

CHAPTER 4

DISCUSSION

4.1 Environmental variables in Thale-Noi

In the present study, the areas of Thale-Noi were divided into four zones according to habitat differences: the peat swamp, the small inlet, the resident and the pelagic zones. Sampling sites within each zone were similar to previous studies (Tunsakul, 1983; Angsupanich and Rukkhiaw, 1984; Angsupanich, 1985; Chiayvareesajja *et al.*, 1988; Nookua, 2003) but the study criteria and objectives for the present study were different. Previous studies did not concentrate on habitat differences but tried to provide complete sampling coverage of all areas. Even though Thale-Noi is comprised of many diverse microhabitats, the environmental variables in each zone did not show clear differences during the study period. However, most of the environmental variables were obviously different among season. The small inlet zone showed relatively high levels of depth, total solid, conductivity and salinity as compared to other zones. This may have been due to the influence of water run-off, the retention time of materials and the incorporation of nutrients (Chiayvareesajja *et al.*, 1988). Low pH values were observed in the peat swamp zone compared to other zones. This was due to the fact that this zone receives acidic water directly from the peat swamp forest. The resident and the pelagic zones do not have distinct environmental characteristics. However, these zones which had optimum pH and rather high dissolved oxygen were found to be have more fluctuation all year round. Also, environmental characteristics of the resident zone are probably due to the

additional effects of discharged water from domestic areas and agricultural land (Tunsakul, 1983; Chiayvareesajja *et al.*, 1988). High organic production and nutrient enrichment encouraged the growth of aquatic plants and phytoplankton which in turn led to high levels of dissolved oxygen. Additionally, environmental factors at the pelagic zone may be explained by the input of water nutrient from the area around Thale-Noi and also the effect of the wind action.

Seasonal changes of environmental factors in Thale-Noi are subject for the influence of the precipitation and monsoon systems (Aiumnau *et al.*, 2000). While these features are common to a large number of the freshwater environments (Chaiubol, 1998), the present study has shown a clear pattern of seasonal environmental factors. The patterns in the light rainy and the dry periods were quite similar, but it was differences in the rainy period.

The present study showed that water depth at Thale-Noi was directly correlated to rainfall as previously observed by Nookua (2003) and Buapetch (2002). It has been demonstrated that water depth closely follows precipitation values. However, the result of precipitation measurement during the year long study was not as expected. Instead of the dry period having the lowest precipitation value, the lowest value was found to be in the light rainy period. This may have been due to the received effects of the southwest monsoon (Suphakason, 1992).

In Thale-Noi, transparency was inversely correlated to pH. Therefore, higher values of transparency were observed in months with lower pH values. Remarkably, the study showed that pH values of water samples collected from the small inlet zone were quite low in the rainy period. This may have been due to the effects of the leaching of acidic water from the peat swamp forests during periods of

flooding (Chiayvareesajja *et al.*, 1988). With regard to pH value, it can be observed that the range of pH values in Thale-Noi, especially in the rainy (5.9-7.7) and the dry (5.0-8.7) periods, were less than the optimum range of pH for fish production (6.5-9.0) (Swingle, 1969).

Seasonal variation of water salinity, total solid and conductivity are essentially controlled by the river flow from Songkhla Lake (Pornpinitpong, 2004). Values for these factors were higher in the light rainy and the dry periods while, in contrast, they were rather low in the rainy period. This was probably due to the great influx of seawater when the water level of the lake is low, and is consistent with a previous study by Pornpinitpong (2004) who found that seawater intrusion in Thale-Noi occurs during the dry season or when the water level is low. An increase in turbidity is caused by the transportation of sediment from canals while in the rainy period the lake receives the effects of dilution from superficial water. In addition, the small inlet zone located in the canals was found to have the highest values of conductivity as per previous investigations (Nookua, 2003; Keowsurat, 1987).

The pattern of seasonal Dissolved Oxygen (DO) variations in Thale-Noi showed rather high levels in the dry period and quite low levels in the light rainy period. However, normal DO concentrations were measured during the rainy period which indicates that the environment is suitable for organism-living. DO concentrations may be dependent on the rate of photosynthesis and temperature variations (Iqbal *et al.*, 2006). Additionally, higher levels of DO may have been the result of wind action which causes the different water layers to mix together (Torres and Rylander, 2006). The DO in Thale-Noi varied widely (0.9-9.1 mg.l⁻¹) but was within the same range as previous studies (0.9-8.8 mg.l⁻¹; Nookua, 2003 and 1-8 mg.l⁻¹

¹; Buapetch, 2002). Furthermore, the patterns of DO concentrations were found to be similar in all zones.

The results of the present investigation indicate that for most of the annual cycle the pico-nanophytoplankton (chl *a* <20 μm) fraction size is the most abundant fraction size of total chl *a* in Thale-Noi. This fraction accounted for 43 and 82 % of the total chl *a* throughout the year, the only exception being recorded in early July when chl *a* of fraction size 20-200 μm dominated the overall concentration. This observation is similar to those of Paphavasit *et al.* (2006) for nearby water areas in Thailand. Investigations in other freshwater (Jong-Jeon *et al.*, 2001) and marine environments (Bruno *et al.*, 1983; Cole *et al.*, 1986; Froneman *et al.*, 2004; Shiomoto, 1997) have also revealed nanophytoplankton to be the most abundant size group. The important question to consider here is why chl *a* < 20 μm become abundant at this time of year? Pico-nanoplankton have been hypothesized to have advantages due to intrinsically higher growth and photosynthetic rates, and to nutrient uptake rates of small algal cells with high surface-to-volume ratios, compared to that found in large cells (Cole *et al.*, 1986; Hamasaki *et al.*, 1998).

Chl *a* fraction size of < 20 μm ranged from 1,192-5,670 $\text{mg}\cdot\text{m}^{-3}$; the mean value of concentration was the highest at the small inlet zone. This indicates that this zone is affected the most by nutrients in the water flowing from Thale Luang through Nang Riam Canal, Ban Glang Canal and Yuan Canal and by wind mixing of surface layers associated to active growth. Chl *a* fraction size of 20-200 μm ranged from 582-3,885 $\text{mg}\cdot\text{m}^{-3}$; the mean value of concentration was the highest at the resident zone, which might have been influenced by the waste water flowing in from the surrounding city area, containing a lot of essential nutrients for

microphytoplankton growth. This result was similar to the results found by Tunsakul (1983), Chiayvareesajja *et al.* (1988) and Nookua (2003) all of whom reported that the highest chlorophyll *a* or phytoplankton density in Thale-Noi was found at station 1 which is closest to the resident area. Although there was no significant difference between sampling periods between the two size fractions of chl *a*, it appears that light and temperature are important factors regulating the dynamics of both size fractions of phytoplankton, and that nutrients are relatively unimportant since they are available in sufficient amounts to meet phytoplankton demand. This has been suggested previously for Thale-Noi (Nookua, 2003) and for marine water in general (Bruno *et al.*, 1983).

4.2 Zooplankton communities in Thale-Noi

The present study has shown a clear pattern (in density) of seasonal total zooplankton fluctuation, as has been observed in other freshwater ecosystems, e.g. Aug kaew Reservoir, Thailand (Chaiubol, 1998), River Danube, Austria (Reckendorfer *et al.*, 1999) and Lake Bracciano, Italy (Ferrara *et al.*, 2002). The results were related to environmental effects, especially seasonal rainfall. In the rainy period, a high abundance of total zooplankton seemed to coincide with high chl *a* concentrations $< 20 \mu\text{m}$ (Inpang *et al.*, 2007), which may indicate increased growth and survival in high productive areas. Moreover, in this period the lake was subject to periodic flooding, which is generally when the greatest density of zooplankton occurs. This is because the flooding establishes a connection with the lower lake which increases food availability by bringing nutrient and material input. In the dry period, a clear pattern in total zooplankton community structure was observed, associated with

a high chl *a* concentration of 20-200 μm fraction size (Froneman, 2001; Inpang *et al.*, 2007), which was due in turn to a large phytoplankton bloom (Nookua, 2003). The dry period brings greater stability and food availability due to organic matter production and decomposition, as exemplified in other freshwater environments (Lam-Hoai *et al.*, 2006; Silva *et al.*, 2004). In the light rainy period, the lack of a peak is probably caused by low chl *a* concentrations. Moreover, we found that predators such as fish larvae and crab larvae, etc. occurred in this period. A similar result was noted by Aiumnau *et al.* (2000) who observed a high abundance of fish in Thale-Noi during this same period. Thus, it may explain that zooplankton density is limited by the presence of predators. Currently, little is known about the size structure of freshwater zooplankton. In Thale-Noi, the small size fraction of zooplankton (20-200 μm), consisting mainly of protozoans and rotifers, accounts for > 70% of total zooplankton. Zooplankton in the size range > 200 μm (mainly cladocerans and copepods) represents the second most important group, generally contributing < 20% of total zooplankton. This result indicates that smaller organisms may be of importance in the community structure as a trophic link between classical and microbial food webs. By virtue of their small body size, these organisms can exploit small food particles that are unavailable to most meso- and macrozooplankton, and thus act as trophic intermediaries between pico- and nanoplankton and meso- and macro-carnivores (Godhantaraman, 2003).

4.2.1 Species composition and diversity

In the present study, the number of phyla found was higher than that found from previous studies in Thale-Noi (Angsupanich, 1995; Chiayvareesajja *et al.*, 1988) and also higher than that found in previous studies for other freshwater bodies in Thailand, such as Ang Kaew Reservoir (Chaiubol, 1998) and Pasak Jolasid Reservoir (Jithlang and Wongrat, 2004). The microzooplankton composition of Thale-Noi consists mainly of protozoans, rotifers, cladocerans, copepods, including larvae and juvenile forms such as juvenile ostracods, crustacean nauplii and copepodite copepods. While the mesozooplankton composition, in addition to the holoplanktonic groups found in the microzooplankton also consists of some meroplanktonic groups such as shrimp larvae, gastropod larvae, bivalve larvae, crab larvae and fish larvae. These meroplanktonic groups were observed in low densities and frequencies. In the rainy period, the freshwater movement from other parts of the lake has a strong influence and the intrusion effect flushes several species out of the lake. This, in turn, allows protozoans, rotifers, cladocerans and copepods to grow, even in areas covered with macrophyte, such as the peat swamp and resident zones which have a higher number of taxa, especially rotifers and cladocerans than those of other areas. This observation is similar to those found by Jithlang and Wongrat (2004) and Pinto-Coelho *et al.* (2005).

Rotifera was the group with the highest taxonomic richness (33 genera) in Thale-Noi. This result concurs with reports from other freshwater environments, especially in the tropical region (Starling, 2000; Sampaio *et al.*, 2002; Akin-Oriola, 2003; Keppeler, 2003; Wansuang and Sanoamuang, 2006). The large species number of this group is due to the fact it is considered to be an opportunistic species in

different environments (Keppeler, 2003). There is a series of advantages in the rotifer's system of reproduction which could favor the participation of most of these animals in an opportunistic, colonizing lifestyle (Birky and Gilbert, 1971). Additionally, the wide spectrum of food particles exploited by this group, which display the ability to consume bacteria, algae and detritus of different size, allows quite distinct diets for the many species simultaneously present in a body of water (Sampaio *et al.*, 2002). The Rotifera families with the greatest number of species were Brachionidae and Lecanidae, which are considered typical for, and most frequent in, tropical environments (Dumont, 1983; Keppeler and Hardy, 2004).

Cladocera was the second most diverse group of the community, as has been reported in other investigations (Pholpunthin, 1997; Maria-Heleni *et al.*, 2000; Ferrara *et al.*, 2002; Bekleyen, 2003). The diversity of Cladocera in Thale-Noi was rather high (26 genera) as compared to other studies on species diversity of cladocerans in temporary waters (Wansuang and Sanoamuang, 2006). This may have been due to Thale-Noi having diverse aquatic plants which act as a habitat, food source and refuge for cladocerans. According to Sa-ardrit (2002), cladocerans prefer to inhabit areas which are largely colonized by submerged and emerging macrophytes. Regarding Cladocera diversity and abundance, it can be observed that Cladocera was equally diversity and abundance in both microzooplankton and mesozooplankton community. This may be due to the effects of clogging of plankton net.

There is little previous data on Protozoa species in the lake, so it is difficult to assess how communities are changing. It is also difficult to make distinct classifications for certain species of protozoa, whether they are zooplankton or

phytoplankton. The 25 protozoan taxa were comprised of seven flagellates (including algal flagellates), ten sarcodines and eight ciliates, indicating less species diversity than previously found in freshwater environments in Thailand (Charubhun and Charubhun, 2000). In general, regarding these three groups of protozoa, the ciliates exhibited the greatest diversity in the lake (Baldock *et al.*, 1983), but it is very difficult to identify some species of the smaller organisms after the preservation process. Many factors are involved, such as water quality, predation and other environmental elements, in influencing species composition and community development of protozoa in aquatic ecosystems (Xu *et al.*, 2005).

Overall, eleven genera of Copepoda were identified in the present study. The genera found were generally similar to those described in previous studies from Northeast Thailand (Sanoamuang and Faitakum, 2005; Wansuang and Sanoamuang, 2006) and Southern Thailand (Pholpunthin, 1997), the exceptions being some species such as *Acartia cf. southwelli* which may be newly recorded species for Thailand. However, in Thailand, the taxonomic richness of Copepoda and Ostacoda is quite low. This may possibly be due to the fact that key to identification of these groups has been limited. However, copepodite copepods and crustacean nauplii were found throughout this study.

Of the Meroplankton community in Thale-Noi, only shrimp larvae were found constantly throughout the present study while the remaining groups appeared only during the dry and light rainy periods. This may have been due to low rainfall which indicates the period most meroplankton groups reproduce and spawn. Although previous zooplankton studies have not reported the presence of

merozooplankton in Thale-Noi, it was evident in Thale Sap Songkhla, where it bloomed during a month of low temperature and low rainfall (Augsupanish, 1997).

In the present study, apart from zooplankton groups, meiofauna and other groups such as, amphipods, gastrotrichs, water mites, chaoborus, midge larvae, oligochaete, free-living nematode, insect larvae and hydra, etc. were usually found in the water samples. This had not been reported in Thale-Noi before. Angsupanich *et al.* (1997) and Angsupanich (1997) found some species of amphipods in Thale Sap Songkhla that typically inhabit the seawater zone. It is of little surprise, perhaps, that this study found them only in the small inlet zone (Nang Riam station), and only in the light rainy period. Possibly, this location obtains seawater from Thale Sap Songkhla through a small canal when the water level is at its lowest.

4.2.2 Occurrence of zooplankton in Thale-Noi

The zooplankton found in Thale-Noi are common species and most genera are cosmopolitan, as recorded in Kanchanaburi province, Thailand (Pipatcharoenchai, 2001), and also similar to those recorded by other authors in tropical regions (Bekleyen, 2002; Keppeler, 2003). In this study, only two genera of zooplankton were represented by season. *Floscularia* occurred during the dry period while *Macrochaetus* occurred during the light rainy period. In Bonita Pond, these genera were the littoral rotifers genera (Starling, 2000). In Lake Vortsjarv, among the recorded species, *Keratella cochlearis*, *Polyarthra dolichoptera*, *Filinia* sp. and *Trichocerca* species are well-known indicators of eutrophy (Haberman, 1998). Additionally, *Brachionus* has been used as an indicator organism for trophic characterization of lakes (Mageed, 2007). Higher genera frequency, mainly of

protozoans occurred during the dry period whereas a higher frequency of rotifers and cladocerans occurred in the rainy period than that of other periods. Variations in genera occurrence and changes due to environmental conditions were generally obvious during all sampling periods.

4.2.3 Relative abundance and density of zooplankton

In the present investigation, microzooplankton was dominated by Protozoa and Rotifera, which made up nearly 70% of the total microzooplankton. The dominance of Protozoa or Rotifera in tropical freshwaters has already been described by Torres-Orozco and Zannatta (1998), Sampaio *et al.* (2002) and Sandacz *et al.* (2006). In this study, the dominant zooplankton groups exhibit differences with previous research (Chiayvareesajja *et al.*, 1988; Angsupanich, 1995). They reported that rotifers were the most abundant group throughout the study, followed by nauplii larvae or copepodite stages. The scarcity of protozoans in their samples suggests that they could have used a mesh diameter wider than 20 μm , and this could have led to underestimating the quantity of smaller organisms. This may be one reason why there was a lack of small groups in previous studies as compared to this study. However, it is difficult to make definite conclusions on the causes of group differences between different studies because of the differences in sample size, differences in sampling methods and differences in sampling frequencies.

In the present study there was a succession of microzooplankton species throughout the year. During the light rainy period, different species of rotifers alternated in dominance, represented mainly by *Polyarthra* and *Anuraeopsis*. This is supported by the fact that these genera were commonly found in many other lakes

(Naves *et al.*, 2003; Yildiz *et al.*, 2007) and were dominant species in tropical freshwater environments (Jithlang and Wongrat, 2004). It is also in agreement with the results of Mageed (2007), who discovered that *Hexathra*, *Polyarthra* and *Filinia* are greatest during the hot period. Torres-Orozco and Zanatta (1998) found that the relative abundance of rotifers was directly related to water temperature variations. It has been demonstrated that abundance of rotifers closely follows temperature variations because temperature has a major influence on their reproductive rate, feeding, movement and longevity (Miksci, 1989). From November to December (the rainy period), low water temperature and high rainfall led to a decrease in rotifer populations and they were replaced by protozoans, represented by *Trachelomonas* and *Peridinium*. Up until the dry period, protozoans were strongly dominant in the community. This is similar to the findings of Graham *et al.* (2004), who found that *Peridinium limbatum* was the dominant dinoflagellate in the sense that it persisted throughout the entire open-water season and was the dominant community in the summer. Hadas and Berman (1998), who studied seasonal abundance and vertical distribution of Protozoa in Lake Kinneret, Israel, have suggested that during the *Peridinium* bloom in late February there was a rise in ciliate abundance, concomitant with the increase of particulate organic detritus and dissolved organic matter, which stimulated bacterial and heterotrophic nanoflagellates outgrowth and they found high numbers of heterotrophic nanoflagellates, coinciding with peaks of chlorophyll *a* and primary production.

The high population density of rotifers has been attributed to their parthenogenesis reproductive pattern, short life cycles and wide tolerance to a variety of environmental factors (Akin-Oriola, 2003; Keppeler and Hardy, 2004; Park and

Marshall, 2000). The abundance of protozoans suggests that it plays a substantial role in nutrient regeneration in the water column, indicating that they often become the main zooplankton in the community. This suggests that protozoans must have a key trophic role that may contribute to the high productivity of the lake food web (Pirlot *et al.*, 2005). In general, and particularly in tropical waters, the microzooplankton distribution and abundance varies considerably due to seasonal fluctuations (Sampaio and Lopez, 2000). This observation agrees with studies of the reservoirs of the Paranapanema River (Sampaio *et al.*, 2002). The highest density of microzooplankton, particularly protozoans, in the dry period may be attributed to a combination of temperature, salinity and chlorophyll *a* concentrations, which are often considered the most important factors in acceleration of the growth rate (Eskinazi-Sant'Anna and Bjornberg, 2006).

Regarding spatial variation, there were no significant differences in microzooplankton density among zones. However, microzooplankton densities at stations located at the small inlet zone, connected to Songkhla Lake, were high as compared to those of other zones. It may be that this zone had high water level and inputs of suspended sediments. The results indicate that these factors, combined with high nutrient levels, are essential for plankton growth (Conde-Porcuna *et al.*, 2002; Pinto-Coelho *et al.*, 2005). Thus, spatial differences in density seem to be related with the entrance of the river waters, as a result of increased food availability due to nutrient and material input. This is consistent with Chiayvareesajja *et al.* (1988) who suggested that this zone seems to be the most appropriate site for aquaculture in Thale-Noi.

The dominant groups of microzooplankton were similar in all zones but different species dominated. Based on the number of sampling times in which a species was numerically dominant in the microzooplankton, the dominance hierarchy for the peat swamp zone was *Trachelomonas* (3) > *Peridinium* (2) = *Stentor* (2) = *Polyarthra* (2) > *Lepocinclis* (1) = *Dinobryon* (1) = *Arcella* (1). In the small inlet zone, *Trachelomonas* (4) > *Polyarthra* (3) > *Keratella* (2) > *Anuraeopsis* (1) = *Tintinopsis* (1). In the resident zone, *Polyarthra* (5) > *Trachelomonas* (3) > *Peridinium* (1) = *Stentor* (1) = *Lecane* (1). In the Pelagic zone, *Trachelomonas* (6) > *Anuraeopsis* (2) > *Polyarthra* (1) = *Keratella* (1) = *Stentor* (1) = *Euglena* (1). The dominance of *Polyarthra* in the resident zone was very common as found in other environments (Duggan *et al.*, 2002). These results are consistent with Torres-Orozco and Zanatta (1998) who suggested that a eutrophic lake is characterized by rotifers genera *Polyarthra*, *Brachionus*, *Keratella*, *Filinia*, *Conochilus* and *Trichocerca*. Additionally, it was discovered in the peat swamp zone that several species of protozoans alternated in dominance; suggesting that water quality in this zone is favorable for protozoan reproduction. The causes for high protozoan levels in this zone could have been high organic production (due to perished vegetation), low water level which made it difficult to sample zooplankton, and possible clogging of the plankton net by organic matter which then led to the measurement of protozoan numbers being overestimated.

The Mesozooplankton group, Cladocera was found to have a relatively high abundance of > 80% in the rainy period while Copepoda and other groups showed a relatively high level of abundance in the light rainy and dry periods. The presence of a clear seasonal pattern in the total abundance of the mesozooplankton

community, as in Thale-Noi, has also been recorded at Lake Heyes (Burns and Mitchell, 1980). The higher densities of mesozooplankton in the rainy period associated with eutrophic water mass may be due to increased quantities of picoplankton and microzooplankton, which are consumed by the mesozooplankton (Pedersen *et al.*, 2005). In addition, the absence or low density of fish, crab and shrimp larvae (predators of zooplankton) during the rainy period may be one of the main causes of the increase in small mesozooplankton. There was a succession of mesozooplankton species throughout the year. Cladocera, mainly *Chydorus* spp., *Bosminopsis deitersi*, Copepoda *Neodiantomus yangtsekiangensis* and *Acartiella sinensis* alternated in community dominance in the light rainy period while high densities of Cladocera were registered mainly in the rainy period, especially *Bosminopsis deitersi*. In the dry period, the mesozooplankton community was dominated by Cladocera *Chydorus* spp. and *Dunhevedia crassa*. During population peaks, a large amount of *Bosminopsis deitersi* was recorded (1,512,000 ind.m⁻³) (Table 6), which might reflect short-term changes in reproductive potential for parthenogenesis, depending on changes in the abundance of food (Paranagua *et al.*, 2005). Some author (Viroux, 2002) have questioned the capacity of cladocerans to accomplish their life cycle in rivers, given the usually short time at their disposal. A dominance of copepods in Thale-Noi occurred occasionally, e.g. *Neodiantomus yangtsekiangensis* and *Acartiella senensis*. Allan (1976) suggested that the K-selected life history of copepods (such as low reproductive rates and low susceptibility to predation) give them a competitive advantage in seasonally stable ecosystems.

Regarding spatial variations, total mesozooplankton abundance was higher for the small inlet and pelagic zones than for the peat swamp and resident

zones. This high abundance could possibly be due to high densities of cladoceran *Bosminopsis deitersi* during late November, copepods, mainly *Pseudodiaptomus* sp. in early March, and *Metacyclops* sp. in late march. The food supplied by freshwater inflow through the small inlets during the rainy period in November and December seemed to be important for inducing growth of all zooplankton taxa when salinity was very low (Angsupanich and Rukkheaw, 1997).

There were remarkable differences in dominant species among zones. Based on the number of sampling times in which a species was numerically dominant in the mesozooplankton, the dominance hierarchy for the peat swamp zone was *Bosminopsis* (5) > *Metacyclops* (2) > *Voticella* (2) > *Neodiaptomus* (1) = *Chydorus* (1) = *Testudinella* (1). In the small inlet zone, *Chydorus* (3) > *Bosminopsis* (2) = *Ephemeroporus* (2) = *Acartiella* (2) > *Mesocyclops* (1) = *Metacyclops* (1) = *Pseudodiaptomus* (1). In the resident zone, *Chydorus* (6) > *Bosminopsis* (2) = *Dunhevedia* (2) = *Latonopsis* (2). In the pelagic zone, *Chydorus* (4) = *Bosminopsis* (4) > *Metacyclops* (2) > *Neodiaptomus* (1) = *Microcyclops* (1). Remarkably, only the small inlet zone was found to have a distinct copepod domination, especially in the light rainy and dry periods. The present results support the theory that these copepods may be distributed from brackish water (Thale Luang). Furthermore, only a single zone of Thale-Noi (the resident zone) was dominated by cladocerans alone, indicating that some species of Chydorids prefer a weed or vegetation habitat (Blindow *et al.*, 2000; Goulden, 1971). The remarkable community of cladocerans indicates abundant phytoplankton with large habitat diversity (Cottenie and Meester, 2003; Lovik and Kjellberg, 2003; Nurminen *et al.*, 2007) and low predation (Ramdani *et al.*, 2001).

4.3 Relationships between zooplankton densities and environmental parameters

From CCA analysis it was revealed that, besides changes in seasonal temperature, salinity and total solids, the main environmental gradients were due to pH, transparency and dissolved oxygen. These gradients are a common feature of other freshwater ecosystems having a pronounced temporal effect on the zooplankton composition and distribution (Branco *et al.*, 2002; Ferrara *et al.*, 2002; Keppeler, 2003; Michaloudi and Kostecka, 2004; Mageed and Heikal, 2006). Nitrate and phosphate concentration, temperature and oxygen levels are very important in determining the seasonality in zooplankton species composition and abundance (Maria-Heleni *et al.*, 2000; Wang *et al.*, 2007). The controlling factor responsible for when species can survive in different periods in Thale-Noi is the individual species range of environmental tolerance. Environmental conditions in the light rainy and dry periods were similar, both periods being associated with low rainfall, which was opposite to that generally described in the rainy period.

According to the present results, the conductivity and pH increased while depth and transparency decreased during the light rainy period. This was due to very low rainfall and a lack of sediment flow which caused inorganic matters to accumulate, especially at the bottom. Similar results have been found in Thale-Noi (Nookua, 2003). The most abundant microzooplankton, such as *Loxodes*, *Peranema*, *Stentor*, *Anuraeopsis*, *Brachionus*, *Colurella*, *Collotheca*, *Euchlanis*, *Filinia*, *Hexathra*, *Lepadella*, *Macrochaetus*, *Testudinella*, *Trichocerca*, *Proales*, *Mytilina* and *Alona*, and species within the mesozooplankton community, such as *Moina*, *Moinodaphnia*, *Neodiaptomus* and *Mesocyclops*, reacted positively to conductivity and pH, but negatively to depth and transparency. It can be suggested that most of

these genera have an optimum set of environmental conditions to ensure their survival. These findings were similar to those findings from the Funil Reservoir (Branco *et al.*, 2002), where *Hexathra mira* and amoeba related to low water transparency, while *Filinia longiseta* were the taxa most positively correlated with high water transparency. Wang *et al.* (2007) found that *Moina micrura* peaked in lakes with low SD (secchi disk visibility) and depth, and suggested that temperature seemed to be an important factor when determining the dominance of *Moina micrura*. Some taxons appeared in Lago Amapa at basic or neutral pH and relatively low dissolved oxygen levels, such as *Platylas quadricornis*, *Lepadella ovalis*, *Trichocerca similis* and *Testudinella patina*. The researchers suggested that these factors are not considered limiting for those species studied in the lake (Keppeler and Hardy, 2004). However, among rotifers, along with *Euchlanis dilatata*, *Trichocerca* sp., *Pompholyx* sp., *Keratell quadrata* and *Filinia longiseta* were often found in eutrophic lakes (Bekleyen, 2003).

Protozoans *Centropyxis*, *Euglyphra*, *Halteria*, *Tracheomonas*, *Undella*, rotifers *Plationus*, cladocerans *Alona*, *Chydorus*, *Ephmeroporus*, *Karualona*, *Macrothrix*, *Latonopsis*, ostracods, *Cypricercus*, *Stenocypris*, and copepods *Acartia*, *Euryalona*, *Metacyclops* and *Thermocyclops* were the most abundant and frequently observed taxa during the dry period. Although, this period has generally low rainfall, it was higher than that in the light rainy period. On the other hand, there was a gradient of moderate to high total solids, salinity, pH, conductivity, and the highest levels of dissolved oxygen and water temperature. The favourable combination of several factors, including intrusion effects from Thale Luang, results in Thale-Noi being colonized by a high biomass during the dry period, that is, phytoplankton, small

zooplankton, vegetation, birds and shrimp (Storer, 1977; Tunsakul, 1983; Nookua, 2003; Leingpornpan and Leingporpun, 2005; Inpang, 2007). Protozoans are important components of microzooplankton communities in lakes during the dry period (Pirlot *et al.*, 2005). Dabes and Velho (2001) reported that the protozoan genus *Centropysis* was equally abundant in both the dry and the rainy seasons. Moreover, they found that some groups of species such as *Centropyxis* spp. and *Diffugiella* sp. were more abundant in the dry season, while *Diffugia*, *Euglypha* and *Trinema* spp. were more abundant during the rainy season (Dabes and Velho, 2001). Among factors that strongly influence the population density of planktonic protozoans are water quality, quantity of available food, temperature, and predation (Beaver and Crisman, 1990 cited by Xu *et al.*, 2005). Cladoceran populations have been associated with trophic gradients in other lakes (Branco *et al.*, 2002). Pinto-Coelho *et al.* (2005a) suggested that cladocerans often occurred simultaneously with blooms of cyanobacteria and floating macrophytes, similar to Nookua (2003) who documented that high densities of blue green algae in Thale-Noi were observed in the dry period and who also found that Cyanophyta has a positive correlation with temperature in April. In addition, the studies of Leingpornpan and Leingpornpan (2005) on aquatic plants and their distribution mapping in Thale Noi Lake, found that the covering of aquatic plants in the dry period was higher than that in the rainy period. Thus, the presence of macrophyte beds in Thale-Noi also influences the zooplankton composition by including Cladocera (Fam. Chydoridae) as observed in the Formosa Pond, Brazilia (Starling, 2000) and in Lake Hanebjerg, Denmark (Romare *et al.*, 2003). Cladoceran species, especially *Chydorus*, live in vegetation habitats most probably to avoid predators such as midges (Goulden, 1971). Among the copepods, *Thermacyclops* and

Mesocyclops are predominant in the lake during this period, and are associated with feeding, hunting for large phytoplankton cells, or eating colonies of Cyanophyceae and small zooplankton, such as the nauplii of other species of Copepoda (Sampaio *et al.*, 2002).

In the rainy period, a period associated with the greatest water depth, were found *Arcella*, *Peridinium*, *Phacus*, *Lepocinclis*, *Asplanchna*, *Ascomorpha*, *Lecane*, *Polyarthra*, *Bosminopsis*, *Ceriodahnia*, *Diaphanosoma*, *Ilyocryptus* and *Microcyclops*. These findings can be related to low levels of salinity, total solids, pH and temperature, but moderate dissolved oxygen. Due to high rainfall during the rainy season, the lake water composition is affected by the ingress of water from the upper stream, the swamp forest, and the land which brings nutrient enrichment into the lake. As a result, some species of microzooplankton such as flagellate phytoplankton, become the primary producer and are well represented in terms of total density in Thale-Noi, similar to Chaohu Lake (Xu *et al.*, 2005). One might expect that small rotifer populations would be correspondingly large later on. *Polyarthra* can consume diverse food particles and it appears that niche differentiation among related species has a strong influence on Rotifera assemblage composition and diversity via competitive interactions (Sampaio *et al.*, 2002). The three dominant cladocerans, *Bosminopsis*, *Ceriodaphnia* and *Diaphanosoma*, occurred frequently and were relatively dominant in Thale-Noi, although being less competitive in exploiting resources than daphnia (Wang *et al.*, 2007). Some researchers believe that the predominance of small cladocerans (*Bosmina* and *Ceriodaphnia*) is related to the interference of filamentous blue green algae, which dominate the phytoplankton under eutrophic conditions (Sampaio *et al.*, 2002).

4.4 Relationships between zooplankton and chlorophyll *a*

The presence of phytoplankton blooms appeared to have a significant effect on the abundance of zooplankton during this study, as species abundance showed a clear seasonal pattern following phytoplankton blooms.

The correlation analysis suggests that protozoan and rotifer densities affected by chl *a* were of < 20 µm fraction size in Thale-Noi, whereas cladocerans, ostracods and copepods affected by chl *a* were of 20-200 µm fraction size. This result is similar to that at Lake Kinneret, Israel (Hadas and Berman, 1998). In the present study, *Peridinium* and *Trachelomonas* were the dominant genera of protozoans throughout the entire rainy period to the dry period, associated with high chl *a* of < 20 µm fraction size while large protozoans *Arcella* were related to chl *a* of 20-200 µm fraction size. This result is similar to other studies on Protozoa in Sao Francisco river floodplain, Brazil (Dabes and Velho, 2001), who suggested that smaller species such as *Diffugiella* and *Trinema* feed on bacteria, fungi and small protozoans. On the other hand, larger species consume filamentous algae, small rotifers and other testate amoebae. In the present study, among rotifers only *Ascomorpha* showed a positive relationship with chl *a* of < 20 µm fraction size, whereas other genera *Lecane*, *Lepadella*, *Monommata* and *Testudinella* showed a negative relationship with this fraction size. *Colurella*, *Euchlanis* and *Hexathra* showed a negative correlation with both size fractions of chl *a*. This may agree with the findings of Abdel Aziz *et al.* (2006) who revealed that the increase in rotifers counts was accompanied by a decrease in *Navicula*, *Scenedesmus*, *Kirchneriella* and *Actinastrum* in June and a decrease in *Actinastrum* in July. They suggested that this pattern may reflect the effect of temperature on grazing efficiency in different months at variable temperatures. It is

remarkable that some zooplankton species demonstrated no food selectivity toward phytoplankton species, such as the rotifers *B. plicatilis* and *B. urceolaris*, and the cladoceran *M. micrura* and cirripede larvae, which grazed on phytoplankton species belonging to different algal groups, as indicated from the significant correlations (Abdel Aziz *et al.*, 2006). However, it has been discovered that *Polyarthra* spp. and *Synchaeta* spp. are indeed considered as specialist feeders on large (~ 30-40 μm) particles and are potential predators for ciliates (Joaquim-Justo *et al.*, 2006). The small cladocerans mainly *Alona* and *Chydorus* were significantly negatively correlated with chl *a* of < 20 μm fraction size. It is indicated that the dominance of small cladoceran species observed in Thale-Noi is probably related to interference in the feeding, given that Cyanophyceae were abundant at most times of the year (Nookua, 2003). However, *Diaphanosoma* was strongly correlated to chl *a* 20-200 μm fraction size, which concurs with the results of Hadas and Berman (1998) who discovered that herbivorous cladocerans (*Diaphanosoma brachyurum*) dominated the zooplankton community at the same time where there was a high abundance of flagellates. The present investigation has shown copepods to have a positive relationship with chl *a* 20-200 μm fraction size. Generally, the life histories of copepods reveal that while juvenile stages are herbivores, the adult stages are frequently carnivores (Abdul Azis *et al.*, 2003). Further, from correlation analysis it was found that copepod copepodites had a strong effect on protozoans. Thus, the preferential feeding by copepod copepodites on microzooplankton indicates that copepod grazing on protozoans can provide a mechanism for transport of the carbon found in smaller size fractions to higher trophic levels (Bundy *et al.*, 2005). A finding

from this study was that seasonal changes in zooplankton abundance in Thale-Noi may be related to the interactive effects of food size-spectra (chl *a* size fractions).