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DISERTATION THESIS

Plankton and Trophic Interactions in Hypertrophic Fish Ponds

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I hereby declare that this thesis has been fully worked out by myself using my own data and cited literature only.

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Jan Potužák

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I. Changes in Fish Production Effectivity in Eutrophic Fish ponds – Impact of Zooplankton Structure.

II. Zooplankton in Hypertrophic Fish ponds: is the „ Top-Down“ Regulation of Phytoplankton Still a Valid Concept?

1. INTRODUCTION

Fish pond systems are unique man-made aquatic ecosystems of the Czech landscape. They represent an important and the most frequent type of stagnant water bodies in the Czech Republic. Most of them are several hundred years old, and they look like natural small shallow lakes. In spite of that, fish ponds represent managed aquatic ecosystems, in which water level, fish stocks, and nutrient input are under human control (Kořínek et al., 1987).

Substantial changes in agricultural management implemented in the previous century, had a profound effect on the individual biotopes, as well as on the entire landscape function. This process can be characterised as intensification of land production use. Fish ponds, as an important part of the hydrologic system of the surface waters in the Czech Republic, naturally integrate all impacts of human management activities in their catchment areas. Current fishery management of fish ponds significantly influences the quality of surface waters and the overall hydrological regime. In fish pond regions, such as in the Třeboň basin, fish ponds play one of the key ecological functions (Pechar et al., 2002).

Since the Middle Ages, fish ponds have been created as multi-purpose water bodies. Their hydrologic functions and retention use for watermills and iron-mills were equally important as fish breeding. The total fish pond area in Bohemia and Moravia reached 180,000 ha by the end of the 16^{th} century (Šusta, 1898). At present, there are approximately 25,000 fish ponds in the Czech Republic (with their total area of about 53,000 ha) and the number of new or restored fish ponds is still growing every year (Květ et al., 2002). According to the Water Framework Directive (WFD 2000/60/EC), fish ponds exceeding the area of 50 ha are considered independent water bodies. The majority of the ponds are much smaller. However, they are integral parts of fish pond systems and in some regions, they can comprise a significant share of the total area. For example, in the Třeboň region, the water area of fish ponds constitutes approximately 10 % of the total area (Třeboň Protected Landscape Area covers the area of 700 km^2). In these regions, fish ponds have a strong impact on the climate of the region and they dramatically influence the hydrology and the hydrochemical regime of surface waters. Presently, their main function is fish breeding, and a rational management is the fundamental precondition of their existence (Janda et al., 1996). Fish breeding is based on the utilization of fish pond ecosystem production. Production potential has been systematically and artificially expanded by various management measures since the beginning of the 20^{th} century. The current intensive fish-production practices (fertilising, fish feeding), together with influences from the fish pond catchments (agriculture, pollution and nutrient inputs), significant accelerated eutrophication. High nutrient concentrations cause excessive growth of algae and cyanophytes biomass, which is associated with extreme fluctuations of pH and oxygen concentration. All these are clear symptoms of highly advanced eutrophication and disturbance of fish pond ecosystems (Janda et al., 1996; Pechar et al., 2002).

Sustainable fish pond management is expected to ensure stabilization or even improvement in water quality. This requires the understanding of long-term changes in fish pond ecosystem and water quality. Water quality itself significantly influences all components of the fish pond ecosystems. But it is the structure of the plankton, and particularly the development of planktonic cyanophytes and algae, that impact on the important parameters of the fish pond water quality.

For the fish pond ecosystem quality assessment, information on species and size composition of zooplankton is substantial. From the fishing and water management points of view, the main group is large *Daphnia* species. These act as effective phytoplankton filter-feeders. At the same time, they are an important fish food. Therefore, they serve as a link enabling the transfer of energy and nutrients between primary production and final fish production.

Current high levels of eutrophication combined with high fish stock densities have a significant influence over zooplankton community structure. The zooplankton consists mainly of small species such as nauplii, cyclopoid copepods, rotifers and small species of Cladocera (species of low filtration efficiency). On the other hand, a high level of eutrophication leads to excessive primary production of phytoplankton (frequently with the dominance of inedible cyanophytes) which is not effectively used by zooplankton. It can be suppose that the use of such enormous primary production in the food chain is low and the efficiency of the whole fish pond ecosystem functioning decreases.

Over the past decades, insufficient attention has been paid to fish pond ecosystems. Fish ponds, however, have undergone a number of changes over this period which enhanced the attractiveness of these areas for recreation, aquculture, watersports, sport fishing etc.

The objectives of this dissertation thesis were:

1. To describe the current species and size composition of zooplankton in the fish ponds of Třeboň and Blatná-Lnáře regions and, subsequently, to compare these two regions.
2. To analyse interrelations of phytoplankton, zooplankton and fish stock, to characterise the effect of basic trophic parameters on zooplankton communities forming under eutrophic and hypertrophic conditions.
3. To assess the role of top-down and bottom-up regulations in relation to final fish production in the conditions of high level of eutrophication.

2. LITERATURE REVIEW

2.1. The Return to a Darwinian Ecology of Plankton

Current concepts of shallow lake and fish pond functions draw largely on the comparison of current status and seasonal dynamics of various reservoirs. To understand the changes that a reservoir undergoes, it is crucial to focus on the mechanisms and processes taking place in plankton community (Scheffer, 1998).

General ecology describes various issues of plankton ecology (e.g. Odum, 1977; Strong et al., 1983; Begon et al., 1990). Therefore, understanding plankton as such will enable us to treat this community as a model for other types of ecological communities.

There are lots of articles describing relations and seasonal changes in species composition of phytoplankton and zooplankton abound in the literature (e.g. Hammer and Sawchyn, 1968; Allan, 1973; DeMott, 1983; Krieger and Klarer, 1991; Nygaard, 1996; Noges et al., 1998; Link et al., 2004; Havel and Pattinson, 2004; Padisák, 2005; Abrantes, 2006). Unfortunately, most of them are only descriptive. Even though the seasonal variability of plankton in different reservoirs may follow quite a recurrent scenario, comparison of individual water bodies can be sometimes problematic (Sommer, 1989). Some authors draw a pessimistic conclusion and consider the understanding of the mechanisms of changes as an insoluble problem (Harris, 1986). Nevertheless, other authors maintain still an optimistic idea, and draw on traditional approaches of theoretical and experimental research (e.g. Reynolds, 2000; Reynolds et al., 2000; Scheffer et al., 2003; Kerfoot et al., 2004; Lampert, 2006; Sass et al., 2006; Sommer et al., 2006; Carpenter et al., 2008; Scheffer et al., 2008).

The superorganism concept (Clements, 1916), views the ecosystems as an organism of higher order and therefore defines a succession as an ontogenesis of this superorganism (self-organization of an ecosystem, Margalef, 1978). The individualistic concept (Gleason, 1927) assumes populations to respond independently to an external, physical, and chemical environment. The Gleasonian point of view is quite common in phytoplankton ecology and quite rare in zooplankton ecology (Sommer, 1989). The third concept of ecosystems and community organization is centred around the nutrition needed for survival and reproduction. This concept implies competition between organisms for common resources (Strong et al., 1983; Begon et al., 1990). Interactions between populations are therefore primarily negative (competition, predation, parasitism), with symbiosis as a very rare phenomenon. The concept of negative interactions is already present in the third chapter of Darwin's *Origin of Species*. In ecology, this approach is sometimes called Darwinian (Sommer, 1989).

While succession theories for terrestrial habitats date back as early as the beginning of the last century (Clements, 1916; Gleason, 1917, 1927), similar theories concerning plankton have been missing for a long time. The few attempts (e.g. Pankin, 1945) to classify algal associations have never received wide acceptance (Symoens et al., 1988). The first general concept of plankton succession, the so-called Plankton Ecology Group (PEG) Model, was developed during the 1980s (Sommer et al., 1986). The PEG-model describes a model sequence of 24 steps of seasonal changes in phytoplankton and zooplankton in an idealized lake. The steps are either inevitable consequences of theprevious ones, or consequences of the regular seasonal change in external forcing factors. For each step a mechanistic explanation is provided. This 'classical' theory of plankton succession has undergone many changes since then (Pickett and McDonnell, 1989; Czárán and Bartha, 1992).

Debates over the role of competition in natural communities often assume clear alternatives. The first one, based on Lotka Volterra model, presumes that populations are equally food-limited (equilibrium model, Schoener, 1982). The second model emphasizes the role of changing conditions in stabilizing species' co-existence (non-equilibrium model, Chesson and Case, 1986; DeAngelis and Waterhouse, 1987).

Natural shallow lakes can be very rich in plankton species. Many of the species are rather unpredictable in their appearance and abundance; others are more predictable, but still very rare compared to the densities of the few dominant species (Padisák, 1992).

The Competitive Exclusion Theory (Hardin, 1960) predicts that only as many species can coexist as there are limiting factors. Observation and theory contradict each other. Hutchinson (1961) termed the apparent contradiction between the number of species and the number of limiting resources as the 'Paradox of Plankton'. In his original paper, Hutchinson suggested several possible explanations for his Paradox, including that the boundary conditions of competition change frequently enough to invert competitive hierarchies before exclusion occurs. This theory is widely accepted and is not limited only to plankton communities (e.g. Grime, 1973).

Early studies describing patterns of zooplankton communities are consistent with 'equilibrium competition theory'. For example, Hutchinson (1951) noted that coexisting copepods often differ considerably in body size; presumably an indication of food-size partitioning. Pennak (1957) commented on the low diversity of zooplankton in Colorado lakes in comparison to the local species pool, inferring that competitive exclusion was a strong force in zooplankton communities. Circumstantial evidence for strong food limitation among herbivorous zooplankton is both widespread and easy to obtain. Because many freshwater zooplankters carry their eggs until hatching, evidence that food limits reproductive rates can be obtained directly from field samples. Food limitation strongly influences overall fertility. For example, clutch sizes in *Daphnia* are typically high during the spring peak of phytoplankton biomass but are much reduced during the remainder of the year (Hebert, 1978). Reduction in fecundity can usually be attributed to food limitation, although selective predation on large, more fecund females can also be important (Threlkeld, 1979; Gliwicz et al., 1981). Low reserves of lipids and decreased slopes in length-body-mass relationships have also been used as indicators of food limitation in field zooplankton populations (Tessier and Goulden, 1982; Geller and Müller, 1985; Duncan, 1985).

Zooplankton populations often show symptoms of strong food limitation. They frequently undergo distinct seasonal successions which correspond to equilibrium models. As many authors have discovered, there are at least four major mechanisms causing species succession. The predominance of one species or another is mostly induced by the change of basic environmental parameters, predation, competition, and by combination of all these factors. Coexistence may depend upon a balance between competition and predation (Scheffer, 1997).

The 'size-efficiency hypothesis', published by Brooks and Dodson (1965) is a illustrative case. They pointed out that large species are superior competitors but are also more vulnerable to predation by visually-feeding fish. According to this mechanism, changes in predator abundance or activity would explain the seasonal succession and long-term persistence of a better ‘escaper’ and superior competitor (Jacobs, 1977a, b). Brooks and Dodson (1965) also drew attention to the fact that large species of zooplankton can gain a competitive advantage in case they are able to feed on large particles, although they are able to feed on small ones effectively as well. On the other hand, the focus of large filter-feeders on large particles and of small filter-feeders on small particles can bring about a decrease in species interactions intensity (Hutchinson, 1959; Wilson, 1975). Non-selective species taking wide range of food can be handicapped when particles are difficult to ingest, with low nutrient value, or are even toxic (Sommer, 1986).

However, if no predation occurs in the community, changes in environmental conditions can lead to competition and thus control seasonal succession (DeMott, 1989).

Seasonal changes in species composition of zooplankton are also controlled by temperature and other environmental parameters (O_2, pH). Hebert (1978) studied the influence of physical conditions on the decrease of grazing pressure and metabolic processes. Studies of zooplankton growth illustrated the expected interaction between food levels and temperature. If the food is abundant, the growth increases with increasing temperatures. However, food levels that support growth at low temperatures may be inadequate at higher temperatures (e.g. Neill, 1981a; Orcutt and Porter, 1984). The *Daphnia* population in shallow lakes and fish ponds frequently displays a considerable ‘clonal’ diversity and high stability of parthenogenetic offspring succession (Hebert and Crease, 1980). In large and deep lakes, it shows a low ‘clonal’ diversity and a relatively high stability of clone production frequency (Mort and Wolf, 1985). The variance of parthenogenetic offspring succession (clones) in fish ponds and large lakes is likely to stem from different environment stabilities in these ecosystems (Sommer, 1989; Søndergaard et al., 2005).

The last of the mechanisms influencing seasonal changes of zooplankton communities is the quantity and attainability of phytoplankton as the major food resource. Apart from the interference between large *Daphnia* species and certain rotifers, interactions between zooplankton are regarded as indirect interactions mediated through resource exploitation (Levitan, 1987). Competition for food generally occurs in a zooplankton community when the large filtering zooplankton reduces the quantity and quality of phytoplankton community (DeMott, 1986). Studies of phytoplankton refer to nutrient limitation and physical factors as the main causes of seasonal changes in productivity and species composition (Sommer, 1986; Reynolds, 1986, 2000; Padisák, 2005). In recent years, a study on phytoplankton ‘categorization’ as a food resource for zooplankton described phytoplankton as a ‘pulsing ephemeral resource’ for zooplankton (Tallberg et al., 1999; Reynolds, 2007). From this point of view, food limitation may be the consequence of seasonal changes in resources which are largely independent of exploitation by large grazers. Seasonal changes in zooplankton communities can thus reflect seasonal changes in phytoplankton communities with a low level of competition (Sommer, 1989).

Since the early days of limnological research, the seasonal changes in the quantity and quality of plankton species composition have been called ‘seasonal successions’. The usage of the term ‘succession’ has been quite loose and the analogies to the century-long, non-cyclic process of terrestrial succession have rarely been explored (Reynolds, 1980). Species shifts in direct response to external forcing factors do not qualify as succession. Reynolds (1980) used the terms ‘reversion’ and ‘shift’ for seasonal species changes in plankton induced by external perturbation. ‘Reversions’ are characterised as short-term episodic events that are often rather unpredictable. 'Shifts' are seasonally recurrent patterns brought about by change of external factors.

Ecologists have been trying to understand the population dynamics of nature for a long time. In the last decade, theoretical and experimental ecologists succeeded in creating mathematical models that can describe and predict behaviour and development of populations and communities (Kendall et al., 1999; Bolker et al., 2003; Polis et al., 2004). Despite the considerable effort devoted to these questions, we are still not able to fully understand mechanisms driving population dynamics of communities (Yoshida, 2005).

2.2. Trophic Cascades

A strong reduction of fish stock usually leads to a significant increase in large Cladocera population that reduces phytoplankton biomass to a low level (Hrbáček et al., 1961; Shapiro and Wright, 1984; Van Donk et al. 1990; Meijer et al., 1994a). Also, an increase in piscivorous fish can reduce the planktivorous fish stock leading to an increase in large *Daphnia* and a decrease in algal biomass (Benndorf et al., 1988; Hambright, 1994; Mittelbach et al., 1995; Søndergaard et al., 1997). This effect of fish stock on zooplankton and consequently of zooplankton on phytoplankton has been termed a 'cascading trophic interactions', as the impact cascades down the trophic levels in the food chain (Carpenter et al., 1985). Since phytoplankton blooms are one of the main problems arising with eutrophication, using this trophic cascade seems an obvious way to enhance the effect of eutrophication control. The idea is appealingly simple: reducing the planktivorous fish induces the increase of large *Daphnia* species which reduce the phytoplankton biomass (Fott et al., 1980; Hrbáček et al., 1986; Schoenberg et al., 1984; Theiss et al., 1990; Reynolds, 1994; Declerck et al., 1997; Sheffer, 1998; Seďa et al., 2000).

Over the past decades, discussion arose whether it is the bottom-up regulation (nutrient limitation) or the top-down regulation (control by predators) that primarily determines the dynamics of plankton communities. The most discussed work on top-down regulation has been worked out by Hairston, Smith and Slobodkin (HSS hypothesis) (Hairston et al., 1960). The principle is that in a world without consumers, plant biomass is abundant and the world looks fresh and green. The introduction of herbivores into this idealized world will lead to the reduction of plants, resulting in desertification. A subsequent introduction of carnivores would reduce the dominance of herbivores and the plants would bloom again. Even though a large number of ecologists accepted his view, HSS hypothesis proves a rather extreme approach. Some contemporary studies on food chains in aquatic ecosystems have not confirmed such strong predation effect (Jeppesen et al., 1997, 1998).

HSS hypothesis as well as the trophic cascade theory has evoked considerable debate among many ecologists indicating that the potential of top-down control is greatly overestimated. The abundance of most organisms is determined by the availability of food rather than by predation (bottom-up effect). Interestingly, the controversy about the importance of top-down regulation was fiercely discussed more than a century ago (Camerano, 1880). Camerano published his explanation of food chain which was revolutionary at the time. He explains in detail how the effect of disturbances on one trophic level will cascade through the food chain. The same idea provoked so much debate almost a century later. Hairston et al. (1960) pointed out that equilibrium can be established by reducing or damping oscillations (random changes). Camerano's work has been recently re-discovered (Cohen, 1994). Apparently, his system at "*ecology avant la* *lettre"* has not been appealing enough to the scientists of his days to create a school that kept the ideas alive. Much more influential were the simple mathematical models of species interactions presented about half a century later by Alfred Lotka (1925) and by Vito Volterra (1926). These and the later more realistic minimal models have catalyzed the understanding of the dynamics resulting from trophic interactions (Rosenzweig, 1971; Noy-Meir, 1975; Caughley and Lawton, 1981; Scheffer et al., 1995b).

A number of researchers throughout the world have been searching for the answer to the question of which factor or combination of factors is crucial for species composition and the nature of plankton communities. Most studies have attributed the diversity of these communities only to the age and fish biomass (e.g. Hrbáček, 1962; Brooks and Dodson, 1965; Mills et al., 1987; Luecke et al., 1990; Jeppesen et al.,1990b; Driver et al., 2005), effect of macrophytes (Irvin et al., 1989, 1990; Moss, 1990; Cazzanelli et al., 2008), or certain biotic factors (Patalas, 1971; Dodson, 1991). Although several easily applicable theories such as the 'top-down' and 'bottom-up' effects have been developed, it is obvious that these theories alone are not able to explain the complex variability of plankton communities. Owing to this fact, extensive studies combining a number of spatial, biotic, and abiotic parameters have emerged in the recent years to complete and interconnect these individual theories (e.g Pinel-Alloul et al., 1995; Cottenie et al., 2001). As a result, models were introduced that are able to foresee the structure of plankton communities based on a profound knowledge of individual conditions of the environment, and *vice versa*.

2.3. The Special Position of *Daphnia* in Zooplankton

Zooplankton is the most important group with respect to top-down control of algae. It is a heterogeneous group of aquatic organisms. In numbers, the most abundant zooplankton groups are rotifers and copepods. They serve as food for fish larvae and carnivorous zooplankton like cyclopoid copepods or carnivorous cladocerans (*Leptodora*, *Polyphemus*), and feed on small algae and bacteria. Due to their restriction to small food particles, these animals cause a shift to larger phytoplankters rather than reducing total algal biomass. Although some studies report a reduction of phytoplankton biomass by small zooplankton (e.g. Jeppesen et al., 1990b), but only large cladocerans can usually cause a significant decline of phytoplankton biomass (Hrbáček et al., 1961; Brooks and Dodson, 1965; Pace, 1984; Dawidowicz, 1990; Berg, 1997, etc.). Species of the genus *Daphnia* (especially the large *Daphnia pulicaria*, *Daphnia magna*, and *Daphnia longispina* species) are well known for their high potential grazing pressure. Their size allows them to feed on a wide spectrum of algal species, excluding only algae and cyanophytes that form large colonies (Scheffer, 1998).

The potential of *Daphnia* to graze down algal biomass to very low levels can be recorded during the spring clear-water phase that occurs in many types of freshwater (Fott et al., 1980; Lampert et al., 1986; Luecke et al., 1990; Carpenter et al., 1993; Rudstam et al., 1993; Jurgens and Stolpe, 1995, etc.).

On the other hand, *Daphnia* are extremely efficient in reducing the food for other species of zooplankton (Brooks and Dodson, 1965). The densities of small zooplankton species frequently drop when the *Daphnia* population is high. *Daphnia* are successful competitors in the zooplanktonic community (Kerfoot et al., 1985a; Bengtsson, 1987; DeMott, 1989). Nevertheless, these organisms are relatively rare in most shallow lakes and fish ponds. Various factors may be involved in suppressing *Daphnia* populations. Several studies, indicate that suspended clay particles are detrimental for *Daphnia* feeding (Arruda et al., 1983; Kirk and Gilbert, 1990; Kirk, 1991), that the animals do not grow and reproduce well when they graze on phosphorus-limited algae (Hessen, 1990; Sommer, 1992; Sterner, 1993), and that *Daphnia* hardly occurs in brackish water (Bales et al., 1993; Jeppesen et al., 1994). A structure of consumed phytoplankton may also add to this phenomenon (Gliwicz, 1990). Large cyanobacterial colonies and algae are usually not easily edible and *Daphnia* growth can be severely reduced in their presence (Arnold, 1971; Schindler, 1971; Gliwicz, 1990; Gliwicz and Lampert, 1990). Toxic substances released by cyanobacteria have proved to be significant factors reducing the filtering rates of daphniids by 50 % or more (Haney et al., 1994).

However, the most important reason for the absence of large *Daphnia* in reservoirs is undoubtedly the fact that they are very profitable food for planktivorous fish. Many studies illustrate the strong effect of *Daphnia* on algal biomass when they are released from fish predation. Examples include alluvial areas (pools) or shallow freezing lakes and ponds. Long ice-cover leads to massive fish-kills due to lack of oxygen. Such natural winter kills are followed by the occurrence of dense *Daphnia* biomass that subsequently reduces phytoplankton biomass (Schindler and Comita, 1972; Haertel and Jongsma, 1982; Sarnelle, 1993). The same was observed after artificial reduction of fish stock by means of fishing or rotenone treatments (Hrbáček et al., 1961; Shapiro and Wright, 1984; Van Donk et al., 1990; Meijer et al., 1994a).

The discussion about the effect of fish on plankton was triggered in the early 1960s by Hrbáček and his colleagues (1961 and 1962). He drew attention to the large differences between the species composition of plankton depending on the presence or absence of fish stock in the small alluvial pools. Where fish was present, zooplankton consisted of small species, and algal biomass was high. On the contrary, where fish was not present, zooplankton was dominated by large filtering cladocerans whose grazing pressure led to low phytoplankton biomass. Shortly after Hrbáček's findings, Brooks and Dodson (1965) observed similar relationships between fish and plankton in New England lakes, and developed the so-called 'size-efficiency hypothesis' to explain such shifts. The large bodied zooplankters are much more efficient at grazing down phytoplankton biomass than smaller zooplankters. Since fish forages selectively on larger zooplankton, it causes a shift in the zooplankton community towards small bodied animals that have little impact on total algal biomass.

Studies published later largely confirm statments of Hrbáček, Brooks and Dodson (Shapiro and Wright, 1984; Hambright, 1994; Seďa and Duncan, 1994). At present, however, the mechanism of zooplankton communities being affected by fish stock appears to be more complicated than originally thought (Sheffer, 1998). It is not only the direct grazing pressure by fish stock that causes the extinction of large *Daphnia* species. *Daphnia* change their behaviour and life strategy according to chemical cues released by fish (Dodson, 1988; Demeester et al., 1995; Stirling, 1995; Macháček, 1995). This leads to a decrease in the average size of individuals (Weider and Pijanowska, 1993; Engelmayer, 1995).

Currently, a lot of freshwaters suffer from nutrient overload. The hypertrophic conditions often lead to a massive development of cyanobacterial water blooms. Primary production expressive increase. The result is dramatical decrease in water transparency (Barica, 1981; Carney, 1990; Sheffer, 1998; Jeppesen et al., 1998). These conditions cause serious fluctuations of basic water environment parameters (dissolved oxygen concentration and pH) along with an increase of the ecosystem's instability (Barica, 1993; Pechar et al., 2002). Highly eutrophic systems are frequently associated with high biomass of fish stock. The fish stock efficiently eliminates large filtering zooplankton (large *Daphnia* species) which is replaced by smaller species with lower grazing pressure (Carpenter et al., 1985). However, a situations when high biomass of planktivorous fish stock are not able to reduce large *Daphnia* occur (Potužák et al., 2007a). Nevertheless, their role as active filter-feeders is restricted, since phytoplankton consists of 'inedible' cyanophyte forms.

Literature worldwide involves a number of studies describing relationships between large *Daphnia* species and cyanophytes (e.g. Lefever, 1950; Hrbáček, 1964; Gliwicz, 1969; Lampert, 1977; Lynch, 1980; Schoenberg et al., 1984; Hawkins and Lampert, 1989; De Bernardi and Giussani, 1990; Gliwicz and Lampert, 1990; Jeppesen et al., 1990b; Kohl and Lampert, 1991; Epp, 1996; Carpenter et al., 2001; Sarnelle, 2007; Ferao et al., 2008). These works, however, generally agree that filamentous or colonial cyanophyte species are not suitable food source for *Daphnia* species. The efficiency of their use is thus generally low. Therefore, the overall efficiency of energy and nutrient transfer through food chain decreases and the whole system becomes ineffective (Potužák et al., 2007b; Rondel et al., 2008). Taking these situations into account (a high biomass of large *Daphnia* and a high biomass of phytoplankton at the same time), a question may be posed: 'Is the top-down regulation of plankton still a valid concept under hypertrophic conditions?'

2.4. The Development of Czech Fish pond Hydrobiology from the End of the 19th Century until Today

Due to the absence of natural lakes (with the exception of several Šumava lakes and lakes that ensued from mining), Czech hydrobiology focused mainly on fish ponds and natural alluvial pools in its early days. In the late 1950s, the construction of water reservoirs intensified and the focus of hydrobiology shifted to these artificially created water bodies.

The first available information on plankton in Czech fish ponds dates back to the 1880s. It comprised studies published by the Archive for Research in Natural Sciences in Bohemia that include early data on the occurrence and, in some cases, on the bloom of certain species in fish pond biocenoses. The 'Prodromus of Bohemian Freshwater Algae´ (Hansgirg, 1889, 1890, 1892) reliably describes the occurrence of numerous cyanophytes and algae that are currently present in fish ponds. Another study from the turn of the 19^{th} century referring to phytoplankton species composition is the study by Dechant from 1914. Dechant studied species composition of phytoplankton in the region of České Budějovice. The first studies on zooplankton species composition in Czech fish ponds also originated in the Archive for Research in Natural Sciences in Bohemia. The most notable are the works by Hellich (1878), Kafka (1891), Frič and Vávra (1895). These are the first studies on species diversity of zooplankton in relation to fish pond management. Langhans (1911) gave account of littoral Cladocera research in Máchovo lake in the years 1900-1909 that had been unprecedented in its scope in our country. The list of found species includes 58 species after removing the synonyms, i.e. approximately two thirds of the Cladocera known in the Czech Republic in a single fish pond (Přikryl, 1996).

In the 1930s, mineral fertilisers, particularly superphosphate, were applied intensively. At the same time, the first studies on the chemical status of fish pond waters were published (Jírovec, 1937; Jírovec and Jírovcová, 1938). Studies by Nováček (1935, 1941) and Fott B. (1938) gave a good description of phytoplankton composition as well as the overall picture of plankton communities in the 1930s. The first works on quantitative research of pelagial zooplankton date back to this period, too. Soudek (1929) devoted himself to a quantitative research of pelagial zooplankton in four large Lednice fish ponds (Nesyt, Hlohovecký, Prostřední, and Mlýnský) in 1925 and 1927. Bayer and Bajkov (1929) presented results in Lednice fish ponds (besides the four above mentioned, they included a small fish pond Allach IV) in the years 1902 – 1928. Unlike Soudek (1929), they carried out their quantitative research based on the sediment volume of zooplankton. Losos and Heteša (1971) reported of further systematic research in Lednice lakes in 1956-1962. Faina and Přikryl (1996) followed them two decades later (1994 – 1995). Sládeček (1951b) carried out observations in Horní and Dolní Padrťský fish ponds together with several smaller fish ponds nearby. He described large multiplicity of rotifers, including eight species which were new for the Czech fauna.

Hydrobiologists and fishermen have long tried to explain why different types of water bodies have specific zooplankton composition. Initially, attempts were made to establish a typology of water bodies. In the fisheries literature are fish ponds frequently classified according to the typology suggested by Schäfferna (1922) (e.g. Janeček, 1976; Starmach et al., 1976). Schäfferna tried to classify lakes based on the presence of certain species of zooplankton related to their natural production. The classification of zooplankton as a community with constant structure was created in the 1960s by Novotná-Dvořáková (1960) and Šrámek-Hušek (1962).

Hrbáček (1962) published a study describing the influence of fish stock on the quantity and species composition of plankton. He was thus the first one to define the so-called top-down regulation of plankton which was later confirmed by many authors (Brooks and Dodson, 1965; Fott et al., 1980; Shapiro and Wright, 1984; Carpenter et al., 1985; Pražáková, 1991; Reynolds, 1994; Jeppesen et al., 1997, etc.).

A great part of works on fish pond plankton in the 1950s – 1970s is related to the fish ponds in the Blatná-Lnáře fish pond region. This period was characterised by the most significant increase in fish production. The results conform with this phenomenon, showing that the efficiency of production processes in the 1960s was very high (Kořínek, 1967). Also the seasonal dynamics of plankton showed a certain recurrence closely related to the manner of fishery management (Fott et al., 1974). An example is the Velký Pálenec fish pond, where the two-year cycle of fishery management was consistently applied in the 1970s (Fott, et al. 1980; Pražáková, 1991). Kořínek et al. (1987) summarized impact of fishery management on plankton and its productivity in Blaná-Lnáře fish ponds. He concluded, that fish pond ecosystem is driven by fish stock. Such generelisation seems to be valid from mesotrophic to slight eutrophic conditions. A recent notable study on fish pond hydrobiology draws on an observation of fish pond regions as part of the IUCN project (European Programme Nr.79887e, IUCN, 1996) carried out during the years 1990 – 1991 in the Třeboň basin fish ponds. The project was aimed at collection of a comprehensive set of data on hydrochemistry and hydrobiology (primarily on plankton) in intensively exploited fish ponds. Following this project, a similar observation was carried out in the years 2000 – 2001 by the researches of the Applied Ecology Laboratory (Faculty of Agriculture at the University of South Bohemia), of the Institute of Botany at the Academy of Sciences of the Czech Republic, and of ENKI, p.b.c., in the fish pond regions of Třeboň and Nové Hrady. In 2004 – 2005, a comparative study of the Blatná and Lnářská fish pond regions was carried out on the grounds of ENKI, p.b.c., and the Applied Ecology Laboratory.

Less attention has been paid to studies on fish pond plankton and fish pond hydrobiology in the last two decades. During this period, fish ponds have undergone changes that have made these ecosystems once again interesting. It is not only the understanding of individual mechanisms interacting in these ecosystems that is required; it is the understanding of fish pond ecosystems in their complexity. Fish ponds are integral parts of our landscape and therefore the understanding of their functions is the way to provide the overall picture of our landscape.

Photo 1. Rod fish pond - Naděje fish pond system (Třeboň region)

Photo 2. Žár fish pond – Nové Hrady fish pond system (Třeboňsko region)

Photo 3. Hadí fish pond – Blatná-Lnáře fish pond region

Photo 4. Velký Pálenec fish pond Blatná-Lnáře fish pond region

3. MATERIAL AND METHODS

The material and data used in this Ph.D. thesis were obtained during a long-term hydrobiological and ecological research, carried out in the fish ponds of Třeboň and Blatná-Lnáře regions (Fig. 1). Comprehensive set of data on hydrochemistry and hydrobiology (primarily on plankton) were collected in the years 1990 – 1991, 2000 – 2001, and 2004 – 2005, in the framework of various research projects. Třeboň fish ponds were observed within the International Union for Conservation of Nature project (European Programme Nr.79887e, IUCN, 1996) during the period 1990 – 1991. The second sampling program in the Třeboň region was realized in 2000 – 2001, and was supported by the research projects VS 96072 and MSM 122200003 of the Faculty of Agriculture (University of South Bohemia). Results of both sampling programs enabled to describe the changes in fish pond water chemistry and plankton structure which reflected changes in aquaculture and fishery management. During the years of 2004 – 2005, an analogous observation was carried out in the fish ponds of the Blatná-Lnáře region (as part of the research project MSM 6007665806).

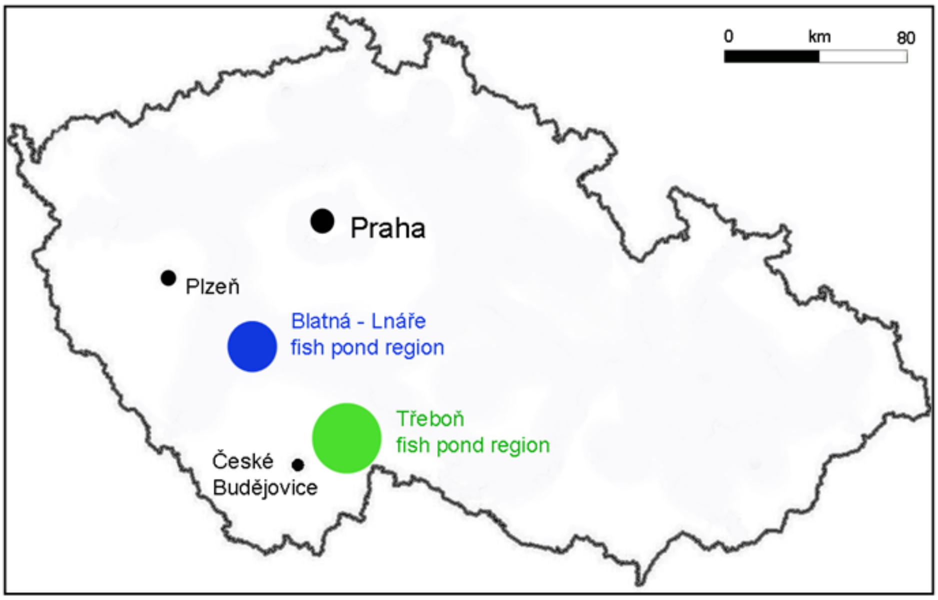

Figure 1. Třeboň and Blatná-Lnáře regions in the context of the Czech Republic

Data from the period 1990 – 1991 were adopted from papers by Pechar (2000) and Pechar et al. (2002) and from unpublished results (Pechar unpubl.). However, I personally participated in processing these data for publications (Potužák, 2004; Potužák et al., 2007a; Potužák et. al., 2007b). I have been a member of the research team and I have actively participated in sampling and processing certain parts of the samples (mostly on zooplankton) since 2001. As part of my doctoral program, I participated in the sampling in 2004 and 2005 and I evaluated zooplankton and data on the fishery management of the Blatná-Lnáře region fish ponds by myself.

Besides these sampling programs, I provided seasonal hydrobiological observation, determination and assessment of zooplankton samples from experimental fish ponds of the Rybářství Třeboň Hld., company in 2004 – 2006. Determination of the effect of supplementary feeding by various grains on carp growth and quality of fish meat, was the aim of those experiments (see Vácha et al., 2007).

3.1. The organization of the two-year sampling programs (1990 – 1991, 2000 – 2001, 2004 – 2005)

3.1.1. Třeboň region, 1990 – 1991 and 2000 – 2001

In the seasons 1990 and 1991, 35 fish ponds within 6 fish pond systems were sampled (Tab. 1, Fig. 2, Pechar et al., 2002). In 2000 – 2001, the observation included two more fish pond systems and the total number of observed fish ponds amounted to 42 (Tab. 2, Fig. 3).
The sampling schedule was identical for both sampling programs. Samples of water and plankton were taken three times during the vegetation season in the periods April-May (spring), June (summer) and August-September (late summer).

In the years 1990 – 1991, the samples were taken and processed by researchers from the Institute of Botany Academy of Sciences of the Czech Republic in Třeboň. In 2000 – 2001, the sampling and subsequent processing was carried out by the Institute of Botany Academy of Sciences of the Czech Republic in Třeboň, by ENKI, p.b.c., Třeboň, and Applied Ecology Laboratory of the Faculty of Agriculture at the University of South Bohemia in České Budějovice (hereinafter as LAE).

3.1.2. Blatná-Lnáře 2004 – 2005

Sampling in the fish ponds of the Blatná-Lnáře fish pond region was organized according to a similar scenario as sampling in the Třeboň region. 41 fish ponds within 7 fish pond systems were sampled (Tab. 3, Fig. 4). The first sampling date was set for spring period (April – May), the second for the beginning of summer (June), and the third for late summer (the first half of September).

Sampling and processing were provided by researches of ENKI, p.b.c., LAE, and Institute of Systems Biology and Ecology Academy of Sciences of the Czech Republic in Třeboň.

3.1.3. Sampling and *in situ* measuring

Each sampling involved measurements of water temperature at the surface and a simultaneous measurement of water transparency by Secchi disk.

Sampling itself was carried out at the outlet of the fish pond dam. With the help of a sampling tubular probe (1,4 litre), a mixed sample was produced of a minimum capacity of 2 litres collected from the surface level to approximately 1 m depth.

3.1.4. Laboratory processing

Chemical parameters were measured in the laboratory, but only some of them were used in this Ph.D. thesis. Here is the list of parameters used in the study:

NH_4-N - ammonia nitrogen

NO_3-N – nitrate nitrogen

SN - total dissolved nitogen, the difference of SN – (NH_4-N + NO_3-N) = SON, i.e. the dissolved organic nitrogen

TN - total nitrogen

DRP - dissolved reactive phosphorus, the degree of phosphate concentrations

SP - total dissolved phosphorus, the difference of SP – DRP = SOP, i.e. the dissolved organic phosphorus in fraction filtered through GF/C glass filter

TP - total phosphorus, the difference of TP – SP = PP, i.e. the particulate phosphorus (organic) in seston, up to the particle size of 100 μm

TOC - total organic carbon, determined in fraction filtered through GF/C glass filter, plus as particulate (organic) in seston, up to the particle size of 100 μm.

For determining the phosphorus, nitrogen concentrations, standard spectrophotometric methods were used, modified for the FIA-Star (Tecator) automatic analyser.

The levels of organic compounds were established by determining the total organic carbon (TOC) and its individual components in 2004 – 2005. The analysis of total organic carbon and its forms was carried out by the Formac - Skalar ™ analyser.

3.1.5. Plankton sampling

A part of the mixed sample (collected by sampling probe) was used for phytoplankton analysis. In situations where the sample was not processed immediately after sampling, it was transferred to a 100 ml glass sample bottle and fixed with Lugol's solution.

Zooplankton samples were collected with a plankton net with 80 μm mesh size thrown from the dam of the ponds (the entire water column was trawled without stirring up the bottom sediments). The traction of planctonic net was three times repeated. The average length of traction was about 5 meter. The obtained sample was subsequently transferred to a 100 ml PE sample bottle and fixed with formaldehyde (36 – 38 %) to a final concentration of 4 %.

3.1.6. Plankton processing and analysis

The amount of cyanophytes and algae was evaluated microscopically by the relative distribution of size-biomass for the major taxonomic groups (Utermöhl, 1958). Chlorophyll-a concentration was estimated spectrophotometrically (Pechar, 1987).

The analysis of zooplankton focused on determining the frequency (%) of the major taxonomic groups and at the same time on specifying size distribution. During the periods

2000 – 2001 and 2004 – 2005, I simultaneously carried out a detailed determination of the zooplankton species.

Before the zooplankton samples were processed, formaldehyde had been extracted from the samples by rinsing them in water on a sieve. Subsequently, I carried out a detailed determination of individual zooplankton species. The analysis itself involved counting in the Sedgewick-Rafter chamber (Wetzel and Likens, 2000). On average, the samples included minimally 300 – 400 individuals of important species that were classified into the major taxonomic groups (*Daphnia magna*, *D. pulicaria*, *D. longispina*, *D. galeata*, *D. cucullata*, *D. parvula*, *D. ambigua*, *Ceriodaphnia, Bosmina*, Chydoridae, other Cladocera, adult Cyclopoida, adult Calanoida, copepodites, nauplii and rotifers). Subsequently, I evaluated the frequency (%) for each group. While counting the individuals, I measured them (using micro-measure in the microscope ocular) and divided into 7 size classes (< 0.3 mm; 0.3 – 0.7 mm; 0.7 – 1.0 mm; 1.0 – 1.5 mm; 1.5 – 2.0 mm; 2.0 – 3.0 mm; > 3.0 mm).

For a detailed determination of zooplankton, I generally utilised the following determination literature: Šrámek-Hušek (1953), Koste (1978), Bartoš (1959), Amoroso (1984), Einsle (1993, 1996), Přikryl and Bláha (2007), Kořínek (2001), Benzie (2005), Mirabdullayev and Defaye (2002), Nogrady and Segers (2002), Mirabdullayev and Defaye (2004).

For microscopic analysis, I used the Olympus BX-51 and Olympus IX-71 microscopes.

3.1.7. Statistical evaluation

Cluster analysis (Ward's method), as part of the Statistica ver. 7 program, was used for fish ponds division in the spring and late summer periods. Selection parameters were: chlorophyll-a concentration ($\mu g.l^{-1}$), fish stock ($kg.ha^{-1}$), TP ($mg.l^{-1}$), TN ($mg.l^{-1}$), TN:TP, TOC ($mg.l^{-1}$), and water transparency (m).

The relations between the occurrence of individual zooplankton species and the level of eutrophication (characterised by chlorophyll-a concentration, fish stock, TP, TN, TN:TP, TOC, and water transparency) were evaluated by ordination methods with the Canoco ver. 4.5 program using direct gradient analysis CCA (Canonical Correspondence Analysis) (Ter Braak, Šmilauer, 1998).

To assess the influence of fish stock size on the abundance of the main zooplankton species, Means with error plots were used as part of the Statistika ver. 7 program. The data on fish stock was initially determined (to correspond with sample-taking periods) by a linear relation between the amount of fish stocking and fishing out. After that, fish stocks were statistically classified into individual size intervals (mostly comprised 8-15 values) which were subsequently assigned average values of frequency of the occurrence (together with the deviation from average) of the taxon analysed. At the same time, regression dependence was estimated for the analysed data together with the coefficient of determination R^2.

Data from the fish ponds of the Blatná-Lnáře region were used for statistical evaluation with respect to the greater diversity of sampled sites in this region. To obtain a larger set of data, the years 2004 and 2005 were evaluated together.

3.1.8. Fish production

Management data used in this study were provided by Třeboň Hld., and Blatná, a.s., fisheries. The management data from the Třeboň fish ponds in 2000 – 2001 were used for the calculation of total productivity, feeding productivity, and natural productivity. This data were utilised to estimate fish production efficiency under hypertrophic conditions. The following parameters were applied in the analysis:

F_S – the amount of stocked fish (kg.ha^{-1})

F_O – the amount of fished-out fish (kg.ha^{-1})

P_T – total fish productivity. The sum of NP + FP = P_T, expressed in kg.ha^{-1}

FP – feeding productivity. The ratio of the consumed feed weight and the absolute feeding coefficient (feed conversion). The absolute feeding coefficient was the weight of feed (kg) used to produce a 1 kg increase by supplementary feeding. With most grains (wheat, barleycorn, rye), the coefficient varies between 4 and 5, with maize between 4 and 6. With starter feed, the coefficient varies between 1.5 and 2.5 (Čítek et al., 1998).

NP – natural fish productivity. The difference of P_T – FP = NP (usually expressed in kg.kg^{-1}

RNP – relative natural productivity of fish. The ratio NP/F_S = RNP

RNP_C – relative natural productivity of carp

The data from the Blatná-Lnáře fish ponds sampled in 2004 – 2005 were utilised to assess the effect of fish stock size on the frequency (%) of the most abundant taxa.

Photo 5. Organization of the autumn catch on Velká Kuš fish pond (Blatná-Lnáře fish pond region, 2006)

Table 1. List of sampling sites in 1990-1991 (Třeboň region). Cadastral area and sampling dates are presented

<table>
<tr><th rowspan="3">Fish pond system</th><th rowspan="3">Sampling site</th><th rowspan="3">Cadastral area [ha]</th><th colspan="6">Sampling date</th></tr>
<tr><th colspan="2">Spring</th><th colspan="2">Summer</th><th colspan="2">Late summer</th></tr>
<tr><th>1990</th><th>1991</th><th>1990</th><th>1991</th><th>1990</th><th>1991</th></tr>
<tr><td rowspan="6">Třeboň</td><td>Stavidlo u Ovčína</td><td>4.83</td><td rowspan="6">Apr 17</td><td rowspan="6">Apr 29</td><td rowspan="6">Jun 19</td><td rowspan="6">Jun 25</td><td rowspan="6">Aug 10</td><td rowspan="6">Sep 2</td></tr>
<tr><td>Ruda</td><td>84.12</td></tr>
<tr><td>Cirkvičný</td><td>19.39</td></tr>
<tr><td>Opatovický</td><td>166.25</td></tr>
<tr><td>Svět</td><td>215.25</td></tr>
<tr><td>Spolský</td><td>139</td></tr>
<tr><td rowspan="8">Chlum –Lutová</td><td>Staré Jezero</td><td>97.59</td><td rowspan="13">Apr 18</td><td rowspan="13">Apr 29</td><td rowspan="13">Jun 20</td><td rowspan="13">Jun 26</td><td rowspan="8">Aug 11</td><td rowspan="13">Sep 3</td></tr>
<tr><td>Starý Hospodář</td><td>68.79</td></tr>
<tr><td>Podsedek</td><td>94.75</td></tr>
<tr><td>Purkrabský</td><td>38.71</td></tr>
<tr><td>Staňkovský[1]</td><td>241</td></tr>
<tr><td>Točník</td><td>16.46</td></tr>
<tr><td>Velká Černá</td><td>63.15</td></tr>
<tr><td>Zájezek</td><td>5.12</td></tr>
<tr><td rowspan="5">Vitmanov</td><td>Starý Vdovec</td><td>40.71</td><td rowspan="5">Aug 12</td></tr>
<tr><td>Nový Vdovec</td><td>84.76</td></tr>
<tr><td>Ženich</td><td>84.62</td></tr>
<tr><td>Starý Spálený</td><td>6.15</td></tr>
<tr><td>Vyšehrad</td><td>32.86</td></tr>
<tr><td rowspan="4">Lomnice</td><td>Velký Tisý</td><td>319.39</td><td rowspan="4">Apr 19</td><td rowspan="4">Apr 30</td><td rowspan="4">Jun 21</td><td rowspan="4">Jun 27</td><td rowspan="4">Aug 13</td><td rowspan="4">Sep 4</td></tr>
<tr><td>Velký Dubovec</td><td>9.89</td></tr>
<tr><td>Malý Dubovec</td><td>7.25</td></tr>
<tr><td>Koclířov</td><td>203.64</td></tr>
<tr><td rowspan="6">Klec –Naděje</td><td>Rod</td><td>34.34</td><td rowspan="6">Apr 17</td><td rowspan="6">Apr 30</td><td rowspan="6">Jun 19</td><td rowspan="6">Jun 25</td><td rowspan="6">Aug 10</td><td rowspan="6">Sep 2</td></tr>
<tr><td>Víra</td><td>18.56</td></tr>
<tr><td>Láska</td><td>16.98</td></tr>
<tr><td>Naděje</td><td>71.81</td></tr>
<tr><td>Klec</td><td>70.44</td></tr>
<tr><td>Potěšil</td><td>75.95</td></tr>
<tr><td rowspan="5">Břilice</td><td>Verfle</td><td>22.02</td><td rowspan="5">Apr 19</td><td rowspan="5">Apr 30</td><td rowspan="5">Jun 21</td><td rowspan="5">Jun 27</td><td rowspan="5">Aug 13</td><td rowspan="5">Sep 4</td></tr>
<tr><td>Starý u Břilic</td><td>16.33</td></tr>
<tr><td>Břilický</td><td>30.11</td></tr>
<tr><td>Káňov</td><td>165.5</td></tr>
<tr><td>Stružky</td><td>5.89</td></tr>
</table>

[1] Fish pond are not used for fish breeding

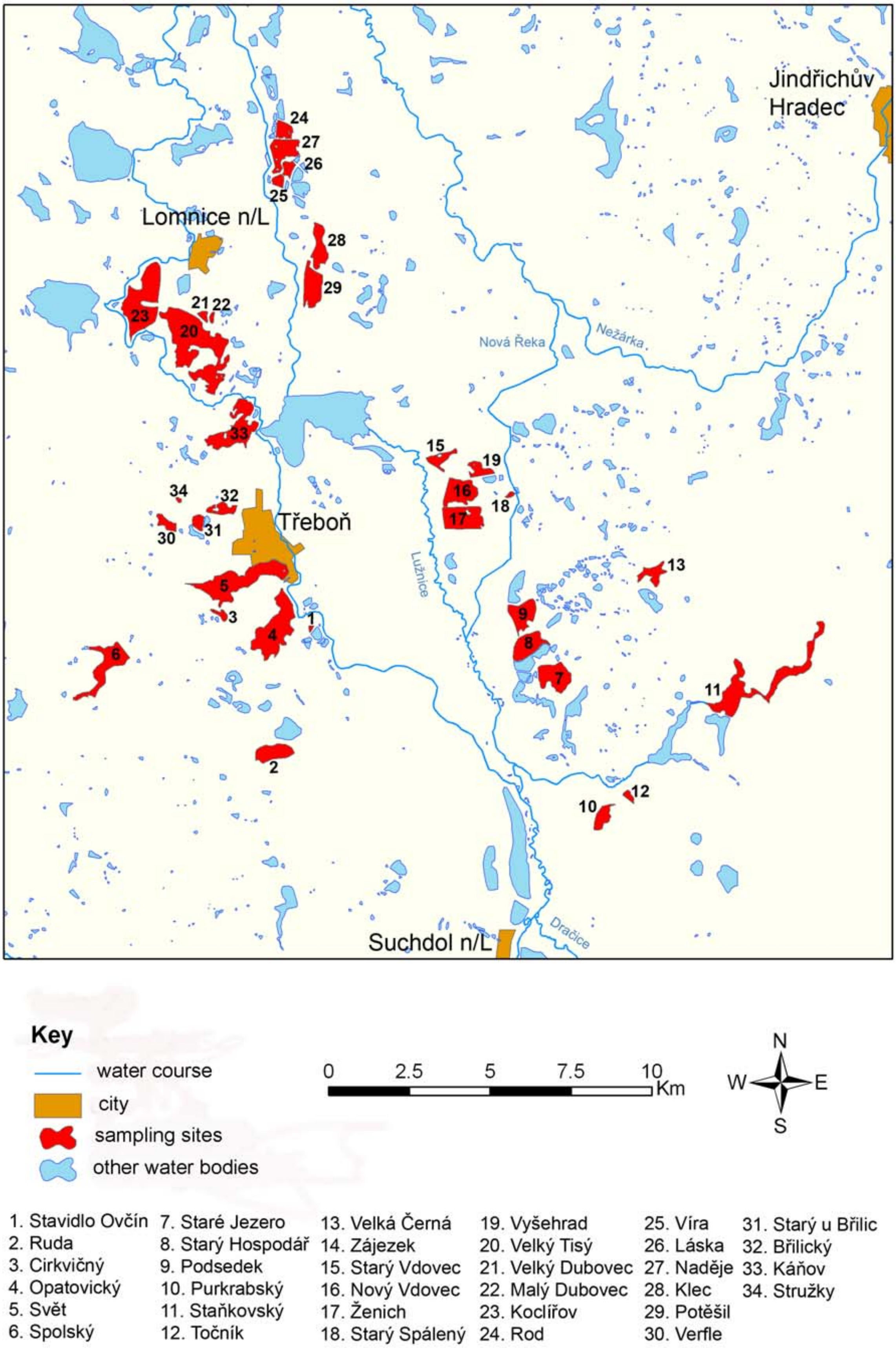

Figure 2. Map of sampling sites in 1990-1991 (Třeboň region)

Table 2. List of sampling sites in 2000-2001 (Třeboň region). Cadastral area and sampling dates are presented

<table>
<tr><th rowspan="3">Fish pond system</th><th rowspan="3">Sampling site</th><th rowspan="3">Cadastral area [ha]</th><th colspan="6">Sampling date</th></tr>
<tr><th colspan="2">Spring</th><th colspan="2">Summer</th><th colspan="2">Late summer</th></tr>
<tr><th>2000</th><th>2001</th><th>2000</th><th>2001</th><th>2000</th><th>2001</th></tr>
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<tr><td>Ruda</td><td>84.12</td></tr>
<tr><td>Cirkvičný</td><td>19.39</td></tr>
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<tr><td rowspan="8">**Chlum –Lutová**</td><td>Staré jezero</td><td>97.59</td><td rowspan="13">Apr 19</td><td rowspan="13">Apr 25</td><td rowspan="13">Jun 28</td><td rowspan="13">Jun 19</td><td rowspan="13">Aug 15</td></tr>
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<tr><td>Potěšil</td><td>75.95</td></tr>
<tr><td rowspan="5">**Břilice**</td><td>Verfle</td><td>22.02</td></tr>
<tr><td>Starý u Břilic</td><td>16.33</td></tr>
<tr><td>Břilický</td><td>30.11</td></tr>
<tr><td>Káňov</td><td>165.5</td></tr>
<tr><td>Stružky</td><td>5.89</td></tr>
<tr><td rowspan="3">**Hluboká u Borovan**</td><td>Žemlička</td><td>0.91</td><td rowspan="8">Apr 19</td><td rowspan="8">Apr 25</td><td rowspan="8">Jun 28</td><td rowspan="8">Jun 19</td><td rowspan="8">Aug 23</td><td rowspan="8">Aug 15</td></tr>
<tr><td>Horní Rohožný</td><td>3.20</td></tr>
<tr><td>Dolní Rohožný</td><td>1.73</td></tr>
<tr><td rowspan="5">**Nové Hrady**</td><td>Žár</td><td>112.3</td></tr>
<tr><td>Byňovský</td><td>70.4</td></tr>
<tr><td>Karolínský Horní</td><td>9.51</td></tr>
<tr><td>Velebil</td><td>9.4</td></tr>
<tr><td>Kačák</td><td>21.4</td></tr>
</table>

[1] Fish pond are not used for fish breeding

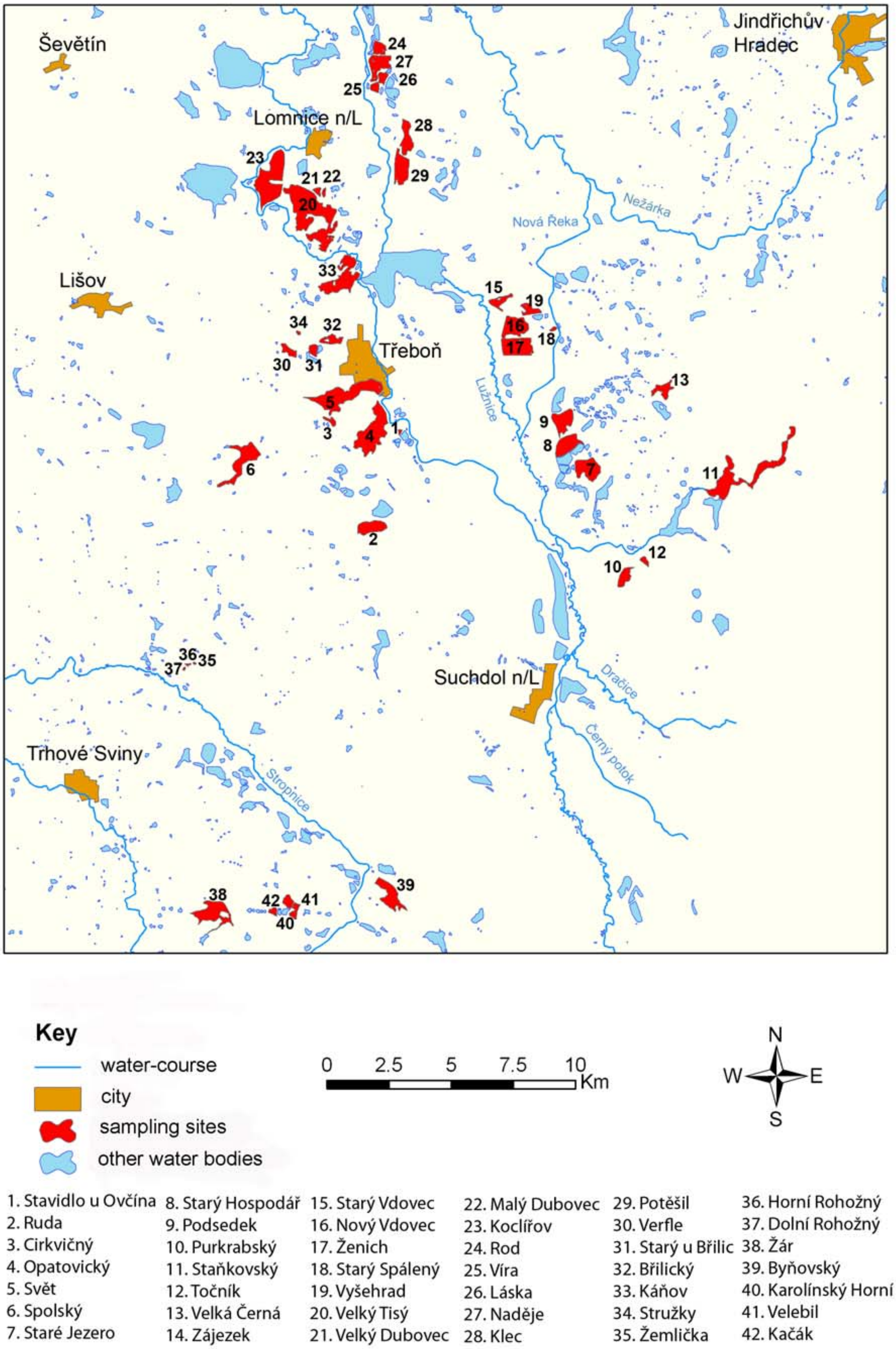


Figure 3. Map of sampling sites in 2000-2001 (Třeboň region)

Table 3. List of sampling sites in 2004-2005 (Blatná-Lnáře region). Numbers of sites used in Cluster analysis (spring/late summer), cadastral area and sampling dates are presented

<table>
<tr><th rowspan="3">River-basin</th><th rowspan="3">Sampling site</th><th colspan="2" rowspan="2">Site Nr.</th><th rowspan="3">Cad. area [ha]</th><th colspan="6">Sampling date</th></tr>
<tr><th colspan="2">Spring</th><th colspan="2">Summer</th><th colspan="2">Late summer</th></tr>
<tr><th>2004</th><th>2005</th><th>2004</th><th>2005</th><th>2004</th><th>2005</th><th>2004</th><th>2005</th></tr>
<tr><td rowspan="3">**Blatenka**</td><td>Velký Ostrý</td><td>-</td><td>61/65</td><td>6.90</td><td rowspan="3">Apr 28</td><td rowspan="3">May 4</td><td rowspan="3">Jun 30</td><td rowspan="3">Jun 28</td><td rowspan="3">Sep 15</td><td rowspan="3">Sep 7</td></tr>
<tr><td>Starý u Lažánek</td><td>30/30</td><td>60/64</td><td>2.54</td></tr>
<tr><td>Bídník</td><td>-</td><td>62/66</td><td>2.42</td></tr>
<tr><td rowspan="3">**Hajanský stream**</td><td>Měleč</td><td>1/1</td><td>30/31</td><td>11.93</td><td rowspan="8">Apr 27</td><td rowspan="8">May 2</td><td rowspan="8">Jun 28</td><td rowspan="8">Jun 27</td><td rowspan="8">Sep 13</td><td rowspan="8">Sep 6</td></tr>
<tr><td>Velký Kocelovický</td><td>7/7</td><td>35/37</td><td>35.18</td></tr>
<tr><td>Hubenov</td><td>6/6</td><td>34/36</td><td>26.41</td></tr>
<tr><td rowspan="5">**Hradišťský stream**</td><td>Hořejší Tchořovický</td><td>-</td><td>41/43</td><td>23.01</td></tr>
<tr><td>Nový (u Tchořovic)</td><td>12/12</td><td>40/42</td><td>34.40</td></tr>
<tr><td>Nový Záhorčičský</td><td>11/11</td><td>39/41</td><td>4.46</td></tr>
<tr><td>Strašil</td><td>10/10</td><td>38/40</td><td>21.12</td></tr>
<tr><td>Pátek</td><td>9/9</td><td>37/39</td><td>2.25</td></tr>
<tr><td rowspan="13">**Mračovský stream**</td><td>Lhotka</td><td>-</td><td></td><td>4.54</td><td rowspan="22">Apr 28</td><td rowspan="2">May 4</td><td>Jun 30</td><td rowspan="22">Jun 28</td><td>Sep 15</td><td rowspan="22">Sep 7</td></tr>
<tr><td>Mostenský</td><td>29/29</td><td>63/63</td><td>0.86</td><td rowspan="14">Jun 29</td><td rowspan="14">Sep 14</td></tr>
<tr><td>Starý Pálenec</td><td>22/22</td><td>55/55</td><td>2.95</td><td rowspan="13">May 3</td></tr>
<tr><td>Žoldánka[1]</td><td>-</td><td>-</td><td>1.07</td></tr>
<tr><td>Velký Pálenec</td><td>21/21</td><td>54/54</td><td>36.56</td></tr>
<tr><td>Nadýmač</td><td>18/18</td><td>49/49</td><td>4.50</td></tr>
<tr><td>Hadí</td><td>23/23</td><td>56/56</td><td>12.56</td></tr>
<tr><td>Velká Kuš</td><td>17/17</td><td>48/48</td><td>52.39</td></tr>
<tr><td>Malý Horský</td><td>-</td><td>53/53</td><td>0.39</td></tr>
<tr><td>Velký Horský</td><td>-</td><td>52/52</td><td>1.27</td></tr>
<tr><td>Velká Lípa</td><td>19/19</td><td>50/50</td><td>2.21</td></tr>
<tr><td>Malá Lípa</td><td>20/20</td><td>51/51</td><td>1.68</td></tr>
<tr><td>Podkadovský</td><td>16/16</td><td>47/47</td><td>2.36</td></tr>
<tr><td rowspan="10">**Pálenecký stream**</td><td>Vitanovy</td><td>24/24</td><td>57/57</td><td>15.97</td></tr>
<tr><td>Radov</td><td>25/25</td><td>58/58</td><td>48.27</td></tr>
<tr><td>Smyslov</td><td>28/28</td><td>61/61</td><td>22.37</td><td rowspan="2">May 4</td><td rowspan="2">Jun 30</td><td rowspan="2">Sep 15</td></tr>
<tr><td>Kubov</td><td>-</td><td>62/62</td><td>4.94</td></tr>
<tr><td>Mlýnský</td><td>14/14</td><td>45/45</td><td>6.54</td><td rowspan="5">May 3</td><td rowspan="5">Jun 29</td><td rowspan="5">Sep 14</td></tr>
<tr><td>Vlasatka[1]</td><td>-</td><td>-</td><td>0.47</td></tr>
<tr><td>Hluboký</td><td>-</td><td>-</td><td>0.94</td></tr>
<tr><td>Krčový</td><td>13/13</td><td>44/44</td><td>1.83</td></tr>
<tr><td>Chmelnice</td><td>-</td><td>-</td><td>1.2</td></tr>
<tr><td>Velký Bezděkovský</td><td>8/8</td><td>38/38</td><td>22.19</td><td>Apr 27</td><td>May 2</td><td>Jun 28</td><td>Jun 27</td><td>Sep 13</td><td>Sep 6</td></tr>
<tr><td rowspan="3">**River-basin of Starý fish pond**</td><td>Starý u Tchořovic</td><td>26/26</td><td>59/59</td><td>29.60</td><td rowspan="3">Apr 28</td><td rowspan="2">May 4</td><td rowspan="2">Jun 30</td><td rowspan="3">Jun 28</td><td rowspan="2">Sep 15</td><td rowspan="3">Sep 7</td></tr>
<tr><td>Paseka</td><td>27/27</td><td>60/60</td><td>1.68</td></tr>
<tr><td>Loužnice</td><td>15/15</td><td>46/46</td><td>4.55</td><td>May 3</td><td>Jun 29</td><td>Sep 14</td></tr>
<tr><td rowspan="4">**Smolivecký stream**</td><td>Veský</td><td>5/5</td><td>35/35</td><td>19.02</td><td rowspan="5">Apr 27</td><td rowspan="5">May 2</td><td rowspan="5">Jun 28</td><td rowspan="5">Jun 27</td><td rowspan="5">Sep 13</td><td rowspan="5">Sep 6</td></tr>
<tr><td>Újezdský</td><td>4/4</td><td>34/34</td><td>24.31</td></tr>
<tr><td>Zámlyňský</td><td>3/3</td><td>33/33</td><td>7.27</td></tr>
<tr><td>Divák</td><td>2/2</td><td>32/32</td><td>24.34</td></tr>
<tr><td>**Metelský str.**</td><td>Metelský rybník</td><td>-</td><td>-</td><td>51.50</td></tr>
</table>

[1] Fish pond are not used for fish breeding

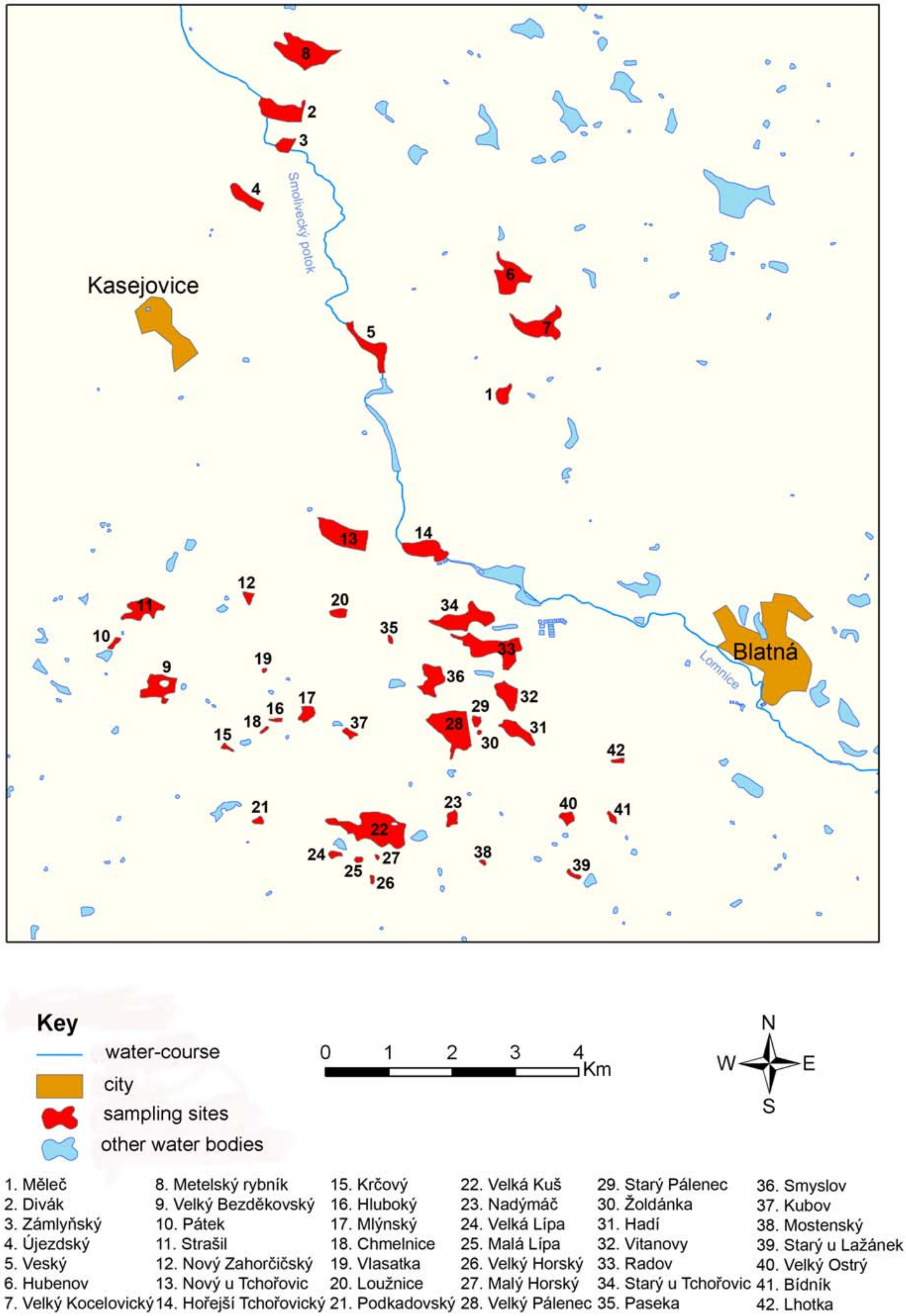


Figure 4. Map of sampling sites in 2004-2005 (Blatná-Lnáře region)

3.2. The organization of the three-year sampling programs (2004 – 2006)

Detailed information on seasonal development of hydrochemical parameters and plankton were obtained during feeding experiments carried out in the 2004 – 2006 seasons in 10 experimental fish ponds in the Lomnice nad Lužnicí region (four fish ponds of the Naděje fish pond system) and in the Chlum u Třeboně region (six fish ponds labelled as Humlena 1-6) (Tab. 4, Figs. 5, 6). Samples were collected tri-weekly from May to September. In the 2004 – 2005 seasons, 9 samples were collected at each site. In the 2006 season, hydrochemical data were obtained solely from the fish ponds in the Lomnice nad Lužnicí region (the total of 8 samplings per season). In the 2006 season, zooplankton was collected in all 10 experimental fish ponds (only 7 samplings were performed in the fish ponds of the Chlum u Třeboně region).

Sampling and processing in 2004 – 2006 was completed by researches of ENKI, p.b.c., LAE, and Institute of Systems Biology and Ecology Academy of Sciences of the Czech Republic in Třeboň.

3.2.1. Chemical samples

Each samplings involved measurements of water temperature at the surface, pH, dissolved oxygen concentration, conductivity, and water transparency by Secchi disk. A boat was used for sampling. Samples for chemical analyses were taken by tubular sampler (1,4 litre). With this sampler, several subsamples were taken at pre-set points of open water. Subsequently, subsamples were mixed into a single mixed representative sample of a 2 litre volume minimum.

3.2.2. Laboratory processing

Hydrochemical samples were processed and analysed in the same manner as in the two-year sampling program (Chapter 3.1.4). However, only limited analyses were carried out.

3.2.3. Plankton sampling

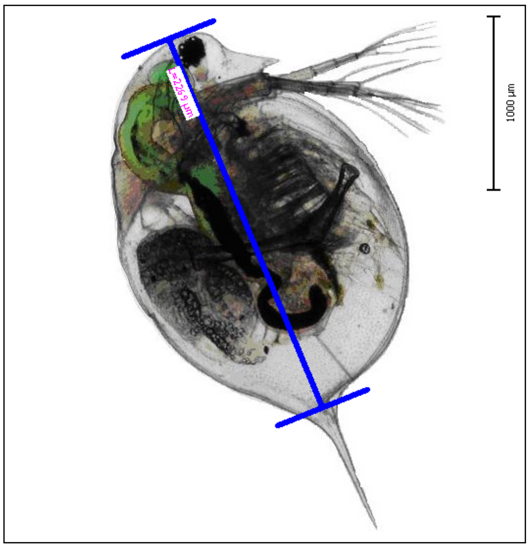
A part of the mixed sample (we used representative sample for chemical analysis) was used for phytoplankton analysis. The sample was transferred to a 100 ml glass sample bottle and fixed with Lugol solution. The key observation for the assessment of feeding experiments was the observation of zooplankton, its species composition and seasonal dynamics. Sampling methods were partly adopted from Dr. Mojmír Vašek (Biology Centre, Institute of Hydrobiology Academy of Sciences of the Czech Republic) who has been taking samples since 2004. Since 2005, I have collected zooplankton samples and analysed them on my own. To facilitate the comparison of data from 2004 and from the 2005 – 2006 seasons, I carried out a new analysis of the 2004 data.

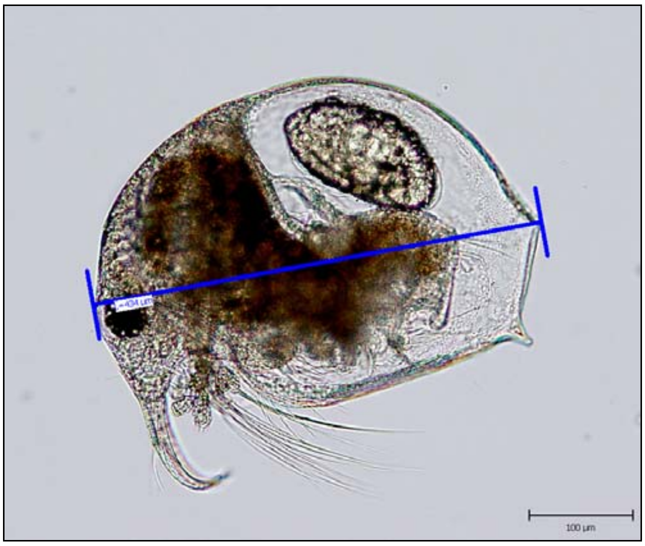
Zooplankton samples were collected tri-weekly, together with chemical samples. For ‘quantitative’ zooplankton sampling, I used the 10-litre Schindler’s quantitative sampler. The sampling and determination may have been considered only semiquantitative, as the sampling technique described may not record the quantitative amount of zooplankton in a reservoir, because of the high spatial heterogeneity of its occurrence. However, the sample determination is quantitative. At each site, ten sampling points on several stations and layers were carried out in open water. The total volume of the collected sample was about 100 litres of water. The samples were preserved in a 100 ml PE sample bottle and fixed with 36 – 38 % formaldehyde to a final concentration of 4 %.

3.2.4. Plankton processing and analysis

The amount of cyanophytes and algae was evaluated microscopically. Volume-biomass was determined for the major taxonomic groups (Utermöhl, 1958). Chlorophyll-a concentration was estimated spectrophotometrically (Pechar, 1987).

Before the zooplankton samples were processed, formaldehyde was extracted from the samples by rinsing them in water on a sieve. Subsequently, I carried out a detailed determination of individual zooplankton species. Then I transferred the zooplankton suspension quantitatively from the sample bottle to a round-bottom flask and added distilled water up to the desired volume (50 or 100 ml). I stirred the contents thoroughly, so that the sample was as homogeneous as possible. With a broad-ended pipette, I took in 2 ml of the sample and transferred it evenly to the Sedgewick-Rafter counting chamber. The samples included at least 300 – 400 individuals of important species. Less abundant organisms were counted throughout the chamber or several chambers. The numbers obtained were calculated per one volume unit. While counting, I measured the individuals of the major taxa (*Daphnia magna*, *D. pulicaria*, *D. longispina*, *D. galeata*, *D. cucullata*, *D. parvula*, *D. ambigua*, *Ceriodaphnia, Bosmina*, Chydoridae, *Diaphanosoma*, adult Cyclopoida, adult Calanoida, copepodites, nauplii and rotifers), and divided them into 8 size classes (< 0.3 mm; 0.3 – 0.7 mm; 0.7 – 1.0 mm; 1.0 – 1.5 mm; 1.5 – 2.0 mm; 2.0 – 2.5 mm; 2.5 – 3.0 mm; > 3.0 mm). Based on length-weight relations, I estimated the total biomass and the biomass of the major taxons. The determination of zooplankton biomass were determined on the basis of the length-weight relationship (Přikryl, 1981).





Photos 6, 7. Measurement of zooplankton body length

Table 4. List of sampling sites during feeding trials in 2004-2006 (Třeboň region). Cadastral area and sampling dates are presented. The same fish stock was used (363 $ind.ha^{-1}$ C_3 – three-year old carps)

Fish pond system	Sampl. Site	Cad. area [ha]	Year	Sampling dates								
				1.	2.	3.	4.	5.	6.	7.	8.	9.
Naděje fish pond system	Horák	2.21	2004	May 5	May 19	Jun 4	Jun 23	Jul 7	Jul 30	Aug 11	Aug 25	Sep 8
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	May 30	Jun 15	Jul 4	Aug 1	Aug 22	Sep 7	Sep 25	Oct 9	-
	Fišmistr	2.81	2004	May 5	May 19	Jun 4	Jun 23	Jul 7	Jul 30	Aug 11	Aug 25	Sep 8
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	May 30	Jun 15	Jul 4	Aug 1	Aug 22	Sep 7	Sep 25	Oct 9	-
	Baštýř	1.73	2004	May 5	May 19	Jun 4	Jun 23	Jul 7	Jul 30	Aug 11	Aug 25	Sep 8
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	May 30	Jun 15	Jul 4	Aug 1	Aug 22	Sep 7	Sep 25	Oct 9	-
	Pěšák	2.71	2004	May 5	May 19	Jun 4	Jun 23	Jul 7	Jul 30	Aug 11	Aug 25	Sep 8
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	May 30	Jun 15	Jul 4	Aug 1	Aug 22	Sep 7	Sep 25	Oct 9	-
Chlum – Lutová fish pond system	Humlena 1	0.65	2004	May 4	May 19	Jun 9	Jun 24	Jul 9	Jul 28	Aug 12	Aug 27	Sep 10
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	Jul 6	Jul 15	Jun 4	Aug 1	Aug 22	Sep 7	Sep 25	-	-
	Humlena 2	2.12	2004	May 4	May 19	Jun 9	Jun 24	Jul 9	Jul 28	Aug 12	Aug 27	Sep 10
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	Jul 6	Jul 15	Jun 4	Aug 1	Aug 22	Sep 7	Sep 25	-	-
	Humlena 3	2.41	2004	May 4	May 19	Jun 9	Jun 24	Jul 9	Jul 28	Aug 12	Aug 27	Sep 10
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	Jul 6	Jul 15	Jun 4	Aug 1	Aug 22	Sep 7	Sep 25	-	-
	Humlena 4	1.13	2004	May 4	May 19	Jun 9	Jun 24	Jul 9	Jul 28	Aug 12	Aug 27	Sep 10
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	Jul 6	Jul 15	Jun 4	Aug 1	Aug 22	Sep 7	Sep 25	-	-
	Humlena 5	1.83	2004	May 4	May 19	Jun 9	Jun 24	Jul 9	Jul 28	Aug 12	Aug 27	Sep 10
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	Jul 6	Jul 15	Jun 4	Aug 1	Aug 22	Sep 7	Sep 25	-	-
	Humlena 6	2.17	2004	May 4	May 19	Jun 9	Jun 24	Jul 9	Jul 28	Aug 12	Aug 27	Sep 10
			2005	May 2	May 17	Jun 7	Jun 21	Jul 12	Jul 26	Aug 9	Aug 23	Sep 13
			2006	Jul 6	Jul 15	Jun 4	Aug 1	Aug 22	Sep 7	Sep 25	-	-

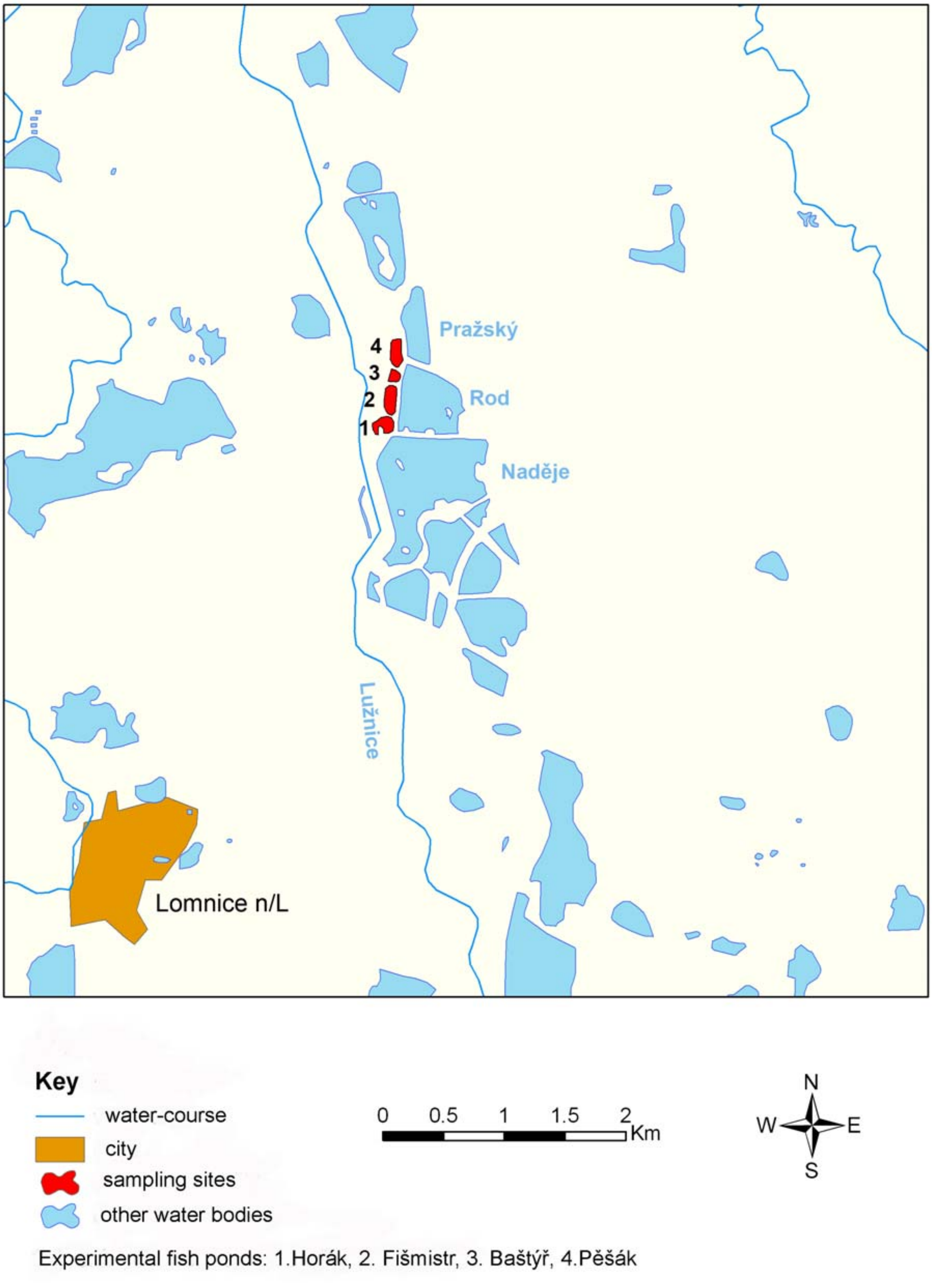


Figure 5. Map of sites sampled during feeding trials in 2004-2006 (Naděje fish pond system)

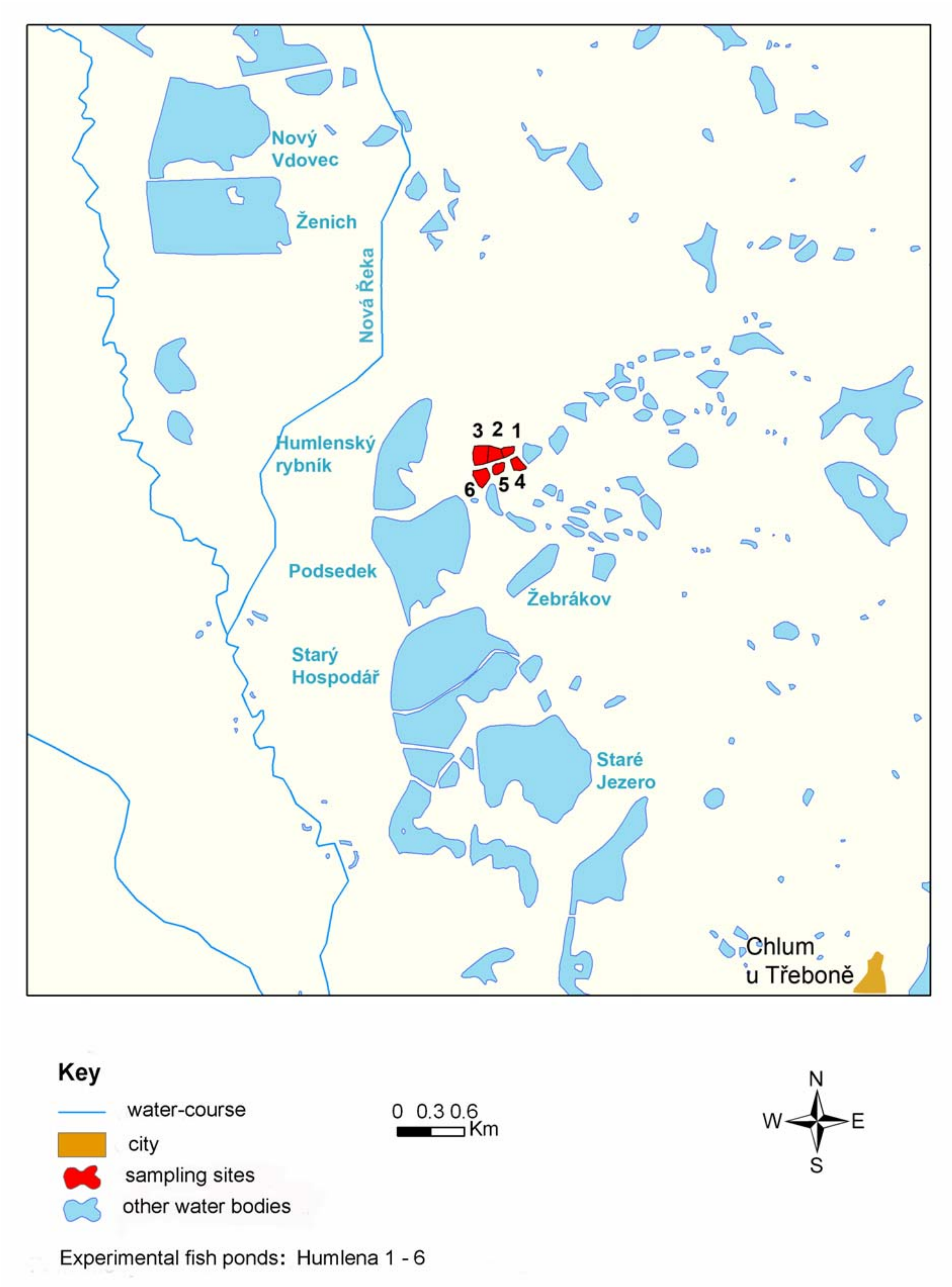


Figure 6. Map of sites sampled during feeding trials in 2004-2006 (Chlum-Lutová fish pond system)

Table 5 shows the numbers of hydrochemical and plankton samples obtained from the sample-taking cycles in the Třeboň and Blatná-Lnáře regions in the seasons 1990 – 1991, 2000 – 2001, 2004 – 2005, and during the feeding experiments of the 2004 – 2006 seasons.

Table 5. Number of sampling sites, sampling cycles and number of chemistry, phytoplankton and zooplankton samples in 1990 -2006

Year	Region	Nr. of sites	Nr. of sampling cycles	Number of samples		
				chemistry	phytoplankton	zooplankton
1990 - 1991	Třeboň	30	6	180	180	180
2000 - 2001	Třeboň	43	6	258	258	258
2004 - 2005	Blatná-Lnáře	41	6	246	246	246
2004 - 2006	Třeboň	10	27	180	180	254

Photo 8. Horák fish pond – Naděje fish pond system (Třeboň fish pond region)

Photo 9. Pěšák fish pond – Naděje fish pond system (Třeboň fish pond region)

Photo 10. Humlena 4 – Chlum-Lutová fish pond system (Třeboň fish pond region)

Photo 11. Humlena 5 – Chlum-Lutová fish pond system (Třeboň fish pond region)

3.3. List of abbreviations and terms

AVG	average zooplankton body length	mm
AVGd	average *Daphnia* body length	mm
AVG DI	average Daphnia index	-
C_1,C_2,C_3	one-year, two-year, three-year-old carps	-
C_M	marketable carp	-
Chl-a	chlorophylly-a concentration	$\mu g.l^{-1}$
DI	Daphnia index	-
DRP	dissolved reactive phosphorus, the degree of phosphate concentrations	$mg.l^{-1}$
F_S	the amount of stocked fish	$kg.ha^{-1}$
FP	feeding productivity. The ratio of the consumed feed weight and the absolute feeding coefficient (feed conversion).	$kg.ha^{-1}$
FP:NP	ratio of feeding productivity and natural productivity	-
F_O	the amount of fished-out fish	$kg.ha^{-1}$
LC	lethal concentration	$mg.l^{-1}$
MAC	maximum allowable concentration	$mg.l^{-1}$
NH_3	non-dissociated ammonia nitrogen	$mg.l^{-1}$
NH_4^+, NH_4-N	ammonium ion, ammonia nitrogen	$mg.l^{-1}$
NP	natural fish productivity. The difference of P_T – FP = NP	$kg.ha^{-1}$
P_T	total fish productivity. The sum of NP + FP = P_T	$kg.ha^{-1}$
RNP	relative natural productivity of fish. The ratio of NP/F_S = RNP	$kg.kg^{-1}$
RNP_C	relative natural productivity of carp.	$kg.kg^{-1}$
SN	total dissolved nitrogen	$mg.l^{-1}$
SP	total dissolved phosphorus	$mg.l^{-1}$
TOC	total organic carbon, determined in fraction filtered through GF/C glass filter, plus as particulate (organic) in seston, up to the particle size of 100 µm.	$mg.l^{-1}$
TN	total nitrogen	$mg.l^{-1}$
TP	total phosphorus	$mg.l^{-1}$
TN:TP	ration of total nitrogen and total phosphorus	-
WT	water transparency	m
Frequency of taxon, frequency of the occurrence	frequency of taxon or taxonomic group in zooplankton	%
Proportion of sites	Proportion of sites, where taxon was found	%
Proportion of size class	proportion of main size class in zooplankton	%

4. RESULTS

4.1. Zooplankton Composition in the Třeboň Fish Pond Region during the period 2000 – 2001

The samples collected in 43 fish ponds of the Třeboň and Nové Hrady regions in 2000 and 2001 revealed the total of 93 zooplankton taxa, including 32 Cladocera species, 11 Copepoda species, and 50 Rotifera species.

Copepodites and nauplii (mostly cyclopoid copepodites in some cases also calanoid copepodites) and rotifers were the most abundant zooplankton groups (according to their frequencies) found at the observed sites. The frequencies of copepodites and nauplii varied from 16.7 to 42.1 % and the frequencies of the occurrence of rotifers varied from 17.6 % up to 47 % (Tab. 6). The average frequencies of adult Cyclopoida and adult Calanoida were significantly lower. Adult Cyclopoida occurrence varied from 3.2 to 5.8 %, and adult Calanoida from 1.6 to 4.4 %. Genus *Bosmina* was the most abundant taxonomic group among Cladocera and its frequency varied from 11 to 32 % in both years. *Bosmina* species were predominantly recorded in the summer season samples. The frequencies of the *Daphnia* species were not higher than 20 % and mainly varied between 6.8 and 13.2 %. *Ceriodaphnia* and the family Chydoridae were the least important cladoceran groups. *Ceriodaphnia* were commonly found in the summer and late summer samples. Nevertheless, their average frequency has never exceeded 5 %. Family Chydoridae reached similar frequencies. Other Cladocera taxa occurred rarely.

Table 6. Average frequency (%) of main taxonomic groups in 2000-2001 (Třeboň region)

Taxon	2000			2001		
	Frequency of taxons[1] [%]			Frequency of taxons[1] [%]		
	Spring	Summer	Late summer	Spring	Summer	Late summer
Daphnia	8.9	9.6	6.0	6.8	13.2	13.2
Ceriodaphnia	0.9	3.2	2.1	0.4	4.2	3.0
Bosmina	16.8	32.0	27.4	10.9	26.8	19.0
Chydoridae	2.8	3.2	4.2	3.0	3.8	5.2
Other Cladocera	1.2	2.4	4.0	0.5	1.8	3.0
Adult Cyclopoida	5.8	3.2	4.3	3.4	3.9	5.3
Adult Calanoida	2.8	1.6	1.8	3.1	2.5	4.4
Copepodites	19.1	20.0	30.3	19.8	16.7	41.3
Nauplii	38.5	34.5	24.8	42.1	32.3	36.6
Rotifera	23.7	17.6	28.3	33.4	37.0	46.7

[1] Average frequency (%) of main taxonomic groups

The proportion of size classes of zooplankton reflected frequencies of the main taxonomic groups. At many sites small zooplankton was dominating. The size classes < 0.3 mm and 0.3 – 0.7 mm were the most frequent in both seasons (Tab. 7). All species of rotifers, nauplii, small cladocerans, a great part of cyclopoid and calanoid copepodites belonged to these classes. Zooplankton belonging to the class 0.7 – 1.5 mm was still relatively frequent and included *Daphnia* species, adult females of *Ceriodaphnia* and other cladocerans and copepodites. The size class 2.0 – 2.5 mm was distinctively less represented and included large Cladocera (the genera *Daphnia* and *Leptodora*), and adult Cyclopoida and Calanoida (e.g. genus *Cyclops*). Zooplankton belonging to size classes 2.5 – 3.0 mm and > 3.0 mm was found very scarcely. Only the representatives of the predatory cladocerans *Leptodora kindtii* and rarely some large individuals of the *Daphnia* species (*Daphnia pulicaria, D. magna*) fell into this classes.

In the 2000 season, the average size of zooplankton reached its maximum in spring (0.62 mm). The smallest average size was recorded in late summer (0.51 mm). In 2001, the average largest (0.50 mm) and smallest (0.45 mm) zooplankton was recorded in the summer and late summer, respectively (Tab. 7).

Table 7. Average proportion (%) of main size classes in 2000-2001 (Třeboň region)

Size classes [mm]	**2000**			**2001**		
	Proportion of size classes[1] [%]			**Proportion of size classes[1] [%]**		
	Spring	**Summer**	**Late summer**	**Spring**	**Summer**	**Late summer**
< 0.3	42.9	43.3	44.7	54.2	48.4	44.6
0.3 – 0.7	26.9	37.0	37.8	28.0	41.2	35.7
0.7 – 1.5	21.2	15.7	13.2	14.6	8.1	18.0
1.5 – 2.0	7.6	3.3	3.6	3.0	2.2	1.5
2.0 – 2.5	1.4	0.5	0.3	0.2	0.1	0.1
2.5 – 3.0	0.0	0.1	0.2	0.0	0.0	0.0
> 3.0	0.0	0.1	0.2	0.0	0.0	0.1
Average size [mm]	**0.62**	**0.52**	**0.51**	**0.47**	**0.45**	**0.50**

[1] Average proportion (%) of main size classes

Bosmina longirostris was the most frequent cladoceran species. This species was recorded at more than 60 % of the observed sites (during all sampling periods) in summer even at 80 % of the observed sites (Tab. 8). *Bosmina coregoni* was recorded in only one fish pond (Staňkovský, 2000, 2001). *Daphnia galeata* was the second most frequent cladoceran species. This species occurred at 47 – 80 % of the observed sites. Large *Daphnia* were represented by three species. *Daphnia pulicaria* was the most frequent, found predominantly in the spring samples. In the 2000 season, *D. pulicaria* was recorded at 31 % of sampling sites, while in 2001 at 41 % of the sites (Tab. 9, 10). It occurred rarely during the summer and late summer sampling periods. The frequency of this species varied between 8 and 11 %. *Daphnia longispina* was recorded at 2 – 6 % of the observed sites. This species was found more frequently in the 2000 season, especially in the spring and summer sampling periods. In 2001, it was recorded only in the summer at 2 % of the sites. *Daphnia magna* was found only during one sampling period in one fish pond (the summer sampling period of the 2000 season, the Byňovský fish pond).

The average sizes of *Daphnia* varied between 1.24 and 1.60 mm in 2000. The largest average size was recorded in the spring sampling period while the smallest one in during the summer sampling period (Tab. 9). In the 2001 season, the average size of *Daphnia* varied from 0.74 to 1.17 mm. The smallest size was recorded in spring, while the largest one was recorded in late summer (Tab. 10).

The Genus *Ceriodaphnia* was largely represented by two species, *Ceriodaphnia affinis* and *Ceriodaphnia pulchella*. *Ceriodaphnia affinis* was found more frequently (in 85 % of the samples). It was recorded at 8 – 49 % of the observed sites. It was scarcer in spring (at 8 – 11 % of the sites on average). The number of findings grew in summer and late summer, when it was recorded at 38 – 49 % of sites. *C. pulchella* was recorded less frequently, at 2 – 10 % of the sites. Other species of this genus (*Ceriodaphnia megops* and *Ceriodaphnia reticulata*) were found randomly.

Diaphanosoma brachyurum was found occasionally at 2 – 6 % of the observed sites. The occurrence of genus *Moina* was rather episodic. Two species were found, *Moina micrura* and *Moina brachyata* with *M. micrura* being the more frequent. Overall, the genus *Moina* was recorded at less than 5 % of the observed sites.

Family Chydoridae was a relatively abundant group and it mainly featured *Chydorus sphaericus*. This species was regularly found at 26 – 56 % of the sites. Other species of this family (e.g. *Alona rectangula*, *Alonella nana, Alona gutata, Alona costata, Chydorus ovalis, Pleuroxus truncatus*) were found more scarcely.

The occurrence of the predatory *Leptodora kindtii* was of seasonal character and it was more frequent in summer and late summer. The frequency of this species was between 2 – 6 % at the observed sites.

Table 8. List of Cladocera taxons. Proportion of sites (%) where taxon was found. I.- spring, II.- summer, III.-late summer (Třeboň region 2000-2001)

Taxon	2000			2001		
	Proportion of sites[1] [%]			Proportion of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Acroperus cf. harpae (Baird,1835)	3	0	6	0	2	3
Alona costata (Sars, 1862)	3	0	3	3	2	0
Alona guttata (Sars, 1862)	6	2	0	0	2	2
Alona rectangula (Sars, 1862)	6	5	6	5	7	9
Alonella nana (Baird, 1843)	6	2	0	3	0	0
Bosmina coregoni (Baird, 1857)	0	2	3	0	2	3
Bosmina longirostris (O.F.Müller, 1776)	72	80	65	53	62	63
Ceriodaphnia affinis (Lilljeborg, 1900)	8	49	30	11	48	34
Ceriodaphnia megops (Sars, 1862)	0	2	0	0	0	0
Ceriodaphnia pulchella (Sars, 1862)	0	2	8	0	10	9
Ceriodaphnia reticulata (Jurine, 1820)	0	2	0	0	0	3
Daphnia ambigua (Scourfield, 1946)	0	5	9	0	0	9
Daphnia cucullata (Sars, 1862)	0	5	6	0	0	6
Daphnia galeata (Sars, 1863)	75	80	47	53	69	49
Daphnia longispina (O.F. Müller, 1785)	6	2	0	0	2	0
Daphnia magna (Straus, 1820)	0	2	0	0	0	0
Daphnia parvula (Fordyce, 1901)	0	7	9	0	0	9
Daphnia pulicaria (Forbes, 1893)	11	0	3	8	7	6
Diaphanosoma brachyurum (Liévin, 1848)	0	5	6	0	2	6
Graptoleberis testudinaria (Fischer, 1848)	3	2	0	3	0	0

Taxon	2000 Proportion of sites[1] [%]			2001 Proportion of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Chydorus ovalis (Kurz, 1875)	0	2	6	0	5	6
Chydorus sp.(Leach, 1816)	3	0	3	3	0	3
Chydorus sphaericus (O.F. Miller, 1776)	33	49	56	26	43	46
Leydigia leydigii (Schoedler, 1862)	0	2	2	0	0	2
Leptodora kindtii (Focke, 1844)	0	2	6	0	2	3
Moina brachiata (Jurine, 1820)	0	2	0	0	2	0
Moina micrura (Kurz, 1875)	0	0	5	0	3	5
Pleuroxus cf. aduncus (Jurine, 1820)	0	2	0	0	2	0
Pleuroxus truncatus (O.F. Müller, 1776)	0	0	6	0	2	0
Scaphloleberis mucronata (O.F. Müller, 1776)	6	2	6	0	5	6
Scapholeberis rammneri (Dumont & Pensaert, 1983)	0	2	0	0	2	0
Simocephalus vetulus (O.F. Müller, 1776)	0	2	0	0	0	2

[1] Proportion of sites (%), where taxon was found

Table 9. Average frequency (%) of *Daphnia* species, average proportion of sites (%) and average frequncy (%) of *Daphnia* species. Average *Daphnia* size (AVG_d) are presented (Třeboň region 2000)

Třeboň region 2000		*Daphnia magna*	*Daphnia pulicaria*	*Daphnia longispina*	*Daphnia galeata*	*Daphnia cucullata*	*Daphnia parvula*	*Daphnia ambigua*	AVG_d [mm]
Spring	Proportion of sites [%][1]	0	11	6	75	0	0	0	1.60
	Frequency of taxon [%][2]	0.0	30.7	6.3	92.6	0	0	0	
Summer	Proportion of sites [%][1]	2	0	2	81	5	7	5	1.24
	Frequency of taxon [%][2]	20.0	0	35.7	94.0	25.0	13.4	13.4	
Late summer	Proportion of sites [%][1]	0	3	0	56	6	9	9	1.33
	Frequency of taxon [%][2]	0.0	100	0	97.8	39.2	15.3	15.3	

[1] Average proportion of sites (%), where *Daphnia* species were found
[2] Average frequency (%) of *Daphnia* species

Table 10. Average frequency (%) of *Daphnia* species, average proportion of sites (%) and average frequncy (%) of *Daphnia* species. Average Daphnia size (AVG_d) are presented (Třeboň region 2001)

Třeboň region 2001		***Daphnia magna***	***Daphnia pulicaria***	***Daphnia longispina***	***Daphnia galeata***	***Daphnia cucullata***	***Daphnia parvula***	***Daphnia ambigua***	**AVG_d [mm]**
Spring	Proportion of sites [%][1]	0	8	0	53	0	0	0	0.74
	Frequency of taxon [%][2]	0	41.2	0	98.8	0	0	0	
Summer	Proportion of sites [%][1]	0	7	2	69	0	0	0	1.08
	Frequency of taxon [%][2]	0	5.8	38.8	96.7	0	0	0	
Late summer	Proportion of sites [%][1]	0	6	0	49	6	9	9	1.17
	Frequency of taxon [%][2]	0	9.5	0	99.6	20.2	13.2	13.2	

[1] Average proportion of sites (%), where *Daphnia* species were found
[2] Average frequency (%) of *Daphnia* species

Copepoda were mostly represented by cyclopoid and calanoid copepodites and nauplii. Adults were less frequent.

Acanthocyclops trajani (formerly determined as *A. robustus*) was the most abundant species of Cyclopoida in the 2000 and 2001. This species was recorded at 22 – 44 % of the observed sites and it was most frequently found in summer and late summer samples (Tab. 11). *Acanthocyclops einseli* (formerly *A. robusuts sensus Brandl*) was found rarely. *Cyclops vicinus* typically occurred in spring. This species was found in 28 % of the observed fish ponds in the spring 2000, and at 29 % of the sites in the 2001 season. *Cyclops strenuus* occurred more rarely (2 – 3 % of the sites). *Thermocyclops crassus* was recorded relatively frequently in summer. This species was found in 7 – 15 % of the observed fish ponds. *Mesocyclops leuckarti* occurred in 3 – 11 % of the fish ponds, predominantly in summer and late summer. Other Cyclopoida species (*Macrocyclops albidus, Metacyclops gracilis*, *Eucyclops serrulatus*, and *Metacyclops gracilis*) were found scarcely.

Calanoida were represented by two species in the observed localities. *Eudiaptomus gracilis* was more frequent. It was recorded at 18 – 20 % of sites in the 2000 and at 17 – 32 % of sites in the 2001 and occurred virtually throughout the year. *Eudiaptomus vulgaris* was more frequent in spring, when it was found in 11 – 33 % fish ponds. In summer and late summer, the frequency of the occurrence decreased significantly and it varied between 3 and 5 % of the sampled sites.

Table 11. List of Copepoda species. Proportion of sites (%) where taxon was found. I.- spring, II.- summer, III.-late summer. (Třeboň region 2000-2001)

Taxon	2000			2001		
	Proportion of sites[1] [%]			Proportion of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Cyclops vicinus (Ulianine, 1875)	28	0	0	29	0	0
Cyclops strenuus (Fischer, 1851)	0	2	0	3	2	0
Acanthocyclops trajani (Mirabdullayev & Defaye, 2002)	22	44	41	16	36	34
Acanthocyclops cf. einslei (Mirabdullayev & Defaye, 2004)	0	2	3	0	2	0
Mesocyclops leuckarti (Claus, 1857)	0	7	3	0	7	11
Thermocyclops crassus (Fischer, 1853)	0	7	15	0	10	14
Eucyclops serrulatus (Fischer, 1851)	0	5	3	3	0	3
Metacyclops gracilis (Lilljeborg, 1853)	0	2	0	0	0	3
Macrocyclops albidus (Jurine, 1820)	3	0	0	0	2	0
Eudiaptomus gracilis (Sars, 1863)	19	20	18	32	24	17
Eudiaptomus vulgaris (Schmeil, 1896)	33	5	0	11	5	3

[1] Proportion of sites (%), where taxon was found

Rotifera were a very abundant zooplankton group in the observed fish ponds with the genus *Keratella* being represented by two species was the most frequent. *Keratella cochlearis* was recorded at 72 – 86 % sites, while the *Keratella quadrata* occurred at 44 – 74 % of the observed sites. I did not record significant decrease in occurrence of the genus *Keratella* throughout the season (Tab. 12).

The genus *Brachionus* was the most diverse Rotifera species. *Brachionus angularis* was the most abundant, found in 29 – 43 % of fish ponds. *B. calyciflorus*, *B. quadridentatus, B. diversicornis*, and *B. urceolaris* were relatively abundant. They were found at 7 – 39 % of the sites. The species *Brachionus falcatus*, *B. rubens*, *B. variabilis*, *B. patulus* were scarcely found. The genus *Polyarthra* was the third most frequent Rotifera species. Four *Polyarthra* species were found in the observed fish ponds. *Polyarthra dolichoptera* (39 – 51 % of the sites) and *Polyarthra major* (11 – 35 % of the sites) were the most frequent in both seasons. *Polyarthra vulgaris* and *Polyarthra remata* were scarcer. *Asplanchna* was the least abundant one of the frequently found Rotifera genus. *Asplanchna priodonta* was the most frequent, found at 16 – 37 % of the sites. The species *Asplanchna girodi* and other species of family Asplanchnidae did not occur abundantly.
The genus *Filinia* was represented by two species, *Filinia longiseta* and *Filinia terminalis*. *Filinia longiseta* was more frequent (13 – 29 % of the fish ponds).

During the spring sampling periods, rotifers of the genus *Notholca* were found in 5 – 8 % of the fish ponds. *Notholca squamula* represented the most frequent species. Rotifers of the genus *Synchaeta* were found in 2 – 16 % of the observed fish ponds. The genus *Hexarthra* and *Trichocerca* occurred predominantly in summer. Genus Hexarthra was always represented by *Hexarthra mira.* The genus *Trichocera*, mostly by *Trichocerca pusilla* and *Trichocerca similis*. These species occurred in 5 – 21 % of the observed fish ponds.

Gastropus stylifer and *Anureopsis fissa* were found with some regularity in certain fish ponds (e.g. Staňkovský, Svět). The frequncy of the occurrence of these species were recorded in less than 15 % of the observed fish ponds.

Table 12. List of Rotifera species. Proportion of sites (%) where taxon was found. I.- spring, II.- summer, III.-late summer. (Třeboň region 2000-2001)

Taxon	2000			2001		
	Proportion of sites[1] [%]			Proportion of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Anuraeopsis fissa (Gosse, 1851)	0	5	12	0	7	9
Asplanchna girodi (De Geurne, 1888)	0	2	6	0	0	6
Asplanchna priodonta (Gosse, 1850)	33	34	35	16	36	37
Asplanchna sp. (Gosse, 1850)	6	15	9	5	14	11
Bdeloidea g.sp.div. (Hudson, 1884)	0	7	6	3	5	6
Brachionus angularis (Gosse, 1851)	36	37	41	37	29	43
Brachionus budapestinensis (Daday, 1885)	0	2	9	0	2	9
Brachionus calyciflorus (Pallas, 1766)	17	39	29	26	26	29
Brachionus diversicornis (Daday, 1883)	0	22	24	3	10	26
Brachionus falcatus (Zacharias, 1898)	0	2	3	0	0	3
Brachionus patulus (O. F. Müller, 1786)	0	5	0	0	0	3
Brachionus quadridentatus (Hermann, 1783)	8	15	12	18	19	9
Brachionus rubens (Ehrenberg, 1838)	0	5	9	0	5	11
Brachionus urceolaris (O. F. Müller, 1773)	0	17	15	0	7	14
Brachionus variabilis (Hempel, 1896)	6	2	0	3	0	0
Collotheca sp.(Harring, 1913)	3	0	0	5	0	3
Colurella uncinata (O.F. Miller, 1773)	3	2	0	0	0	0
Conochiloides sp. (Hlava, 1904)	0	0	3	0	0	6
Conochilus unicornis (Rousselet, 1892)	8	2	0	5	2	0
Epiphanes sp. (Ehrenberg, 1832)	0	5	0	3	2	0
Euchlanis sp. (Ehrenberg, 1832)	3	0	3	0	2	0
Filinia longiseta (Ehrenberg, 1834)	14	29	29	13	14	20
Filinia opoliensis (Zacharias, 1898)	0	0	0	0	0	6
Filinia cf. terminalis (Plate, 1886)	3	0	0	11	0	3
Gastropus stylifer (Imhof, 1891)	8	5	12	3	2	0
Hexarthra mira (Hudson, 1871)	0	10	18	0	12	17
Kellicottia longispina (Kellicott, 1879)	3	10	9	3	14	9
Keratella cochlearis (Gosse, 1851)	72	78	85	76	83	86
Keratella quadrata (O. F. Müller , 1786)	44	68	74	50	60	71
Lecane sp. (Nitzsch, 1827)	8	2	6	3	5	3
Lepadella sp. (Bory De Saint Vincent, 1826)	0	7	0	0	5	3
Notholca sp. (Gosse, 1886)	3	0	0	3	0	0
Notholca squamula (O.F. Müller, 1786)	8	0	0	8	0	0
Ploesoma hudsoni (Imhof, 1891)	0	0	3	0	0	3
Polyarthra dolichoptera (Idelson, 1925)	42	44	59	39	45	51
Polyarthra euryptera (Wierzejski, 1891)	0	2	5	0	0	3
Polyarthra major (Burckhardt, 1900)	11	29	35	21	26	29
Polyarthra remata (Skorikov, 1896)	0	7	12	0	10	11
Polyarthra vulgaris (Carlin, 1943)	8	10	15	5	12	9
Pompholyx sulcata (Hudson, 1885)	0	5	9	0	7	11
Proalides sp. (Ehrenberg, 1832)	0	2	0	3	0	3
Synchaeta pectinata (Ehrenberg, 1832)	5	0	0	10	0	0
Rotaria neptunia (Ehrenberg, 1832)	0	0	3	0	0	3
Synchaeta sp. (Ehrenberg,, 1832)	3	2	0	6	0	0
Testudinella patina (Hermann, 1783)	0	0	0	0	3	3

Taxon	2000 Proportion of sites[1] [%]			2001 Proportion of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Trichocerca capucina (Wierzejski & Zacharias, 1893	0	0	3	0	0	3
Trichocerca cylindrica (Imhof, 1891)	0	0	0	0	0	3
Trichocerca pusilla (Jennings, 1903)	0	7	21	0	10	20
Trichocerca similis (Wierzejski, 1893)	0	5	18	0	7	14
Trichocerca sp. (Lamarck, 1801)	0	5	6	0	5	6

[1] Proportion of sites (%), where taxon was found

4.2. Zooplankton Composition in the Blatná-Lnáře Fish Pond Region in 2004 – 2005

During the two-year sampling cycle, the total of 113 zooplankton taxa were found, including 38 Cladocera species, 14 Copepoda species, and 61 Rotifera species.

Rotifera were the most frequent zooplankton group in the 2004 and 2005. They occurred in 40.7 to 52 % of fish ponds (Tab. 13). Copepodites and nauplii were the second most abundant taxonomic groups. Copepodites reached up to 9 – 17 % of zooplankton, nauplii were more frequent and represented 13 – 27 % of zooplankton in 2004. Copepods comprised 11.5 – 17.3 %, and nauplii 14.8 – 24.2 % of zooplankton in 2005. Adult Cyclopoida did not occur frequently and their overall frequency throughout both seasons did not significantly exceed 1 %. Adult Calanoida were more frequent. Their frequency of the occurrence reached 1.7 – 2.9 % in the 2004 season, and 1.9 – 3.4 % in the 2005 season.

The genus *Bosmina* was the most frequent Cladocera species. In both sampling cycles, its lowest frequency was recorded in spring (5.0 % in 2004, and 10.2 % in 2005) and it reached its highest occurrence frequency during the summer sampling date of 2005 (22.4 %). However, its frequency mostly varied between 10 and 20 % (Tab. 13).

The frequency of the occurrence of the genus *Daphnia* differed in the 2004 and 2005. In the 2004 season, it was lowest in the spring (5.2 %) as opposed to the summer, when it reached its highest occurrence (10.5 %).The occurrence of the genus *Daphnia* was generally higher in 2005. The highest frequency was recorded in spring (15.7 %) in this year. The lowest frequency was recorded in late summer (4.5 %). The occurrence of the family Chydoridae varied between 2.0 and 6.0 %. The frequency of *Ceriodaphnia* varied from 0.3 to 4.1 %, being significantly lower in spring. I recorded the increase of *Ceriodaphnia* occurrence in summer and late summer samples, when the frequency varied between 2.2 – 6.0 %. Other Cladocera species occurred scarcely and their frequency did not exceed 1 %. The exception represented genera *Diaphanosoma*, *Scapholeberis*, and *Polyphemus* in the summer sampling date of 2004. They caused an increase of the frequency of the zooplankton group ‘Other Cladocera’ up to 11.4 % (Tab. 13).

Table 13. Average frequency (%) of main taxonomic groups in 2004-2005 (Blatná-Lnáře region)

Taxon	**2004**			**2005**		
	Frequency of taxons[1] [%]			**Frequency of taxons[1] [%]**		
	Spring	**Summer**	**Late summer**	**Spring**	**Summer**	**Late summer**
Daphnia	5.2	10.1	6.9	15.7	11.3	4.5
Ceriodaphnia	0.3	4.1	3.6	0.6	2.2	3.0
Bosmina	5.0	12.9	21.4	10.2	22.4	10.8
Chydoridae	3.2	3.3	3.4	2.4	2.0	6.0
Other Cladocera	3.0	11.4	0.4	0.3	0.8	1.0
Adult Cyclopoida	1.0	0.6	0.9	0.9	1.1	1.0
Adult Calanoida	2.2	1.7	2.9	3.2	3.4	1.9
Copepodites	13.7	8.6	17.1	11.5	12.5	17.3
Nauplii	27.3	15.5	13.1	23.6	24.2	14.8
Rotifera	51.1	52.0	44.2	43.7	40.7	50.1

[1] Average frequency (%) of main taxonomic groups

The proportion of individual size classes followed the occurrence of the main taxonomic groups. Size class < 0.3 mm was the most abundant. More than 50 % of zooplankton belonged to this size class (Tab. 14). Due to the great amount of rotifers and nauplii which largely fell into this class. 17 – 36 % of zooplankton belonged to the size class of 0.3 – 0.7 mm and this size class was represented mainly by large Rotifera species (e.g. the genus *Asplanchna*), cyclopoid and calanoid copepods, and small cladocerans (e.g the genera *Bosmina* and *Chydorus*). The size class 0.7 – 1.5 mm was the third most frequent. In 2004 and 2005, this class formed less than 9 % and 9.2 - 16.6 % of zooplankton, respectively. It included predominantly the cladoceran genera *Daphnia* and *Ceriodaphnia*, cyclopoid and calanoid copepods, or some adult Copepoda (e.g. the genera *Acanthocyclops* and *Thermocyclops*). Zooplankton belonged to the size class 1.5 – 2.0 mm was distinctively less numerous. The highest proportion of this class was recorded in the spring 2005, when this class comprised 5.1 % of zooplankton. However, it only consisted of about 1 % of zooplankton. Large *Daphnia* species (*Daphnia pulicaria*, *D. longispina*, or *D. galeata* and *D. magna*), and adult Cyclopoida and Calanoida belonged to this size class. The last two size categories (2.5 – 3.0 mm, and > 3.0 mm) included only a very small amount of zooplankton, nearly always the predatory cladoceran *Leptodora kindtii*.

In the 2004 season, the smallest average size of zooplankton was recorded in spring (0.35 mm) while the largest average size was recorded in late summer (0.40 mm). In 2005, the situation was just the opposite. The largest average size of zooplankton was in spring (0.48 mm), while the smallest was in late summer (0.35 mm) (Tab. 14).

Table 14. Average proportion (%) of main size classes in 2004-2005 (Blatná-Lnáře region)

Size classes [mm]	2004 Proportion of size classes[1] [%]			2005 Proportion of size classes[1] [%]		
	jaro	léto	pozdní léto	jaro	léto	pozdní léto
< 0.3	72.8	61.4	54.3	60.6	64.6	68.5
0.3 – 0.7	16.8	28.1	36.1	17.5	22.0	22.0
0.7 – 1.5	8.8	8.6	8.8	16.6	12.0	9.2
1.5 – 2.0	1.4	1.2	0.5	5.1	1.1	0.2
2.0 – 2.5	0.2	0.5	0.2	0.1	0.1	0.0
2.5 – 3.0	0.0	0.1	0.0	0.1	0.1	0.1
> 3.0	0.0	0.1	0.1	0.0	0.1	0.0
Average size [mm]	**0.35**	**0.39**	**0.40**	**0.48**	**0.39**	**0.35**

[1] Average proportion (%) of main size classes

Bosmina longirostris was the most frequently found Cladocera. This species occurred at more than 60 % of the observed sites in both sampling seasons. Its frequency was highest in the summer months and sometimes *B. longirostris* comprised even more than 80 % of zooplankton (Tab. 15). *Daphnia galeata* was found regularly at more than 50 % of the sampled sites, with the highest frequency of the occurrence in summer. Large *Daphnia* species were mostly represented by *Daphnia pulicaria*. The occurrence of *D. pulicaria* was more significant only in spring. In 2004 spring samples, this species was found in 24 %, and in 2005 in 33 % of the observed fish ponds. *Daphnia longispina* was found relatively rarely (e.g. Mostenský 2004-05, V. Lípa 2004-05, Krčový 2004-05). Its occurrence was recorded at 3 – 8 % of sites. *Daphnia magna* occurred scarcely. It was found only in four fish ponds (Kubov 2005, Loužnice 2004-05, Mlýnský 2005, Paseka 2004). *Daphnia cucullata* was recorded infrequently, but regularly in some fish ponds (Smyslov 2005, Vlasatka 2005, V. Pálenec 2005, Velký Kuš 2004, M. Lípa 2004, Nadýmač 2004). It was most frequent in the late summer samples of 2004-2005, when it occurred in 15 – 22 % of fish ponds. Small, originally North American species *Daphnia parvula* and *Daphnia ambigua* were found in 3 – 10 % of fish ponds. They frequently concurred, but their frequencies did not exceed 2 % (on average) of zooplankton.

In both years, the largest average sizes of *Daphnia* were recorded in spring samples (2004 – 1.20 mm, 2005 – 1.18 mm) while the smallest average size was recorded in late summer samples (2004 – 0.85 mm, 2005 – 0.86 mm) (Tabs. 16, 17).

Genus *Ceriodaphnia* was another frequent cladoceran group in the observed fish ponds. *Ceriodaphnia affinis* and *Ceriodaphnia pulchella* were the most common found species. *Ceriodaphnia affinis* was the most frequent species. Its occurrence was recorded largely in summer and late summer, when it was found in 17 – 46 % of the localities. *C. pulchella* was less frequent, found in approximately 10 – 15 % of observed fish ponds. I rarely recorded the occurrence of two larger littoral species *Ceriodaphnia megops* and *Ceriodaphnia reticulata* (Žoldánka 2004-05, Mostenský 2004). The genus *Moina* abundance was not high. Where this genus was present in the sample, it mostly involved the *Moina micrura*, scarcely *Moina brachyata* and *Moina weismanni*. *Diaphanosoma brachyurum* was observed in 5 – 10 % of fish ponds. The family Chydoridae was relatively frequent and under certain conditions the frequency varied from 25 to 59 %. *Chydorus sphaericus* was its main representative and also the only species regularly recorded among pelagial plankton. Other species (e.g. *Alona rectangula*, *Alonella nana, Graptoleberis testudinaria, Alona gutata, Pleuroxus truncatus, Acroperus harpae*) occurred more rarely, and they probably got into the sample after stirring up bottom sediments (e.g. by plankton net or fish), or after pulling the plankton net through littoral macrophytes.

The predatory *Leptodora kindtii* was found mainly in summer. Its frequency was lower than 10 % in summer and late summer samplings of 2004 and 2005. *Polyphemus pediculus* was found in small fish ponds (mostly rich in macrophytes in littoral zone) and the frequency of its occurrence was up to 10 %.

Table 15. List of Cladocera taxons. Proportion of sites (%) where taxon was found. I.- spring, II.- summer, III.-late summer (Blatná-Lnáře region 2004-2005)

Taxon	2004			2005		
	Proportion of sites [%]			Proportion of sites [%]		
	I.	II.	III.	I.	II.	III.
Acroperus cf. harpae (Baird, 1835)	3	0	3	0	2	2
Alona costata (Sars, 1862)	3	3	0	0	2	0
Alona guttata (Sars, 1862)	5	0	0	0	5	2
Alona rectangula (Sars, 1862)	8	3	3	0	5	7
Alonella nana (Baird, 1843)	5	5	3	3	2	2
Alonella sp. (G.O. Sars, 1862)	0	3	0	0	0	0
Alona (Biapertura) affinis (Leydig, 1860)	0	2	0	0	2	0
Bosmina coregonii (Baird, 1857)	0	0	0	0	0	0
Bosmina longirostris ((O. F. Müller, 1776)	61	93	74	78	61	76
Ceriodaphnia affinis (Lilljeborg, 1900)	5	45	46	11	17	46
Ceriodaphnia megops (Sars, 1862)	0	3	0	0	0	3
Ceriodaphnia pulchella (Sars, 1862)	0	10	15	0	12	15
Ceriodaphnia reticulata (Jurine, 1820)	0	0	3	0	0	3
Daphnia ambigua (Scourfield, 1946)	8	3	3	0	5	10
Daphnia cucullata (Sars, 1862)	3	8	15	3	5	22
Daphnia galeata (Sars, 1863)	47	65	56	61	73	71
Daphnia longispina (O. F. Müller, 1776)	8	8	3	8	7	2
Daphnia magna (Straus, 1820)	0	5	3	3	5	0
Daphnia parvula (Fordyce, 1901)	8	3	3	0	5	10
Daphnia pulicaria (Forbes, 1893)	24	5	3	33	10	2
Diaphanosoma brachyurum (Liévin, 1848)	0	10	5	0	7	5
Graptoleberis testudinaria (Fischer, 1848)	5	3	3	0	2	0
Chydorus sp. (Leach, 1816)	8	5	5	0	7	5
Chydorus ovalis (Kurz, 1875)	0	0	3	0	0	3
Chydorus sphaericus (O. F. Miller, 1776)	42	53	51	25	41	59
Leydigia leydigii (Schoedler, 1862)	0	3	5	0	5	3
Leptodora kindtii (Focke, 1844)	0	5	5	0	7	7
Moina brachiata (Jurine, 1820)	0	3	0	0	0	0
Moina micrura (Kurz, 1875)	0	8	0	0	5	2
Moina weismmani (Ishikawa, 1896)	0	0	0	0	2	0
Monospilus sp. (G.O. Sars, 1862)	0	0	3	0	0	0
Pleuroxus aduncus (Jurine, 1820)	0	3	5	0	3	0
Pleroxus truncatus (O. F. Müller, 1785)	5	0	3	3	0	5

Taxon	2004 Proportion of sites [%]			2005 Proportion of sites [%]		
	I.	II.	III.	I.	II.	III.
Polyphemus pediculus (Linnaeus, 1758)	5	10	3	0	0	0
Pseudochydorus globosus (Sars, 1890)	0	3	0	0	0	3
Scapholeberis mucronata (O. F. Müller, 1776)	5	8	3	3	15	2
Scapholeberis rammneri (Dumont & Pensaert, 1983)	0	3	0	0	3	0
Simocephalus vetulus (O. F. Müller, 1776)	0	3	0	0	2	2

[1] Proportion of sites (%), where taxon was found

Table 16. Average frequency (%) of *Daphnia* species, average proportion of sites (%) and average frequncy (%) of *Daphnia* species. Average *Daphnia* size (AVG_d) are presented (Blatná-Lnáře region 2004)

Blatná-Lnáře region 2004		*Daphnia magna*	*Daphnia pulicaria*	*Daphnia longispina*	*Daphnia galeata*	*Daphnia cucullata*	*Daphnia parvula*	*Daphnia ambigua*	AVG_d [mm]
Spring	Proportion of sites [%][1]	0	24	8	47	3	3	3	**1.20**
	Frequency of taxon [%][2]	0.0	71.1	68.8	83.0	7.7	6.7	6.7	
Summer	Proportion of sites [%][1]	5	5	8	65	8	3	3	**0.99**
	Frequency of taxon [%][2]	27.6	20.0	67.4	95.5	39.9	7.7	7.7	
Late summer	Proportion of sites [%][1]	3	3	3	56	15	8	5	**0.85**
	Frequency of taxon [%][2]	9.8	90.2	100	93.2	90.6	17.5	9.7	

[1] Average proportion of sites (%), where *Daphnia* species were found
[2] Average frequency (%) of *Daphnia* species

Table 17. Average frequency (%) of *Daphnia* species, average proportion of sites (%) and average frequncy (%) of *Daphnia* species. Average *Daphnia* size (AVG_d) are presented (Blatná-Lnáře region 2005)

Blatná-Lnáře region 2005		*Daphnia magna*	*Daphnia pulicaria*	*Daphnia longispina*	*Daphnia galeata*	*Daphnia cucullata*	*Daphnia parvula*	*Daphnia ambigua*	AVG_d [mm]
Spring	Proportion of sites [%][1]	3	33	8	61	3	0	0	**1.18**
	Frequency of taxon [%][2]	0.8	61.4	22.3	90.7	100	0	0	
Summer	Proportion of sites [%][1]	5	10	7	73	5	5	3	**0.96**
	Frequency of taxon [%][2]	3.5	21.8	57.3	92.5	55.8	23.4	21.7	
Late Summer	Proportion of sites [%][1]	0	2	2	71	22	10	10	**0.86**
	Frequency of taxon [%][2]	0.0	2.9	16.7	85.0	62.2	13.9	13.9	

[1] Average proportion of sites (%), where *Daphnia* species were found
[2] Average frequency (%) of *Daphnia* species

Cyclopoida and sometime also Calanoida formed a significant part of zooplankton in the observed Blatná-Lnáře fish ponds. However, they were mostly represented only by their nauplii or copepodites. These were found virtually mostly at all sites and their frequencies varied between 13.1 and 27.3 % (nauplii), and 8.6 and 17.3 % (copepodites).

Cyclopoida were more diverse in species and more frequent in occurrence and the total of 12 Cyclopoida species were found in the observed fish ponds. Adult Cyclopoida were recorded at 28 – 54 % of the observed sites. However, their frequency in zooplankton was not high and varied around 1 % on average. *Cyclops vicinus*, *Acanthocyclops trajani*, and in some cases also *Thermocyclops crassus* were the most frequent (Tab. 18). *Cyclops vicinus* was present in the samples predominantly in the spring, when it was recorded in 20 % of the fish ponds., *Acanthocyclops trajani*, sometimes also *Thermocyclops crassus*, were the most frequent species in the summer and late summer. *A. trajanii* (formerly called *Acanthocyclops robustus*) was regularly found in 21 – 37 % of fish ponds in the summer. *Thermocyclops crassus* was mostly recorded in the late summer of 2005. *Macrocyclops albidus*, *Megacyclops gigas*, and *Eucyclops serrulatus* were found very scarcely, only in the fish ponds with a litoral macrophytes. These species are not a common part of pelagial zooplankton. *Mesocyclops leuckarti* was relatively rare species (found less than 10 % of the localities).

Calanoida were represented mostly by their copepodites. Adults formed 2 – 3 % of zooplankton. I found two species, *Eudiaptomus vulgaris* and *Eudiaptomus gracilis*. *E. vulgaris* was mainly found in the spring. *E. gracilis* was present throughout the vegetation season.

Table 18. List of Copepoda species. Proportion of sites (%) where taxon was found. I.-spring, II.-summer, III.-late summer. (Blatná-Lnáře region 2004-2005)

Taxon	2004			2005		
	Proportion of sites[1] [%]			Proportion of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Acanthocyclops cf. einselei (Mirabdullayev & Defaye, 2004)	0	3	0	0	2	2
Acanthocyclops trajani (Mirabdullayev & Defaye, 2002)	18	25	21	8	37	29
Cyclops strenuus (Fischer, 1851)	0	3	8	6	2	2
Cyclops vicinus (Ulianine, 1875)	24	0	0	22	0	0
Diacyclops bicuspidatus (Claus, 1857)	3	0	0	0	0	0
Eucyclops serrulatus (Fischer, 1851)	0	5	8	3	0	5
Eudiaptomus gracilis (Sars, 1863)	16	25	21	22	24	22
Eudiaptomus vulgaris (Schmeil, 1896)	34	13	8	28	12	2
Macrocyclops albidus (Jurine, 1820)	3	0	0	3	0	0
Megacyclops gigas (Claus, 1857)	3	0	0	0	0	0
Mesocyclops leuckarti (Claus, 1857)	0	3	3	0	5	7
Metacyclops gracilis (Lilljeborg, 1853)	0	0	0	3	0	0
Paracyclops fimbriatus (Fischer, 1853)	0	3	0	3	0	0
Thermocyclops crassus (Fischer, 1853)	0	8	10	8	5	22

[1] Proportion of sites (%), where taxon was found

Rotifera were frequent group of zooplankton in Blatná-Lnáře fish ponds. They comprised from 40.7 to 51.1 % of zooplankton with the genus *Keratella* (*K. cochlearis* and *K. quadrata*) being the most frequently found species (Tab. 19). In some cases, this genus was recorded at more than two thirds of the observed sites. Sometimes *K. cochlearis* was the only recorded Rotifera species in zooplankton. Genus *Polyarthra* was highly frequent too. *Polyarthra dolichoptera* (45 – 64 % of the sites) and *Polyarthra major* (7 – 17 % of the sites) were the most frequent species of this genus. Other *Polyarthra* species were found scarcely. The genus *Asplanchna* was another relatively frequent Rotifera species. A regular occurrence of the genus *Asplanchna* was recorded throughout the vegetation season with *Asplanchan priodonta* being the most frequent species and *Asplanchna girodi, A. sieboldi*, *A. brighwelli* being relatively rare.

The genus *Brachionus* was a highly abundant Rotifera genus in the monitored fish ponds and was represented by 11 species. *Brachionus angularis* was the most frequent species (at 15 – 42 % of the observed sites) and *Brachionus calyciflorus*, *Brachionus quadridentatus* and *Brachionus diversicornis* were relatively frequent. I found them regularly throughout the vegetation season. *Brachionus rubens* and *Brachionus urceolaris* were not so common, but frequent in some fish ponds. *Brachionus budapestinensis* and *Brachionus falcatus* were recorded at some sites in the summer. *Brachionus variabilis* (Divák 2005, Starý u Lažánek 2005 fish ponds) and *Brachionus leydigii* (Újezdský 2004, Radov 2004 fish ponds) were found in the spring sampling period.

The genus *Notholca* was found only occasionally in the spring samples. *Notholca squamula* was the most frequent species of this genus. *Hexarthra mira* was recorded in summer and late summer period. The genus *Filinia* was represented by two species, *Filinia longiseta* and *Filinia terminalis*. The genus *Trichocerca* was represented by several species with the *Trichocerca pusilla* and *Trichocera similis* being the most frequent. The occurrence of *Trichocera cylindrica*, *T. elongata*, *T. longiseta* and *T. capucina* was rare and limited to only several fish ponds. The rotifers of this genus were found predominantly in the warmer part of the year (summer and late summer).

Table 19. List of Rotifera species. Sites (%) where taxon was found. I.- spring, II.- summer, III.- late summer. (Blatná-Lnáře region 2004-2005)

Taxon	2004			2005		
	Nr. of sites[1] [%]			Nr. of sites[1] [%]		
	I.	II.	III.	I.	II.	III.
Anuraeopsis fissa (Gosse, 1851)	0	0	0	3	0	3
Ascomorpha ecaudis (Perty, 1850)	0	3	0	3	3	0
Asplanchna priodonta (Gosse, 1850)	54	50	47	34	20	59
Asplanchna girodi (De Geurne, 1888)	4	8	8	0	7	5
Asplanchna sieboldi (Leydig, 1854)	0	3	0	0	3	0
Asplanchna brightwelli (Gosse, 1850)	0	0	3	0	0	5
Asplanchna sp. (Gosse, 1850)	3	3	8	3	5	3
Bdeloidea g.sp.div. (Hudson, 1884)	0	0	3	0	0	3
Brachionus angularis (Gosse, 1851)	32	15	33	15	42	34
Brachionus budapestinensis (Daday, 1885)	0	3	8	0	5	13
Brachionus calyciflorus (Pallas, 1766)	16	33	33	6	29	37
Brachionus diversicornis (Daday, 1883)	0	18	41	6	29	34

Taxon	2004 Nr. of sites[1] [%]			2005 Nr. of sites[1] [%]		
	I.	II.	I.	II.	I.	II.
Brachionus falcatus (Zacharias, 1898)	0	0	5	0	5	5
Brachionus leydigii (Cohn, 1862)	5	0	0	0	0	0
Brachionus patulus (O. F. Müller, 1786)	0	0	0	0	5	0
Brachionus quadridentatus (Hermann, 1783)	5	30	15	3	29	8
Brachionus rubens (Ehrenberg, 1838)	3	8	10	3	5	8
Brachionus urceolaris (O. F. Müller, 1786)	0	10	15	0	8	16
Brachionus variabilis (Hempel, 1896)	0	0	0	6	0	0
Cephalodella sp. (Bory De Saint Vincent, 1826)	0	0	0	0	3	0
Collotheca sp. (Harring, 1913)	0	3	3	0	3	0
Conochilus hippocrepis (Schrank, 1803)	3	0	0	3	0	0
Conochilus unicornis (Rousselet, 1892)	0	8	0	9	8	5
Conochiloides dossuarius (Hudson, 1885)	0	0	3	0	0	3
Conochiloides natans (Seligo, 1900)	0	0	0	0	3	3
Euchlanis dilatata (Ehrenberg, 1832)	0	3	0	3	0	5
Euchlanis sp. (Ehrenberg, 1832)	0	0	3	0	0	3
Filinia longiseta (Ehrenberg, 1834)	16	35	23	15	16	26
Filinia terminalis (Plate, 1886)	3	3	0	3	0	3
Gastropus stylifer (Imhof, 1891)	0	3	3	0	0	3
Hexarthra mira (Hudson, 1871)	0	8	10	0	16	16
Kellicottia longispina (Kellicott, 1879)	0	0	10	12	5	3
Keratella cochlearis (Gosse, 1851)	74	73	80	65	53	68
Keratella quadrata (O. F. Müller , 1786)	84	60	41	88	53	55
Lecane sp. (Nitzsch, 1827)	0	3	0	3	5	0
Lepadella sp. (Bory De Saint Vincent, 1826)	3	0	0	0	3	3
Mytilina mucronata (O. F. Müller, 1773)	3	0	0	0	0	0
Notholca acuminata (Ehrenberg, 1832)	0	0	0	3	0	0
Notholca labis (Gosse, 1887)	0	0	0	3	0	0
Notholca squamula (O. F. Müller, 1786)	3	0	3	0	0	0
Platyias quadricornis (Ehrenberg, 1832)	0	3	0	0	0	0
Ploesoma hudsoni (Imhof, 1891)	0	0	3	0	0	5
Polyarthra euryptera (Wierzejski, 1891)	0	3	5	0	4	5
Polyarthra dolichoptera (Idelson, 1925)	57	49	64	55	45	55
Polyarthra major (Burckhardt, 1900)	6	8	5	6	4	5
Polyarthra remata (Skorikov, 1896)	0	3	3	0	5	4
Polyarthra vulgaris (Carlin, 1943)	17	11	8	10	7	15
Pompholyx sulcata (Hudson, 1885)	3	8	0	3	3	0
Rotaria neptunia (Ehrenberg, 1832)	0	0	3	3	0	3
Synchaeta oblonga (Ehrenberg, 1832)	6	0	0	3	0	0
Synchaeta pectinata (Ehrenberg, 1832)	3	5	3	3	3	8
Synchaeta sp. (Ehrenberg, 1832)	0	0	0	3	0	3
Testudinella patina (Hermann, 1783)	0	3	0	0	3	0
Trichocerca capucina (Wierzejski & Zacharias, 1893	0	0	3	0	0	5
Trichocerca cylindrica (Imhof, 1891)	0	0	5	3	3	5
Trichocerca elongata (Gosse, 1886)	0	3	3	0	3	3
Trichocerca longiseta (Schrank, 1802)	0	0	3	3	3	5
Trichocerca pusilla (Jennings, 1903)	0	5	10	0	7	9
Trichocerca similis (Wierzejski, 1893)	0	3	12	3	3	9

Taxon	2004 Nr. of sites[1] [%]			2005 Nr. of sites[1] [%]		
	I.	II.	I.	II.	I.	II.
Trichocerca sp.(Lamarck, 1801)	0	3	3	0	3	3
Trichotria sp. (Bory De Saint Vincent, 1827)	3	0	0	0	3	0

[1] Proportion of sites (%), where taxon was found

4.3. The Level of Eutrophication – Impact on Zooplankton Structure

The evaluation, how high level of eutrophication influence zooplankton structure has been performed. For this purpose the data from the Blatná-Lnáře fish ponds (2004-2005) has been analysed. The data from spring and late summer sampling period were used for the evaluation. According to, the level of eutrophication the fish ponds have been classified as slightly eutrophic to highly hypertrophic. The level of eutrophication was determined according to these parameters: total phosphorus (TP), total nitrogen (TN), ratio of total nitrogen and total phosphorus (TN:TP). The total amount of organic substances was evaluated using total organic carbon (TOC). The biomass of phytoplankton was assessed by chlorophyll-a (Chl-a) measurement and water transparency (WT). I included the fish stock biomass (kg.ha^{-1}), to assess the influence of fish pond management because the fish stock is a good indicator of the manifestation of eutrophication.
For statistical evaluation, the combination of Cluster (Ward´s method) and CCA ordination analyses were used.

4.3.1. The Spring Season

In Cluster analysis presented in figure 7, three separate groups (called GR1, GR2, and GR3) in the spring sampling period (2004-2005) could be distinguished. The first group of fish ponds (GR1) is characterised by the lowest average concentrations of TP and TOC. Simultaneously, this group displays the lowest average concentration of chlorophyll-a and the lowest average fish stock densities. On the other hand, GR1 fish ponds had the highest average values of TN and of the TN:TP ratio (Tab. 20).

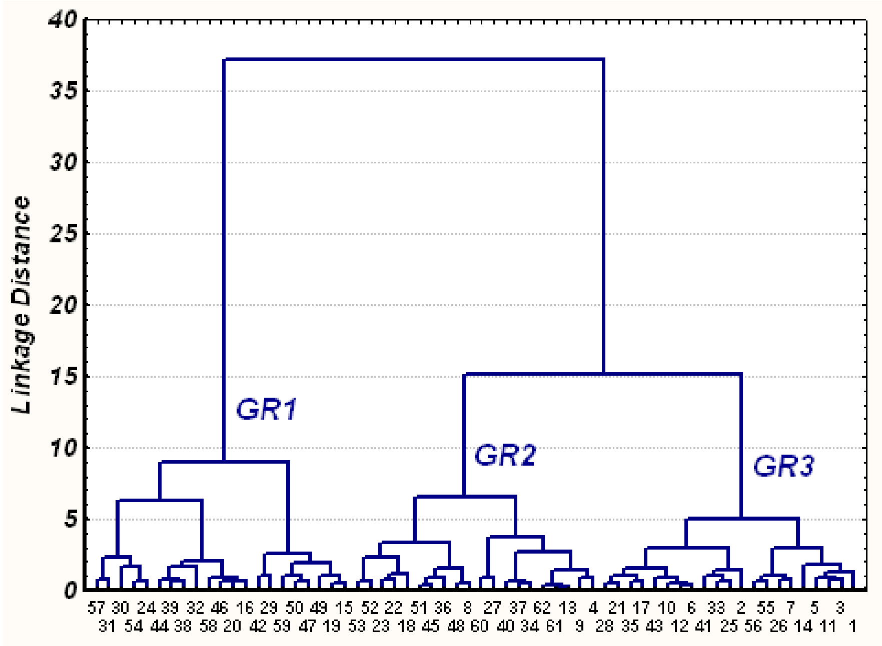


Figure 7. Results of Cluster analysis (Ward's Metod). Similarity among sites on the basis of chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock - spring period 2004-2005 (Blatná-Lnáře region). There are numbers of sites on the axis X and Linkage Distance (Euclidean distance) among sites groups (GR1, GR2, GR3) on the axis Y. Number of sites see table 3.

Table 20. Average values of parameters indicate eutrophication level in individual fish pond groups, spring period 2004-2005 (Blatná-Lnáře region). Chl-a – Chlorophyll-a concentration, TN – Total nitrogen, TP – Total phosphorus, Wt – Water transparency, $kg.ha^{-1}$ – fish stock, TOC – Total organic carbon

Group	Chl-a	TN	TP	TN:TP	Wt	$kg.ha^{-1}$	TOC
Average GR1	6.9	6.60	0.09	72.83	1.4	139	11.23
AverageGR2	44.0	4.36	0.12	35.88	0.6	254	14.33
Average GR3	117.4	3.82	0.17	23.06	0.4	526	15.35

GR2 fish ponds group is characterised by medium average values of TP, TN, TN:TP, TOC, chlorophyll-a and water transparency. Compared to GR1 and GR3, GR2 group exhibited a medium fish stock (Tab. 20).

The third group of fish ponds (GR3), displayed the lowest water transparencies, and the lowest values of of TN:TP. Simultaneously, these fish ponds showed the highest average concentrations of TP, chlorophyll-a, and TOC. The GR3 group also had the highest fish stock density.

Besides cluster analysis, CCA ordination analysis was used to evaluate similarities among observed sites and particular parameters. Subsequently, I combined the results of Cluster and CCA ordination analyses and got group characterising fish ponds groups in the spring period (Fig. 8).

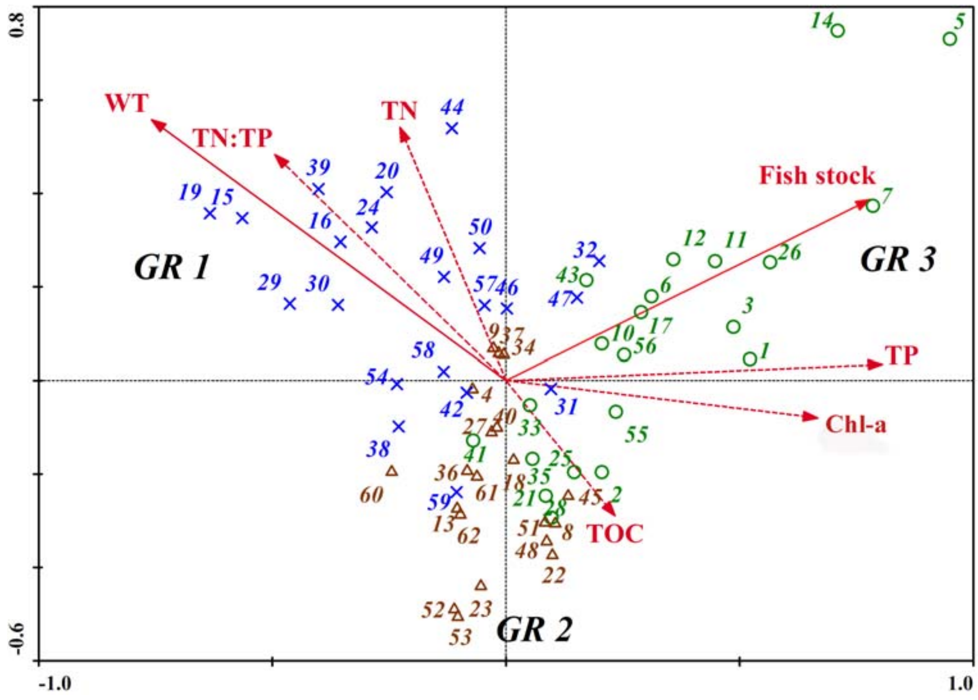


Figure 8. CCA ordinary diagram represents similarity among fish ponds on the basis of chlorophyll_a, water transparency, TP, TN, TN:TP, TOC and fish stock (× GR1, **Δ** GR2, ○ GR3). Conslusive explictive parameters are expressed by solid arrow - spring period 2004 – 2005 (Chl-a = chlorophyll-a, WT = water transparency). Number of sites see table 3.

Fish stock ($kg.ha^{-1}$, $p = 0.005$) and water transparency (Wt, $p = 0.01$) were significant variables (according to forward selection test) in the spring period 2004-2005.

Copepodites and nauplii (36.3 %) and rotifers (33.1 %) were the most frequent zooplankton group in GR1 fish ponds. Genus *Daphnia* had highest frequncies (21.5 %) in these GR1 fish ponds groups too. *Daphnia galeata* (10.8 %) were the most abundant species of this genus. The next most abundant species were *Daphnia pulicaria* (8.7 %) and *Daphnia longispina* (2.2 %). The frequency of the occurrence of other *Daphnia* species (*Daphnia magna*) was lower than 1 %. The average size of genus *Daphnia* (AVGd) was 1.33 mm. *Bosmina longiostris* had the lowest frequencies in GR1 fish ponds (4.3 %) (Tab. 21). Calanoida had the highes frequencies in GR1 fish ponds (3.7 %). The average size of zooplankton (AVG) in GR1 fish ponds was 0.55 mm.

The dominant zooplankton group in GR2 were again copepodites and nauplii (44.5 %). The second most abundant group were rotifers (35.7 %). Cladocera of the genus *Daphnia* comprised 9.1 % of zooplankton. The dominant *Daphnia* species was *Daphnia galeata* (8.6 %). The frequency of other species of this genus was lower than 1 %. The average size of the genus *Daphnia* was 1.18 mm. *Bosmina longirostris* was the last more significant cladoceran species in fish ponds GR2 group. It comprised 6.6 % of zooplankton. The average size of zooplankton in this group was 0.45 mm.

Similarly to the fish ponds of GR1 and GR2 groups, copepodites and nauplii (63.4 %) and rotifers (35.7 %) were dominant in the zooplankton of GR3. These two taxonomic groups presented the main part of zooplankton. *Bosmina longirostris* was the most frequent, comprising 9.6 % of zooplankton. The genus *Daphnia* formed only a small part of zooplankton and their average frequency did not exceed 3 %. *Daphnia galeata* was the most frequent species (2.5 %). The lowest average size of *Daphnia* was recorded (1.04 mm), in the fish ponds of this group. The GR3 group had the lowest average size of zooplankton (0.35 mm) (Tab. 21).

Table 21. Average frequency (%) of main taxonomic groups of zooplankton in fish pond groups, spring period 2004 a 2005 (Blatná-Lnáře region). AVG - average zooplankton body length (mm), AVGd - average *Daphnia* body length (mm), *Σ Daphnia* – sum of genus *Daphnia*

Taxon	**Spring period 2004 - 2005**		
	GR1	**GR2**	**GR3**
Daphnia magna	0.02	0	0
Daphnia pulicaria	8.7	0.4	0.3
Daphnia longispina	2.2	0.1	0
Daphnia galeata	10.8	8.6	2.5
Daphnia parvula	0	0	0.05
Daphnia ambigua	0	0	0.05
Daphnia cucullata	0	0.02	0.02
Σ Daphnia	**21.5**	**9.1**	**2.9**
AVGd [mm]	**1.33**	**1.18**	**1.04**
Ceriodaphnia	0	0.02	0.02
Bosmina longirostris	4.3	6.6	8.6
Chydoridae	0.2	1.3	1.7
Ostatní Cladocera	0.4	0.02	0
Cyclopidae adult	0.2	0.6	0.4
Calanoid adult	3.7	2.2	0.7
Copepoda, Nauplia	36.3	44.5	49
Rotifera	33.1	35.7	37
AVG [mm]	**0.55**	**0.45**	**0.35**

I found a significant difference in frequencies of genus *Daphnia* among GR1, GR2, GR3 fish ponds groups. The GR1 group had the highest average frequency and size of *Daphnia*. The highes average frequencies of *Daphnia* was enabled by the lowest fish stocks in GR1 fish ponds. Simultaneously, the GR1 group had the highest average water transparency combined with the lowest average chlorophyll-a concentration. The GR3 group had the lowest frequency of *Daphnia* but the highes frequencies of copepodites, nauplii, rotifers, and *Bosmina longirostris*. The GR3 fish pond group had the highest fish stocks. Simultaneously, the lowest water transparency and the highes chlorophyll-a concentration was found there.

For a detailed analysis of zooplankton species composition, I used CCA ordination analysis to evaluate the interrelationship of the most frequently found plankton crustaceans and rotifers to different parameters characterising level of eutrophication of individual groups of fish ponds (resulting from Cluster analysis) (Figs 9, 10).

Large *Daphnia* species were common in the GR1 fish ponds group. *Daphnia pulicaria* was the most frequent (8.7 %), *Daphnia longispina* (2.2 %) and *Daphnia magna* (< 1.0 %) were found less frequently. *Daphnia longispina*, were only recorded at the GR1 sites. Adult *Cyclopoida* were most frequently represented by the *Cyclops vicinus* species.

Eudiaptomus vulgaris (*Calanoida*) was found solely in GR1 fish ponds. Moreover, together with common rotifer species, I found *Notholca acuminata, N. labis*, *Trichocerca cylindrica, T. longiseta*, *Conochilus hippocrepis*, *Synchaeta oblonga and Asplanchna girodi* exclusively at these sites.

Ceriodaphnia pulchella and *Cyclops strenuus* species were only recorded in the GR2 group. Rotifers *Asplanchna priodonta* and *Brachionus quadridentatus* were mostly found in the GR2 group. *Acanthocyclops trajani* was only recorded at the GR3 sites. The most frequent rotifers in the GR3 fish ponds were genera *Brachionus* and *Keratella*. The *Pompholyx sulcata* was only found in the GR3 fish ponds.

Species *Daphnia galeata*, *Bosmina longirostris*, *Eudiaptomus gracilis*, *Keratella quadrata* and *Keratella cochlearis*, and some representatives of the genus *Brachionus* (e.g. *B.angularis*) were recorded in all three groups.

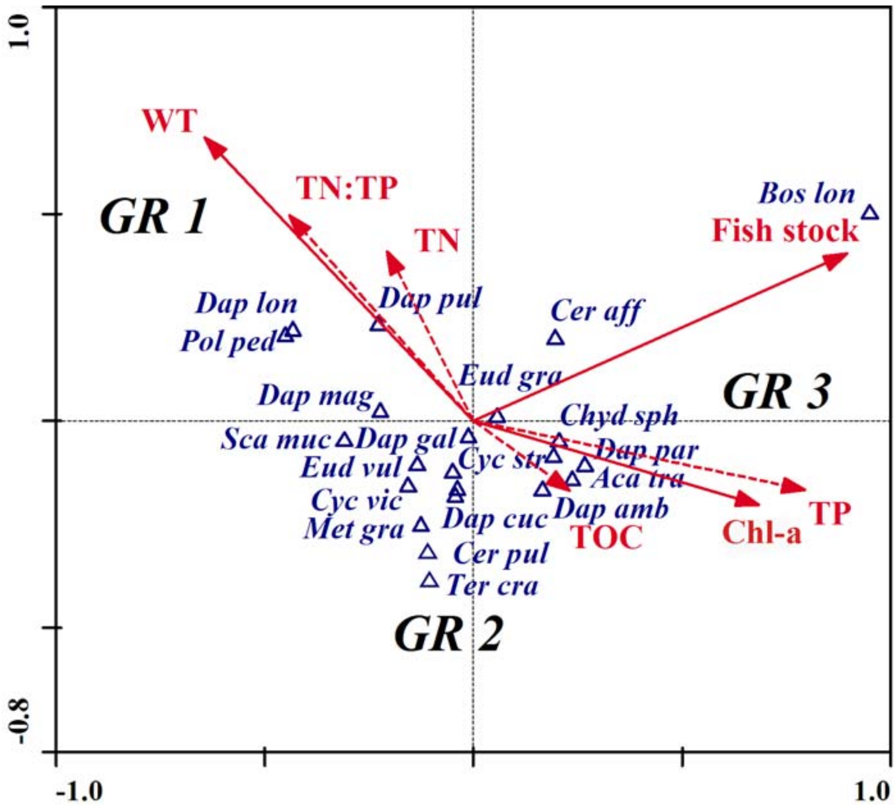


Figure 9. CCA ordinary diagram represents relation among crustacean zooplankton species and chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock – the spring period 2004-2005. For taxons these abbreviations are used: *Aca tra – Acanthocyclops trajani*, *Bos lon – Bosmina longirostris, Cer aff – Ceriodaphnia affinis, Cer pul – Ceriodaphnia pulchella, Cyc vic – Cyclops vicinus, Cyc str – Cyclops strenuus, Dap amb – Daphnia ambigua, Dap cuc – Daphnia cucullata, Dap gal – Daphnia galeata, Dap lon – Daphnia longispina, Dap mag – Daphnia magna, Dap par – Daphnia parvula, Dap pul – Daphnia pulicaria*, *Eud gra – Eudiaptomus gracilis, Eud vul – Eudiaptomus vulgaris, Chy sph – Chydorus sphaericus, Met gra – Metacyclops gracilis, Pol ped – Polyphemus pediculus, Sca muc – Scapholeberis mucronata, Ter cra – Thermocyclops crassus*

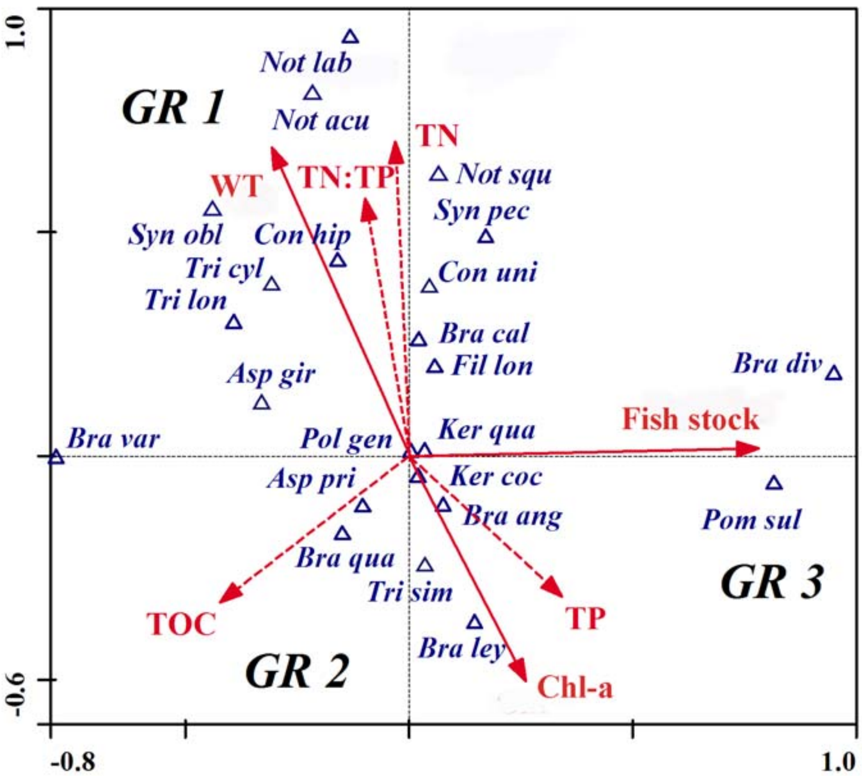


Figure 10. CCA ordinary diagram represents relation among rotifers species and chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock - the spring period 2004-2005. For taxons these abbreviations are used: *Asp gir – Asplanchna girodi*, *Asp pri – Asplanchna priodonta*, *Bra ang – Brachionus angularis, Bra cal – Brachionus calyciflorus, Bra div – Brachionus diversicornis, Bra ley – Brachionus leydigii, Bra qua – Brachionus quadridentatus, Bra var – Brachionus variabilis, Con hip – Conochilus hippocrepis, Con uni – Conochilus unicornis, Fil lon – Filinia longiseta, Ker coc – Keratella cochlearis, Ker qua – Keratella quadrata, Not acu – Notholca acuminata, Not lab – Notholca labis, Not squ – Notholca squamula, Pol gen –* rod *Polyarthra, Pom sul – Pompholyx sulcata, Syn pec – Synchaeta pectinata, Syn obl – Synchaeta oblonga, Tri cyl – Trichocerca cylindrica, Tri lon – Trichocerca longiseta, Tri sim – Trichocerca similis*

4.3.2. The Late Summer Season

The monitored sites were divided into two well defined groups (on the basis of Cluster analysis), in the late summer period of 2004 and 2005,. The GR1 group includes fish ponds with lower average concentrations of chlorophyll-a, TP, TOC. The average fish stock were lower too. Simultaneously, water transparency and TN:TP were higher in GR1 fish ponds.
The group GR2 includes fish ponds with higher average concentrations of chlorophyll-a, TP, TOC and had higher biomass of fish. On the other hand, they are characterised by lower water transparency a lower TN:TP ratio (Fig. 11, Tab. 22).

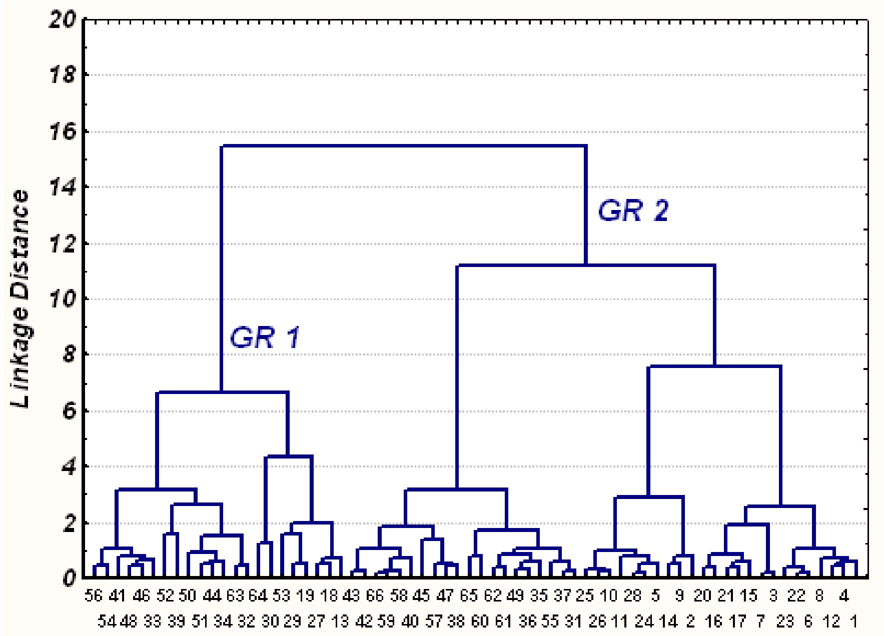


Figure 11. Results of Cluster analysis (Ward's Metod). Similarity among sites on the basis of chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock – late summer period 2004-2005 (Blatná-Lnáře region). There are numbers of localities on the axis X and Linkage Distance (Euclidean distance) among sites groups (GR1, GR2) on the axis Y. Number of sites see table 3.

Table 22. Average values of parameters indicate eutrophication level in individual fish pond groups, late summer period 2004-2005 (Blatná-Lnáře region). Chl-a – Chlorophyll-a concentration, TN – Total nitrogen, TP – Total phosphorus, Wt – Water transparency, $kg.ha^{-1}$ – fish stock, TOC – Total organic carbon

Group	Chl-a	TN	TP	TN:TP	Wt	$kg.ha^{-1}$	TOC
Average GR1	66.4	2.5	0.16	20.42	0.5	439	14.97
Average GR2	184.2	2.8	0.32	12.72	0.2	903	18.07

Water transparency (Wt, $p = 0.003$) and fish stock ($kg.ha^{-1}$, $p = 0.008$) were significant variables (according to forward selection test – CCA ordination analysis) in the fish ponds sampled in late summer period 2004-2005 (Fig. 12).

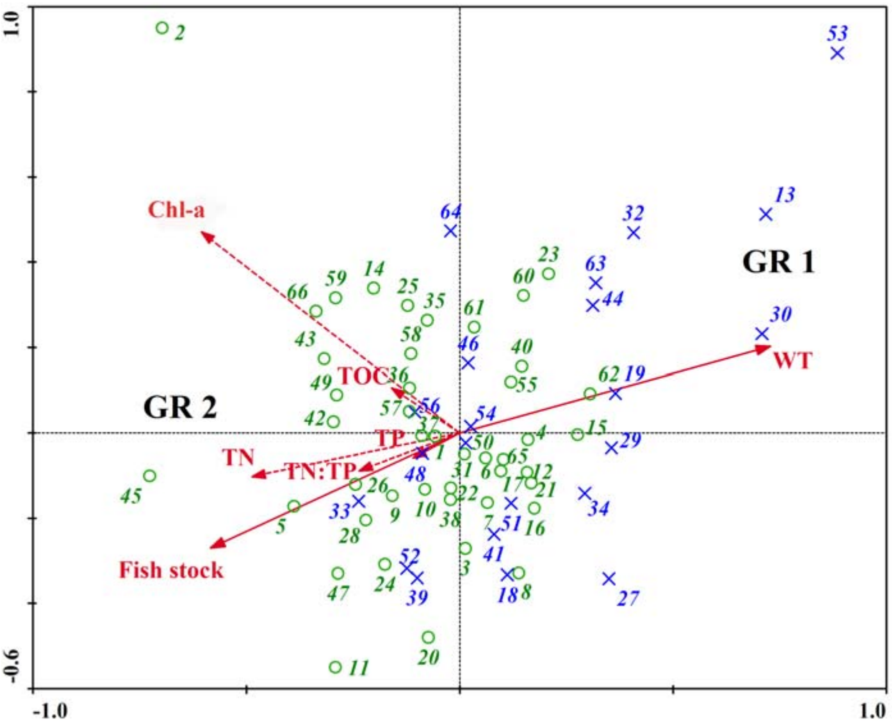


Figure 12. CCA ordinary diagram represents similarity among localities on the basis of chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock (× GR1, ○ GR2). Conslusive explictive parameters are expressed by solid arrow - late summer 2004 – 2005 (Chl-a = chlorophyll-a, WT = water transparency). Number of sites see table 3.

Rotifers were the dominant taxonomic group in GR1 and comprised nearly 58 % of zooplankton. Copepodites and nauplii were the second most frequent group (27.3 %). The genus *Daphnia* formed 6.2 % of zooplankton. *Daphnia galeata* (3.8 %) was the most frequent *Daphnia* species. *Daphni* average size was 0.90 mm in the GR1 fish ponds. Small cladocerans *Bosmina longirostris* comprised 6.0 % of zooplankton on average. *Calanoida* formed over 2 % of zooplankton with *Eudiaptomus gracilis* as a predominant species. The average size of zooplankton was 0.40 mm at the sites group GR1 (Tab. 23).

Rotifers (39.1 %) and copepodites and nauplii (34.3 %) were the most frequent zooplankton group in the GR2 fish ponds. *Bosmina longirostris* was the most frequent cladocerans, comprising 15 % (average) of zooplankton on average. Genus *Daphnia* comprised 5.4 % (average) of zooplankton. *Daphnia galeata* (2.5 %) was the most frequent *Daphnia* species. Other species of this genus comprised less than 2 % of zooplankton. *Daphnia* average size was 0.85 mm at the sites of this group. The average size of zooplankton was 0.32 mm.

I found the significant difference between the GR1 and GR2 fish ponds groups in frequencies (%) of rotifers, copepodites and nauplii and *Bosmina longirostris*. A higher average frequency of rotifers was recorded in the GR1 fish ponds. On the other hand, the GR2 fish ponds exhibited a higher frequency (%) of copepodites, nauplii and *Bosmina longirostris*. The difference in the frequencies of genus *Daphnia* was not significant (the difference is less than 1 %) (Tab. 23).

Table 23. Average percentage frequency of main taxonomic groups of zooplankton in fish pond groups late summer period 2004 a 2005 (Blatná-Lnáře region). AVG - average zooplankton body length, AVGd - average *Daphnia* body length, *Σ Daphnia* – sum of genus *Daphnia*

Taxon	**Late summer 2004 – 2005**	
	GR1	**GR2**
Daphnia magna	0.09	0.0
Daphnia pulicaria	0.8	0.0
Daphnia longispina	0.4	0.0
Daphnia galeata	3.8	2.5
Daphnia parvula	0.01	1.3
Daphnia ambigua	0.01	1.1
Daphnia cucullata	1.1	0.6
Σ Daphnia	**6.2**	**5.4**
AVGd [mm]	**0.90**	**0.85**
Ceriodaphnia	1.3	2.0
Bosmina longirostris	6.0	15.0
Chydoridae	1.7	3.4
Ostatní Cladocera	0.03	0.03
Cyclopidae adult	0.2	0.6
Calanoid adult	2.12	0.4
Copepoda, Nauplia	27.3	34.3
Rotifera	57.6	39.1
AVG [mm]	**0.40**	**0.32**

Similarly to the spring season, I made a detailed analysis of the interrelationship between the most frequent zooplankton taxonomic groups and the parameters of eutrophication level. I mainly recorded the occurrence of large cladocerans *Daphnia pulicaria*, rarely *Daphnia magna* and *D. longispina* at the GR1 sites group.

The group of fish ponds GR1 had higher average frequency of *Daphnia*. Likewise in spring period, this is accompanied by higher water transparency and lower chlorophyll-a concentration. The diffcerence between average *Daphnia* frequencies (%) (between GR1 and GR2) is not so marked, but the difference of water transparency and chlorophyll-a concentration is expressive. I assume, that the effect on water transparency, resp. chlorophyll-a concentration is not predominantly caused by filtration effect of *Daphnia*. GR1 fish pond group includes small ‘sky’ ponds, which are naturally less rich in nutrients. Fish farming is not so intensive here. Zooplankton is relatively scarce in these fish ponds and it mainly consists of rotifers, copepodites and nauplii (species with lower filtration effect on phytoplankton). On the other hand, phytoplankton has realtively low amounts of nutrients available and therefore it is not so abundant.

The difference in the species compositions of main zooplankton taxons in the GR1 and GR2 groups is shown in figures 13, 14.

Diaphanosoma brachyurum, *Ceriodaphnia pulchella*, *Eudiaptomus vulgaris*, and *Cyclops strenuus* were recorded predominantly at GR1 sites. Contrariwise, *Acanthocyclops trajani*, *Leptodora kindtii* and *Ceriodaphnia affinis* were found predominantly at the GR2 sites.

I found the significant difference between GR1 and GR2 groups in the species compositions of rotifers (Fig. 14). *Trichocerca elongata*, *T. cylindrica*, *T. longiseta*, *Asplanchna girodi*, *A. brightwelli*, *Kellicottia longispina*, *Hexarthra mira, Brachionus falcatus*, and *Ploesoma hudsoni* were predominantly found at the GR1 sites. The rofifers species composition were mostly formed by the genus *Brachionus* (*Brachionus angularis*, *B. budapestinensis*, *Brachionus calyciflorus*, and *Brachionus diversicornis*), *Polyarthra* (*Polyarthra dolichoptera*, *P. major, P.vulgaris*,), and *Trichocerca* (*T. similis*, *T. pusilla*) species in GR2 fish ponds group.

Daphnia galeata, *Daphnia cucullata*, *Eudiaptomus gracilis*, *Keratella cochlearis*, *Keratella quadrata*, some representatives of the genus *Brachionus* (*Brachionus angularis*, *Brachionus quadridentatus*, *Brachionus calyciflorus*), and *Asplanchna priodonta* were the species occurring both at GR1 and GR2 sites.

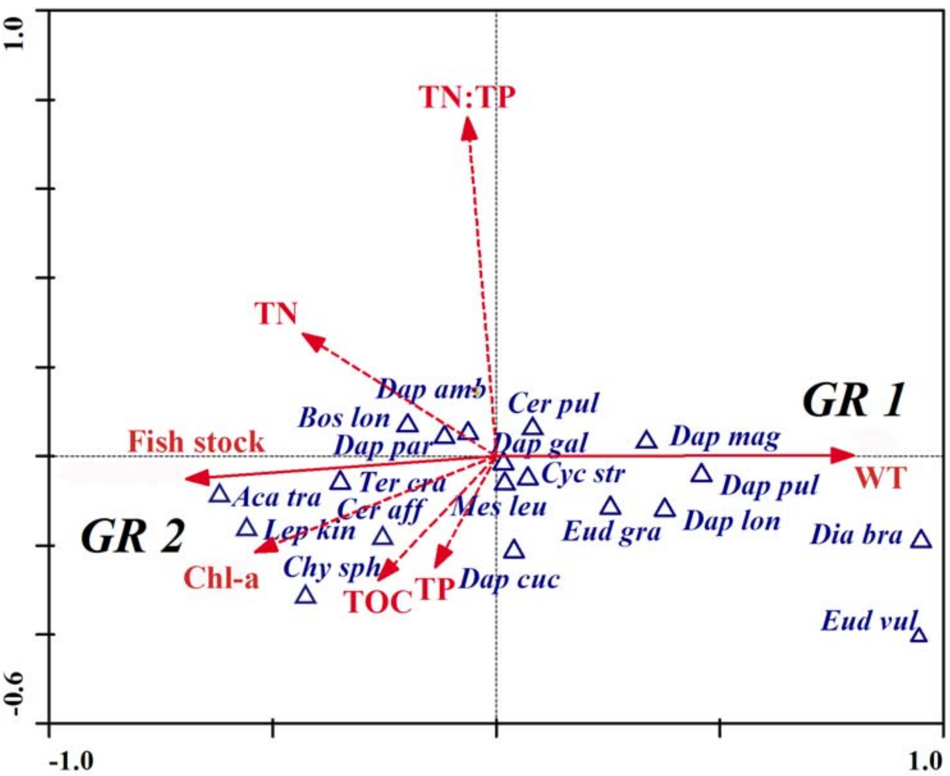


Figure 13. CCA ordinary diagram represents relation among crustacean zooplankton species and chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock - the late summer period 2004-2005. For taxons these abbreviations are used: *Aca tra – Acanthocyclops trajani*, *Bos lon – Bosmina longirostris, Cer aff – Ceriodaphnia affinis, Cer pul – Ceriodaphnia pulchella, Cyc str – Cyclops strenuus, Dap amb – Daphnia ambigua, Dap cuc – Daphnia cucullata, Dap gal – Daphnia galeata, Dap lon – Daphnia longispina, Dap mag – Daphnia magna, Dap par – Daphnia parvula, Dap pul – Daphnia pulicaria, Dia bra – Diaphanosoma brachyurum*, *Eud gra – Eudiaptomus gracilis, Eud vul – Eudiaptomus vulgaris, Chy sph – Chydorus sphaericus Lep kin – Leptodora kindtii, Tre cra – Thermocyclops crassus*

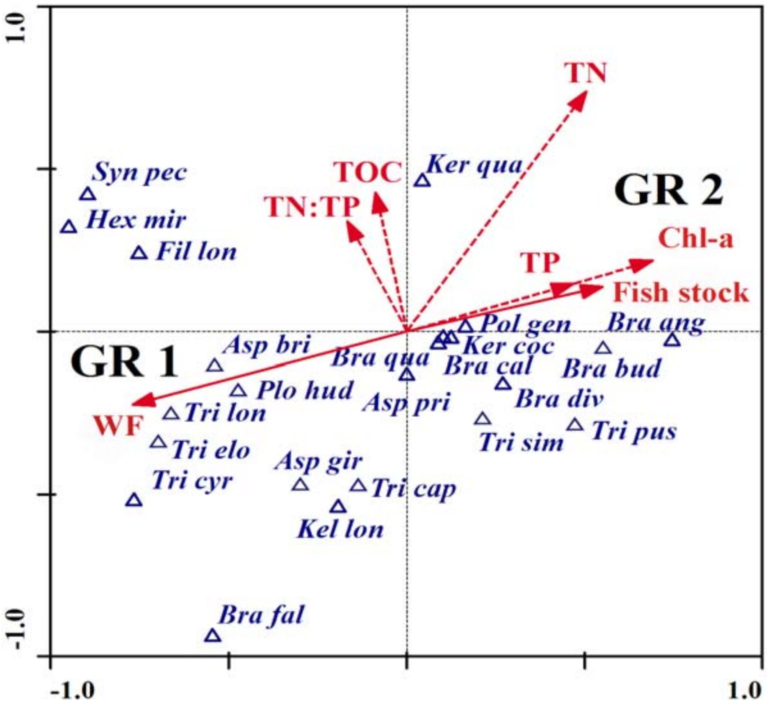


Figure. 14. CCA ordinary diagram represents relation among rotifers species and chlorophyll-a, water transparency, TP, TN, TN:TP, TOC and fish stock - the spring period 2004-2005. For taxons these abbreviations are used: *Asp bri – Asplanchna brightwelli*, *Asp gir – Asplanchna girodi*, *Asp pri – Asplanchna priodonta*, *Bra ang – Brachionus angularis, ,Bra bud – Brachionus budapestinensis, Bra cal – Brachionus calyciflorus, Bra div – Brachionus diversicornis, Bra fal – Brachionus falcatus, Bra qua – Brachionus quadridentatus, Fil lon – Filinia longiseta, Hex mir – Hexarthra mira, Kel lon - Kellicottia longispina, Ker coc – Keratella cochlearis, Ker qua – Keratella quadrata, Pol gen –* rod *Polyarthra, Plo hud – Ploesoma hudsoni, Syn pec – Synchaeta pectinata, Tri cap – Trichocerca capucina, Tri cyr – Trichocerca cylindrica, Tri elo – Trichocerca elongata, Tri lon – Trichocerca longiseta, Tri pus – Trichocerca pusilla, Tri sim – Trichocerca similis*

4.4. The Effect of Fish Stock on the Species Composition of Zooplankton

The key factor for the formation of zooplankton species composition is the biomass of the fish stock. In this chapter, relationship between the frequencies (%) of the most frequent zooplankton species and the fish stock biomass was analysed. Data from fish ponds of the Blatná-Lnáře region (2004-2005) were evaluated.

Next taxonons and taxonomic groups were assessed: *Daphnia pulicaria, D.galeata, D.cucullata, D.parvula, D.ambigua,* the genus *Ceriodaphnia*, *Bosmina longirostris*, the families Cyclopidae and Diaptomidae (including adults and copepodites), nauplii and Rotifera. The biomass of the fish stock varied between 30 and 1.700 kg.ha^{-1} in the evaluated sites.

Figure 15 shows the effect of the size of the fish stock on the frequency (%) of *Daphnia pulicaria*. There is an evident and statistically significant relationship (R^2 = 0.8673) between the biomass of the fish stock and the frequency of *Daphnia pulicaria*. The highest average frequency (48 %) of this species was recorded with the lowest level of fish stock biomass (less than 100 kg.ha^{-1}). On the other hand, at sites with the fish stock level higher than 750 kg.ha^{-1}, this species was not found.

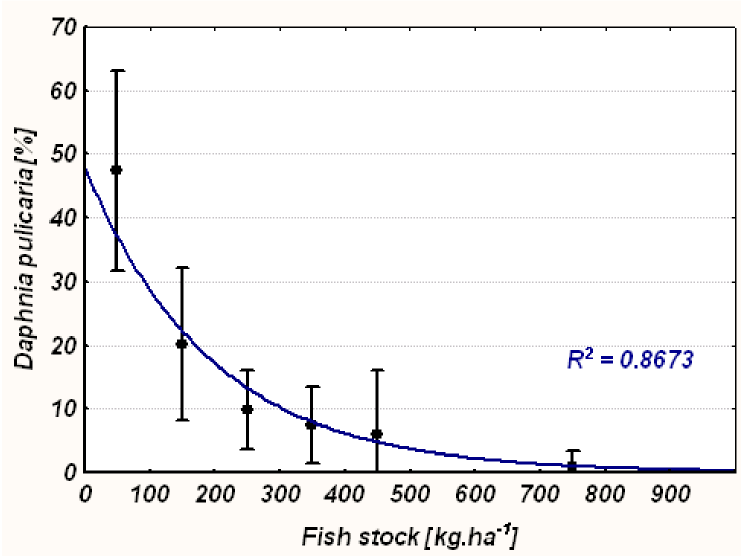


Figure 15. Relationship between frequency (%) of *Daphnia pulicaria* in zooplankton and fish stock biomass. For ternd expression exponential function were used. Coefficient of determination R^2 = 0.8673

Daphnia galeata was found both where the fish stock level was low (less than 100 kg.ha^{-1}) and high (more than 1.200 kg.ha^{-1}). This species reached the highest average frequency (24 %) between the fish stock levels of 250 and 350 kg.ha^{-1} (Fig. 16). Lower average frequency under the conditions of low fish stock level (<150 kg.ha^{-1}) is probably due to the competitive relationship between *D. galeata* and large cladoceran species, such as *Daphnia pulicaria*.

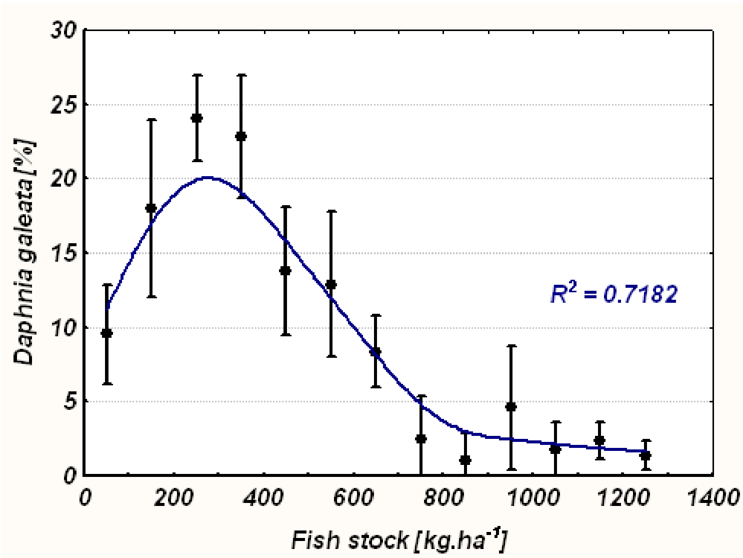


Figure 16. Relationship between frequency (%) of *Daphnia galeata* in zooplankton and fish stock biomass. For ternd expression third-degree polynom were used. Coefficient of determination R^2 = 0.7182

Daphnia cucullata is not abundant in fish ponds subjected to high eutrophication. Nevertheless, at some sites of the Blatná-Lnáře region it comprised a significant part of zooplankton. The occurrence of this species was recorded at both low and high levels of fish stock. Higher average frequencies of this species were recorded, when fish stock biomass were higher than 400 kg.ha^{-1}. The highest frequencies (more than 6.5 % of zooplankton) were recorded at fish stock biomass of 500 – 700 kg.ha^{-1} (Fig. 17).

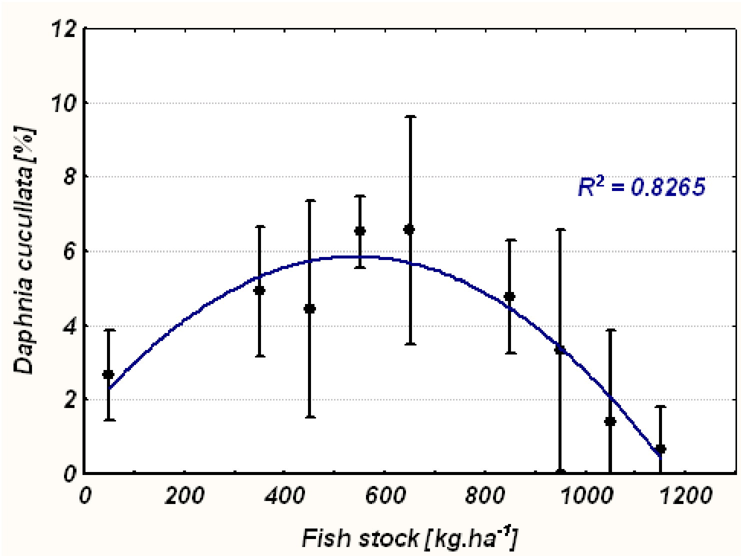


Figure 17. Relationship between frequency (%) of *Daphnia cucullata* in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.8265$

Two small cladoceran species, *Daphnia parvula* and *Daphnia ambiqua*, were found rarely at the observed sites. I evaluated these species together, because they occurred concurrently and had very similar frequencies of the occurrence. Their highest average frequency is not higher than 1.5 % (Fig. 18). Despite such low figures, the statistically significant relationship between these species and fish stock biomass was recorded (R^2 = 0.9714). *Daphnia parvula* and *D. ambiqua* were found very rarely under the conditions of low fish stock biomass. The frequency increased only when the fish stock density was higher than 450 kg.ha^{-1}. These species reach their maximum frequency with fish stock biomass higher than 950 kg.ha^{-1}.

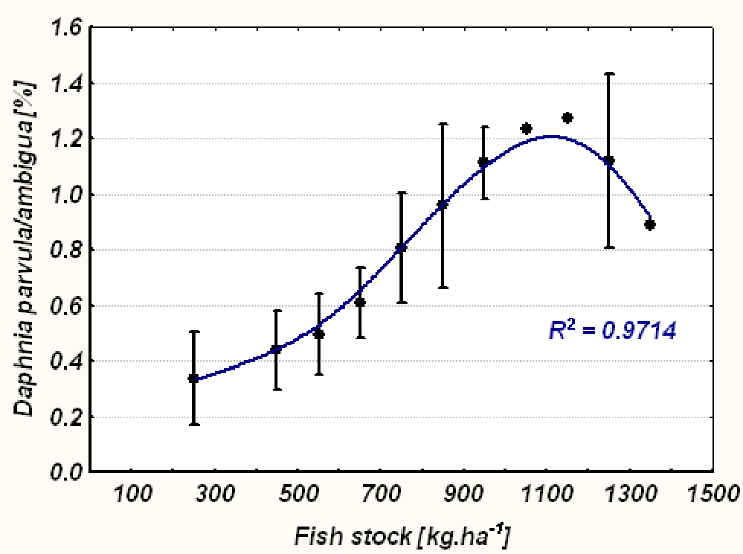


Figure 18. Relationship between frequency (%) of *Daphnia parvula* and *Daphnia ambigua* in zooplankton and fish stock biomass. For ternd expression third-degree polynom were used. Coefficient of determination $R^2 = 0.9714$

Genus *Ceriodaphnia* was found both where the fish stock biomass was relarively low and high (higher than 1.200 kg ha^{-1}). The highest average frequencies were recorded between 500 – 700 kg ha^{-1} (Fig. 19).

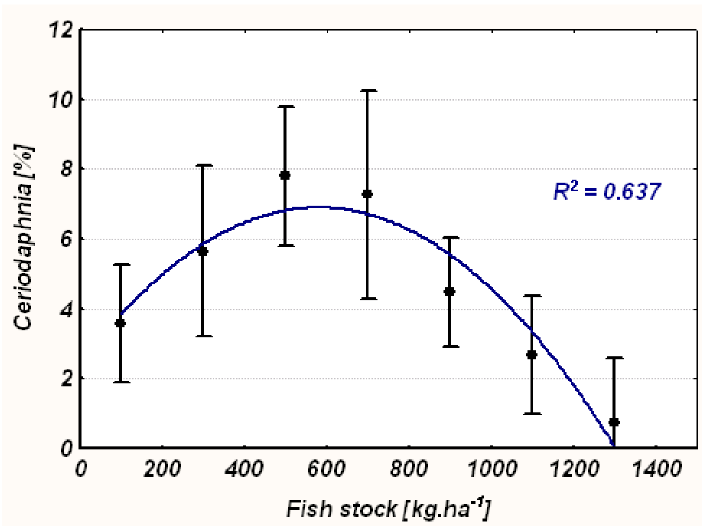


Figure 19. Relationship between pecentage frequency (%) of *Ceriodaphnia* in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.637$

Bosmina longirostris occurred in a wide range of fish stock biomass (Fig. 20). However, the highest frequencies (68.5 %) were recorded when the fish stock level was higher than 1.600 $kg.ha^{-1}$.

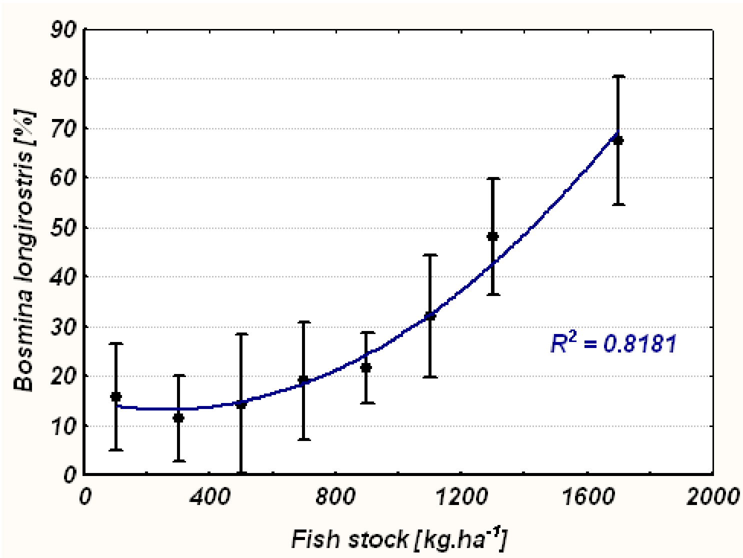


Figure 20. Relationship between frequency (%) of *Bosmina longirostris* in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.8181$

Cyclopidae occurred with all levels of fish stock in relatively high frequencies. They were most frequent with the fish stock levels between 1.300 and 1.500 kg ha^{-1}. With higher fish stocks, their frequency gradually decreased (Fig. 21).

The family Diaptomidae showed the opposite tendency (Fig. 22). This family was represented by two species, *Eudiaptomus vulgaris* and *E. gracilis*. *Diaptomidae* reached their highest average frequencies (11.5 %) with low fish stock biomass. *Eudiaptomus vulgaris* seem to be more sensitive to the grazing pressure of the fish stock compared to the smaller *Eudiaptomus gracilis* (Chapter 4.3., Figs. 9, 13). *E. vulgaris* mostly occurred to 450 – 500 $kg.ha^{-1}$. *E. gracilis* was found when the fish stock biomass was higher than 600 $kg.ha^{-1}$.

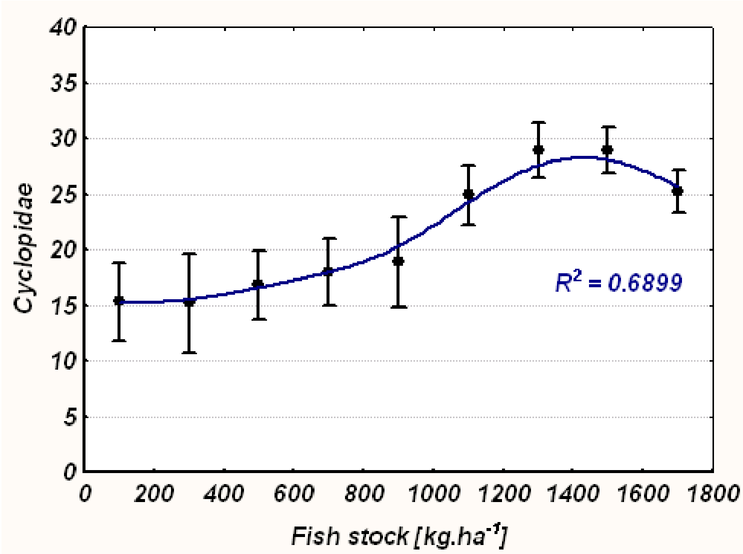


Figure 21. Relationship between frequency (%) of *Cyclopidae* in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.6899$

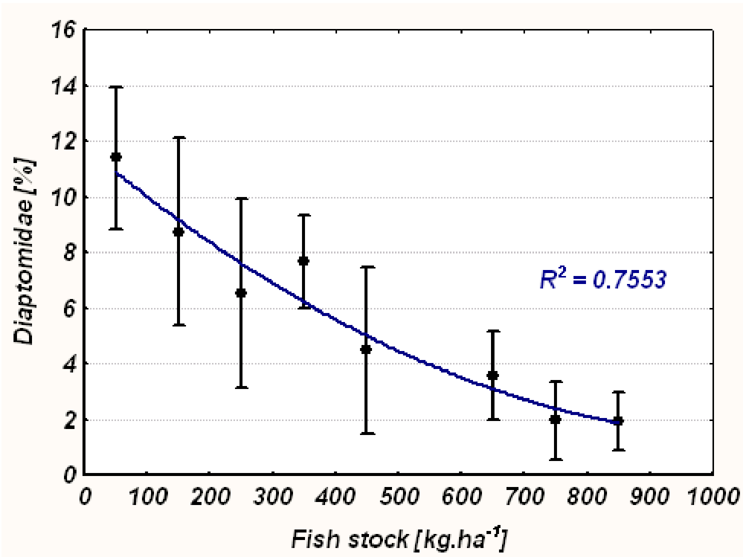


Figure 22. Relationship between frequency (%) of *Eudiaptomidae* in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.7553$

Copepoda nauplii were presented in samples with all levels of fish stock. With fish stock biomass higher than 900 kg.ha^{-1}, the frequency significantly grows. Nauplii reached their highest frequency (40 %) at the highest fish stock biomass (more than 1.600 kg.ha^{-1}) (Fig. 23).

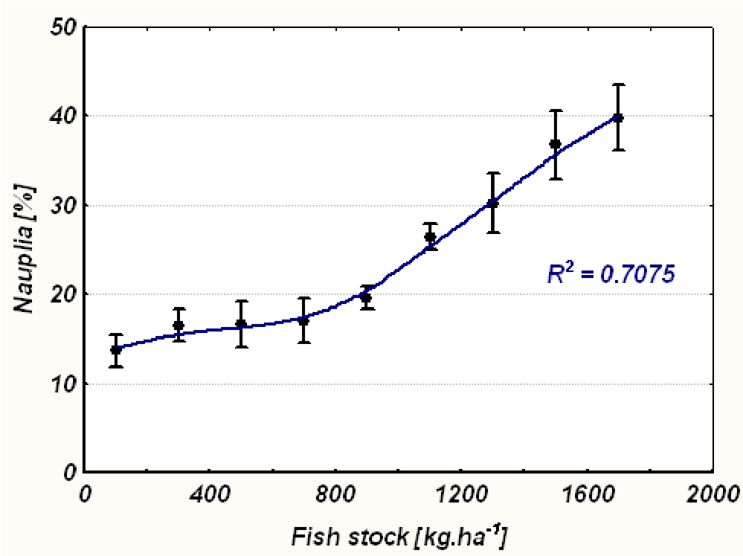


Figure 23. Relationship between frequency (%) of Nauplii in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.7045$

Rotifera average frequencies varied between 39 – 50 %. Under the conditions of a low fish stock biomass, rotifers reached the mean frequency of nearly 40 % on average. With increasing fish stock biomass, slight increase of their frequency was recorded (Fig. 24). It is, however, not so significant as with e.g. nauplii.

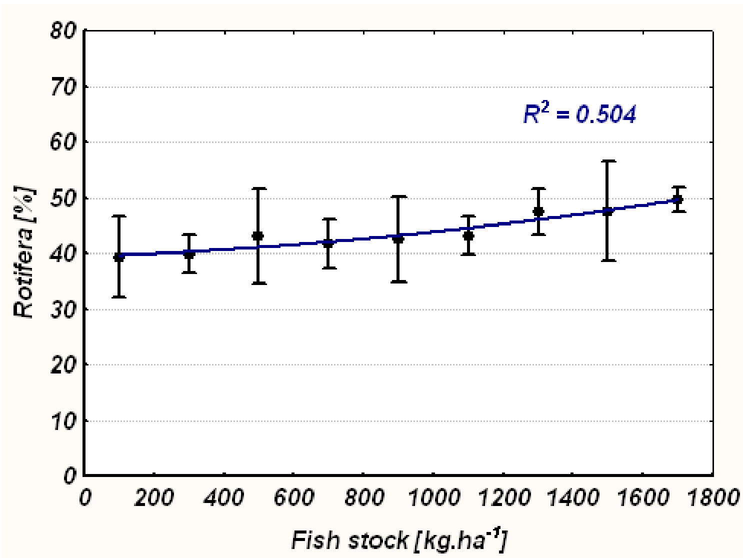


Figure 24. Relationship between frequency (%) of Rotifers in zooplankton and fish stock biomass. For ternd expression second-degree polynom were used. Coefficient of determination $R^2 = 0.504$

4.5. The *Daphnia* index

Most hydrobiological studies on zooplankton specify the amount of zooplankton by abundance (ind.l^{-1}) or biomass. It is, however, extremely time demanding and, under certain conditions, very difficult to obtain a representative quantitative sample.

Besides quantitative expression, the structure of zooplankton community can be described also by frequencies (%) and individual sizes of main taxonomic groups (Wetzel & Likens, 2000). Pechar (1995) showed that there is a relationship between the frequency (%) of genus *Daphnia* and the average size of zooplankton. This relationship corresponds with water transparency and fish stock, and illustrates the overall structure of zooplankton.

The aims of this chapter are: (1) to find out a numerical value (comprising frequencies of the occurence and sizes of *Daphnia*) correlation with biomass or abundance (e.g. ind.l^{-1}) and (2) whether this value is useful in *Daphnia* - phytoplankton interactions evaluation.

4.5.1. Definition of the *Daphnia* index

Daphnia index (DI) combines the average size of *Daphnia* in mm (multiplied by 10 to obtain a value higher than 1, and subsequently cubed) and their frequency of the occurrence (in % divided by 100). This relation is then extracted (Eq.1).

$$DI = \sqrt{\frac{(AVGd \times 10)^3 \times F}{100}}$$

Equation 1. Relationship between average *Daphnia* body length (mm) and frequency (%) of genus *Daphnia* in zooplankton. AVGd - average *Daphnia* body length in mm, F – frequency (%) of genus *Daphnia* in zooplankton

DI is based on allometric relationships between size, quantity, biomass, and filtration activity of cladocerans. The influence of *Daphnia* on phytoplankton depends on a filtration rate that is proportional to *Daphnia* biomass. The biomass is in an allometric relationship to the size of individuals (length), which can be roughly described by an exponential function, a cube (Figs 25A, B) (Egloff and Palmer, 1971; Bottrell et al., 1976; Přikryl, 1981; Haney, 1985). As can be seen from the Figures 1A and 1B, the biomass and the DI start growing significantly when the size is greater than approximately 1.0 – 1.5 mm.

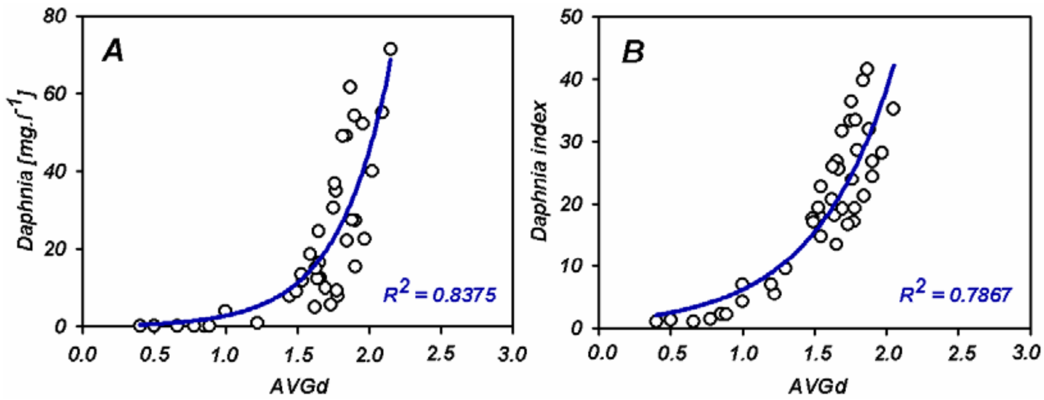


Figure 25. Relationship between average *Daphnia* length (AVGd) and their biomass (**A**) and average *Daphnia* length and Daphnia index (**B**)

The relationship between abundance and filtration rate can be described by the hyperbolic function. The first part of the curve is characterised by a steep increase of filtration rate caused by the increase of *Daphnia* abundance. When *Daphnia* is high in abundance, the effect of their filtration activity is not so strong, and therefore the growth is reduced in the second part of the curve (Sommer, 1989; Cyr & Pace, 1993).

4.5.2. Verification and validity of the *Daphnia* index

The relationship of DI and the "quantitative" characteristics of zooplankton was tested on a set of data from experimental fish ponds in the years 2004-2006 (see the chapter Material and Methods).

Figures 26A, B illustrate the relationships between abundance, biomass and frequencies (%) of *Daphnia*. A significant relationship between *Daphnia* biomass and their frequencies (R^2 = 0.8599) and between *Daphnia* abundance and their frequencies (R^2 = 0.8123) was found. Figure 2B shows the initial sharp increase of *Daphnia* frequencies. After the biomass exceed the level of 20 mg l^{-1} and 60 % frequency, the increase is not so notable. This decline can be explained by the relationship between average size of *Daphnia* (AVGd) and their biomass (Fig. 25A). There is an exponential relation between *Daphnia* size and their biomass. The increase of biomass is initially slow, followed by a significant increase associated with the increase of *Daphnia* size. Therefore, the increase of biomass is faster than the growth of frequencies (%).

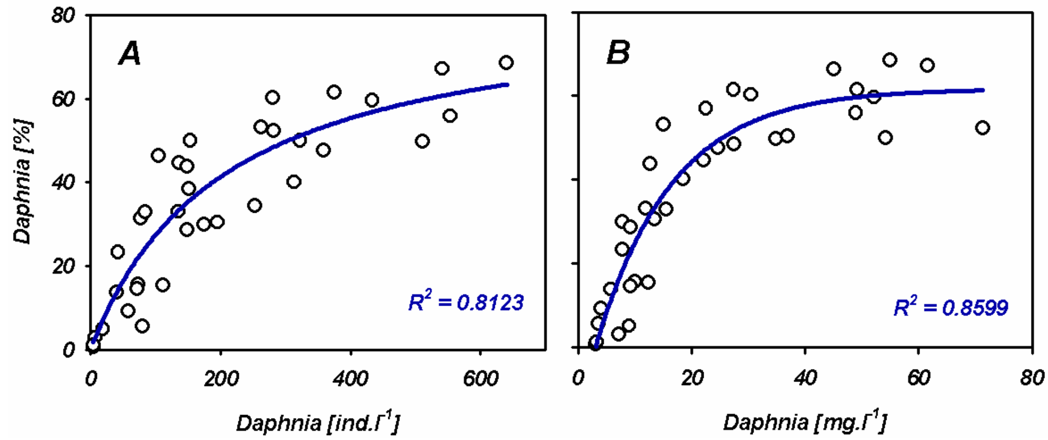


Figure 26. Relationship between abundance and frequency (%) of genus *Daphnia* (**A**) and biomass (**B**) and frequency of genus *Daphnia* (%)

Figures 27C and 27D show the relationship between the DI, biomass and abundance. I found out close relation between *Daphnia* biomass and DI (R^2 = 0.8584) and between biomass of *Daphnia* > 1.0 mm and DI (R^2 = 0.8606).

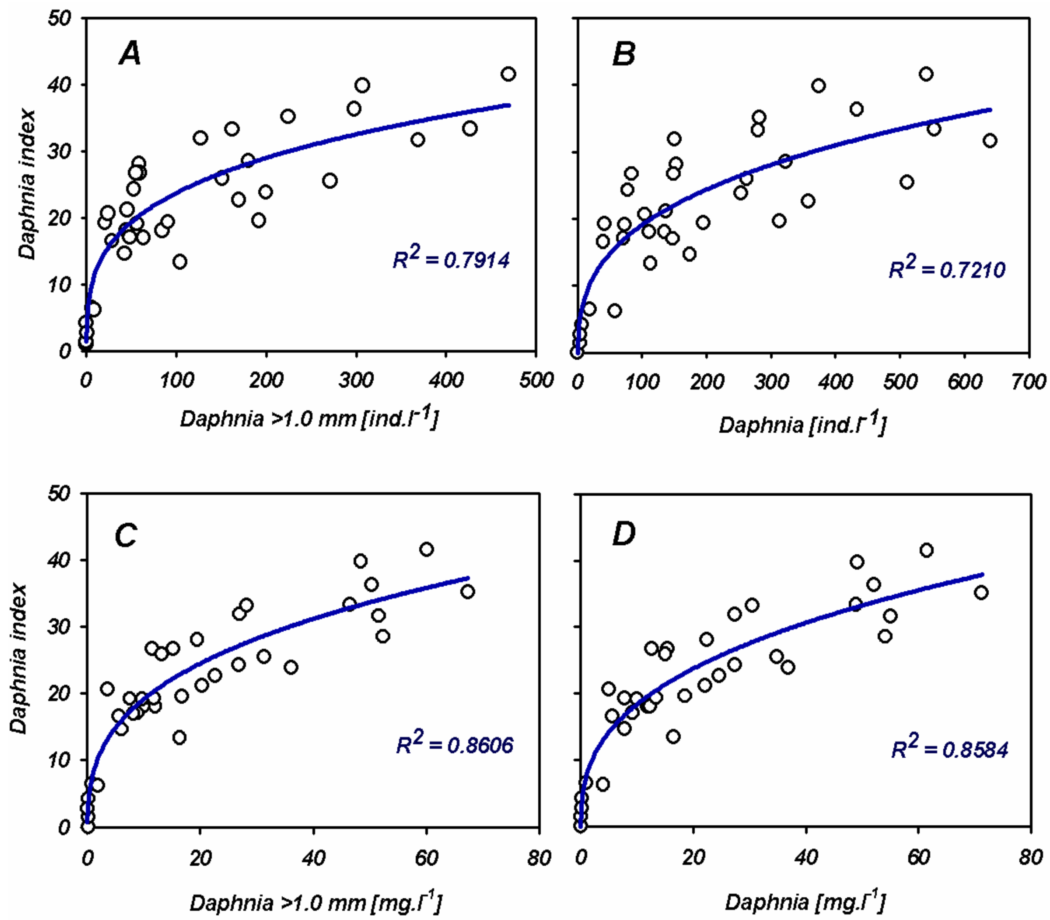


Figure 27. Relationship between *Daphnia* abundance (**A**), abundance of *Daphnia* >1.0 mm (**B**) and *Daphnia* index and *Daphnia* biomass (**C**), biomass of *Daphnia* >1.0 mm (**D**) and Daphnia index

A greater variance of data was recorded with the relationships between *Daphnia* abundance (both total *Daphnia* abundance and abundance of *Daphnia* > 1.0 mm) and DI (Figs 28A, B). Nevertheless, it is still a relation with a high determinant coefficient (R^2 = 0.7210 and 0.7914). Table 1 shows the DI values for different sizes and frequencies of *Daphnia*.

Table 24. Daphnia index values expressed for different body length and different frequency (%) of genus *Daphnia*

***Daphnia* body length [mm]**	**[%]**							
	5	**10**	**20**	**30**	**40**	**50**	**60**	**70**
0.5	2.5	3.5	5.0	6.1	7.1	7.9	8.7	9.4
1.0	7.1	10.0	14.1	17.3	20.0	22.4	24.5	26.5
1.5	13.0	18.4	26.0	31.8	36.7	41.1	45.0	48.6
2.0	20.0	28.3	40.0	49.0	56.6	63.2	69.3	74.8
2.5	28.0	39.5	55.9	68.5	79.1	88.4	96.8	104.6
3.0	36.7	52.0	73.5	90.0	103.9	116.2	127.3	137.5

Different studies indicate that the percentage frequencies of large Cladocera of the genus *Daphnia* (> 1.0 mm) over 20 – 30 % are able to reduce the development of phytoplankton by their filtration activity (Gliwicz, 1969; Kořínek, 1987; Pechar et al., 2002). Figure 28A shows the relationship between DI and chlorophyll-a concentration. With DI higher than 15, no chlorophyll-a concentrations over 100 µg l^{-1} are recorded. This value of DI corresponds to a frequency of approximately 20 % and the size of 1.00 mm. At the same time, the stronger grazing pressure brings about a higher water transparency (Fig. 28B).

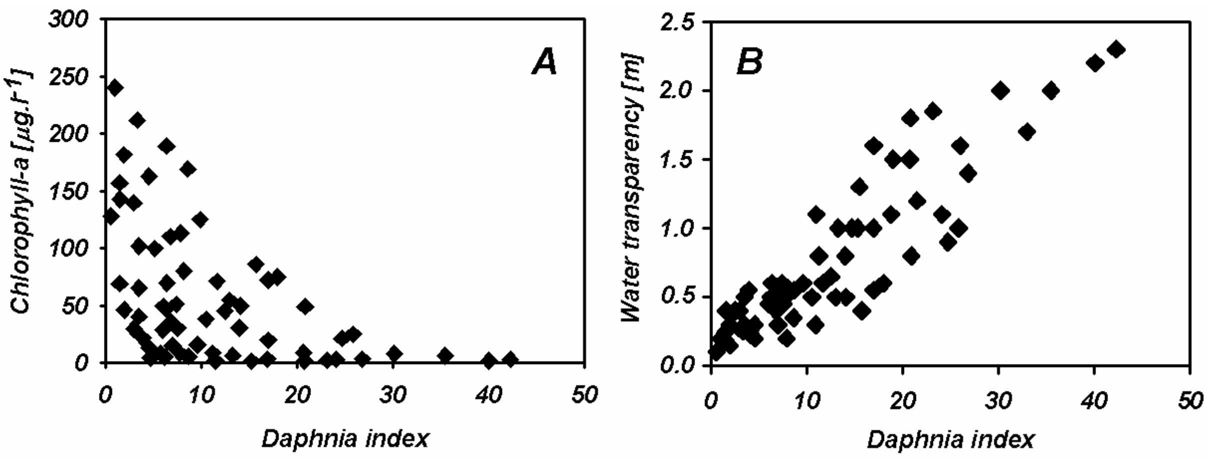


Figure 28. Relationship between Daphnia index and chlorophyll-a concentration (**A**) and Daphnia index and water transparency (**B**)

The total biomass of zooplankton is relatively similar during the vegetation season. The main changes become in zooplankton species composition. Figures 29A and 29B show the seasonal development of zooplankton biomass (divided into fractions <1.0mm and >1.0mm) and development of frequencies (%) of main zooplankton taxonomic groups.

These examples are supplemented by the seasonal course of DI and chlorophyll-a concentration (Fig. 29C)

Based on the mentioned comparisons, the *Daphnia* index may be used as a certain alternative to quantitative indicators. At the same time, it nicely illustrates the status of zooplankton and its possible influence on phytoplankton.

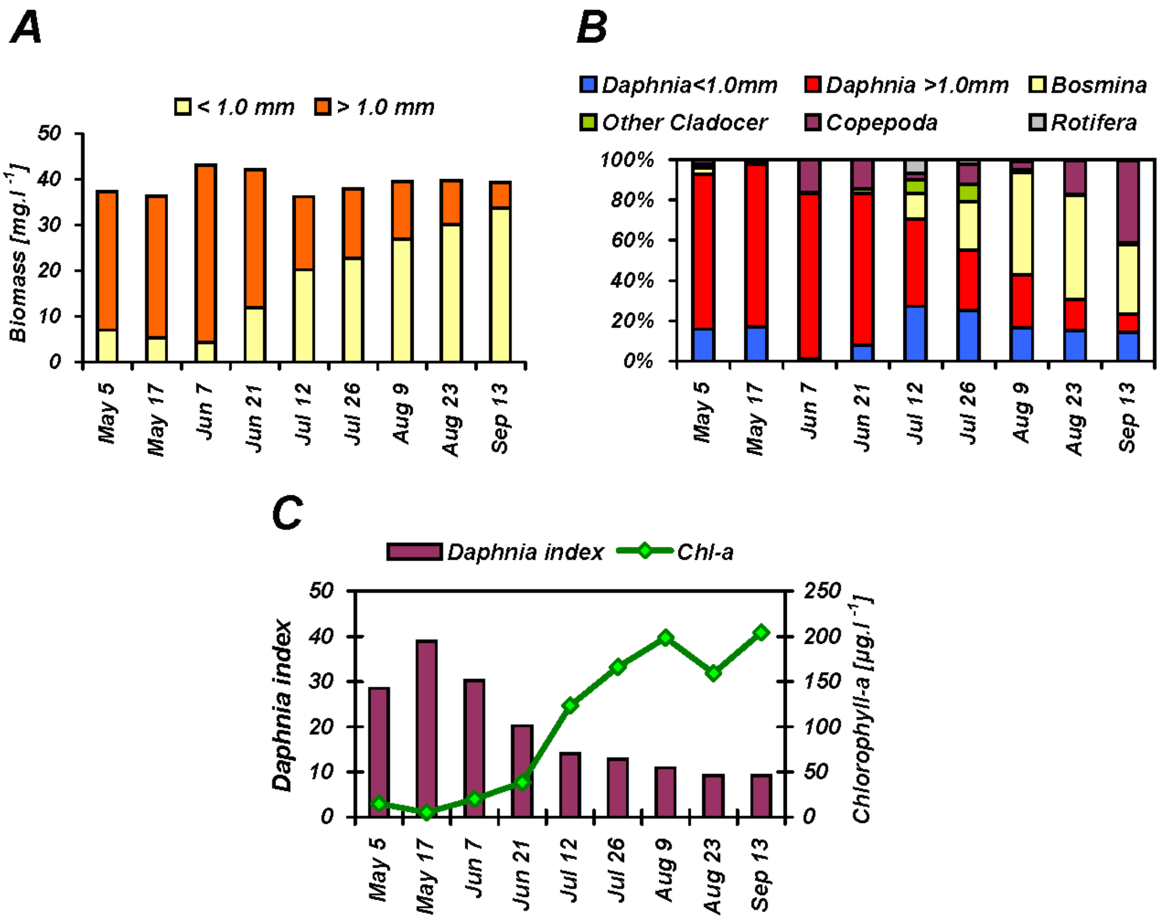


Figure 29. Seasonal development of total zooplankton biomass (divided into fractions < 1.0mm and > 1.0 mm) (**A**), frequencies (%) of main zooplankton taxonomic groups (**B**) and chlorophyll-a and Daphnia index (**C**) in fish pond Humlena 5 (season 2005)

4.6. Plankton and the Top-down Regulation in Hypertrophic Fish Ponds

4.6.1. Třeboň Region 2000-2001

During our investigations in Třeboň region, number of cases when large cladoceran grazers (*Daphnia* >1.0 mm mean length) were not able to reduce the development of phytoplankton were found. In these situations, *Daphnia* index was higher than 15 (see the chapter Material and Methods), while the chlorophyll-a concentration was higher than 100 $\mu g.l^{-1}$. Such situations were relatively rare in the spring sampling period when they occurred at 7 % of the observed sites (Fig. 30). On the other hand, the occurrence of these situations was more frequent in the summer and late summer sampling periods when they were recorded in 18 % of the fish ponds (Fig. 31).

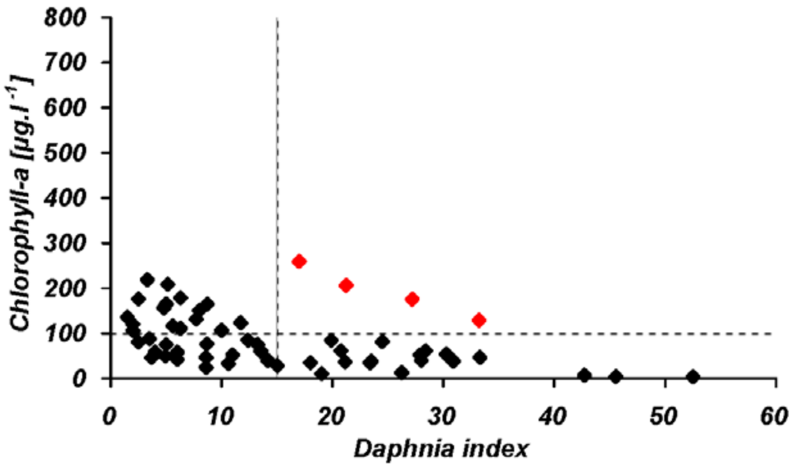


Figure 30. Relationship between Daphnia index and chlorophyll-a concentration in the spring period 2000-2001 (Třeboň region). ♦ - Daphnia index > 15 and chlorophyll-a > 100 $\mu g.l^{-1}$

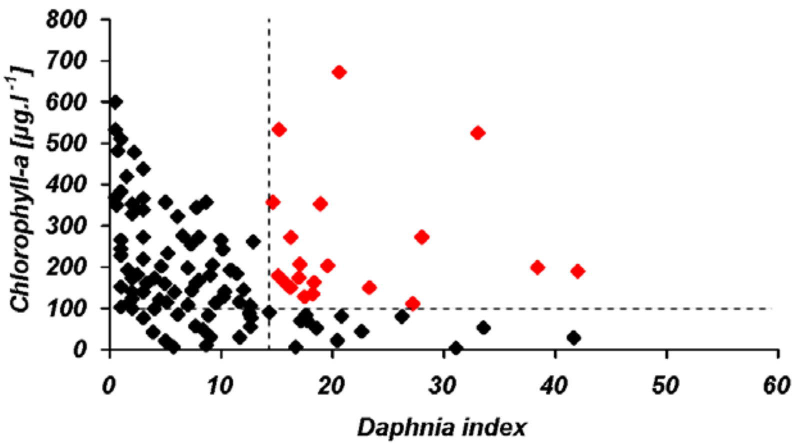


Figure 31. Relationship between Daphnia index and chlorophyll-a concentration in summer and late summer periods 2000-2001 (Třeboň region). ♦ - Daphnia index > 15 and chlorophyll-a > 100 $\mu g.l^{-1}$

Table 25 gives an overview of the cases when large *Daphnia* were not able to reduce the phytoplankton biomass (expresed as chlorophyll_a concentration). The values of the *Daphnia* index and chlorophyll-a concentrations are compared with the frequencies (%) of the dominant phytoplankton taxonomic groups.

The dominant part of phytoplankton mostly consist of single-filamentous or small-colonial Cyanophytes. The predominant genus were *Anabaena*, *Limnothrix*, *Planktothrix*, sometimes *Microcystis*, *Pseudanabaena* and *Aphanizomenon*. But there were some examples of Chlorococales or Cryptophyceae predominance.

Table 25. Examples when structure of plankton does not correspond with top-down regulation of phytoplankton. Daphnia index higher than 15 and simultaneously concentration of chlorophyll-a is higher than 100 $\mu g.l^{-1}$ (DI – Daphnia index, phytoplankton – dominant group of phytoplankton, Chl-a – chlorophyll-a) (Třeboň region 2000-2001). Anab – *Anabaena*, Aphan. – *Aphanizomenon*, Bacillar. – Bacillariophyceae, Crypt. – *Cryptomonas*, Chlamyd. – *Chlamydomonas*, Chloroc. – Chlorococales, Limnoth. – *Limnothrix*, Microcys. – *Microcystis*, Nitzch. – *Nitzchia*, Plankt. – *Planktothrix*, Pseudan. – *Pseudanabaena*, Scened. – *Scenedesmus*, Synech. – Synechococcales,

Year	Date	Fish pond	Phytoplankton	DI	Chl-a [$\mu g.l^{-1}$]
2000	18.4.00	Opatovický	Limnoth.,Nitzch., Crypt.	17.0	259
	18.4.00	Potěšil	Limnoth., Pseudan., Plankt., Chlorococ., Crypt.	27.2	175
	19.4.00	Starý Hospodář	Plankt., Scened.	33.2	129
	19.4.00	Ženich	Limnoth., Chlorococ.	21.2	206
	27.6.00	Velký Tisý	Plankt., Chlorococ.	18.2	135
	27.6.00	Naděje	Scened., Chlorococ.	15.8	161
	27.6.00	Rod	Limnoth., Chlorococ.	17.1	207
	27.6.00	Stružky	Crypt., Chlamyd., Chlorococ.	38.4	199
	27.6.00	Koclířov	Plankt., Chlorococ.	27.2	111
	22.8.00	Ženich	Plankt., Chlorococ., Bacillar.	17.0	174
	22.8.00	Rod	Plankt., Chlorococ.	15.0	357
	22.8.00	Staré Jezero	Plankt., Ananb., Chlorococ.	16.3	272
	22.8.00	Velký Tisý	Plankt.	19.6	203
	Average			**22.8**	**199**
2001	18.6.01	Káňov	Chlorococ., Crypt.	18.3	163
	18.6.01	Vyšehrad	Chlorococ.	28.0	273
	18.6.01	Nový Vdovec	Plankt., Anab., Chlorococ.	17.5	128
	14.8.01	Starý Hospodář	Anab, Aphan.	15.1	179
	14.8.01	Káňov	Chlorococ., Crypt.	16.2	150
	14.8.01	Purkrabský	Anab., Plankt., Chlorococ.	15.2	533
	15.8.01	Naděje	Microcys., Anab.	20.6	672
	15.8.01	Nový Vdovec	Anab., Plankt.	33.0	525
	15.8.01	Potěšil	Plankt., Anab.	42.0	190
	15.8.01	Verfle	Chlorococ., Crypt., Anab.	20.0	190
	15.8.01	Cirkvičný	Synech.	23.3	150
	Average			**22.7**	**287**

Subsequently, relationships between the occurrence of large *Daphnia* (expressed as Daphnia index), fish stock biomass, and the individual weights of fish stock were analysed. The relation between the occurrence of large *Daphnia* and the fish stock biomass corresponds to the top-down regulation mechanism (the higher the fish stock biomass, the lower the number of large cladocerans) in the spring period. Only in 5 % of the cases, situations when relatively high fish stock (more than 500 kg.ha^{-1}) was not able to eliminate large *Daphnia* were recorded (Fig. 32). These situations occurred under conditions when the average weight of breeding carp was higher than 1 kg (Fig. 33).

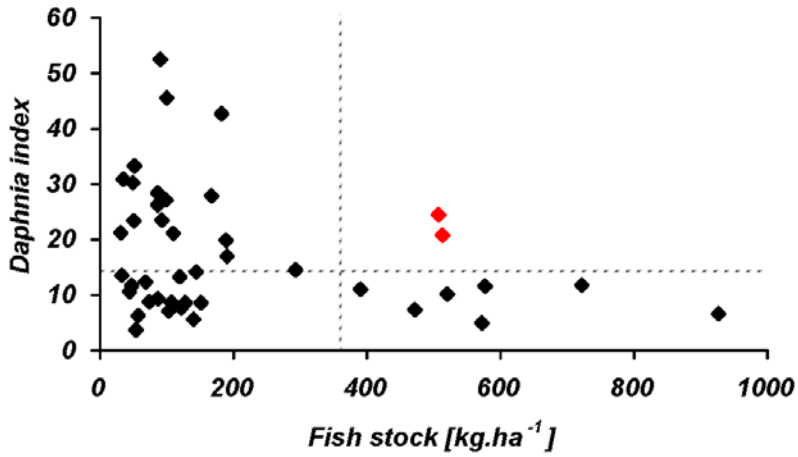


Figure 32. Relationship between Daphnia index and fish stock biomass in spring period 2000-2001 (Třeboň region). ♦ - Daphnia index > 15 and fish stock > 500 kg.ha^{-1}

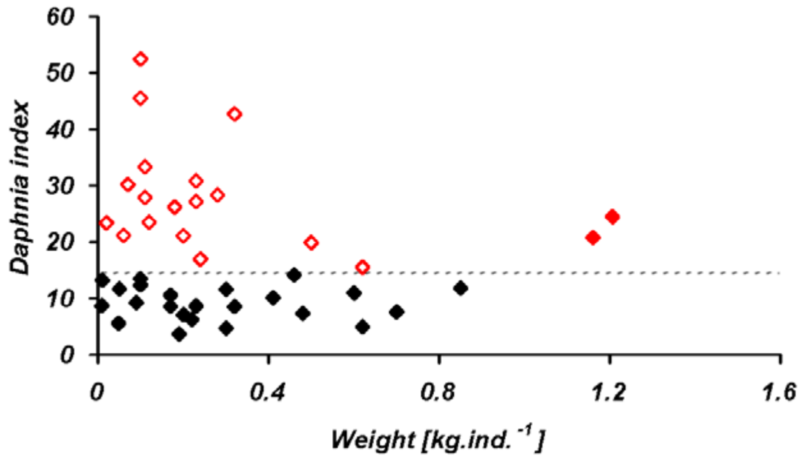


Figure 33. Relationship between Daphnia index and average individual weight of carp in spring period 2000 – 2001 (Třeboň region). ♦ - Daphnia index > 15 and weight > 1.0 kg ◊ - Daphnia index > 15 and weight < 0,8 kg, ♦ - Daphnia index < 15

At the top of the vegetation season (the late summer sampling period), the occurrence of situations when high fish stock was not able to eliminate large *Daphnia* was distinctively more frequent than in the spring sampling period. The frequency of these situations was almost 31 % (Fig. 34). Most of them (63 %) were recorded when fish stock biomass was higher than 800 kg.ha^{-1}. Simultaneously, these cases occurred most frequently (64 %) when the average individual weight of carp was higher than 1.8 kg (Fig. 35).

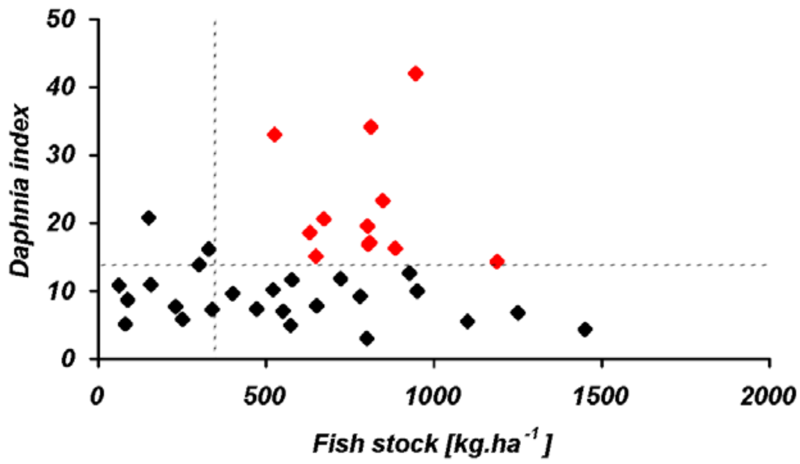


Figure 34. Relationship between Daphnia index and fish stock biomass in late summer period 2000-2001 (Třeboň region). ♦ - Daphnia index > 15 and fish stock > 500 kg.ha^{-1}

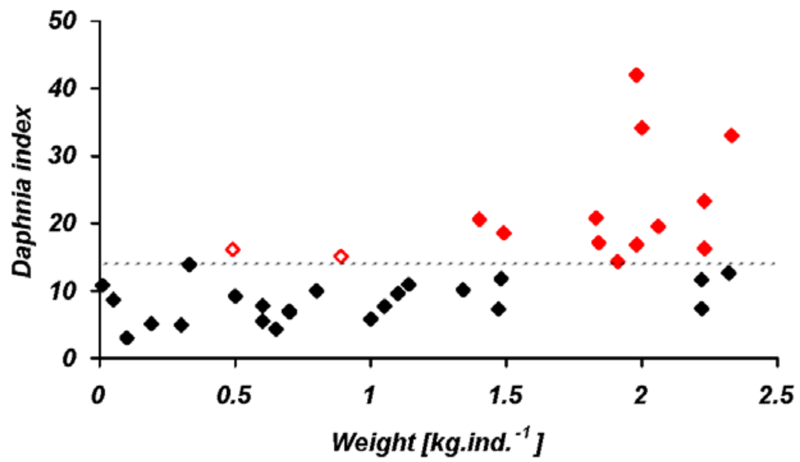


Figure 35. Relationship between Daphnia index and average individua weight of Carp in late summer period 2000-2001 (Třeboň region). ♦ - Daphnia index > 15 and weight > 1.3 kg ◊ - Daphnia index > 15 and weight < 0,8 kg, ♦ - Daphnia index < 15

4.6.2. Blatná-Lnáře Region 2004-2005

I also recorded cases when large *Daphnia* (expressed by the *Daphnia* index > 15) were not able to reduce the development of phytoplankton (chlorophyll-a concentration higher than 100 μg.l^{-1}) at the sites of the Blatná-Lnáře region. These situations occurred less frequently than in the fish ponds of the Třeboň region. No such case was recorded in the spring sampling periods of 2004-2005 (Fig. 36). This situations was detected at 6 % of the observed sites, in summer and late summer sampling periods (Fig. 37).

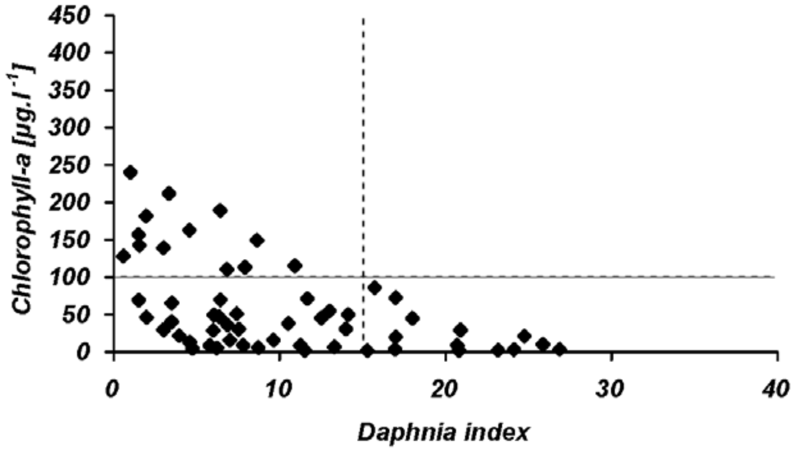


Figure 36. Relationship between Daphnia index and chlorophyll-a concentration in spring period 2004-2005 (Blatná-Lnáře region)

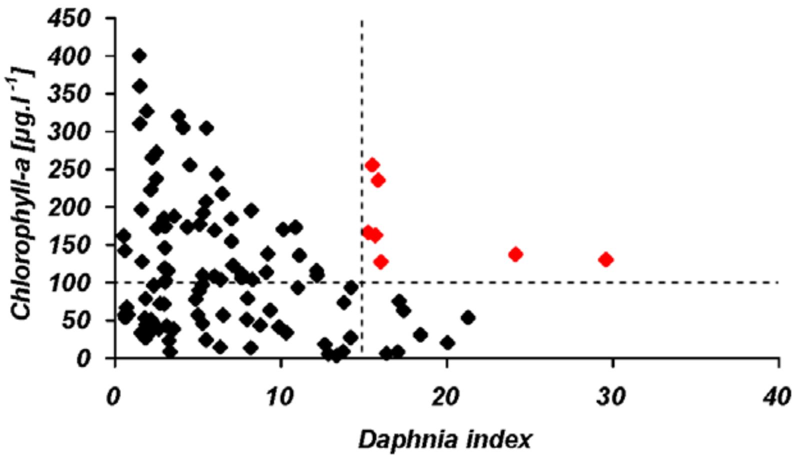


Figure 37. Relationship between Daphnia index and chlorophyll-a concentration in summer and late summer periods 2004-2005 (Blatná-Lnáře region). ♦ - Daphnia index > 15 and chlorophyll-a > 100 μg.l^{-1}

Table 26 summarized situations when large *Daphnia* were not able to reduce phytoplankton in the Blatná-Lnáře region. The values of the *Daphnia* index and chlorophyll-a concentrations are supplemented frequencies of the dominant taxonomic groups of phytoplankton. In most of cases, large *Daphnia* were not able to reduce phytoplankton biomass, when single-filamentous (*Anabaena*, *Planktothrix*, *Aphanizomenon*, *Cylindorspermopsis*) and small-colonial (*Microcystis*) Cyanophyceae species prevailed in phytoplankton.

Table 26 Examples when structure of plankton does not correspond with top-down regulation of phytoplankton.Daphnia index higher than 15 and simultaneously concentration of chlorophyll-a is higher than 100 µg.l^{-1} (DI – Daphnia index, phytoplankton – dominant group of phytoplankton, Chl-a – chlorophyll-a) (Blatná-Lnáře region 2004-2005). Anab – *Anabaena*, Aphan. – *Aphanizomenon*, Chloroc. – Chlorococales, Cylindrosp. – *Cylindrospermopsis*, Microcys. – *Microcystis*, Plankt. – *Planktothrix*.

Year	Date	Fish pond	Phytoplankton	DI	Chl-a [µg.l^{-1}]
2004	13.9.04	V. Kocelovický	Anab., Aphan., Chlorococ.	29.6	131
	28.6.04	Pátek	Microcys., Aphan., Plankt.	16.0	128
	28.6.04	Mlýnský	Anab., Plankt., Chlorococ.	15.7	163
	28.6.04	Nadýmač	Anab., Plankt., Cylindrosp.	15.5	256
	Average			**19.2**	**170**
2005	6.9.05	Smyslov	Microcys., Anab., Chlorococ.	15.3	167
	6.9.05	H.Tchořovický	Plankt., Chlorococ.	15.0	235
	Average			**15.2**	**201**

Accordingly to the Třeboň region, situations when high fish stock biomass were not able to reduced the occurrence of large *Daphnia* were recorded. These situations (fish stock higher than 500 kg.ha^{-1}) were infrequent in the spring season. Their frequency was less than 9 % (Fig. 38). The average individual weight of carp was higher than 1 kg in these situations (Fig. 39).

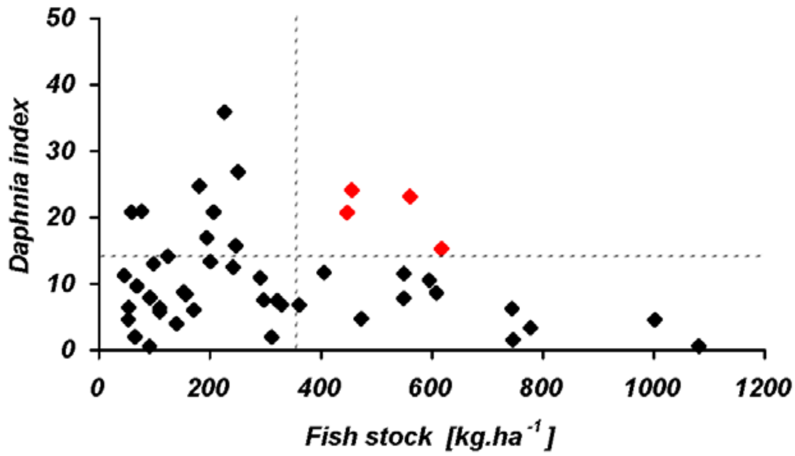


Figure 38. Relationship between Daphnia index and fish stock biomass in spring period 2004-2005 (Blatná-Lnáře region). ♦ - Daphnia index > 15 and fish stock > 400 kg.ha^{-1}

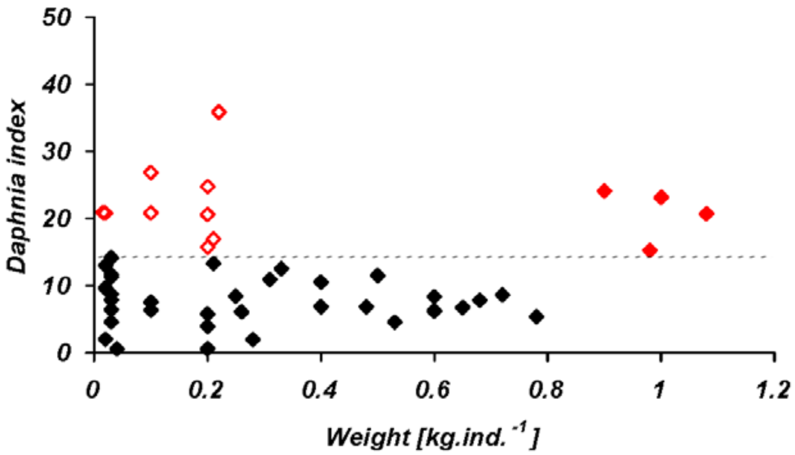


Figure 39. Relationship between Daphnia index and average individual weight of Carp in spring period 2004-2005 (Blatná-Lnáře region). ♦ - Daphnia index > 15 and weight > 0.8 kg ◊ - Daphnia index > 15 and weight < 0.3 kg, ♦ - Daphnia index < 15

At the top of the vegetation season (the late summer sampling period), the frequency of situations, when high fish stock was not able to reduce large *Daphnia* was about 6 % (Fig. 40). It is thus much lower than the occurrence frequency of these situations in the fish ponds of the Třeboň region. All these situations appeared when the individual weight of carp exceeded 1.8 kg (Fig. 41).

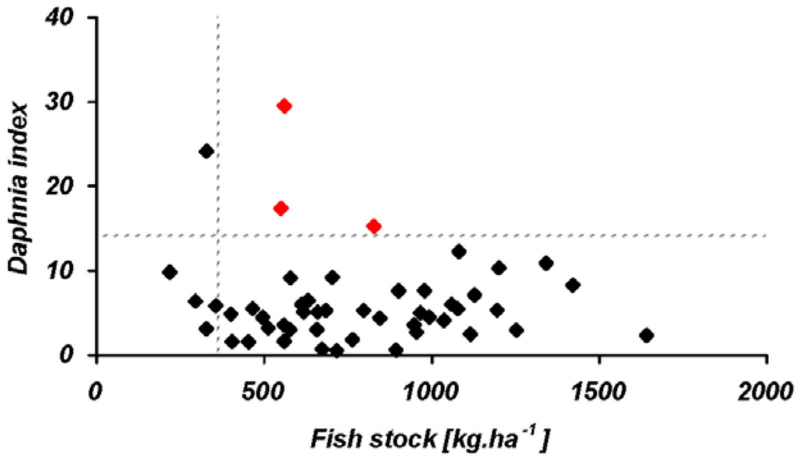


Figure 40. Relationship between Daphnia index and fish stock biomass in late summer period 2004-2005 (Blatná-Lnáře region). ♦ - Daphnia index > 15 and fish stock > 500 kg.ha^{-1}

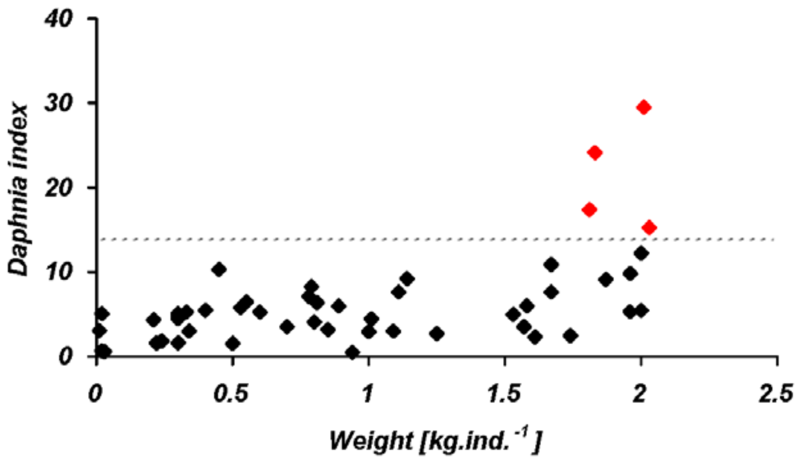


Figure 41. Relationship between Daphnia index and average individua weight of Carp in late summer period 2004-2005 (Blatná-Lnáře region). ♦ - Daphnia index > 15 and weight > 1.8 kg, ♦ - Daphnia index < 15

Generally, the occurrence of situations which did not corespond to classical concenpt of top-down regulation were more frequent in Třeboň region fish ponds. Frequent occurence of these situations advert to poor trophic coupling and low production effectiveness.

4.7. The Efficiency of Top-down Regulation in Hypertrophic Condition – Impact on Fish Production

The efficiency of the fish pond productivity is depended on plankton structure. Zooplankton, especially large *Daphnia* play a key role in energy and matter transfer from phytoplankton to final fish production. Therefore, the amount of natural fish stock production is mainly dependent on the abundance of large *Daphnia* (Kořínek et al., 1987).

In this chapter, I evaluated the impact of plankton structure on natural fish stock production and compared the efficiency of top-down regulation in Třeboň (2000-2001) and Blatná-Lnáře (2004-2005) fish ponds. Daphnia index (DI) was used as a parameter indicating amount and body size of genus *Daphnia*. Relative natural carp productivity (RNPc) represented the amount of natural increment of breeding carp (see chapter 3 - Material and methods). High value of Daphnia index (high frequency of large Daphnia) should enable high relative natural productivity and *vice versa*.

The results show explicit differences between the Třeboň and Blatná-Lnáře fish ponds. There was no statistically significant correlation between RNPc and DI (R^2 = 0.2166) in Třeboň fish ponds in 2000-2001 (Fig. 42). Contrariwise, statistically significant correlation between RNPc and DI (R^2 = 0.7057) was recorded in the fish ponds of the Blatná-Lnáře region in 2004-2005 (Fig. 43).

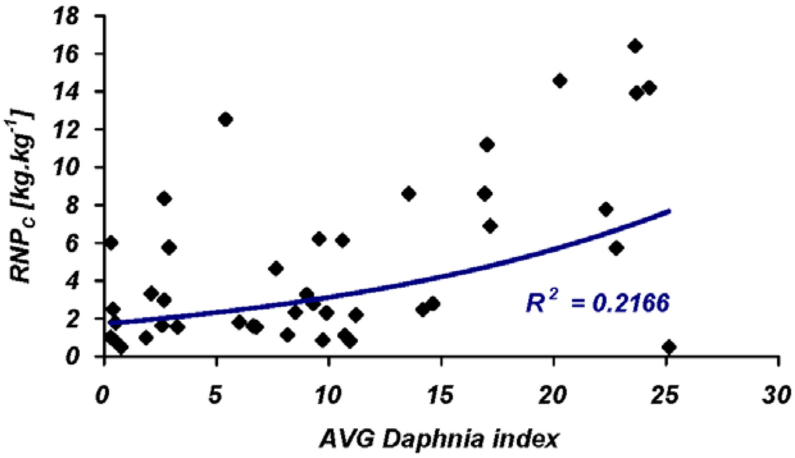


Figure 42. Relationship between average Daphnia index and relative natural productivity of carp (RNP_C) in 2000-2001 (Třeboň region)

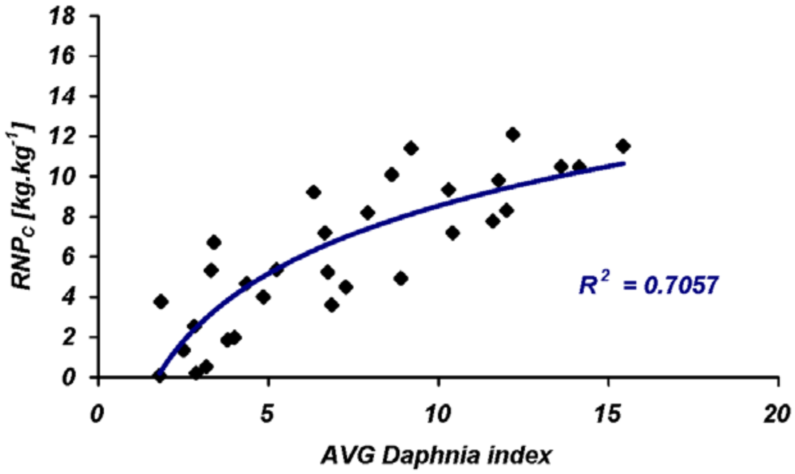


Figure 43. Relationship between average Daphnia index and relative natural productivity of carp (RNP_C) in 2004-2005 (Blatná-Lnáře region)

The explanation for these difference could be found in the relationship between the occurrence of large *Daphnia* (expressed as average *Daphnia* index), the phytoplankton biomass (expressed as chlorophyll-a concentration), and the level of fish stock biomass. Significantly more frequent occurrence of situations (7 % in spring, 18 % in summer and late summer) when large *Daphnia* grazers were not able to regulate phytoplankton biomass, were recorded in Třeboň fish ponds in 2000-2001 (Figs 30, 31, Chapter 4.6.1.). These situations were much scarcer (no case in the spring, 6 % in summer and late summer) in Blatná-Lnáře fish ponds in 2004 - 2005 (Figs 36, 37, Chapter 4.6.2.). Also, situations when a relatively abundant fish stock was not able to reduce the occurrence of large *Daphnia* were recorded more frequently in the fish ponds of the Třeboň region (Fig. 32, 34; Chapter 4.6.1.) than in the Blatná-Lnáře region (Fig. 38, 40; Chapter 4.6.2.).

The difference in the relationships between DI and the RNPc was recorded also between the individual sampling seasons. The Třeboň fish ponds sampled in the years 2000 and 2001 may serve as an example. Evaluating both years together, I did not detect a statistically significant relationship between the AVG DI (the average Daphnia index) and the RNPc. However, when I evaluated these two years separately, I discovered a statistically significant relationship (R^2 = 0.7029) between the AVG DI and the RNPc in the year 2000 (Fig. 44). Contrariwise, the values from 2001 do not display any statistically significant relationship (Fig. 45).

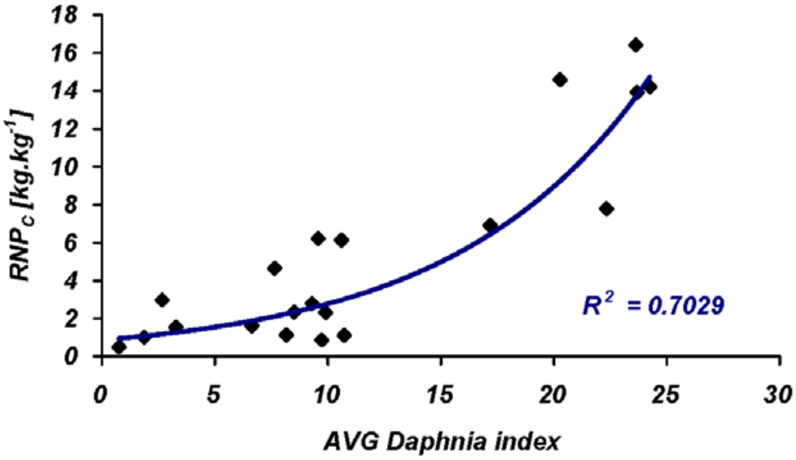


Figure 44. Relationship between average Daphnia index and relative natural productivity of carp (RNP_C) in 2000 (Třeboň region)

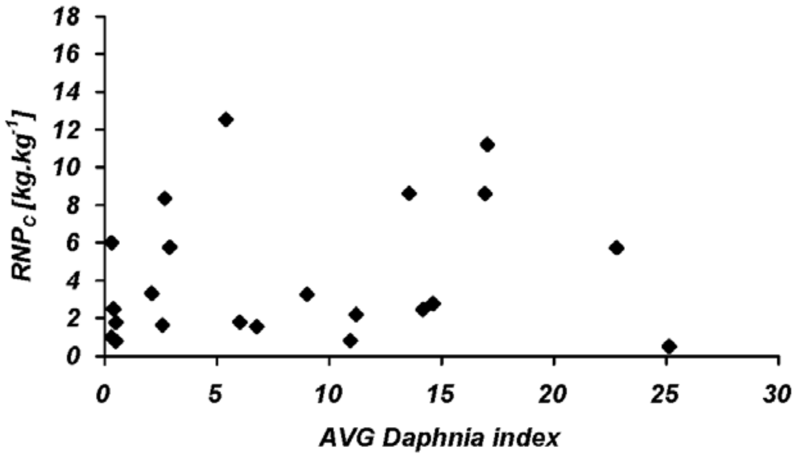


Figure 45. Relationship between average Daphnia index and relative natural productivity of carp (RNP_C) in 2001 (Třeboň region)

A possible explanation again provide the relationship between the DI, chlorophyll-a concentration and fish stock biomass. In 2000, there were 13 % of cases when large *Daphnia* individuals were not able to reduce the development of phytoplankton in the summer and late summer periods (Fig. 46A). I recorded almost 30 % of these cases, in the following year (Fig. 47C). Analyzing the relationship between the DI and fish stock, I recorded 11 % of cases when fish stock was not able to reduce the occurrence of large *Daphnia* in the 2000 (Fig. 46B). In 2001 season, these situations were substantially more numerous, with their frequency reaching 33 % (Figure 47D).

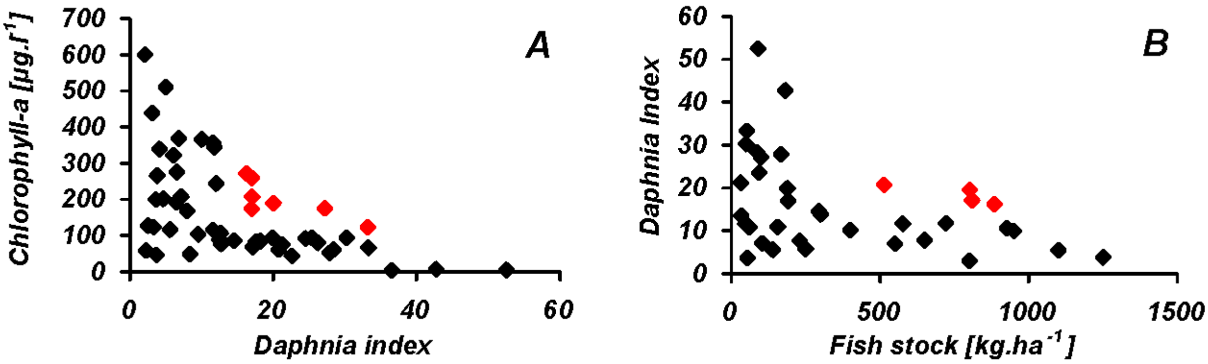


Figure 46. Relationship between Daphnia index and chlorophyll-a concentration in the summer and late summer period (**A**) and relationship between Daphnia index and fish stock biomass (**B**) in season 2000 (Třeboň region),). ♦ - Daphnia index > 15 and chlorophyll-a > 100 ug.l^{-1} (**A**), ♦ - Daphnia index > 15 and fish stock > 400 kg.ha^{-1} (**B**)

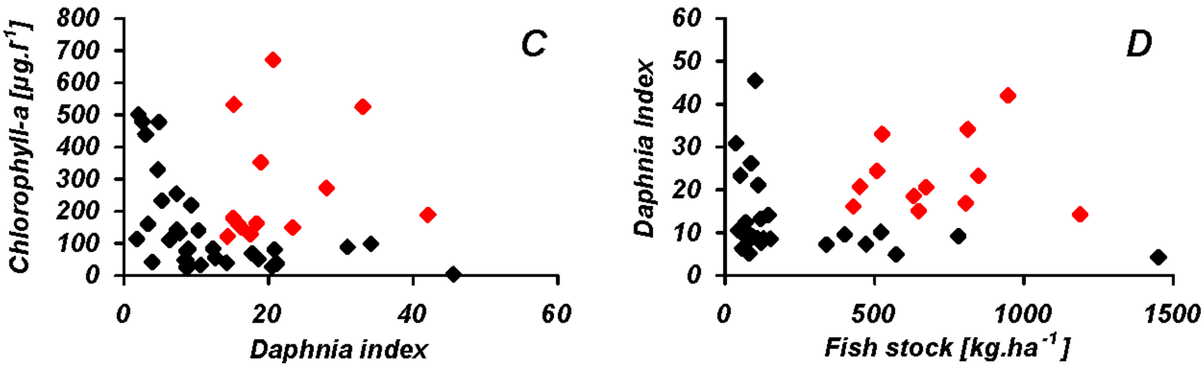


Figure 47. Relationship between Daphnia index and chlorophyll-a concentration in summer and late summer period (**C**) and relationship between Daphnia index and fish stock biomass (**D**) in season 2001 (Třeboň region). ♦ - Daphnia index > 15 and chlorophyll-a > 100 ug.l^{-1} (**A**, **C**), ♦ - Daphnia index > 15 and fish stock > 400 kg.ha^{-1} (**B**, **D**)

5. DISCUSSION

5.1. Changes in the Zooplankton Community of Czech Fish Ponds since the End of the 19th Century to Present

The first fish ponds (intended primarily for fish breeding) were built in the 12th century. The biggest boom of fish pond building took place between the 14th and the 17th centuries. Fish ponds have become an integrate part of the landscape over time. Over the centuries, fish ponds have been colonized by a diverse community of water and swamp organisms. These communities originate in pools and alluvials, relatively wide-spread in the past, but gradually disappearing due to increased demands on landscape management. Newly built fish ponds represented free niche for these organisms. At the end of the 19th century, most Czech fish ponds could have been considered as oligotrophic and mesotrophic. No intensification measures have been applied and no intensive management has been exercised in their catchment areas. Fish farming consisted only in fish stocking and fishing out. Thereby, nutrients have been gradually depleted from fish ponds and their carrying capacity has decreased (Pechar et al., 2000).

Early works on fish pond zooplankton (from the 1880s) reported that the species composition then was similar to the present situation. However, older studies also showed a low biomass, low species diversity and similar species composition throughout the year (Frič and Vávra, 1895).

For example, the Dolnopočernický fispond near Prague, studied by Frič and Vávra between 1888 and 1893, contained in all samples taken over a year *Cyclops vicinus*, and commonly *Daphnia cucullata*, *D. longispina*, *Leptodora kindtii*, *Eudiaptomus gracilis* and species of *Diaphanosoma*. *Daphnia galeata* and *Bosmina longirostris* were found only occasionally. Rotaria occured only for about six weeks each year from May to June, probably in association with the spawning of *Leucaspius delineatus* and other thrash fish. Only exceptionally rotatorians represented up to 90% of the zooplankton (*Asplanchna brightwelli*, *Brachionus calyciflorus*, *Keratella quadrata*, *Keratella cochlearis*, *Polyarthra*, sometimes *Synchaeta tremula*, *Brachionus angularis*, *B.diversicornis*, *Filinia longiseta*, *Conochilus hippocrepis*).

Kafka (1891) carried out the research of several tens of fish ponds in the Třeboň and Jidřichův Hradec regions between 1884 and 1890. Kafka found the total of 70 taxa of the Cladocera, Copepoda, and Rotatifera in the plankton of the littorals of the 45 observed fish ponds. The list of pelagial plankton regularly comprised: *Leptodora kindtii*, *Daphnia cucullata*, *Diaphanosoma brachyurum, Eudiaptomus gracilis*. In the surroundings of the towns of Třeboň and Jindřichův Hradec, *Holopedium gibberum* and sometimes some other species also occurred: *Kellicottia longispina*, *Polyarthra* spp., *Asplanchna priodonta*, *Daphnia pulicaria*, *Ceriodaphnia megops*, *C. reticulata*, *Bosmina longirostris*, *Conochilus hippocrepis*, *Daphnia* sp. Around Jindřichův Hradec species *Polyphemus pediculus*, *Heterocope saliens, Limnosida frontosa* occurred rarely.

Already at that time, some fish ponds could be characterised as eutrophic. This phenomenon was caused mainly by the direct inflow of waste water, especially through the village ponds. Several authors noted the occurrence of the cyanophyte blooms *Aphanizomenon flos aque* and *Anabaena* spp. under such eutrophic conditions. The zooplankton structure was different and species typical for more intensively managed sites started to appear. The subsequent increase of trophic level had an effect on higher increase of plankton biomass and species diversity of the ponds (Pechar et al. 2002).

Langhans (1911) informed about the research of littoral Cladocera in Máchovo Lake during 1900-1909. It included the collection of 102 samples (80 quantitative) from 11th to 17th August 1900, a year-round observation in the years 1905 – 1909, and collection of a significant number of littoral Cladocera samples from June to November 1909. The list of recorded taxa after removing synonyms comprised 58 species. There were two thirds of cladoceran species known in our territory in a single pond. *Leptodora kindtii, Diaphanosoma* sp., *Ceriodaphnia pulchella, Daphnia galeata, Daphnia cucullata, Bosmina longirostris*, and *Bosmina coregoni* were regularly occurred pelagial species. The regular occurrence of the cladoceran *Bosmina longirostris* is interesting. Nowadays, this species is common in fish ponds with high fish stock (Pechar et al. 2002, Potužák, 2004).

The first signs of intentional and systematical increase of fish pond production started back in the 1930s. Liming of fish ponds and increased nutrient input via fertilisation, as well as supplementary fish feeding (implemented at the end of the 19th century), led to a slight increase and stabilization of fish production. Nevertheless, the average production in the early 1930s varied between 50 and 100 $kg.ha^{-1}$ (Mokrý, 1935; Jírovec a Jírovcová, 1938). Studies by Nováček (1935, 1941) and Fott (1938) provided a good general overview of plankton communities in the 1930s. Their results suggested that a higher supply of nutrients, in particular hydrogencarbonates and phosphates, enabled the development of phytoplankton especially in the spring period and as a result, vegetation bloom appeared in fish ponds. The water transparency decreased to values as low as 1 meter due to the development of small species of chlorococcal algae, green flagellates and diatoms. The occurrence of small phytoplankton stimulated the increase of the zooplankton biomass. Strong development of zooplankton was enabled by still low levels of fish stock (100 – 300 $ind.ha^{-1}$). Among zooplankton large cladoceran filter feeders, especially large *Daphnia*, which generally reduced small phytoplankton by their grazing activity in late spring and early summer. More nutrients and excessive amounts of phosphorus, in particular, stimulated development of cyanophytes in the summer. Mostly *Aphanizomenon flos-aque*, *Microcystis aeruginosa*, and some species of *Anabaena* and *Gomphosphaeria* were present. Cyanophycean bloom became a regular phenomenon in the phytoplankton of many fish ponds; this is undoubtedly related to the period of intensive superphosphate fertilisation (Nováček, 1935; Wunder et al., 1935; Jírovec and Jírovcová, 1938).

The large cladoceran *Daphnia pulicaria* became the dominant part of zooplankton. Other representatives of this genus, e.g. *Daphnia magna* and *Daphnia galeata*, were abundant as well. This situation is apparent in a study by Bayer, Bajkov (1929) carried out in the Lednice region fish ponds. The authors mentioned a great number of species found within the classes: Rotifera (61), Copepoda (21), and Cladocera (44). In Cladocera, the occurrences of *Daphnia pulicaria*, *Daphnia magna*, *Daphnia longispina*, *Daphnia galeata*, *Moina brachiata* were significant and these species were found in all observed fish ponds. *Diaphanosoma* sp., *Ceriodaphnia* sp., *Bosmina longirostris* and a number of phytophylic and bentic Cladocera species occurred regularly. However, *Daphnia cucullata* and *Leptodora kindtii* were not recorded. The first record of *Acanthocyclops robustus* (today in our territory classified as *Acanthocyclops trajani*) in our territory comes from the Nesyt fish pond. A. *robustus* formed an important part of zooplankton in fish ponds with dense fish stock. The number of rotifers found was unusually high, with this trend continuing throughout the year. The genera *Brachionus*, *Keratella* were dominant.

The impact of liming and fertilizer application on fish pond water chemistry and consequent changes in phytoplankton have been well documented since the 1950s. A considerable part of the applied fertilisers (i.e. superphosphate and saltpetre), has had a great effect on the phosphorus and nitrogen compounds available. Low fish stock (under 400 ind.ha^{-1}), or, more precisely, lower predatory pressure of fish on zooplankton, maintained a similar zooplankton composition as in the 1930s. Large cladocerans often made up a dominant part of the zooplankton biomass and controlled the development of small phytoplankton efficiently. The phytoplankton biomass was under control of zooplankton for the most of the season, thus mineral nutrients were not completely exhausted (Květ, Jeník, 2002).

Fertiliser application and densities of fish stock were unbalanced in the 1950s and 1960s. The fish ponds significantly differed from one another in the amounts of fertilizers applied and in densities of fish stocks. In most cases, the intensity of fish pond management was increasing but a large number of fish ponds were still understocked and fertilised only little. Some fish ponds were removed from economic use and remained almost uninfluenced by eutrophication. A large variety of sites with different trophic status were distributed on the landscape. In the 1960s, new fish species were included into fish pond farming (peled, grass carp, silver carp, and bighead carp). Submerged macrophytes were strongly reduced (primarily due to the increased carp stock levels and subsequent decrease of water transparency) and reed vegetation gradually declined. Reed vegetation was further reduced by extensive rolling up of fish pond edges.

Phytoplankton displayed strong seasonal dynamics and where large zooplankton had been reduced by fish, phytoplankton blooms occurred. Water transparency dropped under 1 m, sometimes even to 50 cm, with green or brown-green water colour. In this situation, chlorococcal algae, green flagellates, and cyanophytes prevailed (Pechar et al., 2002).

The summer period was characterised by the occurrence of the *Aphanizomenon flos-aque* blooms accompanied by large populations of cladocerans of the genus *Daphnia*.

The dominant cyanophyte, *Aphanizomenon flos-aquae*, formed flakes up to 2 cm long and was largely accompanied by cladoceran populations of *Daphnia galeata* and *Daphnia pulicaria* (Hrbáček, 1964; Lynch, 1980; Komárková, 1983; Ganf, 1983). The *Aphanizomenon – Daphnia* type of plankton generally forms in June when the water temperature reaches 18 – 20 °C. It follows the 'clear water' period and it can remain throughout the summer season. Its long-term existence requires low predatory pressure by fish, i.e. low fish stock level in fish ponds (Pechar, Fott, 1991).

In the 1970s, the seasonal dynamics of zooplankton displayed certain regularity which was closely connected to the methods used by fish production managers. An example illustrating this situation is the Velký Pálenec fish pond, where the two-year cycles of fishery management were consistently kept in the 1960s and the 1970s (Fott et al., 1980).

The dominant fish was common carp, reaching its market size in the second year. In some fish ponds, maraena whitefish (*Coregonus maraena*) was grown with the carp (Hrbáček, 1966). In the first vegetation season, adult individuals of *Daphnia pulicaria* and smaller individuals of *Daphnia galeata* prevailed in zooplankton and the share of small zooplankton in the biomass was low. In the second year, the share of *Daphnia galeata*, *Daphnia pulicaria*, calanoid copepods and adults of the *Eudiaptomus gracilis* species occurred very rarely. Small zooplankton (rotifers, copepod nauplii, small cladoceran species) was relatively abundant. *Bosmina longirostris* in particular was very abundant. During these studies, fish predation was identified as the major factor influencing the occurrence of zooplankton. The fish pond was stocked in the first year, and fished out in the second year. In the first year, the predatory pressure of fish was not so strong, and therefore *Daphnia pulicaria* was dominant. This species is very sensitive to fish predation, and it is a very efficient phytoplankton filter-feeder (Hrbáček and Hrbáčková-Esslová, 1960; Hrbáčková and Hrbáček, 1978).

The period between 1980s and 1990s was typical for intensive fish farming. Farm fertilizers were still widely used and most of fish ponds became over-fertilised. High amounts on nutrients enabled vigorous development of algae and cyanophytes. Summer period was typical with cynobacterial blooms. The development of large zooplankton (especially large *Daphnia*) was mostly restricted by high biomass of fish stock. *Daphnia galeata*, *Bosmina longirostris*, *Ceriodaphnia*, *Acanthocyclops trajani*, *Thermocyclops crassus* (mostly represented by copepodites and nauplii) and some species of rotifers (*Keratella cochlearis*, *K. quadrata*, *Brachionus angularis*, *B. calyciflorus*, *Polyarthra dolichoptera*, *Asplanchna priodonta*) were most common (Pechar et al., 2002).

Present fish pond farming still maintains relatively high intensity. Fish stocks are still on a high level (mostly higher than 1500 $kg.ha^{-1}$). Gradually, the use of farm fertilisers decreases, but many fish ponds are still over-fertilised. At the same time, nutrient runoff from agricultural catchment areas declined. Due to an intensified construction of waste-water treatment plants, the inflow of organic substances from waste water into fish ponds decreased; however, the decrease of phosphorus concentration was much slower. Assessing today's fish ponds according to the most common trophic criteria (i.e. total nitrogen and phosphorus concentrations, and the quantity of phytoplankton expressed by chlorophyll concentration), a majority of fish ponds with intensive fish breeding (the Třeboň region, the South Moravian region, and partly also the Blatná-Lnáře region) may be described as highly eutrophic or hypertrophic (Pechar, 2006).

Phytoplankton is abundant in most fish ponds and forms algal blooms even in winter and early spring. The spring period is characterised by the development of planktonic diatoms of the genera *Stephanodiscus*, *Cyclotella, Nitzschia*, and of green flagellates (Vovocales). To a smaller extent, representatives of Cryptophyceae and Chlorophyceae occur, sometimes accompanied by some planktonic cyanophytes. The onset of a summer-type phytoplankton is usually followed by the decrease of diatoms and the increase in the share of chlorococcal algae and flagellates of the family Cryptophyceae. The amount of phytoplankton rises in the April-May period and the share of planktonic cyanophytes increases as well. In today's fish ponds, the 'clear water' stage is mostly nonexistent. The phytoplankton biomass reaches its peak in August. At that time, the phytoplankton biomass is dominated by small species of planktonic cyanophytes *Aphanizomenon gracile, Aphanizomenon flos-aque var. klebahnii*, followed by the species of the genus *Anabaena*, together with the small forms of cyanophytes of the genus *Microcystis*. These small species replace large colonial forms. At present, the cyanophytes *Limnothrix redekei* and *Plantothrix agardhii* (solitary filaments), which form intense water blooms and were very rare 15-20 years ago, are present (Pechar, 2006).

Besides cyanobacterial blooms, chlorococcal algae frequently prevail in the summer phytoplankton, and in many situations the occurrence of monospecific communities, formed almost exclusively by a single species (*Acanthosphaera zachriasii, Dictyosphaerium pulchellum*, *Pediastrum duplex*), were recorded. Such species reduction of phytoplankton, as well as cyanobacterial water bloom, may be considered as definite sign of plankton community instability (Pechar et al, 2002).

Our results, obtained during investigations in Třeboň and Blatná-Lnáře fish ponds, well illustrate current species composition of zooplankton in intensively managed fish ponds.

In total 117 taxons of mostly pelagial zooplankton were recorded. Out of those 38 were Cladoceran species, 14 were Copepod species, and 65 were Rotifera species.

Bosmina longirostris was the most frequently found cladoceran species in both regions. This species reaches its highest abundance in the summer period, replacing larger cladocerans of the genus *Daphnia* which are significantly reduced by the grazing pressure of fish stock at that time. *Bosmina coregoni* was not so frequent as *Bosmina longirostris* and it was not recorded in fish pond plankton in the past (Přikryl, 1996). At some sites of the Třeboň region, this species made up a substantial part of crustaceoplankton (the Staňkovský fish pond 2000-2001, the Humlenské fish ponds 2005), and in some cases it was even the dominant species of Cladocera (Hejtman near Chlum u Třeboně 2007, Velký Ratmírov 2007). The occurrence of *B. coregoni* was recorded in both observed regions.

Cladocera of the genus *Daphnia* were represented by seven species at the monitored fish pond sites. *Daphnia galeata*, the most frequently found species occurred throughout the vegetation season (excluding sites with strong grazing pressure by fish stock). The highest frequency of the *Daphnia galeata* was recorded in the spring and summer periods (Figs 49, 50). Often only a single cladoceran species of the genus *Daphnia* was recorded in the studied fish ponds during the vegetation season. In the Blatná-Lnáře region, this species was typical for the spring and early summer periods of the second year at sites where the two-year cycles of fishery management were practised.

Daphnia pulicaria is very sensitive to grazing pressure by fish (Kořínek et al., 1987), and therefore this species was not so frequent at the sampling sites. *D. pulicaria* mostly occurred for a short episode during the spring period (Fig. 49). It was also observed that when a large part of fish stock suddenly died out, and an extensive development of this cladoceran species followed (for example fish pond Paseka 2004). On the other hand *D. pulicaria* is an extremely successful competitor in zooplanktonic community. They are efficient in reducing the food to levels that are too low to sustain most competitors (Brooks and Dodson, 1965). Figure 48 shows the relationship between the abundance (ind.l^{-1}) of *Daphnia pulicaria* and *Daphnia galeata*.

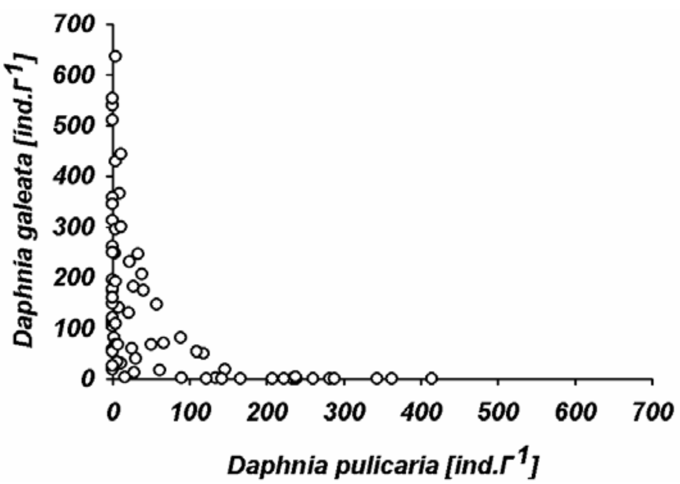


Figure 48. Relationship between abundance (ind.l^{-1}) od *Daphnia pulicaria* and *Daphnia galeata* (Naděje and Chlum fish pond area 2005)

Daphnia magna was not frequent in most of the observed fish ponds. It included a short episode in the spring, or in the summer (e.g. the Byňovský fish pond 2000, Rožmberk fish pond 2007). Similarly, as with the cladoceran *D. pulicaria*, a more abundant occurrence of *D. magna* was recorded after a more significant fish stock kill (Loužnice, June 2004). This species prefers fish ponds with higher organic load with low or no fish stock (e.g. sewage ponds or village ponds) (Šrámek-Hušek, 1962; Benzie, 2005). This may be the reason for its occurrence e.g. in the Byňovský fish pond, which is strongly affected by the near duck farm and hence larger input of organic substances may be assumed.

Daphnia longispina is not a typical species of intensively managed fish ponds. It is more likely to be found in smaller fish ponds with a rich littoral (Hakkari, 1972; Pejler, 1983; Hudec, 1991). Similarly to the previous two species, it is very sensitive to grazing pressure by fish stock and therefore it is found at sites with lower fish stocks and mostly with a lower nutrient load at the same time. At the studied sites, *D. longispina* was found more frequent in the Blatná-Lnáře fish ponds e.g. the Mostenský 2004-2005 and Krčový 2004-2005. Both these localities had relatively low fish stock (up to 150 kg ha^{-1} C_3) with lower nutrient concentrations (TP up to 0.08 $mg.l^{-1}$, the average for the Blatenské fish ponds 0.242 $mg.l^{-1}$) and concentrations of organics (TOC up to 10 $mg.l^{-1}$, the average for the Blatenské fish ponds 15 $mg.l^{-1}$).

At present, *Daphnia cucullata* is not a typical part of fish pond plankton and is mostly recorded in water reservoirs (Přikryl, 1996; Seďa et al., 2000, Seďa et al., 2007). *D. cucullata* was more frequent in the Blatná-Lnáře fish ponds. Thanks to its small size and low pigmentation, it resists the grazing pressure by fish stock the longest (Hartman et al., 2005). This corresponds to the predominant occurence of this species in the summer and late summer samples, i.e. during the periods of the strongest grazing pressure by fish stock (Fig 50, 51).

The cladocerans *Daphnia parvula* and *Daphnia ambigua* are non-indigenous species in Europe. They are North American cladocerans that first spread in the Western Europe (in the 2^{nd} half of the 20^{th} century) and hence they spread further south and east (Flössner and Kraus, 1976, Louette et al., 2007). In the Czech Republic, *Daphnia parvula* appeared in the 1970s for the first time. *Daphnia ambigua* was not recorded in our country until 1994, and today it occurs together with the above mentioned species (Žofková et al., 2000). These species occurred mostly in the summer or late summer, in the studied fish ponds (Figs 50, 51). This small species are are often the last *Daphnia* species to be found under the conditions of high fish stock level (Hartman et al., 2005). Their frequency (%) in zooplankton was mostly less than 2 % but rarely, the situations when *D. ambigua* or *D. parvula* formed majority of zooplankton could be recorded. For example, in Bezdrev[1] fish pond *Daphnia ambigua* comprised 44 % of zooplankton and 98 % of all cladocerans in the April sample (2007).

[1] Data from the monitoring of fish ponds carried out within the scope of operational monitoring by the River Basin Authority laboratory in České Budějovice.

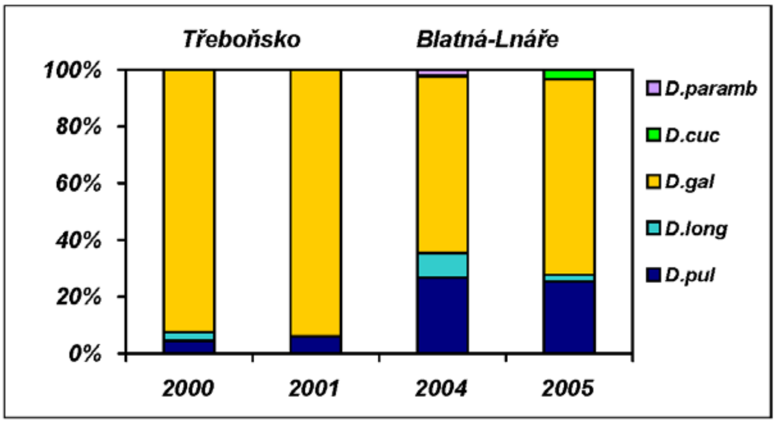


Figure 49. Average frequency (%) of individual species of genus *Daphnia* in spring period 2000-2001 (Třeboň region) and 2004-2005 (Blatná-Lnáře region) (D.paramb = *Daphnia parvula* + *Daphnia ambigua*, D.cuc = *Daphnia cucullata*, D.gal = *Daphnia galeata*, D.long = *Daphnia longispina*, D.pul = *Daphnia pulicaria*)

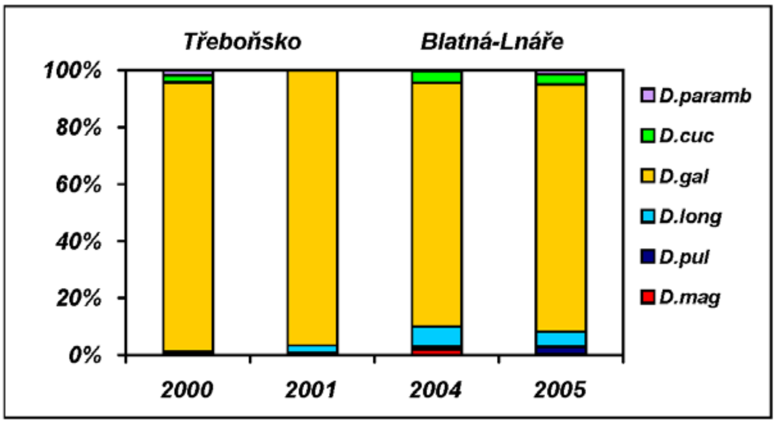


Figure 50. Average frequency (%) of individual species of genus *Daphnia* in summer period 2000-2001 (Třeboň region) and 2004-2005 (Blatná-Lnáře region) (D.paramb = *Daphnia parvula* + *Daphnia ambigua*, D.cuc = *Daphnia cucullata*, D.gal = *Daphnia galeata*, D.long = *Daphnia longispina*, D.pul = *Daphnia pulicaria*)

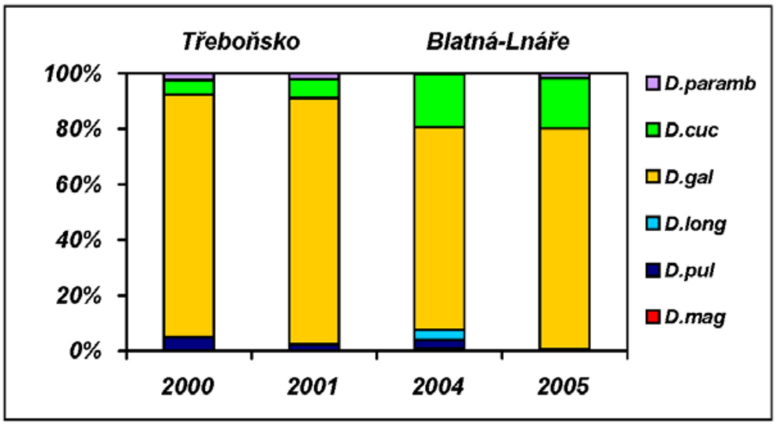


Figure 51. Average frequency (%) of individual species of genus *Daphnia* in late summer period 2000-2001 (Třeboň region) and 2004-2005 (Blatná-Lnáře region) (D.paramb = *Daphnia parvula* + *Daphnia ambigua*, D.cuc = *Daphnia cucullata*, D.gal = *Daphnia galeata*, D.long = *Daphnia longispina*, D.pul = *Daphnia pulicaria*)

Table 27 shows the comparison of the occurrence of situations when large *Daphnia* were dominant from the 1950s until present. The results have revealed the apparent decrease of these situations since the 1950s.

Table 27. Examples with large *Daphnia* predominance since the 1950s to present (Třeboň and Blatná-Lnáře fish pond region)

Period	**1954 - 1958**	**1979 - 1984**	**1990 - 1991**	**2000 – 2001**	**2004 - 2005**
Author	Hrbáček unpubl.	Fuka (1985)	Pechar (1995)	Potužák (2004)	Potužák (2009)
Region	Třeboň	Třeboň	Třeboň	Třeboň	Blatná-Lnáře
Number of sites	27	57	91	43	41
Number of samples	88	157	153	258	246
Number of large Daphnia predominance (%)	68 (77%)	26 (17%)	20 (13%)	8 (3%)	12 (5%)

Genus *Ceriodaphnia* was frequently recorded in the summer and late summer sampling periods. Together with *Bosmina longirostris*, they replace *Daphnia* species which were eliminated by the grazing pressure of fish. *Ceriodaphnia affinis* and *Ceriodaphnia pulchella* species were recorded most frequently with *Ceriodaphnia affinis* being more common. Our results showed that this species can withstand a substantially higher level of eutrophication than the *C. pulchella*. The large littoral species *Ceriodaphnia megops* and *Ceriodaphnia reticulata* occurred rarely in studied fish ponds. Single findings were recorded in localities with rich shore vegetation (the Žoldánka fish pond in 2004, the Žemlička fish pond in 2000).

The genus *Diaphanosoma* was represented only by the *Diaphanosoma brachyurum* at the observed sites. It was more abundant in the Blatná-Lnáře fish ponds (regularly the Krčový, V. Lípa, M. Lípa, and Mostenský fish ponds). In the Třeboň fish ponds, its occurrence was -much rarer (regularly the Staňkovský fish pond). It is a species which was relatively common in fish ponds in the past; however, its occurrence substantially declined with higher trophic levels (Přikryl, 1996). It found new refuge in water reservoirs, where it now forms a common part of summer plankton (regularly e.g. the Husinec, Nýrsko, or Lipno water reservoirs – own findings).

The genus *Moina* was represented by two species, *Moina micrura* and *Moina brachyata*. This genus was relatively rare; however, at the sites where it was present it was usually the most abundant cladoceran species. *M. micrura* was found more frequently and replaced larger cladoceran species eliminated by fish stock. *M. brachyata* species is more typical for periodic waters and it does not occur frequently in fish ponds (Přikryl, 1984). The occurrence of this species was recorded in the cases of freshly filled fish ponds (Mlýnský, 2004).

Leptodora kindtii typically occurred in the summer and late summer periods (e.g. Klec 2000 – 2001, Potěšil 2000 – 2001). Its occurrence was very often accompanied by cyanobacterial blooms and high chlorophyll concentrations at the observed localities (Fig. 52). Under these conditions, *Leptodora* can find sufficient amount of food (nauplii, rotifers, small cladocerans), and, in spite of its considerable size, it can resist the grazing pressure by fish stock (Branstrator and Lehman, 1991; Chang and Hanazato, 2004; Vijverberg et al., 2005). *Polyphemus pediculus* was recorded in smaller fish ponds with littoral shore vegetation (Žoldánka 2004 – 2005, Mostenský 2004 – 2005). Unlike the distinctively pelagial *Leptodora kindtii*, this species prefers littoral parts of fish ponds, where fish management is not so intensive.

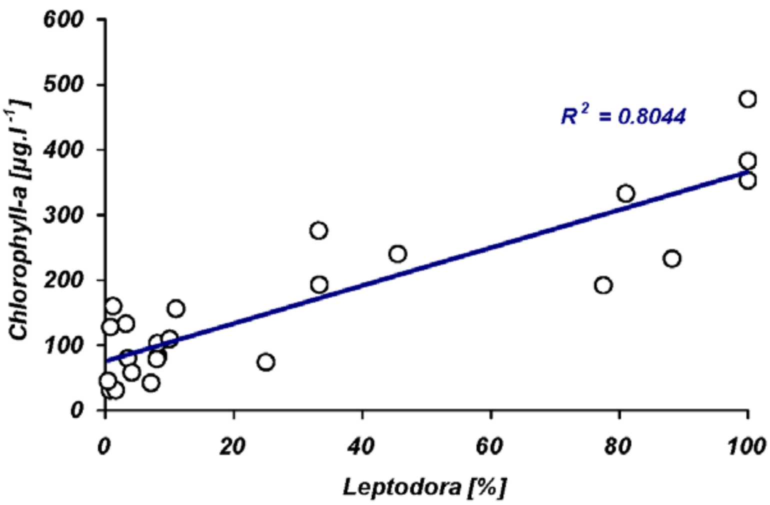


Figure 52. Relationship between frequency (%) of *Leptodora kindtii* and chlorophyll-a concentration in summer and late summer period in 2000-2001 (Třeboň region) and 2004-2005 (Blatná-Lnáře region). Frequency (%) of *Leptodora kindt*ii is related to the total numer of cladocerans

The family Chydoridae was represented by several species. However, only *Chydorus sphaericus* was identified regularly in pelagial plankton. C. *sphaericus* mostly occurred in the situations of heavy cyanobacterial bloom in fish ponds. This phenomenon may be attributed to the food specialization of this cladocerans which is adapted to grazing bacterial and algal mats from various surfaces (bottom, plants, filamentous algae, etc.) (Pejler, 1983).

The species composition of Copepoda is generally similar in most observed fish ponds. Only nauplii and copepodites were mostly recorded. It corresponds to a strong grazing pressure by fish stock. Adults of common species (*Cyclops vicinus*, *Acanthocyclops cf. trajani*, *Thermocyclops crassus, Eudiaptomus gracilis*) were predominantly recorded. *Cyclops vicinus* occurred mostly during the spring season. It is a relatively large species which gradually vanished during the vegetation season with increasing water temperature and grazing pressure by fish stock (Šrámek-Hušek, 1953, 1962; Einsle 1993; Kobari and Ban, 1998). It is replaced by smaller species such as *Acanthocyclops cf. trajani* and *Thermocyclops crassus*. These species resist the grazing pressure by fish stock better due to their small size (Maier, 1989; Kobari and Ban, 1998). The *Cyclops strenuus* and *Mesocyclops leuckarti* species did not constitute a common part of plankton in the observed fish ponds. *C. strenuus* occurred rarely in smaller fish ponds less loaded with organic substances (V. Horský 2004, Hadí 2005) (Einsle, 1996). In the past, *Mesocyclops leuckarti* was a common part of fish pond zooplankton (Přikryl, 1996) but today, it is not abundant in highly eutrophic fish ponds. Results suggested that *M. leuckarti* prefers rather slight and medium eutrophic sites than hypertrophic ones. Calanoida were represented by two species, *Eudiaptomus vulgaris* and *Eudiaptomus gracilis*. *Eudiaptomus vulgaris* mostly occurred at sites with lower levels of fish pond management, i.e. with lower fish stock levels and lower fertiliser input (Jacobs and Bouwhuis, 1979). *E. gracilis* is a smaller species which can withstand fish pond management with higher fish stocks (Svensson, 1997). Other Copepoda (*Eucyclops serrulatus, Macrocyclops albidus, Megacyclops gigas, Paracyclops fimbriatus, Diacyclops bicuspidatus, Metacyclops gracilis*) were recorded only rarely. This was due to the preference of different habitats than open water, or due to their relatively rare occurrence at fish pond sites (Einsle, 1993; Maier, 1990).

Rotifera were an abundant group rich in species in the observed fish ponds. A great species diversity was found especially in the Blatná-Lnáře fish ponds due to the higher diversity of sampled sites. Rotifera of the genera *Keratella* and *Brachionus* were the most frequent. The genus *Keratella* was represented by two species, *Keratella cochlearis* and *Keratella quadrata*. These are eurytrophic, commonly occurring species recorded at all types of observed sites. The genus *Brachionus* (alternatively *Platyias*) was represented by 12 species in the Třeboň and Blatná-Lnáře regions. *B. angularis*, *B. calyciflorus*, *B. quadridentatus* were the most abundant species. The occurrence of *B. leyidigii* (Újezdský, Radov 2004, Dehtář 2007), *B. variabilis* (Divák 2005, Rožmberk 2007), *B. falcatus* (M. Lípa 2004, Mostenský 2004), and *Platyias quadricornis* (Starý Pálenec 2004) were recorded rarely. *Brachionus budapestinensis* was recorded in the summer period. The highest species diversity of genus *Brachionus* was recorded at sites with high levels of fish management and thus high eutrophication (Mäements, 1983; Berzins and Pejler, 1989).

Also genera *Polyarthra* were commonly found with *Polyarthra dolichoptera*, *P. major* being the most abundant species. Other species of this genus occurred rarely (*P. vulgaris, P. euryptera*, *P. remata*).

Asplanchna priodonta was the dominant species of the genus *Asplanchna*. *A. girodi*, *A. brightwelli* and *A.sieboldii* were found very rarely. The last three species prefer moderately eutrophic localities to distinctly hypertrophic localities (Lynche, 1990).

The occurrence of genera *Hexarthra, Notholca*, *Synchaeta* (excluding *S. pectinata*) exhibited seasonal patterns. Representatives of the genus *Notholca* are typically spring (psychrophile) species (Nogrady et al., 1993). This genus was represented by the *Nothloca* *squamula* – most abundant (e.g. Bídník 2004, Velký Horský, 2004), *N. labis*, and *N. acuminata* (both Velký Horský 2005) at the observed sites. Genus *Synchaeta* most frequently represented by *Synchaeta pectinata*. This species was found during the all sampling periods. On the other hand, *Synchaeta oblonga,* cold-stenoterm species which were recorded only in spring period (Radwan and Popiolek, 1989; Nogrady and Segers 2002). Conversely *Hexarthra mira* prefers a warmer part of the year and was found in the summer and late summer samples. The genera *Hexarthra, Notholca*, and *Synchaeta* occurred mostly in fish ponds with lower level of eutrophication.

Genus *Filinia* was represented by three species. The *Filinia longiseta* was the most common, occurring throughout the year. *Filinia terminalis* is psychrophile and therefore it was recorded mainly during the spring sampling period (Ruttner-Kolisko, 1980). *Filinia opoliensis* was found in several localities near Chlum u Třeboně (Humlenské rybníky 2005), predominantly in the August – September period. *T. opoliensis* is a subtropical and tropical thermophile rotifer species (Nogrady and Segers, 2002) and it occurred episodically during the periods when water temperature exceeds 25 °C for a longer time.

The genus *Trichocerca* was mostly found in warmer part of the year. The occurrence of two typically pelagial species *Trichocerca pusilla* and *Trichocerca similis* in the summer sampling was commonly recorded (Segers, 2003). Our results confirmed suggestion of Mäements (1983) that these two species can withstand higher level of eutrophication. Contrariwise, *Trichocerca cylindrica*, *T. elongata*, and *T. longiseta* were found at sites with lower level of eutrophication and fish pond management. The results (mostly from the Blatná-Lnáře fish ponds) have shown that a higher diversity of this species in fish ponds can be considered as indicator of a relatively good ecological status (according to WFD) of the sites (e.g. Mostenský, V. Horský, M. Horský).

The differences between the present and past data on species richness of zooplankton cannot be explained only by more analyses of zooplankton collected by earlier authors, as they used plankton nets with larger mesh size. Some underestimates were certainly made with respect to small rotatorians, particularly those without a crust. In the middle of nineteenth century, oligotrophic fish ponds were characterised by a relatively low diversity of zooplankton. The abundance of the predatory *Leptodora kindtii* that resisted predation pressure of a poor fish stock and directly influenced the zooplankton composition seemed to have been the essential factor (Přikryl, 1996).

The subsequent increase in fish pond productivity, together with denser fish stock, induced a higher species diversity of zooplankton, at least in some periods, and also introduced distinct seasonal dynamics into the planktonic community (Pechar et al., 2002).

If the present changes are evaluated, the picture is not so optimistic. Some larger marginally distributed species have disappeared and their return cannot be expected, even after restoration of original conditions.

The cladoceran *Holopedium gibberum* can be mentioned as an example of the species that disappeared from most of fish ponds. *H. gibberum* was a relatively abundant in fish pond at the end of 19^{th} century. This oligotrophic species is described as distinctly calciphobic and stenoionic. It is mostly reduced at the site if the pH level exceeds 7.5 and the alkalinity level exceeds 1.5 mmol/l (Hamilton, 1958; Stenson, 1973). It is likely to have disappeared from fish ponds due to intensive liming and overly high fish stock levels at the same time. At present, it occurs more regularly in certain extensively managed fish ponds in Jindřichův Hradec and Dačice regions (the Karhov water body 2006 – 2008, fish ponds Zhejral and Dědek u Slavonic 2006 – 2008)[1]. Episodically, it occurred in some water bodies (Nýrsko 2007, Lipno 2005 – 2008, Husinec 2007 – 2008)[1]. Some species rare on the past have remained rare e.g. *Monospilus dispar* (Svět, Káňov, Rožmberk – Šrámek-Hušek 1961, Hellich 1878) and *Heterocope saliens*. *H. saliens* is currently found in some extensively managed, acidic fish ponds in the Vysočina region (e.g. fish ponds Dědek u Slavonic 2006, Zhejral 2006 – 2008, Velký Pařezitý 2008, Velký Troubný 2008, Pstruhovec 2008)[1].

Contrariwise, the less frequent species, not recorded in fish pond plankton in the past, include the cladocerans *Bosmina coregoni* (N. Hospodář 1981 - Přikryl, 1996, at present regularly e.g. Humlenské fish ponds 2005-2006, Ratmírovský fish pond 2007[1], Hejtman 2007[1], Staňkovský 2007[1]) and *Scapholeberis rammneri* (Velký Tisý, Velký Dubovec, Malý Dubovec 2000 – 2001). *S. rammneri* was very rare in the past, while now it is common throughout the Czech Republic in lower altitudes (Přikryl, 1996).

Only a small number of species spread in the Czech fisponds from other areas during the evaluated period (since the end of the 19th century). They include e.g. two small North American cladoceran species *Daphnia parvula* and *Daphnia ambiqua* (Flössner, Kraus, 1976), or the *Moina weissmanni* species (originally described in paddy fields of the Far East) (Hudec, 2004). As for rotifers, the *Brachionus variabilis* species can be mentioned (Coussement et al., 1976). By contrast, no planktonic species of Cladocera, Copepoda and Rotifera have presumably disappeared.

Over the past more than one century, the zooplankton species structure has undergone substantial changes in fish ponds. These changes were brought about by species widespreading into fish ponds from other types of waters where they found the fish pond environment suitable, and by leaving fish ponds where their conditions changed (Pechar et al.2002).

Table 28 shows the examples of species richness of three main zooplankton taxonomic groups (Cladocera, Copepoda, Rotifera) obtained by different authors since the end of 19th century to the present. Information about number and estimation of trophy of observed sites were presented.

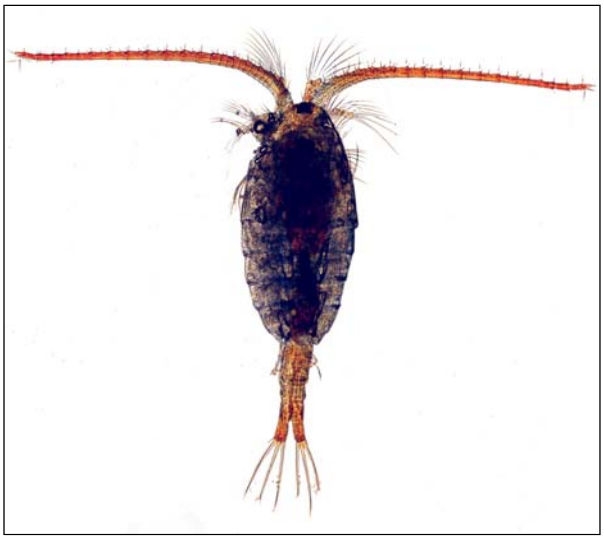


Photo 12. *Heterocope saliens* (Zhejral fish pond) fish pond 2005). Mag. 20x

Photo 13. *Holopedium gibberum* (Karhov fish pond 2005). Mag. 40x

Table 28. The examples of species richness of three main zooplankton taxonomic groups (Cld. - Cladocera, Cop.- Copepoda, Rot. - Rotifera) obtained by different authors since the end of the 19th century to the present. Information about number and estimation of level of eutrophication (Le) of observed sites were presented. Le (Level of eutrophication)- o-e = oligotrophy-eutrophy, m-e = mesotrophy-eutrophy, e = eutrophy, e-h = eutrophy-hypertrophy, NM – taxonomic group was not mentioned.

Period	Author	Region	Nr. of sites	Le	Nr. of Cld.	Nr. of Cop.	Nr. of Rot.
1884-1890	Kafka (1891)	Czech Republic	45	o-e	44	10	14
1902-1928	Bayer, Bajkov (1929)	Lednické fish ponds	4	e	44	21	61
1948-1950	Sládeček (1951b)	Padrťské fish ponds	6	m-e	37	17	87
1954-1956	Pravda, Bican, Brom (Přikryl, 1996)	České Budějovice fish ponds	4	e-h	24	15	NM
1961-1967	Losos, Heteša (1971)	Lednické fish ponds	12	e-h	40	18	72
1976-1977	Přikryl (1979)	Vodňanské fish ponds	8	e-h	18	7	39
1994-1995	Faina, Přikryl (1996)	Lednické fish ponds	4	e-h	20	6	29
2000-2001	Potužák (2004)	Třeboň fish ponds	35	e-h	32	11	50
2004-2005	Potužák (2009)	Blatná-Lnáře fish ponds	41	e-h	38	14	61

As for cladocerans, the amount of species found in fish ponds is decreasing compared to early studies, mostly due to the decrease of phytophylic species. The amount of Copepoda species initially increased slightly compared to early studies; however, after the onset of intensive fish farming in the 1950s, it started falling rapidly. The species diversity of rotifers and their frequency in zooplankton were also growing together with the growth of intensification until approximately the 1950s. After that, the number of species started to decrease, but the frequency of rotifers in zooplankton continued to increase. The zooplankton structure thus shows a certain decrease of biological value of fish ponds over the past decades. The greatest species diversity of zooplankton is presently not recorded in non-productive fish ponds with distinctly extensive fish farming, but in more productive fish ponds with low or medium levels of intensification.

[1] Data from the monitoring of fish ponds carried out within the scope of operational monitoring by the River Basin Authority laboratory in České Budějovice.

5.2. Plankton and the Top-Down Regulation in Hypertrophic Fish ponds

Fish ponds represent a type of ecosystem where most important processes are driven by fish stock. The first information that fish stock can influence the size structure and the biomass of plankton was published by Hrbáček et al. in 1961. Shortly after this, Brooks and Dodson (1965) observed the same relationship between the fish stock and plankton in New England Lakes. Subsequently, the phenomenon of the so-called top-down regulation was confirmed by many authors (Shapiro et al., 1975; Shapiro and Wright, 1984; Carpenter et al., 1985; Seďa and Duncan, 1994; Brett and Goldman, 1996; Matyas et al., 2004 and others). Nowadays, the concept of top-down regulation is a generally accepted mechanism, widely utilised in so-called biomanipulations.

Throughout the second half of the 20th century, the fishery management in most fish pond regions underwent gradual intensification. Fish stock levels increased and nutrient load in fish ponds grew. Most of fish ponds have become eutrophic or hypertrophic water bodies. At the same time, the occurrence of planktonic cyanobacteria species became more frequent, including species that had not been common in the past (the genera *Planktothrix, Limnothix, Cylindrospermopsis*) (Marvan et al., 1997; Pechar et al., 2002; Maršálková et al., 2008). Due to high fish stock levels, often supported by the frequently occurring non-indigenous species *Pseudorazbora parva*, large *Daphnia* are eliminated in spring (if they occur at all). They are subsequently replaced by smaller species with lower filtration activity. The reduction of large filter-feeders is followed by a development of phytoplankton, characterised by cyanobacteria prevalence in the summer period (Figs. 53, 54).

Photo 14. Zooplankton composition in June 7 (Horák, Naděje fish pond system, 2005). Mag. 20x

Photo 15. Zooplankton composition in August 9 (Horák, Naděje fish pond system 2005). Mag. 40x

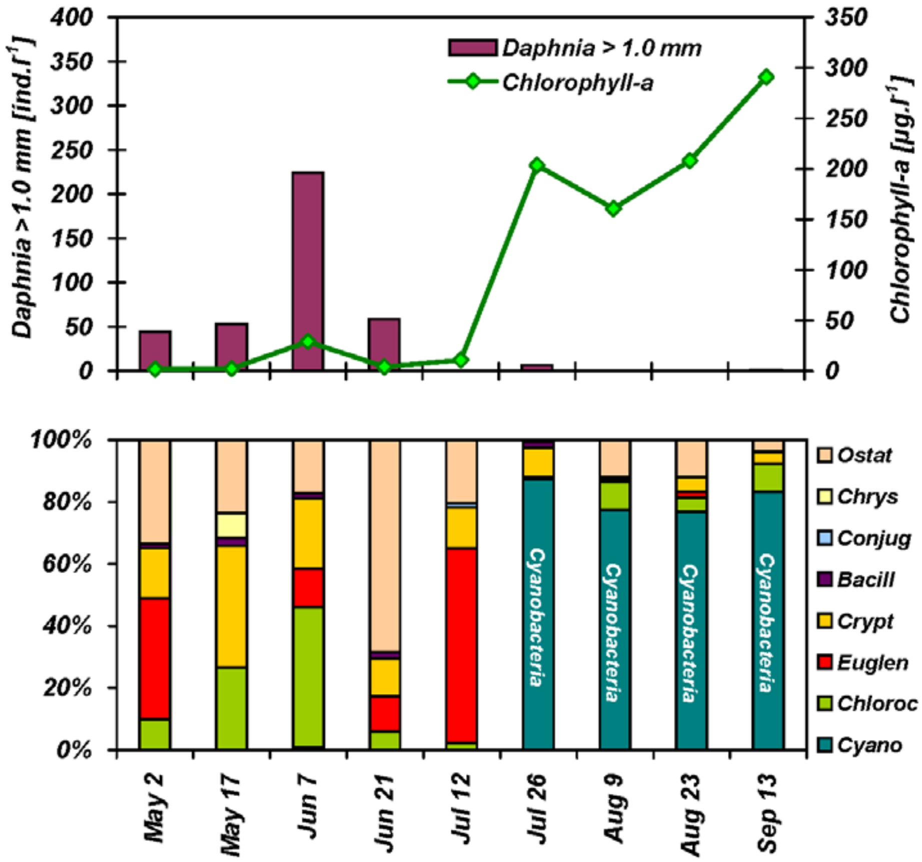
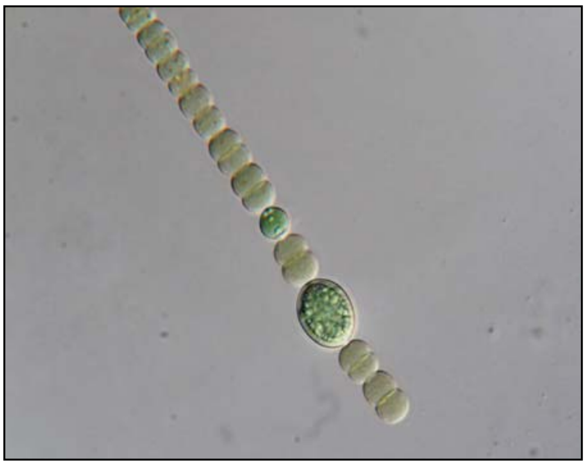


Figure 53. The seasonal course of *Daphnia* > 1.0mm abundance (ind.l^{-1}) in zooplankton and concentration of chlorophyll-a (µg.l^{-1}) in fish pond Horák (2005)

Figure 54. The seasonal course of main phytoplankton taxonomical groups (%) in fish pond Horák (2005) (*Cyan. – Cyanobacteria*, *Bacill. – Bacillariophyceae*, *Chrys. – Chrysophyceae*, *Conjug. – Conjugatophyceae*, *Crypt. – Cryptophyceae*, *Euglen. – Euglenophyceae*, *Chlorococ. – Chlorococcales*)



Photos 16., 17. Examples of most common cyanobacterial genera – *Anabaena* (left) and *Microcystis* in summer phytoplankton. Mag. 400x and 100x.

5.2.1. Relationship between Large *Daphnia* and Phytoplankton – Is the Top-down Regulation of Phytoplankton Still a Valid Concept?

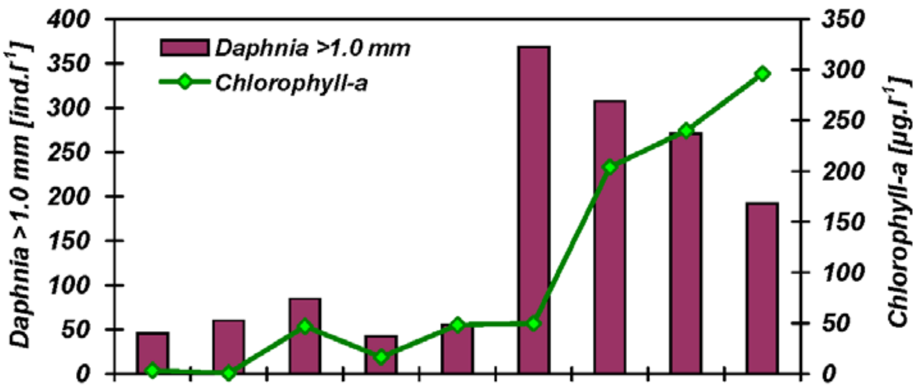
During the last 20 years the situations when the plankton structure did not correspond to the scheme described as the 'cascading trophic effect' (Carpenter et al., 1985) have been observed (Tab. 29).

Table 29. Examples when the sturcture of plankton does not correspond with 'cascading trophic effect'. Frequency (%) of large *Daphnia* is higher than 20-30% and simultaneously concentration of chlorophyll-a is higher than 100 µg.l^{-1} (AVGd – Average body length of genus *Daphnia*, DI – Daphnia index, phytoplankton – dominant group of phytoplankton). Anab. – *Anabaena*, Aphan. – *Aphanizomenon*, Crypt. – *Cryptomonas*, Chlorococ. – Chlorococales, Limnoth. – *Limnothrix*, Microcys. – *Microcystis*, Plankt. – *Planktothrix*, Pseudan. – *Pseudanabaena*.

Period	Region	Sites	Daphnia [%]	AVGd	DI	Phytoplankton	Chl_a [µg.l^{-1}]	Fish stock [kg.ha^{-1}]
Jun 1990	Třeboňsko	Vyšehrad	37	1,53	36,4	Limnoth., Anab.	190,9	547 C_2
Aug 1990	Třeboňsko	Koclířov	28	1,20	21,9	Crypt.	131,1	985 C_3
Aug 1991	Waldviertel (A)	Stegluss	79	1,93	42,6	Limn., Plan, Pseudan.	748	620 C_3
Aug 1991	Třeboňsko	Ženich	33	1,20	23,9	Chloroc.	120,5	2143 C_M
Jun 2000	Třeboňsko	Stružky	35	1,62	38,4	Chlorococ., Crypt.	199	132 C_1
Jun 2000	Třeboňsko	Koclířov	25	1,43	27,2	Plankt., Chlorococ.	111	429 C_M
Aug 2001	Třeboňsko	Nový Vdovec	47	1,33	33,0	Anab., Plan.	177	817 C_M
Aug 2001	Třeboňsko	Potěšil	70	1,36	42,0	Plan., Limn., Anab.	190	1307 C_3
Jun 2004	Blatná Lnáře	Velký Kocelovický	36	1,35	29,6	Anab., Aphan, Chlorococ.	131	1212 C_2
Jun 2004	Blatná Lnáře	Pátek	21	1,10	16,0	Microcys., Aphan., Plankt.	128	223 C_2
Sep 2005	Blatná Lnáře	Smyslov	21	1,03	15,3	Microcys., Anab., Chlorococ., Crypt.	167	827 C_2
Sep 2005	Blatná Lnáře	Hořejší u Tchořovic	21	1,01	14,9	Plankt., Chlorococ.	235	676 C_2

These 'controversial' situations occur both at sites with relatively low fish stock levels (approximately 400 ind.ha^{-1}, or 300 kg.ha^{-1}) and at sites with high fish biomass (over 800 kg.ha^{-1}).

For example, Fišmistr (observed in 2005) is a fish pond with a relatively low fish stock level. At this site, a substantial development of phytoplankton was observed in the summer period in spite of the abundance of large *Daphnia* species (especially from July to September; the quantity of large *Daphnia* varied between 192 – 368 ind.l^{-1} at that time). The reason why large *Daphnia* were not able to reduce phytoplankton bloom can be found in its species composition. Hardly edible cyanobacteria (mainly colonial cyanobacteria of the genus *Microcystis*) had prevailed in phytoplankton since July (Figs. 55, 56).



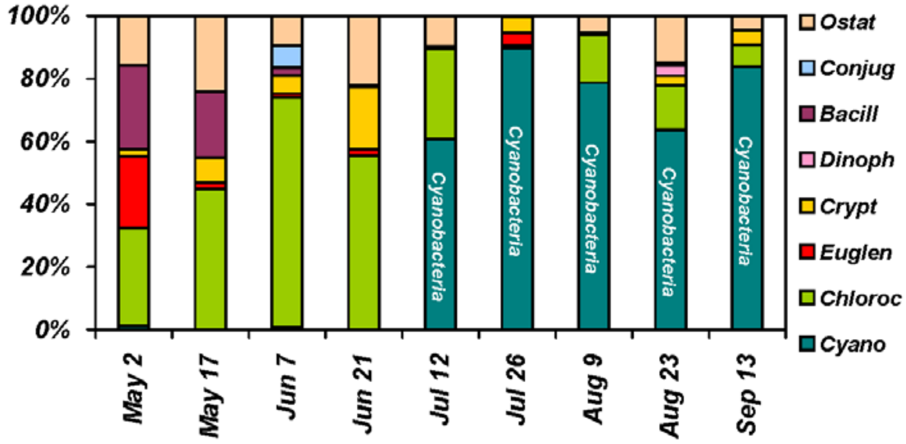


Figure 55. The seasonal course of *Daphnia* > 1.0mm abundance (ind.l^{-1}) in zooplankton and concentration of chlorophyll-a (µg.l^{-1}) in fish pond Fišmistr (2005)

Figure 56. The seasonal course of main phytoplankton taxonomical groups (%) in fish pond Fišmistr (2005) (Cyan. – Cyanobacteria, Bacill. – Bacillariophyceae, Dinoph. – Dinophyceae, Conjug. – Conjugatophyceae, Crypt. – Cryptophyceae, Euglen. – Euglenophyceae, Chlorococ. – Chlorococcales)

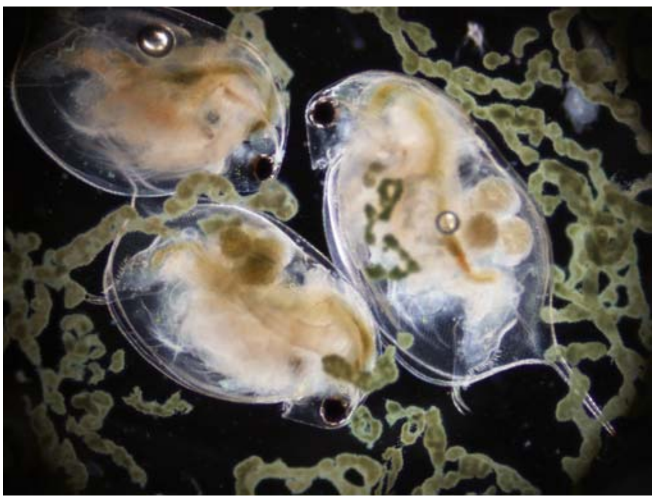


Photo 18. Situation when large *Daphnia* grazers (*D. magna*) were not able to reduce phytoplankton development (Fišmistr fish pond, July 2005). Mag. 20x

From the 1950´s to the 1970´s large cladocerans were unable to regulate the phytoplankton biomass only when *Aphanizomenon flos-aquae* was presented in the summer phytoplankton. The mass development of large sickles of *A. flos-aquae* was associated with large *Daphnia* (*Daphnia pulicaria*, *D. galeata*), which removed the small algae which were potential competitors of *Aphanizomenon* (Hrbáček, 1964; Lynch, 1980; Komárková, 1983; Ganf, 1983; Pechar and Fott, 1991). Other situations when large cladocerans were not able to reduce the development of phytoplankton (e.g. chlorococcal algae) were rare (e.g. the Jezárko fish pond – Fott et al., 1974).

Species composition of phytoplankton is probably the main reason why it is not reduced in presence of large *Daphnia*. In the summer period, planktonic cyanobacteria started to dominate significantly the phytoplankton. They mostly involve colonial (the genus *Microcystis*) or filamentous forms (the genera *Anabaena*, *Aphanizomenon*, or *Plantothrix* and *Limnothrix*). The problem of the suitability of cyanobacteria as food for herbivores in planktonic communities has been widely studied during the last decades. Three points seem to have an important role in this respect.

The first reason is the so-called 'mechanical interference'. That means, the possibility for zooplankton of gathering food items that are often present in the form of colonies of filamentous shape. The mechanical interference of cyanobacteria colonies, mainly of filamentous form, has been reported by many authors as one of the main reasons for the inadequacy of cyanobacteria as food for zooplankton herbivores (e.g. Lefever, 1950; Burns, 1968; Lampert, 1977; Lynch, 1980; Porter and Orcutt, 1980; Starkweather, 1981; Gliwicz, 1969, 1977; Hanazato and Yasuno 1984; Hanazato et al., 1984; Holm et al., 1984; Porter and McDonough, 1984; Hartman, 1985; Sommer et al., 1986; Fulton and Paerl, 1987; Gilbert, 1990; Epp, 1996; Carpenter, 2001; Sarnelle, 2007).

The second cause of the low efficiency of zooplankton feeding on cyanobacteria is their potential toxicity. Cyanobacteria are widely recognized to produce substances which are often poisonous to animals (from planktonic organisms to mammals and birds). However, toxin production cannot be considered a general feature for all the cyanobacteria species at all times and phases of population growth (Eloff and Vann Der Westhuizen, 1981; Lampert, 1982; Nizan et al., 1986). Moreover, the same cyanobacteria species can include toxic or non-toxic strains. Interestingly, cyanobacterial water blooms are often accompanied by rich zooplankton population of diverse species. As it has already been discussed, large *Daphnia* populations are often associated with *Aphanizomenon* blooms (Hrbáček, 1964; Lynch and Shapiro, 1981; Pechar and Fott, 1991), and many rotifers and small cladocerans such as *Bosmina* and *Ceriodaphnia* are known to maintain high population densities when blooms of cyanobacteria occur. Despite these common observations, a series of experimental results indicates that there is a direct toxic effect of different cyanobacteria species on zooplankton (see Arnold, 1971; Lampert, 1981; Holm and Shapiro, 1984; Rohrlack et al., 1999; Naji et al., 2005; Lauren-Maatta et al.,1997; Ferao et al. 2008). But as Nandini and Rao (1998) proved, it appears populations of cladocerans and rotifers species which could be genetically more resistant to *Microcystis* toxins, and they can have a better ability to utilise them. Claska et al. (1998) identified the impact of different temperatures on the toxic effect of the cyanophytes *Anabaena affinis*, *A. flos-aque*, and pure anatoxin-a on the cladocerans *Daphnia pulex*. The results of this study suggest that increasing water temperature (e.g. in the summer) intensifies the toxic effect of cyanophytes on the growth of *Daphnia* populations.

A third point suggested to explain the poor value as food of cyanobacteria is the low assimilation efficiency on ingestion, or their low nutritional value for zooplankton herbivores (Sorokin et al.,1965; Arnold, 1971; Lampert, 1977; Infante and Abella, 1980; Lampert, 1981; Lampert, 1982; Hanazato and Yasumo, 1984; Holm and Shapiro, 1984; Hartman, 1985; Gunnel et al., 1990; Gunnel, 1992; Genkai-Kato, 2004; Gladyshev et al., 2007).

It is however important to notice that in the natural environment cyanobacteria never occur as ‘axenic cultures’ and this may explain the success of some zooplankton species that often grow and reproduce normally during cyanobacteria blooms. That means that if cyanobacteria are present in grazable forms and in non-toxic strains, they can represent an important complementary food source for zooplankton herbivores (De Bernardi and Giussani, 1990).

5.2.2. Relationship between Fish Stock and Zooplankton – Why are High Fish Stocks Unable to Reduce Large *Daphnia*?

Table 29 shows situations when large cladocerans are not able to reduce phytoplankton population. These situations do not occur only under the conditions of low fish stock, but also under the conditions when the fish pond is stocking with high fish stock (over 800 $kg.ha^{-1}$). A subsequent analysis of these situations showed that several factors exist which may bring about the situations of high fish stocks unable to eliminate the development of large cladocerans.

Current fishery management uses supplementary feeding of fish in large measure. Cereals are used most often for supplementary feeding (particularly wheat, barleycorn, rye, and corn). Feeding mixtures are used for rearing fry and fish seed (Čítek et al., 1998). High fish stocks bring strong grazing pressure on zooplankton and right supplementary feeding enables persistence of large or middle sized zooplankton during the season (Schlott-Idl, 1991). Excess supplemetary feeding results in high feeding production, which can significantly surpass natural productivity. Table 30 shows that certain situations when high fish stocks are unable to reduce large cladocerans occur under the conditions when feeding production is considerably higher than natural productivity. A hypothesis can thus be defined that an intensively carp fed can be more attracted by supplementary feeding than by natural food.

Table 30. Situations, when fish stocks are intesivelly fed with artificial food and large Daphnia (expressed as Daphnia index), occurred frequently (FP – feeding productivity, NP – natural fish productivity, Chl-a – chlorophyll-a concentration, C_1,C_2 – one-year, two-year old carps, C_M – marketable carp)

Fish pond	Region	Date	FP:NP [kg.ha^{-1}]	DI	Chl-a [μg.l^{-1}]	Fish stock [kg.ha^{-1}]
Naděje	Třeboň	15.8.01	30:1	20.60	672	611 C_M
V. Kocelovický	Blatná-Lnáře	28.6.04	24:1	29.58	131	1212 C_2
Nadýmač	Blatná-Lnáře	28.6.04	7:1	15.50	256	227 C_1
Smyslov	Blatná-Lnáře	6.9.05	3:1	15.25	167	827 C_2
Cirkvičný	Třeboň	15.8.01	2:1	23.29	150	847 C_M
Pátek	Blatná-Lnáře	28.6.04	2:1	16.01	128	223 C_2
Mlýnský	Blatná-Lnáře	28.6.04	2:1	15.69	163	324 C_1

Different age and weight categories of fish culture can also contribute to the conditions not corresponding with the general description of top-down regulation. Results revealed that situations when large *Daphnia* occurred together with high chlorophyll-a concentrations arose more frequently under conditions when the fish stock consists of older and heavier carp (Figs 57, 58). As Lammens and Hoogenboezem (1991) proved, and Yako et al. (1996) later confirmed, larger carp (over 2 kg) is less effective zooplanktivor than smaller individuals. A large carp can therefore more often focus on feeding on benthos. Carp of 10-30 cm is able to retain large zooplankton with their branchial sieve (Sibbing et al., 1986), but the efficiency of this retention diminishes with carp size. Large carps (> 30 cm) are less efficient zooplanktivores due to the larger mesh width of their branchial sieve (Sibbing, 1988).

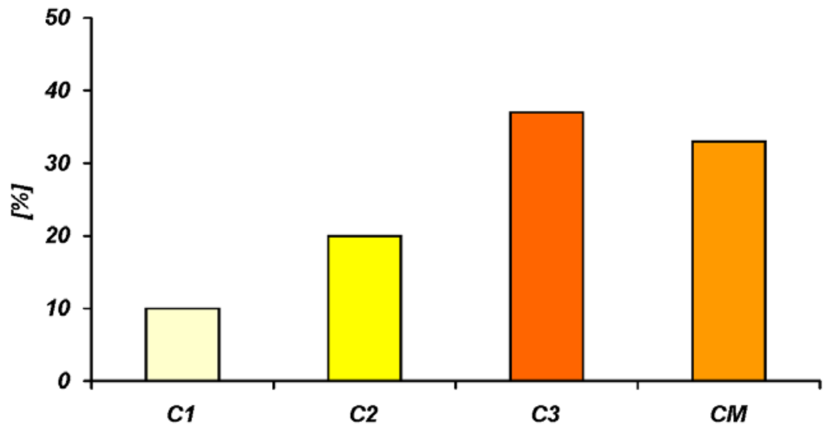


Figure 57. Age structure (frequency %) of breeding carp in situations when large *Daphnia* occurred together with chlorophyll-a concentration higher than 100 μg.l^{-1}. (C_1,C_2, C_3 – one-year, two-year, three-year old carps, C_M - marketable carp)

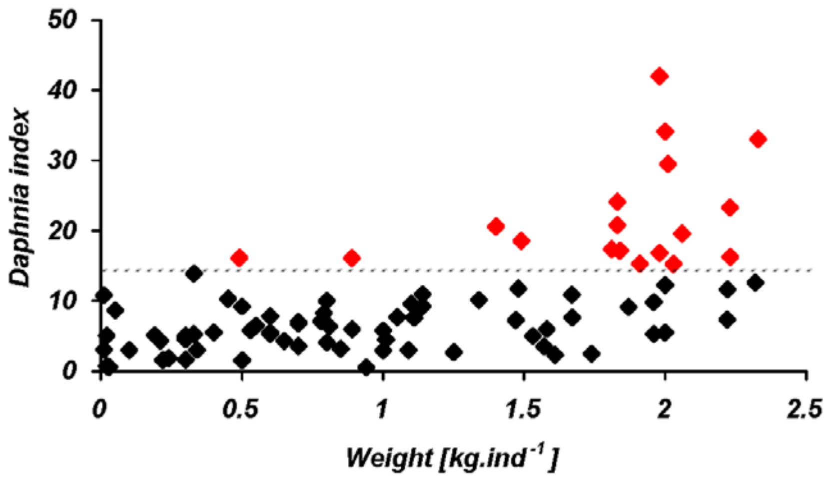


Figure 58. Relationship between the occurrence of large *Daphnia* (expressed as Daphnia index) and individual weight of rearing carp (Třeboň 2000-01 and Blatná 2004-05 fish pond regions), ♦ - Daphnia index > 15, ♦ - Daphnia index < 15

The influence of different weight categories and biomass of carp on the mobilization of phosphorus, nitrogen and phytoplankton biomass was proved by Driver et al. (2005). Their experiments confirmed that the effect of older and larger carp (2 kg) on the mobilization of phosphorus from sediments is more notable than that of a younger and smaller carp (0.3 kg).The influence of carp and other benthivorous fish on phosphorus mobilization was further confirmed by other authors (Kelton et al, 2005; Persson and Svensson, 2006). Results have confirmed that the highest concentrations of total phosphorus and chlorophyll-a were recorded under conditions when the carp biomass was high (>800 $kg.ha^{-1}$) and average weight of carp was higher than 2 kg (Figs. 59A, B and 60A, B).

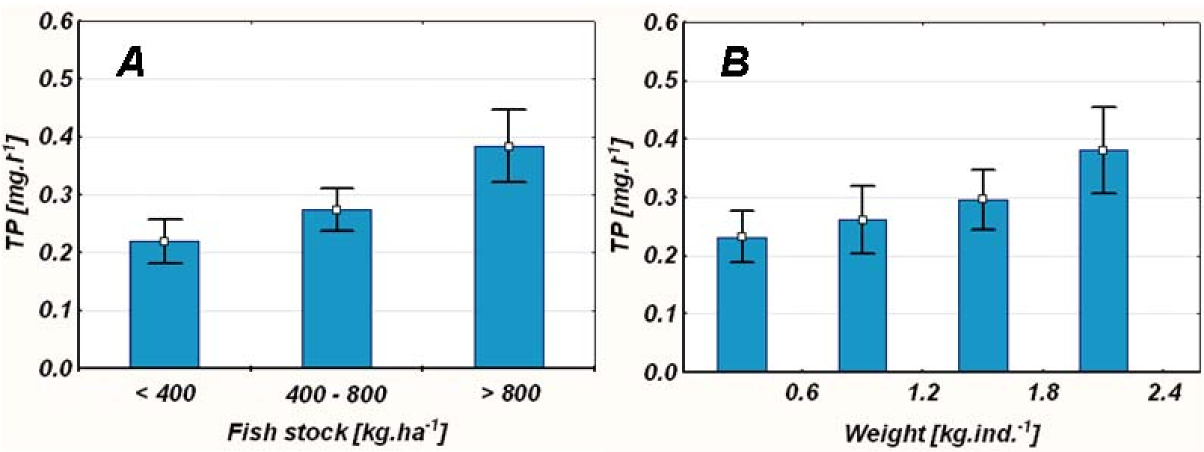


Figure 59. Relationships between average concentration of total phosphorus and carp biomass (**A**) and total phosphorus and average individual weight of carp (**B**) (Třeboň fish pond area, late summer period 2000-2001)

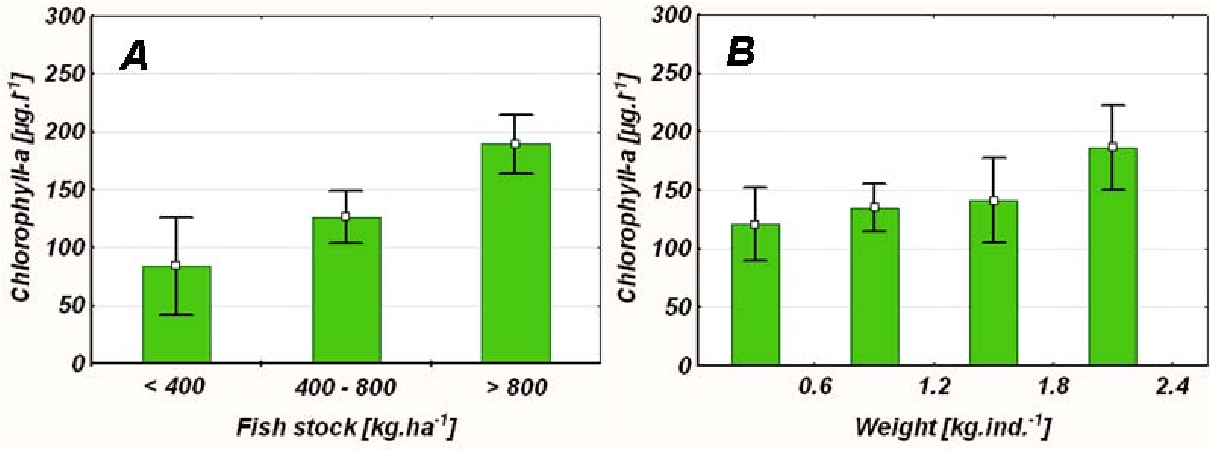


Figure 60. Relationships between average chlorophyll-a concentration and carp biomass (**A**) and chlorophyll-a concentration and individual weight of carp (**B**) (Třeboň fish pond area, late summer period 2000-2001)

All these 'controversial' situations arose in hypertrophic fish ponds. Sites with high level of eutrophication are characterised by high risk of fluctuations of water parameters, such as concentrations of dissolved oxygen and pH (Pechar et al., 2002). During the intensive photosynthesis, the pH values can reach values up to 10, which can cause serious problems due to toxic action of free ammonia. According to Čítek et al. (1998), 78 % of ammonia is in a toxic form at the pH value of 10. A large phytoplankton bloom substantially limits the penetration of light through the water column and thus the photosynthetic activity is reduced in the lower layers of water column. This leads to a strong oxygen stratification, i.e. the upper layer of approximately to 20 cm is over-saturated with oxygen, while anoxia occurs near the bottom (Fott et al., 1980). This situation creates conditions where denitrification may proceed at the bottom and free ammonia (NH_3) concentration increases within the surface layer due to high pH values and subsequent shift in NH_3/NH_4^+ balance (Čítek et al., 1998). For toxic ammonia assessment it is necessary to look at the concentration of dissolved oxygen. When water is highly saturated with oxygen, fish can withstand higher toxic ammonia concentrations (Vámos and Szöllössy, 1974). For example, in Humlenské fish ponds the occurence of situations with high concentration of toxic ammonia were recorded. This fish pond system is loaded with waste waters from nearby duck farm and therefore the risk of toxic ammonia occurrence is possible (Fig. 61)

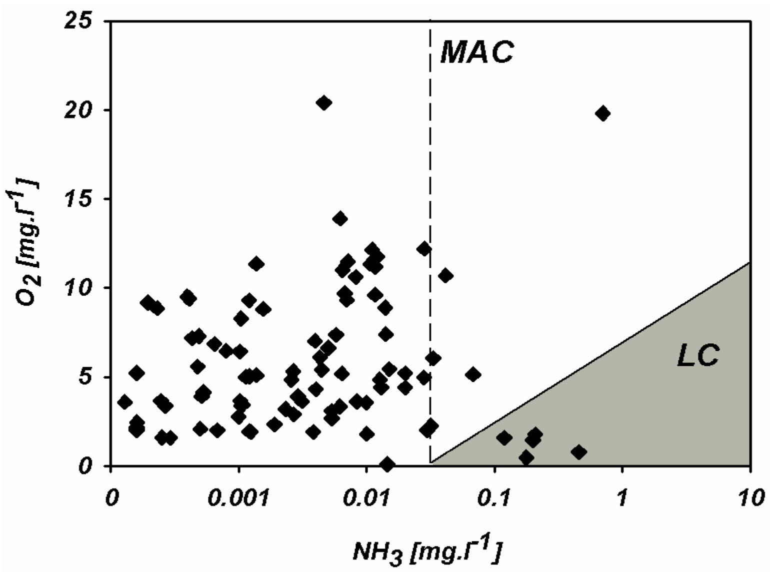


Figure 61. Relationship between non-dissociated ammonia (NH_3) and dissolved oxygen concentration in Humenské fish ponds in season 2005. Dashed line indicates maximum allowable concentration (MAC) of non-dissociated ammonia (NH_3) for Cyprinid fish. Grey area illustrates lethal concentration (LC) for cyprinid fish in different dissolved oxygen concentration (modified from Vámos & Szöllössy, 1974)

The anoxic conditions facilitate the decrease in redox potential and the risk of phophorus release from sediments arises. Diel substantial fluctuations of pH and dissolved oxygen concentration can be recorded under hypertrophic conditions. In the early morning respiration in the water column and in the sediment can decrease the concentration of dissolved oxygen and pH. Conversely, remarkable shift occurs during the day due to photosynthetic assimilation which results in an increase of dissolved oxygen concentration and pH values. The highest values can be recorded in the afternoon hours (Pechar et al., 2002). In the summer, the water column is intensively heated and in the upper layers, the water temperature can reach 25 °C, which facilitates more intensive assimilation processes (Fig. 62).

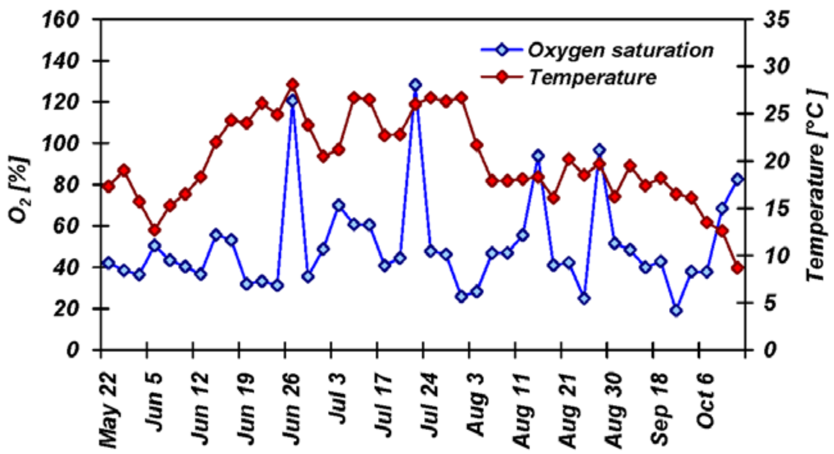


Figure 62. Seasonal course of water temperature and dissolved oxygen saturation in fish pond Baštýř 2006

Situations of large *Daphnia* predominance under conditions of high fish stock are rather easy to explain. For example, large daphnias rapidly acquire dominance in the zooplankton, when some fish are weaker or die because of gill necrosis, oxygen deficiency or disease. Figures 63A and 63B show an example of seasonal development of *Daphnia* > 1.0 mm abundance and Daphnia index under condition of low and high total mortality of fish stock.

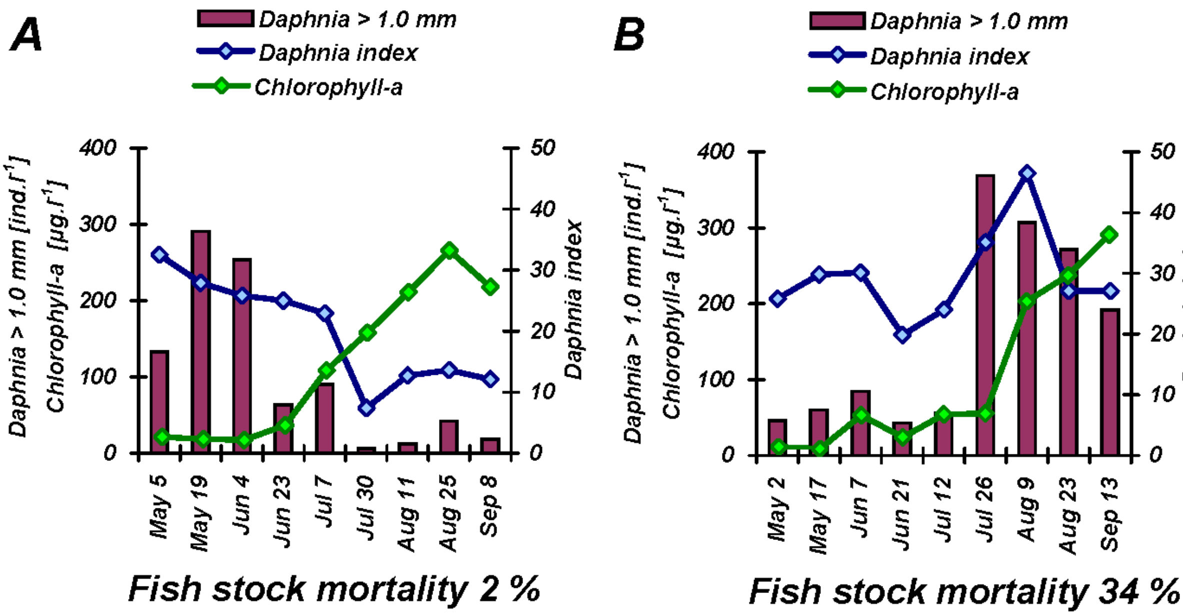


Figure 63. Seasonal development of *Daphnia* >1.0 mm abundance, Daphnia index and chlorophyll-a concentration in fish ponds with fish stock total mortality of 2 % (**A**) (Fišmistr fish pond 2004) and 34 % (**B**) (Fišmistr fish pond, 2005)

Abundant daphnias are able to completely eliminate phytoplankton. Such a situation can stabilize and last for a long time when a high concentration of organic matter in water can support bacteria that, in turn, support stable populations of large daphnias. Organic matter decomposition on the bottom represents a high oxygen demand that the negligible photosynthetic activity of remaining phytoplankton cannot compensate for. A paradoxical situation develops when the ´clear-water stage´ becomes dangerous to fish (Svobodová and Faina, 1984). A simple, but hazardous way of changing the situations is to add a small quantity of the organophosphate insecticide (Diazinon, early Soldep) that kills the daphnias and thus restores favourable conditions for development of phytoplankton, resulting in an increased concentration of oxygen in the water (Figs. 64A, B).

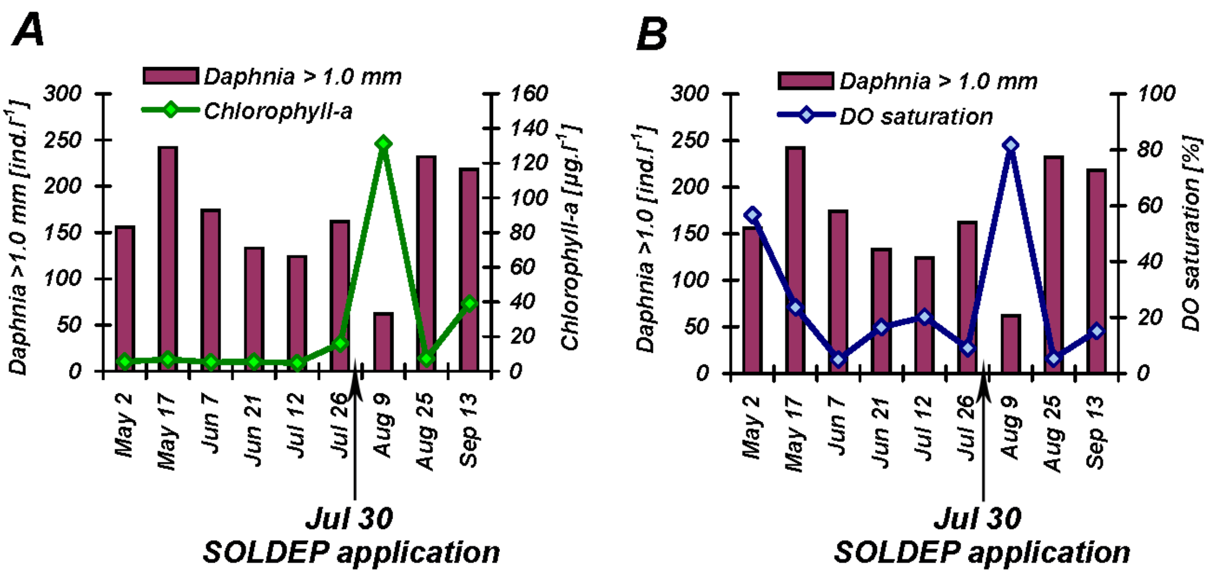


Figure 64. Seasonal course od *Daphnia* > 1.0 mm abundance and chlorophyll-a concentration (**A**) and dissolved oxygen saturation (**B**). The date of Soldep application is shown (Humlena 4 fish pond, 2005)

Macrophytes can play a certain role in reducing the grazing pressure of the fish stock on zooplankton. Several studies have shown that submerged, emergent and floating-leaved macrophytes provide a refuge for zooplankton against fish predation (Irwine et al., 1989, 1990; Moss, 1990).

Cazzanelli et al. (2008) have discovered that emergent and floating-leaved macrophytes harboured significantly higher densities of pelagic as well as plant-associated zooplankton species, compared to the open water, even during the periods when the predation pressure was presumably high (during the recruitment of 0+ fish fry). Zooplankton abundance in open water and among vegetation exhibited low values in July and peaked in August. *Bosmina* and *Ceriodaphnia* dominated the zooplankton community in the littoral vegetated areas (up to 4,400 ind.l^{-1}among *Phragmites australis* and 11,000 ind.l^{-1} between *Polygonum amphibium* stands), whereas the dominant species in the pelagic water were *Daphnia* (up to 67 ind.l^{-1}) and *Cyclops* (41 ind.l^{-1}). It is suggested that emergent and floating-leaved macrophytes may play an important role in enhancing water clarity due to increased grazing pressure by zooplankton migrating into the plant stands.

In most fish pond, the development of macrophytes was substantially reduced during the last 50 years but where they remained they can serve as important refugia for zooplankton.

The growth of submerged and emersed aquatic vegetation has a strong effect on water quality (Kenneth et al., 1989; Pokorný et al., 1990; Takamura et al., 2003; James et al., 2004; Sollie et al., 2008). Macrophytes are especially important as the so-called ‘binders’ of phosphorus, and therefore they act as an important competitor of phytoplankton (Gross, 2003; Nilssen, 2004; Lurling, 2006). Therefore the abundant macrophytes can resist excessive development of phytoplankton in lakes (Mulderij et al., 2007). However, under hypertrophic conditions, high biomass of aquatic macrophytes often does not prevent a significant development of phytoplankton. In fish pond Horák (observed in 2006) *Potamogeton crispus* and *P. natans* formed huge biomass and covered more than 80 % of the site. In spite of that, a massive development of phytoplankton made up predominantly of the cyanobacteria of the genus *Microcystis*, occurred in August. Several combined factors may explain this situation. In August, the concentration of dissolved oxygen dropped substantially to values as low as 0.8 mg.l^{-1} (in the surface layer). Anaerobia probably occurred on the bottom and it led to the release of large amounts of phosphorus from the sediment (Fig. 65A). At the same time, abundance of large *Daphnia* decreased significantly. On the other hand, phytoplankton biomass increased and water transparency decreased (Figs. 66A, B). Phytoplankton apparently utilised the free supply of phosphorus and, not controled by zooplankton, formed a huge biomass (Fig. 65B). The supply of phosphorus was probably so high that even abundant macrophytes did not prevent the development of phytoplankton.

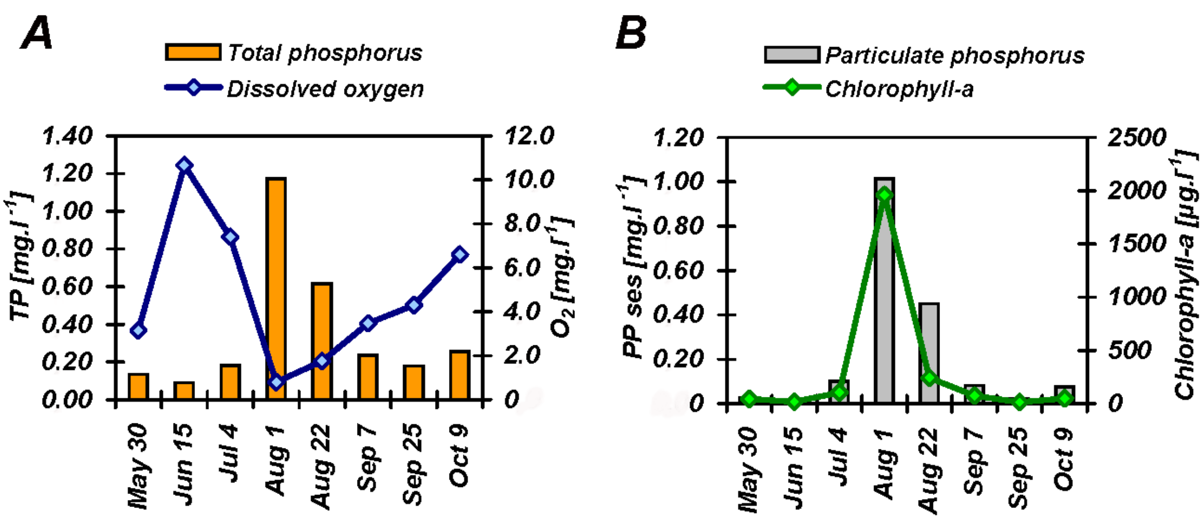


Figure 65. Seasonal course of total phosphorus (TP) concentration and dissolved oxygen concentration (**A**) and phosphorus in seston (Pses) (**B**) in fish pond Horák (2006)

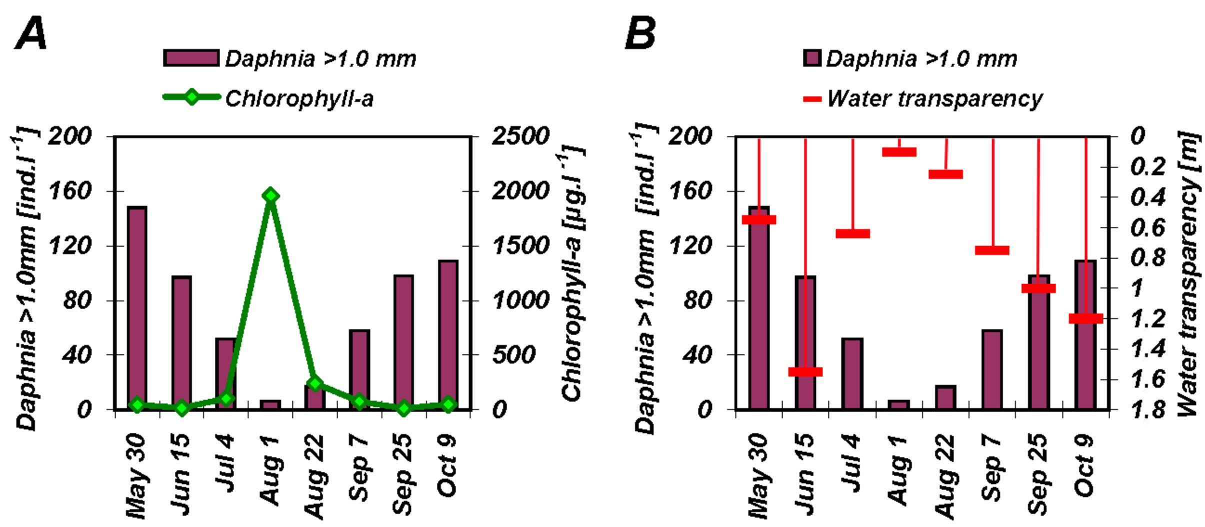


Figure 66. Seasonal course of Daphnia >1.0 mm abundance and chlorophyll-a concentration (**A**) and Daphnia > 1.0 mm abundance and water transparency (**B**) in fish pond Horák (2006)

It is apparent that hypertrophic conditions may generate situations which do not correspond with the generally valid concepts of top-down and bottom-up regulations. This status can be considered as signal of instability and overall inefficiency of production processes in these ecosystems. Most production fish ponds are characterised by excessive development of phytoplankton in the summer period, consisting largely of filamentous or colonial cyanobacteria. Large cladoceran grazers are usually reduced by high fish stocks throughout the vegetation season. Nevertheless, under certain conditions, large *Daphnia* populations are presented in these situations, but they are not able to effectively eliminate phytoplankton consisting mostly of ‘inedible’ cyanobacteria. Excessive production of phytoplankton is thus not used in the higher levels of food chain (zooplankton and fish). Unutilised primary production is realized in ‘microbial loop’ grazed down by a diverse community of heterotrophic organisms (Pechar et al, 2002; Kopylov et al., 2007). This leads to increased overall heterotrophic activity which can result in a substantial drop of dissolved oxygen concentration. This has a negative impact on the vitality of the fish stock and generally further impairs the stability of water environment.

Photo 19. Development of macrophytes does not necessarily prevent a significant development of cyanobacteria

6. CONCLUSIONS

1. Comprehensive set of data on hydrochemistry and hydrobiology (primarily on plankton) in intensively managed fish ponds were carried out during the periods of 2000-2001 and 2004-2005. The main objective was to describe the current status of fish pond zooplankton and to explore in detail the feeding interactions of plankton communities in hypertrophic fish ponds. The focus was especially on the understanding of the concepts of top-down and bottom-up regulation in hypertrophic fish ponds.

2. The observed sites were characterised by a wide range of eutrophication level, from slightly eutrophic (TP_{min} = 0.050 – 0.069 $mg.l^{-1}$, $Chl\text{-}a_{min}$ = 5.8 – 8.7 $\mu g.l^{-1}$) to strong hypertrophic (TP_{max} = 0.856 – 2.000 $mg.l^{-1}$, $Chl\text{-}a_{max}$ = 646 – 824 $\mu g.l^{-1}$) fish ponds. Approximately 65 % of the observed sites in the Třeboň region were hypertrophic, the rest was eutrophic. In the Blatná-Lnáře region, approximately 44 % of sites were hypertrophic and about 66 % eutrophic.

3. Fish stock density varied from several tens of $kg.ha^{-1}$ to almost 2,000 $kg.ha^{-1}$. However, the average fish stock level (more than 60 %) was higher than 600 $kg.ha^{-1}$ at most sites.

4. 93 zooplankton taxa (32 Cladocera species, 11 Copepoda species, and 50 Rotifera species) were recorded in the Třeboň basin fish ponds during the 2000-2001 season.

5. Nauplii and copepodites were the most frequently zooplankton taxonomic groups in the fish ponds of the Třeboň region. They comprised over 50 % of zooplankton. Adults occurred rarely. If they were present in the samples, they mostly comprised common fish pond species: *Acanthocyclops trajani*, *Thermocyclops crassus*, and *Cyclops vicinus*. Rotifers comprised 18 – 47 % of zooplankton. *Keratella cochlearis*, *Keratella quadrata* were the most frequent species occurring e.g. in the summer at more than 75 % of the sites. Besides the representatives of the genus *Keratella*, the following species were common: *Polyarthra dolichoptera*, *Brachionus angularis*, *Asplanchna priodonta*, and *Brachionus calyciflorus*. Cladocera formed from 18.1 to 44.2 % of zooplankton. Small species *Bosmina longirostris* was the most frequent. *Daphia galeata* was the most common *Daphnia* species. Large species of the genus *Daphnia* (mainly *Daphnia pulicaria* scarcer *D. longispina* and *D. magna*) occurred more significantly only in spring. *Daphnia cucullata*, *D. parvula*, *D. ambigua* occurred predominantly in summer and late summer period. Their frequency in zooplankton was low (less than 2 %). Other cladocerans, *Chydorus sphaericus* and genus *Ceriodaphnia* were other relatively frequent species.

6. The proportion of size classes of zooplankton reflected frequencies of the main taxonomic groups. The small zooplankton dominated the sampled sites of the Třeboň region. The size classes < 0.3 mm and 0.3-0.7 mm were the most frequent in both seasons; on average, over 70 % of zooplankton fell into these size classes.

The size class 0.7-1.5 mm was represented by 8 – 21 %. Less than 8 % of zooplankton was larger than 1.5 mm.

7. 113 zooplankton taxa (38 Cladocera species, 14 species of Copepoda, and 61 Rotifera species) was recorded in the Blatná-Lnáře fish ponds during the 2004 and 2005 seasons.

8. The most frequent taxonomic group in the Blatná-Lnáře fish ponds were rotifers, forming from 41 to 52 % of zooplankton. *Keratella quadrata* and *K. cohlearis* were the most frequent species, recorded at more than two thirds of the observed sites. *Polyarthra dolichoptera*, *Asplanchna priodonta*, *Brachionus angularis*, *B. calyciflorus*, and *B. diversicornis* were also frequent. Nauplii and copepodites, comprised 26 – 43 % of zooplankton. Adults of *Copepoda* did not frequent. The frequency of adult *Calanoida* varied between 2 and 3 % and the frequency of adult *Cyclopoida* formed around 1 % of zooplankton. The most frequent *Calanoida* species was *Eudiaptomus gracilis*. *Acanthocyclops trajani*, *Cyclops vicinus*, and *Thermocyclops crassus* were the most common *Cyclopoida* species. Cladocerans comprised 17 – 42 % of zooplankton. Similarly to the Třeboň fish ponds, the most frequent cladoceran species was *Bosmina longirostris* (occurring at more than 60 % of the sites). Genera *Ceridaphnia* (mostly *C. affinis*) and *Chydorus* (*Chydorus sphaericus*) were relatively frequent. *Daphnia galeata* was the most common *Daphnia* species (more than 50 % of the observed fish ponds). Large *Daphnia* species were largely represented by *Daphnia pulicaria*. The occurrence of *D. pulicaria* prevailed in spring, when this species was recorded at 24 – 33 % of the sites. The occurrence of *Daphnia longispina* and *D.magna* was scarcer. *Daphnia cucullata*, *Daphnia ambiqua* and *D.parvula* were, with few exceptions, relatively rare, and mostly occurred in the summer zooplankton.

9. The proportion of individual size classes was primarily affected by the occurrence of the main taxonomic groups. Size class < 0.3 mm was the most numerous in Blaná-Lnáře fish ponds. On average, this category comprised over 50 % of zooplankton; 17 – 36 % of zooplankton belonged into the size class 0.3 – 0.7 mm and 9 – 17 % of zooplankton was found within the 0.7 – 1.5 mm size class. The class over 1.5 mm comprised less than 5 % of zooplankton.

10. Blatná-Lnáře fish ponds were more diverse in zooplankton species than fish ponds in Třeboň region which were more uniform. High number of cases of large *Daphnia* predominance were recorded in Blatná-Lnáře fish ponds. In this region, the two-year cycle management is still practised and this system enables the occurrence of large daphnias in the first year of the cycle, as the fish stock biomass is lower. However, the species composition of both regions was similar and adequate for sites with intensive fishery management.

11. The biomass of the fish stock proved to be the key factor of zooplankton community formed under highly eutrophic conditions. The increasing fish stock biomass has the strongest effect on the species composition of Cladocera with *Daphnia pulicaria* being the most sensitive species. The decrease of its frequency under 20 % occurs with the fish stock over 250 kg ha^{-1}. The highest frequencies of *Daphnia galeata* were recorded for the fish stocks between 250 – 350 $kg.ha^{-1}$.

Ceriodaphnia and *Daphnia cucullata* reached their maximum frequency of the occurrence with the fish stocks between 500 – 700 kg.ha^{-1}. *Bosmina longirostris*, *Daphnia parvula*, and *Daphnia ambiqua* were the last cladocerans occurring at the fish stocks over 1,200 kg.ha^{-1}. *Cyclopidae* were most frequent with the fish stock biomass between 1.300 and 1.500 kg.ha^{-1}. The family *Calanoida* reached their maximum frequency of the occurrence with the lowest fish stock biomass. They were not recorded under the conditions of fish stock biomass higher than 900 kg.ha^{-1}. *Copepoda* nauplii reached their highest frequency (40 %) at the highest fish stock biomass (more than 1.600 kg.ha^{-1}).

12. Daphnia index (DI) derived from frequency of genus *Daphnia* and average *Daphnia* body length was suggested as quantitative indicator. Therefore Daphnia index is usuable for evaluation of the influence of zooplankton on phytoplankton.

13. In spring, the plankton structure corresponded with the generally accepted principles of top-down regulation at most observed sites. Situations which did not corespond to the classical concept of top-down regulation occurred mostly in summer and the last summer periods. This involved cases when a relatively high frequency of large *Daphnia* (*Daphnia* >1.0mm mean length) was not able to eliminate the development of phytoplankton and, at the same time, high fish stocks were not able to eliminate the development of large *Daphnia*. The situations when large *Daphnia* were not able to reduce the development of phytoplankton were more common in the fish ponds of the Třeboň region. This phenomenon occurred at 18 % of the sites. On the other hand, in the Blatná-Lnáře fish ponds, this phenomenon occurred only at 6 % of the sites. At the same time, the Třeboň sites displayed a higher frequency of situations (Třeboň – 31 %, Blatná-Lnáře – 6 % in summer and late summer period) when high fish stocks were not able to eliminate large *Daphnia*.

14. The situations where large *Daphnia* were not able to eliminate phytoplankton occurred particularly when phytoplankton consisted mainly of single-filamentous (*Anabaena*, *Aphanizomenon*, *Planktothrix*) or small-colonial (*Microcystis*) cyanobacteria species, i.e. forms hardly usable by herbivorous zooplankton.

15. More than one half of the cases when high fish stocks were not able to eliminate large *Daphnia* occurred under conditions when the average individual weight of rear carp was higher than 1.8 kg. These situations mostly involved intensive supplementary feeding of the fish stock when the feeding production exceeded the natural productivity severalfold.

16. The results further suggest that the more frequent occurrence of situation when the top-down regulation is inefficient restrains the natural growth increment increase of fish and thus adds to the requirements on intensified supplementary feeding. Subsequently, the economic costs of carp culture grow.

SUMMARY

Fish pond systems represent unique and important water man-made ecosystems in the Czech landscape. Fish production is their main function and rational management is an inevitable condition for their existence. Most of them are several hundred years old and they look like small natural shallow lakes. In spite of that, fish ponds represent a managed aquatic ecosystem in which water level, fish stocks, and nutrient input are under human control. In spite of the fact, they have nature-close character often with a great biological diversity.

The first attempts to increase intentionally the nutrient status of the nutrient poor fish ponds with organic manure and inorganic fertilisers were described by Šusta (1898). Since the 1930s fish production has usually been enhanced by liming and fertilisation of the fish ponds together with fish feeding introduced at the and of the 19th century. Since the 1950s, the use of artificial feed such as grain and fish pelleds has become a more intensive and common practice. Fish production increased from a value of 50-100 $kg.ha^{-1}$ to more than 500 $kg.ha^{-1}$ during the period of intensification from the 1930s to the 1980s (Pechar et al., 2002). This rapid increase in fish production occurred in the period when high efficiency of energy transfer through the food web was observed (Kořínek et al., 1987). Current intensive fish production practices have an important impact on both the structure and dynamics of the aquatic ecosystem. High nutrient loads, especially in the form of manure, result in an increased eutrophication level, ultimately reaching a state of hypertrophy. The main symptoms of this stage are the massive development of phytoplankton, summer cyanobacterial blooms and large fluctuations in oxygen concentration and pH. A tenfold increase in fish stocks in the last 50 years has changed species and size composition of zooplankton comunities. A shift from the dominance of large *Daphnia* species (effective phytoplankton filter-feeders) to the small individuals such as nauplii, copepodites, small species of Cladocera and rotifers has been observed. This species are not so effective filter-feeders and therefore high primary production is not utilised at higher levels of the food chain. On the other hand, we can record situations, when high fish stock biomass and high quantities of large daphnias (*Daphnia* >1.0mm mean length) occur together with high biomass of phytoplankton (mostly consisting of inedible forms of cyanobacteria). This type of plankton structure does not fit the concept of top-down regulation. Occurrence of these situations is another example of certain instability of current fish pond ecosystems.

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APPENDIX

Published papers:

I. Potužák, J., Hůda, J., Pechar, L. (2007a): Changes in fish production effectivity in eutrophic fish ponds – impact of zooplankton structure. Aquaculture International, 15: 201-210.

II. Potužák, J., Hůda, J., Pechar, L. (2007b): Zooplankton in Hypertrophic Fish ponds: is the „ Top-Down“ Regulation of Phytoplankton Still a Valid Concept? Acta Universitatis Carolinae Environmentalica, 21: 115-120.