trichocerca pusilla		+		
T. tenuior		+		
	7	**15**	9	7

The results demonstrate that rotifer species diversity was affected by exposure condition. The highest number of species hatched from sediment kept under cold and dark condition, fewer hatched from sediments kept in ambient temperature and in the dark, and the lowest number was recorded from sediment kept in ambient and light condition (Table 3.4.2). This effect is significant even after short-term storage, but is especially obvious when comparing long-term effects (Figure 3.4.4). After 24 months of storage, hatching of rotifers could only be observed from sediments stored under cold and dark condition.

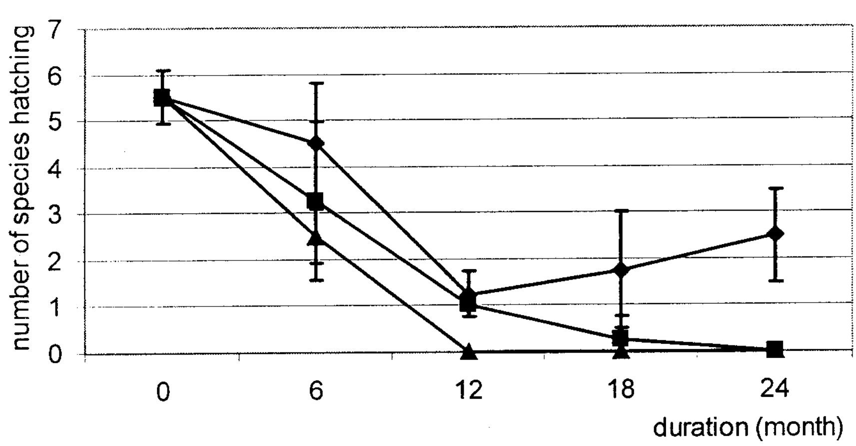

Figure 3.4.4 The number of species hatching from different exposure condition and duration (◆=Cool and Dark, ■=Ambient and Dark and ▲=Ambient and Light).

3.4.1.2 The number of individuals hatching

The number of rotifers hatching initially from the sediment amounts to 470-956 per gram. No short-term effects of differences in treatment condition on the numbers of rotifers hatching were found (F = 0.68, p >0.05, df = 2), although an increase in duration did have an effect (F = 6.55, p < 0.01, df = 3). Significant effects of treatment occurred after 6 months (F = 14.83, p < 0.01, df = 2), in addition to prolonged effects of duration (F = 42.00, p < 0.01, df = 4). Again, both factors interacted significantly (short-term: F = 0.54, p < 0.01, df = 6; long-term: F = 9.05, p < 0.01, df = 8) (Table 3.4.3).

Table 3.4.3 Repeated measurement analysis of the short- and long-term effect of exposure conditions and duration on the number of rotifer hatching

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Short term effect					
Duration	48.474	3	16.158	6.546	0.002
Exposure condition	0.267	2	0.134	0.681	0.530
Duration*Exposure condition	7.971	6	1.329	0.538	0.774
Long term effect					
Duration	515.447	4	128.862	42.004	0.000
Exposure condition	25.949	2	12.974	14.826	0.001
Duration*Exposure condition	148.523	8	18.565	9.052	0.000

The results point out that time also has a significant effect on rotifer diversity in term of number of specimens hatching. An additional effect of exposure condition only becomes significant after 6 months. As before, cold and dark condition appears to affect hatching the least (Figure 3.4.5).

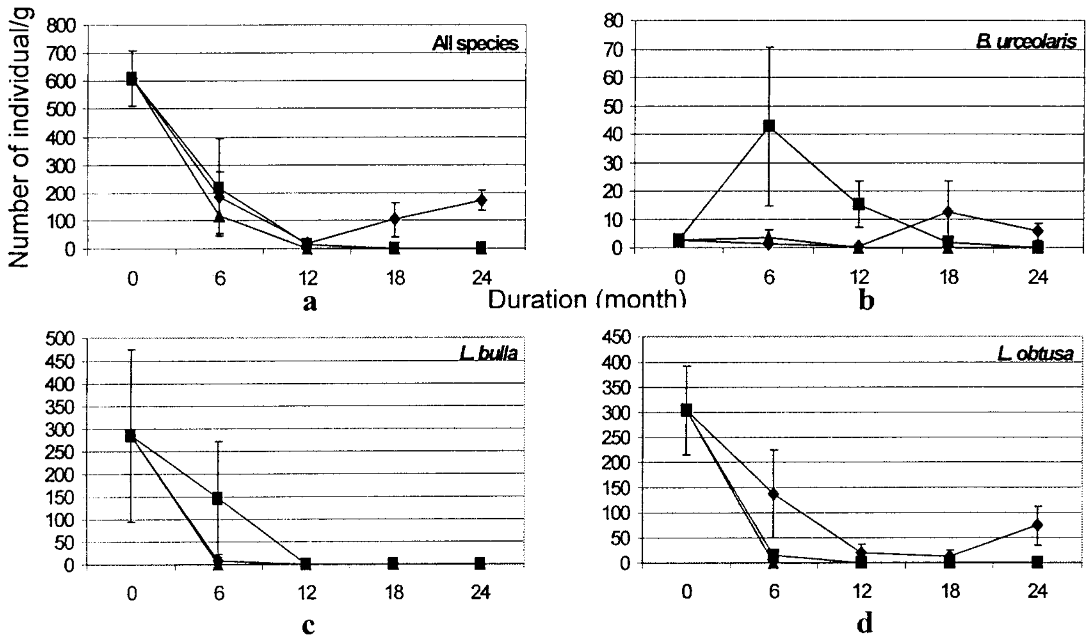

Figure 3.4.5 The number of specimens hatching of all species (a) and three commonest species from different exposure condition and duration (b,c,d): a = all species, b = *B. urceolaris*, c = *L. bulla*, d = *L. obtusa* (◆=Cool and Dark, ■=Ambient and Dark and ▲=Ambient and Light).

Discussion

Species composition

Throughout the two years of the experiment, seventeen rotifer species emerged from the sediment (Table 3.4.2). This equals to only 23.5% of the total rotifer record from the swamp. One species, *Lindia torulosa*, emerged from the sediment but was never found in regular plankton samples collected in the swamp. This discrepancy is not unexpected. Evidently, it reflects the difference in sampling intensity between the zooplankton survey (ca. 10 vertical hauls in different parts of the swamp monthly, over a period of 16 months) and the collection of sediment for the experiment (point sample). Moreover, it is unlikely that the single sediment sample adequately reflects the habitat heterogeneity of a shallow peat swamp in the composition of its resting egg bank. It should also be noted that the majority of species recorded in the zooplankton samples are littoral or benthic animals, and it is known that at least some of these attach their resting eggs to a substratum, or are otherwise selective in this respect. Hence, some rotifers inhabiting Mai Khao peat swamp may not have been present as resting eggs in the sediment collected for the experiment. Additionally, as this work collected exposed sediment, it cannot be excluded that particularly vulnerable taxa may already have been eliminated from the active resting egg bank. Finally, the incubation procedure applied in the experiment may not have generated the necessary cue for hatching of some taxa.

A striking observation is that the first species to emerge from the sediment invariably turned out to be *B. urceolaris* (Figure 3.4.6). More than fifty percent of *B. urceolaris* individuals hatched within two weeks of incubation. Both observations support the hypothesis that *B. urceolaris* is a pioneer species, and suggest that the species responds relatively quickly to environmental cues.

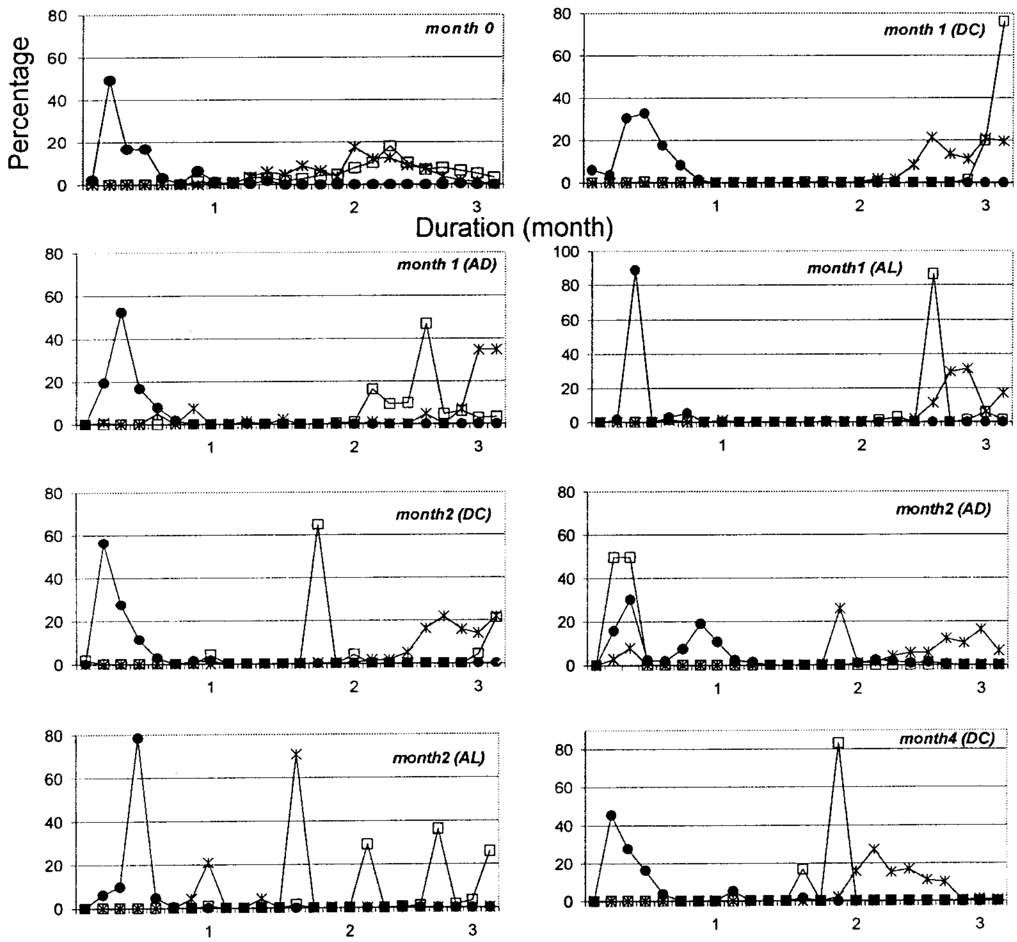

Figure 3.4.6 Percent hatching of three commonest species for three months (● = *Brachionus urceolaris*, □ = *Lecane bulla*, ✳ = *L. obtusa*).

Species specific

Temperature and light influenced on viability of resting eggs of have been proposed by many rotiferogist (Minkoff *et al.*, 1983; Pourriot *et al.*, 1980; Pourriot and Snell, 1983; Hagiwara and Hino, 1989) and thess can be also observed in *Lecane obtusa* and *L. bulla* from this study. Accoding to the experiment, after long period *L. obtusa* still emerge only from the sediment, which was exposed under CD condition while *L. bulla* hatches only from the AD condition sediment (Figure 3.4.7). The results suggest that low temperature can extend *L. obtusa* viability, whereas ambient temperature expands for *L. bulla*.

A study of biogeography of *Lecane* show unclear result of *L. bulla* distribution, ranking from cold– to warm-water preference (Segers, 1996). From this study, the result proves that *L. bulla* is a warm-water species, because its resting eggs can not survive under low temperature. Therefore, this result demonstrates that *L. bulla* is cosmopolitan taxa, which is common in tropical regions but can be found from habitats with relatively higher temperature in temperate region

Effects of treatment and exposure time

Exposure time plays an important role in the recovery of rotifer diversity from the sediment egg bank. The longer the sediment egg bank is stored, the lower the number of species and individuals of rotifer that emerge. Our observations clearly demonstrate that resting eggs have a limited, and probably species-specific viability. The results were obtained for various rotifer species are in contrast with the report on *Brachionus plicatilis*-group, in which 100% of resting eggs desiccated for up to 6 months can be made to hatch (Lubzens *et al.*, 1980). This variability in resting egg duration is further illustrated by Kotani *et al.* (2001), who report hatching of resting eggs of *B. plicatilis* of over 60 years old. In addition, this work here present the first quantitative data indicating that the time lapse between dehydration and effective hatching also varies between species.

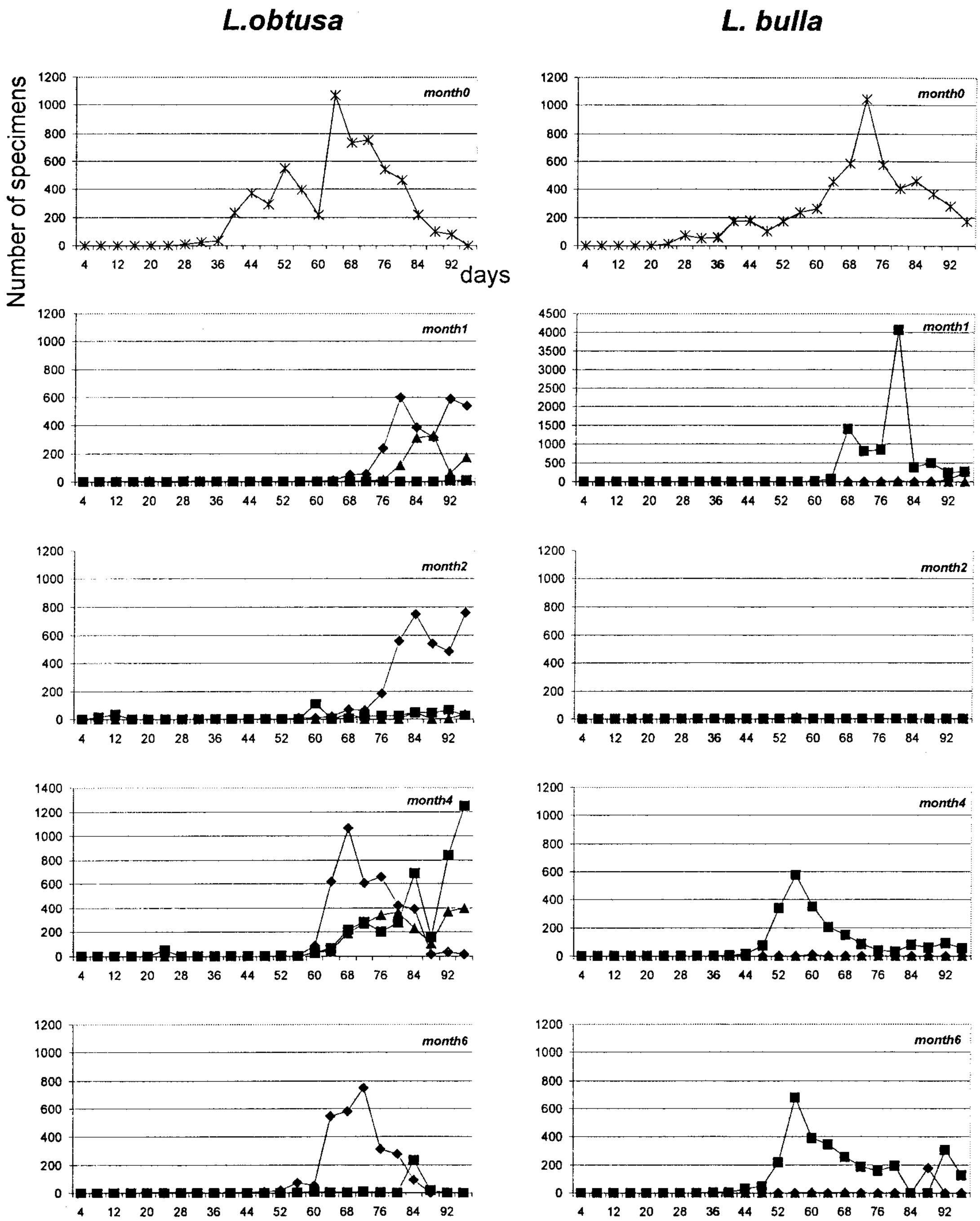

Figure 3.4.7 Number of *Lecane obtusa* (left) and *L. bulla* (right) hatching from sediment, which expose under in different conditions and duration (✻ = 0 month, ◆ = CD, ■ = AD and ▲= AL).

Exposure conditions have obvious effects after 6 months of storage. There is a significant difference in the number of species and individuals hatching after exposure to cold and dark condition, in comparison to resting eggs exposed to ambient temperatures and light condition. That cool and dark condition extends diapause, and increase the viability of stored rotifer resting eggs has been reported by many researchers (Minkoff *et al.*, 1983; Pourriot *et al.*, 1980; Pourriot and Snell, 1983; Hagiwara and Hino, 1989). The lower temperature and absence of light may prevent degradation of compounds, and/or inhibit bacterial development damaging the resting eggs.

Conclusion

Our results demonstrate a strong effect of duration on diversity both in term of species richness as in number of specimens hatching. Exposure conditions start having significant effects after periods as short as 6 months. This contrast with general views that rotifer resting eggs are effective for long-term survival of rotifers (e.g., see Nogrady et al., 1993). It should be borne in mind that most studies on rotifer diapause are conducted on material stored under optimal conditions (cold and dark), which may not realistically reflect natural conditions, especially when dealing with tropical organisms. This may result in over-estimating the significance of resting egg banks as source for re-establishing populations in nature. The results presented here show that rotifer resting eggs have only a limited viability, and may not be effective in serving as source for recovery of rotifer diversity, even for short-term disturbances.

So, recovery of rotifer communities from sediment egg banks in disturbed peat swamps can only be effectively attained when restoration occurs within a relatively short period after perturbation.

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4. CONCLUSION

The rotifer fauna from five coastal peat swamps, Jik, Jae-Son, Jood, Mai-Khao and Sra-Boua, on Phuket Island were examined. A total of 133 rotifer species was identified. Of these, *Dicranophoroides* sp. was a new record to the Oriental region and *Harringia rousseleti* was new to Thailand. Twenty five, *Anuraeopsis fissa*, *A. navicula*, *Brachionus quadridentatus*, *Cephalodella forficula*, *C. gibba*, *Colurella uncinata*, *Dicranophorus epicharis*, *Keratella tropica*, *Lecane arcula*, *L. bulla*, *L. closterocerca*, *L. curvicornis*, *L. furcata*, *L. hamata*, *L. inermis*, *L. obtusa*, *L. pyriformis*, *L. undulata*, *Lepadella acuminata*, *L. eurysterna*, *L. patella*, *L. rhomboides*, *Polyarthra vulgaris*, *Proales sp.* and *Trichocerca pusilla*, were common species, distributed over the five coastal swamps. The most diverse genus belong to *Lecane* (30.82%), followed by *Lepadella* (12.03%). The highest species richness area was Jae-Son containing 100 species, followed by Jik (84 species), Jood (67 species), Mai-Khao (65 species) and Sra-Boua (48 species), respectively. These results, presently, contributed to the number of peat swamp rotifer in Thailand up to 193 species. Of the 193 species, 14 species had been report as first record to Oriental region and 28 species had been first record to Thailand. In addition, six species were described as new to science. Of these, four (*Colurella sanoamuangae* Chittapun, Pholpunthin and Segers, *C. psammophila* Segers and Chittapun, *Encentrum pornsilpi* Segers and Chittapun and *Lepadella desmeti* Segers and Chittapun from Mai-khao peat swamp) of them were recorded from Phuket province.

To assess rotifer biodiversity in the five coastal peat swamps through extrapolation, the research found that Chao2 was the least bias estimator for rotifer community in peat swamps. Comparison of total species richness among sites, the most diverse area in term of species richness was Jae-Son, followed by Jik, Mai-Khao, Jood and Sra-Boua, respectively. In term of species diversity index, Simpson' diversity index was applied to interpret the result in this study. The most diverse peat swamps was Jik, followed by Jae-Son, Jood, Sra-Boua, and Mai-Khao respectively. Equally abundant species can be achieved in Jik, Jood, Sra-Boua and Mai-Khao, while, Mai-Khao contained a few dominant species. However, species diversity measures have been suggested to be poor indicator of pollution and environmental changes (Hawthorne and and Dauer, 1983 quoted Angsupanich and Kuwabara, 1999). Moreover, the disturbed areas showed discrete species assemblages from the pristine one. This indicates that the three anthropogenic activities result in change of rotifer composition and different human impact affect species composition in different ways. The most severe treat on the rotifer composition in peat swamp areas is discharged saline water from aquatic farms.

Quantitative rotifer data from fives peat swamps was performed on multivariate analysis. Based on rotifer communities, the five areas can be classified into four distinct groups at 80% similarity level; Mai-Khao+Jood (salanisation), Jik (pristine area), Jae-Son (transform to reservoir) and Sra-Boua (eutrophication). Mai-Khao and Jood contain the highest similar in rotifer communities, 99.93% similarity level, and this group was obviously separated and greatly different from the other three areas. According to the other three, Jik showed 78.40% similarity to Jae-Son and they had 46.20% similarity to Sra-Boua. The most significant variables result in different rotifer assemblage in peat swamps were salinity and conductivity. Considering only on freshwater habitats, the most important factors were percent cover of macrophyte, followed by conductivity, Chlorophyll a, turbidity and nitrate, respectively.

Moreover, the result revealed six indicator species. At first level (λ = 0.4418 at iteration 4), two freshwater indicator species; *Anuraeopsis fissa* and *Trichocerca similis* and three saline indicator species; *Brachionus plicatilis*, *B. urceolaris* and *Colurella sanoamuangae* are specified. In addition, *Hexathra mira*, a noneutrophication indicator species was indicated at second level (λ = 0.3410 at iteration 4).

All studied types of anthropogenic activities have an effect on rotifer composition among five coastal peat swamps. The most significantly influence is anthropogenic salinisation, followed by eutrophication. The first visible effect in salinisation process is the disappearance of macrophytes and riparian trees from fresh water undergoing salinisation in Mai-Khao and Jood peat swamps. Such event is a common feature involved in the process of increase salinities (William, 2001). In addition, it causes a big change of species composition in the two areas. This has consequence to decrease biodiversity in peat swamp areas, because of the reduction of number of linkage food webs.

Since rotifer can survive under hard condition by producing resting eggs, they can recover after favorable condtions return. However, our results demonstrate a strong effect of duration on diversity both in term of species richness and in number of specimens hatching. Exposure conditions start having significant effects after periods as short as 6 months. This contrast with general views that rotifer resting eggs are effective for long-term survival of rotifers (e.g., see Nogrady et al., 1993). This may result in over-estimating the significance of resting egg banks as source for re-establishing populations in nature. The results presented here show that rotifer resting eggs have a limited viability, and may not be effective in serving as source for recovery of rotifer diversity, even for short-term disturbances.

From the findings, the research hypothesis can not be rejected. Therefore, anthropogenic activities around the peat swamps have exerted their influence on the decrease of rotifer diversity and the recovery of rotifer communities from sediment egg banks in the disturbed peat swamps can only be effectively attained when restoration is implemented within a relatively short period after perturbation.

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Estimates Program for randomization:

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Rotifera from Peat-Swamps in Phuket Province, Thailand, with the Description of a New *Colurella* BORY DE ST. VINCENT

key words: rotifera, Thailand, zoogeography, taxonomy, *Colurella*, new species.

Abstract

The rotifer fauna of three peat-swamps in Phuket province, southern Thailand was investigated. A total of 77 species is identified, 12 of which are new to Thailand. A new species, *Colurella sanoamuangae* n. sp., is described. The zoogeography of the registered species is discussed.

1. Introduction

Although the Thai rotifer fauna has been extensively investigated recently (SANOAMUANG, 1996; SANOAMUANG *et al.*, 1995; SEGERS and PHOLPUNTHIN, 1997; SEGERS and SANOAMUANG, 1994), many habitat types have not been considered yet. One of such types is peat-swamp forest, which is an important wetland habitat in Thailand. Water in these peat-swamps is characterized by its brownish color and high acidity, and these habitats are inhabited by a fairly diverse rotifer fauna. In order to document this community, and to contribute to the knowledge of Thai rotifers, we studied the rotifers from three peat-swamps (Mai-khao, Jood ans Jik) in Phuket province, Thailand. We here report on the composition of the rotifer fauna of the swamps, and describe a new species that was found during the study.

2. Material and Methods

Samples were collected in the littoral zone of three peat-swamps (Mai-khao, Jood and Jik peak-swamps) in Phuket province, Thailand on July 7, 1998 (Fig. 1). The samples were taken by several horizontal hauls using a 26 µm plankton net, and immediately preserved in 4% formaldehyde solution. Specimens were sorted under an Olympus VM dissecting microscope, and examined and drawn using an Olympus CH-2 attached with a camera lucida. Some specimens were prepared for scanning electron microscopy by placing the specimens on a nucleopore membrane, which was subsequently placed in a stainless steel case. Specimens were dried by dehydration using graded ethanol, and subsequent critical-point drying. The dried specimens were then mounted on a metal specimen stub (diameter 10 mm, height 5 mm) using a double-sided adhesive tape and coated with gold, and observed using a JEOL 5800LV scanning electron microscope. All measurements are in µm.

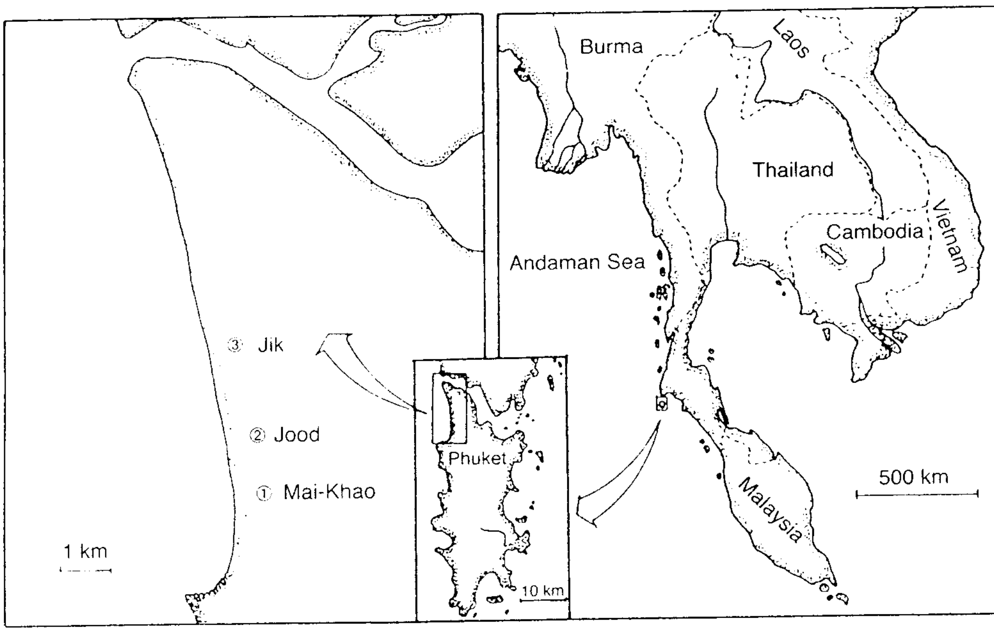


Figure 1. Map of Thailand showing the location of Phuket province and the peat-swamp areas.

3. Results and Discussion

A total of 77 species of monogont Rotifera was identified. Twelve of these are new to Thailand, one is new to science (Table 1). The samples contained many contracted Bdelloidea, which were deformed beyond identification. A description of the new species is as follows.

Family Colurellidae

Colurella sanoamuangae n. sp. (Figs. 2–4, 7–8)

Type locality

Littoral of Mai-khao peat-swamp, Phuket province, Thailand on July 7, 1998. Other locality: Thale-noi lake, Pattalung province, Thailand on September 16, 1995.

Material examined

Holotype and one paratype in Natural History Museum, Prince of Songkla University (PSU), Thailand, one paratype in Plankton Research Unit, PSU (PRU 1), the Belgian Institute for National Sciences (KBIN) and the Science Museum, Khon Kaen University, each. More specimens were present in the original sample (in PSU) from the type locality.

Differential diagnosis

The new species resembles *C. colurus* (EHRENBERG) and *C. adriatica* EHRENBERG. It can be distinguished from these by its relatively large size, but especially by its peculiar head

Table 1. List of the Rotifera from peat-swamps in Phuket province

Anuraeopsis fissa (GOSSE): 1, 2
A. navicula (ROUSSELET): 2
Brachionus angularis GOSSE
B. falcatus ZACHARIAS: 2
B. quadridentatus HERMAN: 1, 2, 3
B. rubens EHRENBERG: 1
**B. variabilis* (HEMPEL): 1
***Cephalodella* cf. *hyalina* MYERS: 3
***C. innesi* MYERS: 1, 2
Colurella colurus (EHRENBERG): 1
C. obtusa (GOSSE): 1, 2
***C. sanoamuangae* **new species**: 1, 2
Dicranophorus epicharis HARRING & MYERS: 1
Euchanis dilatata EHRENBERG: 2, 3
E. incisa CARLIN f. *mucronata* AHLSTROM: 1, 2, 3
***E. lyra* HUDSON f. *myersi* KUTIKOVA: 3
E. meneta MYERS: 3
Filinia longiseta (EHRENBERG): 2
F. novaezaelandiae SHIEL & SANOAMUANG: 2
F. opoliensis (ZACHARIAS): 2
Keratella tropica (APSTEIN): 1, 2
Lecane aculeata (JAKUBSKI): 1, 2
L. arcuata (BRYCE): 3
L. arcula HARRING: 1, 3
L. bifurca (BRYCE): 3
L. bulla (GOSSE): 1, 2, 3
L. closterocerca (SCHMARDA): 1, 2, 3
L. crepida HARRING: 1, 2, 3
**L. decipiens* (MURRAY): 1, 2, 3
L. flexilis (GOSSE): 2
L. furcata (MURRAY): 1, 3
**L. grandis* (MURRAY): 1
L. hamata (STOKES): 1, 2, 3
L. inermis (BRYCE): 1, 3
L. inopinata HARRING & MYERS: 1, 3
L. leontina (TURNER): 2, 3
L. ludwigii (ECKSTEIN): 1, 2
L. luna (MÜLLER): 1, 3
L. lunaris (EHRENBERG): 1, 2
L. monostyla (DADAY): 3
L. obtusa (MURRAY): 1, 2, 3
L. papuana (MURRAY): 1, 2, 3
L. pyriformis (DADAY): 1, 2, 3
L. quadridentata (EHRENBERG): 2
L. rhytida HARRING & MYERS: 1, 2
L. signifera (JENNINGS): 2, 3
L. shieli SEGERS & SANOAMUANG: 2
L. stenroosi (MEISSNER): 1
L. tenuiseta HARRING: 1
L. unguitata HAUER: 1, 2, 3
L. unguitata (FADEEV): 2
L. ungulata (GOSSE): 2
Lepadella acuminata (EHRENBERG): 3
L. apsida HARRING: 1
L. discoidea SEGERS: 3
L. ovalis (MÜLLER): 3
L. patella (MÜLLER): 1, 2, 3
L. quadricarinata (STENROOS): 2
L. rhomboides (GOSSE): 1, 2
L. triba MYERS: 3
Macrochaetus collinsi (GOSSE): 2, 3
**Monommata grandis* TESSIN: 1, 2, 3
***M. longiseta* (MÜLLER): 1, 2, 3
Mytilina ventralis (EHRENBERG): 1
***Notommata pygmaea* HARRING & MYERS: 3
Plationus patulus (MÜLLER): 2, 3
Platyias quadricornis (EHRENBERG): 3
Polyarthra minor VOIGT: 1, 2, 3
P. vulgaris CARLIN: 1, 2
Scaridium longicaudum (MÜLLER): 3
***Squatinella leydigii* (ZACHARIAS) f. *longiseta* (POURRIOT): 2
**Taphrocampa annulosa* GOSSE: 1, 2
Testudinella patina (ZACHARIAS): 2, 3
Trichocerca braziliensis MURRAY: 1, 3
T. insulana (HAUER): 3
T. pusilla (LAUTERBORN): 2
T. similis (WIERZEJSKI): 1, 2

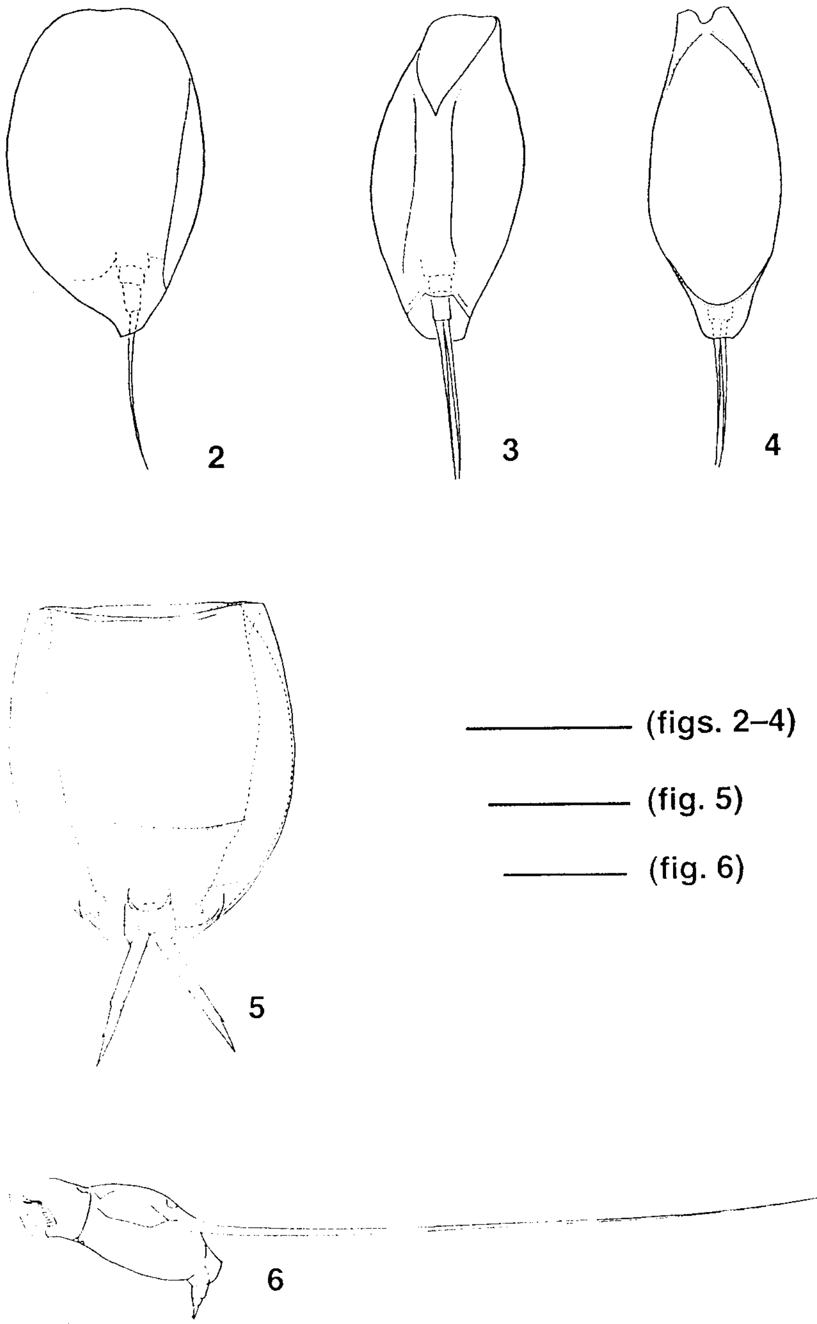
* New to Thailand.
** New to the Oriental region.

Numbers refer to localities as in Figure 1.

aperture margins having a small concavity midlaterally. The peculiar caudal projection overlaying the foot is unique to *C. sanoamuangae* n. sp.; in *C. colurus*, no separate caudal projection is present, whereas in *C. adriatica* there is a pair of triangular posteriorly projections extending from the postero-lateral margins of the lorica plates, laterally of the foot.

Description

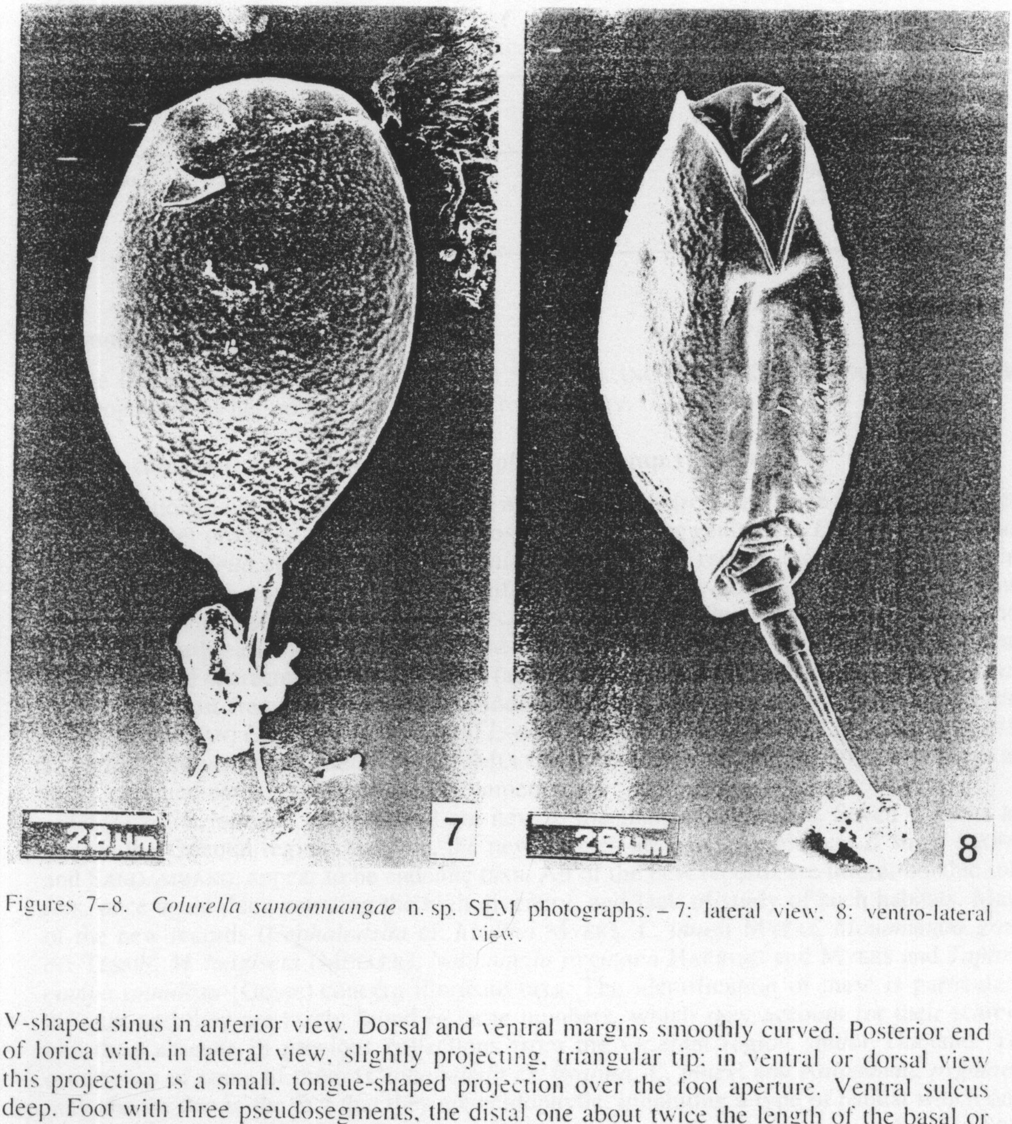
Parthenogenetic female: Body ellipsoidal in dorsal, oval in lateral view. Lorica three times as long as wide, about one and a half time as high as wide. Head aperture margins rounded, with median concavity in lateral view; dorsally a small U-shaped sinus, ventrally a deep



Figures 2–4. *Colurella sanoamuangae* n. sp. – 2: lateral view. 3: ventral view. 4: dorsal view. Scale bar = 50 µm.

Figure 5. *Lecane grandis* (MURRAY). – vental view. Scale bar = 50 µm.

Figure 6. *Squatinella leydigii* (ZACHARIAS). f. *longiseta* (POURRIOT). – lateral view. Scale bar = 50 µm.



Figures 7–8. *Colurella sanoamuangae* n. sp. SEM photographs. – 7: lateral view, 8: ventro-lateral view.

V-shaped sinus in anterior view. Dorsal and ventral margins smoothly curved. Posterior end of lorica with, in lateral view, slightly projecting, triangular tip; in ventral or dorsal view this projection is a small, tongue-shaped projection over the foot aperture. Ventral sulcus deep. Foot with three pseudosegments, the distal one about twice the length of the basal or median one. Toes relatively long, weakly curved ventrally, smoothly tapering to an acute point distally. Male unknown.

Measurements: Lorica length 98–102 µm, heigh 66–72 µm, last foot pseudosegment length 8–10 µm, toe length 44–48 µm (n = 6).

Distribution and Ecology

A single specimen of *C. sanoamuangae* n. sp. was found in Thale-noi lake, Thailand (Fig. 1 *in* SEGERS and PHOLPUNTHIN 1997). During the present study, the species was found in Mai-khao peat-swamp only; at the time of sampling, water temperature was 28.1–29.3 °C, pH 5.6–5.9, the concentration of dissolved oxygen was 3.35–4.25 mg · l^{-1}, conductivity was 1.98–2.90 mS · cm^{-1}, and turbidity 4–18 NTU. A list of the accompanying rotifer fauna is as in Table 2.

Table 2. Some physical and chemical variables of the sampled peat-swamps

Swamp:	water temp. (°C)	pH	diss. O_2 ($mg \cdot l^{-1}$)	conduct. ($mS \cdot cm^{-1}$)	turbidity (NTU)
Mai-Khao	28.1–29.3	5.6–5.9	3.35–4.25	1.98–2.90	4–18
Jood	28.2–28.5	5.6	3.05–4.35	0.78–0.82	4–7
Jik	30.3	5.9	4.15	0.63	6

Etymology

The species is named after Dr. LA-ORSRI SANOAMUANG (Khon Kaen University; Thailand) in recognition of her contribution to Thai rotiferology.

Species composition and zoogeography of peat-swamp rotifers

As mentioned above, 77 rotifer species were identified from the three peat-swamps sampled in Phuket province, Thailand. The most diverse rotifer genus was *Lecane* (40.3%), followed by *Lepadella* (10.4%) and *Brachionus* (6.5%). These results agree well with existing knowledge on the composition of the rotifer fauna of Thale-noi Lake, Pattalung province (South Thailand: SEGERS and PHOLPUNTHIN, 1997) and Nam Pung reservoir, Sakon Nakhon province (North-east Thailand: SEGERS and SANOAMUANG, 1994). Such assemblage appears to be a general characteristic of the rotifer faunas of soft, tropical waters (e.g. DUSSART *et al.*, 1984). The most frequently encountered individual rotifer species were *Brachionus quadridentatus* HERMAN, *Lecane bulla* (GOSSE), *L. closterocerca* (SCHMARDA), *L. hamata* (STOKES), *L. obtusa* (MURRAY), *Lepadella patella* (MÜLLER) and *Polyarthra minor* VOIGT. All these are fairly common rotifers in tropical environments.

Of 77 rotifer species recorded, 12 are new to the fauna of Thailand. Seven of these are new to the Oriental region, and two, the new species described herein and *L. shieli* SEGERS and SANOAMUANG, appear to be endemic taxa. All of the new records are littoral-benthic rotifers, once again demonstrating the high diversity, and lack of study of such habitats. Many of the new records (*Cephalodella* cf. *hyalina* MYERS, *C. innesi* MYERS, *Monommata grandis* TESSIN, *M. longiseta* (MÜLLER), *Notommata pygmaea* HARRING and MYERS and *Taphrocampa annulosa* (Gosse) concern illoricate taxa. The identification of these is particularly difficult and they are rarely found in large numbers, which may account for their scarcity and their absence in previous collections from the Oriental region and/or Thailand. The occurrence of some of them (*Cephalodella* cf. *hyalina*, *C. innesi* and *Notommata pygmaea*) may also be due to the fact that they are acidophylic, inhabiting a type of habitat which only occasionally attracts the attention of researchers. Others, like *Brachionus variabilis* (HEMPEL), *Euchlanis lyra* HUDSON f. *myersi* KUTIKOVA and *Lecane decipiens* (MURRAY) are widespread but relatively infrequent rotifers species. A peculiar record is that of *Lecane grandis* (MURRAY) (Fig. 5), which is a cosmopolitan species inhabiting saline waters (SEGERS 1995a, b). Its occurrence in the present collection may be due to the location of the study areas, near the Andaman Sea. *Squatinella leydigii* (ZACHARIAS) f. *longiseta* (POURRIOT) (Fig. 6) is a noticeably rare but cosmopolitan species (see DE RIDDER and SEGERS, 1997; JOS DE PAGGI, 1996), that inhabits acid waters (KOSTE, 1978; KOSTE and SHIEL, 1989).

The results presented here demonstrate that, notwithstanding the recent research effort towards the Thai rotifer fauna, still much remains to be discovered, especially regarding littoral-benthonic and illoricate Rotifera. Also, all of the new records are littoral-benthic rotifers, while some of the illoricate species and *Squatinella leydigii* are restricted to soft, (moderately) acid waters connected to peat-swamps. This illustrates that such habitats should be more adequately covered in biodiversity inventories.

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L. Sanoamuang, H. Segers, R.J. Shiel & R.D. Gulati (eds), Rotifera IX.

The rotifer fauna of peat-swamps in southern Thailand

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Key words: Rotifera, peat-swamps, Thailand

Abstract

The Rotifera from four peat-swamps in the provinces Suratthanee (Kra-Jood and Kun-Thu-Lee peat-swamps), Nakhonsri-thammarat (Khuan-Kreng peat-swamp) and Yala (Lan-Kway peat-swamp) in southern Thailand were examined by the study of qualitative samples collected on three occasions during July, October and November, 1998. A total of 96 species was identified, seventeen of which are new to the Thai rotifer fauna. The most diverse genera were *Lecane* (40.6%), followed by *Lepadella* (8.3%) and *Trichocerca* (7.3%). The most diverse rotifer fauna was found in Kra-Jood peat-swamp (61 species), followed by Kun-Thu-Lee (57 species), Lan-Kway (41 species) and Khuan-Kreng (24 species) peat-swamps, respectively.

Introduction

In recent years, the number of studies on Thai Rotifera has increased steadily (Segers & Sanoamuang, 1994, 1997; Sanoamuang et al., 1995; Sanoamuang 1996, 1998; Pholpunthin, 1997; Segers & Pholpunthin, 1997; Sanoamuang & Segers, 1997; Sanoamuang & Savatenalinton, 1999). Most of the studies sampled canals, rivers, ponds, rice fields or reservoirs, but peat-swamps, an important wetland habitat in Thailand, have largely been ignored. The formation of these peat-swamps, by the accumulation of dead plant material and debris, has taken thousands of years. The vegetation of the peat-swamps depends on the peaty soil and on the fluctuation of the water levels. This water is acid and brownish (Phengklai et al., 1989). A previous study on Rotifera from Phuket peat-swamps reported 77 species, including 12 new records for Thailand, and a new species, *Colurella sanoamuangae* was described (Chittapun et al., 1999). This result illustrates that peat-swamps are interesting areas for the study of rotifer biodiversity. The purpose of the present study is to expand our knowledge of the rotifers inhabiting peat-swamps, by investigating four peat-swamps in southern Thailand.

Materials and methods

Samples were collected qualitatively in four peat-swamps (Kra-Jood and Kun-Thu-Lee peat-swamps, Suratthanee province; Khuan-Kreng peat-swamp, Nakhornsri-thammarat province and Lan-Kway peat-swamp, Yala province, Southern Thailand (Fig. 1) on three occasions in July, October and November, 1998. Some physical and chemical parameters of the peat-swamps are as in Table 1. The samples consist of several horizontal hauls made using a 26-μm plankton net, which were immediately preserved in 4% formaldehyde solution. Specimens were sorted under an Olympus VM dissecting microscope. They were examined and drawn using an Olympus CH-2 compound microscope with camera lucida. Some specimens were prepared for scanning electron microscopy as described by Chittapun et al. (1999).

Results and discussion

Ninety-six rotifer species, 17 of which are new to the Thai fauna, were identified from the four peat-swamps studied (Table 2). Of the 17 new records, two: *Lecane*

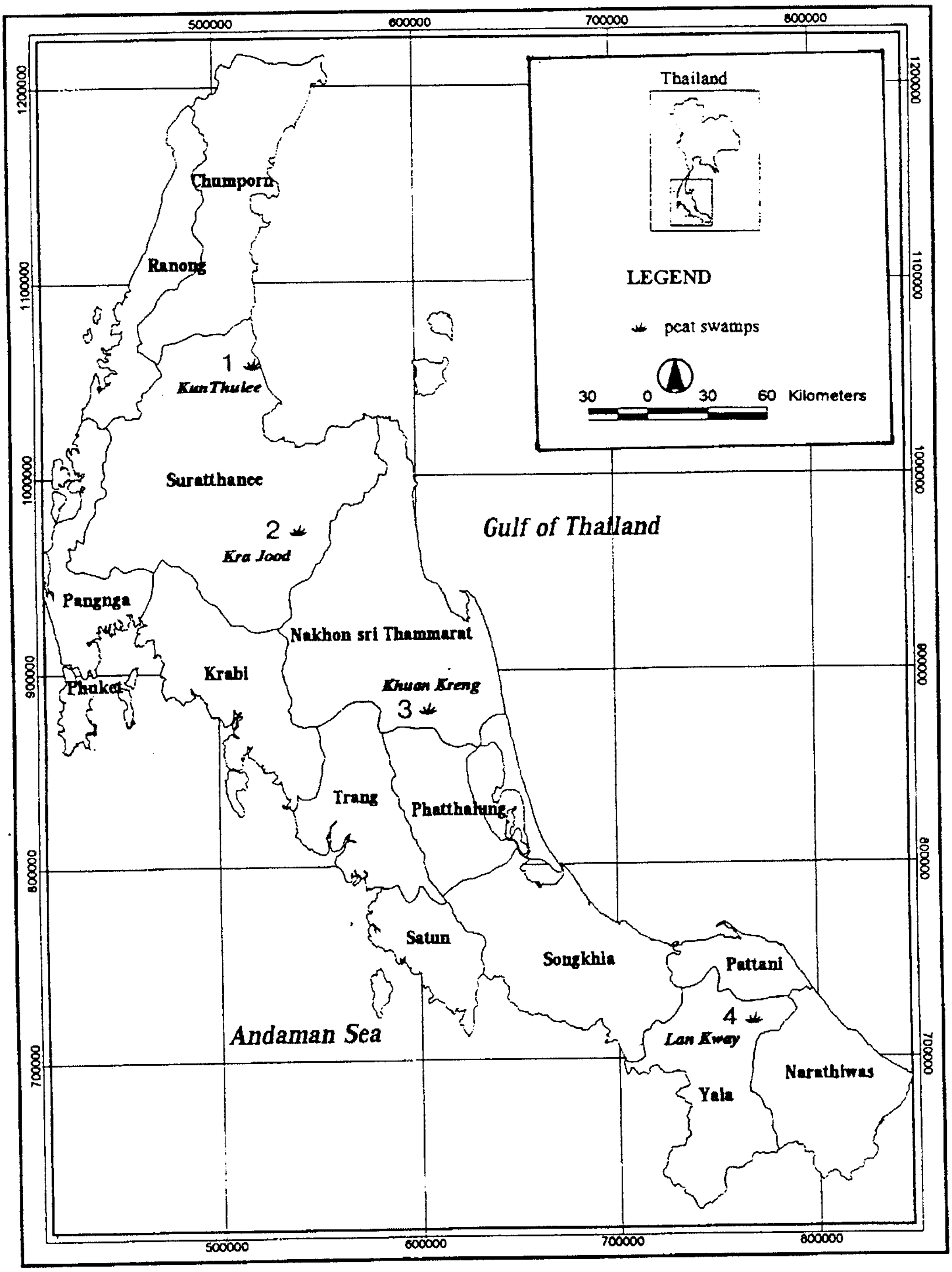
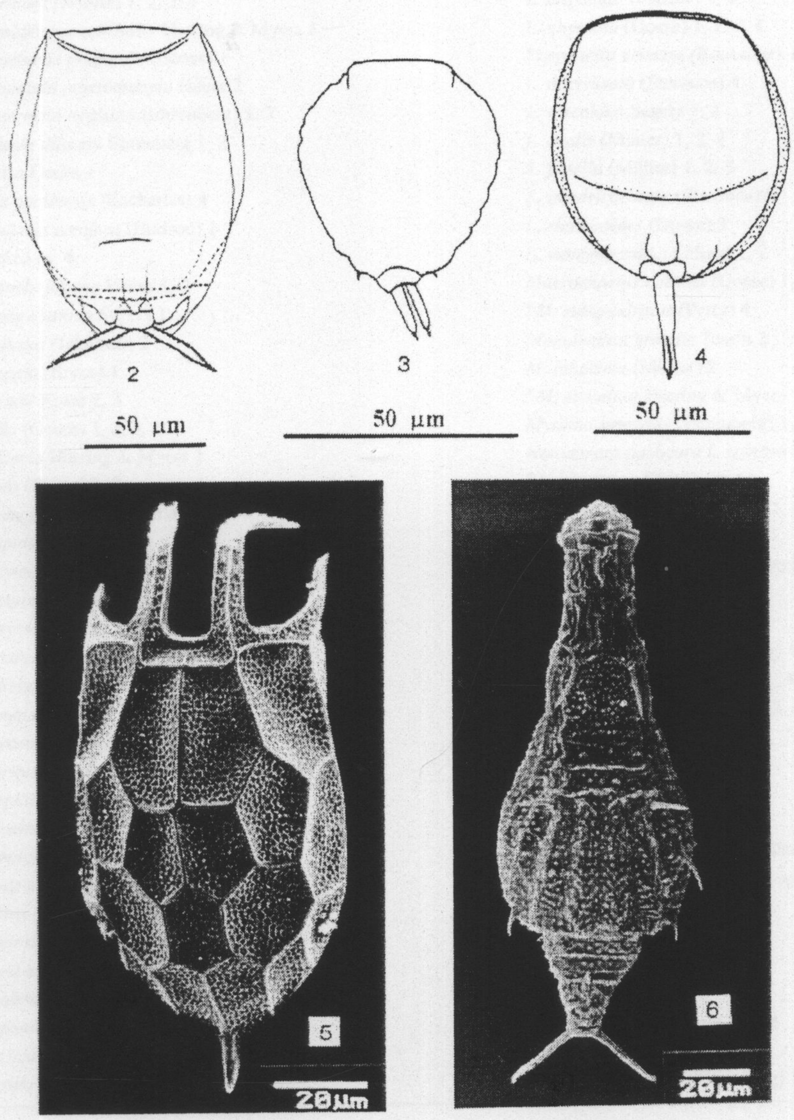


Figure 1. Map of Thailand showing the location of the southern part and the peat swamp areas.

Table 1. Physical and chemical parameters of the sampled peat-swamps

Swamp	Water temp. (°C)	pH	Diss. O_2 (mg l^{-1})	Conduct. (mS cm^{-1})	Turbidity (NTU)
Kun Thulee	25.7–26.6	4.93–5.37	2.27–4.30	0.03	11.0–12.0
Kra Jood	25.8–27.2	5.59–5.98	2.30–7.88	0.03	11.0–43.0
Khuan Kreng	27.2–30.1	5.20–7.14	5.60–7.40	0.04–0.07	11.0–69.0
Lan Kway	29.3–30.8	6.01–6.37	4.46–5.65	0.02	14.0–54.0



Figures 2–6. (2) *Lecane mitis* (Harring & Myers) – ventral view. (3) *Lecane palinacis* Harring & Myers – ventral view. (4) *Lecane syngenes* (Hauer) – ventral view. (5) *Keratella javana* (Hauer) SEM photograph – dorsal view. (6) *Dissotrocha aculeata* (Ehrenberg) SEM photograph – dorsal view.

Table 2. List of Rotifera from peat-swamps in Southern Thailand * New to Thailand; Numbers refer to localities as in Figure 1

Anuraeopsis fissa (Gosse) 1, 2, 3, 4
Ascomorpha sp. 4
Brachionus quadridentatus f. *mirabilis* (Daday) 2, 4
**Cephalodella mucronata* Myers 2
Colurella adriatica Ehrenberg 4
C. colurus (Ehrenberg) 3
C. obtusa (Gosse) 4
**C. sulcata* (Stenroos) 1, 2
**C. tesselata* (Glascott) 1, 2
C. uncinata (Müller) 1, 2, 3, 4
Dicranophorus epicharis Harring & Myers 1
Dipleuchanis propatula (Gosse) 1
D. propatula macrodactyla Hauer 2
**Dissotrocha aculeata* (Ehrenberg) 2, 3
Euchlanis dilatata Ehrenberg 1, 2
E. incisa Carlin 1
Filinia opoliensis (Zacharias) 4
Floscularia conifera (Hudson) 1
Hexathra sp. 4
**Keratella javana* Hauer 1, 2
**Lecane abanica* Segers 1
L. aculeata (Jakubski) 2
L. arcuata (Bryce) 1
L. braumi Koste 2, 3
L. bulla (Gosse) 1, 2, 3, 4
L. calcaria Harring & Myers 1
L. clara (Bryce) 1, 2
L. closterocerca (Schmarda) 1, 2
L. crepida Harring 4
L. curvicornis (Murray) 1, 2
L. decipiens (Murray) 3
L. doryssa Harring 1, 2, 4
L. furcata (Murray) 2, 4
L. haliclysta Harring & Myers 1, 2
L. hamata (Stokes) 1, 2, 3, 4
L. hornemanni (Ehrenberg) 1, 2
L. inermis (Bryce) !, 3, 4
L. inopinata Harring &Myers 1, 2
L. leontina (Turner) 1, 2, 3, 4
L. ludwigii (Eckstein) 1, 2, 4
L. lunaris (Ehrenberg) 1, 2, 3, 4
**L. mitis* (Harring & Myers) 3
L. monostyla (Daday) 1, 2, 3
L. obtusa (Muray) 2, 3
**L. palinacis* Harring & Myers 1
L. papauna (Murray) 3
L. pertica Harring & Myers 1, 2, 3, 4
L. pusilla Harring 4
L. pyriformis (Daday) 1, 2, 4
L. quadridentata (Ehrenberg) 1, 2
L. rhytida Harring & Myers 1
L. signifera (Jennings) 1, 2, 3, 4
**L. simonneae* Segers 3
**L. syngenes* (Hauer) 1
L. tenuiseta Harring 2, 4
L. thienemanni Hauer 2
L. undulata Hauer 1
L. unguitata (Fadeev) 1, 2, 4
L. ungulata (Gosse) 1, 2, 3, 4
**Lepadella cristata* (Rousselet) 1, 2
L. dactyliseta (Stenroos) 4
L. discoidea Segers 1, 2
L. ovalis (Müller) 1, 2, 4
L. patella (Müller) 1, 2, 3
L. quadricarinata (Stenroos) 2
L. rhomboides (Gosse) 3
L. vandenbrandei Gillard 1, 2
Macrochaetus collinsi (Gosse) 1, 2, 4
**M. subquadratus* (Perty) 4
Monommata grandis Tessin 2
M. longiseta (Müller) 2
**M. maculata* Harring & Myers 1, 2
Mytilina ventralis (Ehrenberg) 1, 2
Notommata pachyura f. *spinosa* Koste 2, 4
**N. saccigera* Ehrenberg 1
Plationus patulus (Müller) 1, 2, 4
Polyarthra vulgaris Carlin 2, 4
Scaridium elegans Segers & De Meester 2
S. grande Segers 1, 2
S. longicaudum (Müller) 2, 4
Squatinella mutica (Ehrenberg) 4
Testudinella amphora Hauer 1, 4
T. incisa ahlstromi (Hauer) 1, 2, 4
**T. mucronata* (Gosse) 4
T. parva (Ternetz) 1, 2
T. patina (Hermann) 1, 2, 3, 4
T. tridentata Smirnov 1, 2
**Tetrasiphon hydrocora* Ehrenberg 4
Trichocerca brasiliensis (Murray) 4
**T. collaris* (Rousselet) 2
T. flagellata Hauer 2
T. hollaerti De Smet 1, 2
T. insignis (Herrick) 1
T. similis grandis Hauer 2, 3, 4
T. tropis Hauer 1
Trichotria tetractis (Ehrenberg) 1, 2, 3, 4

mitis (Harring & Myers) and *L. palinacis* Harring & Myers are new to the Oriental Region. The former species (Fig. 2) has been found in the Nearctic and Neotropical Regions, while the latter (Fig. 3) has been recorded from the U.S.A. and the Galapagos Islands (Segers, 1995; Segers & Dumont, 1995; De Ridder & Segers, 1997). Many of the new records (*Cephalodella mucronata* Myers, *Colurella sulcata* (Stenroos), *C. tesselata* (Glascott), *Keratella javana* Hauer, *Lecane syngenes* (Hauer), *Macrochaetus subquadratus* (Perty), *Notommata saccigera* Ehrenberg, *Tetrasiphon hydrocora* Ehrenberg and *Trichocerca collaris* (Rousselet)) are widely distributed in the Oriental Region, occurring in Indonesia, Malaysia, Singapore and Sri Lanka (De Ridder & Segers, 1997). Among them, *K. javana* (Fig. 5) and *N. saccigera* are cosmopolitan species, common in acid waters (Sudzuki, 1991; Nogrady & Pourriot, 1995), while *L. syngenes* (Fig. 4) is a rare, warm-stenothermic Pan(sub)tropical species (Segers, 1995). The rest of the new records, *Dissotrocha aculeata* (Ehrenberg), *Lecane abanica* Segers, *L. simonneae* Segers, *Lepadella cristata* (Rousselet), *Monommata maculata* Harring & Myers and *Testudinella mucronata* (Gosse), are new to Southeast Asia. However, *D. aculeata* (Fig. 6) is thought to be a cosmopolitan species (Koste & Shiel, 1986).

Of the 96 taxa, the most diverse genera were *Lecane* (40.6%), followed by *Lepadella* (8.3%) and *Trichocerca* (7.3%). These results, together with the most frequently encountered rotifer species in all peat-swamps agree well with the existing knowledge on the composition of the rotifer fauna of Phuket peat-swamps (Chittapun et al., 1999). Kra-Jood peat-swamp contained the most diverse rotifer taxocoenosis (61 species) followed by Kun-Thu-Lee (57 species), Lan-Kway (41 species) and Khuan-Kreng (24 species) peat-swamps, respectively.

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Rotifer diversity in a peat-swamp in southern Thailand (Narathiwas province) with the description of a new species of *Keratella* Bory de St. Vincent

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H. Segers[2]

Keywords : rotifers, zoogeography, biodiversity, *Keratella*, new species, Thailand

We studied the rotifer fauna of one of the most pristine peat-swamps in the Southern Thai province of Narathiwas, To Daeng peat swamp. The samples yielded a total of sixty-seven rotifer species. Of these, three -*Keratella mixta* (Oparina-Charitonova), *Lecane enowi* Segers & Mertens and *Monommata dentata* Wulfert- are new to the Oriental region and the Thai fauna, one, *Keratella taksinensis* n. sp., is new to science. The fauna consists mainly of cosmopolitan (*sensu lato*) species, complemented by some Paleotropical and endemic taxa, and is dominated by littoral-benthonic taxa, especially *Lecane* and, to a lesser extent, *Lepadella*.

Diversité des rotifères dans un marais tourbeux du sud de la Thaïlande (Province de Narathiwas) avec la description d'une espèce nouvelle de *Keratella* Bory de St. Vincent

Mots-clés : rotifères, zoogéographie, biodiversité, *Keratella*, espèce nouvelle, Thaïlande.

Une étude des rotifères d'un marais tourbeux vierge dans le sud de la Thaïlande, le marais de To Daeng, a révélé un total de 67 espèces, dont trois -*Keratella mixta* (Oparina-Charitonova), *Lecane enowi* Segers & Mertens et *Monommata dentata* Wulfert- sont nouvelles pour la région Orientale et la Thaïlande. Une espèce, *Keratella taksinensis* n. sp., est nouvelle pour la science. La faune est composée en majorité d'espèces cosmopolites (*sensu lato*), accompagnées par quelques espèces paléotropicales et endémiques. Elle est dominée par des espèces littorales et benthiques, notamment des *Lecane* et, moins nombreuses, des *Lepadella*.

1. Introduction

Recently, the study of Rotifera inhabiting peat swamps in Thailand, representing the most diverse group of primary freshwater Metazoa in these peculiar tropical ecosystems, has attracted much interest (e.g., Chittapun et al. 1999, Chittapun & Pholpunthin 2001, Segers & Chittapun 2001). However, all studies to date, report on peat swamps that have been influenced, to a greater or lesser extent, by human activities such as farming. These and other disturbances have had a substantial impact on the macrophyte vegetation and on water quality, crucial to the zooplankton communities inhabiting these environments.

One of the few pristine peat swamps in Thailand is To-Daeng peat swamp in the southern province Narathiwas, and the study of its rotifer fauna may be informative about the natural biodiversity of this habitat type. Such information is required to assess the impact of human activities on tropical peat swamps. Here we report on the rotifer fauna of this peat swamp.

To Daeng peat swamp (101°55'E-102°03'E, 06°03'N-06°03'E, Fig. 1) is the largest pristine peat swamp in Thailand. It covers an area of ca. 17,352 hectares. The region has a tropical monsoon climate, with heavy rainfall from September to January, and a relatively drier period from February to April. The peat swamp developed under the influence of the deposition of marine sediments near the shoreline, and strong, continuous winds that formed a raised sandy beach parallel to the shoreline. This process finally separated a large, elongate depression from the sea.

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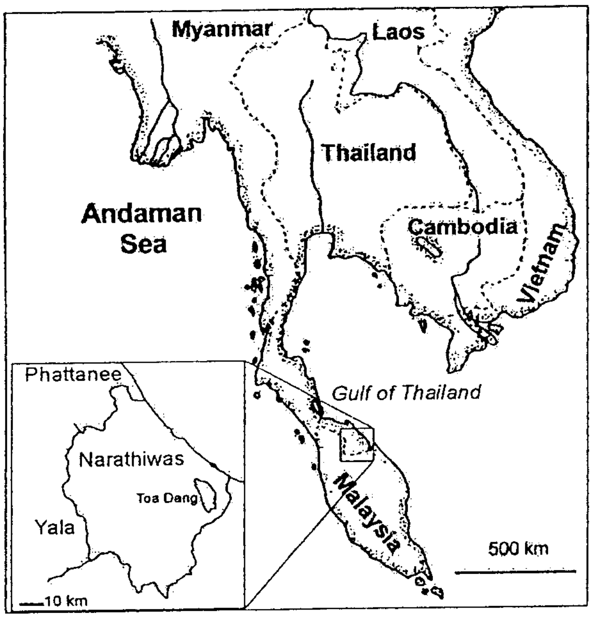


Fig. 1. Map of Thailand showing the location of To Daeng peat swamp in Narathiwas province.

Fig. 1. Carte de la Thaïlande indiquant la localisation du marais tourbeux To Daeng dans la province de Narathiwas.

When the connection to the sea was lost, a freshwater lake and swamp, fed by the heavy precipitation in the area, were formed. However, due to the high Sodium sulphate content of this coastal lake, decomposition rates are relatively low. This resulted in the formation of peat layers of varying thickness by the accumulation of dead organic material. In To Daeng peat swamp, this layer is generally over, or about 50 cm deep, and reaches a maximum thickness of up to 10 m in the central area of the swamp. The surface layer of peat (0-30 cm depth) is pronouncedly acidic (pH ca. 4), has a dark brown colour, and consists of decomposing organic material. Accordingly, the water in the swamp is acid, and has a characteristic brownish color (Phengklai et al. 1989).

2. Material and methods

Qualitative samples were collected in June and October 1998, and February 1999. The samples consist of several horizontal and oblique hauls, using a 26 μm mesh plankton net at several stations in the center and near the edges of the swamp. The samples were immediately preserved in 4% formaldehyde solution. Measurements of some physical and chemical parameters were made using a HORIBA, U-10 multimeter (see Table 1). Specimens were sorted, identified, drawn and prepared for scanning electron microscopy (SEM) following Chittapun et al. (1999).

3. Results and discussion

Species composition and zoogeography

A total of 67 rotifer species (66 Monogononta, 1 Bdelloidea) were identified (Table 2). The majority belonged to the genus *Lecane* (40.30 %), followed by *Lepadella* (10.45 %). This result corresponds well with existing information on the composition of the rotifer fauna of Thai peat swamps (Chittapun et al. 1999, Chittapun & Pholpunthin 2001).

One of the species recorded is new to science, and three are new to the Oriental region and Thailand. *Keratella taksinensis* n. sp. is described below. *Keratella mixta* (Oparina-Charitonova) (Fig. 2) is a rare rotifer, so far known only from temperate and cold regions in the Northern hemisphere (De Ridder & Segers 1997). Its occurrence in tropical Asia is surprising and it is, as yet, unclear what factor(s) account for its presence in Toa-Dang peat swamp. *Lecane enowi* Segers & Mertens (Fig. 3) has only recently been described from a temporary pond on an old palm plantation in Cameroon (Segers & Mertens 1997), and the present record is the second of this species. Considering that it is known only from two widely separated geographic localities, it appears premature to speculate on its biogeography. However, it may be part of a group of tropical Old-World taxa, which especially consists of *Lecane* species (Segers 1996, 2001). This group is here represented by nine taxa (Table 2), of which only three (*Lecane enowi*, *L. simonneae* and *Scaridium grande*) have not yet been recorded from tropical Australia. The third species, *Monommata dentata* Wulfert, is probably rare only because of the taxonomic difficulty of the genus, making that records of all but the largest and most easily recognized species are few. It is probably cosmopolitan, and has previously been recorded from the Ethiopian, Palaearctic, Nearctic and Australian regions (De Ridder 1986, De Ridder & Segers 1997). In addition to these, the record of the Thai endemic *Lecane superaculeata* Sanoamuang & Segers is noteworthy. This species had already been recorded from several localities in the North and Northeast (Sanoamuang 1997, 1998), and now also from Southern Thailand.

Table 1. Ranges of some physical and chemical measurements in To Daeng Peat swamp.
Tableau 1. Valeurs de quelques caractéristiques physico-chimiques mesurées dans le marais tourbeux de To Daeng.

Date	18/06/1998	31/10/1998	27/02/1999
Temperature (°C)	25.7-35.4	25.7-31.1	25.9-31.4
pH	4-6.0	4.0-6.1	4.2-5.9
Conductivity ($mS.cm^{-1}$)	0.04-0.14	0.01-0.42	0.01-0.11
Turbidity (NTU)	2.0-40.0	2.0-52.0	3.0-37.0

Table 2. Rotifers record from To Daeng peat swamp. Narathiwas province, southern Thailand.
Tableau 2. Rotifères dans le marais tourbeux de To Daeng, province de Narathiwas, Sud de la Thaïlande.

Anuraeopsis fissa (Gosse)
Brachionus quadridentatus Hermann, incl. f. *mirabilis* Daday
Cephalodella gibba (Ehrenberg)
C. innesi Myers
Colurella colurus (Ehrenberg)
C. obtusa (Gosse)
C. uncinata (Müller), incl. f. *bicuspidata* (Ehrenberg)
Dipleuchlanis propatula (Gosse) f. *macrodactyla* Hauer
Dissotrocha aculeata (Ehrenberg)
Euchlanis incisa Carlin
†*Keratella javana* Hauer
**K. mixta* (Oparina-Charitonova)
**K. taksinensis* n. sp.
Lecane aculeata (Jakubski)
L. arcula Harring
†*L. braumi* Koste
L. bulla (Gosse)
L. closterocerca (Schmarda)
L. curvicornis (Murray)
L. doryssa Harring
†**L. enowi* Segers & Mertens
L. furcata (Murray)
L. hamata (Stokes)
L. hornemanni (Ehrenberg)
L. inermis (Bryce)
†*L. lateralis* Sharma
L. leontina (Turner)
L. ludwigii (Eckstein)
L. lunaris (Ehrenberg)
L. monostyla (Daday)
L. obtusa (Murray)
L. papuana (Murray)
L. pertica Harring & Myers
L. pyriformis (Daday)
L. signifera (Jennings)
†*L. simonneae* Segers
L. superaculeata Sanoamuang & Segers
L. tenuiseta Harring
†*L. unguitata* (Fadeev)
L. ungulata (Gosse)
Lepadella apsicora Myers
†*L. discoidea* Segers
L. ehrenbergi (Perty)
L. patella (Müller)
L. monodactyla (Bērzins)
L. rhomboides (Gosse)
†*L. vandenbrandei* Gillard
Macrochaetus collinsi (Gosse)
Manfredium eudactylotum (Gosse)
**Monommata dentata* Wulfert
M. grandis Tessin
M. longiseta (Müller)
Notommata saccigera Ehrenberg
Plationus patulus (Müller)
Platyias quadricornis (Ehrenberg) f. *brevispinus* Daday
Polyarthra minor Voigt
†*Scaridium grande* Segers
S. longicaudum (Müller)
Squatinella leydigii (Zacharias) f. *longiseta* Pourriot
Testudinella parva (Ternetz)
T. patina (Hermann)
T. tridentata Smirnov
Trichocerca brasiliensis (Murray)
T. jenningsi Voigt
T. siamensis Segers & Pholpunthin
T. similis (Weirzejski) f. *grandis* Hauer
Trichotria tetractis (Ehrenberg)

* New to the Oriental region and to Thailand
† Palaeotropical species

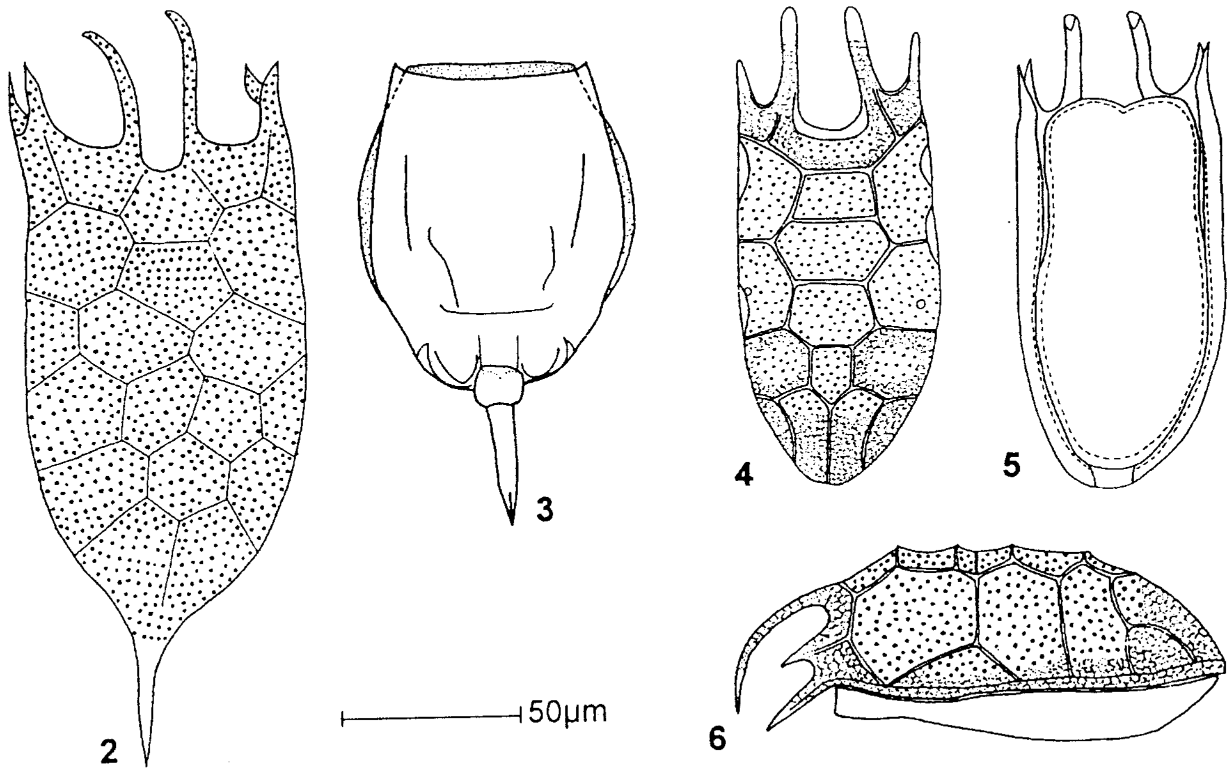


Fig. 2. *Keratella mixta* (Oparina-Charitonova) - dorsal view ; Fig. 3. *Lecane enowi* Segers & Mertens - ventral view ; Figs 4-6. *Keratella taksinensis* n. sp. - 4: dorsal view, 5: ventral view, 6: lateral view.

Fig. 2. *Keratella mixta* (Oparina-Charitonova) - vue dorsale; Fig. 3. *Lecane enowi* Segers & Mertens - vue ventrale, Figs 4-6. *Keratella taksinensis* n. sp. - 4: vue dorsale, 5: vue ventrale, 6: vue latérale.

Description of *Keratella taksinensis* n. sp.

(Figs 4-6, 7-11)

Type locality : Littoral area of Toa-Dang peat-swamp, Narathiwas province, Thailand, coll. October 1998.

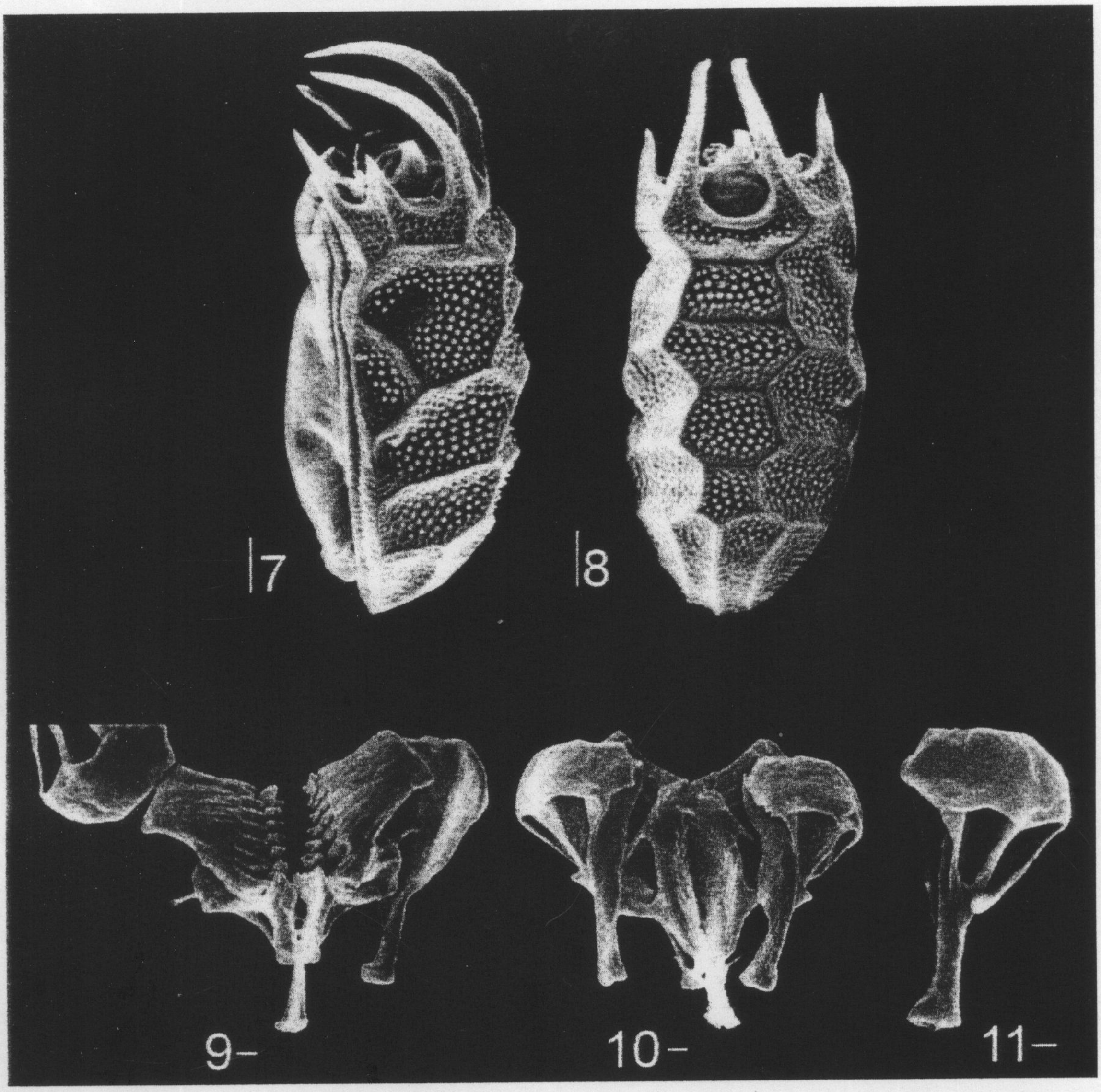
Material examined : Holotype and paratype in the royal Belgian Institute for Natural Sciences, Brussels, Belgium (IG: 29717, RIR 136) ; one paratype in the collection of the Institute of Animal Ecology, Ghent University, Ghent, Belgium. Numerous additional specimens present in the original sample (in PSU) from the type locality.

Differential diagnosis

Keratella taksinensis n. sp. is diagnosed by the presence of four enclosed median facets on the dorsal lorica, posteriorly terminating in a mid-dorsal ridge. As such, it can hardly be confused with any other *Keratella*. The new species bears some resemblance with *K. procurva* (Thorpe) and *K. serrulata* (Ehrenberg), but these species have only three or two enclosed median facets, respectively. Four enclosed median facets occur also in *K. paludosa* (Lucks), *K. ticinensis* (Callerio) and *K. trapezoida* Zhuge & Huang. However, the presence of elongate postero-carinal facets distinguishes *K. taksinensis* n. sp. from these.

Description

Parthenogenetic female (male unknown) : Lorica stiff, relatively thick, nearly twice as long as wide. Lateral margins nearly parallel, posteriorly rounded. Ventral plate relatively soft, anterially bilobate with median concavity. Dorsal plate stiff; ridges delimiting the facets well-developed. Lorica surface ornamented with large pustules on median and lateral facets, with re-



Figs 7-11. *Keratella taksinensis* n. sp. SEM photographs. - 7: lorica, lateral view, 8: lorica, dorsal view, 9-11: trophi: 9: frontal, 10: caudal view, 11: manubrium, lateral view. Scale bars: 7-8: 10μm, 9-11: 1μm.

Figs 7-11. *Keratella taksinensis* sp. n., MEB photographies. - 7: lorica, vue latérale, 8: lorica, vue dorsale, 9-11: trophi: 9: vue frontale, 10: vue caudale, 11: manubrium, vue latérale. Echelle :7 -8: 10μm, 9-11: 1μm.

ticulate patterns on lateral frontal posterior facets. Six thick, well-developed anterior spines, median pair long and curved ventral, lateral pair longer than intermediate pair, relatively sharp and twice as long as the intermediate pair. Apertures to the lateral antennas approximately half way along the lorica.

Foundation pattern consisting of a row of five median facets. Median frontal area broad, anterior median facet trapezoidal, second hexagonal, wider than long and widest anteriorly, third hexagonal and forth pentagonal, extending posteriorly in a median ridge. A pair of elongate posterocarinal facets present. Three pairs of lateral facets, and a pair of elongate postero-marginal facets present. A small triangular facet present between the first and second lateral facets. Second lateral facet with aperture to the lateral antenna, this aperture bordered by six fused pustules. No posterior spines.

Trophi malleate, nearly symmetrical. Fulcrum short, with basal plate. Ram triangular, with well developed inner projections consisting of fused, minute teeth. Allulae absent. Both unci with eight teeth, anterior teeth the strongest, with remnants of additional anterior teeth. Two dorsal pairs of teeth weaker than main teeth. Shafts of teeth connected. Manubria with posterior lamellae prolonged along the shaft.

Measurements (in µm) : Dorsal plate length 87 - 109, width 48 - 61, Ventral plate length 92 - 100, width 41 - 45, Lorica depth 39, Head aperture : antero-median spine length 31 - 48, intermediate spine 11 - 18, lateral spine 17 - 20. Trophi : fulcrum length 3, rami width 5, uncus length 1.4, manubrium length 13.

Distribution and ecology

This species is known only from a water body under the hiking trail bridge near To Daeng sanctuary office. Water temperature 25.7 - 25.9 °C, pH 4.9 - 5.8, DO 0.89 - 1.74 $mg.l^{-1}$, conductivity 0.015 - 0.028 mS. cm^{-1}, turbidity 2 - 3.6 NTU.

Etymology

The name of the new species is a toponym, and is derived from the word 'Taksin', Thai for the Southern part of Thailand.

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Contribution to the knowledge of Thai microfauna diversity: notes on rare peat swamp Rotifera, with the description of a new *Lecane* Nitzsch, 1872

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Abstract

During an ongoing study of the rotifer diversity in Thai peat swamps, several new or rare species were found. We here report on one new species, *Lecane kunthuleensis* n.sp., from a canal in Kun Thu Lee peat swamp, and on three rare species: *Paracolurella aemula* (Myers, 1934) and *Lecane junki* Koste, 1975 from Kra Jood peat swamp (Suratthanee province), and *Lepadella punctata* Wulfert, 1939 from To-Daeng peat swamp (Narathiwas province).

Introduction

The rotifer fauna of peat swamps in Southern Thailand has been studied extensively in recent years (Chittapun et al., 1999; Chittapun & Pholpunthin, 2001; Segers & Chittapun, 2001; Chittapun et al., 2002). To date, a total of 148 different rotifer species was recorded from this habitat. This number includes many species that had not been recorded from the Oriental region or Thailand before, and five that were new to science. This contributed significantly to the Thai rotifer record, which now stands at some 340 species (Sanoamuang, 2001; Segers, 2001; Segers & Chittapun, 2001; Chittapun et al., 2002). Clearly, the peat swamp ecosystems of Southern Thailand have a highly diverse and distinct rotifer fauna, a result of their long history, and characteristic ecological conditions (see Phengklai et al., 1989). Although contributions dealing with the rotifer fauna of Kun Thu Lee and Kra Jood peat swamps in Suratthanee province, and To-Daeng peat swamp in Narathiwas province are available (Fig. 1; Chittapun & Pholpunthin, 2001; Chittapun et al., 2002), we here report on an additional number of remarkable species.

Materials and methods

The peat swamp rotifers were sampled during several occasions (see Chittapun & Pholpunthin, 2001; Chittapun et al., 2002) using a 26 μm mesh plankton net. Samples were immediately preserved in 4% formaldehyde solution. Measurements of some physical and chemical parameters were done using a HORIBA, U-10 multimeter. Specimens were sorted, identified, drawn and prepared for scanning electron microscopy (SEM) following Chittapun et al. (1999). Light microscopy photographs were taken under an Olympus CX40RF2000 dissecting microscope fitted with an Olympus DP11 camera connected to a personal computer.

Results and discussion

Notes on selected taxa

Lecane kunthuleensis **new species (Figs 2, 3 and 8)**
Type locality: Between submerged macrophytes in a canal in Kun Thu Lee peat swamp, Suratthanee province, Thailand (Fig. 1: 99° 07.39′ E-99° 07.45′

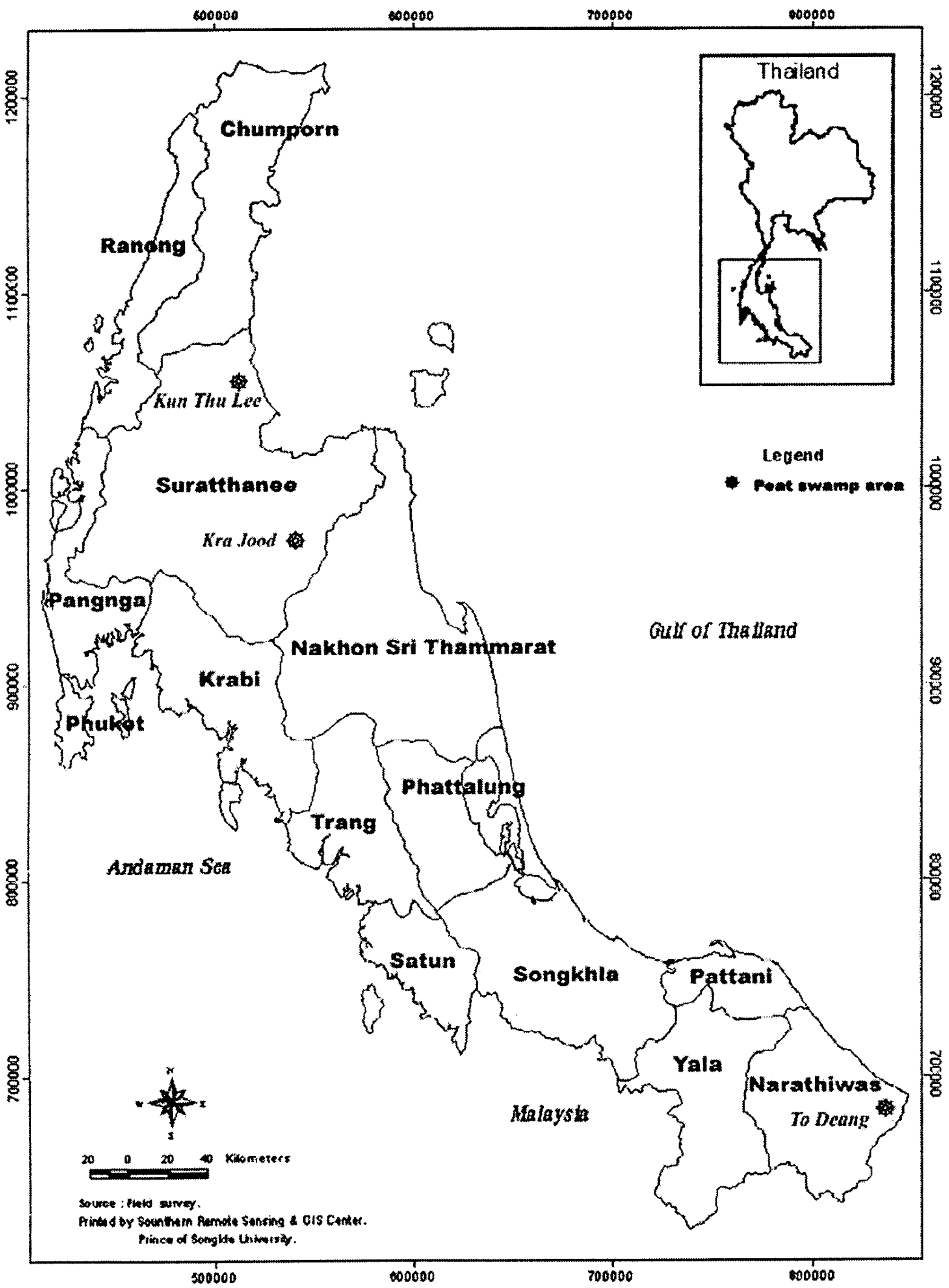
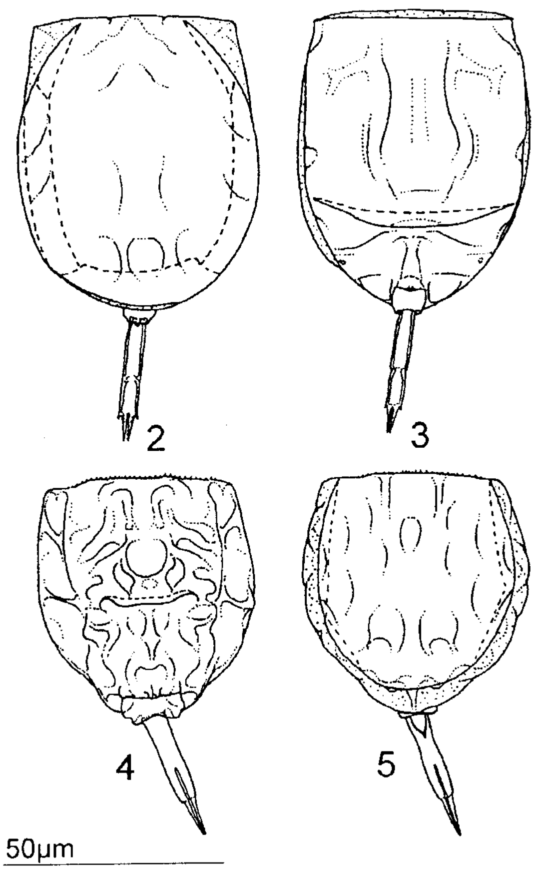


Figure 1. Map of Southern Thailand showing the location of the three peat swamps areas: Kun Thu Lee, Kra Jood and To-Daeng.



Figures 2–5. Lecane spp., habitus. 2: *L. kunthuleensis* n.sp. ventral, 3: *L. kunthuleensis* n.sp. dorsal; 4: *L. junki* Koste ventral, 5: *L. junki* Koste dorsal.

E, 9° 41.03′ N-9° 41.08′ N), coll. 23 October 1998.

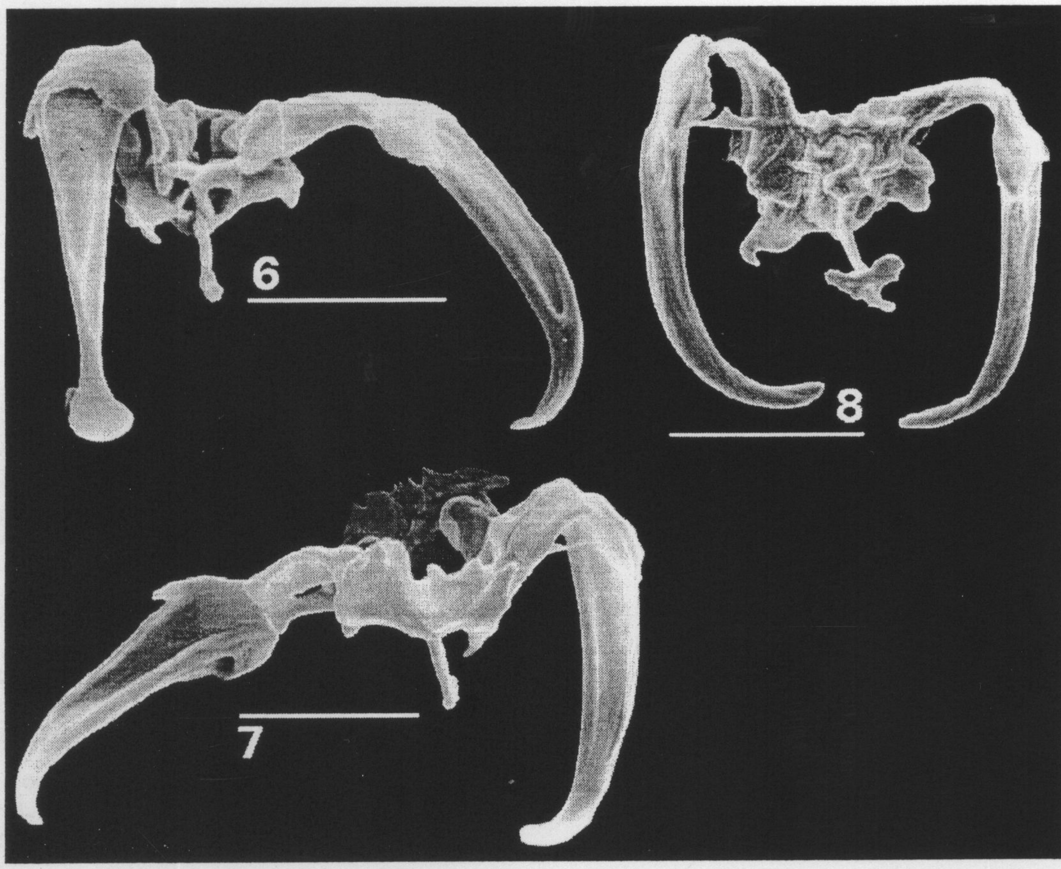
Material examined:
Holotype and paratype in Natural History Museum, Prince of Songkhla University (PSU), Hat Yai, Songkla province, Thailand; one paratype and one trophi slide in Plankton Research Unit, PSU (PRU2), and in the Science Museum, Khon Kaen University (KKU), Khon Kaen; two paratypes in the royal Belgian Institute for Natural Sciences, Brussels, Belgium (IG 29747 RIR 137-138). More specimens were present in the original sample (in PSU) from the type locality.

Differential diagnosis:
Lecane kunthuleensis n. sp. belongs to the *L. lunaris* group, and keys out to this species following the key by Segers (1995). It especially resembles *L. nigeriensis* Segers and *L. namatai* Segers & Mertens, as it shares with these its general lorica shape and complete, posteriorly smoothly curved transverse fold on the ventral lorica plate. In contrast to these two, *L. kunthuleensis* n. sp. has straight and concurrent head aperture margins (with distinct median concavity in *L. nigeriensis* and *L. namatai*). In addition, it has an ornamented, and relatively wide lorica (smooth in *L. nigeriensis* and *L. namatai*). Compared to the remaining taxa in the *L. lunaris* group, *L. kunthuleensis* n. sp. can only be confused with *L. scutata,* which has superficial lateral sulci and a different toe shape.

Description:
Female: Loricate *Lecane*. Dorsal plate anteriorly narrower, medially wider than ventral plate. Head aperture margins straight, nearly coincident with the dorsal projecting, and with a pair of notches dividing the dorsal head aperture margin in a narrow median and two wider lateral parts. Head aperture only slightly narrower than ventral lorica. Antero-lateral corners angulate. Ventral plate length ca. 1.3–1.4 times width, with complete, posteriorly smoothly curved transverse fold, ornamented. Lateral margin notched. Foot plate broad, coxal plate triangular. Prepedal fold broadly rounded distally. Foot pseudosegment simple, widest in distal third, lateral margins smooth, not or only slightly projecting, bearing a single toe and a relatively large dorsal pedal lobe. Toe parallel-sided, with a pair of pseudoclaws and accessory claws and a transverse constriction at 2/5th from the toe tip.
Trophi (Fig. 8): Manubria and unci symmetrical. Fulcrum with well developed basal plate. Rami asymmetrical: right ramus with oblique downward and strongly bend hook-shaped alulus. Unci strongly asymmetrical, right frontal teeth particularly developed.

Measurements:
Dorsal plate length 59.2–67.3 μm, width 49.4–52.9 μm, Ventral plate length 64.4–68.3 μm, width 45.8–49.5 μm, Toe 20.6–24.5 μm, Pseudoclaw 5.1–7.0 μm. Trophi length 20.8 μm, fulcrum 6.2 μm, incus width 11.0 μm, uncus length 7.2 μm.

Distribution and ecology:
This species is known only from a pond and a canal in Kun Thu Lee peat swamp, Suratthanee province. Water temperature was 25–25.4 °C, pH 5.35–5.75, DO 3.26–4.58 mg.l^{-1}, Cond. 0.015–0.019 mS.cm^{-1} and turbidity 23–37 NTU.



Figures 6–8. Lecane spp., trophi SEM. 6: *L. junki* Koste ventral, 7: *L. junki* Koste dorsal; 8: *L. kunthuleensis* n.sp. dorsal ventral (scale bars: 10 μm).

Etymology:
The name of the new species refers to type locality of the animal, Kun Thu Lee peat swamp.

Lecane junki **Koste, 1975 (Figs 4–5, 6–7)**

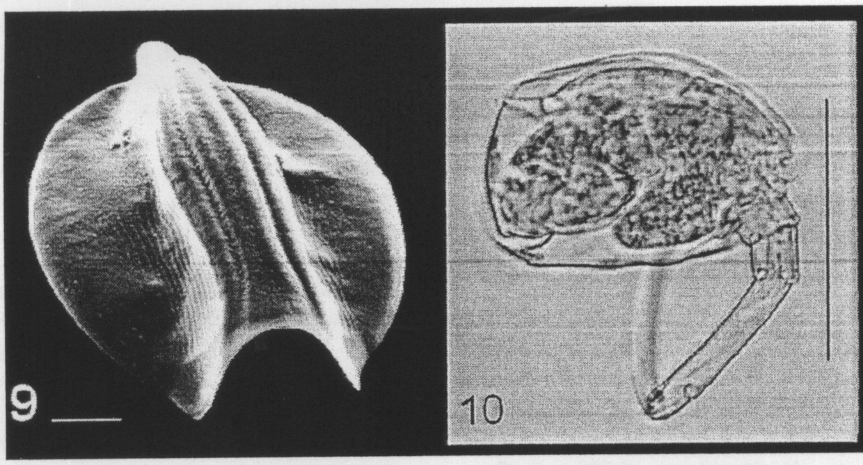
Material examined: Numerous specimens from the littoral zone of Kra Jood peat swamp, Suratthanee province, Thailand (Fig. 1: 99° 16.27′ E–99° 16.31′ E, 8° 53.65′ N–8° 53.71′ N), collected 23 October 1998. Permanent slides are deposited in the Plankton Research Unit, Department of Biology, Faculty of Science, Prince of Songkla University, Hat Yai, Songkhla, Thailand, the Department of Biology, Khon Kaen University (KKU), Khon Kaen, Thailand.

Comments:
L. junki was described from the littoral of Bung-Borapet Lake, North Thailand (Koste, 1975), and has only now been found again. The present record is from a different type of habitat, and confirms the status of this species as a Thai endemic. The species is unmistakable by the small spicules on the ventral head aperture margin and by the presence of characteristic coxal plates, foot with relatively large pedal lobe, and toe.

Trophi (Figs 6–7): Manubria symmetrical. Fulcrum straight, rod-shaped. Rami asymetrical, right ramus with downwardly curved alulus. Unci weakly asymmetrical.

Measurements:
Dorsal plate length 52 μm, width 55 μm, ventral plate length 54 μm, width 58 μm, Toe 30 μm, claw 19 μm. Trophi length 19.6 – 20.4 μm, fulcrum 4.1 – 4.2 μm, incus width 9.4 – 10 μm, uncus length 8.3 – 8.9 μm.

Ecology:
Water temperature 25.8 – 27.2 °C, pH 5.59 – 5.98, DO 7.1 – 7.8 $mg.l^{-1}$, conductivity 0.023 – 0.032 mS. cm^{-1}, turbidity 11 – 43 NTU.



Figures 9–10. Lepadella punctata Wulfert, oblique frontal and dorsal, SEM photograph (scale bar: 10 μm). *Paracolurella aemula* Myers, lateral. Light microscopy photograph (scale bar: 50 μm).

Lepadella punctata **Wulfert, 1939 (Fig. 9)**
Material examined:
A few specimens from To Daeng peat swamp, Narathiwas province, Thailand, (Fig. 1: 101° 55′ E–102° 03′ E, 06° 03′ N–06° 03′ E), collected on 18 July 1998.

Ecology: Water temperature 27–35 °C, pH 4.0–6.04, conductivity 0.035–0.138 mS.cm^{-1}, turbidity 7–24 NTU.

Note:
L. punctata was to date only known from two specimens from type locality in Germany, Europe (Wulfert, 1939). The species is related to *L. triptera* (Ehrenberg), but is unmistakable by the presence of four more or less parallel ridges on the dorsal plate. This apparently rare species is new to the Oriental region.

Paracolurella aemula **(Myers, 1934) (Fig. 10)**
Material examined:
A few specimens from the littoral of Kra Jood peat swamp, Suratthanee province, Thailand, (Fig. 1: 99° 16.27′ E–99° 16.31′ E, 8° 53.65′ N–8° 53.71′ N), collected on 23 October 1998. Permanent slides are in the Plankton Research Unit, Department of Biology, Faculty of Science, Prince of Songkla University, Hat Yai, Songkhla, Thailand.

Ecology:
Same as for *L. junki.*

Note:
Paracolurella aemula can be distinguished from its congener *P. logima* by its third foot pseudosegment being only slightly longer than the toes, and species-specific lorica shape. Although this is the first record of *P. aemula* from Thailand, it had been reported from the Oriental region before (Singapore, India, Indonesia: Sudzuki, 1989; De Ridder & Segers, 1997). This rare Pantropical species is also known from South America (Brazil: De Ridder & Segers, 1997), and Africa (Congo, Nigeria, Lake Tanganyika: De Ridder, 1986, 1991, 1994).

Measurements:
Lorica length 62 μm, width 43 μm, Last foot pseudosegment length 38 μm, Toe length 30 μm.

Concluding remarks

In addition to the species treated above, two more remarkable taxa were found. *Lepadella minoruoides* Koste & Robertson, 1983 and *Testudinella walkeri* Koste & Shiel, 1980, both found by us in Kra Jood peat swamp, have been recorded from Thailand before (Segers & Pholpunthin, 1997; Sanoamuang & Savatenalinton, 2001), but these species remain rare globally. The former is widely distributed in tropical regions (Segers et al., 1993), whereas the latter is apparently Australasian (Segers & Pholpunthin, 1997; Segers, 2001). However, records of both are few. That these rare species are known from several localities in Thailand illustrates that the coverage of freshwater biodiversity studies in the country is relatively good, compared to other tropical regions.

Notwithstanding that Thailand has recently become the most well studied Southeast Asian country (Segers, 2001), it is clear that the record on the biodiversity of the most species-rich group of primarily freshwater Metazoa, the Rotifera, remains incomplete. This is exemplified by the present additions, and those in other recent publications (e.g., Segers & Chittapun, 2001; Chittapun et al., 2002). The present results moreover expand the gap in knowledge on freshwater biodiversity between Thailand and other Southeast Asian countries, which argues for more extensive research in these countries.

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