Cladoceran Community in Different Habitats in Thale-Noi, Phatthalung Province

Wijitra Choedchim

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Ecology (International Program)

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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Candidate

ชื่อวิทยานิพนธ์ สังคมของคลาโดเซอแรนในถิ่นอาศัยที่แตกต่างกันในทะเลน้อยจังหวัดพัทลุง
ผู้เขียน นางสาววิจิตรา เฉิดฉิ้ม
สาขาวิชา นิเวศวิทยา
หลักสูตร 2558

บทคัดย่อ

ศึกษา ความหลากชนิด องค์ประกอบชนิด การเปลี่ยนแปลงของชนิดเด่น และ ความชุกชุมของคลาโดเซอรา ในเชิงสถานที่ (ถิ่นอาศัย H1, H2 and H3) และการผันแปรในเชิงเวลา (พฤษภาคม 2557 - พฤษภาคม 2558) ในทะเลน้อยซึ่งเป็นทะเลสาบน้ำตื้นขนาดใหญ่ ทางตอนใต้ของประเทศไทย เก็บตัวอย่างทุกเดือน โดยใช้กับดักวางข้ามคืน บริเวณริมฝั่ง (littoral zone) ที่มีผืนสาหร่ายหางกระรอก (H1.Hy) และพุงชะโด (H1.Ce) บริเวณกลางน้ำ (open water zone) ที่มีผืนสาหร่ายหางกระรอก (H2) และบริเวณริมฝั่งที่มีผืนสาหร่ายข้าวเหนียว (H3) พร้อมทั้งตรวจวัดปัจจัยสิ่งแวดล้อม 8 ปัจจัย ผลการศึกษาพบคลาโดเซอแรนทั้งหมด 7 วงศ์ 28 สกุล 40 ชนิด พบชนิดที่ไม่เคยมีรายงานในประเทศไทย 2 ชนิดได้แก่ *Alona kotovi* Sinev, 2012 และ *Diaphanosoma celebensis* Stingelin, 1900 ผลการศึกษาแสดงให้เห็นว่า บริเวณผืนพืชน้ำทั้ง 3 ถิ่นอาศัยพบความหลากชนิดของคลาโดเซอแรนในจำนวนมากและมีจำนวนใกล้เคียงกัน (30-34 ชนิด) ความหลากชนิดสูงสุด 22 ชนิดต่อ 0.09 ตารางเมตรและส่วนใหญ่เป็นวงศ์ Chydoridae พบความชุมชุมของคลาโดเซอราสูงสุดถึง 513,767 ตัวต่อตารางเมตรต่อถิ่นอาศัย พบความชุกชุมของสกุลเด่น (*Anthalona, Kurzia, Ephemeroporus, Ceriodaphnia*) ระหว่าง 7,233 - 61,933 ตัวต่อตารางเมตรต่อคืน นอกจากนี้พบว่าความผันแปรในช่วงเวลามีผลเด่นชัดต่อความหลากชนิดในบริเวณริมฝั่ง (H1.Hy และ H1.Ce) ในขณะที่มีผลเด่นชัดต่อความชุกชุมในทุกถิ่นอาศัย โครงสร้างองค์ประกอบชนิดและการเลือกที่อยู่อาศัยของคลาโดเซอแรนได้รับปัจจัยหลักมาจาก ความลึกและความเป็นกรดด่าง ซึ่งแตกต่างอย่างมีนัยสำคัญระหว่างถิ่นอาศัย แต่ไม่มีความแตกต่างระหว่าง H1.Hy และ H1.Ce การศึกษาครั้งนี้เป็นการศึกษาแรกที่ศึกษานิเวศวิทยาเชิงลึกของคลาโดเซอแรนโดยใช้วิธีการวางกับดักในทะเลสาบน้ำตื้นเขตร้อน ซึ่งเผยให้เห็นว่า สังคมของคลาโดเซอแรนมีการเลือกถิ่นที่อยู่อาศัยตามปัจจัยสิ่งแวดล้อม และวิธีการใช้กับดักทำให้พบชนิดที่พบได้ยาก รวมถึงชนิดที่ไม่เคยพบมีรายงานในทะเลน้อยมาก่อน ดังนั้นการศึกษานิเวศวิทยาของคลาโดเซอแรนในอนาคตควรมีการเก็บตัวอย่างหลายวิธีให้ครอบคลุมแหล่งอาศัยย่อยเพื่อให้ได้ข้อมูลที่ใกล้เคียงความเป็นจริงในธรรมชาติมากที่สุด นอกจากนี้ การศึกษาความผันแปรในช่วงเวลาต่อความหลากชนิด ความชุกชุม และโครงสร้าง

ทางสังคมของคลาโดเซอแรนต้องมีการศึกษาอย่างต่อเนื่องในระยาวมากกว่าหนึ่งปีเพื่อให้ทราบถึงรูปแบบเชิงฤดูกาลที่ถูกต้อง

Title	The Cladoceran community in different habitats in Thale-Noi, Phatthalung Province.
Student Name	Wijitra Choedchim
Program	Ecology (International Program)
Academic year	2015

ABSTRACT

We studied the cladoceran species richness, composition, abundance and community shifts in dominant, assessing spatial (H1, H2 and H3) and monthly (May 2014-2015) variations in Thale-Noi, a large shallow tropical lake in Southern Thailand. Monthly sampling with activity traps deployed overnight in littoral with *Hydrilla* (H1.Hy) and *Ceratophyllum* beds (H1.Ce), open water with *Hydrilla* beds (H2) and littoral zones with *Utricularia* beds (H3), eight environmental factors were measured. A total of seven families 28 genera and 40 species of Cladocera were recorded. Of which, two species are new record in Thailand, *Alona kotovi* Sinev, 2012, and *Diaphanosoma celebensis* Stingelin, 1900. The result revealed that these macrophyte beds support high cladoceran diversity regardless of the habitat. Total species richness in all studied habitats were similar (30-34 species), supporting up to 22 species in a trapping area of 0.09 m^2 at peak moments, the majority of which are Chydoridae. Mixed densities reached maximally over 513,767 ind/m^2 per habitat, dominant genus peaking between 7,233 and 61,933 ind/m^2 (*Anthalona, Kurzia, Ephemeroporus, Ceriodaphnia*) per night during dry and/or rainy seasons. We found temporal variation, with effects that were most marked in the littoral zone for species richness and for all sites in abundance. Cladoceran composition and habitat preference were mainly structured by depth and pH, with significantly different assemblages per habitat, but not between the littoral (*Hydrilla* and *Ceratophyllum*) beds in a single area. Our study presents the first in-depth ecological survey of Cladocera using activity traps in a shallow tropical lake. The result indicated that the cladoceran showed habitat preference influenced by environmental factors and the trap provides rare and species that have not been recorded in Thale-Noi. Therefore, the studying ecology of cladoceran in the future should be practice with many methods for

covering microhabitat of cladoceran, to receive the truly information in nature. Moreover, temporal variation of zooplankton species richness, abundance and community structure in shallow tropical lakes requires studies over a longer time period than a single year, in order to assess truly seasonal trends.

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LIST OF ABBREVIATIONS AND SYMBOLS

et al.	=	Et. Ali (Latin), and other
Fig.	=	Figure
˚C	=	degree Celsius
chl *a*	=	Chlorophyll *a*
DO	=	Dissolved Oxygen
m	=	meter
ml	=	millimeter
m^2	=	square meter
mgO_2/l	=	milligram oxygen per liter
mg/l	=	milligram per liter
µS/cm	=	microsiemens per centrimeter
ppt	=	part per thousand
ind	=	individual
CCA	=	Canonical Correspondence Analysis
ANOVA	=	Analysis of Variance
SPSS	=	Statistical Package for Social Science

CHAPTER 1

INTRODUCTION

1. Background and Rationale

Cladocerans are microcrustacean and they belong to Phylum Arthropoda, more specifically to the branchiopod crustaceans. They are small in size, ranging from 0.2-18.0 mm in length (Korovchinsky and Smirnov, 1996). They can be found in freshwater, brackish and salt water, including acidic waters such as peat swamps. Cladocerans play a crucial role in food webs of standing waters because of their high diversity and abundance. Their densities are only surpassed in zooplankton meiobenthic biomass by copepods, therefore cladoceran are one of the major groups of freshwater zooplankton, make up a vital part in aquatic foodwebs worldwide, by linking the lower (phytoplankton, bacteria, fungi) to the higher trophic levels (fish, macro-invertebrates). Moreover, they play an important role in the degradation of organic matter (Dodson and Frey, 1991) and they are important bio-indicators for monitoring environmental change at community level. Despite their ecological importances, not many aimed ecological studies on Cladocera exist, and little is known about ecological preferences, except for a few studies (e.g. Whiteside *et al*., 1978; Tremel *et al*., 2000and Walseng *et al.*, 2008).

The non-pelagic cladocerans, of which the majority consists of the speciose Chydoridae family, thrive in the littoral area of freshwater habitats, where aquatic macrophytes are dominated ((Smirnov, 1974; Whiteside and Harmsworth, 1967). This habitat zone provides either shelters against predators as well as an important food source, as they feed on epiphyton and *Aufwuchs* (Stansfield *et al*., 1997; Geraldes and Boavida, 2004). Often, the littoral is understood as a single habitat, however it is clear that under this general term, a high diversity in micro-habitats is present for small species such as cladocerans (eg. Whiteside *et al*., 1978).Accordingly, niche separation may affect species composition of cladocerans in various habitat types.

Many cladocerans seem to prefer a particular plant species (Hann, 1995) or substrate (Whiteside *et al.*, 1978). However, most phytophilic cladocerans are represented by both generalist as well as highly specialized lineages, from general grazers to specialized benthic species (Fryer, 1968). There are some researches indicated that non-pelagic cladoceran are affected by physical and chemical factors such as depth (Nevalainen, 2012; Adamczuk, 2014), pH (Saardrid, 2002; de Eyto et al., 2003; Nachai, 2006; Belyaeva and Deneke, 2007 and Adamczuk, 2014), temperature (Sa-ardrid, 2002 and Nevalainen, 2012), conductivity (Saardrid, 2002; Nevalainen, 2012) and total organic carbon (TOC) (Adamczuk, 2014).

The effects of the habitat types on the abundance of non-pelagic cladocerans therefore remain relatively unclear and debatable. Most studies focusing on the association between the organism and their microhabitat, used different sampling methods such as the Downing box, Ekman grab, or plexiglass tubes (Hann, 1995). Cladocera can escape from such traps while being collected, which negatively influences the accuracy of the result and reproducability of the methods. Moreover, all detailed studies on habitat preference in non-pelagic cladocerans have been limited so far to temperate lakes only (Whiteside and Harmsworth, 1967; Whiteside *et al.*, 1978; Barton and Carter 1981; Paterson, 1993; Di Fonzo and Campbell, 1998 Hann, 1995; Tremel *et al*., 2000 and Walseng *et al*., 2008). This leaves the tropical freshwater ecosystems virtually unexplored with regards to non-pelagic cladoceran ecology, despite the fact that their diversity in tropical waters is high (Fernando, 1980) and their importance as food for fish and invertebrates (in turn, for birds and amphibians), cannot be underestimated. In fact, it is surprising that so little is known of cladoceran communities in association with different habitats in tropical wetlands.

Thale-Noi lake lends itself to such an endeavour, as it is among the best studied wetlands in Thailand, with large diversity in macrophyte stands and with a zooplankton fauna of which the identification was recently updated, and Cladocera ecology explored (Pholpunthin *et al*., 2009 and Inpang, 2008). This study aims to investigate cladoceran community in different habitats in Thale-Noi Lake, using a quantitative sampling method.

2. Literature review

2.1) Classification of the Cladocera

The Classification of the Cladocera has been revised several times, recognizing two ctenopod, 11 anomopod and 3 onychopod families (Negrea *et al*., 1999; Santos –Flores and Dodson, 2003). Two orders of the Cladocera have been recorded in Thailand; Order Ctenopoda and Order Anomopoda.

Phylum Arthropoda

Superclass Crustacea

Class Branchiopoda

Superorder Cladocera

Order Ctenopoda

Family Holopedidae

Family Sididae

Order Anomopoda

Family Acantholeberidae

Family Bosminidae

Family Chydoridae

Family Daphniidae

Family Dumontiidae

Family Gondwanotrichidae

Family Eurycercidae

Family Ilyocryptidae

Family Macrothricidae

Family Moinidae

Family Neothricidae

Family Ophryoxidae

Family Sayciidae

Oder Onychopoda

Family Polyphemidae

Family Podonidae

Family Ceropagidae

2.2) General Characteristics and biology of the Cladocera

2.2.1) General Characteristics

The body of cladocerans is divided into three parts include head, thorax and abdomen, but it is not clearly segmented. The thoracic and abdominal regions are enclosed in shall or carapace that has a general bivalve appearance but it is actually a single folded piece that opens ventrally. Only the head part is outside of the carapace. In lateral view, shapes of shell (valve) are several shapes such as oblate, sphere, elongated or angular. There are often various type markings on the surface of valves; it may be reticulation, striations or other type. In many species, the posterior end has spine or spinules and the ventral edge of the shell usually bear setae. In the head of cladocerans have two types of light sensitive organs including compound eye is large and ocellus is smaller, which is situated ventral to the compound eye, except some species of cladocerans such as *Moina* do not have an ocellus. All cladocerans have antennules (first antennae) and antennae (second antennae). The antennules are located on the ventral of the rostrum. There are 1-2 lateral setae and sensory setae at the end of antennules. The antennules are uniramous and small while the antennae are biramous, in general, very large, and inserted on the side of the head. The mouth part

is situated near notches between head and body. The mouth part comprises of maxillae, mandibles labium and labrum. Moreover, all cladocerans also have small structure on or near mid-dorsal line called “head pore”. They occur on head shield, which is single plate covering the frontal and lateral part of head (Frey, 1959). There are 5-6 pairs of thoracic limb, each limb have numerous hair and setae. Normally, two first pairs of thoracic limb are developed for catching the food thus they are different from the other limbs, but in Holopedidae and Sididae all thoracic limb are similar. The abdomen of cladocerans is narrow but there is large at the posterior end of the body known as postabdomen. It is usually curved antero-ventrally, and acts in whisk the excess food from the mouth. There are two long setae on postabdomen called natatorial setae. They have two claws at the end of postabdomen and have the basal spine at the base, which the base of the posabdoment usually a series of anal denticles and lateral spinules. In addition, the cladoceran has the broad chamber in the posterodoral region of the carapace above the thorax (Pennak, 1978).

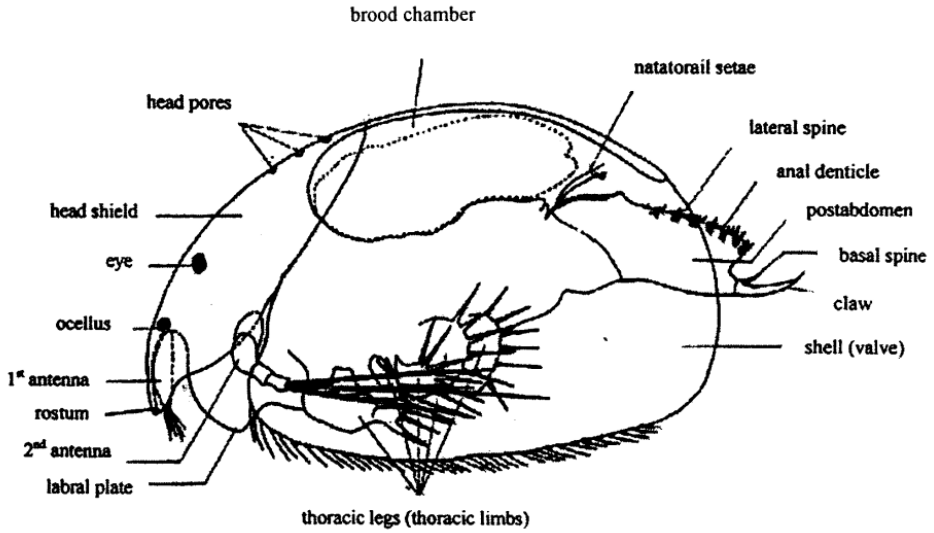


Figure 1. General characteristics of the chydorid Cladocera (Idris,1983)

2.2.2) Habitats

The Cladocera live in several kinds of freshwater habitat both permanent and temporary water bodies, such as large lakes, ponds, puddles, ground water, caves and water in the tire ruts. They are widely distribute, from the Arctic to Antarctic, at temperate and tropical latitudes, on isolated islands, in high mountain water bodies and in moss growing on trees in rain forests several meters above the ground. Moreover, they also found in desert zones (Dumont, 1979) but the mainly of species is found in littoral and benthic areas of lakes, which has been found in saline lakes up to 19.9 g/l (Griggs, 2001). However, all groups are not successful in the marine environment. A few others of the family Chydoridae live in semi-terrestrial conditions (Forró *et al*., 2008), and about 20 % have now been recorded from one or another type of subterranean environment (Dumont and Negrea, 1996).

2.2.3) Locomotion

Onychophoda group moves by swimming. Their propulsion is commanded by the beating of the large biramous antennae. Ctenopoda and Anomopoda show variable swimming abilities. The plankton species are usually rather good, if not very agile swimmers, that move on the rhythm of the strokes of their large antennae. Most pelagic species have a vertical position in the water column, and each beat of the antennaes cause them to jump upwards. Between strokes, they sink a little. This progression has been called hop and sink. In spite of its apparent inefficiency, it permits pelagic species to undertake diurnal vertical migration of considerable amplitude. Among the many hypotheses formulated to explain the causes of vertical migration, avoidance of excess light, of alkaline pH, the search for a relative or absolute light optimum, the avoidance of competitors, and the avoidance of predation have been quite successful. An abundance of recent reviews is available (Dumont and De Meester, 1990; Davidowicz, 1990; Lampert, 1989, 1993a, b; Kerfoot, 1985; Loose, 1993; Pijianowska, 1993 and Ringelberg, 1993). The smaller a species, the more viscous the environment in which it lives; it will therefore sink more slowly when not active. Floatation is also facilitated by a specific weight close to unity, and

by the spreading out of the antenna and their setae, mimicking an open parachute. Littoral species spend most of their lifetime hiding in the protective cover of submerged macrophyte. Some have evolved adaptations to that effect. *Simocephalus* has a back-to-the-wall protective behavior that is facilitated by small hook at the tip of one of its antennal setae (Fryer, 1991; Orlova-Bienkowskaya, 2001). Some phytophilic chydorids (*Alonella, Graptoleberis*) on the lower surface of submerged leaves with the help the short plumose setae on the ventral rim of the valves. Benthic chydorids and macrothricids have reduced antennae, which they hardly use for moving. They ramp, on or inside the crevices between sediment grains, using their postabdomen and part of the trunk limbs similar with the locomotion of *Ilyocryptus* sp., a benthic species digging into the surface layer of the sediment (Dumont and Negrea, 2002).

2.2.4) Reproduction

The males are smaller than the females and are usually similar in form. They are distinguished by the large antennules; the postabdomen is usually somewhat modified and the first trunk limb is frequently armed with a stout hook. Males are often absent for many successive generations because they usually reproduce by cyclical parthenogenesis of diploid females which is the asexual reproduction type, hence populations are mostly dominated by females. Under unfavorable environmental conditions or poor food supplies the sexual reproduction occurs by some of the eggs develop into males. Females then produce a few haploid sexual eggs that are deposited in a brood pouch in a cavity dorsal to the body. After fertilization, the carapace around the brood chamber thickens and encloses the eggs. This encased fertilized egg is called an ephippium or diapausing eggs. Ephippia can withstand severe environmental conditions such as in desiccation conditions (Forró *et al*., 2008), and may even survive passage through the digestive track of birds (Figuerola and Green, 2002); thus they are important propagules for passive dispersal.

2.3) Relevant studies

Many researches have focused on habitat preference especially a relation between freshwater organisms and macrophytes (e.g. Krecker, 1939; Andrews and Hasler, 1943; Rosine, 1955; Gerking, 1957; Bownik, 1970; Krull, 1970; Kofinkova, 1971 Gerrish and Bristow, 1979; Dvorak and Best, 1982; Rooke, 1986a Cry and Downing, 1988 and Bogut, 2009). Most studies focus on macroinvertebrate abundance in different macrophyte species or macrophyte morphology (root and leaf). For example, a comparative study of the animal population studied many invertebrates of certain submerged aquatic plants by Krecker (1939) such as annelids, crustaceans, insects, molluscs, planarians, hydra, nematoda, molluscs, sponges and fish eggs (not cladocerans). He collected samples by snipping the macrophytes at 20 foot lengths. The result showed that abundance of invertebrates in fine leaved plants was higher than in broad leaved ones. He suggested that plants with dissected leaves systematically support more invertebrates than plants with broad leaves. The reason is that plants with dissected leaves would provide more substrate for the growth of periphytic algae (Dvorak and Best, 1982) which is an important food source for invertebrates (Downing, 1981; Cattaneo, 1983). Moreover they would offer more surface area for invertebrate attachment (Rosine, 1955), they might act as sieves that filter and accumulate phytoplankton and detrital particles from water (Rooke, 1984, 1986b) and they might offer more protection to the invertebrates from predators (Harrod, 1964; Dvorak andBest, 1982). Krecker's model has been confirmed by studies in lakes and streams such as Gerking (1957) and Rooke (1986b). However, some contradictory observations exist (Bownik, 1970; Krull, 1970; Kofinkova, 1971; Cry and Downing, 1988; Bogut *et al*., 2009 and Hann, 1995). Hann (1995) studied the relations between microinvertebrates and different species of submersed aquatic plants (*Ceratophyllum demersum*, *Chara vulgaris* and *Potamogeton zosteriformis*) in a prairie wetland using a Downing box. The results showed that the most abundant taxonomic group in the study was the Cladocera and the highest cladoceran abundance was found in *Ceratophyllum* followed by *Potamogeton* and *Chara* respectively. Many species of Cladocera favored both *Ceratophyllum* and *Potamogeton* but not *Chara*. Despite, *Ceratophyllum* and *Chara* are more similar

morphologically and the both macrophyte are fine dissected leave plant, so in this case the cladoceran abundance is not affected by plant morphology or degree of leaf dissected. The very low abundance of many species in association with *Chara* is perhaps attributable to the allelochemical properties of macroalgae. It is therefore interesting that "Are there the differences of species compositions and abundance of cladocerans in different fine dissected leaves macrophyte habitat

Moreover, it has been studied about the habitat specificity of littoral Chydoridae (Crustacea, Branchiopoda, Anomopoda) in Plastic Lake, Ontario, Canada. Twenty chydorid species were collected in 15 over-night sets of funnel traps in each of four habitat types. Habitat 1 was characterized by organic-rich mud and silt strewn with large boulders and rocks interspersed with a sparse cover 10% of *E. septangulare*. Habitat 2 was the most structurally diverse type consisting of a flat mud bottom with very few rocks and 40% *E.septangulare* cover. The third habitat type consisted of exposed bedrock shelves covered with a thin layer of silt. This habitat had sparse and isolated *E. septangulare* patches in the extreme shallows. Habitat 4 was characterized by rich *E. septangulare* beds (80% bottom cover) with bark and stick debris in the extreme shallows. The result showed that the assemblages of cladocerans differed among the habitats. *Alona intermedia*, *Alona quadrangularis* and *Chydorus bicornutus* were particularly abundant in the most structurally diverse habitat type – muddy, rock-strewn areas with approximately 40% bottom cover by the pipewort, *Eriocaulon septangulare*. In contrast, *Anchistropus* cf. *minor* was caught most often on bare shelves of rock and found that chydorid assemblages also differed at a smaller scale, i.e. with local patchiness in bottom cover by the dominant macrophyte (*E. septangulare*). The abundance of *Alona affinis* was positively correlated with cover by *E. septangulare*, whereas *Anchistropus* cf. *minor* was caught mainly in microhabitats without vegetation. *Alona intermedia* and *A. quadrangularis* were most abundant in microhabitats with intermediate amounts of vegetation, suggesting their abundance is influenced by habitat factors other than vegetation (Tremel *et al*., 2000). There are some researches showed the dynamics of zooplankton populations are affected by numerous environmental factors such as depth, pH,

dissolved oxygen, temperature, salinity, conductivity, total organic carbon (TOC) and water flow.

Depth is important factor on benthic chydorids distribution in lake even within the littoral zone (Adamczuk, 2014). They show the different patterns of distribution along the lake depth, forced upon them by UV exposure, the thermal properties, food resources and predators associated with these varying depths (Nevalainen, 2012). Chittapun (2004) reported that zooplankton diversity and abundance fluctuation relation to the water depth. This is due to the water volume provide niche in term of habitats for zooplankton consistent with a study by Humphries (1996) showed water level was a determinant of invertebrate richness and abundance in rivers. Similarly, Timms (1981) found water depth was correlated with invertebrate abundance and community composition in three lakes studied.

Some studies reported that community structure of Chydoridae affected by pH such as the distribution of *Alona harpae* was correlated to the pH level (Adamczuk, 2014) which is the important factor of chydorids distribution in a geographical scale (de Eyto *et al*., 2003) and determining influence on the composition and diversity of freshwater faunas (weber and Pirow, 2009). Walton *et al*. (1982) studies the effect of acid stress on survivorship and reproduction of *Daphnia pulex*. The result indicated that an acute test using exposure times of 1 to 96 h and pH levels of 3.7 and 6.5 revealed virtually no effect at 4.3 and higher, while 4.2 and lower severely reduced survivorship. Very short (3-h) exposures caused nearly complete mortality at pH 3.7, while > 12 h exposure caused high mortality at pH of 4.0–4.2. A chronic 21 d-life was reduced survivorship and delayed onset of reproductive maturity.

Oxygen concentration is an important factor controlling distribution and community structure of zooplankton in lakes (Wright and Shapiro 1990; Hanazato 1992). Low oxygen induces hemoglobin synthesis in *Daphnia*, as it does in many other zooplankton (e.g. Landon and Stasiak 1983; Engle 1985). Hemoglobin increases the uptake efficiency of oxygen from water, supporting higher rates of survival, feeding, respiration, swimming activity, and egg development under -low oxygen conditions (e.g. Heisey and Porter 1977; Weider and Lampert 1985).

Moreover, the segregation of some chydorids showed relation with temperature such as *Chydorus parvus*, *C. pubescens* and *Ephemeroporus barroisi* showed positive correlation with temperature, they are found at temperature higher than 29.2 ^{o}C (Sa-ardrid, 2002 and Nevalainen , 2012).

Salinity is a serious threat to freshwater ecosystems, an increase in salinity produces drastic changes in community structure of freshwaters. Thus, freshwater species must cope with salinity stress in a manner proportional to their degree of tolerance. The salinity caused a significant reduction in fecundity and a developmental delay (increase in age at first reproduction), as well as a decrease in the growth rate of daphnids (Gonçalves *et al*., 2007).

Conductivity is also one important factor that showed significantly influenced on some littoral-benthic cladoceran distribution (Saardrid, 2002; Nevalainen, 2012).

In addition, it has been reported that the distribution of *Alonella exigua*, *Camptocercus rectirostris*, *Pleuroxus aduncus* and *Pseudochydorus globosus* showed relation to Total organic carbon (TOC). TOC values provide information about utilizing and non-utilizing fraction of carbon amount in an organic compound. Thus, although that variable cannot influence the chydorids directly, high correlations between the TOC concentration and elevated densities of some Chydoridae suggested that these species could prefer areas of higher productivity and/or they can also utilize organic matter suspended in the water (Adamczuk, 2014).

Water flow affects the dissolved oxygen and water turbulent. Angsupanich (1985) found that the dissolved oxygen content was the main environmental factor determining rotifer density.

However, there are some evidences to support the greater cladoceran species diversity and abundance associated with the greater macrophyte species diversity because dense monospecific stands can negatively impact on water quality and degrade cladoceran habitat (Quade, 1969). Nevertheless, in nature, the population dynamics of cladocerans are likely to be influenced by many factors simultaneously, and there are likely to be synergistic interactions among the factors (Hanazato and Dodson 1992).

The reviewed literatures indicated that each previous study used different sampling methods, e.g., Downing box, Ekman grab, plexiglass tube, PVC cylinder, plankton net, or by cutting the macrophyte in a frame or bag. Then they are difficult to make a comparison among the results later on and the disadvantage of these methods is that the Cladocera can escape while collecting samples which may lead to the loss of the number or species of Cladocera and affect the accuracy of the result. However, this disadvantage has been improved when using the activity trap or funnel trap method which Örnólfsdóttir and Einarsson (2004) modified based on the principle of "pattern sampler" developed by Whiteside and Williams (1975) for cladocerans. The trap is easily deployed as the frame creates little turbulence when lowered through the water column from a boat. The trap consists of a plastic recipient with a funnel mounted on the lid, suspended upside down, 3 centimeters above the sediment surface. The Cladocera venture through the funnel and get trapped in the bottle. Örnólfsdóttir and Einarsson (2004) carried out experiments to test the efficiency of these traps at different heights between funnel mouth and the sediment surface. Besides being efficient traps, this method allows quantitative estimations, by converting the number of individuals per m^2 from the total surface area of the funnels. Moreover, the authors suggested that active sampling device (traps) provide higher efficiency, a larger number of benthic invertebrates than passive sampling device such as grabs or corers with a scooping or penetrating action (e.g., Hopkins, 1964 and Sly, 1969). The trap method based on the vertical movements of the animals themselves (the animals move up into the water column during the night and down during the day as a predator-escape response) instead of the scooping action of grabs and similar equipment; therefore, the cladocera cannot escape while collecting the sample. This method also provides clean samples and the traps is very effective when dealing with minute taxa (e.g., *Chydorus, Alonella, Acroperus* and *Alona rectangula*) which are very numerous and difficult to separate from sediment in normal dragnet samples. Another advantage is that the traps are less dependent on substrate types so they can easily be deployed on sand, gravel or plant substrate.

2.4) The study in Thale-Noi

In Thale-Noi Lake, research has been conducted on the ecology of the zooplankton community diversity and taxonomy, starting from Angsupanich and Rukkhiaw (1984) who studied the distribution of Rotifera between April 1982 and March 1983. The results indicated that rotifer density showed no significant differences between stations or seasons. Later, Angsupanich (1985) investigated the zooplankton communities in Thale-Noi, comparing composition and density of zooplankton between stations and seasons. Six major groups occurred in the community, namely protozoans, rotifers, nauplii, copepods, cladocera, and ostracods. Zooplankton density showed significant differences between station and season and it was suggested that dissolved oxygen content was the main environmental factor determining rotifer density. Pholpunthin (1997) studied the freshwater zooplankton (Rotifera, Cladocera and Copepoda). The study focused on taxonomy using samples collected from nine localities. He found 106 species of Rotifera, 17 species of Cladocera and three species of Copepoda and went on to describe 20 species of rotifers, seven species of cladocerans and two species of copepods, which were new to Thailand. In cladocerans group, his result found four families, 14 genera and 17 species of Cladocera. Of which, 11 species are Chydoridae, three species are Macrotricidae and one species are Bosminidae and Sididae. Maiphae (2005) studied taxonomy and biogeographical distribution of the Cladocera using qualitative samples that were collected in freshwater localities throughout Southern Thailand in rainy and summer season, in total fifty-nine sampling sites. The samples collected from Thale - Noi showed four families, 21 genera and 15 species. Ten species of these belong to the Chydoridae, three species belong to Sididae and one species belong to Daphniidae and Macrothricidae. After that, Inpang (2008) studied annual changes of zooplankton communities (microzooplankton, body size 20-200 μm and mesozooplankton body size >200 μm) of different size fractions in Thale-Noi that were investigated over three periods: the light rainy period, the rainy period and the dry period. Seven groups of zooplankton occurred in the microzooplankton composition, namely Protozoa, Rotifera, Cladocera, Copepoda, Crustacean, nauplii, juvenile ostracods and copepodite copepods. Inpang (2008) found 7 family 29 genera and 41 species of

cladoceran, including Chydoridae 25 species, Macrothricidae five species, Daphniidae three species, Sididae four species, Moinidae two species and Bosminidae and Ilyocryptidae one species. The mesozooplankton composition, besides containing holoplanktonic groups that were found in the microzooplankton, the community was also included some meroplanktonic groups, such as shrimp, larvae, crab larvae, mollusk larvae and fish larvae. The result showed that there were spatial and temporal differences in dominance of zooplankton genera. Moreover, Meksuwan *et al*. (2011) studied diversity of sessile rotifers (Gnesiotrocha, Monogononta, Rotifera) in Thale-Noi Lake. The result showed a total of 44 taxa of sessile rotifers, including thirty-nine fixosessile species and three planktonic colonial species. In addition, ten of the species recorded are added to the fauna of the Oriental region, twenty-seven are new to Thailand.

These researches indicated that most previous studies consider macroinvertebrates and that there are few studies that focus on cladocerans. Moreover, they are still unclear about the effect of different habitats defined by plants dominated to these organisms. The information about species composition of Cladocera and their relation to the habitat types has not been studied in detail in the tropics. Moreover, the methods used in the previous studies have low efficiency and low statistical value for the study of cladocerans related to the habitats. Thus the present study is aimed to study the relations between the phytophilic cladoceran communities and their microhabitats at Thale-Noi Lake using a quantitative sampling method.

3. Research question

Are there differences of species richness, species compositions and abundance of cladocerans in different habitats in Thale-Noi?

4. Hypothesis

The species richness, species composition and abundance of cladocerans are different in each habitat types.

5. Objectives

1. To examine the species richness, species composition, abundance and population change of cladocerans in different habitats in Thale-Noi.

2. To compare species richness and abundance of cladocerans in different habitats in Thale-Noi.

3. To compare species richness and abundance in each macrophyte patch between seasons.

5. To analyse the relationship between cladoceran community and environmental factors.

CHAPTER 2

MATERIALS AND METHODS

1. Study site

Thale-Noi Lake is a shallow tropical freshwater lake situated in Phatthalung Province, Southern Thailand, making up the northern part of the large Songkhla Lake system, and is located between latitude 7^{o} 45' 44'' N to 7^{o} 48' 26'' N and longitude 100^{o} 7' 31'' E to 100^{o} 11'12'' E (Leingpornpan and Leingpornpan, 2005). The water runoff from Bunthad Mountain slopes forms the principle inflow to Thale-Noi Lake and the outflow is via the Klong Nang Riam, Klong Yuan and Klong Ban Glang canals into Thale Lung, Lake Songkhla. Thale-Noi Lake itself is usually freshwater with salinity ranges between 0.1-0.8 ppt (Inpang, 2008), however it can become brackish in some areas due to the saltwater influx from Songkhla Lake during the dry season - the salinity ranges in Songkhla Lake fluctuate with the precipitation (Angsupanich and Rakkheaw 1997; Angsupanich *et al*., 2005; Ruensirikul *et al*., 2007). Thale-Noi Lake is shallow, with an average depth of 1.2 m (Pholpunthin *et al*., 2009) ranging between 0.7 and 2.3 m. It is slightly acidic because of accumulation of peat in the lake as well as acidic water influx from peat swamp forests near the northern shore of lake (Inpang, 2008). Because Thale-Noi is a shallow wetland, the bottom of the lake is largely covered in macrophyte stands. The macrophytes are classified into four categories; marginal plant comprises thirty-eight species, emerged plant comprises eight species, floating plant comprises eigth species, and submerged plant comprises six species (Leingpornpan and Leingpornpan, 2005) The most common macrophytes in Thale-Noi are *Cyperus pilosus* Vohl., *Hanguana malayana* (Jack.) Merr., *Salvinia cucullata* Roxb., *Eleocharis ochrostachys* Steud., *Nymphoides indica* (L.) Kuntze., *Nymphaea lotus* L., *Nelumbo nucifera* Gaertn., *Eichornia crassipes* (Mart.) Solms., *Hydrilla verticillata* (L.f.) Royle., *Utricularia* spp. and *Hygroryza aristata* (Retz.) Nees. Most of the macrophytes were found to growth in the same old location due to their natural characteristic of bulbs (Leingpornpan and Leingpornpan, 2005). This wetland is characterized by its high biodiversity and

structural complexity (Artharamas, 1984). Therefore, it can be considered ecologically as well as economically important for the country. Among its many functions, Thale-Noi Lake is important in providing habitats for a diverse range of animals, aquatic animals, phytoplankton, and zooplankton including waterfowl. More than 187 species of waterfowl both indigenous and migratory birds live in Thale-Noi Lake (Aiumnau *et al.,* 2000). Moreover, Thale-Noi Lake also play a role in the provision of clean water, flood control, stabilizing local climate, acting as global carbon dioxide sink and as source of revenue coming from fisheries and ecotourism (Aiumnau *et al.,* 2000; Leingpornpan & Leingpornpan, 2005). Consequently, Thale-Noi Lake is one of the large conserved freshwater wetlands in Thailand and aims to preserve the sustainable ecology of the area (Aiumnau *et al.,* 2000).

2. Climate of Thale-Noi

Climate of Thale-noi is strongly influenced by the tropical monsoon system, the northeast monsoon during November and April and the southwest monsoon during May to October (Colborn, 1975 cited by Suphakason, 1992). In addition, Thale-Noi Lake is a humid tropical climate which the season principally determined by the precipitation. Hembunthid (2001) divided the season of Thale-Noi into three periods: the dry period from January to April, the light rainy period from late April to August and the rainy period from August to December. The precipitation level during 1992 to 1995 in Thale-Noi Lake recorded from Banpraw village, Papayom District, ranged between 54.3 mm (January) and 645.5 mm (November), the precipitation average throughout the year 193.3 mm (Thungwa *et al.*, 1990 cited by Hembanthid, 2001). Moreover, Inpang (2008) determined the season of Thale-Noi Lake from the annual pattern of precipitation at Khuan-Khanun District during July 2004 to June 2005. There are three obvious periods, the dry period from March to April 2005, the light rainy period from July to August 2004 and the rainy period from November and December 2004. The average precipitation ranges from 0 mm to 69mm.

In the present study, we determine the season by the precipitation and monsoon system of Thale-Noi Lake during our study (May 2014 – May 2015). The

annual pattern of precipitation in Phatthalung Province (Phatthalung Agrometeorological Station) during our study showed two distinct periods, the summer period, associated with the lowest water phase during January and July (the total precipitation level rage 0-164.2 mm) and the rainy period, associated with the highest water phase during August and December (the total precipitation level rage 98-742.4 mm) (Fig. 2). The precipitation overall monthly average 181.9 mm

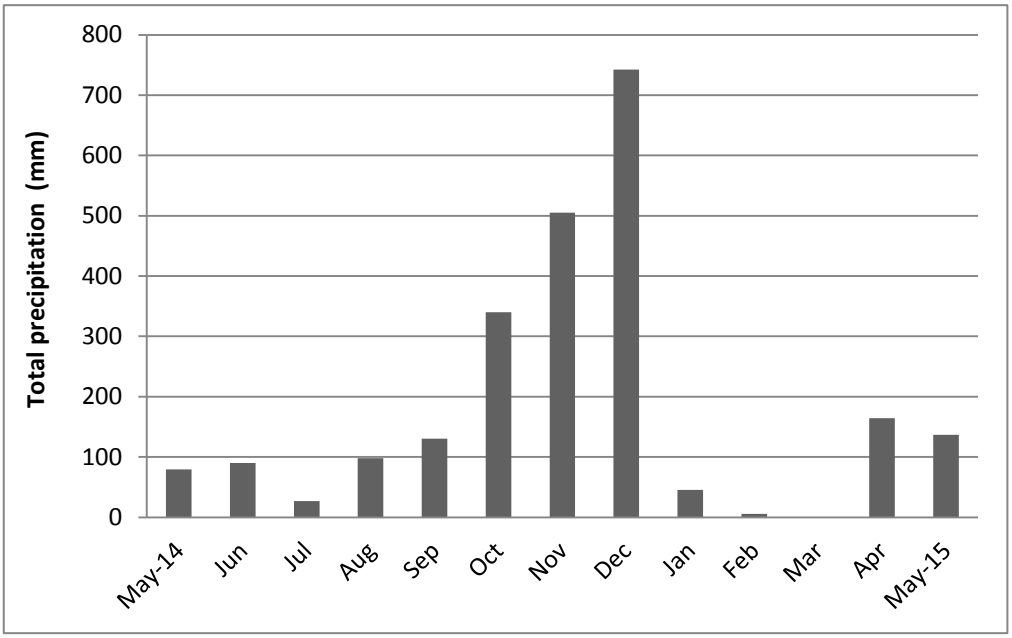


Figure 2. Annual pattern of total precipitation at Phatthalung measured at the Agrometeorological Station during May 2014 to May 2015.
Source: Meteorological Department of Thailand

3. The selected habitats

We selected three different habitat types, according to the dominant species of submerged macrophytes, all with fine dissected leaves (Fig. 3). All habitats were on similar substrates (muddy/detritus substrate). Habitat 1 (H1) (Fig. 4) is situated closest to the mouth of the Yuan River in the Southwest of Thale-Noi Lake, an area with high diversity and density of submerged, emerged and floating and marginal macrophytes. The dominant submerged macrophyte species here are *Hydrilla verticillata* (L.f.)

Royle (H1.Hy) and *Ceratophyllum demersum* L. (H1.Ce), forming dense stands. The dominant floating macrophyte is *Eichhornia crassipes* (Mart.) Solms. Dominant emerged macrophyte is *Nymphaea lotus* L. and dominant marginal plant is *Hanguana malayana* (Jack.) Merr. This habitat is typical for the "resident zone"/littoral in previous studies in Thale-Noi Lake (Inpang, 2008). Habitat 2 (H2) is part of the large open water area in the centre of Thale-Noi Lake, characterized by low macrophyte diversity (Fig. 5). Only fine submerged macrophytes cover the lake bottom and the bottom is covered with a thick detritus layer (Inpang, 2008). *Hydrilla verticillata* (L.f.) Royle. and *Najas graminea* Del. were found here and the dominant species *Hydrilla verticillata*. We can label this as "open water zone", the equivalent to Thale-Noi's pelagic. The third habitat (H3) (Fig. 6) is located near the Nang Riam river in the North East of the wetland, where the water chemistry depends on the sea level, with elevated salinity and conductivity during the dry seasons. This habitat is highly diverse in macrophytes consist of submerged, emerged and marginal macrophytes, yet distinctively different from the previous habitats, with *Utricularia* spp. the submerged dominant species. Other submerged macrophyte that found in this habitat are *Najas graminea* Del., *Hydrilla verticillata* (L.f.) Royle., *Blya echinosperma* (C.B. Clarke) Hook.f. The dominant emerged plant are *Nelumbo nucifera* Gaertn., and *Nymphaea lotus* L. *Hanguana malayana* (Jack.) Merr. and *Eleocharis ochrostachys* Steud. are the dominant marginal aquatic macrophyte in this area. This area occurs in previous studies as the "small inlet zone" (Inpang, 2008). Main differences between the three habitat types are listed in Table 1.

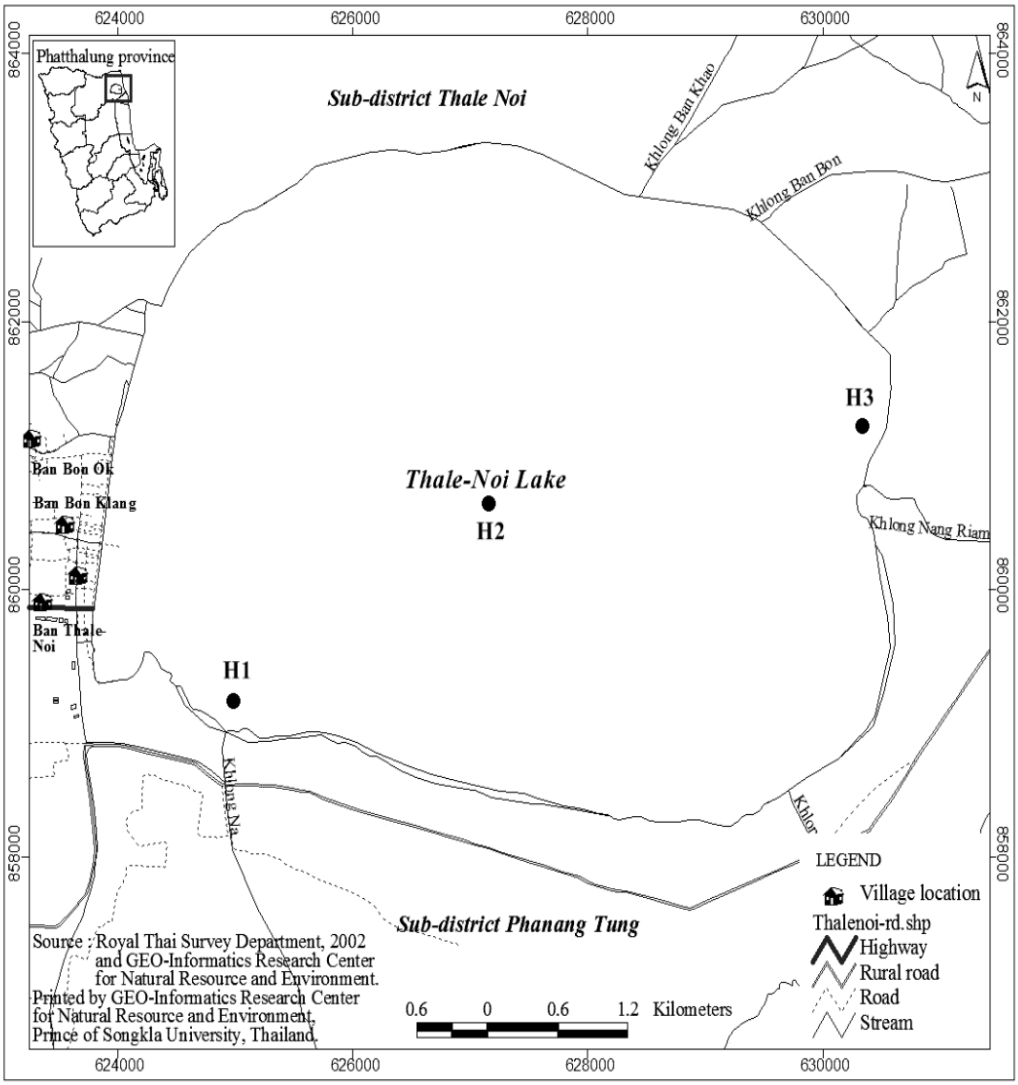


Figure 3. Study area and selected habitats at Thale-Noi Lake, Southern Thailand

A

B

C

Figure 4. A: Habitat 1, B: *Hydrilla* patch and C: *Ceratophyllum* Patch in Habitat 1

Figure 5. A: Habitat 2, B: *Hydrilla* patch in Habitat 2.

A B

Figure 6. A: Habitat 3, B: *Utricularia* patch

4. Characteristics of the selected macrophyte

***Ceratophyllum demersum* L.** (Fig. 7)

Submerged, rootless fresh water, slender, monoecious herb; leave exstipulate, 2-4 time forked, segment narrow, with serrulate magins, Leaf whorled 7-10, dark-green (Artharamas, 1984).

***Hydrilla verticillata* (L. f.) Royle** (Fig. 8)

Submerged freshwater herb, stolon often thicked and with crowded fleshy scale leaves 3-8 nately whorled, oblong or linear, usually sharply serrate dentate 0.75-4 cm long (Artharamas, 1984).

***Uticularia* sp.** (Fig. 9)

Submerged, filiform with short branched, sometime forming tuber or shoot; leaves opposite with numerous finely segments which usually bear minute bladders like traps randomly, distributed over the length of the leaves (Artharamas, 1984).

Figure 7. *Ceratophyllum demersum* L.

Figure 8. *Hydrilla verticillata* (L. f.) Royle

Figure 9. *Utricularia* sp.

Figure 7 – 9. Characteristics of the selected macrophyte

5. Methodology

5.1 Sampling periods

The cladoceran samples were collected monthly between May 2014 and May 2015.

5.2 Sampling methods

Animals were collected by a quantitative sampling method (activity traps), successful method to estimate cladoceran abundances per lake volume and area, modified from the funnel trap model of Örnólfsdóttir and Einarsson (2004). Our traps (Fig. 10) consist each of an array of four plastic bottles, each with a funnel attached to the lid (funnel diameter 10 cm, height 12 cm, total area of four funnel openings 0.03 m^2, bottle volume 370 ml.). The bottle-funnel sets are mounted on a metal frame with grid squares and there are four legs to fix the frame. The distance between the funnel opening and the sediment is about 5 cm. During each sampling, three individual traps (= 3x4 bottles) were deployed per selected macrophyte patch in each habitat. (6 replicates in H1 and 3 replications in H2 and H3) (Fig. 11). A total of 48 samples

were collected every month and altogether 624 samples were collected for the whole field work period. Field sampling protocol of the funnel trap are described below.

1. Filter water from the lake through 22 micrometer mesh of plankton net and fill into the bottles in order to prevent contamination of predators and planktonic species from the water column.

2. Place the trap horizontally over the lake sediment and the macrophytes (the funnel opening above the lake bottom 3 cm.)

3. Leave the traps overnight (12 hr), allowing the cladocerans to enter by their own swimming motion (vertical migration)

4. Pick up the traps and pour the samples from each bottle through 60 micrometer mesh of plankton net and keep it in new bottle

5. Samples were fixed in the field with 95% Alcohol and transported to the laboratory.

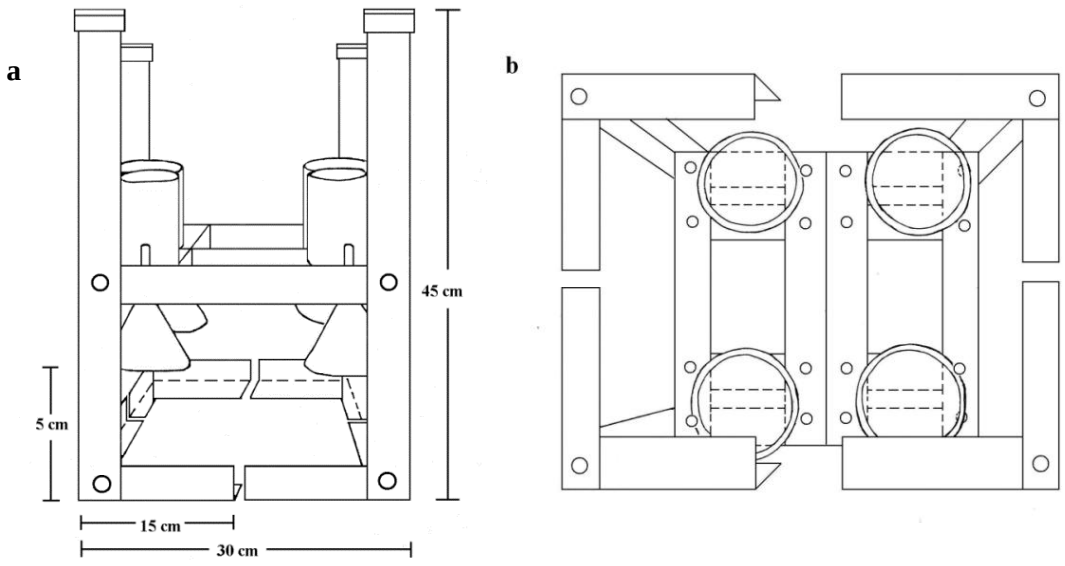


Figure 10. The funnel trap, a= lateral view and b= top view

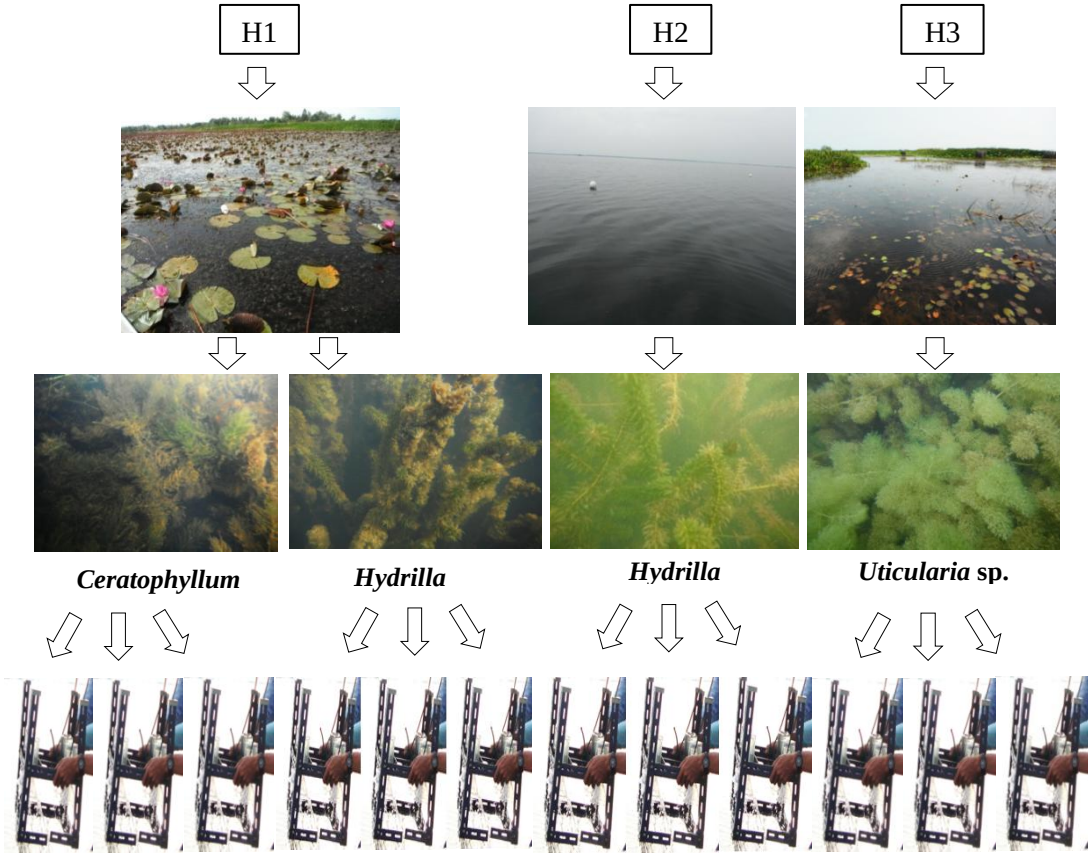


Figure 11. The experimental design

5.3 Laboratory work

5.3.1) Specimen preparation

Specimens were sorted, identified and counted under a stereo microscope (Olympus SZ- 40). At the same time, some specimens were prepared on permanent glass slides to examine morphological details, using an Olympus CH-2 compound microscope. The specimens were put in glycerin which is helps to preserve their shape and to protect them from drying out (Haney and Hall, 1973 referred by Duigan, n.d.). Before the specimens are covered with cover slide, small piece of clay were placed in each corner of the cover slide in order to protect them from pressure. The cover slides were then sealed with nail enamel.

5.3.2) Identification and counting

All the specimens of each species found in each sample were counted and identified to species level following several keys and up-to-date references such as Idris (1983); Smirnov (1996); Dumont and Silva – Briano (2000); Yalim and Ciplak, (2005); Kotov (2003) and Kotov *et al*. (2004) and the taxonomical updates by Maiphae (2005), Van Damme *et al.* (2011). Sinev (2012), Sinev and Kotov (2012), Van Damme and Maiphae (2013) and Van Damme *et al.* (2013), together with consultation of experts. Calculate individual/m^2 as the following (based on Tremel *et al*., 2000);

surface area of each funnel = (22/7)x 0.05^2 m^2 = $0.007857m^2$

Four funnels surface area = 0.0078 x 4 = 0.03 m^2

Abundance/ trap; individual/ m^2 = individual/0.03

5.3.3) Parameter measurements

Eight environmental parameters (depth, pH, salinity, water temperature, conductivity, transparency, dissolved oxygen and chlorophyll *a*) were measured for each macrophyte patch, per sampling. Each parameter was measured as the following methods: Depth was measured by a rope with weighted pendulum, pH was measured by pH metermeter YSI 60 model 60/10 FT., Salinity, water temperature and conductivity were measured by YSI 30 model 30/10 FT., Transparency was measured by a Secchi disc, Dissolved oxygen was analyzed using the Azide Modification of Iodometric Method and Chlorophyll *a* using the Spectrophotometric method (Thermo Electron Corporation, Spectronic 20+) (APHA, AWWA, and WEF, 1998).

5.3.4) Data analysis

1. The differences of cladoceran species richness, total cladoceran abundance and abundance in each species between and within habitats were analyzed using a nonparametric (Kruskal-Wallis) (using R program, version 3.2).

2. We used one-way ANOVA to test the differences of species richness and total abundance in each macrophyte patch between seasons (using R program, version 3.2).

3. The differences of each species of cladoceran abundance between seasons were analyzed using a nonparametric (Kruskal-Wallis) (using R program, version 3.2).

4. We used one-way ANOVA (factor are normality assumption) and nonparametric (Kruskal-Wallis; factor are not normality assumption) to test the differences of environmental factor in each macrophyte patch between seasons (using R program, version 3.2).

5. To explore similarities in species composition, we used Cluster analysis with PCORD.

6. The relationship between species and environmental factors was analyzed using Canonical Correspondence Analysis (CCA) using PCORD (5.0).

The raw data of environmental factor were log10 (x+1) transformed to increase normality for the subsequent analyses. Depth and chlorophyll *a* were tested using one-way ANOVA (the post hoc analysis was run using the Tukey Test) and dissolved oxygen, pH, transparency and salinity were tested by a nonparametric Kruskal-Wallis Test (the significant different factors were tested with the Mann-Whitney U test to compare means between groups) in R program (3.2). The factors that imported for CCA analysis are the factors that significantly different among habitats and species of cladoceran that have relative abundance lower than 0.1% were excluded. All traps were counted and sum of all samples in each trap were obtained for all statistical analyses except in Cluster analysis.

6. Expected outcomes

1. Obtain information about the species richness, abundance, composition and Community shifts in dominance of cladoceran among different habitats at Thale-Noi.

2. Obtain the information about environmental effects on cladoceran community.

3. Basic information for long term monitoring fluctuation of cladocerans community at Thale-Noi.

4. Basic information to predict the stability of lake ecosystem and benefits for lake management

5. Provide the first thorough and systematic study of niche separation and ecology of Cladocera in tropical freshwater ecosystems.

CHAPTER 3

RESULT

1. Environmental condition

Environmental factors in the three sampling sites in Thale-Noi Lake showed that depth ranged between 0.63-2.1m, pH 3.54 – 10.17, salinity 0 – 1.5 ppt, water temperature 25.5 – 34.8 C°, conductivity 51.5 – 3026 µS, transparency 0.3 – 1.7 m, dissolved oxygen 2.39 – 13.26 mgO_2/l and chlorophyll *a* 0 – 102.46 mg/l. Only two environmental factors, pH and depth, showed significant difference between H2 and H3 and depth significant difference between H1 and H3 (depth; p = 0.001, F=8.242, df = 2, pH; p = 0.007, x^2= 9.934, df = 2). Table 1 lists the ranges for each sampling site. Depth range in H1.Ce 0.80 - 2.10 m, H1.Hy 1.04 - 2.10 m, H2. 1.05 - 2.05 m and H3 0.63- 1.70m. The deepest in all habitats found in January and the shallowest found in July except in H3 the shallowest found in September. H1.Ce transparency range 0.55-1.35 m, the highest found in February and the lowest found in December. Transparency range in H1.Hy 0.5 - 1.55 m, the highest found in February and the lowest found in December. Transparency range in H2 0.3 - 1.33 m, the highest found in March and the lowest found in November. Transparency range in H3 0.55 - 1.7 m, the highest found in November and the lowest found in July. Temperature range in H1.Ce 27.4 - 34.7 ^oC, the highest found in May and the lowest found in September. Temperature range in H1.Hy 26.4 - 32.6 ^oC, the highest found in December and the lowest found in February. Temperature range in H2 25.5 - 32.9 ^oC, the highest found in May and the lowest found in February. Temperature range in H3 26.7 - 34.8 ^oC, the highest found in June and the lowest found in February. Conductivity range in H1.Ce 68.2 - 2127 µS/cm, the highest found in October and the lowest found in January. Conductivity range in H1.Ce 68.2 - 2127 µS/cm, the highest found in October and the lowest found in January. Conductivity range in H1.Hy 51.5 - 2578 µS/cm, the highest found in October and the lowest found in June. Conductivity range in H2 66.6 - 1555 µS/cm, the highest found in May and the lowest found in January. Conductivity range in H3 67.85 - 3026 µS/cm, the highest found in October and the lowest found in

February. pH range in H1.Ce 5.96 - 9.59 and H1.Hy 6.08 - 9.97, the highest pH in this macrophyte patch found in September and the lowest found in June. pH range in H2 6.70 - 10.17, the highest found in August and the lowest found in November. pH range in H3 3.54 - 9.77, the highest found in August and the lowest found in January. Chlorophyll *a* range in H1.Ce 2.30 - 102.46 mg/l, the highest found in October and the lowest found in May. Chlorophyll *a* range in H1.Hy 0 - 28.59 mg/l, the highest found in November and the lowest found in December. Chlorophyll *a* range in H2 1.30 - 17.11 mg/l, the highest found in May and the lowest found in February. Chlorophyll *a* range in H3 6.70 - 10.17 mg/l, the highest found in August and the lowest found in November. Dissolve oxygen in H1.Ce range 3.26 - 12.13 mgO_2/l, the highest found in April and the lowest found in June. Dissolved oxygen in H1.Hy range 2.39 - 12.13 mgO_2/l, the highest found in April and the lowest found in June. Dissolved oxygen in H1.Hy range 2.39 - 13.26 mgO_2/l, the highest found in April and the lowest found in June. Dissolved oxygen in H2 range 2.82 - 12.30 mgO_2/l, the highest found in December and the lowest found in November. Dissolved oxygen in H3 range 4.13 - 11.24 mgO_2/l, the highest found in August and the lowest found in June. In H1.Ce and H1.Hy was the same salinity range 0-1 ppt, the highest found in October and the lowest found in December-February. Salinity range in H2 0 - 0.7 ppt, the highest found in May and the lowest found in December-February. Salinity range in H3 0-1.5 ppt, the highest found in October and the lowest found in January-March (Fig.12). In addition, the environmental factors were not significant difference between two seasons except transparency. We found that transparency in H1.Hy showed a significant difference between dry and rainy season ($P<0.05$, $F=7.909$, $df = 1$). In dry season (1.18 ± 0.24) transparency is higher than in the rainy season (0.77 ± 0.28)

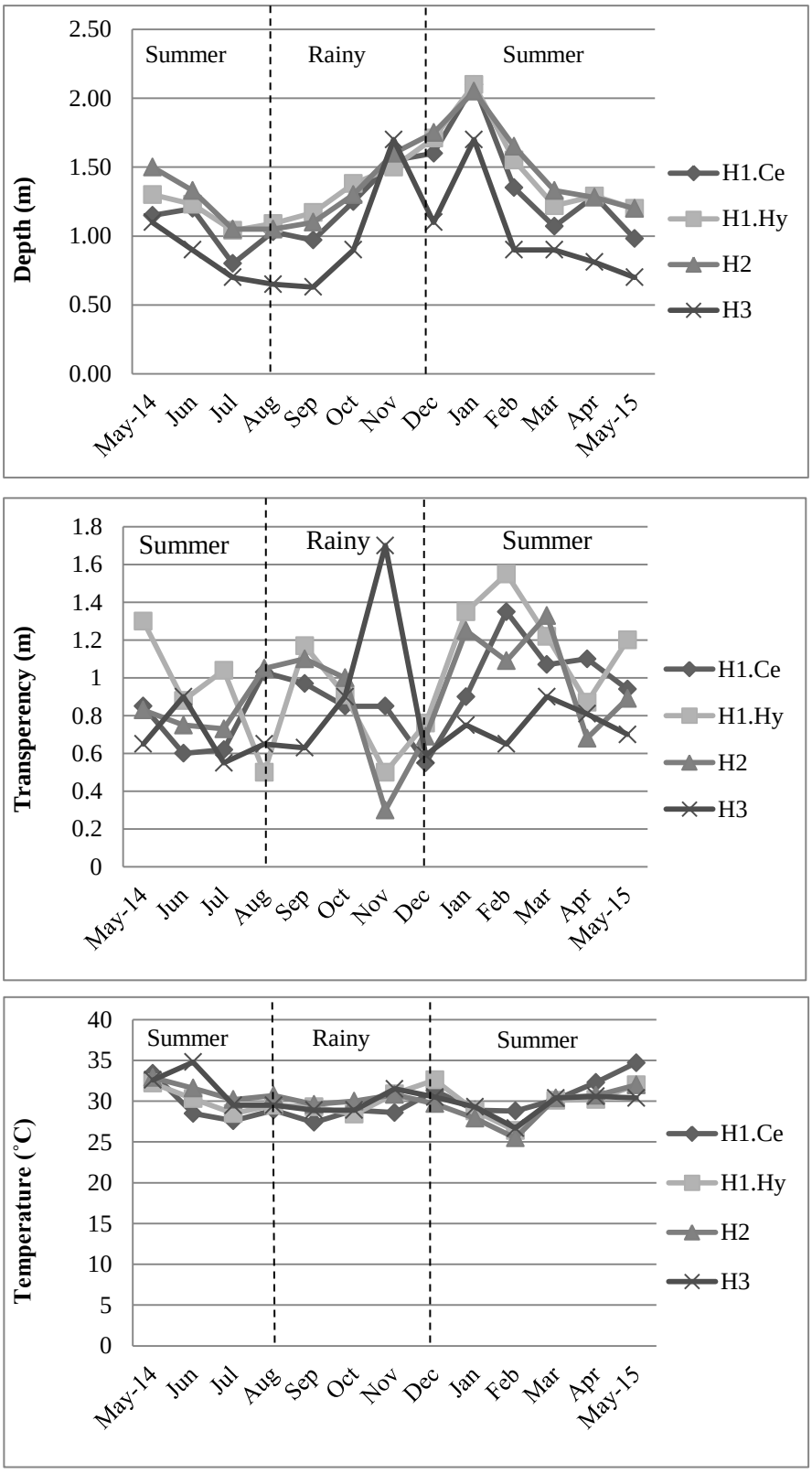


Figure 12. The monthly fluctuation of each parameters between May 2014-May 2015.

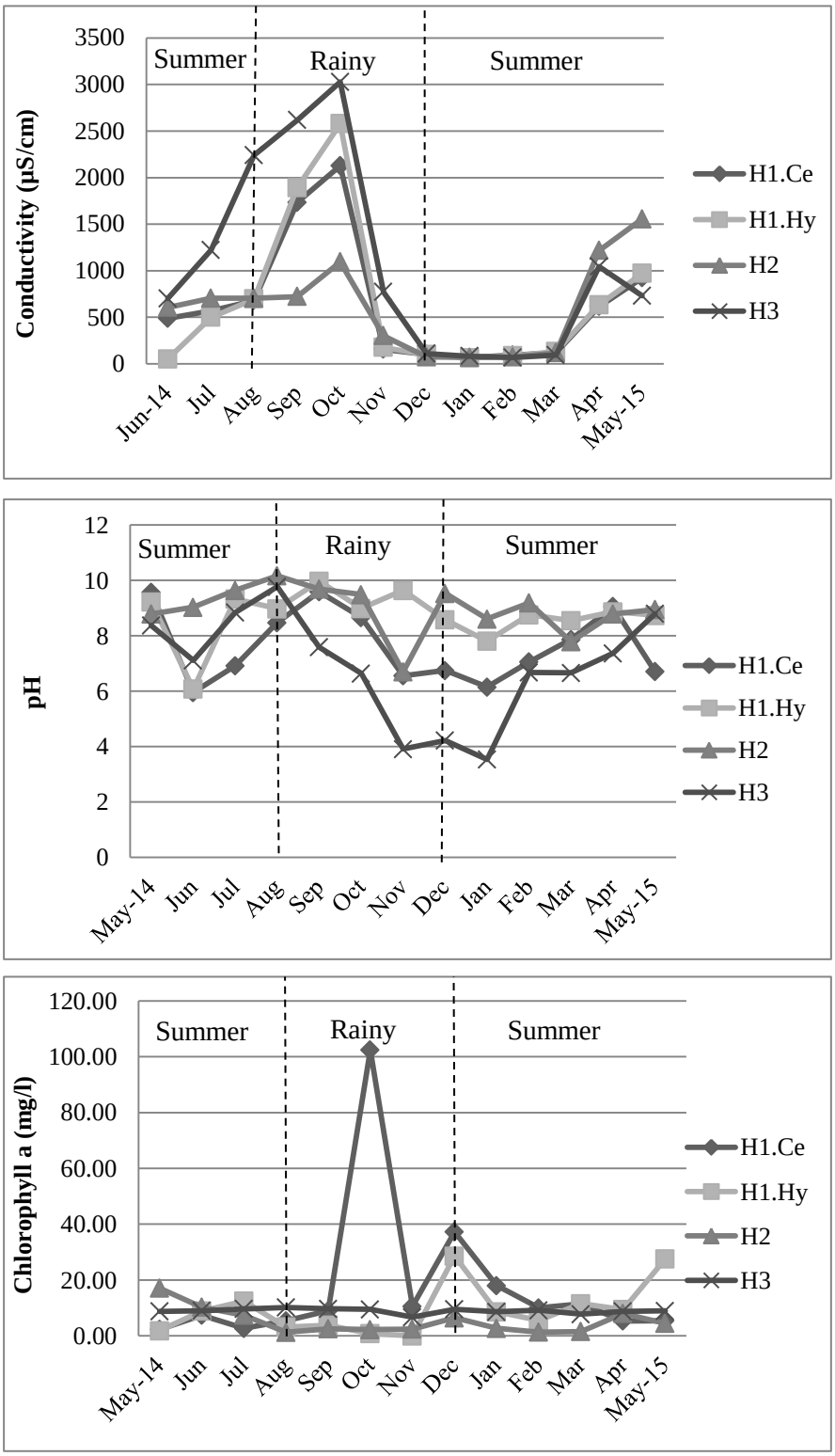
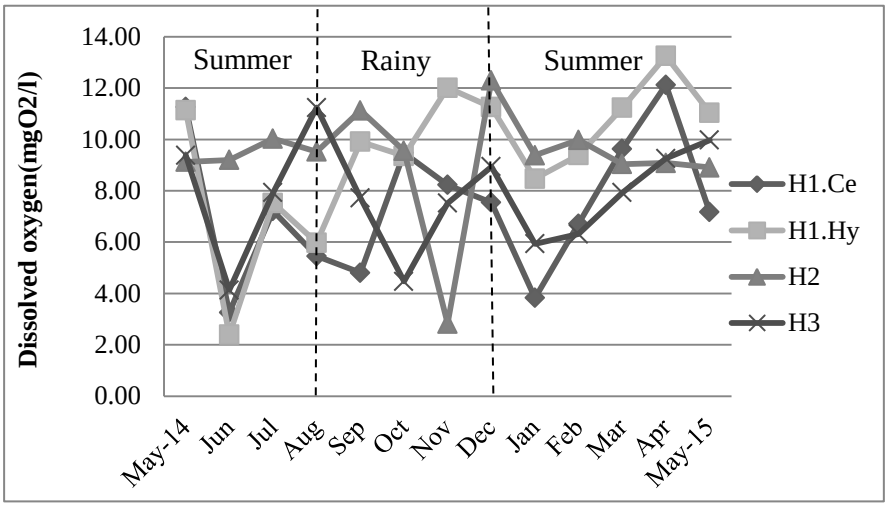


Figure 12. Continued. *Conductivity was not measured in May 2014.



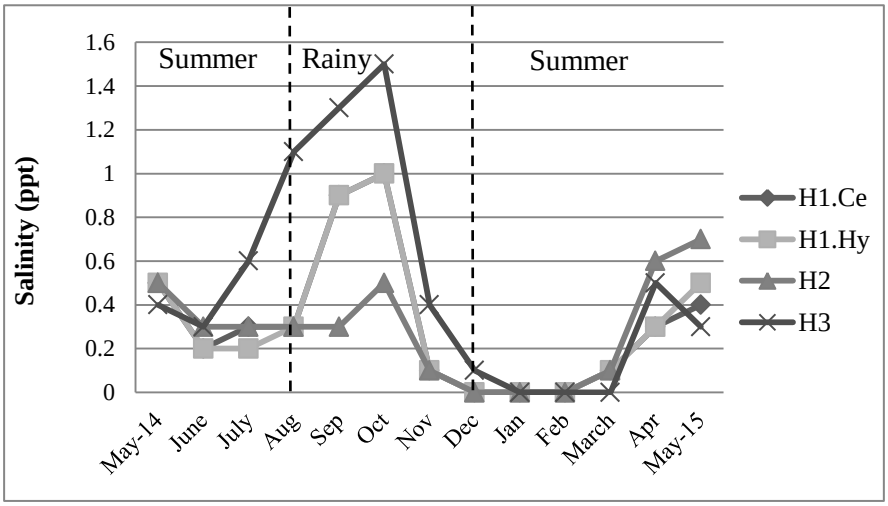


Figure 12. Continued.

Table 1. General characteristics of three different habitat type and environmental factors (range) in each sampling site between May 2014 and May 2015

Sampling sites	H1.Hy	H1.Ce	H2	H3
Coordinates	7° 46’ 276’’ N 100° 8’ 60’’ E	7° 46’ 257’’ N 100° 7’ 956’’ E	7° 46’ 835” N 100° 8’ 820” E	7° 47’474” N 100 ° 10’445” E
Location	Southwest	Southwest	Center	Northwest
type of habitat	Littoral zone	Littoral zone	Open water zone	Littoral zone
Macrophytes -Submerged plant	*Hydrilla verticillata* (L.f.) Royle. (dominant)	*Ceratophyllum demersum* L. (dominant)	*Hydrilla verticillata* (L.f.) Royle. (dominant) *Najas graminea* Del.	*Utricularia* spp (dominant) *Najas graminea* Del. *Hydrilla verticillata* (L.f.) Royle. *Blya echinosperma* (C.B. Clarke) Hook.f.
-Emerged plant	*Nymphaea lotus* L. *Nymphoides indicum* (L.) Kuntze.	*Nymphaea lotus* L. *Nymphoides indicum* (L.) Kuntze.		*Nelumbo nucifera* Gaertn. *Nymphaea lotus* L. *Nymphaeas tellata* Wild.

Table 1. Continued.

Sampling sites	H1.Hy	H1.Ce	H2	H3
- Floating plant -Marginal plant	*Eichornia crassipes* (Mart.) Solms. *Neptunia oleracea* Lour. *Salvinia cucullata* Roxb. *Hanguana malayana* (Jack.)	*Eichornia crassipes* (Mart.) Solms. *Neptunia oleracea* Lour. *Salvinia cucullata* Roxb. *Hanguana malayana* (Jack.)		*Hanguana malayana* (Jack.) *Eleocharis ochrostachys* Steud.
Depth (m)	1.04 - 2.03	0.8 - 2.0	1.05 - 2.05	0.63 - 1.7
pH	6.08 - 9.97	5.96 - 9.59	6.7 - 10.17	3.54 - 9.77
Salinity (ppt)	0 - 1	0 - 1	0 - 0.7	0 - 1.5
Water temperature (^oC)	26.4 - 32.6	27.4 - 34.7	25.5 - 32.9	26.7 - 34.8
conductivity (µS/cm)	51.5 - 2578	68.2 - 2127	66.6 - 1555	67.85 - 3026
Dissolved oxygen (mgO_2/l)	2.39 - 13.26	2.30 - 102.46	2.82 - 12.30	4.13 - 11.24
Chlorophyll *a* (mg/l)	0 - 28.59	2.30 - 102.46	1.30 - 17.11	0.63 - 22.91

2. Species richness

2.1 Total species richness and species richness among habitat

A total of seven families, 28 genera and 40 species of Cladocera was retrieved from the samples over the complete period. The most represented families are Chydoridae (22 species), Macrothricidae (6 species), followed by Sididae (4 species), and the Daphniidae (3 species) (Table 2). Two species are new records for Thailand, *Alona kotovi* Sinev, 2012 (Fig. 16) (sibling species of *A. quadrangularis*) and *Diaphanosoma celebensis* Stingelin, 1900 (Fig. 17). There were 7 families 26 genus and 32 species were found in habitat 1 in *Hydrilla* bed (H1.Hy) while *Ceratophyllum* bed (H1.Ce) found 6 families 23 genera and 30 species. Habitat 2 found 7 family 27 genera and 34 species of cladoceran which is similar with habitat 3 that found 7 families 25 genera and 34 species. All habitats can be found cladoceran in 7 families except in *Ceratophyllum* bed found 6 families. This macrophyte bed was not found family Bosminidae and there was the lowest number of genus and species of cladoceran (Fig. 13). The species richness of Cladocera per habitat is similar (along the year with total of 30-34 species). The highest species richness was found in habitats 2 and 3 (34 species) followed by habitat 1 in the *Hydrilla* bed (H1.Hy; 32 species) and the lowest in the *Ceratophyllum* beds (H1.Ce; 30 species). Six species were found restricted in only one habitat: *Leberis macronyx* (H1.Ce), *A. sanoamuangae* and *Alonella nana* (H2), *A. kotovi*, *M. odiosa* and *Macrothrix pholpunthini* (H3). Species richness of cladoceran per trap ranges between 0-21 species. Variance among three traps in each macrophyte patch range between 0-7 species but about 90% of macrophyte patch showed variance between 1-4 species (Appendix, 1). The species richness were not significantly different among particular habitats in the same period ($P = 0.051$, $x^2 = 5.937$ $df = 2$).

Table 2. Cladocera species occurrence as retrieved from the samples at Thale-Noi Lake in each of the four sampling localities over the course of a year (May 2014-2015). Asterisks indicate new records for Thailand.

	H1.Ce	H1.Hy	H2.	H3
Family Bosminidae				
Bosminopsis deitersi Richard, 1895		X	X	X
Bosmina meridionalis Sars, 1930		X	X	X
Total species of Bosminidae	-	2	2	2
Family Chydoridae				
Alona guttata Sars,1862	X	X	X	X
*Alona kotovi** Sinev, 2012				X
Alonella nana (Baird, 1843)			X	
Anthalona harti (Van Damme, Sinev & Dumont 2011)	X	X	X	X
Anthalona sanoamuangae Sinev & Kotov, 2012			X	
Camptocercus cf. *australis* Sars, 1896	X	X	X	X
Chydorus cf. *eurynotus* Sars, 1901	X	X	X	X
Chydorus parvus Daday, 1898	X	X	X	X
Chydorus ventricosus Daday,1898	X	X	X	X
Coronatella cf. *monacantha* (Sars, 1901)	X	X	X	X
Coronatella cf. *rectangula* (Sars, 1862)	X	X	X	X
Dunhevedia crassa King, 1853	X	X	X	X
Ephemeroporus barroisi (Richard, 1894)	X	X	X	X
Euryalona orientalis (Daday, 1898)	X	X	X	X
Karualona cf. *karua* (King, 1853)	X	X	X	X
Kurzia longirostris (Daday, 1898)	X	X	X	X
Leberis diaphanus (King, 1853)	X	X	X	X
Leberis macronyx Daday, 1898	X			
Leydigia acanthocercoides (Fischer,1854)			X	X
Leydigia australis Sars, 1885			X	X
Notoalona globulosa (Daday, 1898)	X	X		X
Pseudochydorus cf. *globosus* (Baird. 1843)	X	X	X	X
Total species of Chydoridae	17	16	19	19
Family Daphniidae				
Ceriodaphnia cornuta Sars, 1885	X	X	X	X
Simocephalus latirostris Stingelin, 1906	X	X		
Simocephalus serrulatus (Koch, 1841)	X	X	X	X
Total species of Daphniidae	3	3	2	2
Family Ilyocryptidae				
*Ilyocryptus spinife*r Herrick, 1882	X	X	X	X

Table2. (Continued).

	H1.Ce	H1.Hy	H2.	H3
Total species of Ilyocryptidae	1	1	1	1
Family Macrothricidae				
Grimaldina brazzai Richard, 1892	X	X	X	X
Guernella raphaelis Richard, 1892	X	X	X	X
Macrothrix odiosa Gurney, 1916				X
Macrothrix pholpunthini Kotov, Maiphae and Sanoamuang, 2005				X
Macrothrix spinosa King, 1853	X	X	X	X
Macrothrix triserialis Brady, 1886	X	X	X	X
Total species of Macrothricidae	4	4	4	6
Family Moinidae				
Moina micrura Kurz, 1874.		X	X	
Moinodaphnia macleayi (King, 1853)	X	X	X	
Total species of Moinidae	1	2	2	-
Family Sididae				
*Diaphanosoma celebensis** Stingelin, 1900	X	X	X	X
Diaphanosoma excisum Sars, 1885	X	X	X	X
Latonopsis australis	X	X	X	X
Pseudosida bidentata Herrick, 1884	X	X	X	X
Total species of Sididae	4	4	4	4
Total number of species richness	30	32	34	34

* New records for Thailand

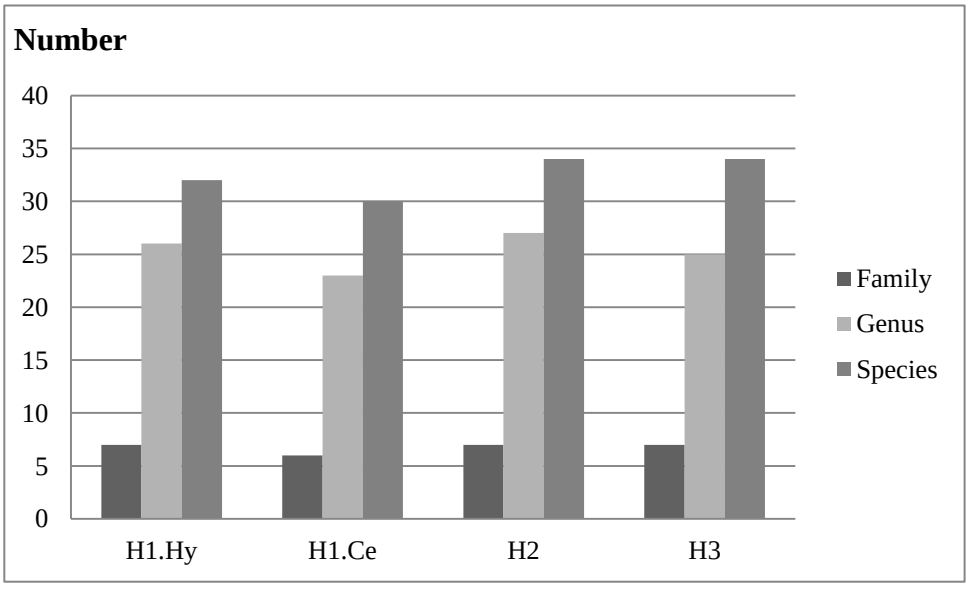


Figure 13. Total number of families, genera and species of cladoceran in each macrophyte patch.

2.2 Species richness in each macrophyte patch between season

Six families, 23 genus and 30 species of cladoceran were recorded in *Ceratophyllum* patch in summer season while in the rainy season 6 families, 19 genus and 23 species were recorded. Another patch of macrophyte, *Hydrilla* patch, in H1Hy found seven families, 26 genus and 32 species in summer while in the rainy season found six families, 20 genus and 23 species. The species richness between the macrophyte patch in H1 found the equal number in rainy season. In H2, seven families, 24 genus and 29 species of cladoceran were recorded in the summer season while in the rainy season found six families, 20 genus and 27 species. In the summer season, the *Utricularia* patch showed seven families, 22 genus and 29 species of cladoceran while in the rainy season found six families, 21 genus and 26 species. Our study showed that total number of family, genus and species richness of cladoceran over the year in all macrophyte patches in summer season was higher than in rainy season except in *Ceratophyllum* patch which found the equal number of family in two seasons and in habitat 2 and habitat 3 number of species in summer season was slightly higher than in rainy season (Fig. 14, Table 3). The result found 36 species of total cladoceran species richness in summer season and 35 species in rainy season (Table 4). However, the species richness showed significantly differ between seasons in H1.Hy (P = 0.005, F= 9.025 df =1), in H1.Ce (P = 0.000, F= 15.532 df =1) and in H2 (P = 0.010, F= 7.462, df =1). Mean of species richness in H1.Hy and H1.Ce were higher during summer than during rainy season while it showed the opposite in H2 (the average of species richness in dry season; H1.Hy = 11.96 ± 4.80, H1.Ce = 12.54 ± 4.90 and H2= 6.92 ± 3.76, species richness average in rainy season; H1.Hy = 8.53 ± 2.26, H1.Ce = 7.67 ± 2.82 and H2 = 10.13 ± 3.25). Species richness in H1.Hy was highest in March and April (22 species) and lowest in August and September (8 species), as well as in H1.Ce where species richness was highest in May (22 species) and lowest in September (7 species). Species richness in H2 was highest in August and April (17 species) and lowest in May (5 species; but not as low in the consecutive year, with 12 species) while species richness in H3 was highest in August (21 species) and lowest in January (6 species) (Fig. 15).

Four species were found only in the dry season (*Bosminopsis meridionalis*, *Leberis macronyx*, *Macrothrix odiosa* and *Macrothrix pholpunthini*) and three species were found only in the rainy season (*Alona kotovi*, *Alonella nana* and *Anthalona sanoamuangae*), of which two species were only encountered only once (*Alona kotovi and Alonella nana*) (August) and in low numbers. 33 species of cladoceran were found in both two seasons (Table 4).

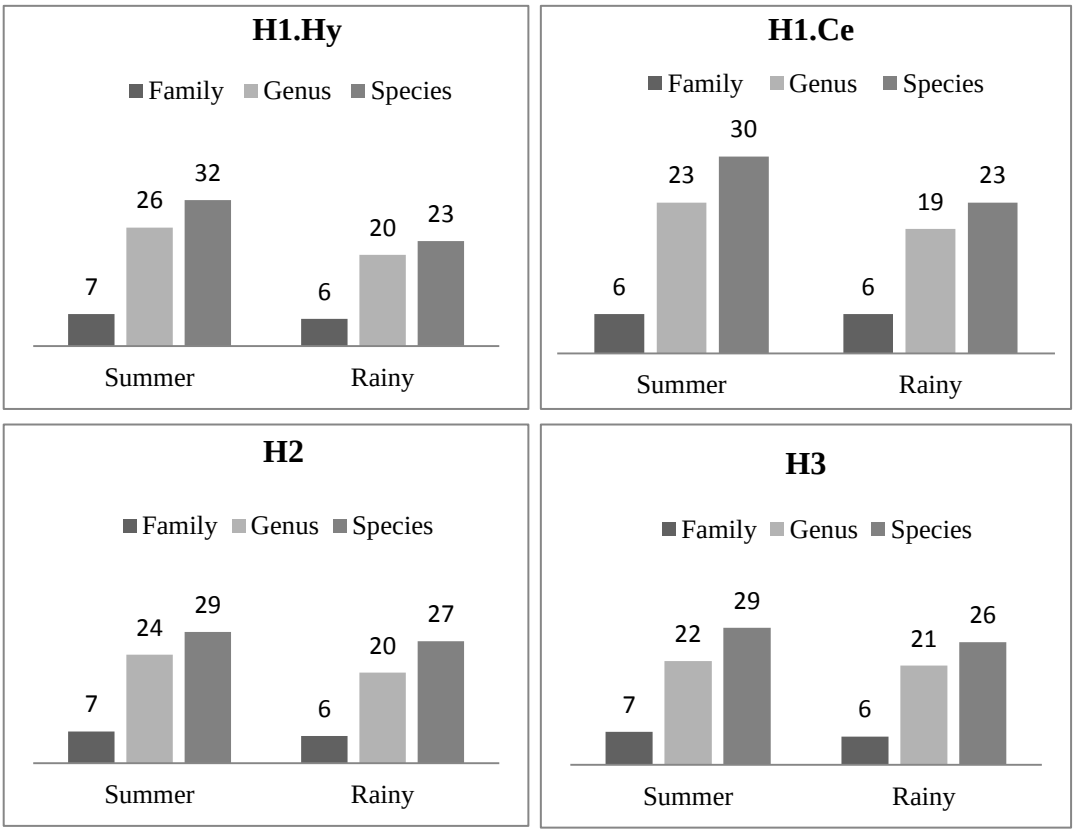


Figure 14. Number of families, genera and species of Cladocera in each habitat in two seasons

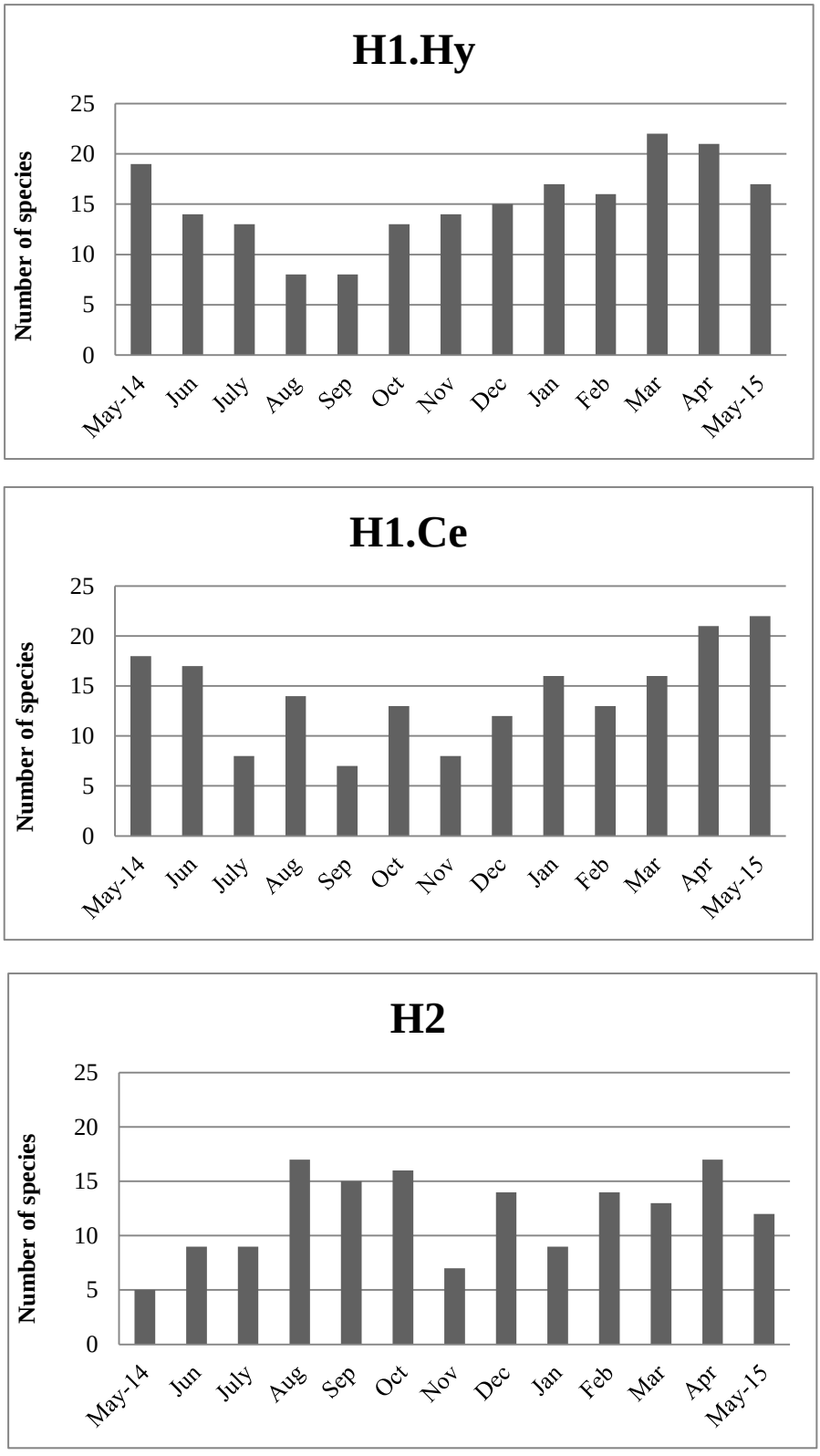


Figure 15. Total species richness as recorded from activity traps (n=3), Thale-Noi Lake, Southern Thailand, May 2014-2015.

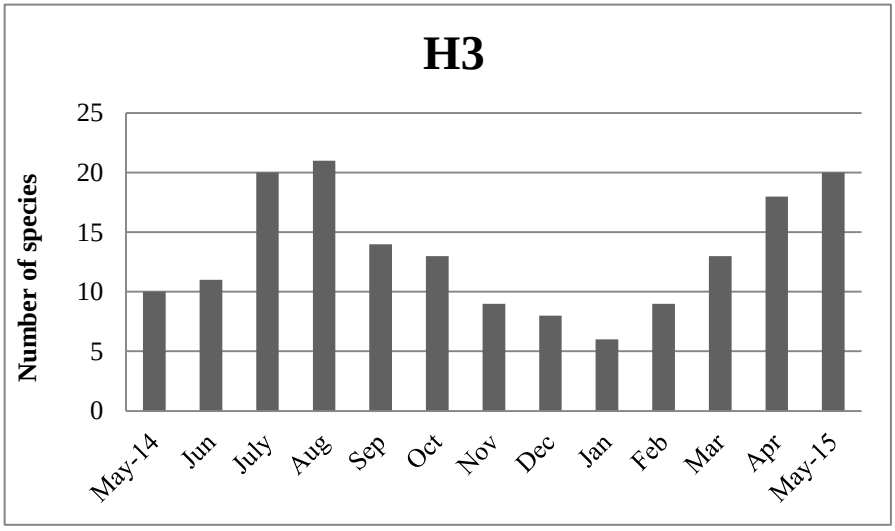


Figure 15. Continued.

Table 3. Cladoceran species in each seasons in each of the four sampling localities over a year (May 2014-2015) (S = summer season and R = rainy sason).

Cladocera	H1.Ce		H1.Hy		H2.		H3	
	S	R	S	R	S	R	S	R
Family Bosminidae								
Bosminopsis deitersi Richard, 1895			X		X		X	
Bosmina meridionalis Sars, 1930			X			X	X	
Family Chydoridae								
Alona guttata Sars,1862	X		X	X	X		X	X
*Alona kotovi** Sinev, 2012								X
Alonella nana (Baird, 1843)						X		
Anthalona harti (Van Damme, Sinev & Dumont 2011)	X	X	X	X	X	X	X	X
Anthalona sanoamuangae Sinev & Kotov 2012						X		
Camptocercus cf. *australis* Sars, 1896	X	X	X		X	X	X	X
Chydorus cf. *eurynotus* Sars, 1901	X	X	X	X	X	X	X	X

Table 3. Continued

Cladocera	H1.Ce		H1.Hy		H2.		H3	
	S	R	S	R	S	R	S	R
Chydorus parvus Daday, 1898	X		X		X	X	X	
Chydorus ventricosus Daday,1898	X		X		X	X	X	X
Coronatella cf. *monacantha* (Sars, 1901)	X	X	X		X	X	X	X
Coronatella cf. *rectangula* (Sars, 1862	X	X	X		X	X	X	
Dunhevedia crassa King, 1853	X	X	X	X	X	X	X	X
Ephemeroporus barroisi (Richard, 1894)	X	X	X	X	X	X	X	X
Euryalona orientalis (Daday, 1898)	X	X	X	X	X	X	X	X
Karualona cf. *karua* (King, 1853)	X	X	X	X	X	X	X	X
Kurzia longirostris (Daday, 1898)	X	X	X	X	X	X	X	X
Leberis diaphanus (King, 1853)	X		X	X	X	X	X	X
Leberis macronyx Daday, 1898	X							
Leydigia acanthocercoides (Fischer,1854)					X	X	X	X
Leydigia australis Sars, 1885					X	X	X	X
Notoalona globulosa (Daday, 1898)	X		X					X
Pseudochydorus cf. *globosus* (Baird. 1843)	X		X	X	X		X	
Family Daphniidae								
Ceriodaphnia cornuta Sars, 1885	X	X	X	X	X	X	X	X
Simocephalus latirostris Stingelin, 1906	X	X	X	X	X			
Simocephalus serrulatus (Koch, 1841)	X	X	X	X			X	

Table 3. Continued

Cladocera	H1.Ce		H1.Hy		H2.		H3	
	S	R	S	R	S	R	S	R
Family Ilyocryptidae								
Ilyocryptus spinifer Herrick, 1882	X	X	X	X	X	X	X	X
Family Macrothricidae								
Grimaldina brazzai Richard, 1892	X	X	X	X	X			X
Guernella raphaelis Richard, 1892	X	X	X	X	X			X
Macrothrix odiosa Gurney, 1916							X	
Macrothrix pholpunthini Kotov, Maiphae and Sanoamuang, 2005							X	
Macrothrix spinosa King, 1853	X	X	X	X	X	X	X	X
Macrothrix triserialis Brady, 1886	X	X	X	X		X	X	X
Family Moinidae								
Moina micrura Kurz, 1874.			X			X		
Moinodaphnia macleayi (King, 1853)	X	X	X	X	X	X		
Family Sididae								
*Diaphanosoma celebensis** Stingelin, 1900	X	X	X	X	X	X		X
Diaphanosoma excisum Sars, 1885	X	X	X	X	X	X	X	X
Latonopsis australis group	X	X	X	X	X	X	X	X
Pseudosida bidentata Herrick, 1884	X	X	X	X	X		X	X
Total number of species richness	**30**	**23**	**32**	**23**	**29**	**27**	**29**	**26**

* New records for Thailand

Table 4. Species of Cladoceran between seasons.

Species	**Summer**	**Rainy**
Family Bosminidae		
Bosminopsis deitersi Richard, 1895	**X**	
Bosmina meridionalis Sars, 1930	X	X
Family Chydoridae		
Alona guttata Sars,1862	X	X
*Alona kotovi** Sinev, 2012		**X**
Alonella nana (Baird, 1843)		**X**
Anthalona harti (Van Damme, Sinev & Dumont 2011)	X	X
Anthalona sanoamuangae Sinev & Kotov 2012		**X**
Camptocercus cf. *australis* Sars, 1896	X	X
Chydorus cf. *eurynotus* Sars, 1901	X	X
Chydorus parvus Daday, 1898	X	X
Chydorus ventricosus Daday,1898	X	X
Coronatella cf. *monacantha* (Sars, 1901)	X	X
Coronatella cf. *rectangula* (Sars, 1862)	X	X
Dunhevedia crassa King, 1853	X	X
Ephemeroporus barroisi (Richard, 1894)	X	X
Euryalona orientalis (Daday, 1898)	X	X
Karualona cf. *karua* (King, 1853)	X	X
Kurzia longirostris (Daday, 1898)	X	X
Leberis diaphanus (King, 1853)	X	X
Leberis macronyx Daday, 1898	**X**	
Leydigia acanthocercoides (Fischer,1854)	X	X
Leydigia australis Sars, 1885	X	X
Notoalona globulosa (Daday, 1898)	X	X
Pseudochydorus cf. *globosus* (Baird. 1843)	X	X
Family Daphniidae		
Ceriodaphnia cornuta Sars, 1885	X	X
Simocephalus latirostris Stingelin, 1906	X	X
Simocephalus serrulatus (Koch, 1841)	X	X
Family Ilyocryptidae		
Ilyocryptus spinifer Herrick, 1882	X	X
Family Macrothricidae		
Grimaldina brazzai Richard, 1892	X	X

Table 4. Continued

Species	**Summer**	**Rainy**
Guernella raphaelis Richard, 1892	X	X
Macrothrix odiosa Gurney, 1916	**X**	
Macrothrix pholpunthini Kotov, Maiphae and Sanoamuang, 2005	**X**	
Macrothrix spinosa King, 1853	X	X
Macrothrix triserialis Brady, 1886	X	X
Family Moinidae		
Moina micrura Kurz, 1874.	X	X
Moinodaphnia macleayi (King, 1853)	X	X
Family Sididae		
*Diaphanosoma celebensis** Stingelin, 1900	X	X
Diaphanosoma excisum Sars, 1885	X	X
Latonopsis australis	X	X
Pseudosida bidentata Herrick, 1884	X	X
Cladocera total	36	35

Bold; species that were found only in one season.
* New records for Thailand

3. Note on new records of Thailand

***Alona kotovi* Sinev, 2012** (Fig. 16)

Short description

Body oval, moderately high, compressed laterally. Posterodorsal and posteroventral angles broadly rounded. Posterior margin convex. Posteroventral angle with 3–5 groups of large setules. Carapace sculpture as weak longitudinal lines, labral keel wide, height about 1.5 – 1.7 times width. Anterior margin of keel convex, sometimes with notch near the apex, apex blunt or rounded, posterior margin with two clusters of setae. Antennule elongated, length about 3–3.5 width. Antennular seta arising at 2/3 distance from the base. Broad postabdomen with convex postanal margin, armed with 10 –12well-developed marginal denticles and 10–11lateral fascicles of setules. Postabdominal claw slender, of moderate length, equal to preanal portion of

postabdomen. Basal spine long and slender, about 1/3 of the claw length. Parthenogenetic female moderate size, length up to 0.67 mm (Sinnev, 2012).

Habitat

Alona kotovi belongs to the *quadrangularis*-group of *Alona* which *Alona quadrangularis* considered to be sediment-dwelling chydorid, inhabits the lower muddy regions (Evans, 1984; Sminov, 1971; Flössner, 1964, Moore, 1939 and Whiteside *et al*., 1978) and the present study found *Alona kotovi* in littoral zone with sediment under *Utricularia* patch. Therefore, it is possible that *Alona kotovi* inhabit in mud and sediment habitat. In addition, we found *A. kotovi* in shallow habitat, depth 0.65 m, salinity 1.1 ppt and pH 9.77.

Distribution

This species has been found in South Vietnam. They were found in forest stream near Bau Chim lake, Cat Tien National Park, Dong Nai Province, Vietnam (Sinnev, 2012) and they were found in the present study in Thale-Noi Lake, Phatthalung Province, Thailand.

Figure 16. *Alona kotovi* Sinev, 2012

***Diaphanosoma celebensis* Stingelin, 1900** (Fig. 17)

Short description

Head small, rounded, conical, is weakly developed dorsal part steeply sloping and imperceptibly passing into the frontal margin. Swimming antennae short, not reaching posterior valve margin; second segment of upper 2 - segmented branch with only 7 setae. Ventral vale margin with a wide flap-form inflexion which, posteriorly, approaches the postero ventral margin and is connected with it. Posterior margin rounded, bearing 3 - 4 long feathered setae with 4 - 8 thin long setules between each pair of them, proximally of them 5-6 short spine-like setae and then again 14 – 17 long feathered setae decreasing in size anteriorly. Two slightly bent dorsal spine of unequal length on each valve. Terminal claws massive, their distal basal spine wavy. Males with small spine on distal part of basipodite and long, tubular copulatory appendages, somewhat narrowing distally. Length of females ranges 0.63-0.91 mm and male 0.56-0.67(Korovchinsky, 1992).

Habitat

This species possible inhabits nearshore and estuarine water (Korovchinsky, 1992) and they were found in littoral zone with *Hydrilla* and *Ceratophyllum* patch, open water zone with *Hydrilla* patch and the littoral zone with *Utricularia* patch in this study.

Distribution

A rare species has been recorded from few localities, Makassar Area (Sulawesi Island, Indonesia), neighborhood of the city of Nha Trang (South of Vietnum), two sites in Sri Lanka (Korovchinsky, 1992) and in the present study, it was found in three sites in Thale-Noi Lake, Phatthalung Province, Thailand.

Figure 17. Male *Diaphanosoma celebensis* Stingelin, 1900

4. Abundance

4.1 Abundance among habitats

The highest cladoceran abundance was found in H3, the total abundance is 513,767 ind/m^2 over one year followed by H1.*Ce* 431,700 ind/m^2, comparable to with H1.*Hy* 424,733 ind/m^2 and the lowest in H2 (202,700 ind/m^2) (Fig. 18, Table 5). Total number of cladoceran per trap ranges between 0-1,481 individuals. Variance among three traps in each macrophyte patch ranges between 1-544 individuals but about 86% of macrophyte patch showed variance less than 250 individuals (Appendix, 2). The total abundances differed significantly between H1 and H2, H2 and H3 (P = 0.002, x^2 = 12.522, df = 2) while H1 and H3 did not differ significantly. Abundance of 26 species of cladocerans showed significant differences among habitats including *Bosminopsis deitersi, Alona kotovi*, *Anthalona sanoamuangae*, *Camptocercus* cf. *australis, Chydorus* cf. *eurynotus*, *C. ventricosus, Coronatella* cf. *monacantha, C.* cf. *rectangular, Dunhevedia crassa, Ephemeroporus barroisi*, *Euryalona orientalis, Kurzia longirostris*, *Leberis diaphanus, Leydigia australis, L. acanthocercoides*, *Ceriodaphnia cornuta, Simocephalus latirostris, Ilyocryptus spinifer*, *Grimaldina brazzai*, *Guernella raphaelis*, *Macrothrix odiosa, M. pholpunthini, M. triserialis*, *Diaphanosoma excisum*, *Latonopsis australis* and *Pseudosida bidentata* (Fig, 19; Table 5). *A. sanoamuangae* found in H2 (1,033 ind/m^2), *A. kotovi* (100 ind/m^2), *M. odiosa* (11,133 ind/m^2) and *M. pholpunthini* (1,467 ind/m^2)) found in H3. *E. orientalis* (23,833 ind/m^2), *K. longirostris* (67,967

ind/m^2), *S. latirostris* (4,100 ind/m^2), *I. spinifer* (6,767 ind/m^2) *and P. bidentata* (22,500 ind/m^2) showed highest abundance in H1.Ce. *G. brazzai,* (2,867 ind/m^2), *G. raphaelis* (833 ind/m^2) *and D. excisum* (15,600 ind/m^2) showed highest abundance in H1.Hy. *Bosminopsis deitersi* (10,00 ind/m^2), *C.* cf. *australis* (5,100 ind/m^2), *C.* cf. *eurynotus* (17,633 ind/m^2), *D. crassa* (59,133 ind/m^2), *Leydigia australis* (1,000 ind/m^2) and *L. acanthocercoides* (2,233 ind/m^2) were dominant in H2 while *C. ventricosus* (47,433 ind/m^2), *E. barroisi* (107,667 ind/m^2), *L. diaphanous* (14,133 ind/m^2), *C. cornuta* (total 69,500 ind/m^2), *M. triserialis* (62,600 ind/m^2) and *L. australis* (total 60,800 ind/m^2) are mainly abundant in H3.

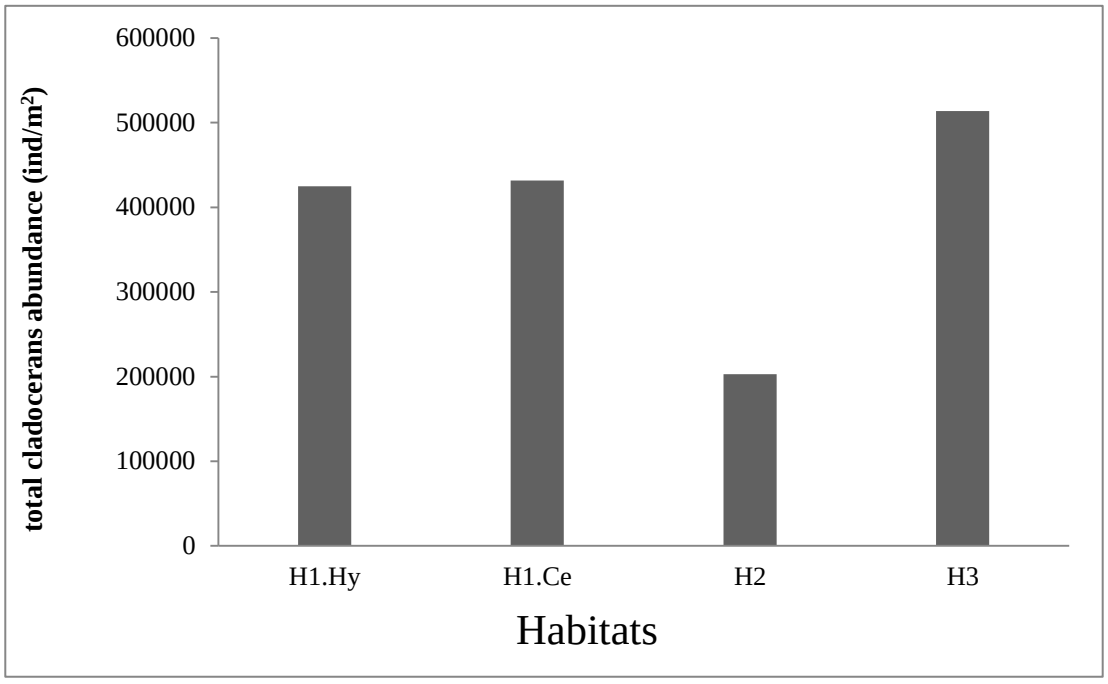


Figure 18.Total cladoceran abundance as recorded from activity traps (n=39) in each macrophyte patch over the year (May 2014 – May 2015).

Table 5. Cladoceran abundance (ind/m^2) and *P*-value from nonparametric Kruskal-Wallis test (Test the difference of cladoceran abundance in each species among habitat). Bold; species that showed significant difference among habitat.

Species	*P*-value	H1.Hy	H1.Ce	H2	H3
Bosminopsis deitersi	**0.042**	366.67	0.00	1000.00	66.67
Bosmina meridionalis	0.370	1900.00	0.00	0.00	100.00
Alona guttata	0.923	733.33	133.33	333.33	133.33
Alona kotovi	**0.010**	0.00	0.00	0.00	100.00
Alonella nana	0.223	0.00	0.00	33.33	0.00
Anthalona harti	0.468	214600.00	45666.67	40533.33	65666.67
Anthalona sanoamuangae	**0.002**	0.00	0.00	1033.33	0.00
Camptocercus cf. *australis*	**0.004**	1166.67	2333.33	5100.00	900.00
Chydorus cf. *eurynotus*	**0.001**	6133.33	10700.00	17633.33	2533.33
Chydorus parvus	0.604	166.67	33.33	133.33	66.67
Chydorus ventricosus	**0.010**	11866.67	9366.67	1433.33	47433.33
Coronatella cf. *monacantha*	**0.003**	166.67	166.67	2500.00	1900.00
Coronatella cf. *rectangula*	**0.007**	66.67	233.33	1500.00	133.33
Dunhevedia crassa	**0.010**	28066.67	20566.67	59133.33	8700.00
Ephemeroporus barroisi	**0.000**	7200.00	36966.67	8433.33	107666.67
Euryalona orientalis	**0.000**	4033.33	23833.33	633.33	500.00
Karualona cf. *karua*	2.800	27833.33	14166.67	27933.33	18166.67
Kurzia longirostris	**0.016**	3800.00	67966.67	9600.00	4333.33
Leberis diaphanus	**0.035**	666.67	2933.33	1466.67	14133.33
Leberis macronyx	0.219	0.00	333.33	0.00	0.00
Leydigia acanthocercoides	**0.000**	0.00	0.00	2233.33	800.00
Leydigia australis	**0.001**	0.00	0.00	1000.00	400.00

Table 5. Continued

Species	P-value	H1.Hy	H1.Ce	H2	H3
Notoalona globulosa	0.464	400.00	33.33	0.00	33.33
Pseudochydorus cf. *globosus*	0.158	233.33	400.00	200.00	66.67
Ceriodaphnia cornuta	**0.000**	30400.00	58733.33	11333.33	69500.00
Simocephalus latirostris	**0.000**	1433.33	4100.00	0.00	0.00
Simocephalus serrulatus	0.088	833.33	3933.33	700.00	21733.33
Ilyocryptus spinifer	**0.006**	933.33	6766.67	400.00	2233.33
Grimaldina brazzai	**0.004**	2866.67	2000.00	200.00	200.00
Guernella raphaelis	**0.006**	833.33	666.67	33.33	33.33
Macrothrix odiosa	**0.000**	0.00	0.00	0.00	11133.33
Macrothrix pholpunthini	**0.001**	0.00	0.00	0.00	1466.67
Macrothrix spinosa	0.251	1833.33	800.00	233.33	1733.33
Macrothrix triserialis	**0.000**	5266.67	35233.33	1966.67	62600.00
Moina micrura	0.605	33.33	0.00	33.33	0.00
Moinodaphnia macleayi	0.064	666.67	500.00	1033.33	0.00
Diaphanosoma celebensis	0.101	4766.67	6366.67	166.67	300.00
Diaphanosoma excisum	**0.000**	15600.00	11933.33	266.67	1133.33
Latonopsis australis	**0.000**	46166.67	42233.33	4300.00	60800.00
Pseudosida bidentata	**0.000**	3700.00	22500.00	166.67	7066.67
Total		424733.33	431600.00	202700.00	513766.67

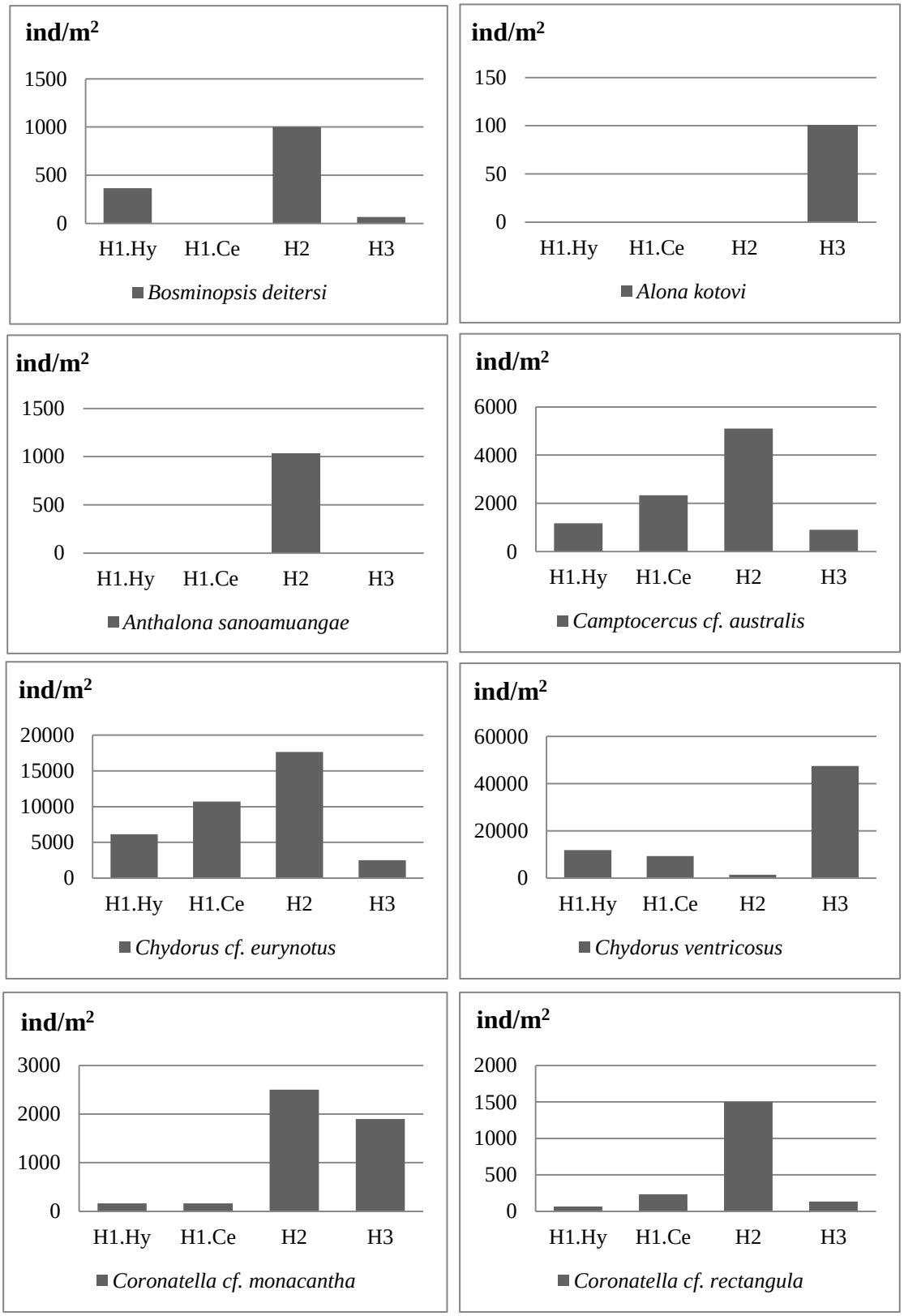


Figure 19. Total abundances of cladoceran as recorded from activity traps (n=39) in each macrophyte patch between May 2014-2015.

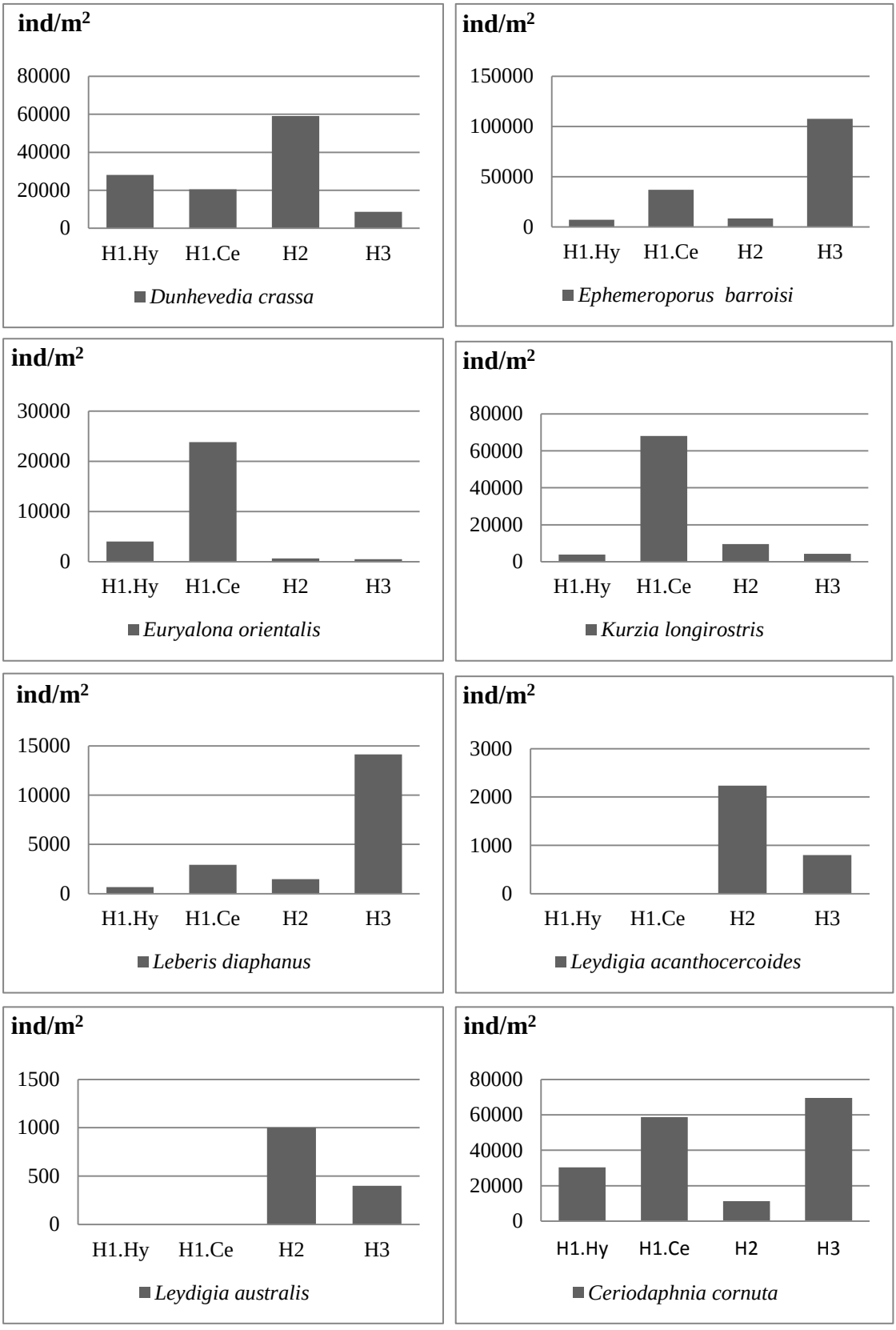


Figure 19. Continued.

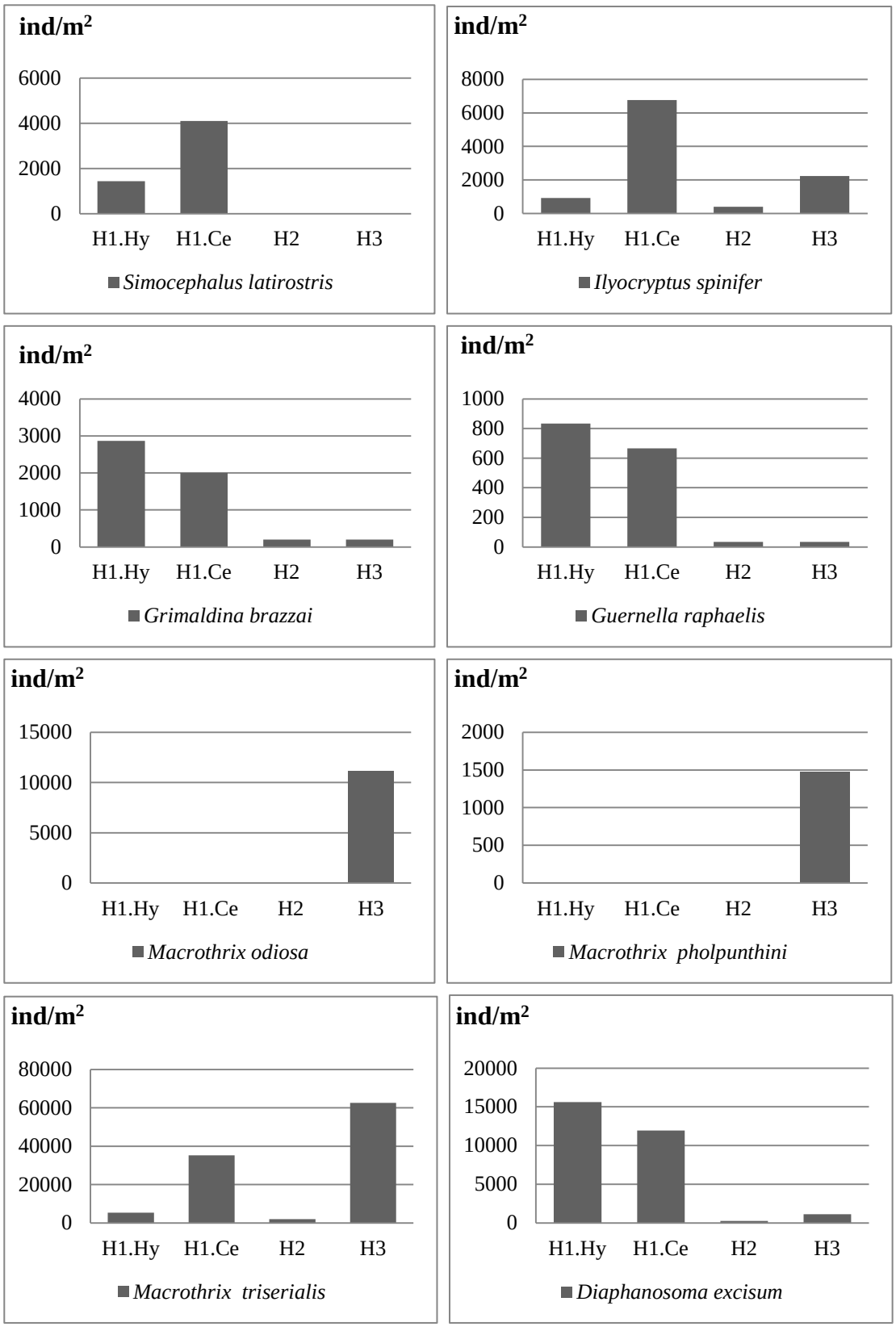


Figure 19. Continued.

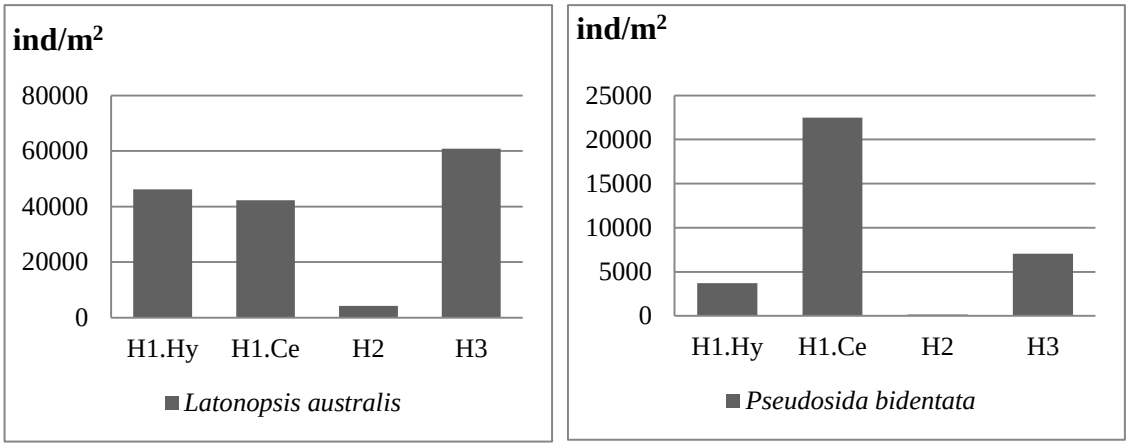


Figure 19. Continued.

4.2 Relative differences in abundances between genus and species in the habitats.

Anthalona harti is the highest relative abundance of cladoceran in H1.Hy (50%) followed by *Latonopsis australis* (11%), *Ceriodaphnia cornuta* (7%) and the lowest is *Moina micrura* (0.007%) (Figure 20a). The highest relative abundance in H1.Ce is made up by the *Kurzia longirostris* (16%) followed by *Ceriodaphnia cornuta* (14%), *Anthalona harti* (11%) and the lowest in *Chydorus parvus* (0.007%). In H2, *Dunhevedia crassa* showed the highest relative abundance (29%) followed by *Anthalona harti* (20%), *Karualona* cf. *karua* (14%) and the lowest are *Alonella nana* and *Guernella raphaelis* (0.016%). *Ephemeroporus baroisi* is the highest relative abundance in H3 (21%) followed by *Ceriodaphnia cornuta* (14%), *Anthalona harti* (13%) and the lowest in *Notoalona globulosa* (0.006%).

Anthalona harti was found in all macrophyte patches but showed distinctly dominant in H1.Hy, where the relative abundance was high at 50% while the abundance are less than 25% in the other sites.

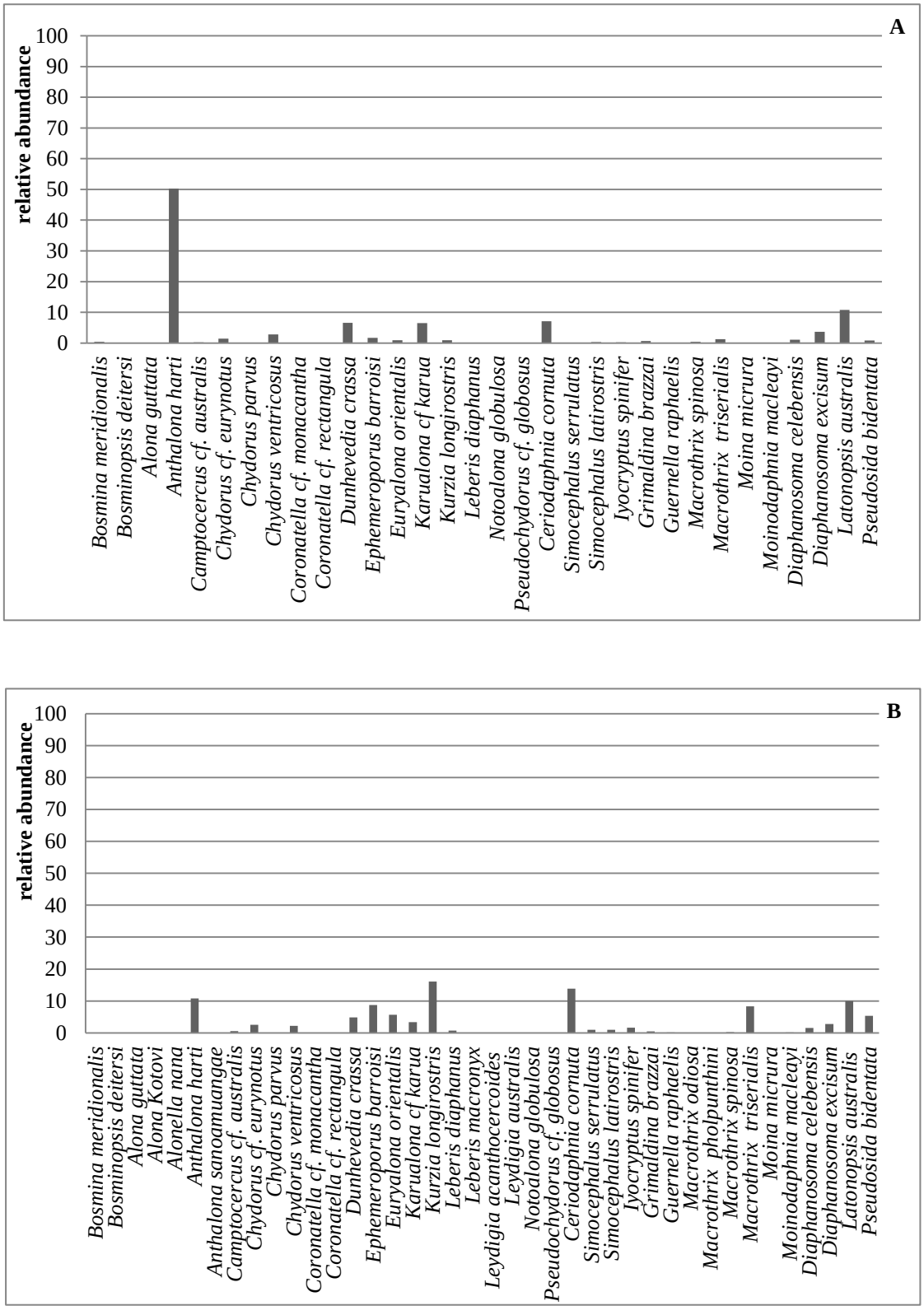
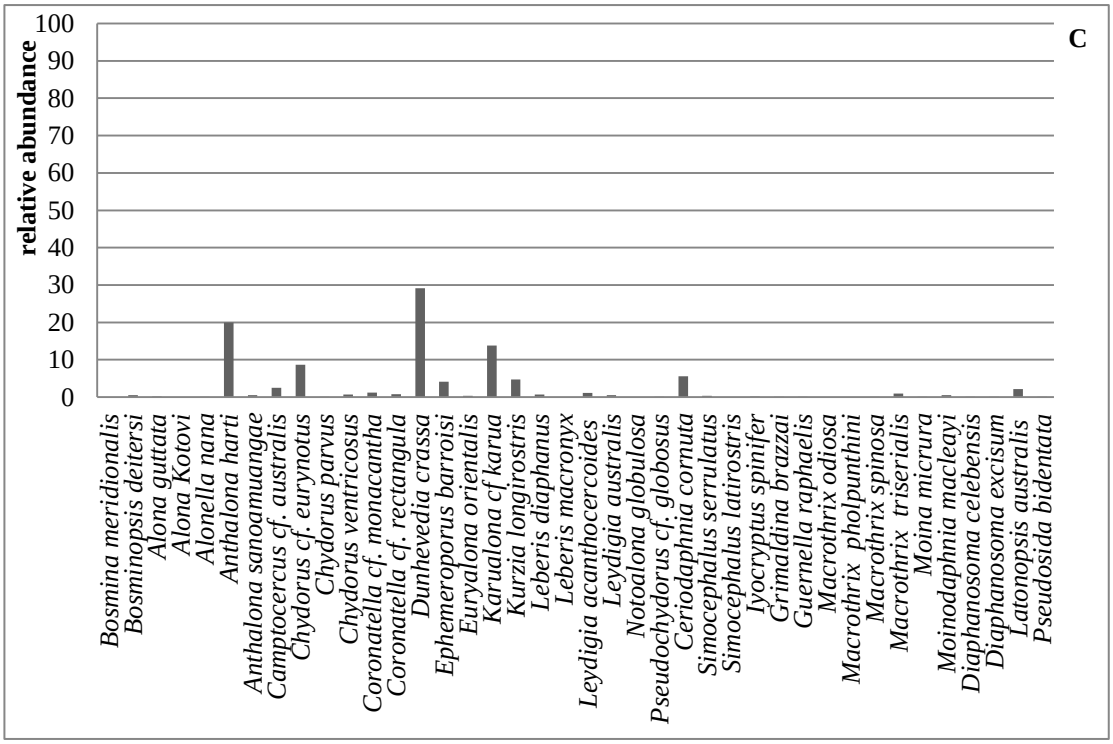


Figure 20. Relative abundances of each cladoceran species in Thale-Noi Lake between May 2014 and May 2015. A: H1.Hy, B: H1.Ce, C:H2, D:H3



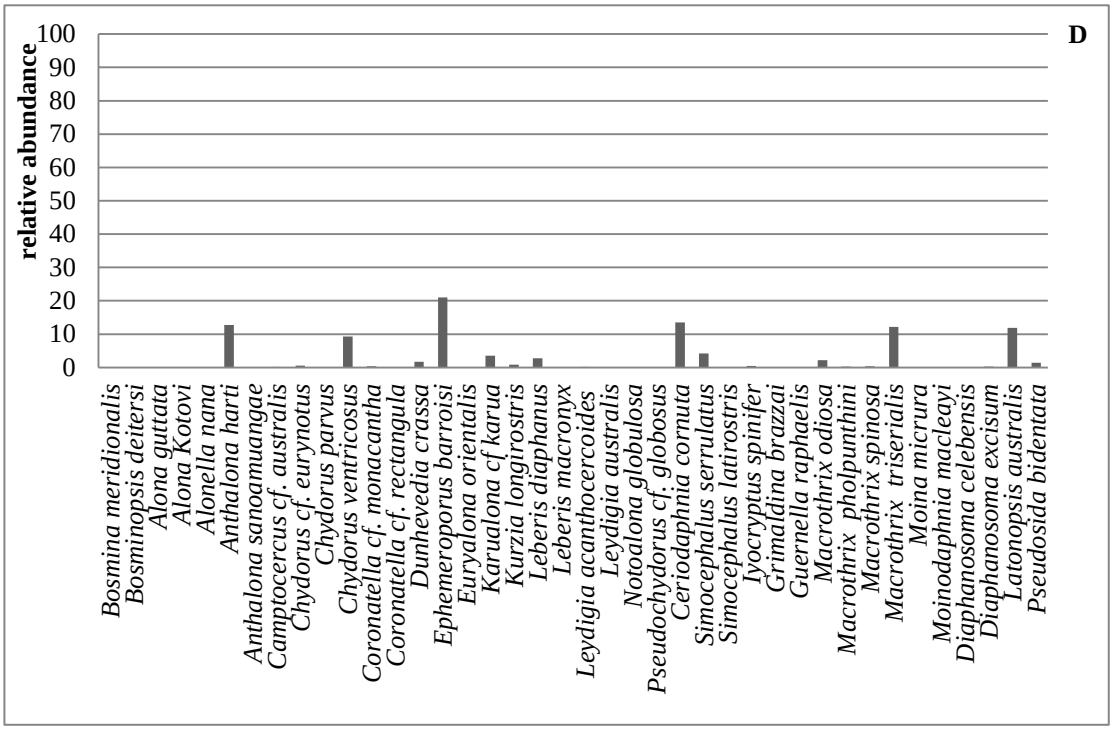


Figure 20. continued.

4.3 Monthly abundance and abundance between seasons

Monthly abundance varied most in H3 and H1.Ce, with the highest numbers in April (101,467 ind/m^2) and May (106,333ind/m^2) and lowest in January (1,200 ind/m^2) and Saptember (2,533ind/m^2), respectively. Highest densities in H1.Hy were found in April (82,767ind/m^2) and the lowest in August (5,367ind/m^2); in H2 the highest density was found in October (55,967ind/m^2), the lowest in May (500ind/m^2).Total cladoceran abundances over the year in each habitat peaked in mid-rainy season (September and October) and in mid-summer season (February and April), lowest overall abundances occur in June, November and January (Fig. 21). The total cladoceran density in each macrophyte patch showed that they are not significantly different between seasons (*P*; H1.Hy = 0.843, H1.Ce = 0.651, H2 = 0.070 and H3 = 0.862).

In addition, males of three cladoceran species were also found in the present study though with low density and have been recorded only five times over the year. Of which, male of *Moinodaphnia macleayi* were found in H1 and H3 in December (total abundance ; 567 ind/m^2 and 33 ind/m^2, respectively), male of *Anthalona harti* were found in H2 and H3 in August (100 ind/m^2 and 67 ind/m^2, respectively) and in H3 in June (200 ind/m^2), male of *Diaphanosoma celebensis* were found in H1 in April (33 ind/m^2), November (33 ind/m^2) and December (100 ind/m^2). Moreover, resting eggs were found in the samples in January, February, June, August, September and November (but did not count the number).

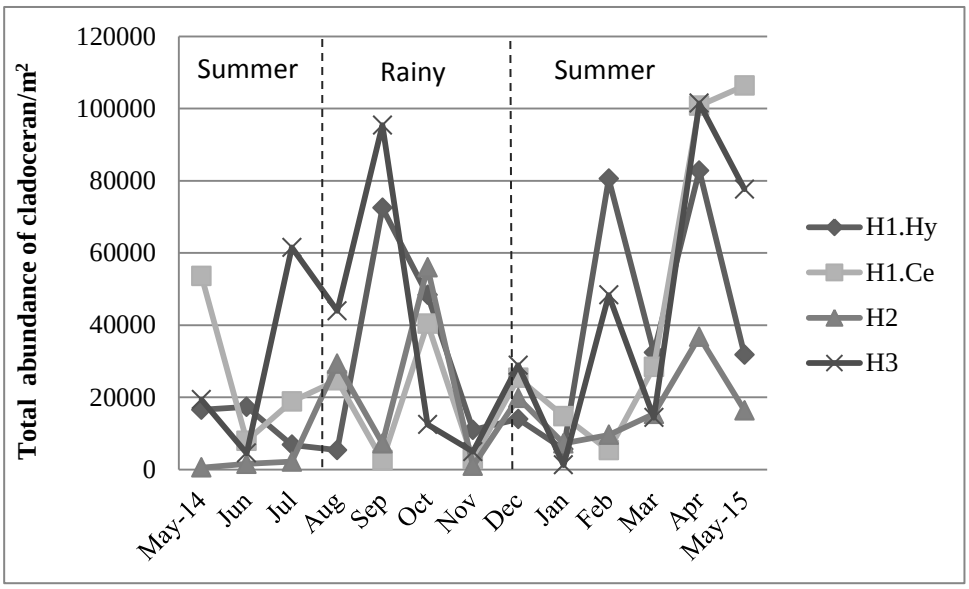


Figure 21. Abundances of Cladocera in Thale-Noi Lake over consecutive seasons, total of all habitat traps.

Total cladoceran abundance in each macrophyte patch is not significantly different between these two seasons but when we compared abundance for each species between dry and rainy seasons, 15 species showed significant differences. *A. kotovi* and *A. sanoamuangae* were found only in the rainy season, *M. pholpunthini* and *M. odiosa* were found only in dry season. *Camptocercus* cf. *australis*, *Chydorus* cf. *eurynotus*, *C. ventricosus*, *D. crassa*, *E. barroisi*, *Pseudochydorus* cf. *globosus*, *Simocephalus serrulatus* and *Macrothrix spinosa* were found in dry season, with higher abundance than in the rainy season whereas *Leydigia acanthocercoides*, *G. raphaelis* and *Diaphanosoma celebensis* were found in the rainy season more than in the dry season (Table. 6).

Table 6. Cladoceran abundance between season (ind/m^2) (*P*-value were analyzed by nonparametric Kruskal-Wallis test. Bold; species that showed significant difference between seasons.

Species	*P*-value	Summer	Rainy
Bosminopsis deitersi	0.262	1033	400
Bosmina meridionalis	0.110	2000	0
Alona guttata	0.220	667	667
Alona kotovi	**0.027**	0.00	100
Alonella nana	0.206	0.00	33
Anthalona harti	0.393	226433	140033
Anthalona sanoamuangae	**0.011**	0.00	1033
Camptocercus cf. *australis*	**0.011**	5433	4067
Chydorus cf. *eurynotus*	**0.000**	30467	6533
Chydorus parvus	0.119	367	33
Chydorus ventricosus	**0.000**	69467	633
Coronatella cf. *monacantha*	0.533	1433	3300
Coronatella cf. *rectangula*	0.862	1033	900
Dunhevedia crassa	**0.033**	71100	45367
Ephemeroporus barroisi	**0.000**	139733	20533
Euryalona orientalis	0.280	12333	16667
Karualona cf. *karua*	0.533	54300	33800
Kurzia longirostris	0.797	73500	12200
Leberis diaphanus	0.860	12867	6333
Leberis macronyx	0.168	333	0
Leydigia acanthocercoides	**0.000**	167	2867
Leydigia australis	0.909	400	1000
Notoalona globulosa	0.572	433	33
Pseudochydorus cf. *globosus*	**0.005**	867	33
Ceriodaphnia cornuta	0.056	75300	94667
Simocephalus latirostris	0.704	3967	1567
Simocephalus serrulatus	**0.006**	26767	433
Ilyocryptus spinifer	0.507	5667	4667
Grimaldina brazzai	0.951	4300	967
Guernella raphaelis	**0.008**	300	1267
Macrothrix odiosa	**0.015**	11133	0
Macrothrix pholpunthini	**0.033**	1467	0
Macrothrix spinosa	**0.014**	2667	1933

Table 6. Continued

Species	*P*-value	Summer	Rainy
Moina micrura	0.736	33	33
Moinodaphnia macleayi	0.168	300	1900
Diaphanosoma celebensis	**0.032**	1700	9867
Diaphanosoma excisum	0.056	20933	8000
Latonopsis australis	0.061	83533	69967
Pseudosida bidentata	0.987	23000	10433
Total		1027167	545600

5. Community shifts in dominance

Anthalona harti (214,600 ind/m^2), *L. australis* (46,167 ind/m^2), *C. cornuta* (30,400 ind/m^2), *D. crassa* (28,067 ind/m^2) and *Karualona* cf. *karua* (27,833 ind/m^2) are dominant species in H1.Hy. *A. harti* showed the greatest abundance in September and a second pronounced increase in February and April and disappeared completely in November and December. *L. australis* was the most abundant in October and a second (smaller) increase in April. *D. crassa* and *K.* cf. *karua* were presented all the time but had maximum numbers in February, while *C. cornuta* was found all year round, yet most abundant only in November. Most species exhibited two population peaks, one during September-November and January – May. Dominance in H1.Ce is different, with *K. longirostris* the most abundant (67,967 ind/m^2), followed by *C. cornuta* (58,733 ind/m^2), *A. harti* (45,667 ind/m^2), *L. australis* (42,233 ind/m^2) and *E. barroisi* (36,967 ind/m^2). They were not found in September, October and January-March and increase greatly in May 2015. *C. cornuta* and *A. harti* have similar fluctuation densities; their first peak in October and peak again in April. *L. australis* is most abundant in October, as in H1.Hy and *E. barroisi* had greatest abundance in March when other species are at low density.

In H2, *D. crassa* (59,133 ind/m^2) is the dominant species, followed by *A. harti* (40,533 ind/m^2), *K.* cf. *karua* (27,933 ind/m^2), *Chydorus eurynotus* (17,633 ind/m^2) and *C. cornuta* (11,333 ind/m^2). *D. crassa* and K. cf. *karua* showed similar population patterns, with maximal abundances in October, low in November and a second peak in December. *A. harti* is highly abundant in April, *C. eurynotus* has its greatest density in

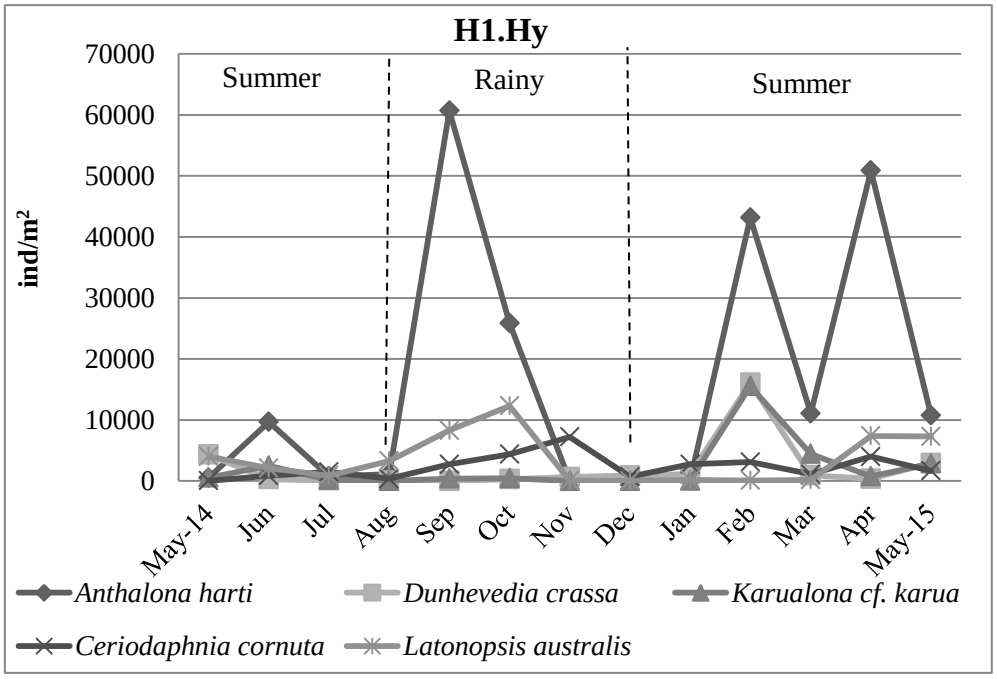
August, March and April. *C. cornuta* is very low in abundance and peaks only in March when *A.harti* was not found and *D. crassa* and *K. karua* are very low.

E. barroisi (107,667 ind/m^2), *C. cornuta* (69,500 ind/m^2), *A. harti* (65,667 ind/m^2), *M. triseralis* (62,600 ind/m^2) and *L. australis* group (60,800 ind/m^2) are the most abundant cladoceran species in H3. *E. barroisi* has the highest densities and their maximum occurred in April. *C. cornuta* has low densities, and was not found in May 2014 and also was not found during November- February. They have peak abundance only in September. *A. harti* was found throughout the year but with a density peak in September and April, while *M. triseralis* had a maximum in February.

Moreover, we found that smaller size species (Chydoridae) showed high density when larger size species (Macrothricidae, Sididae and Daphniidae) fall peak while smaller cladoceran showed low density when larger size species peaked. In H1.Hy *Anthalona harti* (0.3 - 0.34 mm (Van Damme *et. al*, 2011)) were found high density while the larger species, *Latonopsis australis* and *Ceriodaphnia cornuta* (Up to 1.8 mm (korovchinsky, 1992)) showed low density in June, September, February and April. In the contrary, *Anthalona harti* showed lower density when *L. australis* and *C. cornuta* begin high density in October and November. In the same time in H1.Ce, *Anthalona harti*, *Ephemeroporus barroisi* (Up to 0.3 mm (Smirnov, 1886)) *and Kurzia longirostris* (0.41- 052 mm (Idris, 1983)) showed low density when larger species, *L. australis* and *C. cornuta* tend to show higher density in May and October, *E. barroisi* and *K. longirostris* showed highest density when *L. australis* and *C. cornuta* showed very low density in March and May respectively. In H2, *Dunhevedia crassa* (up to 0.36 mm (Smirnov, 1996)) was high dominant while larger species, *C. cornuta* was low density in October and December. In H3, *E. barroisi* showed higher density than larger species, *Macrothrix triserialis* (Up to 0.6 mm (Smirnov, 1992)), *L. australis* and *C. cornuta* in July and April. However, after that *E. barroisi* lower density when *C. cornuta* peaked in September. In addition, *E. barroisi*was lower density when *M. triserialis* and *L.australis* reach high density in December. Then *E. barroisi* decreased while *M. triserialis* high density in Febuary and *L. australis* increased May.

Moreover, we noted that density of *A. harti* found inversely with *E. barroisi*. In H1.Ce, *A. harti* were found high density when *E. barroisi* low density in October and

April and the opposite in May and March. In H3, *A. harti* showed high density when *E. barroisi* low density in September, the opposite in July, April and May. Most of the dominant species in each habitat peaked during the rainy season, in Sep and Oct and the dry season (April) (Fig.22).



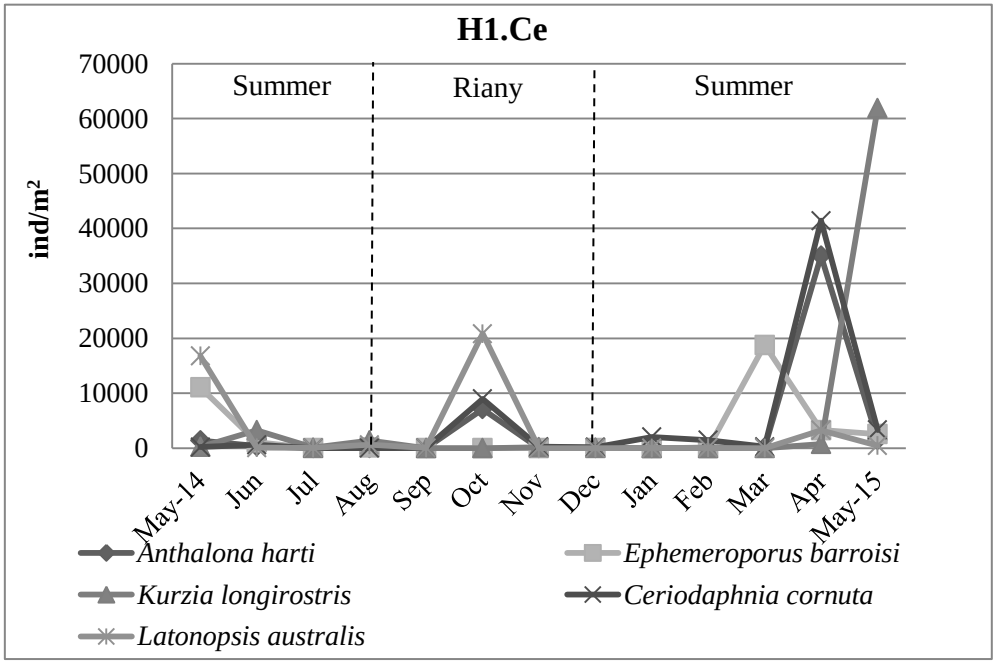
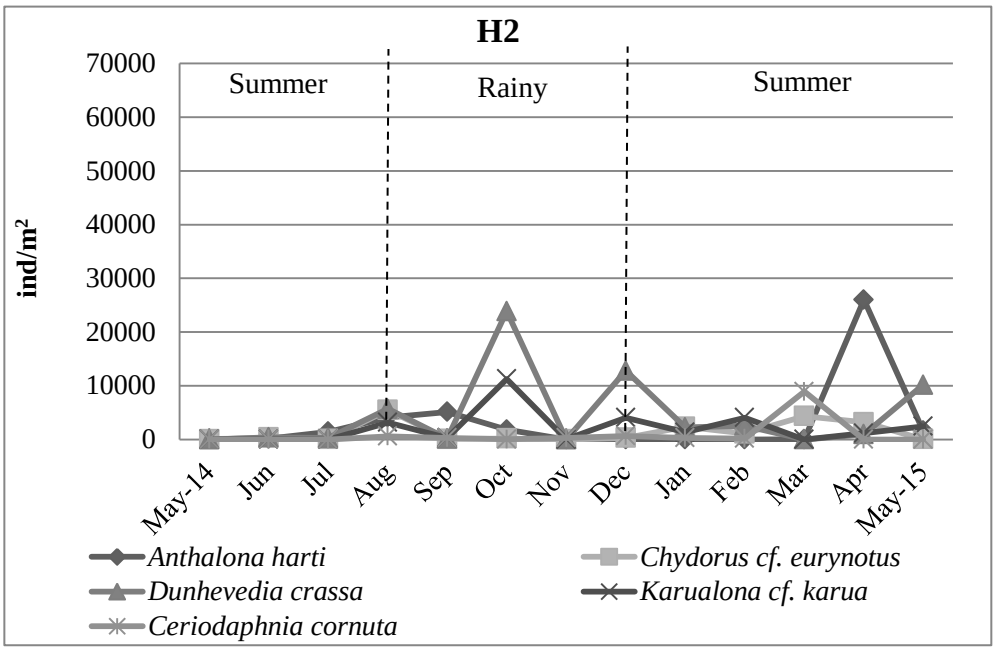


Figure 22. Monthly fluctuations in abundances of the five most dominant Cladocera in each habitat in Thale-Noi Lake over one year (2014-2015).



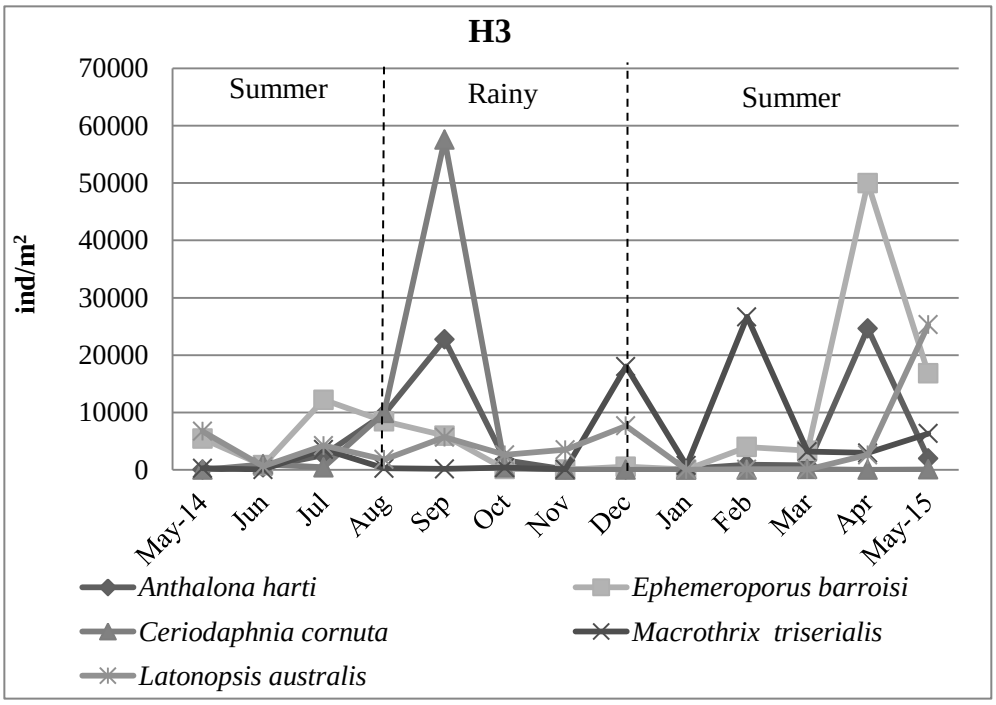


Figure 22. Continued.

6. Cladoceran species composition

The Cluster analysis showed that the cladoceran species composition can be divided into three groups according to the habitat (Fig. 23) as follows: **Group 1**: H2 separated from other groups, the cladoceran community in habitat 2 is not similar to other group. **Group 2:** H1.Hy and H1.Ce were separated from group 1, the cladoceran communities in these two microhabitats; the *Ceratophyllum* and *Hydrilla* patch; in H1 are 100% similar. **Group 3**: H3 separated from group 2, the cladoceran community in habitat 3 shares about 50% similarity with group 2. *Alona kotovi, Macrothrix odiosa and M. pholpunthini* were found only in group 3. *Leberis macronyx* was found only in group 2 and *Alonella nana* and *Anthalona sanoamuangae* occurred only in group 1.

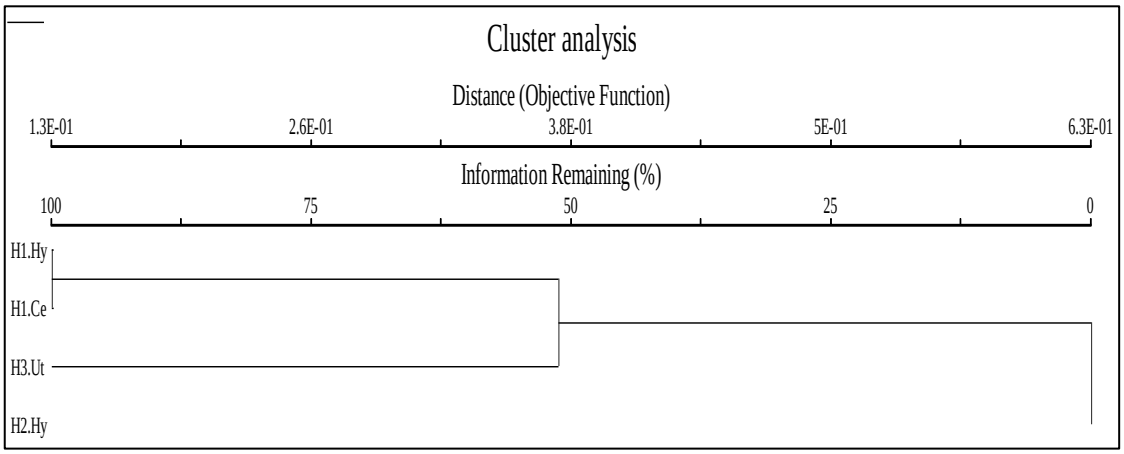


Figure 23. Cluster analysis of the habitats distinguishes the three main habitat types, according to the cladoceran communities.

7. Species-environmental factors relationships

The Canonical Correspondence Analysis suggested that the cladoceran community and the environmental variables are significantly correlated (Fig.24). Eigenvalue Axis1= 0.432, Axis 2 = 0.322, the first axis explained 43.2% of the total variance and the second axis explain 32.2%. The canonical eigenvalues accounted

together for 74.6%, Monte Carlo permutation test *p* = 0.016, Pearson Correlation coefficient *r* = 0.840; i.e the *r* value that represents the environmental variables in relation on cladoceran distribution is 84.0%. pH and depth are the environmental variables that show highest correlation with the cladoceran communities (pH Axis1 r = -0.313, r^2 = 0.098, Axis 2 r = -0.634, r^2 = 0.402; depth Axis1 r = 0.726, r^2 =0.527, Axis2 r = -0.224, r^2 = 0.050). There is a high positive correlation between pH and a species cluster consisting of *L. australis, Macrothrix spinosa, Anthalona harti Karualona* cf. *karua, Camptocercus* cf. *australis, Coronatella* cf. *rectangula, C.* cf. *monacantha* and *L. acanthocercoides.* Most of them are found at pH ranges between 7.11 - 10.17, whereas *I. spinife*r, *E. orientalis* and *Simocephalus latirostris* showed negative correlation with pH. They distribute at pH range between 3.58 - 8.48. Depth showed high positive correlation with *Chydorus* cf. *eurynotus, Diaphanosoma celebensis, Moinodaphnia macleayi, G. brazzai, Guernella raphaelis, D. excisum, Bosmina meridionalis and D. crassa.* They are found in depth ranges between 1.1- 2.05 m., while *M. triserialis, L. diaphanus, K. longirostris, P. bidentata, E. barroisi, C. ventricosus, M. odiosa* and *C. cornuta* showed negative correlation with depth factor and are found in shallower conditions, with depth ranges between 0.7- 1.1 m. Moreover, the correlation test also found that total cladoceran abundance (sum of all sample in three traps) in H3 showed negative correlation with depth (P = 0.03, Spearman Correlation Coefficient; r = - 0.750 (Correlation test)).

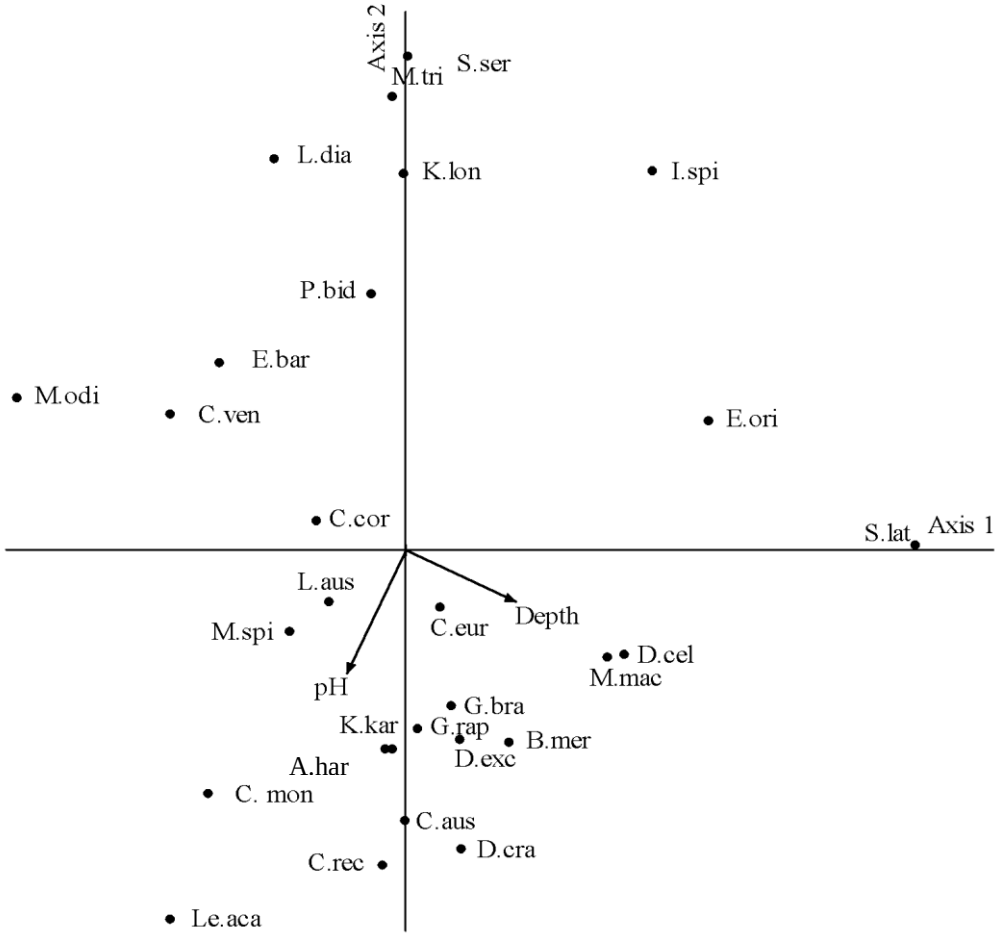


Figure 24. The Canonical Correspondence Analysis (CCA) ordination diagram for Cladocera assemblages showing species and environmental variables in Thale-Noi Lake. Species code; A.ver = *Anthalona harti*., B. mer = *Bosmina meridionalis, C.aus* = *Camptocercus* cf. *australis, C.eur* = *Chydorus* cf. *eurynotus*, C,ven = *Chydorus ventricosus*, C.mon = *Coronatella* cf. *monacantha*, C.rec = *Coronatella* cf. *rectangula*, D. cra = *Dunhevedia crassa*, E.bar = *Ephemeroporus barroisi*, E.ori = *Euryalona orientalis*, K.kar = *Karualona* cf. *karua*, K.lon = *Kurzia longirostris*, L.dia = *Leberis diaphanus*, Le.aca = *Leydigia acanthocercoides, C.cor = Ceriodaphnia cornuta*, S.ser = *Simocephalus serrulatus*, S.lar = *Simocephalus latirostris*, I.spi = *Ilyocryptus spinife*r, G.bra = *Grimaldina brazzai*, G.rap = *Guernella raphaelis*, M.odi = *Macrothrix odiosa*, M.spi = *Macrothrix spinosa*, M.tri = *Macrothrix triserialis*, M.mac = *Moinodaphnia macleayi*, D.cel = *Diaphanosoma celebensis*, D.exc = *Diaphanosoma excisum*, L.aus = *Latonopsis australis* and P.bid = *Pseudosida bidentata*.

CHAPTER 4

DISCUSSTION

1. Environmental factors

Remark of some environmental factors in our study noted that pH is lowest in littoral *Utricularia* habitat (H3) (pH range 3.54 - 9.77) because this habitat got the acidity from the peat swamp zone that situated at the north of the lake by water flow. It was consistant with the records of Inpang (2008) reported that during the rainy period, pH decreased to 5.6 at the small inlet zone. Moreover, in littoral *Utricularia* habitat showed higher salinity than other habitats (see table 1). The salinity in littoral *Utricularia* habitat was high in August, September and October (1.1, 1.3 and 1.5 ppt respectively) with low depth (0.65, 0.63 ana 0.9 m respectively), and the salnity may increase during the lowest depth.

2. Species diversity

We retrieved 40 species through the activity traps, a large portion (about 85%) of the total number of Cladocera that have been recorded for Thalei-Noi. Of which, they include 71% of Chydoridae, 100% of Daphniidae, Ilyocryptidae and Moinidae. However, we found one more species from each family of Bosminidae, Macrothricidae and Sididae. (Pholpunthin, 1997; Maiphae, 2005 and Inpang, 2008) (Table 7). The present records bring the total number of cladoceran species in Thale-Noi Lake to 58 species (previous records are 47 species), the cladoceran diversity in the South of Thailand to 88 species (previous records are 86 species) and that of Thailand to 110 species (previous records are 108 species) in comparison to the latest estimate (Maiphae, 2008 and Van Damme et al., 2013) (Fig. 25).

Table 7. Comparison of species richness of cladoceran in each family of previous and present study in Thale-Noi

	Total	**Bosminidae**	**Chydoridae**	**Daphniidae**	**Ilyocryptidae**	**Macrothricidae**	**Moinidae**	**Sididae**
Pholpunthin, 1997	17	1	12	-	-	3	3	1
Maiphae,2005	15	-	10	1	-	1	-	3
Inpang,2008	41	1	25	3	1	5	2	4
All previous studies	**47**	**1**	**31**	**3**	**1**	**5**	**2**	**3**
This study	**40**	**2**	**22**	**3**	**1**	**6**	**2**	**4**

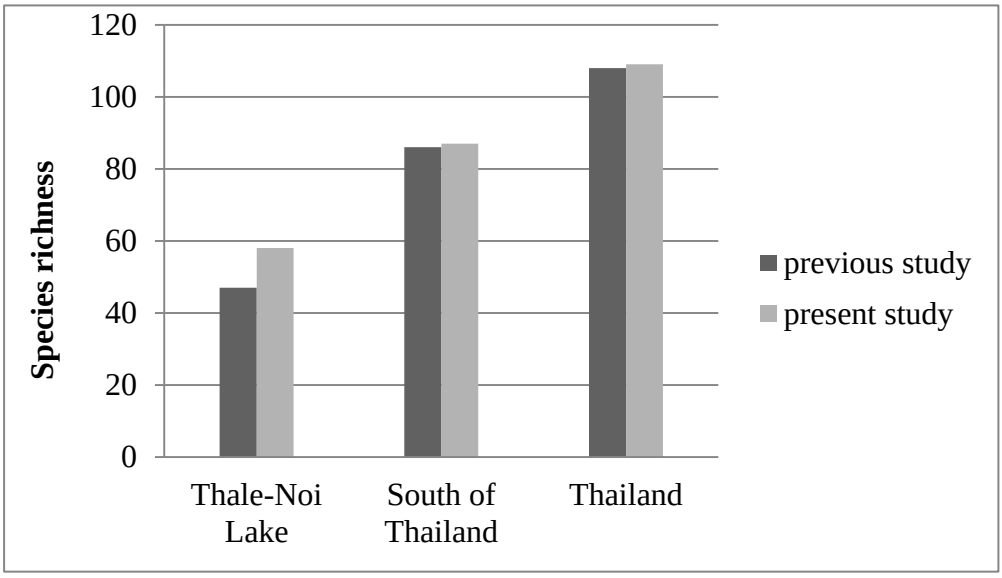


Figure 25. species richness in previous studies and present study in Thale-Noi lake, South of Thailand and Thailand

Diaphanosoma celebensis is a new record, expected in Thailand and found in the neighboring regions; Vietnam and Malaysia (Korovchinsky, 2013). *Alona kotovi* is a taxonomical update, for which we now confirmed the identity, and replaces previous records of its sister species (*A. quadrangularis*) in Thale-Noi and most likely the rest of Thailand (the latter species seems restricted to the Palaearctic) (Sinev, 2012). Previous records in Thale-Noi (and most of Thailand) labelled "*Alona verrucosa*", are updated here since revision of this group revealed new species in the region (Van Damme *et al*., 2011; Sinev and Kotov, 2012) – in fact, two species could be clearly distinguished in Thale-Noi, *Anthalona sanoamuangae* and *Anthalona harti*, which are both present in Thailand (Sinev and Kotov, 2012) and these have distinct ecologies, *A. harti* being the most common one.

Six species were restricted to a single habitat and they are rarely found in this study *A. kotovi* and *Alonella nana* (found 1 time), *Leberis macronyx* (found 2 time) *A. sanoamuangae* (found 2 times), *M. odiosa* (found 3 times) and *M. pholpunthini* (found 4 times)). *M. pholpunthini* has been found only in Thailand in 2 localities in Trang Province, Yon peatswamp and Natum swamp (Van Damme *et al*, 2013). *A. sanoamuangae* has been reported in Mekong River, Mukdahan Province, Thailand and a roadside ditch in Dong Nai National Park, Dong Nai Province, Vietnam, (Sinev & Kotov, 2012). *A. kotovi* has been reported only in Southern, Vietnam (Sinev, 2012) and *M. odiosa* has been recorded in swamp at Chakradharpur, Chaibassa district, Chota Nagpur, India (Gurney, 1907) and reported from Perendeniya pound and Anuradhpura in Sri Lanka (Gurney, 1916). Moreover, *M. odiosa* has been reported in Thungtong swamp, Kiensa district, Surattani Provine, Sounthern Thailand (Maiphae, 2005).

The specie richness of cladoceran found in this study is higher than records of Pholpunthin (1997) (17 species) and Maiphae (2005) (15 species) due to the sampling frequency. Of which Phopunthin (1997) collected sample only one time and Maiphae (2005) collected sample four times in one year (two times in each season). In contrast, the present study and Inpang (2008) found almost the same numbers (40 and 41species, respectively) as the samples were collected more frequent throughout the year. Due to Inpang (2008) collected samples in more habitats (resident, peat swamp,

pelagic and small inlet habitats, 12 stations in total) than our study. There are five species, *Alona affinis*, *Alona intermedia*, *Alonella excisa*, *Oxyurella singalensis* and *Scapholeberis kingi* were found in Inpang (2008) but were not found in our study. However, 13 species of cladoceran found in the present study were the first time recorded in Thale-Noi. Collecting sample by plankton net usually ignore benthic species and collecting with funnel traps we could find *Alona kotovi*, *Leydigia acanthoceriodes* and *L. australis* which considered to be sediment-dwelling chydorid (Fryer, 1968; Flössner, 1964; Evans, 1984; Sminov, 1971and Moore, 1939). Therefore, the collecting sample in many methods cover microhabitat of cladoceran will provide nearest species diversity in natural.

The total species richness (over one year) amounts to similar numbers for each of the habitats (31-34 spp.), between which 27 cladoceran species are shared consistent with Walseng *et al*. (2008). They reported that the number of cladoceran and copepod species in 21 Canadian Shield lakes was only minor difference between floating leaved and non-floating leaved habitat. As expected from shallow, well vegetated lakes, Chydoridae form the most diverse group (22 species), followed by Macrothricidae (6 species) and Sididae (4 species). Species richness fluctuates temporally, with two - to three-fold increases in each of the habitats, sometimes between consecutive months. The *Hydrilla* and *Ceratophyllum* beds in the southern littoral zone (H1) showed significantly higher species richness in the dry season (mean 21-22 species) than in the rainy season (mean 7-8 species), linked with changes in water transparency (significantly higher in the dry season). Thale-Noi is a shallow lake (even shallower in this area, 0.8-2.1 m) and turbidity increases strongly during the rainy season, which in turn affects light intensity, limiting epiphyton and phytoplankton. Turbidity and light penetration are inversely related which light is important factor for photosynthesis of photoautotroph (Michaud, 1991). Therefore, high solar radiation will support high productivity in tropical lakes (Tailing and Lemoalle, 1998). Species richness in the open water habitat, situated in the deeper zones (1.05-2.05 m) and less diverse in macrophytes, showed an opposite trend, with higher species richness during the rainy season (17 species) than in the dry season (5 species). *Alonella nana* and *Anthalona sanoamuangae* appeared only during the rainy

season and in this locality (in small numbers) whereas *Leydigia acanthocercoides*, a strictly benthic species, dominated here during the rainy season, together with more generalist species such as *D. crassa* and *Chydorus* cf. *eurynotus*, which showed a high correlation with depth.

Species richness differed strongly between consecutive years in some habitats (H2; 5 and 12 species, H3; 10 and 20 species in May 2014 and 2015 respectively). This might due to the fluctuation and differs in environmental factors e.g. depth, pH and salinity which may influence the species diversity of the cladoceran (H2; depth 1.5 and 1.2, Salinity 0.5 and 0.7, H3; depth 1.1 and 0.7, pH 8.38 and 8.80 in May 2014 and 2015 respectively) (Fig. 3). In tropical systems, seasonality is often not so pronounced as in temperate lake (Hart, 1985) however in general, we found the short term fluctuations of cladoceran species richness throughout one year in Thale-Noi Lake more pronounced than expected, and dependent on the microhabitat. Indeed, it is a general misconception that all tropical lakes are relatively uniform and stable throughout the year (Twombly, 1983). Therefore it is possible that zooplankton in tropical lakes may not be as subject to seasonal fluctuations as in temperate lakes, but shallow tropical lakes have pronounced effects from seasonal rainfall regimes (Melack and Kilham, 1974; Tailing & Lemoalle, 1998). The same is true for river deltas, where Cladocera diversities and densities are highly influenced by precipitation (eg., Borges and Pedrozo, 2009) and consistent with the study in a tropical floodplain lake of the Brahmaputra river basin, Northeast India which reported that Chydoridae densities are influenced by high rainfall (Sharma and Sharma, 2012). Seasonality effects on the cladoceran species richness could be pronounced in this shallow tropical lake, depending on the microhabitat. However, temporal variation of zooplankton species richness, abundance and community structure in shallow tropical lakes requires studies over a longer time period than a single year, in order to speak of true seasonal trends.

3. Abundance

The overall cladoceran abundance was significantly lower in the open water habitat (H2) than in the more littoral habitats. Relatively lower densities of Cladocera in the pelagic in Thale-Noi, have been recorded before with different sampling methods (Inpang, 2008). Littoral zones provide a more diverse environment and richer food source for Cladocera, as well as more efficient refuge areas for predators, than more open water zones (Whiteside and Harmsworth, 1967; Stansfield *et al*., 1997; Geraldes and Boavida, 2004). However, most comparisons in cladoceran abundances between littoral and pelagic zones in lakes are based on limited sampling and ignore bottom-inhabiting species. Using the activity traps, abundance (and diversity) of cladocerans in a shallow lake can be approached with more robustness. Even though the substrate in the open water areas of Thale-Noi is largely covered by *Hydrilla*, providing opportune niches, the environment is not as sheltered as in the littoral and cladocerans abundances not as reach as high as in the more marginal sites (total species richness here is however similar, see above). The amount of floating plant in open water is very low. It could be explained by the effect of wind and wave action (Inpang, 2008). Moreover, the lowest of cladocerans abundance in open water area probably due to high fluctuation of some factors i.e. depth, pH and salinity in open water area were higher fluctuate than in the littoral zone (depth; 1.32±0.30 m, pH; 8.95±0.90 and salinity; 0.28±0.24 ppt). Salinity is a serious threat to freshwater ecosystems, an increase in salinity produces drastic changes in community structure of freshwaters. Thus, freshwater species must cope with salinity stress in a manner proportional to their degree of tolerance. The salinity caused a significant reduction in fecundity and a developmental delay (increase in age at first reproduction), as well as a decrease in the growth rate of daphnids (Gonçalves et al., 2007). Inaddition, cladoceran abundance are affected by depth and pH due to depth, pH and total cladoceran abundance showed significant difference between pelagic habitat (H2) and litoral area with *Utricularia* habitat (H3)

Our study found 26 species showed significant differences in abundance depending on the habitat, *Coronatella* cf. *rectangular* was the highest dominant in open area (H2) that covered with thick detritus layer at the bottom. This cladoceran

species has been reported that they are obviously avoided area covered with submerged marcrophyte (Adamczuk, 2014). *Leydigia leydigi* and *L.acanthoceriodes* have been recorded as being mud-dwellers (Fryer, 1968 and Flössner, 1964) and *L.acanthoceriodes* showed positive correlation with depth but they were not found at water level more than 5 m. (Adamczuk, 2014). Likewise, this study we found *Leydigia acanthoceroides* and *L. australis* were highest abundance in open area covered with thick detritus, highest depth (1.05 - 2.05m) and *L. australis* showed significantly higher abundance in rainy season than in dry season. The evident in habitat-specificity has been reported that 1/4 of chydorid assemblages (*Alona affinis*, *Anchistropus* cf. *minor*, *Alona intermedia* and *Alona quadrangularis*) differ among four habitats at one time in one lake (Plastic Lake in Canada). *A. quadrangularis* was the highest abundance in intermediate amounts of vegetation and suggested that their abundance affected by habitat factor other than vegetation (Tremel *et al.*, 2000). In addition, *Alona quadrangularis* considered to be sediment-dwelling chydorid (Evans, 1984; Sminov, 1971; Flössner, 1964 and Moore, 1939). Whiteside (1974) did not catch this species in ElK Lake when collect chydorids sample on the surface of *Chara* during daylight. Whiteside et al. (1978) suggested that *A. quadrangularis* inhabits the lower muddy regions of the *Chara*. This study we found *A. kotovi* that related to *Alona quadrangularis* in *Utricularia* patch using funnel trap which has not been collected in previous study using plankton net. Therefore, *A. kotovi* might be inhabited in sediment under the *Utricularia* patch. There is little available information about the habitat-specificity of the species that distinguished the chydorid assemblages; a distinction is not recognized in earlier studies in tropical region.

Total cladoceran abundance peaked in Thale-Noi during the rainy season (Sep-Oct) and the dry season (Apr-May) and lowest overall abundances occur in June, November and January. Their fluctuation might be influenced by the environmental variables. Our study found that total cladoceran abundance in *Ceratophyllum* patch are positively correlated with water temperature (Correlation analysis; $p = 0.001$, $r = 0.818$) and dissolved oxygen was the lightly factor ($p = 0.035$, $r = 0.588$). The highest abundance of total cladoceran abundance were found in May (106,333 ind/m^2) while the highest temperature 34.7 ˚C, dissolved oxygen 7.17 mgO_2/l and lowest abundance

in September (2,533 ind/m^2) while lowest temperature 27.4 ˚C, dissolved oxygen 4.80 mgO_2/l. We found that *K. longirostris*, the circumtropical species, was the most abundant (61,933 ind/m^2) in this habitat (H1.Ce). They reached peak in May and they were absent in September, October, January, Febuary and March. It has been reported that temperature was related with duration of egg development and growth of Cladocera (Vijverberg, 1980; Bottrell, 1975). Moreover, Geller (1975), Gophen (1976), Kersting and Van Der Leeuw (1976) have confirmed that the temperature was the important factor on the Cladocera filtering rates and we also found that the filtering feeder cladoceran, *Ceriodaphnia cornuta* and *Latonopsis australis* were five most dominant in *Ceratophyllum* patch. However, the influence of temperature might be difficult to assess in a shallow lake that well-mixed water body as the result showed less difference in temperature between surface and bottom (Mourelatos and Lacroix, 1990). On the other hand, total cladoceran abundance in *Utricularia* patch are negatively correlated with depth ($p = 0.003$, $r = - 0.750$). We found total cladoceran in *Utricularia* patch was lowest in November and January (1,633 ind/m^2 and 400 ind/m^2) while the lake was deepest (1.7 m) whereas they were highest density when low depth (0.63-0.9 m)in September, July, April, February and December (31,789 ind/m^2 at 0.63 m, 20,500 ind/ m^2 at 0.7 m, 33,822 ind/ m^2 at 0.81m, 16,100 ind/ m^2 at 0.9, and 9,622 ind/ m^2 at 1.1 m) . Moreover, we found that 15 species (37.5%) show significant differences in term of abundance between seasons. Of which *Chydorus* cf. *eurynotus* were higher abundance in dry season than in rainy season. Our results consistent with Güntzel and Panarelli (2010) which reported that *Chydorus eurynotus* in oxbow lakes in the Taquari River floodplain (Brazil) seemed to be favored by dry conditions. Nevertheless, when compared, the two seasons did not show a significant difference in total density, nor in changes in environmental variables, except for turbidity in the littoral *Hydrilla* beds. Güntzel and Panarelli (2010) reported that the canonical correspondence analysis showed a particularly important factor determining species distribution in oxbow lake, Brazil was the seasonal variation in rainfall, nutrient (chlorophyll, nitrogen, and phosphorus), water transparency, dissolved oxygen, water temperature, and electrical conductivity. Nevalainen (2012) found some chydorids separation related to temperature. Oxygen concentration is an important factor controlling distribution and community structure

of zooplankton in lakes (Wright and Shapiro 1990; Hanazato 1992). Low oxygen induces hemoglobin synthesis in *Daphnia* which hemoglobin increases the uptake efficiency of oxygen from water, supporting higher rates of survival, feeding, respiration, swimming activity, and egg development under -low oxygen conditions (e.g. Heisey and Porter 1977; Weider and Lampert 1985). De Stasio (1990) also suggested that dissolved oxygen concentration together with other factors can determine the interruption of zooplankton dormancy eggs. This shows that while most species might profit from better conditions during the relatively short dry and rainy season, their abundances might be mostly determined by the biotic factors such as predation, competition and life history. However, as stated earlier, as our data only spans a single year, we cannot determine a recurrent seasonal trend, only that the highest abundances in this particular year corresponded to the dry and the rainy seasons.

Mixed densities (sum of all species) reached maximally just over 513,767 ind/m² per habitat at a given sampling, the dominant species (*Anthalona harti, Kurzia longirostris, Ceriodaphnia cornuta* and *Ephemeroporus barroisi*) peaking easily between 7,233 and 61,933 ind/m² per night during dry and/or rainy seasons. This study found mean chydorid abundance in four macrophyte patches ranges between 4,638 – 7,017 ind/m^2 (three funnel traps per macrophyte patch, 4 pseudo replications (number of bottom set on trap), total 624 samples), there are lower number than the studies in Plastic Lake, Ontario, Canada by using the same method but difference replication (15 funnel traps in each of 4 habitats, 3 pseudo replications, 520 samples in total). The abundance of Chydoridae in four difference habitats showed mean ranges 5,000 – 17,097 ind/m^2 (Tremel *et al*., 2000). Although cladoceran abundance in the present study is lower than Tremel *et al*. (2000) but species richness was similar. We found 22 chydorid species (5.5ind/m^2/habitat) while Tremel *et al*. (2000) found 20 species (5ind/m^2/habitat). When compare mean abundance of chydorid in the same species, *Pseudochydorus globulosus* in our study showed wider range, 2-10 ind/m^2 than Tremel *et al.* (2000), 0.5-2 ind/m^2. The higher abundance of cladoceran in Tremel *et al*. (2000) can be explained by the number and season in sampling sample. Tremel *et al.* (2000) have higher number in collecting samples (15 traps/habitat) than

our study (3 traps/macrophyte patch) and they collected samples consecutive three days, 30 September – 2 October 1987 which is the autumn season. This season may provide high density of cladoceran. Yiğit (2004) recorded that peaks of cladoceran were observed in spring (May, June) and autumn (September, October) and Primo *et al*. (2009) who studied zooplankton diversity and distribution pattern under varying precipitation regimes in a southern temperate estuary reported that cladoceran were high abundances in autumn. Moreover, Smirnov (1974) mentions millions of *Chydorus* per m^2 which higher number than our study. We found total *Chydorus* in all macrophyte patch 2,569 ind/m^2. The lower density of cladoceran in tropical area may be explained that in tropics were higher prevalent predation levels than in temperate (Dumount, 1994).

4. Community shifts in dominant

Although we did not look into biotic interactions in detail, the monthly fluctuations of several species could result from competitive interactions. The fact that there is a similar maximal diversity at any given time per habitat (15-22 species), indicates that there is a limit to the number of species that can coexist within a certain niche of the dimensions studied here and therefore, that competition must play a role. Such a competitive interaction could be present for example between the most dominant chydorids (*Anthalona, Karualona, Kurzia, Chydorus* etc.) which we noted that *A. harti* usually found low density when *E. barroisi* was high density in all habitats (Fig. 22). This merits further study, combined with lab experiments to assess competitive interactions under a range of conditions. Descriptions of competitive interactions among cladocerans have been limited primarily to pelagic species (Kerfoot *et al*., 1985; DeMott and Kerfoot, 1982; Vanni, 1986), leaving the competitive interactions among Chydoridae virtually unstudied. However, during the daytime (after which animals started to accumulate in our traps in their way up), not only typical littoral phytophilic-benthic species will interact on the bottom of the lake, but all vertically migrating cladocerans will be competing for the available resources within a limited space, including more pelagic species (Bosminidae, Daphniidae, pelagic Ctenopoda, etc.). So, not only should we consider that some littoral species can easily venture into the open water and feed on available food sources, yet some of

the more pelagic species have to compete with bottom dwelling species when staying down. Of course, several specialists rarely leave their specific niche (eg., *Ilyocryptus*, although these also occurred in the traps in considerable numbers).

In addition, cladoceran display a wide range of body sizes and we found that smaller cladoceran species reach high density when larger species fall peak while smaller cladoceran low density when larger size species peaked. This result supported by size-efficiency hypothesis of Brooks and Dodson in 1965 which suggested that large species are more competitive than small-size species. However, size-efficiency hypothesis pronounce between Chydoridae and other groups (e.g. Macrotricidae, Daphniidae, Sididae and Ilyocryptidae). The consideration within Chydoridae group might be difficult due to Chydoridae display a wide range of body sizes even in the same species they showed high variation of body size. Nevertheless, lower density in both larger and smaller size species might be the influence of life cycle or environmental factor in habitat.

5**. Cladoceran composition and environmental relationship**

The cladoceran community is similar in composition and abundance in different macrophyte species beds in the same zone (communities are 100% similar between *Hydrilla* and *Ceratophyllum* patches in H1) whereas the same macrophyte species in a different zone showed marked differences (cladoceran community in *Hydrilla* beds in the littoral is not similar to the community in *Hydrilla* beds in the open water zone). Tremel *et al*. (2000) suggested that cladoceran abundance is influenced by habitat factors other than vegetation. Our results indicated that different species of similar plant morphology, which we considered all fine dissected submerged macrophytes, has little effect on the cladoceran community compositions in comparison to other factors.

Cladoceran communities differed most between the open water zone and the marginal zones. Moreover, depth and pH seem to be the major factors structuring the cladoceran communities more than the macrophyte compositions. There is a high

positive correlation between pH and *Latonopsis australis, Macrothrix spinosa, Anthalona harti, Karualona* cf. *karua*, *Camptocercus* cf. *australis*, *Coronatella* cf. *rectangula, C.* cf. *monacantha* and *Leydigia acanthocercoides*. Most of them usually found at pH ranges between 7.11 - 10.17, consistent with Inpang (2008) for the same wetland, who reported that pH was high correlated for at least two of these taxa (*Latonopsis* and *Macrothrix*). Nachai (2006) reported pH as a main factor in cladoceran distribution for *Coronatella* cf. *rectangula* and *C.* cf. *monacantha* (found at pH >6.9) and Sa-ardrid (2002) suggested that *Macrothrix spinosa* and *Anthalona* sp. occurred in habitats with a pH higher than 7.1. Indeed, pH is a strong factor governing zooplankton species composition in the littoral (eg., copepods and cladocerans; Walseng *et al*., 2008), and in general, acidity exerts a determining influence on the composition and diversity of freshwater faunas (Weber and Pirow, 2009).

pH was found to be an important factor in the distribution of Chydoridae in a geographical scale (de Eyto et al., 2003). On the other side of the spectrum, some species are better adapted to low pH, as we found *I. spinifer, E. orientalis* and *Simocephalus latirostris* are distributed at generally lower pH ranges between 3.58 and 8.48.

Depth, as the second most important variable, showed high positive correlation with several cladocerans that were more able to venture into the open water (1.1-2.05 m) of Thale-Noi, such as *Chydorus* cf. *eurynotus*, *Diaphanosoma celebensis*, *Moinodaphnia macleayi*, *Grimaldina brazzai*, *Guernella raphaelis*, *Diaphanosoma excisum*, *Bosmina meridionalis* and *Dunhevedia crassa*. Previously, Nachai (2006) reported that cladocerans such as *Diaphanosoma* were associated with high depth. On the other hand, *M. triserialis, L. diaphanus, K. longirostris, P. bidentata, E. barroisi, C. ventricosus, M. odiosa* and *C. cornuta* seemed to prefer relatively shallower conditions. Therefore, it indicates niche separation between morphologically quite similar species (eg., *C. ventricosus* and *C.* cf. *eurynotus*). Likewise, we found the monthly fluctuation of total Cladoceran abundance in the *Utricularia* patch to show a negative correlation with depth, with *M. triserialis, L. diaphanus, E. barroisi, C. ventricosus, M. odiosa* and *C. cornuta* the dominant species

when levels were lower. Indeed, depth is important factor in lakes even within the littoral zone (eg., benthic chydorids; Adamczuk, 2014), and in general many cladoceran species are influenced by lake depth. (Korhola *et al*., 2000; Amsinck *et al*., 2006). Depth provides different niches in term of habitat (Chittapun, 2009). In addition, even in homogeneous lakes, chydorids can show different patterns of distribution along the lake depth, forced upon them by UV exposure, the thermal properties, food resources and predators associated with these varying depths (Nevalainen, 2012)

CHAPTER 5

CONCLUSION

1. Species richness

This study indicated that species richness was influenced by precipitation and transparency. Total species richness of cladoceran is not significant difference among habitats but showed significant difference between season. Total species richness in *Hydrilla* and *Ceratophyllum* beds (H1) showed significantly higher in the dry season than in the rainy season, linked with changes in water transparency (significantly higher in the dry season). Our result showed high species diversity of cladoceran (40 species) and the funnel trap method provides 13 species that were newly recorded in Thale-Noi. Of which, 2 species were new recorded in Thailand.

2. Abundance

Total cladoceran abundance influenced by habitat type (littoral or open water zone) and physical and chemical factors including depth, pH, temperature, dissolved oxygen, transparency and salinity.

The overall cladoceran abundance was significantly lower in the open water habitat (H2) than in the more littoral habitats due to littoral zones provides a more diverse environment, richer food source, more efficient refuge areas for predators of cladocera. Moreover, depth, pH and salinity in open water area were higher fluctuation than littoral zone.

Cladoceran abundance are affected by depth and pH due to depth, pH and total cladoceran abundance showed significant difference between *Hydrilla* and *Utricularia* patch (H2-H3) and depth also showed high negative correlation with total cladoceran in *Utricularia* patch (H3).

In addition, temperature and dissolved oxygen showed positive relation with total cladoceran abundance in *Ceratophyllum* patch.

When considered between season, total cladoceran abundance in each macrophyte patch did not showed significant difference between seasons consistent with there is no significant difference of environmental factors between season (except for turbidity in the littoral *Hydrilla* beds). However, when focus in density of each species found that 16 species (40%) show significant differences between seasons. For example, *Chydorus* cf. *eurynotus* were higher abundance in dry season than in rainy season which they seemed to be favored by dry conditions (Maria Güntzel and Aparecida Panarelli, 2010).

3. Community shift in dominance

Population change of dominant cladoceran was could result from competitive interactions and body size-efficiency; explain that large species are more competitive than small-size species. The fact that there is a similar maximal diversity at any given time per habitat (15-21 species), indicates that there is a limit to the number of species that can coexist within a certain niche of the dimensions studied here and therefore, that competition must play a role. Such a competitive interaction could be present for example between the most dominant chydorids (*Anthalona, Karualona, Kurzia, Chydorus,* etc.) which we noted that *A. harti* usually found low density when *E. barroisi* was high density in all habitats.

4. Cladoceran community and species-environmental factors relationships.

The cladoceran community is similar in composition and abundance in different macrophyte species beds in the same zone whereas the same macrophyte species in a different zone showed marked differences. This indicates that all fine dissected submerged macrophytes have little effect on the cladoceran community. Depth and pH seem to be the major factors structuring the cladoceran communities

more than the macrophyte compositions due to depth and pH showed high relation significantly between cladoceran communities. Depth showed high positive correlation with *Chydorus* cf. *eurynotus, Diaphanosoma celebensis, Moinodaphnia macleayi, Grimaldina brazzai, Guernella raphaelis, Diaphanosoma excisum, Bosmina meridionalis* and *Dunhevedia crassa* and pH showed high positive correlation with *Latonopsis australis, Macrothrix spinosa, Anthalona harti, Karualona* cf. *karua*, *Camptocercus* cf. *australis*, *Coronatella* cf. *rectangula*, *C.* cf. *monacantha* and *Leydigia acanthocercoides*.

Finally we conclude that cladoceran community in Thale-Noi Lake was influenced by several factors including habitat type in term of littoral and open water area, environmental factors; depth, pH, transparency, temperature. Especially, depth and pH seem to be major factors. In nature, the population dynamics of cladocerans are likely to be influenced by many factors simultaneously, and there are likely to be synergistic interactions among the factors (Hanazato and Dodson, 1992)

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APPENDIX

Appendix 1. Average and standard deviation in three traps of cladoceran richness in all habitats (May 2014 - May 2015).

Month	Habitat	Trap	Richness	Mean	S.D.
	H1.Hy	1	13		
	H1.Hy	2	4		
May-14	H1.Hy	3	16	11.00	6.24
	H1.Hy	1	12		
	H1.Hy	2	10		
Jun	H1.Hy	3	8	10.00	2.00
	H1.Hy	1	5		
	H1.Hy	2	12		
Jul	H1.Hy	3	10	9.00	3.61
	H1.Hy	1	6		
	H1.Hy	2	7		
Aug	H1.Hy	3	5	6.00	1.00
	H1.Hy	1	7		
	H1.Hy	2	6		
Sep	H1.Hy	3	6	6.33	0.58
	H1.Hy	1	9		
	H1.Hy	2	11		
Oct	H1.Hy	3	10	10.00	1.00
	H1.Hy	1	10		
	H1.Hy	2	9		
Nov	H1.Hy	3	9	9.33	0.58
	H1.Hy	1	12		
	H1.Hy	2	12		
Dec	H1.Hy	3	9	11.00	1.73
	H1.Hy	1	6		
	H1.Hy	2	15		
Jan	H1.Hy	3	5	8.67	5.51
	H1.Hy	1	12		
	H1.Hy	2	9		
Feb	H1.Hy	3	9	10.00	1.73
	H1.Hy	1	19		
	H1.Hy	2	7		
Mar	H1.Hy	3	19	15.00	6.93
	H1.Hy	1	16		
	H1.Hy	2	21		
Apr	H1.Hy	3	13	16.67	4.04

Appendix 1. Continued.

Month	Habitat	Trap	Richness	Mean	S.D.
	H1.Hy	1	13		
	H1.Hy	2	17		
May-15	H1.Hy	3	16	15.33	2.08
	H1.Ce	1	15		
	H1.Ce	2	9		
May-14	H1.Ce	3	14	12.67	3.21
	H1.Ce	1	12		
	H1.Ce	2	14		
Jun	H1.Ce	3	11	12.33	1.53
	H1.Ce	1	4		
	H1.Ce	2	4		
Jul	H1.Ce	3	4	4.00	0.00
	H1.Ce	1	9		
	H1.Ce	2	11		
Aug	H1.Ce	3	8	9.33	1.53
	H1.Ce	1	4		
	H1.Ce	2	3		
Sep	H1.Ce	3	5	4.00	1.00
	H1.Ce	1	12		
	H1.Ce	2	8		
Oct	H1.Ce	3	8	9.33	2.31
	H1.Ce	1	6		
	H1.Ce	2	5		
Nov	H1.Ce	3	6	5.67	0.58
	H1.Ce	1	12		
	H1.Ce	2	8		
Dec	H1.Ce	3	10	10.00	2.00
	H1.Ce	1	10		
	H1.Ce	2	10		
Jan	H1.Ce	3	13	11.00	1.73
	H1.Ce	1	9		
	H1.Ce	2	10		
Feb	H1.Ce	3	9	9.33	0.58
	H1.Ce	1	12		
	H1.Ce	2	15		
Mar	H1.Ce	3	12	13.00	1.73
	H1.Ce	1	19		
	H1.Ce	2	18		
Apr	H1.Ce	3	19	18.67	0.58
	H1.Ce	1	18		
	H1.Ce	2	19		
May-15	H1.Ce	3	21	19.33	1.53

Appendix 1. Continued

Month	Habitat	Trap	Richness	Mean	S.D.
	H2	1	0		
	H2	2	4		
May-14	H2	3	4	2.67	2.31
	H2	1	3		
	H2	2	4		
Jun	H2	3	7	4.67	2.08
	H2	1	5		
	H2	2	1		
Jul	H2	3	8	4.67	3.51
	H2	1	13		
	H2	2	15		
Aug	H2	3	13	13.67	1.15
	H2	1	12		
	H2	2	10		
Sep	H2	3	10	10.67	1.15
	H2	1	12		
	H2	2	9		
Oct	H2	3	13	11.33	2.08
	H2	1	7		
	H2	2	2		
Nov	H2	3	7	5.33	2.89
	H2	1	11		
	H2	2	8		
Dec	H2	3	10	9.67	1.53
	H2	1	6		
	H2	2	8		
Jan	H2	3	1	5.00	3.61
	H2	1	11		
	H2	2	11		
Feb	H2	3	8	10.00	1.73
	H2	1	7		
	H2	2	8		
Mar	H2	3	7	7.33	0.58
	H2	1	12		
	H2	2	14		
Apr	H2	3	12	12.67	1.15
	H2	1	10		
	H2	2	5		
May-15	H2	3	10	8.33	2.89
	H3	1	3		
	H3	2	8		
May-14	H3	3	8	6.33	2.89

Appendix 1. Continued

Month	Habitat	Trap	Richness	Mean	S.D.
	H3	1	5		
	H3	2	8		
Jun	H3	3	6	6.33	1.53
	H3	1	18		
	H3	2	9		
Jul	H3	3	15	14.00	4.58
	H3	1	13		
	H3	2	19		
Aug	H3	3	21	17.67	4.16
	H3	1	9		
	H3	2	10		
Sep	H3	3	13	10.67	2.08
	H3	1	12		
	H3	2	11		
Oct	H3	3	11	11.33	0.58
	H3	1	5		
	H3	2	4		
Nov	H3	3	9	6.00	2.65
	H3	1	5		
	H3	2	6		
Dec	H3	3	7	6.00	1.00
	H3	1	2		
	H3	2	5		
Jan	H3	3	3	3.33	1.53
	H3	1	7		
	H3	2	4		
Feb	H3	3	6	5.67	1.53
	H3	1	9		
	H3	2	11		
Mar	H3	3	6	8.67	2.52
	H3	1	14		
	H3	2	15		
Apr	H3	3	11	13.33	2.08
	H3	1	14		
	H3	2	13		
May-15	H3	3	18	15.00	2.65
			0		0.00
			21		6.93
					4 trap Sd>4

Appendix 2. Average and standard deviation in three traps of cladoceran abundance (ind/trap) in all habitats (May 2014 - May 2015).

Month	Habitat	Trap	Abundance(ind/trap)	Mean	S.D.
	H1.Hy	1	294		
	H1.Hy	2	13		
May-14	H1.Hy	3	189	165.33	141.99
	H1.Hy	4	282		
	H1.Hy	5	158		
Jun	H1.Hy	6	80	173.33	101.87
	H1.Hy	7	41		
	H1.Hy	8	102		
Jul	H1.Hy	9	61	68.00	31.10
	H1.Hy	10	32		
	H1.Hy	11	114		
Aug	H1.Hy	12	15	53.67	52.94
	H1.Hy	13	589		
	H1.Hy	14	1142		
Sep	H1.Hy	15	442	724.33	369.10
	H1.Hy	16	442		
	H1.Hy	17	523		
Oct	H1.Hy	18	485	483.33	40.53
	H1.Hy	19	194		
	H1.Hy	20	27		
Nov	H1.Hy	21	107	109.33	83.52
	H1.Hy	22	129		
	H1.Hy	23	242		
Dec	H1.Hy	24	47	139.33	97.91
	H1.Hy	25	22		
	H1.Hy	26	126		
Jan	H1.Hy	27	21	56.33	60.34
	H1.Hy	28	1268		
	H1.Hy	29	461		
Feb	H1.Hy	30	686	805.00	416.45
	H1.Hy	31	430		
	H1.Hy	32	39		
Mar	H1.Hy	33	503	324.00	249.50
	H1.Hy	34	626		
	H1.Hy	35	1241		
Apr	H1.Hy	36	616	827.67	357.99
	H1.Hy	37	328		
	H1.Hy	38	333		
May-15	H1.Hy	39	292	317.67	22.37

Appendix 2. Continued.

Month	Habitat	Trap	Abundance(ind/trap)	Mean	S.D.
	H1.Ce	40	431		
	H1.Ce	41	97		
May-14	H1.Ce	42	1079	535.67	499.30
	H1.Ce	43	128		
	H1.Ce	44	62		
Jun	H1.Ce	45	47	79.00	43.09
	H1.Ce	46	204		
	H1.Ce	47	190		
Jul	H1.Ce	48	171	188.33	16.56
	H1.Ce	49	273		
	H1.Ce	50	213		
Aug	H1.Ce	51	254	246.67	30.66
	H1.Ce	52	27		
	H1.Ce	53	24		
Sep	H1.Ce	54	25	25.33	1.53
	H1.Ce	55	510		
	H1.Ce	56	281		
Oct	H1.Ce	57	421	404.00	115.44
	H1.Ce	58	20		
	H1.Ce	59	16		
Nov	H1.Ce	60	48	28.00	17.44
	H1.Ce	61	258		
	H1.Ce	62	248		
Dec	H1.Ce	63	255	253.67	5.13
	H1.Ce	64	46		
	H1.Ce	65	119		
Jan	H1.Ce	66	277	147.33	118.08
	H1.Ce	67	36		
	H1.Ce	68	40		
Feb	H1.Ce	69	83	53.00	26.06
	H1.Ce	70	184		
	H1.Ce	71	230		
Mar	H1.Ce	72	438	284.00	135.34
	H1.Ce	73	1481		
	H1.Ce	74	545		
Apr	H1.Ce	75	997	1007.67	468.09
	H1.Ce	76	528		
	H1.Ce	77	1416		
May-15	H1.Ce	78	1246	1063.33	471.34
	H2	79	0		
	H2	80	7		
May-14	H2	81	8	5.00	4.36

Appendix 2. Continued.

Month	Habitat	Trap	Abundance(ind/trap)	Mean	S.D.
	H2	82	6		
	H2	83	16		
Jun	H2	84	24	15.33	9.02
	H2	85	18		
	H2	86	1		
Jul	H2	87	46	21.67	22.72
	H2	88	242		
	H2	89	444		
Aug	H2	90	193	293.00	133.05
	H2	91	89		
	H2	92	68		
Sep	H2	93	59	72.00	15.39
	H2	94	547		
	H2	95	411		
Oct	H2	96	721	559.67	155.39
	H2	97	13		
	H2	98	8		
Nov	H2	99	8	9.67	2.89
	H2	100	178		
	H2	101	205		
Dec	H2	102	211	198.00	17.58
	H2	103	96		
	H2	104	119		
Jan	H2	105	1	72.00	62.55
	H2	106	96		
	H2	107	128		
Feb	H2	108	63	95.67	32.50
	H2	109	271		
	H2	110	116		
Mar	H2	111	74	153.67	103.76
	H2	112	359		
	H2	113	268		
Apr	H2	114	476	367.67	104.27
	H2	115	212		
	H2	116	31		
May-15	H2	117	248	163.67	116.29
	H3	118	78		
	H3	119	300		
May-14	H3	120	202	193.33	111.25
	H3	121	9		
	H3	122	98		
Jun	H3	123	28	45.00	46.87

Appendix 2. Continued.

Month	Habitat	Trap	Abundance(ind/trap)	Mean	S.D.
	H3	124	1123		
	H3	125	40		
Jul	H3	126	682	615.00	544.60
	H3	127	249		
	H3	128	560		
Aug	H3	129	509	439.33	166.79
	H3	130	949		
	H3	131	1281		
Sep	H3	132	631	953.67	325.03
	H3	133	87		
	H3	134	202		
Oct	H3	135	84	124.33	67.28
	H3	136	86		
	H3	137	18		
Nov	H3	138	43	49.00	34.39
	H3	139	212		
	H3	140	294		
Dec	H3	141	360	288.67	74.14
	H3	142	13		
	H3	143	14		
Jan	H3	144	9	12.00	2.65
	H3	145	265		
	H3	146	531		
Feb	H3	147	653	483.00	198.40
	H3	148	192		
	H3	149	192		
Mar	H3	150	46	143.33	84.29
	H3	151	1145		
	H3	152	973		
Apr	H3	153	926	1014.67	115.29
	H3	154	740		
	H3	155	591		
May-15	H3	156	998	776.33	205.92
Min			0		1.53
Max			1481		544.60
					7 trap>250

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