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

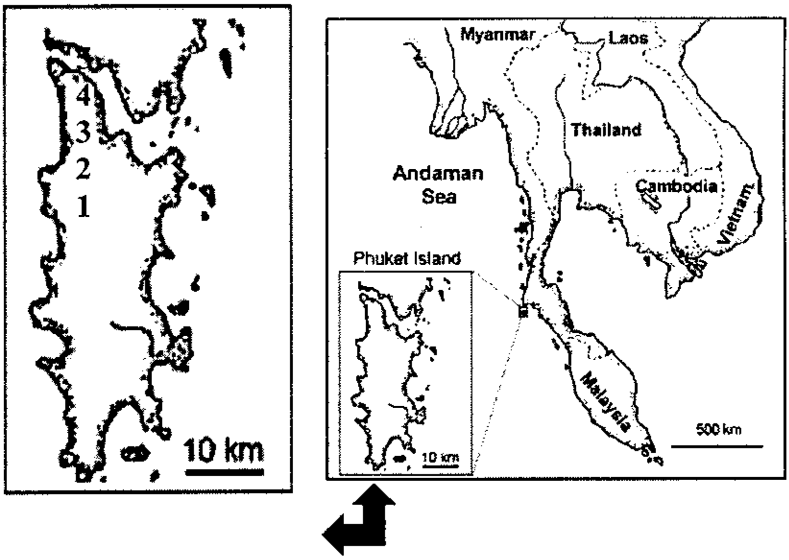

Figure 3.1.1 Map of Thailand showing the location of five coastal peat swamps in Phuket province (1: Mai-Khao, 2: Jood, 3: Jik, 4: Jae-Son and 5: Sra-Boua).

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

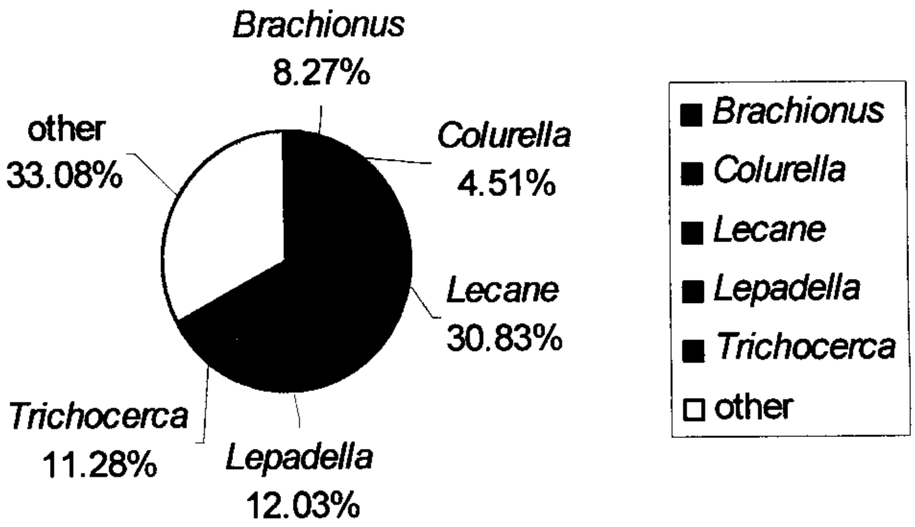

Figure 3.1.2 Percentages of the rotifer composition of five coastal peat swamps along Mai-Khao coast in Phuket province.

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. arcula Harring
L. crepida Harring
L. curvicornis (Murray)
L. doryssa Harring
L. grandis (Murray)
L. haliclysta Harring and Myers
L. hastata (Murray)
L. hornemanni (Ehrenberg)
L. leontina (Turner)
L. monostyla (Daday)
L. obtusa (Murray)
L. palinacis Harring and Myers
L. rhenana Hauer
L. rhytida Harring and Myers
L. signifera (Jennings)
L. subtilis Harring and Myers
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. capucina (Wierzejski and Zacharias)
T. pusilla (Jinnings)
T. similis (Wieszejski)
T. tenuior (Gosse)
T. tigis (Müller)
T. weberi (Jinnings)

Warm-water taxa (5 species – 33.33%)

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

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)

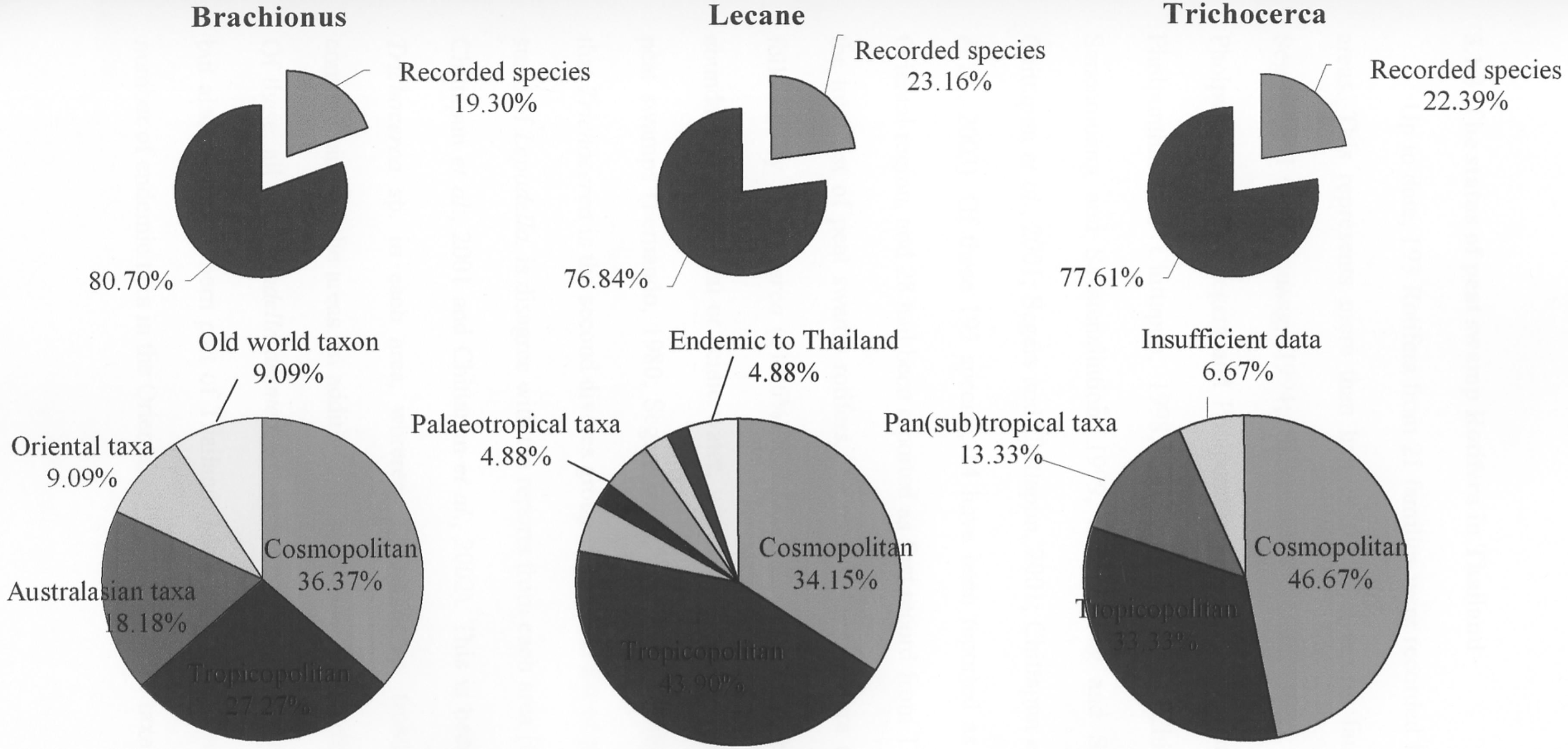

Figure 3.1.3 Proportional occurrence of distribution patterns in genera *Brachionus*, *Lecane* and *Trichocerca* of the five coastal peat swamps

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)

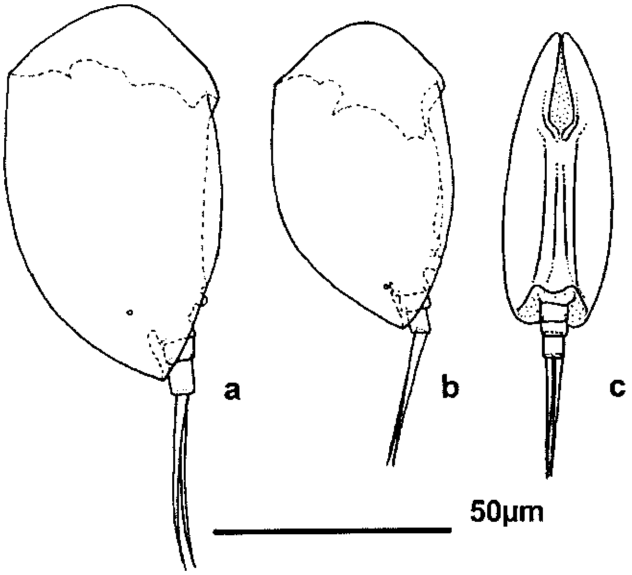

Figure 3.1.4 *Colurella psammophila* Segers and Chittapun, 2001 (a, b: lateral view, c: ventral view).

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)

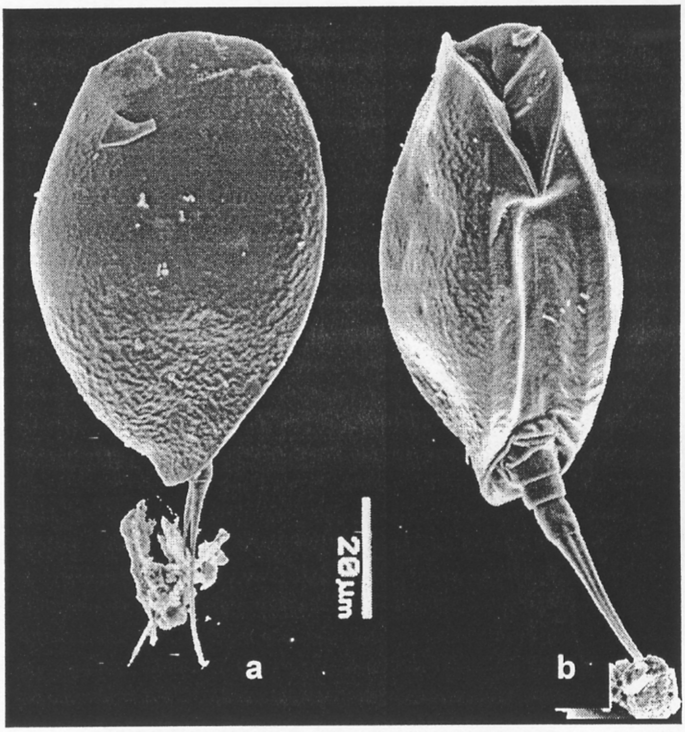

Figure 3.1.5 *Colurella sanoamuangae* Chittapun, Phonpunthin and Segers, 1999 (a: lateral view, b: ventral view).

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)

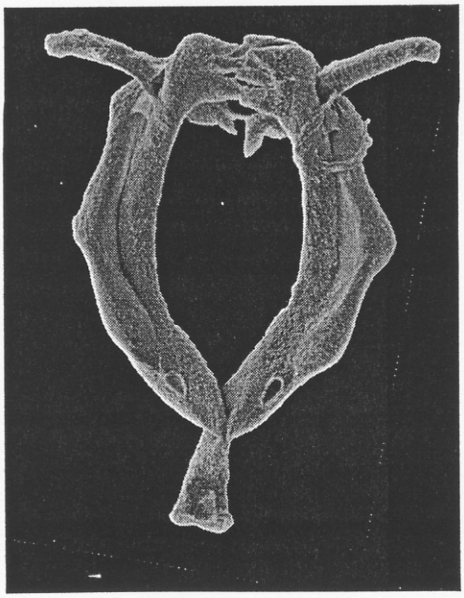

Figure 3.1.6 Ventral view of *Dicranophoroides* sp. trophi.

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)

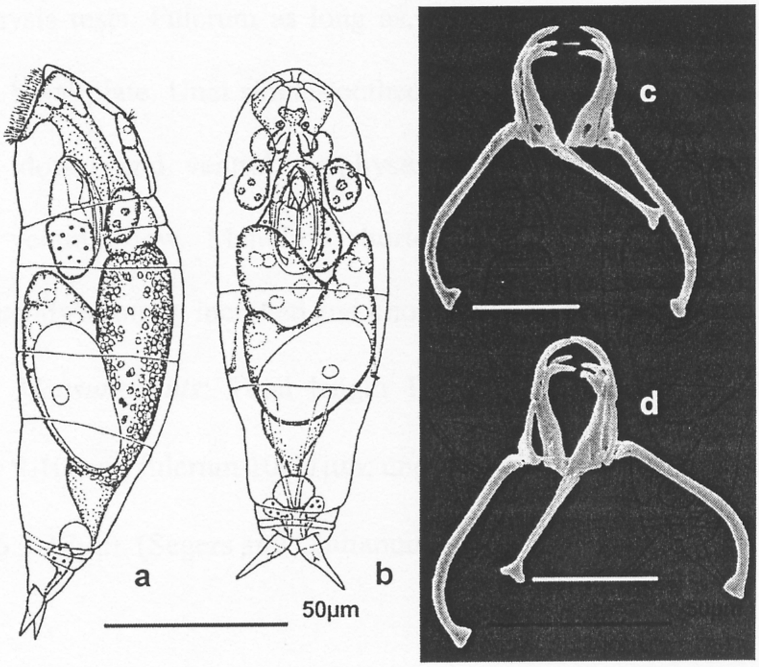

Figure 3.1.7 *Encentrum pornsilpi* Segers and Chittapun, 2001 (a: lateral view, b: ventral view, c: ventral view of trophi, d: dorsal view of trophi).

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)

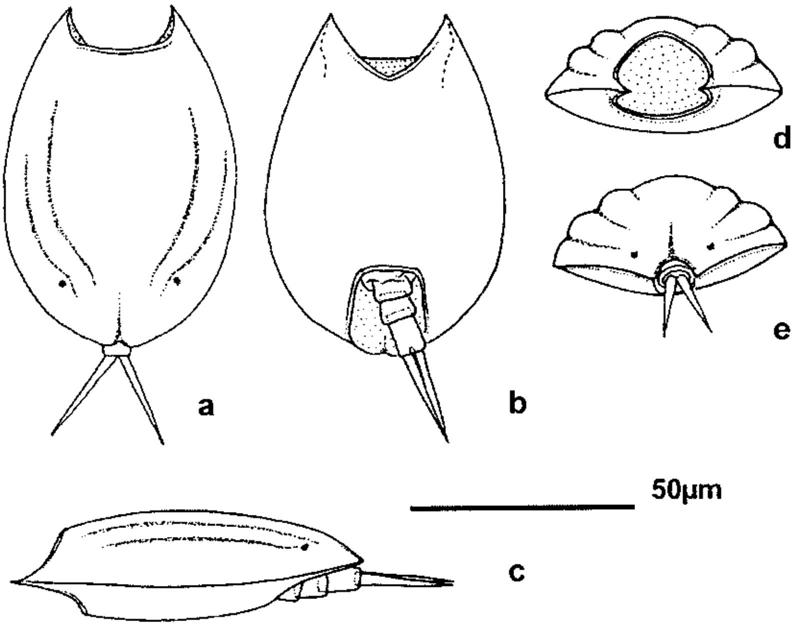

Figure 3.1.8 *Lepadella desmeti* Segers and Chittapun, 2001 (a: dorsal view, b: ventral view, c: lateral view, d: anterior view, e: posterior view).

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)

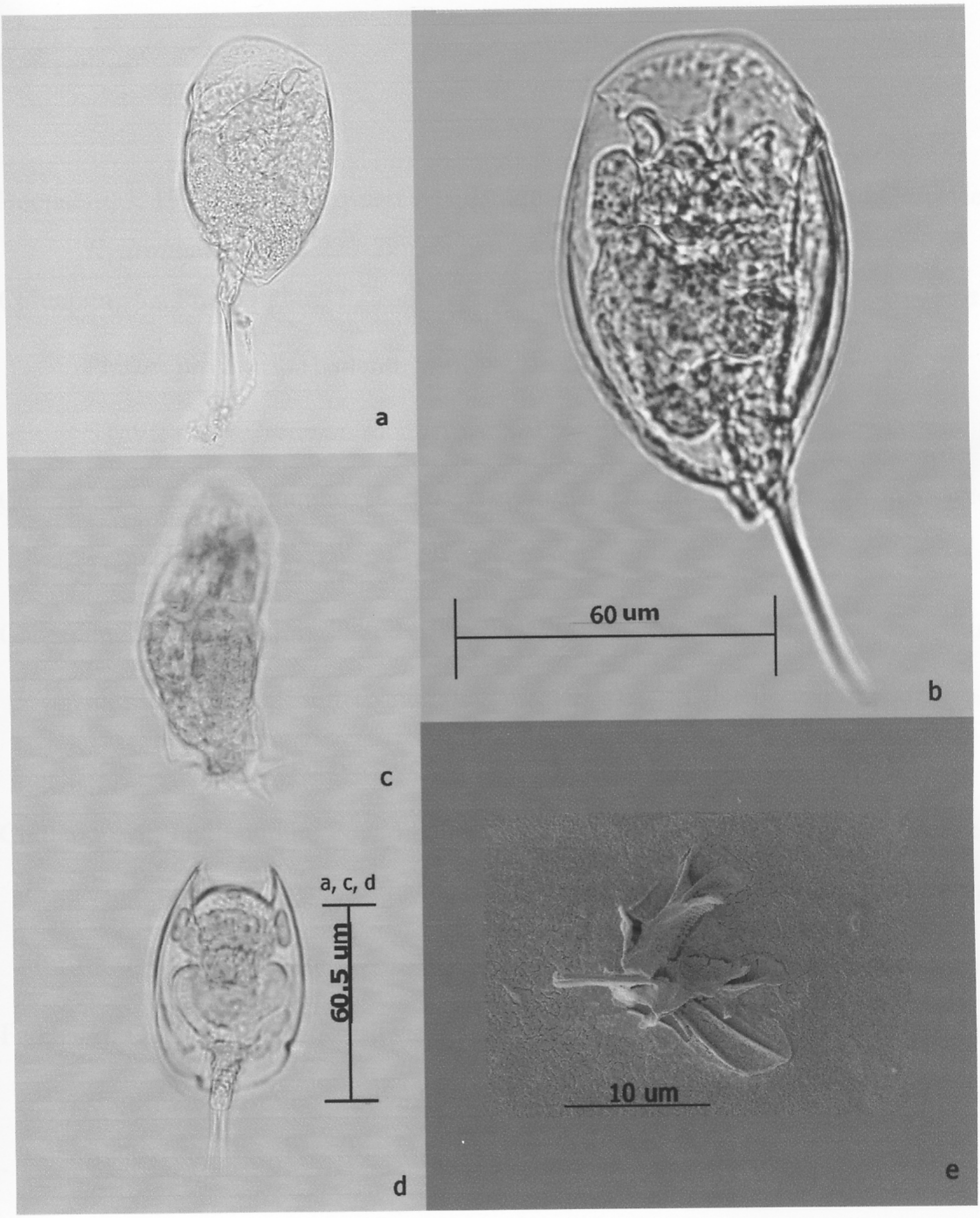

Figure 3.1.9 Microscopic pictures of rotifers; a: *Colurella psammophila,* b: *C. sanoamuangae,* c: *Encentrum pornsilpi*, d: *Lepadella desmeti,* e: *Harringia rousseleti.*

References

Boonsom, J. 1984. The freshwater zooplankton of Thailand (Rotifera and Crustacea). *Hydrobiologia* 113:223-229.

Chittapun, S., Pholpunthin, P. and Segers, H. 1999. Rotifera from peat-swamps in Phuket province, Thailand, with the description of a new *Colurella* BORY DE ST. VINCENT. *Internat. Rev. Hydrobiol.* 84(6):587-593.

Chittapun, S. and Pholpunthn, P. 2001. The rotifer fauna of peat-swamps in southern Thailand. *Hydrobiologia* 446/447:255-259.

Chittapun, S., Pholpunthin, P. and Segers, H. 2002. Rotifer diversity in a peat-swamp in southern Thailand (Narathiwas province) with the description of a new species of *Keratella* Bory de St. Vincent. *Ann. Limnol.* 38(3):185-190.

Chittapun, S., Pholpunthin, P. and Segers, H. 2003. Contribution to the knowledge of Thai microfauna diversity: notes on rare peat swamp Rotifera, with the description of a new *Lecane* Nitzsch, 1872. *Hydrobiologia* 501: 7-12.

Fernando, C. H. 1980. The freshwater zooplankton of Sri Lanka, with a discussion of tropical freshwater zooplankton composition. *Int. Revue ges. Hydrobio*. 65: 85-125.

De Ridder, M. and Segers, H. 1997. *Monogonont Rotifera recorded in the World literature (except Africa) from 1960 to 1992*, 481 pp. Brussel: Studiedocumenten van het Koninklijk Belgisch Instituut voor Natuurwetens chappen.

De Smet, W. H and Pourriot, R. 1997. *Guides to the identification of the Microinvertebrates of the Continental Waters of the World, Rotifera Volume 12: The Dicranophoirae (Monogononta) and The Ituridae (Monogononta)*, 344 pp. Amsterdam: SPB Academic Publishing.

De Smet, W. H. 2001. Some Rotifera from Ile Amsterdam (Terres Australes et Antarctiques Francaises), with description of *Brachinonus amsterdamensis* sp. nov. (Monogononta: Brachionidae). *Annales de Limnologie* 37(1): 9-20.

Dumont, H. J. 1983. Biogeography of rotifers. *Hydrobiologia* 104: 19-30.

Pejler, B. 1977. On the global distribution of the family Brachionidae (Rotatoria). *Archiv f. Hydrobiologie* 53(2): 255-306.

Sanoamuang, L. 1996. *Lecane segersi* n. sp. (Rotifera, Lecanidae) from Thailand. *Hydrobiologia* 339(1-3):23-25.

Sanoamuang, L. and Segers, H. 1997. Addition to the *Lecane* fauna (Rotifera: Monogononta) of Thailand. *Internationale Revue des Gesamten Hydrobiologie* 82(4): 525-530.

Sanoamuang, L, Segers, H. and Dumont, H. J. 1995. Additions to the rotifer fauna of south-east Asia: new and rare species from north-east Thailand. *Hydrobiologia* 313/314: 35-45.

Sanoamuang, L. and Savatenalintion, S. 1999. New records of rotifers from Nakhon Ratchasima province, northeast Thailand, with a description of *Lecane baimaii* n. sp.. *Hydrobiologia* 412: 95-101.

Sanoamuang, L. and Savatenalintion, S. 2001. The rotifer fauna of Lake Kud-Thing, a shallow lake in Nong Khai Province, northeast Thailand. *Hydrobiologia* 446/447:297-304.

Segers, H. 1996. The biogeography of littoral *Lecane* Rotifera. *Hydrobiologia* 323: 169-197.

Segers, H. 1997. Some Rotifera from the collection of the Academy of Natural Sciences of Philadelphia, including new species and new records. *Proceedings of the Academy of Natural Sciences of Philadelphia* 148(31): 147-156.

Segers, H. 2001. Zoogeography of the Southeast Asian Rotifera. *Hydrobiologia*: 446/447: 233-246.

Segers, H. 2003. A biogeographical analysis of rotifers of the genus *Trichocerca* Lamarck, 1801 (Trichocercidae, Monogononta, Rotifera0, with notes on taxonomy. *Hydrobiologia*. (in press)

Segers, H. and Mbogo, D. K. and Dumont, H. J. 1194. New Rotifera from Kenya, with a revision of the Ituridae. *Zoological Journal of the Linnean Society* 110(2): 193-206.

Segers, H. and Dumont, H. J. 1995. 102+ rotifer species (Rotifera: Monogononta) in Broa reservoir (SP., Brazil), on 26 August 1994, with descriptions of three new species. *Hydrobiologia* 316: 183-197.

Segers, H. and Baribwegure, D. 1996. On *Lecane tangayikae* new species (Rotifera: Monogononta, Lecanidae). *Hydrobiologia* 324(2): 179-182.

Segers, H. and Mertens, J. 1997. New Rotifera from the Korup National Park, Cameroon. *Journal of Natural History* 31(5): 663-668.

Segers, H. and Pholpunthin, P. 1997. New and rare Rotifera from Thale-Noi Lake, Pattalang Province, Thailand, with a note on the taxonomy of *Cephalodella* (Notommatidae). *Annls Limnol.* 33(1):13-21.

Segers, H. and Pourriot, R. 1997. On a new and puzzling American rotifer (Rotifera: Monogononta, Lecanidae). *Journal of Natural History* 31(3): 383-388.

Segers, H. and Chittapun, S. 2001. The interstitial Rotifera of a tropical freshwater peat swamp on Phuket Island, Thailand. *Belg. J. Zool.* 131(2):25-31.

Silva-Briano, M. and Segers, H. 1993. Una nueva especie del genero *Brachionus* (Rotifera: Monogononta) del Estado de Aguascalientes, Mexico. *Revue d'Hydrobiologie Tropicale* 25(4): 283-285. (cited from Zoological record 1992/1993)

Sudzuki, M. and Xiang-fei, H. 1997. New Rotifera from Wuhan. *Chinese Journal of Oceanology and Limnology* 15(2): 181-185. (cited from Zoological record, vol. 134, 1997/1998).

Youqin, X., Yinshan, C. and Xiaozhen, R. 1997. New material of freshwater rotifer of Fujian. *Jounal of Fujian Teachers University of Natural Science* 13(3): 77-80. (cited from Zoological record, vol. 134, 1997/1998).

Zhuge, Y. and Koste, W. 1996. Two new species of Rotifera from china. *Internationale Revue der Gesamten Hydrobiologie* 81(4): 605-609.

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}^n = 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^*	$Var(S_5^*) = \sum (1-p_i)^n \left[1-(1-p_i)^n\right] + \sum\sum \left\{q_{ij}^n - \left[(1-p_i)^n (1-p_i)^n\right]\right.$		

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).

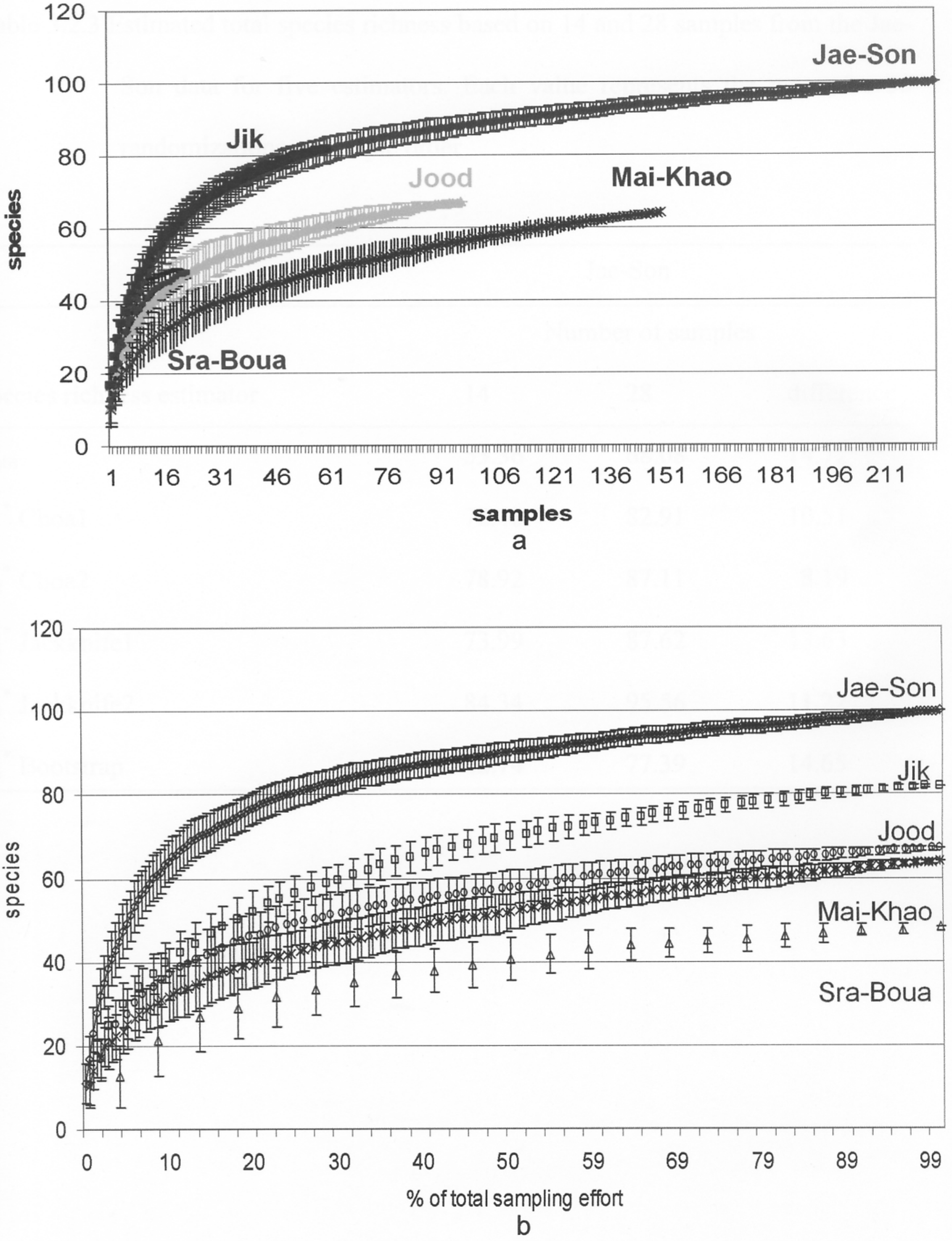

Figure 3.2.1 (a) Observed species accumulation curves of the five areas (±1SD); (b) Observed species accumulation curves (±1SD) of the percent of total sampling effort from five coastal peat swamps.

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

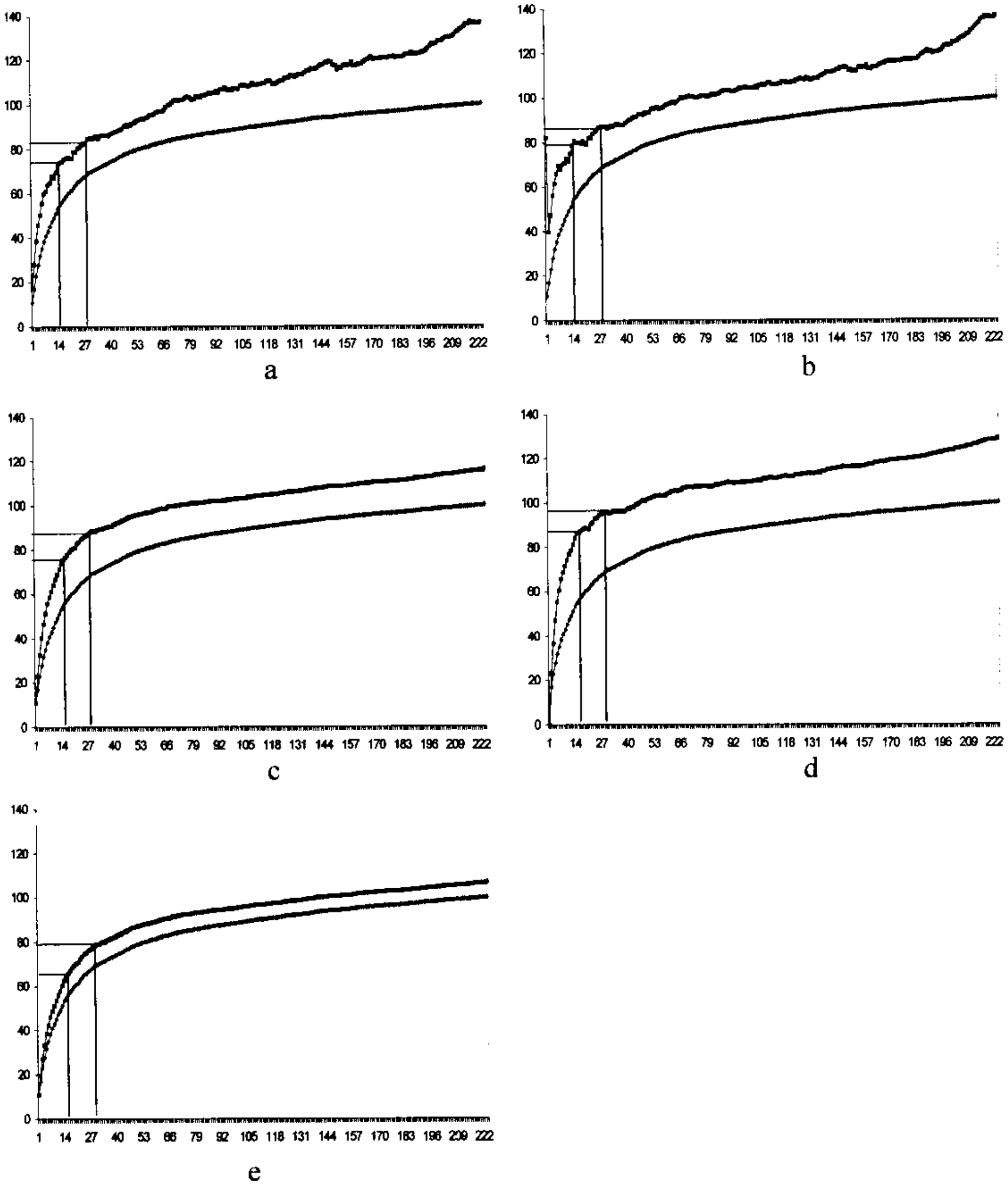

Figure 3.2.2 Performance of five non-parametric estimators of species richness for Jae-Son peat swamp. (a) S_1^*, Choa 1; (b) S_2^*, Choa 2; (c) S_3^*, First-order Jackknife; (d) S_4^*, Second-order Jackknife; (e) S_5^*, Bootstrap. The blue curve in each panel (the species accumulation curve) plots the 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.

References

Beger, M., Jones, G. P. and Munday, P. L. 2003. Conservation of coral reef biodiversity: a comparison of reserve selection procedures for corals and fishes. *Biological Conservation* 111: 53-62.

Begon, M., Harper, J. L. and Townsend, C. R. 1998. *Ecology* (3rd ed.), 1068 pp. United Kingdom: Blackwell Science.

Beisel, J. N., Philppe, U. P., Vincent, P. and Jean, C. M. 2003. A comparative analysis of Evenness index sensitivity. *Internat. Rev. Hydrobiol.* 88(1): 3-15.

Colwell, R. K. 1997. EstimateS: Statistical estimation of species richness and shared species from samples. Version 6. User's Guide and application published at: http://viceroy.eeb.uconn.edu/estimates.

Colwell, R. K. and Coddington, J. A. 1994. Estimating terrestrial biodiversity through extrapolation. *Phil. Trans. R. Soc. Lond.* B: 101-118.

Dumont, H. J. and Segers, H. 1990. Estimating lacustrin zooplankton species richness and complementarity. *Hydrobiologia* 341: 125-132.

Ferrari, I., Farabegoli, A. and Mazzoni, R. 1989. Abundance and diversity of planktonic rotifers in the Po River. *Hydrobiologia* 186/187: 201-208.

Foggo, A., Attrill, M. J., Frost, M. T. and Rowden, A. A. 2003. Estimating marine species richness: an evaluation of six extrapolative techniques. *Marine Ecology Progress Series* 248: 15.26.

Galkovskaya, G. A, and Molotkov, D. V. 2001. Species diversity and dominance in the planktonic rotifer community of the Pripyat River in the Chernobyl region (1988-1996). *Hydrobiologia* 446/447: 179-185.

Gotelli, N. J. and Colwell, R. K. 2001. Review: Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4: 379-391.

Green, J. 1993. Diversity and dominance in planktonic rotifers. *Hydrobiologia* 255/256: 345-352.

Hellmann, J. J. and Fowler, G. W. 1999. Bias, precision, and accuracy of four measures of species richness. *Ecological Applications* 9(3): 824-834.

Henry, M., Stevens, H. and Carson, W. P. 2001. Phenological complementarity, species diversity, and ecosystem function. *Oikos* 92: 291-296.

Kempton, R. A. 2002. *Species diversity. Encyclopedia of Environmetrics 4 : 2086-2092*, Chichester: John Wiley and Sons, Ltd.

Loreau, M. 2000. Mini review: Biodiversity and ecosystem functioning: recent theoretical advances. *Oikos* 91: 3-17.

Mackenzie, A., Ball, A. S. and Virdee, S. R. 1998. *Instant Notes in Ecology*, 321 pp. Singapore: BIOS Scientific Publishers Limited.

Magurran, A. E. 1988. *Ecological Diversity and Its Measurement*, 179 pp. USA: Princeton University Press.

Odegaard, F. 2000. How many species of arthropods? Erwin's estimate revised. *Biological Jounal of the Linnean Society* 71: 583-597.

Oltra, R., Alfonso, M. T., Sahuquillo, M. and Miracle, M. R. 2001. Increase of rotifer diversity after sewage diversion in the hypertrophic lagoon, Albufera of Valencia, Spain. *Hydrobiologia* 446/447: 213-220.

Putman, R.J. 1994. *Community ecology*, 178 pp. London: TJ Press Ltd.

Sharma, B. K. and Sharma, S. 2001. Biodiversity of Rotifera in some tropical floodplain lakes of the Brahmaputra river basin, Assam (N.E. India). *Hydrobiologia* 446/447: 305-313.

Southwood, T. R. E. and Henderson, P. A. 2000. *Ecological methods* (3rd ed.), 575 pp. United Kingdom: Blackwell Science Ltd.

Thompson, G. G. and Withers, P. C. 2003. Effect of species richness and relative abundance on the shape of the species accumulation curve. *Austral Ecology* 28: 355-360.

Thompson, G. G., Withers, P. C., Pianka, E. R. and Thompson, S. A. 2003. Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. *Austral Ecology* 28: 361-383.

Ugland, K. I., Gray, J. S. and Ellingsen K. E. 2003. The species-accumulation curve and estimation of species richness. *Journal of Animal Ecology* 72: 888-897.

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.

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                        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.

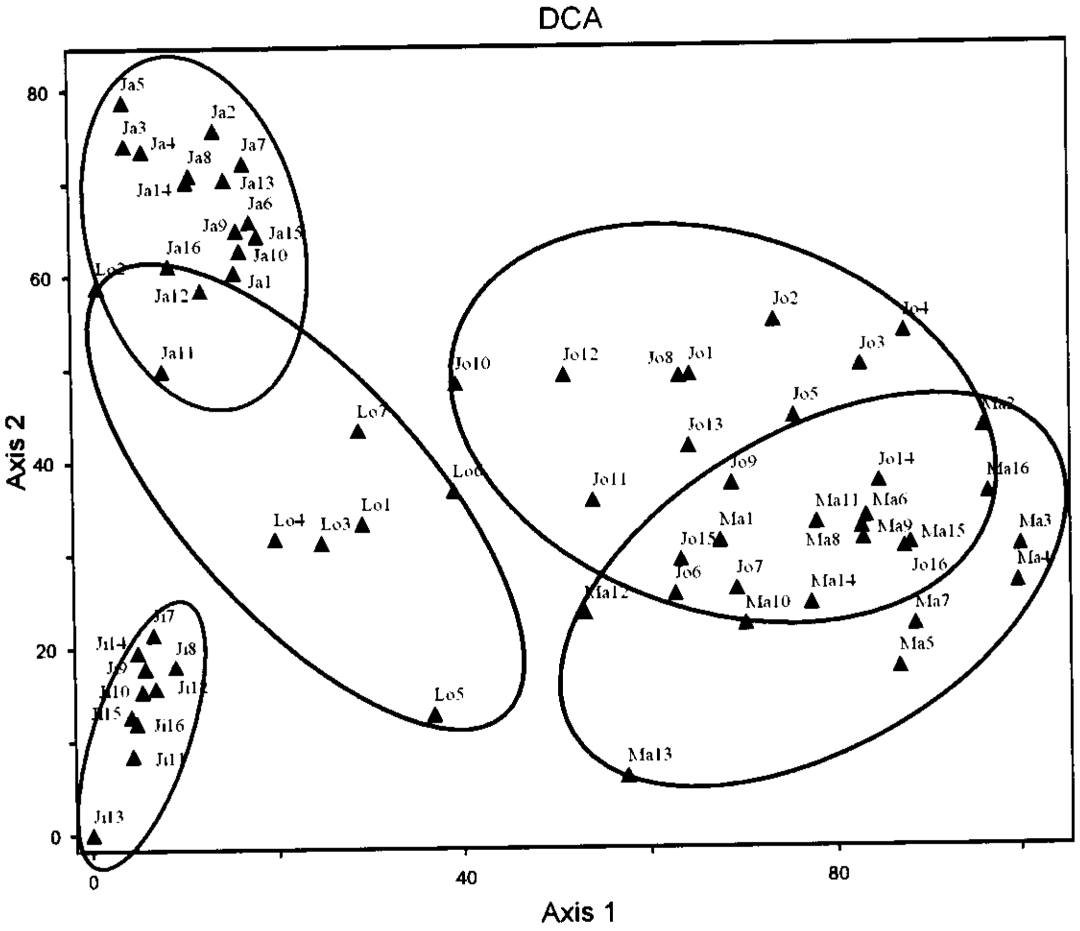


Figure 3.3.2 DCA ordination of rotifer community of monthly samples from five coastal peat swamps (number = sampling month, Ma = Mai-Khao, Jo = Jood, Ji = Jik, Ja = Jae-Son and Lo = Sra-Boua).

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

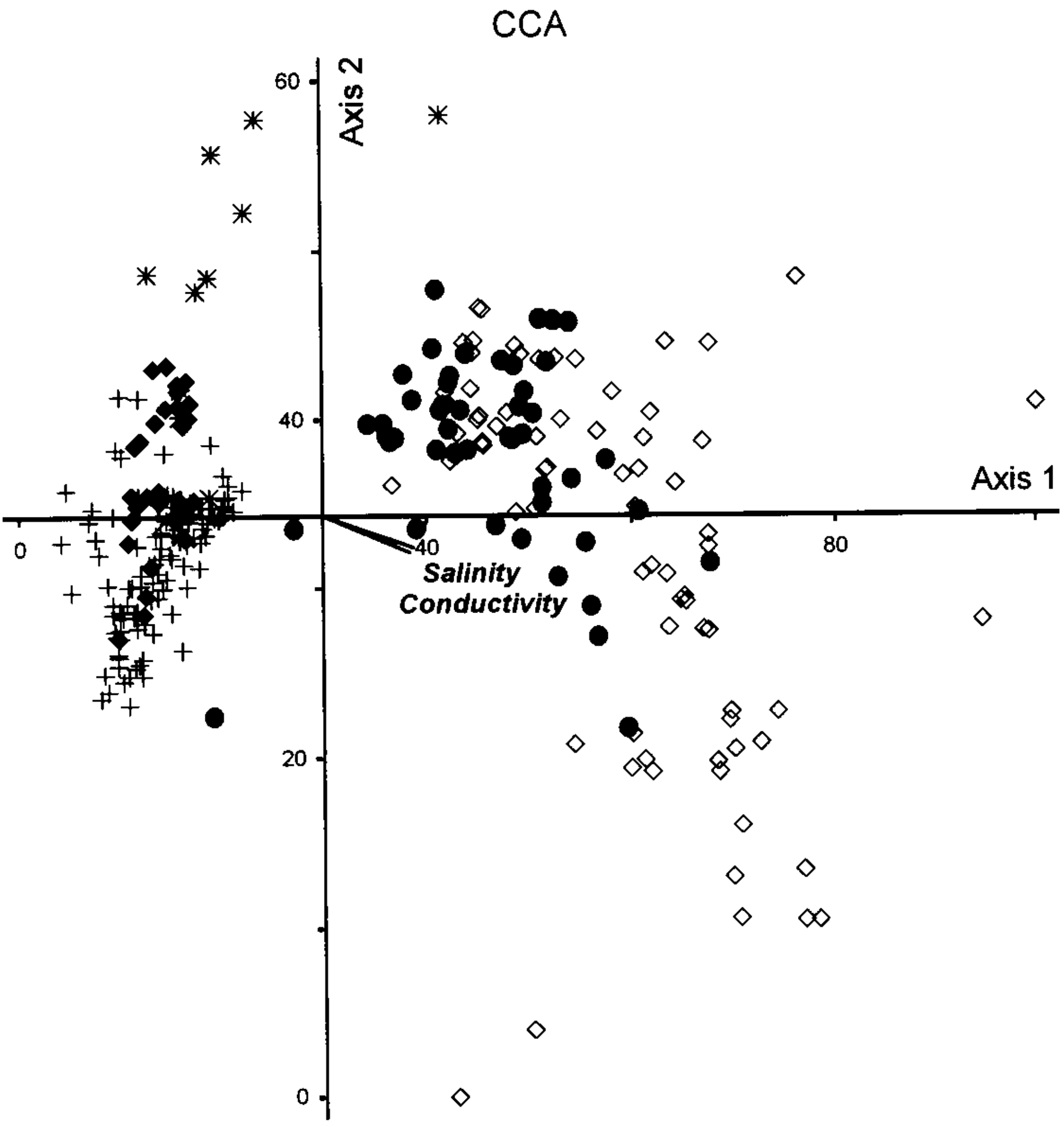


Figure 3.3.3 The CCA ordination of samples and important variables of the five peat swamps (◇ = Mai-Khao samples, ● = Jood samples, ◆ = Jik samples, + = Jae-Son samples and ✳ = Sra-Boua samples).

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.

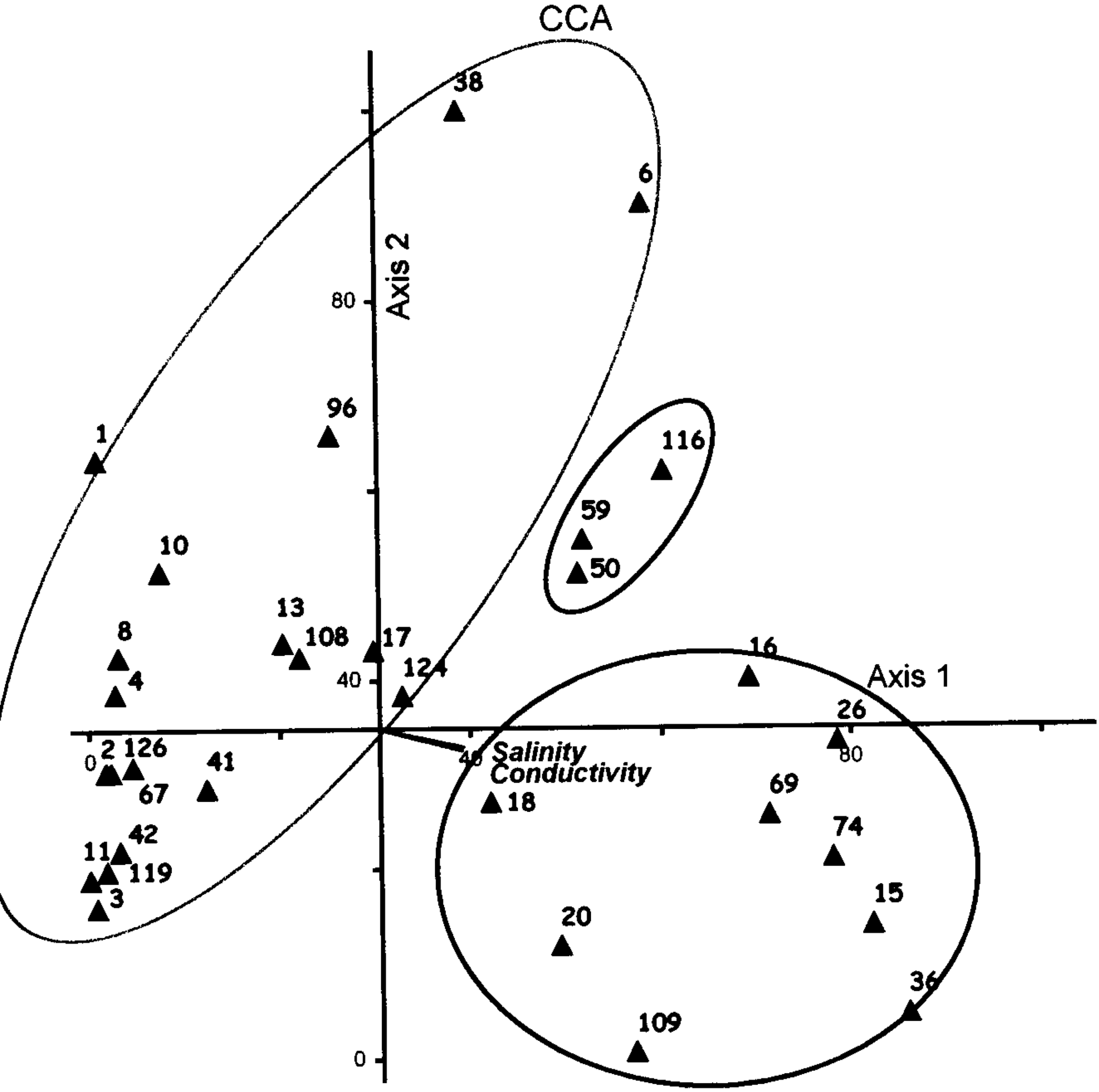


Figure 3.3.4 The CCA ordination of rotifer species and important variables of the five peat swamps, 1 *Anureaopsis coelata*,2 *A. fissa,* 3 *A. navicula,* 4 *Ascomorpha ovalis,* 6 *Brachionus angularis,* 8 *B. dichotomus,* 10 *B. falcatus,* 11 *B. forficula,* 13 *B. quadridentatus,* 15 *B. plicatilis,* 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.

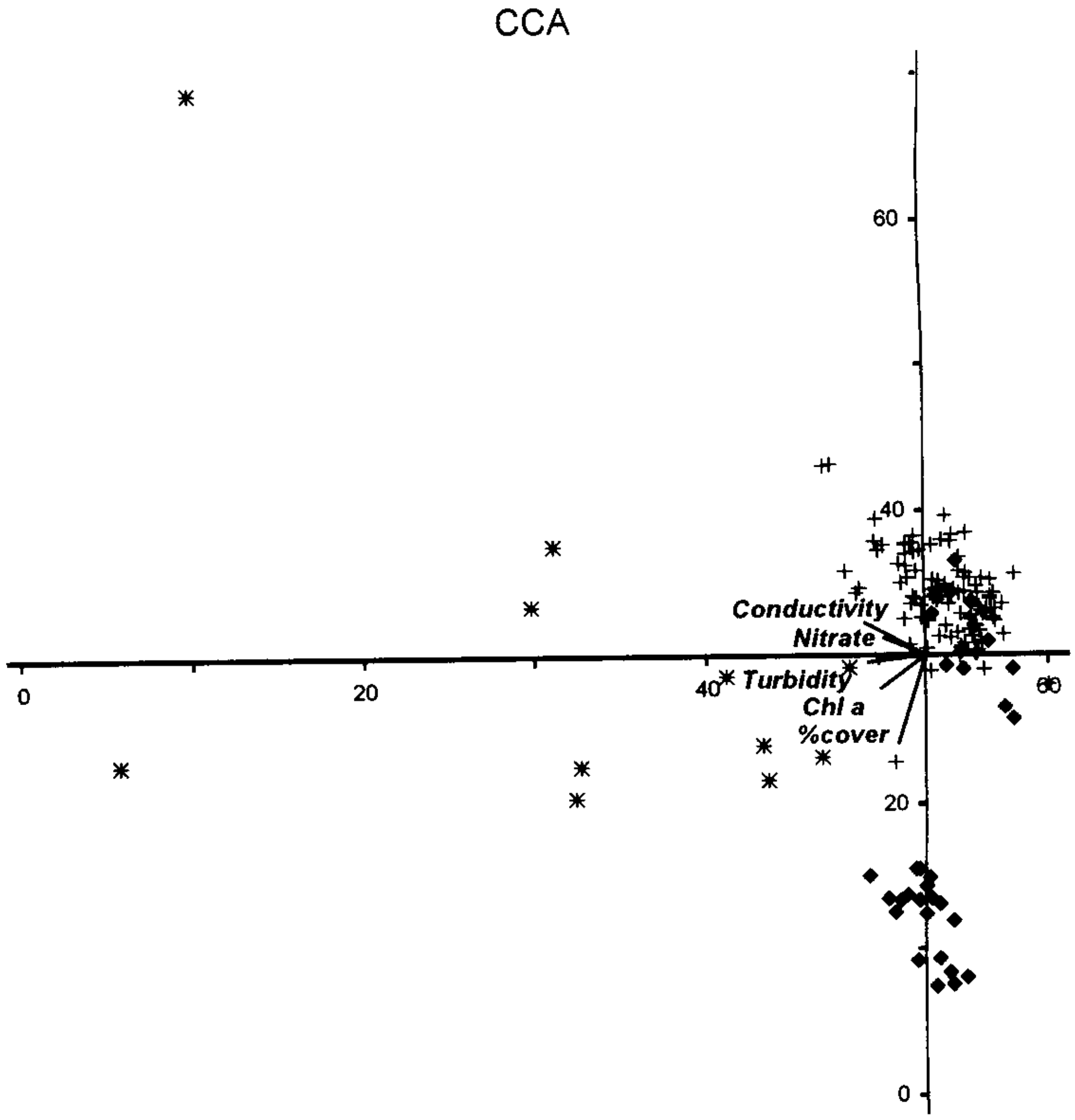


Figure 3.3.5 The CCA ordination of samples and important variables of the three peat swamps (◆ = Jik samples, + = Jae-Son samples and ✳ = Sra-Boua samples).

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.

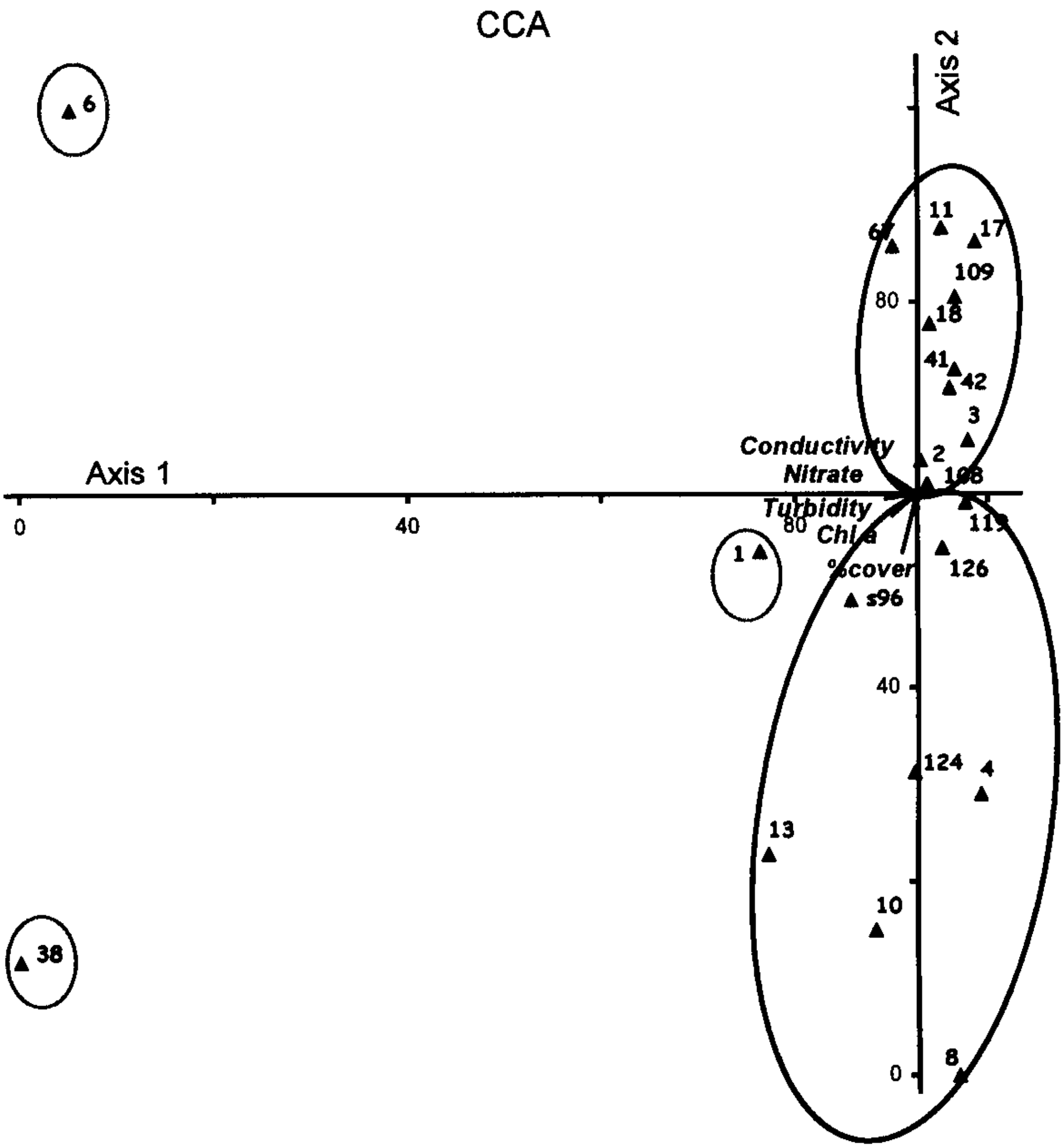


Figure 3.3.6 The CCA ordination of rotifer species and important variables of the three peat swamps, 1 *Anureaopsis coelata*, 2 *A. fissa*, 3 *A. navicula*, 4 *Ascomorpha ovalis*, 6 *Brachionus angularis*, 8 *B. dichotomus*, 10 *B. falcatus*, 11 *B. forficula*, 13 *B. quadridentatus*, 17 *Cephalodella 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.

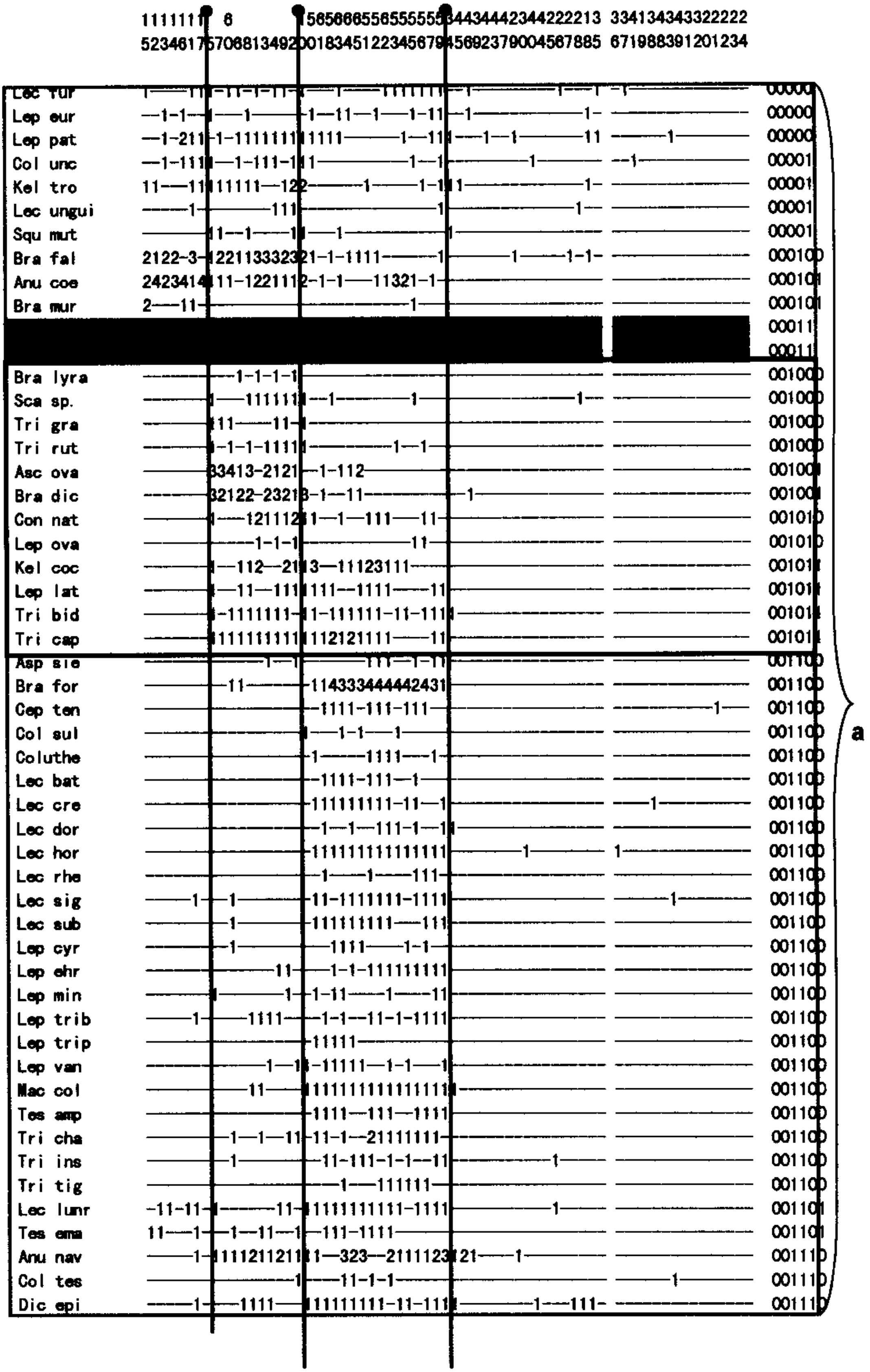
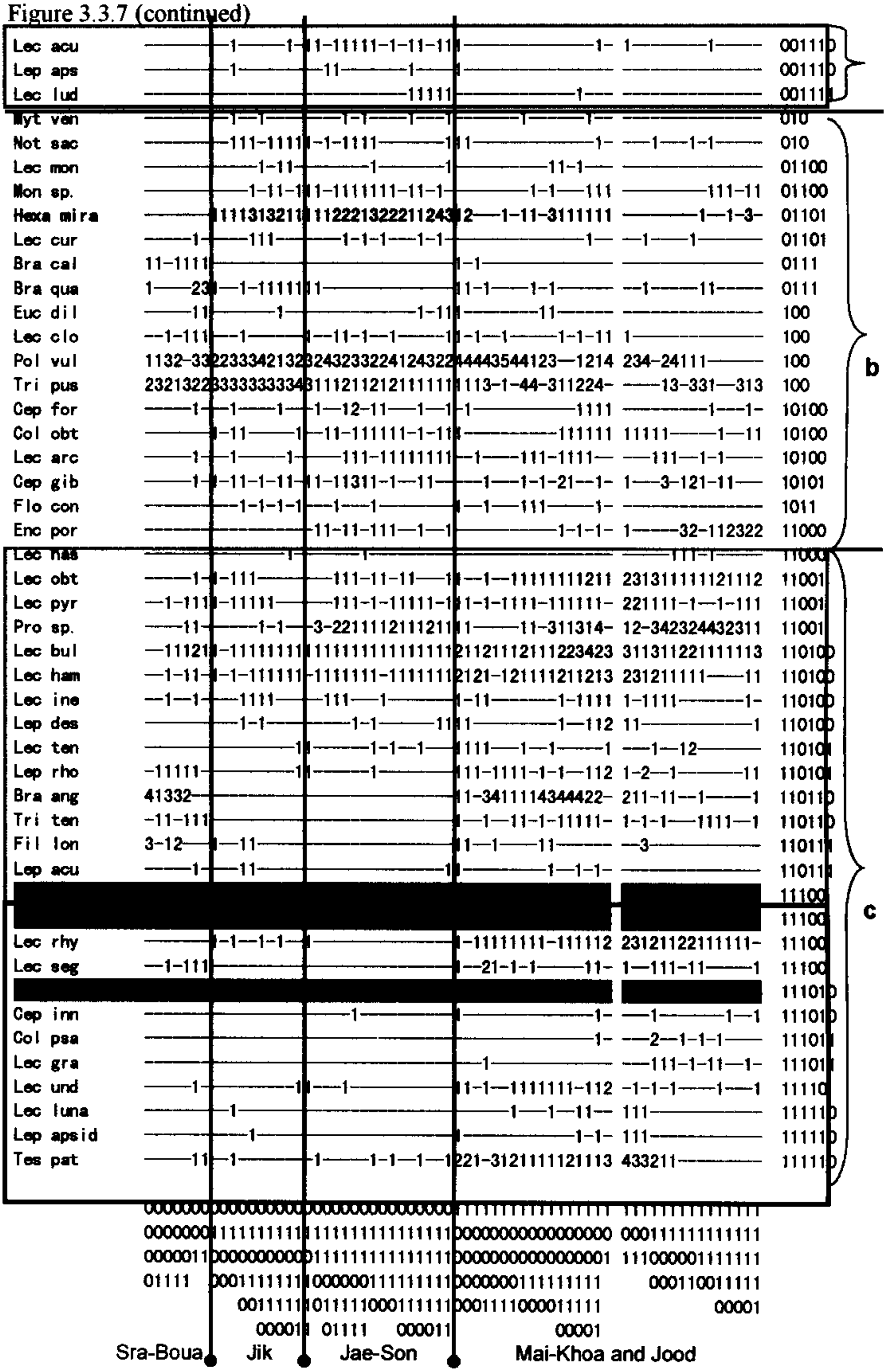


Figure 3.3.7 (continued)



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Lec lud     ———————————————————————11111——————1——— ————————— 001111
Myt ven     ———————1—1————1-1———1———1————1————1—— ————————— 010
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Sra-Boua
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Jae-Son
Mai-Khoa and Jood

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.

References

Bērziņš, B. and Pejler, B. 1987. Rotifer occurrence in relation to pH. *Hydrobiologia* 147: 107-116.

Blinn, D. W. and Bailey, P. C. E. 2001. Land-use influence on stream water quality and diatom communities in Victoria, Australia: a response to secondary salinization. *Hydrobiologia* 466:231-244.

Caley, M. J., Buckley, K. A. and Jones, G. P. 2001. Separating ecological effects of habitat fragmentation, degradation, and loss on coral commensals. *Ecology* 82(12):3435-3448.

Chittapun, S., Pholpunthin, P. and Segers, H. 1999. Rotifera from Peat-Swamps in Phuket Province, Thailand, with the Description of a New *Colurella* BORY DE ST. VINCENT. *Internat. Rev. Hydrobiol.* 84(6):587-593.

Chittapun, S. and Pholpunthn, P. 2001. The rotifer fauna of peat-swamps in southern Thailand. *Hydrobiologia* 446/447:255-259.

Chittapun, S., Pholpunthin, P. and Segers, H. 2002. Rotifer diversity in a peat-swamp in southern Thailand (Narathiwas province) with the description of a new species of *Keratella* Bory de St. Vincent. *Ann. Limnol.* 38(3):185-190.

Chittapun, S., Pholpunthin, P. and Segers, H. 2003. Contribution to the knowledge of Thai microfauna diversity: notes on rare peat swamp Rotifera, with the description of a new *Lecane* Nitzsch, 1872. *Hydrobiologia* 501: 7-12.

Halse, S. A., Shiel, R. J. and Williams, W. D. 1998. Aquatic invertebrates of Lake Gregory, northwestern Australia, in relation to salinity and ionic composition. *Hydrobiologia* 381:15-29.

Jersabek, C. D. 1995. Distribution and ecology of rotifer communities in high-altitude alpine sites – a multivatiate approach. *Hydrobiologia* 313/314: 75-89.

Lelane, H. V. and Berkar, W. R. 1998. Temporal variation in plankton assemblages and physiocochemistry of Devils Lake, North Dakota. *Hydrobiologia* 377(1):57-71.

Mäemets, A. 1983. Rotifers as indicators of lake types in Estonia. *Hydrobiologia* 104: 357-361.

Miracle, M. R. and Serra, M. 1989. Salinity and temperature influence in rotifer life history characteristics. *Hydrobiologia* 186/187:81-102.

Pejler, B. and Berzins. B. 1993. On the ecology of Trichocercidae (Rotifera). *Hydrobiologia* 263: 55-59.

Pontin, R. M. and Langley, J. M. 1993. The use of rotifer communities to provide a preliminary national classification of small water bodies in England. *Hydrobiologia* 225/226: 411-419.

Segers, H. and Dumont, H. J. 1993. Rotifera from Arabia, with Description of Two species. *Fauna of Saudi Arabia* 13:3-26.

Segers, H. and Chittapun, S. 2001. The interstitial Rotifera of a tropical freshwater peat swamp on Phuket Island, Thailand. *Belg. J. Zool.* 131(2):25-31.

Southwood, T.R.E. and P.A. Henderson. 2000. *Ecological Methods* (3rd ed.), 575pp. United Kingdom: Blackwell Science Ltd.

Stilling, P. 2002. *Ecology: Theories and Applications* (4th ed.), 403 pp. USA: Prentice-Hall, Inc.

Tiffany, M. A., Swan, B. K., Walts, J. M. and Hurlbert, S. H. 2002. Metazooplankton dynamics in the salton Sea, California, 1997-1999. *Hydrobiologia* 473:103-120.

Turner, P. N. 1993. Ditribution of rotifers in a Floridian saltwater beach, with a note on rotifer dispersal. *Hydrobiologia* 225/226: 435-439.

Ueda, S., Go. C. U., Yoshioka, T. Yoshida, N., Wada, E., Miyajima, T. Sugimoto, A., Boontanon, N., Vijarnsorn, P., and Boonprakub. S. 2002. Dynamics of dissolved O_2, CO_2, CH_4 and N_2O in a tropical coastal swamp in southern Thailand. *Biogeochemistry* 41:191-215.

Williams, W. D. 2001. Anthropogenic salinisation of inland waters. *Hydrobiologia* 466: 329-337.

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

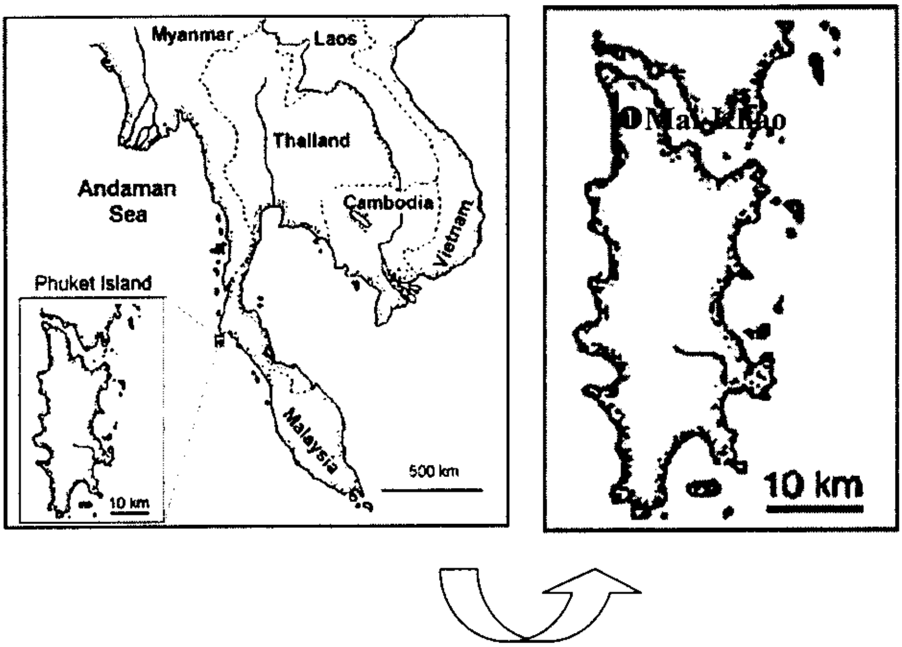

Figure 3.4.1 Map of Thailand showing the location of Mai-Khao peat swamps on Phuket Island, southern Thailand.

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).

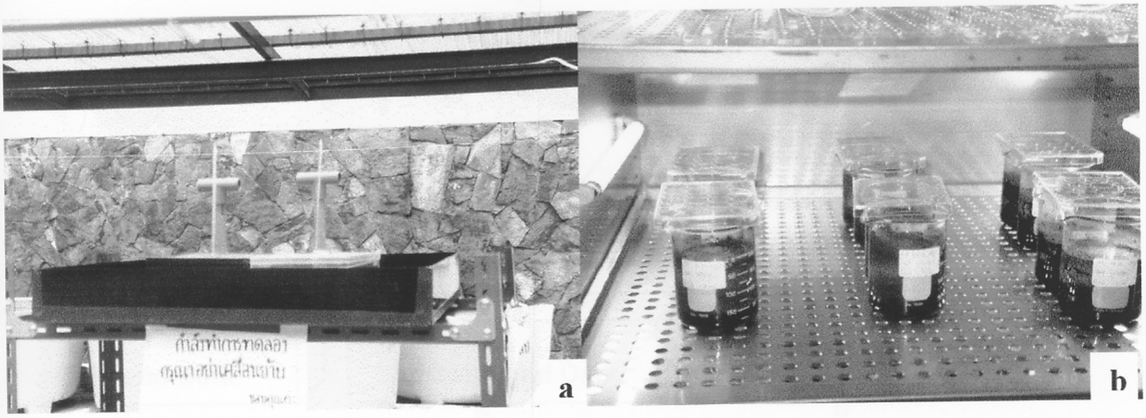

Figure 3.4.2 (a) The sediment stored in AD and AL condition and placed under clear roof in culture laboratory building; (b) The sediment placed in Jermaks incubation.

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.

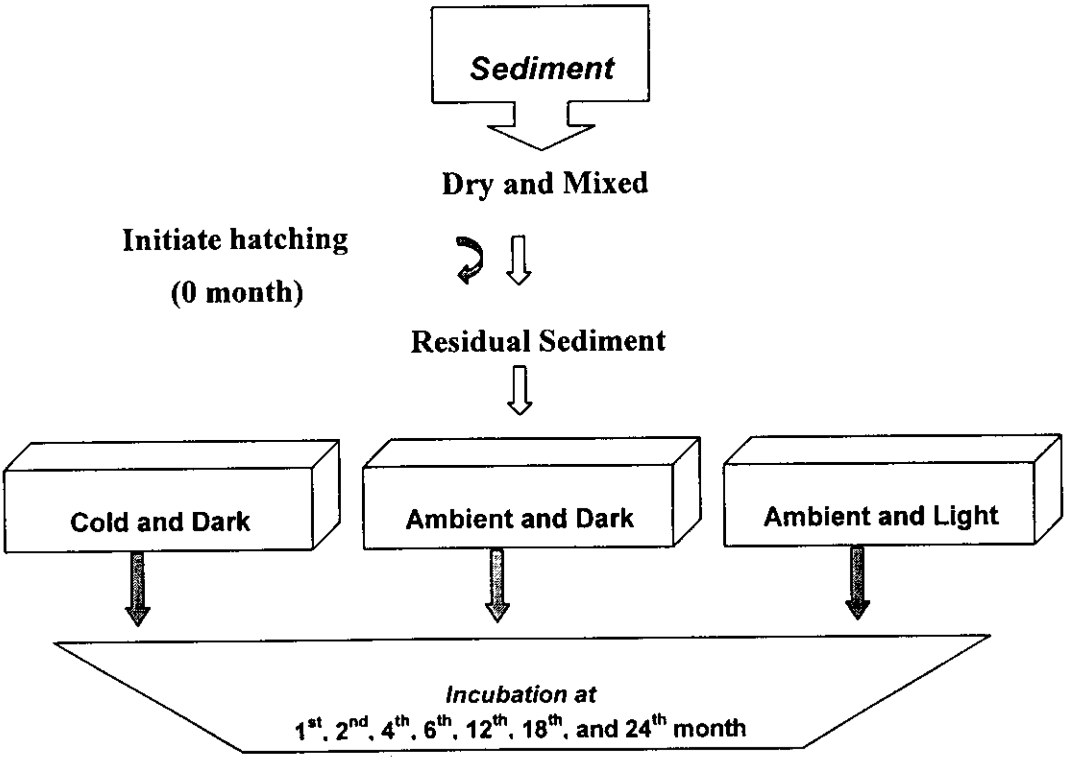

Figure 3.4.3 Process of study recreates capability of rotifer population.

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.

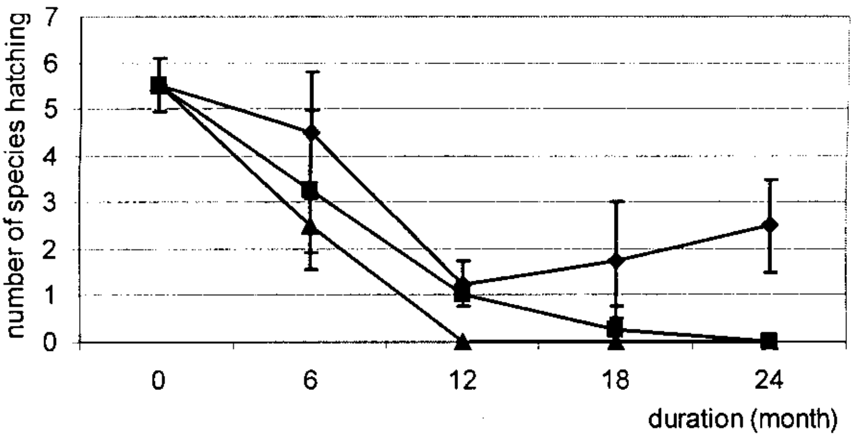

Figure 3.4.4 The number of species hatching from different exposure condition and duration (◆=Cool and Dark, ■=Ambient and Dark and ▲=Ambient and Light).

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).

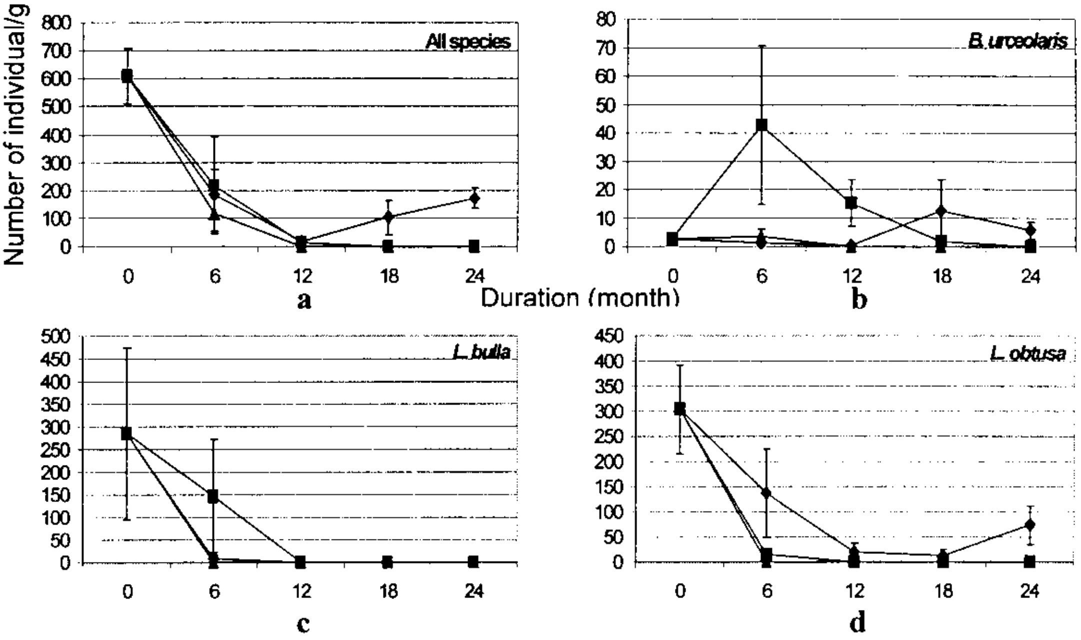

Figure 3.4.5 The number of specimens hatching of all species (a) and three commonest species from different exposure condition and duration (b,c,d): a = all species, b = *B. urceolaris*, c = *L. bulla*, d = *L. obtusa* (◆=Cool and Dark, ■=Ambient and Dark and ▲=Ambient and Light).

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.

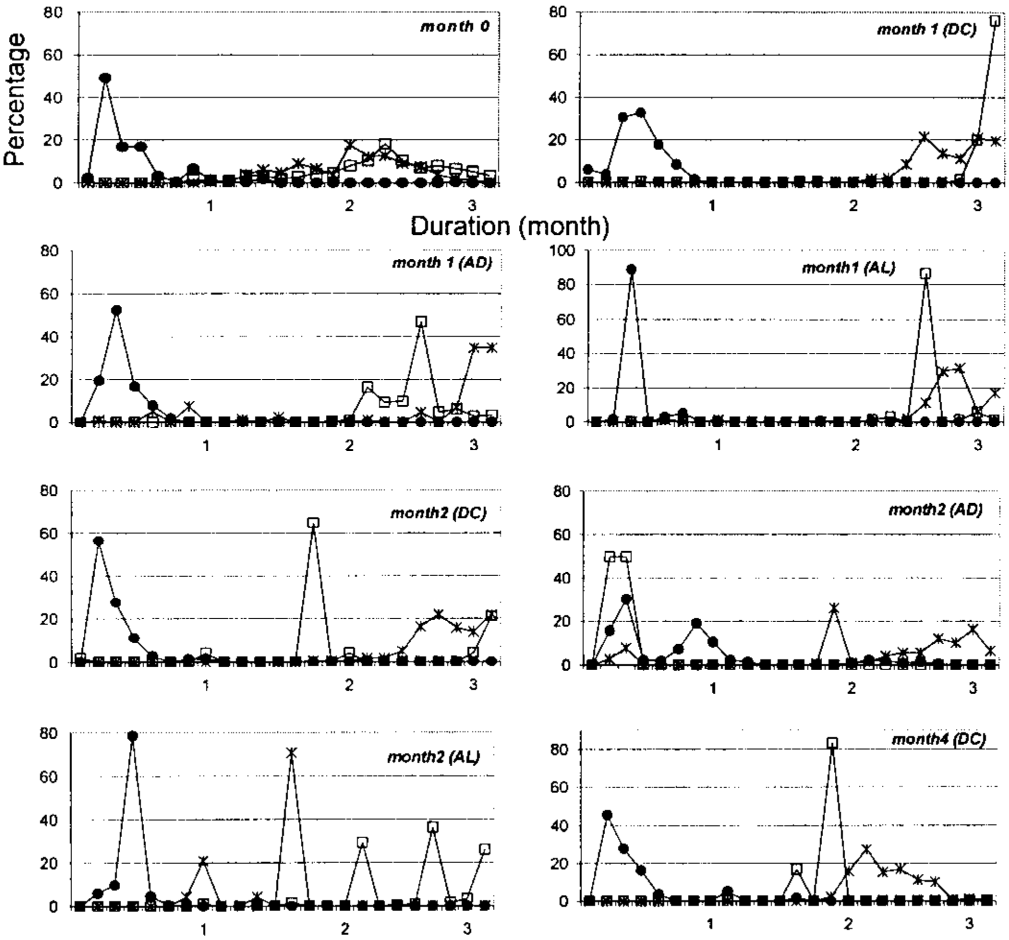

Figure 3.4.6 Percent hatching of three commonest species for three months (● = *Brachionus urceolaris*, ☐ = *Lecane bulla*, ✱ = *L. obtusa*).

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.

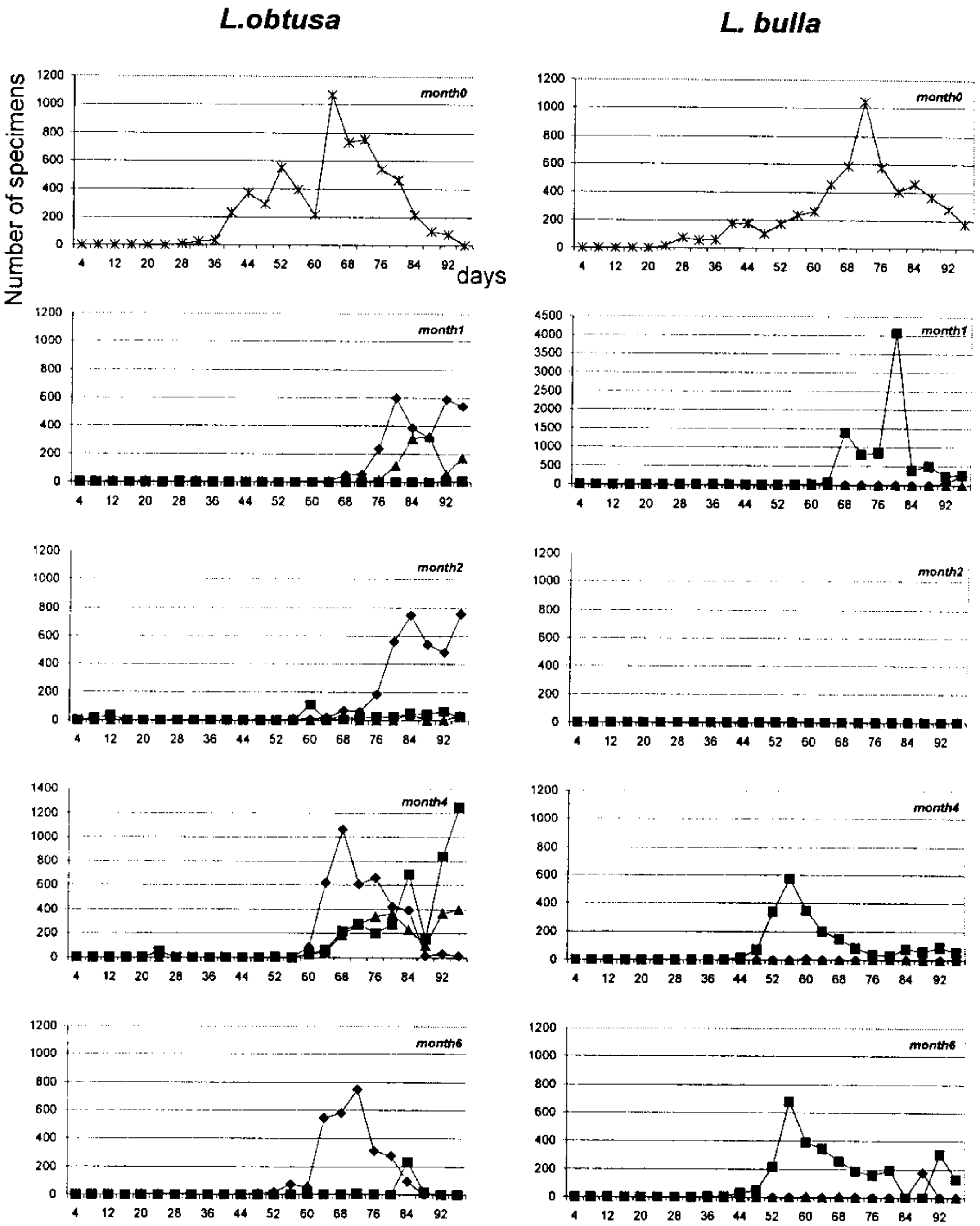

Figure 3.4.7 Number of *Lecane obtusa* (left) and *L. bulla* (right) hatching from sediment, which expose under in different conditions and duration (✻ = 0 month, ◆ = CD, ■ = AD and ▲= AL).

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.

References

Chittapun, S., P. Pholpunthin and H. Segers. 1999. Rotifera from peat-swamps in Phuket province, Thailand, with the description of a new *Colurella* BORY DE ST. VINCENT. *Internat. Rev. Hydrobiol.* 84(6): 587-593.

Chittapun, S. and P. Pholpunthn. 2001. The rotifer fauna of peat-swamps in southern Thailand. *Hydrobiologia* 446/447: 255-259.

Chittapun, S., P. Pholpunthin and H. Segers. 2002. Rotifer diversity in a peat-swamp in southern Thailand (Narathiwas province) with the description of a new species of *Keratella* Bory de St. Vincent. *Ann. Limnol.* 38(3): 185-190.

Chittapun, S., P. Pholpunthin, and H. Segers. 2003. Contribution to the knowledge of Thai microfauna diversity: notes on rare peat swamp Rotifera, with the description of a new *Lecane* Nitzsch, 1872. *Hydrobiologia* 501: 7-12.

Finlayson, M. and M. Moser. 1991. *Wetland*, 224 pp. New York: Fact on File.

Gilbert, J. J., 1974, Dormancy in rotifers. *Transactions of the American Microscopy Society* 93: 490-513.

Gilbert, J.J. and E.S. Wurdak. 1978. Species-specific morphology of resting eggs in the rotifers *Asplanchna*. *Transactions of the American Microscopy Society* 97: 330-339.

Hagiwara, A. and A. Hino. 1989. Effect of incubation and preservation o resting egg hatching and mixis in the derived clones of the rotifer *Brachionus plicatilis*. *Hydrobiologia* 186/187: 415-421.

Kotani, T., M. Ozaki, K. Matsuoka, T.W. Snell and A. Hagiwara. 2001. Reproductive isolation among geographically and temporally isolated marine *Brachionus* strains. *Hydrobiologia* 446/447: 283-290.

Langley, J. M., R. J. Shiel, D. L. Nielsen and J. D. Green. 2001. Hatching from the sediment egg-bank, or aerial dispersing? – the use of mesocosms in assessing rotifer biodiversity. *Hydrobiologia* 446/447: 203-211.

Lubzens, E., R. Fishler and V. Berdugo-White. 1980. Induction of sexual reproduction and resting egg production in *Brachionus plicatilis* reared in sea water. *Hydrobiologia* 73: 55-58.

Lubzens, E., Y. Wax, G. Minkoff and F. Adler. 1993. A model evaluating the contribution of environmental factors to the production of resting eggs in the rotifer *Brachionus plicatilis*. *Hydrobiologia* 255/256: 127-138.

May, L. 1987. Effect of incubation temperature on the hatching of rotifer resting eggs collected from sediments. *Hydrobiologia* 147 : 335-338.

Minkoff, G., E. Lubzen and D. Kahan. 1983. Environment factors affecting hatching of rotifer (*Brachionus plicatilis*) resting eggs. *Hydrobiologia* 104: 61-69.

Nogrady, T., R.L. Wallace and T.W. Snell. 1993. *Rotifera vol. 1: Biology, Ecology and Systematics. Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 4 (H.J. Dumont ed.)*, 142pp. The Hague: SPB Academic Publishing bv.

Pourriot, R. and T. W. Snell. 1983. Resting eggs in rotifers. *Hydrobiologia* 104: 213-224.

Pourriot, R., C. Rougier and D. Benest. 1980. Hatching of *Brachionus rubens* O. F. Muller resting eggs (Rotifers). *Hydrobiologia* 73: 51-54.

Pourriot, R., D. Benest, P. Clément and C. Rougier. 1984. Morphologie comparée d'oeufs de durée de brachionides. *Bulletin de la Société Zoologique de France* 109: 231-138.

Ricci, C. 2001. Dormancy patterns in rotifers. Hydrobiologia 446/447: 1-11.

Serrano, L., M. Serra and M. R. Miracle. 1989. Size variation in *Brachionus plicatilis* resting eggs. *Hydrobiologia* 186/187: 381-386.

Segers, H. and S. Chittapun. 2001. The interstitial Rotifera of a tropical freshwater peat swamp on Phuket Island, Thailand. *Belg. J. Zool.* 131(2):25-31.