# Marine-glacial relict crustaceans in Lake Ivösjön

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Abstract

The first inventory of the marine glacial relict crustaceans in Lake Ivösjön was done by Holmquist in 1955. She found *Mysis relicta, Pallasea quadrispinosa* and *Pontoporeia affinis* in vigorous populations both on that occasion and on the following occasions until her last visit in 1959. This investigation is an attempt to replicate the studies done by Holmquist and to look into what kind of marine glacial relict crustaceans that exist within Lake Ivösjön today. The sampling took place on three occasions, end of May-beginning June, beginning of July and end of August 2006. By trawling the deep hauls, four relict crustaceans; *M. relicta, P. quadrispinosa, P. affinis* and *Limnocalanus macrurus* were found to be quite abundant. *Mysis relicta* was the most common species and in early June they were still releasing their offspring. There has been a dramatic change in the size and fecundity of *M. relicta* over the last 50 years, where the number of offspring has decreased with about 50%. Holmquist observed the females to carry 40-50 mysids on average, while the females today carried about 25 mysids on average according to this study. There was also a highly significant difference in length between females from 1955 and 2006 (P=0.002 ), where females of 2006 were about 3 mm shorter. Further, the average length of juveniles of *M. relicta* had decreased with 1-2 mm compared to 1955, and that too was a significant difference (P=0.05). The relict copepod *L. macrurus* was not investigated by Holmquist. Sampling in 2006 revealed that it was present Lake Ivösjön although in low numbers.

Sammanfattning

Ivösjöns ishavsrelikta kräftdjur inventerades för första gången 1955 av Holmquist. Hon fann *Mysis relicta, Pallasea quadrispinosa* och *Pontoporeia affinis* i livskraftiga populationer både vid det första tillfället och vid de nästkommande besöken fram till det sista besöket 1959. Den här studien är ett försök i att replikera studierna gjorda av Holmquist som nämnts ovan och att ta reda på vilka ishavsrelikta kräftdjur som förekommer i Ivösjön idag. Inventeringen skedde mellan maj-augusti 2006 och sjön besöktes vid tre tillfällen. Genom att tråla sjöns djuphålor befanns de fyra relikterna *M. relicta, P. quadrispinosa, P. affinis* och *Limnocalanus macrurus* att vara relativt vanligt förekommande. *Mysis relicta* var den vanligaste arten och tidigt i juni pågick fortfarande kläckning av avkomma. Det har skett en dramatisk förändring i storlek och fekunditet hos *M. relicta* de senaste 50 åren, där antalet avkomma minskat med cirka 50 %. Holmquist observerade att honorna i genomsnitt bar på 40-50 mysider medan dagens honor i genomsnitt bar på 25 mysider. Där var också en högst signifikant skillnad i längd mellan honor från 1955 och 2006 (P=0,002) där dagens honor är 3 mm kortare. Vidare är juveniler av *M. relicta* 1-2 mm kortare, vilket också är en signifikant skillnad (P=0,05). Den relikta copepoden *L. macrurus* inventerades inte av Holmquist, men är enligt den här studien närvarande i Ivösjön om än ganska ovanlig.

# 1.0 Introduction

The word *relict* is a form of the Latin verb *relinquere* meaning “to remain” and “to remain from an ancient time”. In biology and ecology the expression is used as a description of “an organism or species of an earlier time surviving in an environment that has undergone considerable change” (Wikipedia, 2006) and it is usually a question of “an isolated organism that once was abundant in a more widespread area but now is occurring at only one or a few small areas” (Reuter, 2003).

The relict crustaceans in focus here originate from the marine environment of the former stages of the Baltic Sea during the Pleistocene (Holmquist, 1963a). Their colonization to inland waters is not linked to a spreading by birds or any other way, nor is the mysids able to migration upstream (Holmquist, 1963b). Their migration was probably eased by turbulent climate changes and by floods (Holmquist 1963a, b) and when the ice withdrawn and the land uplifted, small areas of water became isolated from the sea and the animals within these areas were trapped (Brehm- Ekman, 1955).

Many have studied the distribution, morphology, behaviour and ecology etc. of the relict crustaceans, trying to distinguish how their findings are related to other freshwater relict crustaceans over Europe and North America and to learn more about how they originate (Ekman (1922), Segerstråle (1982), Lasenby et al. (1981), Holmquist (1959, 1963a-b, 1970). *Mysis relicta* has the widest distribution of the relict crustaceans (Kinsten, 1998) and it is probably also the most studied one. Holmquist (1959) studied the mysids of fresh as well as brackish waters trying to distinguish their evolutionary differences. She found some differences in morphology among the mysids, but they showed no specific geographical or environmental pattern. She came to the conclusion of an ancestor of the *M. relicta* that must have migrated to freshwaters. However, with regard to *M. relicta* and morphological differences, yesterday’s issues are with the techniques of today more or less solved, even though there is still a lot more to be studied. Through genetic studies it has become clear that the different mysids can be grouped as either continental or marine mysids based on their dispersal, where *M. relicta* goes under the group continental mysids (Audzijonyté, 2006). Further, genetic studies have revealed that *M. relicta* is a complex of four specific species of which three (sp. I-III) are found in northern Europe and a fourth (sp. IV) in North America (Väinölä et. al, 2002). *Mysis relicta* is belonging to sp. I (Väinölä & Vainio, 1998).

The crustaceans I have studied are called “marine glacial relicts”, as a result of their distribution in lakes in the northern hemisphere during the last glaciation (Holmquist, 1962). These crustaceans live at or near the bottom of a lake where the temperature is low and the oxygen content is high and where light cannot reach. These parameters are crucial for their survival, since they are quite sensitive to low oxygen levels and rapid changes of different kind in their environment (Holmquist, 1959). The pollution of waters is a severe threat to relict crustaceans, since it changes these life supporting parameters in a negative direction. Pollution can result in defects in eggs and embryos and at worse their disappearance.

Pollution in different forms can enter Lake Ivösjön and contribute to the status of the lake by the many inflows of streams, channels and sewage treatment plants etc., that are found over the whole catchment area (Ivösjökommittén, 2006). The lake is under anthropogenic influence since it is surrounded by agriculture and industries, which will affect the quality of the inflows. Today the "Committee of Lake Ivösjön" performs chemical and biological measurements at several stations in the lake following the status of the lake over time (Ivösjökommittén, 2006). It is important to include both chemical and biological measurements and that they are included controlled programs over time (Spellerberg, 2005) and this is where this study comes in. By making an inventory and performing other studies on these relict crustaceans, they can become an important instrument for future use in different monitoring programmes, serving as bioindicators for their environment.

This study is an attempt to replicate the study made by Charlotte Holmquist in 1959, to determine what kind of relict crustaceans that exists within Lake Ivösjön today compared to the results obtained by Holmquist (1959) more than 50 years ago. The goals of this study are to:

i. Determine the species composition and distribution of relict crustaceans present in Lake Ivösjön today.

ii. Determine if changes have occurred in relict crustaceans composition/abundance during the last 50 years.

iii. Propose a future monitoring programme for relict crustaceans.

Since I found *L. macrurus* in Lake Ivösjön the following important questions were added;

iv. Is the distribution of *L. macrurus* in Lake Ivösjön common or not?

v. Where in the water column is this copepod most abundant?

Relicts are fascinating to study because they are remains from an ancient time and most important; they play a major role in the ecosystem and contribute to the biodiversity of the lake. Other known relicts are for example the gull (*Larus relictus*) (www.arkive.org/species/GES/birds/Larus_relictus/more_info.html, 2008), the endangered arctic char (*Salvelinus umbla*) (Artdatabanken, SLU 2005) as well as the rare flower (*Bartsia alpina L.*) (Naturhistoriska riksmuseet, 2008).

The topic of this study was proposed by the County Board of Scania.

## 2.0 Lake regulation

In 1874 lake Ivösjön was lowered 1.8 meters, which resulted in more land for farmers to cultivate (Almer, 1978). Today Lake Ivösjön lies about 6 m above sea level (Ivösjökommittén, 2006). The in- and outflow of water is regulated by "Stora Enso Nymölla AB" since 1962. The water level is set between 5.70 – 6.00

meters above sea level. In 2005 the mean discharge of that year was 7.6 $m^3/s$ (Al control AB, 2005).

### 3.0 Hydrology

Lake Ivösjön is a dimitic lake, with turnover during spring and autumn, during which the top and bottom water layers mix bringing up the nutrients to the surface. The lake might be stratified during winter and summer. In summer the different densities of the upper warm layer and the colder lower layer (4°C) produce a thermocline, which can be localized by measurements of the temperature (Wetzel, 2001). Sometimes in winter, ice formation occurs on Lake Ivösjön, which might last until spring (pers. communication Almer) which, again, might cause a stratification of the water.

### 3.1 Eutrophication and the hydrological cycle

Pollutants of various kinds can enter the lake through different transport paths in the hydrological cycle. Organic pollutant for instance, could lower the oxygen content at the bottom of the lake, since the decomposition process demands oxygen. The bottom living species will at worse disappear and the phytoplankton production will increase, which contributes to even lower oxygen content when they fall to the bottom and decompose (Almer, 1973, Ivösjökommittén, 2006). When no oxygen is left at the bottom, the bindings of iron and phosphate break and phosphorous enter the water as soluble. The so called “internal phosphorous loading” is hereby started (ALcontrol, 2005). This leads to an even greater spreading of phytoplankton and the lake will in time become eutrophic (Wetzel, 2001). This “internal phosphorous loading” has according to some already started in Lake Ivösjön (Ivösjökommittén 2006, pers. comment Lars Collvin) so the question is more about suppression and staying in balance with the levels already existing.

In 2005 a total of 30 ton N and 140 kilos P entered Lake Ivösjön from river Holjeån. The nutrients in the river are mainly coming from one contributor, “Olofströms ARV” (ALcontrol, 2005). Since the level of phosphorous from river Holjeån represents 10% of the overall entering to the Lake Ivösjön, reduction from single sewage treatment plants, like Olofströms ARV should take place (Ivösjökommittén, 2006). In addition, diffuse leakage from surrounding land must also be considered (Ivösjökommittén, 2006). Generally, the input of pollution to Lake Ivösjön has probably declined since the 1960s, due to the improvement of sewage treatment (ALcontrol, 2005).

## 4.0 Lake Ivösjön and EU

In Sweden we are working actively with 16 environmental quality objectives for the environment. The goals are presented at a national (the government of Sweden), regional (county board) and at a local level (the municipality). For Lake Ivösjön the following environmental quality objectives is applicable:

- “Living lakes and streams”
- “No eutrophication”
- “Only natural acidification”
- “Good quality of drinking water”
- “Non- toxic environment”

Lake Ivösjön and its surroundings serves as shelter for endangered species, as recreation area, and as a water supply, which has made this region part of a EU-network called Natura 2000 (Länsstyrelsen i Skåne län, 2005). A Natura 2000 area is described as “an area that holds great nature- and species values and therefore shall function as important habitats for the maintenance of species population with in a long term perspective” (Naturvårdsverket, 2006). The Natura 2000 area of this region is 6 165 ha large and it hosts redlisted and/or Natura 2000 species like spined loach (*Cobitis taenia*) (NT), eel (*Anguilla anguilla*) (CR), sea eagle (*Haliaeetus albicilla*) (VU), bittern (*Botaurus stellaris*) (VU), *Leptodora kindtii, Holopedium gibberum* , the glacial relict crustaceans, and the relict smelt (*Osmerus eperlanus*) that all are incorporated within this protected area and part of the Bird directive (79/409/EEG) and/or the Species- and habitat directive (92/43/EEG) (Länsstyrelsen i Skåne län, 2005). Lake Ivösjön also has the most southern population of rendace (*Coregonus albula*) (Länsstyrelsen i Skåne län, 2005).

Being a Natura 2000- area creates some demands i.e. several different protection laws and certain goals, as seen below, that have to be followed and verified (Länsstyrelsen i Skåne län, 2005).

- The water quality with clear water and low nutrient levels must not get any worse.
- The incoming nutrient to the lake must not increase.
- The bottom sediment must contain oxygen to keep the internal phosphorous loading low.
- The today remaining near lake land must not be exploited.
- The population growth of Natura 2000- species shall continue.

Any operation that could affect the environment in the Natura 2000 area is forbidden without permission from the County Board. This is especially relevant to any building within the land protection area that reaches 100 meters out in the lake and 100 meters up on land (Länsstyrelsen i Skåne län, 2005).

# 5.0 Studies of the marine glacial relict crustaceans in Sweden

Studies of the marine glacial relict crustaceans have been done in several Swedish inland lakes. Björk et al. (1964) and Kinsten (1998) studied abundance and distribution of relict crustaceans in the lakes “Stora Kroksjön”, “Galtsjön” and ”Blanksjön” in the province of Blekinge. Holmquist (1959) visited several lakes as well when studying the relicts.

There have also been former inventories of the relict crustaceans in Lake Ivösjön. Holmquist (1959) paid several visits to Lake Ivösjön trawling for the relicts to distinguish their abundance, distribution, morphology and life history. Hamrin et al. (1980) made an inventory the relict crustaceans as well for the “Sydsvenska kraft AB”, when there were plans to build a power station in “Västanå”. In addition Almer (1972) has made inventories of these animals in Lake Ivösjön. But it is mainly the inventories made by Holmquist (1959) that I use as a reference to my studies.

### 5.1 Studies of the marine glacial relict crustaceans in the world

Studies of the relicts and mainly *M. relicta* have been done in different countries in the world; for instance in Norway, Canada, Finland, Russia, Germany, and Poland. Although genetic studies have answered a lot of questions about the linkage of these animals to each other, there are still questions that need to be answered to understand their ecology and the possibility to use them as bio-indicators.

## 6.0 The Ecology of the marine glacial relict crustaceans

Mysids and amphipods shed their exoskeleton while growing, which is called moulting. They moult several times during their lifetime. The shedding rate is rapid when they are juveniles and when reaching maturity the rate is declining. They do not shed at all when carrying embryos. Moulting is controlled by food availability and temperature, but to some extent also pollutants, which can delay or even inhibit this growing process (Viherluoto, 2001).

Figure 1. *Mysis relicta*.
(Photo: Hans Berggren)

*Scientific name: Mysis relicta Lovén*
Other name: opossum shrimp

*Mysis relicta* was first found in the 1860s in Lake Vättern by Sven Lovén (Brehm- Ekman, 1955). After this it has been found in many more lakes all over the world. It is the most spread animal of the marine glacial relict crustaceans (Kinsten, 1998) and probably also the most studied one. *Mysis relicta* is a long stretched, transparent opossum shrimp with characteristic black spots and stalked eyes (Museum Victoria, 1996). They can have a 1-2 year life cycle (Kinsten, 1998). Mating in Lake Ivösjön takes place once a year in November-December and the males die shortly after (Holmquist, 1955). It has eight pair of legs which is used when swimming and stirring up the sediment searching for food (Brehm-Ekman, 1955). Between the legs of the females has a pouch or marsupium used for carrying their offspring in during the winter months until about May, when they are released. At this point the offspring is a copy of the adults but only about 3 or 4 mm in length (Holmquist, 1955). *Mysis relicta* is sensitive to high temperatures and light, which makes them live closely to the bottom in the deep parts of the lake during day time (Holmquist, 1959). At night they apply vertical migration reaching the thermocline where the availability of food like zooplankton and phytoplankton is higher than at the bottom. The migration is also a way to avoid predators (Hakala, 1978). There have been reports of adult mysids reaching a length of 21 mm in inland lakes, but there is no specific length or length interval at where you can say that a species is an adult or not. This is highly individual and differs from lake to lake and from population to population. When mature they have developed specific characters and are adults. Before this they are called juveniles and/or sub adults. (pers. communication Asta Audzijonyté)

Figure 2. *Pallasea quadrispinosa*. (Photo: Charlotta Lorenzen)

*Scientific name: Pallasea quadrispinosa* G.O.Sars
Other names: scuds

*Pallasea quadrispinosa* is a brown-red laterally flatted gammarid with four backwards pointed spines on the back on the first abdominal segments (Enckell, 1980), which have given them their scientific name. They are found in freshwaters of Scandinavia, Poland and Germany and in brackish-waters along the coast of the Baltic Sea (Hill 1988). In lakes they can be found both with the littoral zone swimming in the vegetation at a couple of meters depth and in the deeper parts of the lake. They feed upon detritus, plants and small animals (Kinsten, 1998). The life cycle is one to two years and they reproduce during the autumn and winter until the summer when the young ones are released (Hill, 1988).

Figure 3. P*ontoporeia affinis. (*Photo: Charlotta Lorenzen)

*Scientific name: Pontoporeia affinis Lindström*
Other names: *Monoporeia affinis*

*Pontoporeia affinis* is only about 10 mm in size and white in colour. The characteristic last pair of legs has a wide plate, which is adapted to a digging behaviour (Enckell, 1980). The females are bad swimmers and they are mainly seen imbedded in the sediment in the deeper parts of the lake during daytime. Females only attend vertical migrations when it is time for reproduction in the autumn. The males on the other hand, have well developed swimming legs and improved eyes (Museum Victoria, 1996). These skills are mainly used to find a female easily during the mating period after which the males die (Byrén, 2004). The young ones are released in the early spring and the females often die after release of the hatchlings (Byrén, 2004). Their life cycle is one to two years (Tjärnö marinbiologiska laboratorium, 1998) but at greater depths than 45m they can have a 3 year life cycle (Sundelin, 2001). They are mainly deposit feeders, but in the Baltic they might also feed upon newly attached mussel larvae that are close to them, or they coexist with them (Tjärnö marinbiologiska laboratorium, 1998).

Figure 4. *Limnocalanus macrurus*. (Photo: Hans Berggren)

*Scientific name: Limnocalanus marcurus G. O Sars*

*Limnocalanus macrurus* is a big calanoid copepod that reaches a size of 2.4-2.9 mm as adult, with males somewhat smaller than females. They are omnivorous and filtered-feed on particles of 4-24µm in size, which mainly consist of diatoms, chrysophytes and nanoplankton, but they also eat other copepods, cladocerans and *L. macrurus* naupliars (Central Michigan University, 2006). The males and females are hard to distinguish from each other. However, the right antenna of the male is somewhat curved, males have a urosome with five segments and females with three segments of which one is enlarged and used as a genital segment. This species reproduction takes place once a year in the autumn and the whole evolving process from egg to adult takes about 6-8 months. The adults tend to live for another 6 months. Other calanoid copepod females carry egg sacs, but not females of *L. macrurus*. The males attach spermatophores to the enlarged genital segment on the female urosome, where after the females drop 10-20 fertilized eggs into the water. The eggs sink to the bottom of the lake and after 17-38 days, depending on water temperature, they have developed into a naupliar. The larva grows very slowly and goes through a couple of naupliar-stages by molting before they enter the copepodid form in spring during the plankton bloom (Central Michigan University, 2006). *Limnocalanus macrurus* was described in 1863 by G. O. Sars and in 1886 as *L. grimaldi* by DeGuerne. Both believing the other person’s species was a variant of the other one since the morphology of the two animals differed, but the findings of *L. grimaldi* have been explained as a subspecies to *L. macrurus* and the difference in morphological is an effect of its separation from the ocean over time (Central Michigan University, 2006). *Limnocalanus macrurus* lives both in marine waters and in freshwater in countries of the northern hemisphere like Canada, Sweden, Norway, Finland, Poland, Russia and the Arctic (Central Michigan University, 2006).

## 6.1 The food web in lakes with relicts

Relict crustaceans and especially *M. relicta* can be a main food source to predators like fish, invertebrates and birds, thereby serving as a link between primary- and secondary production at higher trophic levels in the aquatic ecosystem (Viherluoto, 2001). In the lakes where they are found they are usually an important food source to all bottom living fishes and in particularly to burbot (*Lota lota*) and smelt (*Osmerus eperlanus*) in the winter (Fürst et al. 1984).

*Mysis relicta* has been introduced to several lakes in Sweden as well as in other countries to improve the food supply to fish, with varying success (Fürst et al. 1986). In some lakes, an introduction of mysids have resulted in a change in the zooplankton community, resulting in a decrease in grazing on phytoplankton, which in turn can lead to an increase of algae giving rise to algae bloom (Fürst et al. 1986).

Earlier *M. relicta* was believed to feed on detritus and phytoplankton but not on zooplankton (Fürst et al. 1978, 1986). This belief led to an introduction of *M. relicta* in lakes where it was less suitable, resulting in a change in the zooplankton community and gradually also the whole ecosystem. In 1964 the first introduction of *P. quadrispinosa* and *M. relicta* was done in order to improve the food supply to fish in Lake Blåsjön (Fürst et al. 1986, 1978). This resulted in *M. relicta* dominating the whole ecosystem competing with the fish population for food instead of the mysids being the food source to the fishes (Fürst et al. 1978). However, introductions of mysids have not only been negative to the fish populations. In Lake Blåsjön the population of char has improved both in size and in flesh colour compared to the same fish species in lakes where no mysids have been introduced (Fürst et al. 1986). Introduction of *P. quadrispinosa* caused an increase in number of individuals of both trout (*Salmo trutta*) and char (*Salvelinus fontinalis*), but the length of the fish species decreased at the same time. Studies have revealed that the young fish seem to have benefited more than adults of introduction of *P. quadrispinosa* (Fürst et al. 1986).

To suppress an eventual unbalanced ecosystem where mysids are present, fish like smelt, which is pelagic and eats mysids, can decrease the mysid population if present in appropriate quantities (Almer, 1978). Regarding *L. macrurus,* no particular data have been found on their contribution to the ecosystem or even if they have been introduced as food supply.

# 7.0 Material & Method

## 7.1 Site description

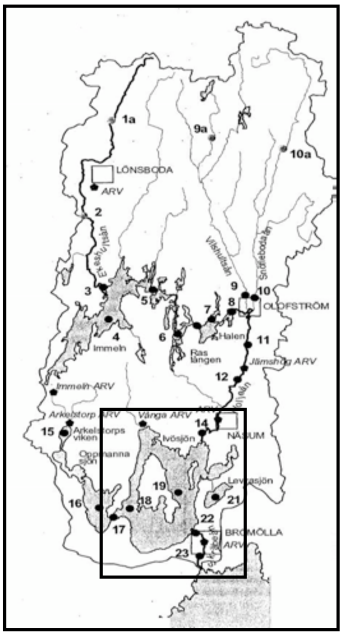
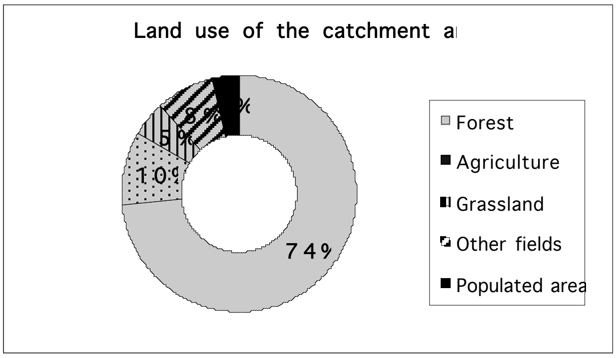



Figure 5. The catchment area of Skräbeå with Lake Ivösjön marked in the black box (Source: Ivösjökommittén)

Lake Ivösjön is situated in the northeastern part of Scania, southern Sweden (56°05´N 14°25´E), and is with its area of 52 km$^2$ and a depth of 50m, the biggest and deepest lake of this province. It is a meso-oligotrophic lake on bedrock of limestone with a pH being circum neutral (Ivösjökommittén, 2006). Trees like alder (*Alnus glutinosa*), oak (*Quercus robur*) and beech (*Fagus sylvatica*) can be seen along the lake. The composition of the trees varies depending on whether the land is cultured or not. In summertime cows graze on fields stretching down near the lakeshore in the southwestern part of the lake. From the shoreline and some meters out in the water the lake has a reed mat of *Phragmites australis*. Lake Ivösjön is a dimictic lake, turning over during spring and autumn. During winter and summer time stratification of the lake occurs. Lake Ivösjön is part of the "Skräbeå catchment area" (Figure 5), which is approximately 1000 $km^2$ (Ivösjökommittén, 2006). There are several inflows to Lake Ivösjön, but only one outflow. Some of the inflows are streams that are coming from the agricultural and forested areas up north. Others are channels from other lakes in the immediate area. The area has significant ground water reservoirs and the inflows to the lake are rich in carbonates as well as lime (Länsstyrelsen Skåne län, 2005). The main inflow to Ivösjön is the stream Holjeån which makes up 78% of the drainage basin of the inflows. The other inflows to Lake Ivösjön are the channel from Lake Oppmannasjön in the southwest (10%) and the small stream from Lake Levrasjön in the east (12%). The outflow of Lake Ivösjön is the stream Skräbeå in the south at Bromölla, which will enter the Baltic Sea after an approximately four kilometres long journey (Ivösjökommittén 2006). The land use of the catchments area today is dominated by agriculture, mainly in the north, where also the main inflow comes from. The north-western parts is dominating by orchards, occupying the hills down to the lake. Industries of various kinds, gas stations, establishment for waste products etc. are occupying the land along the eastern part of the lake (Ivösjökommittén, 2006) (Figure 6).




Figur 6. The distribution of the land use in the catchment area of Skräbeå. (Source: Ivösjökommittén, 2006)

### 7.1.1 The study area

The sampling locations, A-E, can be seen in figure 9. A total of five stations were sampled throughout the lake. Station 65 (A) (depth 33m), station Alsterberg (B) (depth 45m), station Malte (C) (depth 50m), and station Bromölla (D) (depth 42m) which have all been studied before and station Kjuge (E) (depth 20m) which has not been inventoried for the relicts before.


Figure 7. Map of lake Ivösjön with visited stations marked A-E (Source: Ivösjökommittén, 2006)

## 7.2 The inventory

June 22 2006 the coordinates of the greatest depths were located with help of a GPS (315 Magellan) to facilitate future sampling. The actual sampling took place on the 27th and 31st of May, 2nd of June, 1st and 4th of July and on the 25th of August 2006. The sampling started in the morning and was carried out during daylight from a boat with an outboard motor. Since one of the major goals was to compare the results of this study with an inventory made by Charlotte Holmquist in 1959, I have tried to use the same procedure with similar equipment as she did (Figure 8, 10). One change is that the trawling was carried out under a constant time instead of after a constant distance, since the GPS did not register any movement when travelling slowly on the lake.

Figure 8. Field equipment used. (Photo: Charlotta Lorenzen)

### 7.2.1 Field analyses

Water was collected from known depths with a so called "Ruttner sampler" (Figure 8). Sampling started 0.5 m below surface and samples were collected every 2.5 meters in June for station Bromölla and every 5 meters in July and August for station 65, Alsterberg, Malte, and Kjuge. The sampling ended just above bottom. The water was analysed for oxygen content (mg/l), oxygen saturation (%) and temperature (°C) with an oxygen recorder (model YSI 85). Oxygen and temperature was measured at:

| | |
|---|---|
| Station 65: | 27th of May, 1st of July and 25th of August |
| Station Alsterberg: | 27th of May, 1st of July and 25th of August |
| Station Malte: | 27th of May and 1st of July |
| Station Bromölla: | 2nd of June and 1st of July |
| Station Kjuge: | 4th of July |

See appendices 2-6 for more specific information.

A secchi-disk (20 cm in diameter) was used to measure the transparency of the lake water, also called secchi depth. The disk was lowered down the water column until just visible and the depth was recorded. Transparency was measured on every occasion except for station Bromölla in June, since it was too windy at that time. See appendices 2-6 for more specific information.

The water colour (mg Pt/l) was determined at five stations in July while the lake colour was estimated at station 65 and Alsterberg 25th of August. The lake colour was determined by studying the colours reflecting on the secchi disk at half the distance of the maximum transparency. Water colour was measured at:

| | |
|---|---|
| Station 65: | 4th of July |
| Station Alsterberg: | 1st of July |
| Station Malte: | 1st of July |
| Station Bromölla: | 1st of July |
| Station Kjuge: | 4th of July |

See appendices 2-6 for more specific information.

### 7.2.2 Qualitative sampling

On the 27th of May and 2nd of June qualitative samplings for the relict copepod *L. macrurus* were conducted at station 65, Alsterberg, Malte and Bromölla. The sampling began by lowering the plankton-net (100µm) with a diameter of 20 cm down to just above the bottom and straight up again over the greatest depth of each deep haul. The procedure was repeated five times per sample and a total of five samples at each of the four stations were collected. The samples were kept in 100ml bottles preserved in alcohol to a concentration of about 80% (Figure 9).

Figure 9. Plankton sampling with help from Bengt Bengtsson. (Photo: Brodde Almer)

### 7.2.3 Trawling

A bottom-sledge was chosen for the inventories of the relict crustaceans, since this was the method used by Holmquist as well. When first starting to dredge the deep hauls for relicts, a borrowed sledge was used with a mesh size too large for the smaller animals to be caught in. With a new net of smaller mesh size (1mm) and less seams all together, both adults and juveniles of different sizes could be caught and get more true and reliable results (Figure 10). This new construction of the net was also better for the animals, since fewer animals got stuck in between the mesh- openings of the net when travelling through on their way down to the bottle. The net was also easier to rinse afterwards. The frame where the net was attached at was 800 x 400mm. I followed an illustration of Ulf Lettevall when making the sledge, while the construction itself was made according to Holmquist (1959). Ropes were holding the frame into place when it was dredged after the boat and it was important not to have too much rope or too little rope stretched out since the sledge had a tendency to turn around at this. With help of an ecosonar and a depth-chart of the area (Persson 1926-1928) the greatest depth of the haul was found and the position recorded by the GPS. The net was slowly lowered down into the water until it reached the bottom. The boat was driving at low speed for about 10- 12 minutes towards an already picked landmark or direction. After stopping and having the sledge pulled up the final position on the GPS was written down. The frame was in the boat while the net was kept in the water. Depending on the amount of sediment in the sample, it was either preserved immediately with 95 % etanol to a final concentration of 70-80% or taken to the laboratory where the sample was rinsed and preserved.

Figure 10. The "Mysis-sledge" from up front. (Photo: Charlotta Lorenzen)

Trawling was done at:

| | |
|---|---|
| Station 65: | 31st of May and 4th of July |
| Station Alsterberg: | 2nd of June and 1st of July |
| Station Malte: | 1st of July |
| Station Bromölla: | 1st of July |
| Station Kjuge: | 4th of July |

7.2.4 Quantitative sampling

On the 25th of August *L. macrurus* was collected at specific depth intervals in the water column to study where in the water column these relict copepods prefer to live in the summer. Station Alsterberg and station 65 were chosen to represent the whole lake for this sampling.

A depth profile was done with oxygen and temperature to detect the thermocline. Six samples were collected throughout the water column (5m from water surface, 1m above thermocline and 1 position in between these, and 5m above the bottom, 1m below the thermocline and 1 position in between these). The plankton-net was lowered to the specific depth and pulled up to the water surface five times per depth-interval until a total of 6 samples per station were obtained. The samples were kept in 100ml bottles preserved in ethanol to a concentration of 70- 80%.

7.2.5 Analyses in the laboratory

All animals collected by trawling and/or plankton-net were stored under similar conditions. The actual identification and measurements were done in the laboratory later on with the help of a stereo-microscope.

**Analyses of dredge samples**

The dredge samples from each station were first rinsed, sorted and stored in ethanol (70-80%). The sorting and identification of the animals were done with a stereo-microscope. During the identification the length (from rostrum to telson) of all specimens of *M. relicta* and of *P. quadrispinosa* was measured. The gender of *M. relicta* was identified and counted as well as all females with unborn mysids in their marsupium. All unborn mysids were also counted.

**Analyses of qualitative net samples of *Limnocalanus macrurus***

The animals were studied under a stereo-microscope (Olympus SZ40) and the relict copepod was identified according to the taxanomic books (Enckell (1980), Harding & Smith (1974)) and counted. The copepods not being *L. macrurus* was also counted but not taxonomically identified. The petri-dish was marked with a square-net to ease the counting of the copepods. At least 1000 copepods per station were counted. The numbers of *L. macrurus* counted resulted in an overview of which stations that serve as best habitat for these animals and which can represent the whole lake for future inventories.

### Analyses of quantitative net samples of *Limnocalanus macrurus*

Two out of five 100ml bottles from each depth interval at both stations were chosen to represent the quantification of the copepods in the lake. The procedure began with shaking the chosen bottle before taking a 10ml sample with an automatic pipette. The sample was transferred to the petri-dish with the marked square-net at the bottom and all the copepods were counted under stereo-microscope. All the *L. macrurus* were picked aside and counted as well. When possible the gender of the *L. macrurus* was determined. This procedure was repeated three times per bottle. The total amount of sample investigated was 720ml at station Alsterberg and 600ml at station 65.

# 8.0 Results

## 8.1 Chemical analysis

### 8.1.1 Oxygen concentration & Oxygen saturation

Station 65

The oxygen concentration (mg/l) and oxygen saturation (%) for the three sampling dates at station 65 can be seen in figures 11-12. At the depth of 10m concentration varied from 5.5 mg/l in August to10 mg/l in May and at 32.5m values varied from 11 mg/l in May to 7 mg/l in August. The lowest value measured at this station was 5.5 mg/l (58%) in August at a depth of 10m, while the bottom value was 7 mg/l (58%) on the same occasion. According to the classification system of Naturvårdsverket this indicates a water relatively rich in oxygen i.e. class 2 (Naturvårdsverket 2006).

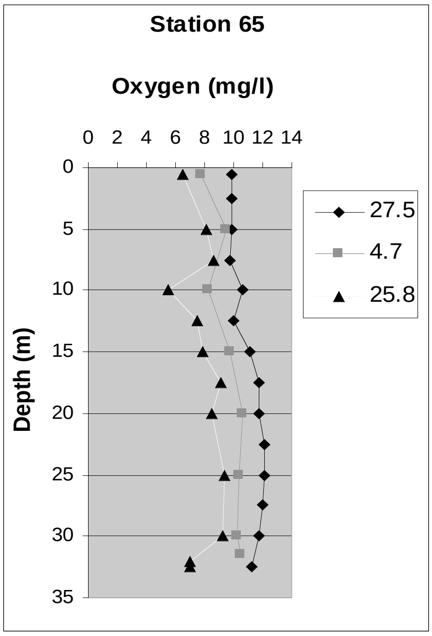



Figure 11. Oxygen concentration (mg/l) at station 65.

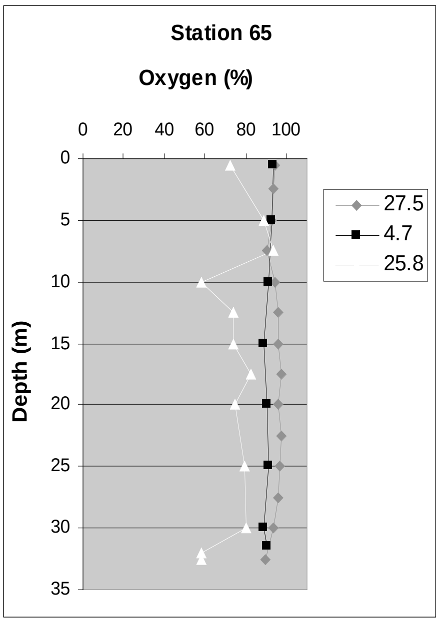



Figure 12. Qxygen saturation (%) at station 65.

Station Alsterberg

The oxygen level (mg/l) at this station is similar to the one at station 65 (Figure 13-14). The oxygen content decreased from 11 mg/l (89%) in May to 7 mg/l (57%) in August at the bottom, which indicate water with relatively good oxygen content i.e. class 2 (Naturvårdsverket 2006). The depth at station Alsterberg is about 45 m compared to station 65, which is about 33 m.

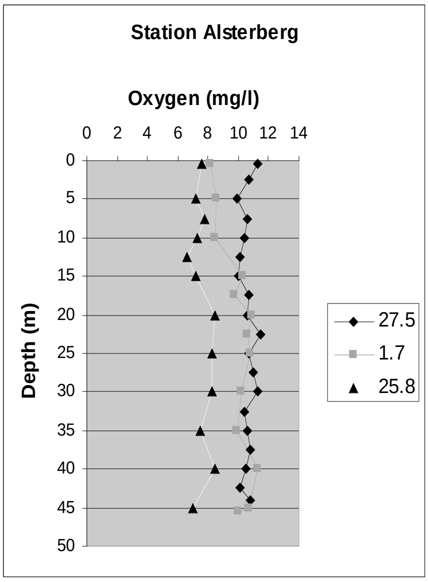



Figure 13. Oxygen concentration (mg/l) at station Alsterberg.

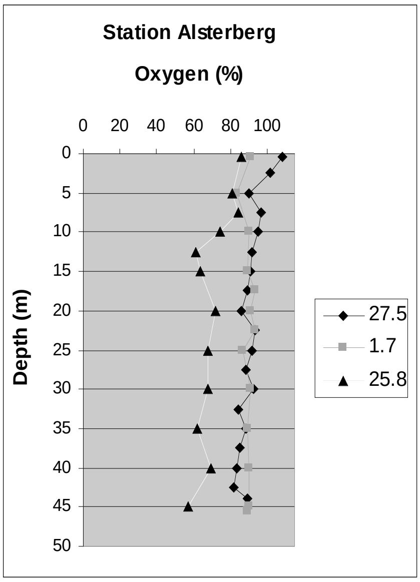



Figure 14. Oxygen saturation (%) at station Alsterberg.

Station Malte

Oxygen was measured in May and July and showed high levels (11 mg/l) at a depth of 47.5 m on both occasions (Figure 15-16). There was little change throughout the water column compared to station Alsterberg and 65 in August.

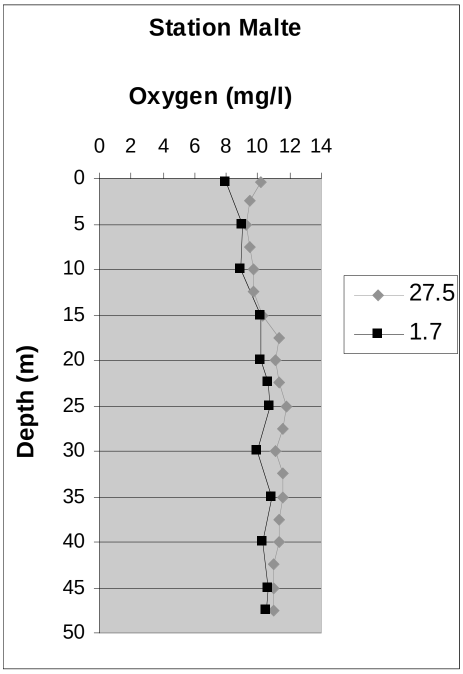



Figure 15. Oxygen concentration (mg/l) at station Malte.

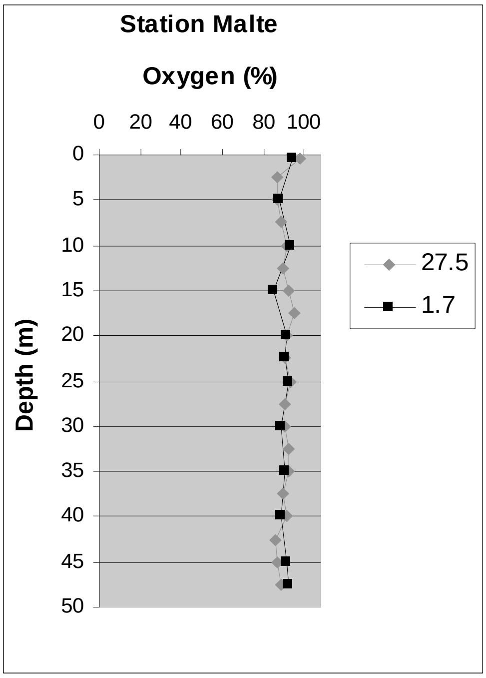



Figure 16. Oxygen saturation (%) at station Malte.

Station Bromölla

Oxygen (mg $O_2$/L and % saturation), was measured in June and July at station Bromölla. The oxygen levels were high, 11 mg/l and 12 mg/l respectively, at a depth of 40 m which is almost 100% oxygen saturation (Figure 17-18).

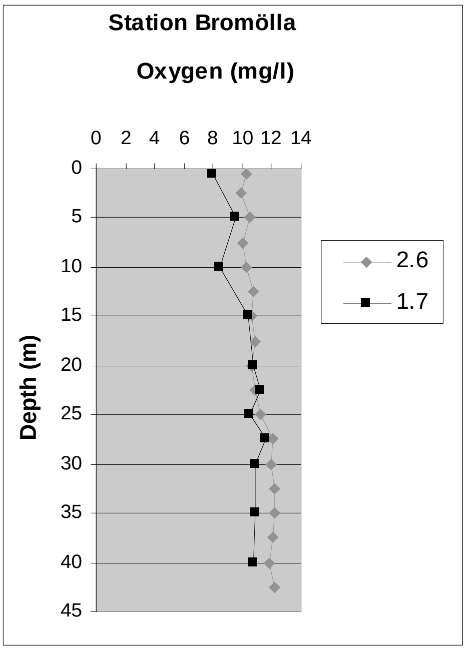



Figure 17. Oxygen concentration (mg/l) at station Bromölla.

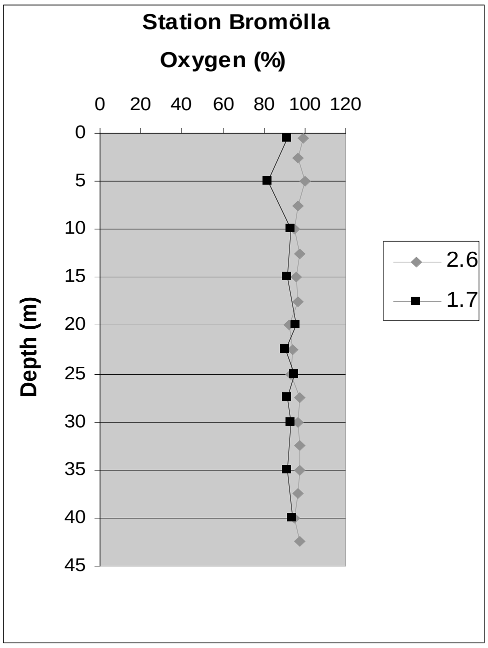



Figure 18. Oxygen saturation (%) at station Bromölla.

Station Kjuge

Oxygen levels were measured in July (Figure 19-20). This station was the most different compared to the other stations. The oxygen level was 7.9 mg/L (66% saturation) at the bottom (22m) and according to Naturvårdsverket this is class 2 (Naturvårdsverket 2006).

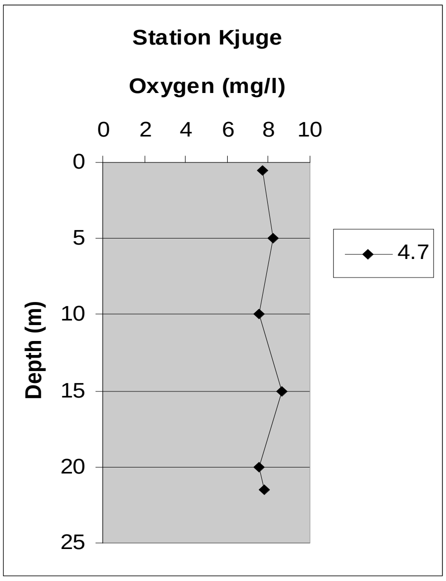



Figure 19. Oxygen concentration (mg/l) at station Kjuge.

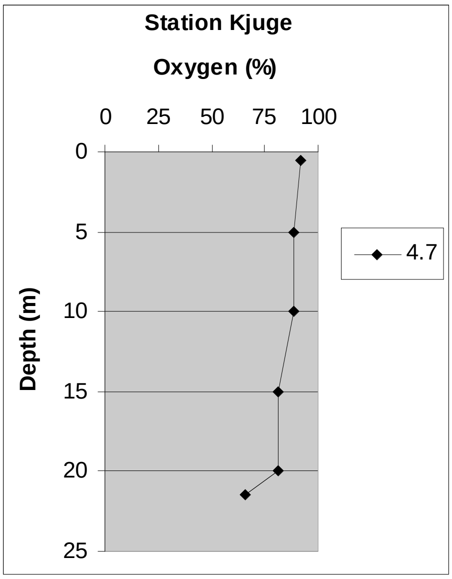



Figure 20. Oxygen saturation (%) at station Kjuge.

## 8.1.2 Temperature & Thermocline 

The summer of 2006 was warm. The surface water temperature was high during the whole sampling period and reached 22°C at station Alsterberg in August. The depth of the thermocline for station Alsterberg went from 15- 17.5 m in May to 10- 15 m in August (Figure 22). For station 65 the thermocline stayed at the same depth (12.5 – 17.5 m) throughout the summer, although it became more pronounced towards the end of the summer (Figure 21). For station Malte the thermocline appeared to be about 15m in both May and July (Figure 23) while the thermocline for station Bromölla was hard to determine in June and in July it was observed at a depth of 10m (Figure 24). At station Kjuge no clear thermocline was seen (Figure 25).

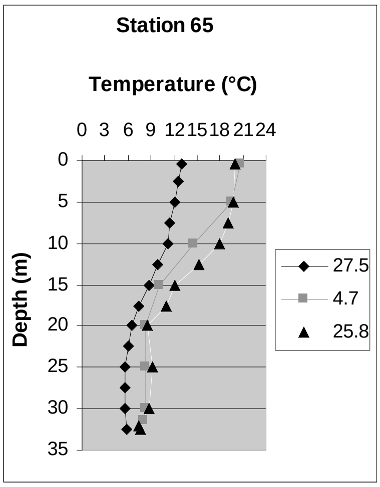



Figure 21. Temperature & thermocline at station 65.

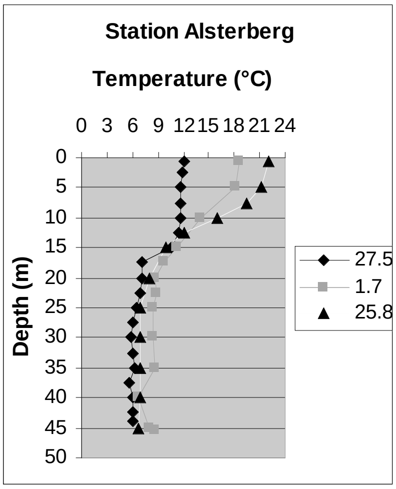



Figure 22. Temperature & thermocline at station Alsterberg.

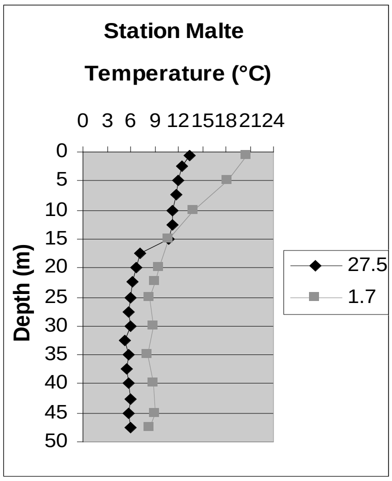



Figure 23. Temperature & thermocline at station Malte.

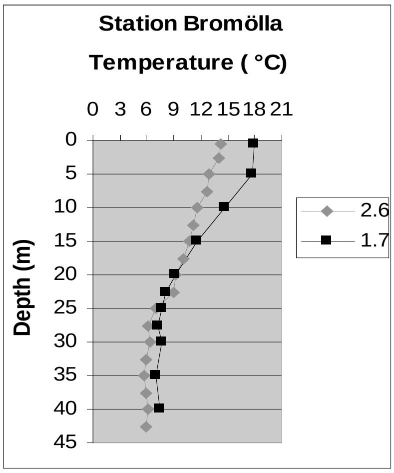



Figure 24. Temperature & thermocline at station Bromölla.

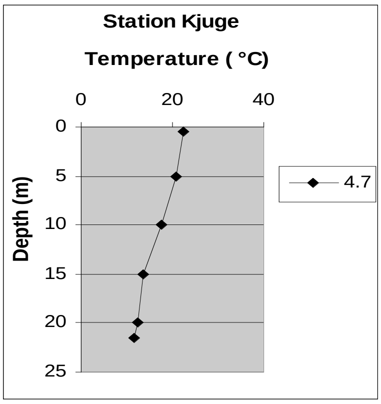



Figure 25. Temperature & thermocline at station Kjuge.

### 8.1.3 Secchi disk transparency, Water colour & Lake colour

The colour of the lake was low with 15 mgPt/L in July at the stations of 65, Alsterberg, Malte and Bromölla. The Secchi disk transparency varied between stations and months from 3.5 m (class 3), which indicates fairly good transparency to 5.6 m (class 2), which indicates good transparency according to the classification system of Naturvårdsverket (Naturvårdsverket, 2006). The lake colour was green-yellow at both station Alsterberg (appendix 2) and station 65 (appendix 5) in August.

See also appendices 2-6 for more specific information.

## 8.2 Distribution and composition of relict crustaceans

### 8.2.1 Distribution of the relict crustaceans from trawling

The species collected on the different sampling occasions and the number of individuals caught per station and per species can be seen in Table 1 and 2. In June female mysids had either released their offspring or was about to (Table 1), this was not seen in July (Table 2). For *P. quadrispinosa* unborn juveniles were found both in June and July for some females, while others still carried early embryos (eggs). The number of females was not counted, so they are not grouped as males and females. As regards *P. affinis* none of this was studied.

Table 1. Individuals caught per station and per species in May/June 2006.

| V.-VI. 2006 | *Mysis relicta* | | | | | *Pallasea quadrispinosa* | | | | *Pontoporeia affinis* |
|---|---|---|---|---|---|---|---|---|---|---|
| | Small | Adults | | Amount | Total sum | Small | Adults | Amount | Total sum | |
| Station | | ♀ | ♂ | unborn juv. | *M .relicta* | | | unborn juv. | *P. quadrispinosa* | |
| Alsterberg | 5 | 107 | - | 325 | 112 | 11 | 90 | 40 | 101 | - |
| 65 | - | 14 | - | 51 | 14 | - | 12 | 13 | 12 | - |

Table 2. Individuals caught per station and per species in July 2006.

| VII. 2006 | *Mysis relicta* | | | | | *Pallasea quadrispinosa* | | | | *Pontoporeia affinis* |
|---|---|---|---|---|---|---|---|---|---|---|
| | Small | Adults | | Amount | Total sum | Small | Adults | Amount | Total sum | |
| Station | | ♀ | ♂ | unborn juv. | *M .relicta* | | | unborn juv. | *P. quadrispinosa* | |
| Alsterberg | 181 | 52 | - | - | 233 | 2 | 32 | 14 | 34 | 87 |
| Bromölla | 63 | 11 | - | - | 74 | 19 | 95 | - | 114 | 162 |
| Kjuge | 106 | 10 | - | - | 116 | - | 1 | - | 1 | - |
| Malte | 20 | 4 | - | - | 24 | - | 3 | - | 3 | 13 |
| 65 | 209 | 60 | - | - | 269 | 28 | 10 | - | 38 | 3 |

In May/June (Table 1) the relicts were caught with a sledge with larger mesh opening. This is why few small mysids were caught compared to July (Table 2). I decided to include these samples anyway, since they show that the females of *M. relicta* still are releasing their offspring in June (Table 1) and having released all of them in July (Table 2). A similar pattern is seen with the females of *P. quadrispinosa* only they are still releasing their offspring in July. Most individuals were caught at station Alsterberg and station 65 regarding *M. relicta*, while *P. quadrispinosa* was most abundant at station Alsterberg in May/June (Table 1) and at station Bromölla in July (Table 2). Overall *P. quadrispinosa* had the greatest number of adult individuals caught and *M. relicta* had the greatest number of small individuals caught. *Pontoporeia affinis* was only caught in July with the greatest numbers found at station Bromölla (Table 2).

### 8.2.2 Distribution of *Limnocalanus macrurus* from plankton-netting

An inventory was made of *L. macrurus* in May/June along with the first oxygen measurements. Qualitative samples were collected and the results can be seen in table 3. The results show the distribution of the copepod throughout the lake and indicate where to look for the relict when wanting to monitor them. I did not look for *L. macrurus* at station Kjuge. *Limnocalanus macrurus* was at the sampling time, most numerous at station Alsterberg with 154 individuals out of a total of 1007 copepods counted (15%) and most rare at station Bromölla with 31 individuals out of a total of 1449 copepods counted (2%).

Table 3. Number of *Limnocalanus macrurus* found at the different stations from May and June 2006.

| Station | | *Limnocalanus macrurus* | *Distribution (%)* | Other copepods | Total sum copepods |
|---|---|---|---|---|---|
| | | | | | |
| Alsterberg | | 154 | 15% | 853 | 1007 |
| Malte | | 167 | 11% | 1369 | 1536 |
| Bromölla | | 31 | 2% | 1418 | 1449 |
| 65 | | 35 | 3% | 1058 | 1093 |
| Sum (all stations) | | 387 | 7,6% | 4698 | 5085 |
| Total (65 & Alsterberg) | | 189 | 0,8% | 1911 | 2100 |

A total of at least 1000 copepods or 100ml water sample per station was counted to determine if it is common or not in Lake Ivösjön.

### 8.3 Quantitative sampling of *Limnocalanus macrurus* in August

At station 65 the thermocline was located between 10-19 m and the zooplankton samples were positioned and taken from the depths of 5 m, 7 m, 9 m, 20 m, 25 m and 31.5m (Figure 26). At station Alsterberg the thermocline was located between 7.5-12.5 m and the zooplankton samples were positioned and taken from the depths 5 m, 6.5 m, 13.5 m, 30.5 m and 44 m (Figure 27).

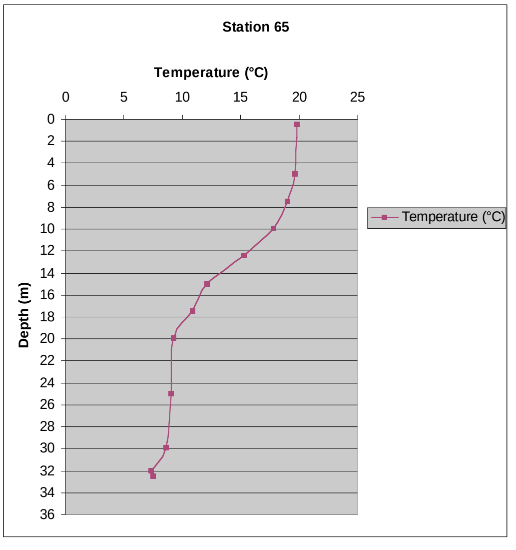



Figure 26.The positions of *L. macrurus* samples from station 65 in August 2006.

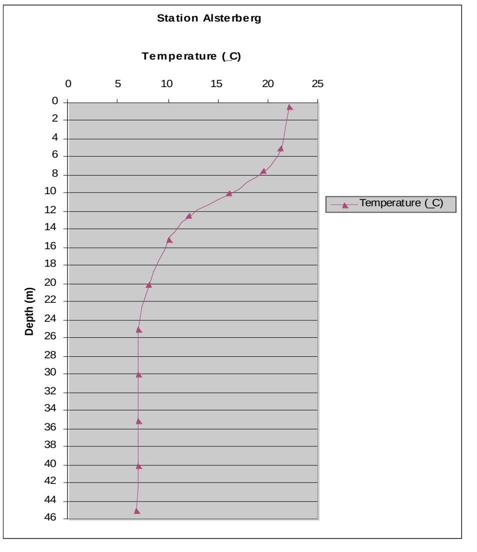



Figure 27. The positions of *L.macrurus* samples from station Alsterberg in August 2006.

### 8.3.1 Distribution of the relict copepod *Limnocalanus macrurus* from August sampling

Since the samples were taken from a specific depth to the water surface at each sample position (5-0 m; 6.5-0 m; 45-0 m etc), the number of copepods/L in the water column was calculated firstly and secondly at what specific interval in the water column they were obtained. *Limnocalanus macrurus* was caught in the deepest part of the lake at both stations (Figure 28-29). Further, *L. macrurus* was also found quite abundant between 7-9 meters at station 65 (Figure 29).

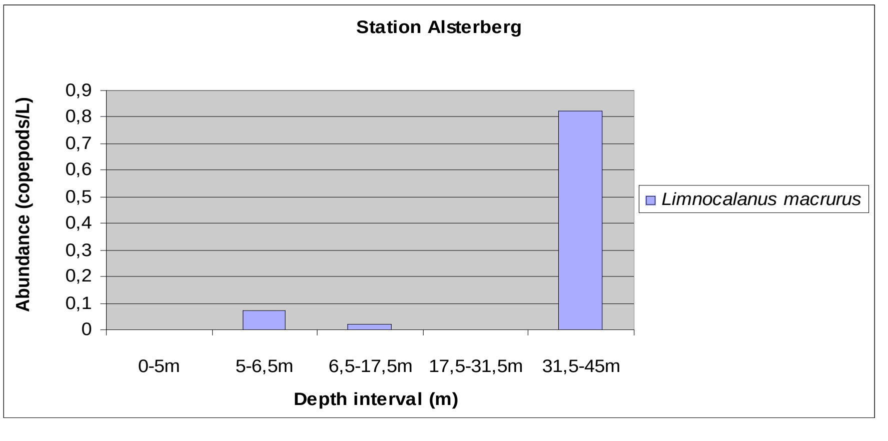



Figure 28. Distribution of *L. macrurus* in the strata at station Alsterberg in August 2006.

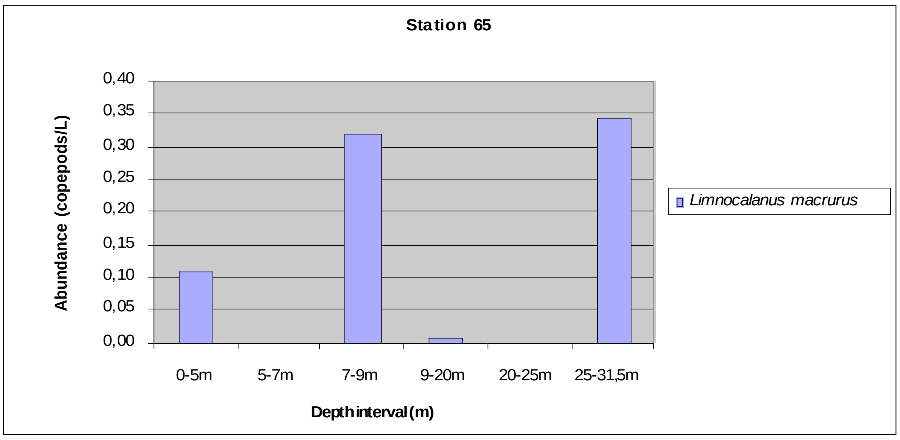



Figure 29. Distribution of *L. macrurus* in the strata at station 65 in August 2006.

### 8.3.2 Gender distribution of *L. macrurus*

The relict copepod caught was identified as females and males through specific characters of maturity. At station Alsterberg, 67% were females and 33% were males, while the composition of females (52%) and males (48%) were about equal at station 65 at the same occasion.

### 8.4 Overview of the species found

A comparison of the number of individuals of the different species found in Lake Ivösjön from each station is illustrated in figure 30. *Limnocalanus macrurus* was not collected with the same method as the other three crustaceans and is therefore likely to be over-represented. *Limnocalanus macrurus* was not collected at station Kjuge. Only one *P. quadrispinosa* was found at station Kjuge. Most animals were found at Alsterberg. Alsterberg also had the highest number of *M. relicta* (349). The minimum number of animals was, except for Kjuge, found at station Malte. This station also had the lowest number of *M. relicta* (25). Station 65 had many *M. relicta* (280) compared to the other stations. Regarding the number of individuals of *P. affinis,* station Bromölla had the highest number with 155 individuals followed by station Alsterberg with 80 individuals. The lowest number of *P. affinis* was collected at station Malte. *Limnocalanus macrurus* was most abundant at station Malte and station Alsterberg, which are representing the two deepest stations investigated.

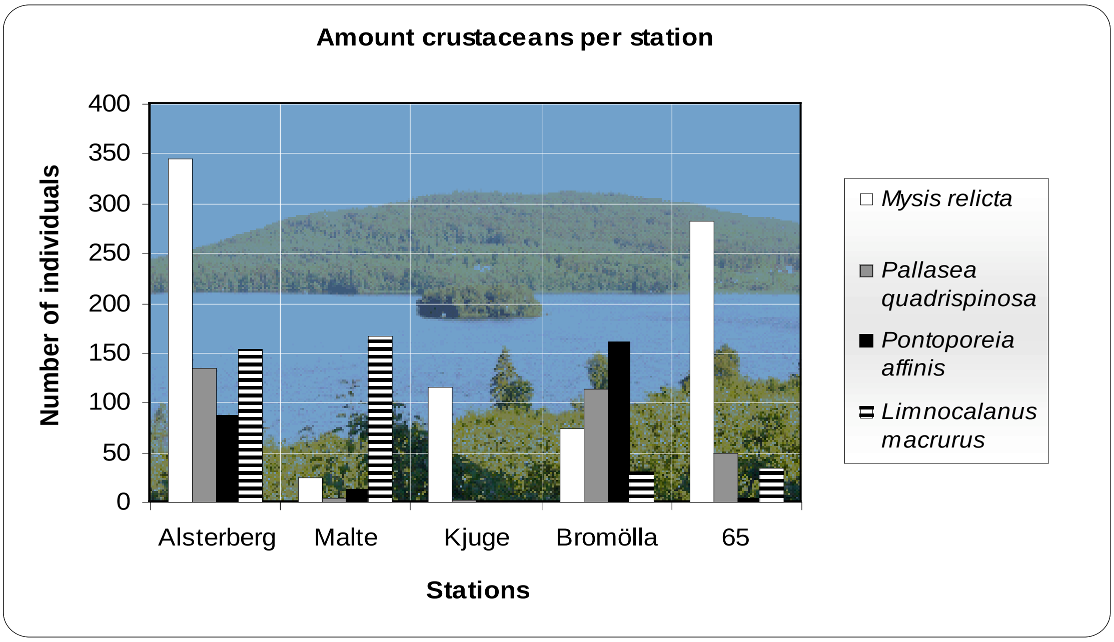



Figure 30. Comparsion of the relict crustaceans caught per station and per species. (Photo: Charlotta Lorenzen)

### 8.5 Life history of *Mysis relicta*

The mysids that were collected by a sledge drawn at the bottom of every deep haul on different occasions, is shown in the figures 31- 35. Because there is no specific length or length interval at which mysids are said to be adults, the sexes are determined with help from specific characteristics of maturity. No males were found in this study at any of the stations at either occasion. The reason for not catching any males is that they die shortly after mating (Holmquist, 1955), but some males are probably hidden in the column of juveniles that later on will mature to become adults. The females had a pouch that either was filled with small mysids or eggs or the pouch was already emptied. The most dominated length among the females in June was 14-15 mm represented by 42 individuals and in July 51 females of a length of 15-16 mm. Station Kjuge (Figure 33) had the largest individuals found at any of the stations, represented by 2 females of 20-21 mm and 1 female of 21-22 mm in length. The fourth biggest individual was caught at station Alsterberg in June with a length of 19-20 mm (Figure 31). Most adults were found in June, mainly from station Alsterberg. The shortest two females were found at station Alsterberg (Figure 31) and station 65 (Figure 32) in June with a length of 10-11 mm and in July 1 female of 11-12 mm at station Alsterberg. Station Bromölla (Figure 34) and station Malte (Figure 35) had similar length intervals for females (16-17mm) and juveniles (6-7mm). The juveniles or sub adults were caught in July and a total of 204 individuals had a length of 4-5 mm at this time.

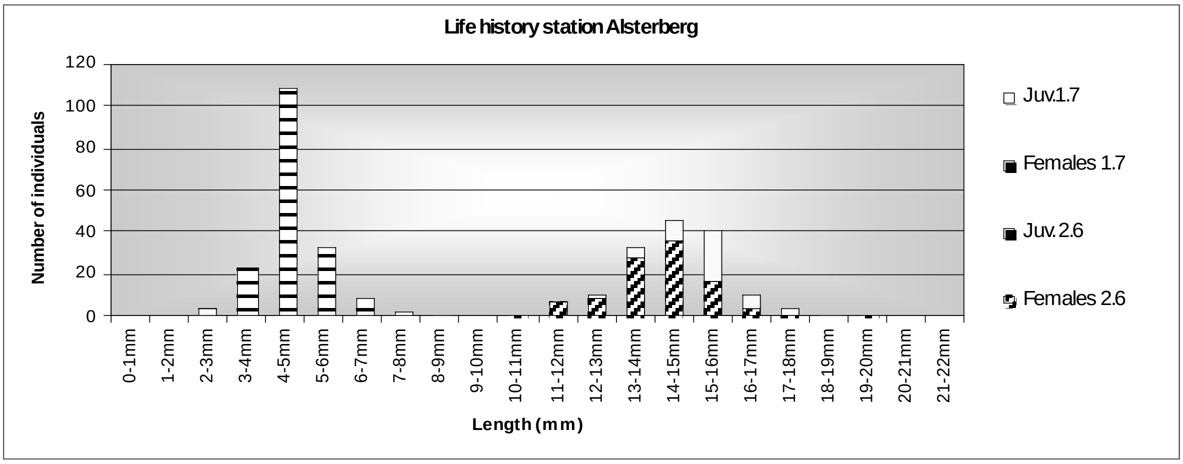



Figure 31. Length distribution of *M. relicta* at station Alsterberg on two occasions.

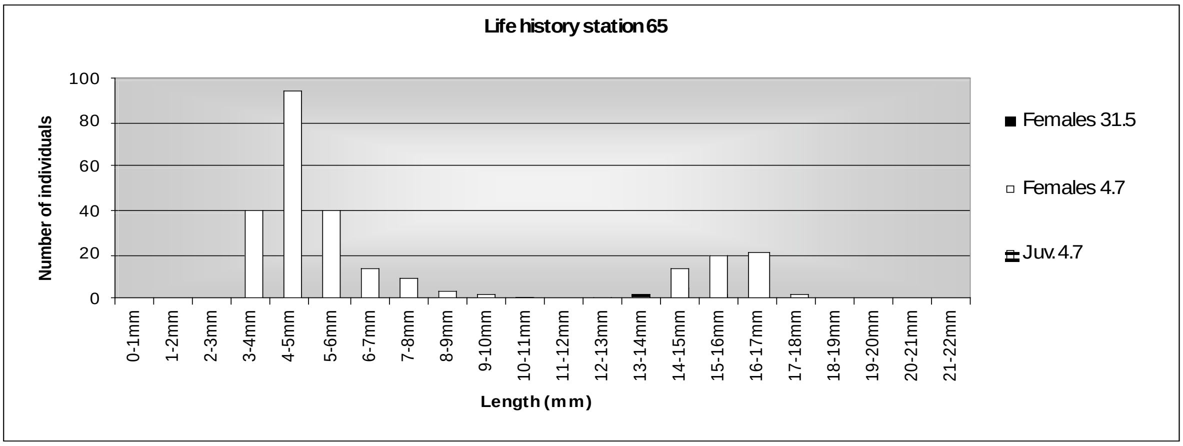



Figure 32. Length distribution of *M. relicta* at station 65 on two occasions.

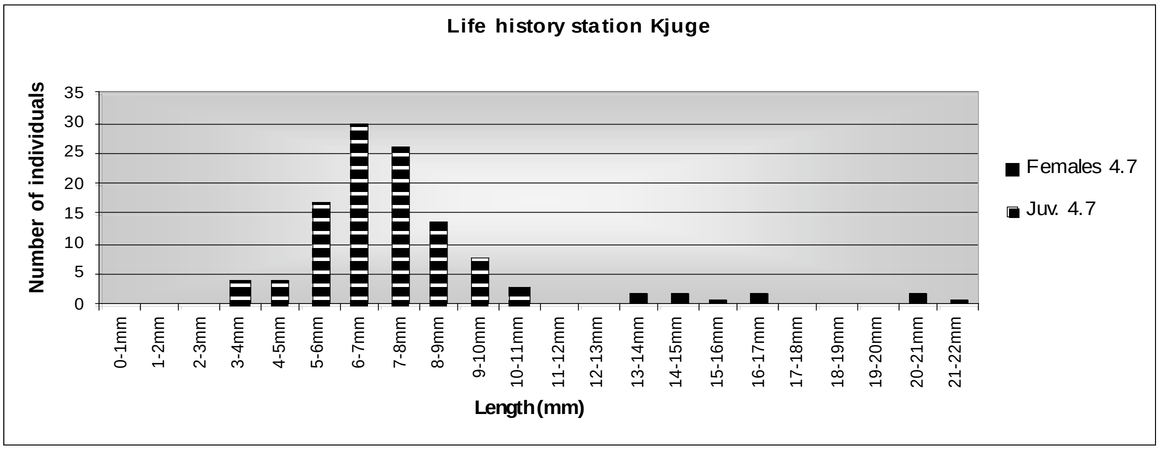



Figure 33. Length distribution of *M. relicta* at station Kjuge on one occasion.

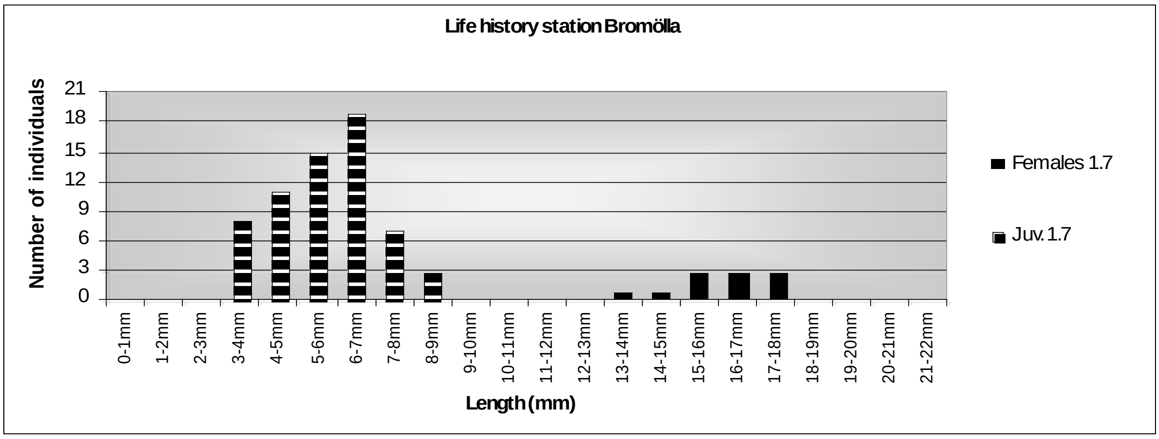



Figure 34. Length distribution of *M. relicta* at station Bromölla at one occasion.

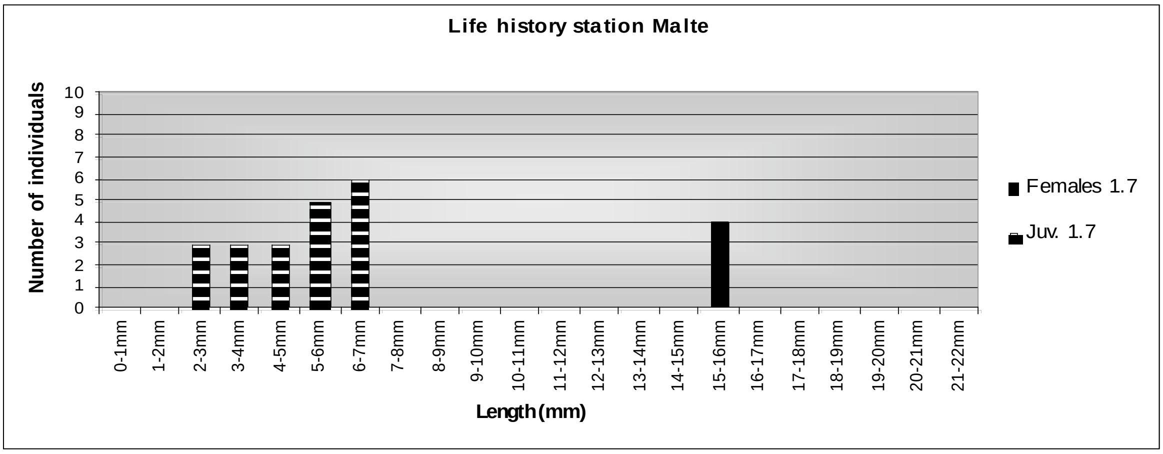



Figure 35. Length distribution of *M. relicta* at station Malte on one occasion.

## 8.6 Fecundity of *M. relicta*

Holmquist (1955) studied the fecundity of the females from Lake Ivösjön and found that they carried on average 40-50 mysids. Today 50 years later, this number has declined by about 50%, where the females only carried an average of 25 mysids (Table 4). The maximum number of unborn juveniles per female was 34 and the lowest number was 3 where these females were 14 and 11,5mm in length respectively. A total of 17 females were measured in this study and all carried unborn juveniles at the same embryonic stage. The sum of the total unborn mysids was 426. Others that have made such observations are for instance Hakala (1978) and Fürst (1972b) who looked at the fecundity of females in relation with their body size. Hakala (1978) studied females from Lake Pääjärvi and found that his females carried 29 embryos at the most.

Table 4. The fecundity of *M. relicta* females inventoried in May and June was studied and the result is seen below.

| *M. relicta* | V-VI.2006 | Station Alsterberg & 65 |
|---|---|---|
| Length (mm) Female | Nb. Females | Nb.unborn juveniles |
| 11 | 1 | 22 |
| 11,5 | 1 | 3 |
| 12 | 1 | 18 |
| 13 | 3 | 58 |
| 13,5 | 3 | 80 |
| 14 | 4 | 123 |
| 14,5 | 2 | 58 |
| 15 | 1 | 34 |
| 16 | 1 | 30 |
| Total sum: | **17** | **426** |
| Mean: | | 25 |
| Variance: | | 3-34 |

## 8.6.1 Distribution test of *M. relicta*

To detect a statistical difference of the length between the mysids found in 1955 by Holmquist compared to my findings in 2006, a one-tailed t-test assuming unequal variances was made. The result show P-values of great significant difference ranging from P> $5.2E^{-16}$ to P> 0.05 between both juveniles and females (Table 5-6). Females from 1955 were in general 3mm longer i.e 17-18 mm than the females from 2006, which were 14-15 mm (Table 6a-6b). Further were the juveniles from 1955 were about 6mm in length, while those in 2006 were about 1-2 mm shorter i.e. 4-5 mm (Table 5a-5b). My samples were caught at two different occasions one in June and one in July why two tables of juveniles and females are compared to the findings of 1955.

Table 5a. A one-tailed t-test comparing the length of the juveniles of *M. relicta* between 1955 and 2006 at station Alsterberg.

| Alsterberg 2.6 t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *06 Juv* | *55 Juv* |
| Mean | 4,2 | 6,727273 |
| Variance | 7,2 | 0,579545 |
| Observations | 5 | 33 |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | -2,09333 | |
| **P(T<=t) one-tail** | **0,052218** | |
| t Critical one-tail | 2,131847 | |
| P(T<=t) two-tail | 0,104436 | |
| t Critical two-tail | 2,776445 | |

Table 5b. A one-tailed t-test comparing the length of the juveniles of *M.relicta* between 1955 and 2006 at station Alsterberg.

| Alsterberg 1.7<br>t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *06 Juv* | *55 Juv* |
| Mean | 5,220994475 | 6,727273 |
| Variance | 0,750890117 | 0,579545 |
| Observations | 181 | 33 |
| Hypothesized Mean Difference | 0 | |
| df | 48 | |
| t Stat | -10,22279887 | |
| **P(T<=t) one-tail** | **6,12526E-14** | |
| t Critical one-tail | 1,677224197 | |
| P(T<=t) two-tail | 1,22505E-13 | |
| t Critical two-tail | 2,010634722 | |

Table 6a. A one-tailed t-test comparing the length of the females of *M.relicta* between 1955 and 2006 at station Alsterberg.

| Alsterberg 2.6<br>t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *06 Fem* | *55 Fem* |
| Mean | 14,66355 | 17,05263 |
| Variance | 1,92347 | 10,38596 |
| Observations | 107 | 19 |
| Hypothesized Mean Difference | 0 | |
| df | 19 | |
| t Stat | -3,17949 | |
| **P(T<=t) one-tail** | **0,002468** | |
| t Critical one-tail | 1,729133 | |
| P(T<=t) two-tail | 0,004936 | |
| t Critical two-tail | 2,093024 | |

Table 6b. A one-tailed t-test comparing the length of the females of *M.relicta* between 1955 and 2006 at station Alsterberg.

| Alsterberg 1.7<br>t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *06 Fem* | *55 Fem* |
| Mean | 15,76923077 | 18,11765 |
| Variance | 1,906485671 | 0,235294 |
| Observations | 52 | 17 |
| Hypothesized Mean Difference | 0 | |
| df | 67 | |
| t Stat | 10,44989978 | |
| **P(T<=t) one-tail** | **5,23162E-16** | |
| t Critical one-tail | 1,667916115 | |
| P(T<=t) two-tail | 1,04632E-15 | |
| t Critical two-tail | 1,996008331 | |

## 8.7 Life history of *Pallasea quadrispinosa*

The length of the amphipod *P. quadrispinosa* was also measured, which has been divided into juveniles and adults (Figures 36-38). The length interval varied from 3- 17 mm. The juveniles had a dominated length of 3-5 mm during the months June and July at station Alsterberg (Figure 36), station 65 (Figure 37) and station Bromölla (Figure 38), while the fourth station, Malte (Figure 38), had juveniles of 7-9 mm in length dominating in July. The dominating length of adults was 10-11 mm the same month at this station. The biggest adult was found at station Alsterberg in July with a length of 17 mm. Station Bromölla had the smallest adults with a length of 5-6 mm dominating. All stations were sampled in June and July except station 65 which was sampled in May and July. No juveniles were found in May at this station, only adults. In July more juveniles were found with fewer adults present.

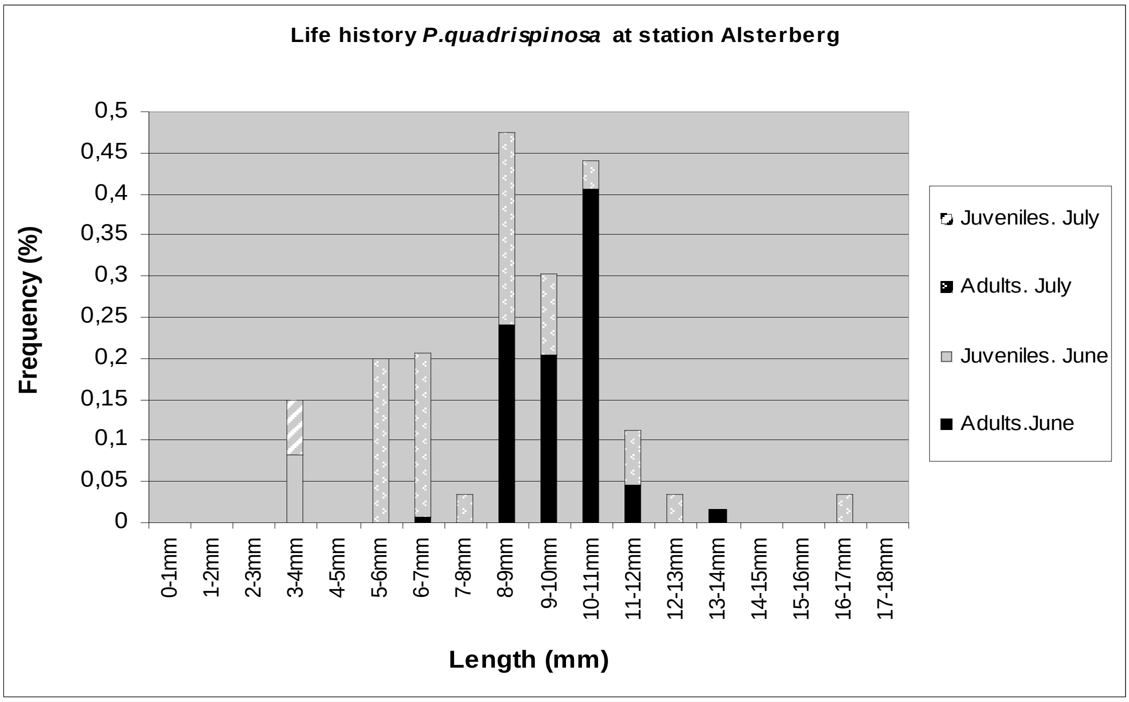



Figure 36. Length distribution of *P. quadrispinosa* at station Alsterberg in June and July 2006.

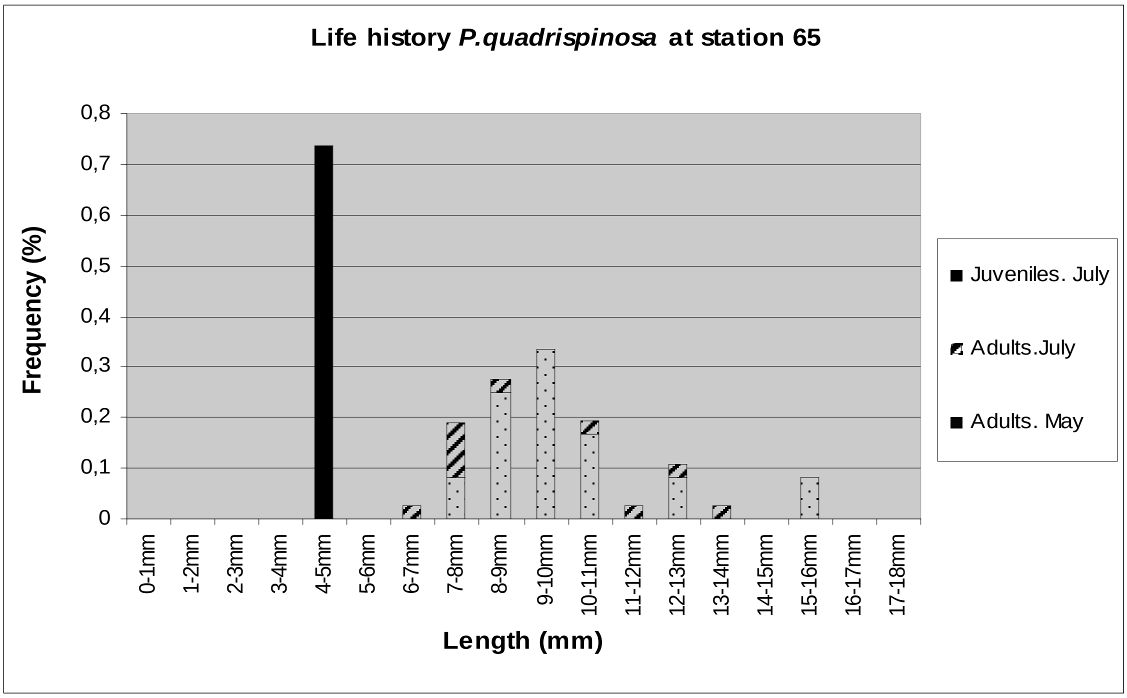



Figure 37. Length distribution of *P. quadrispinosa* at station 65 in May and July 2006.

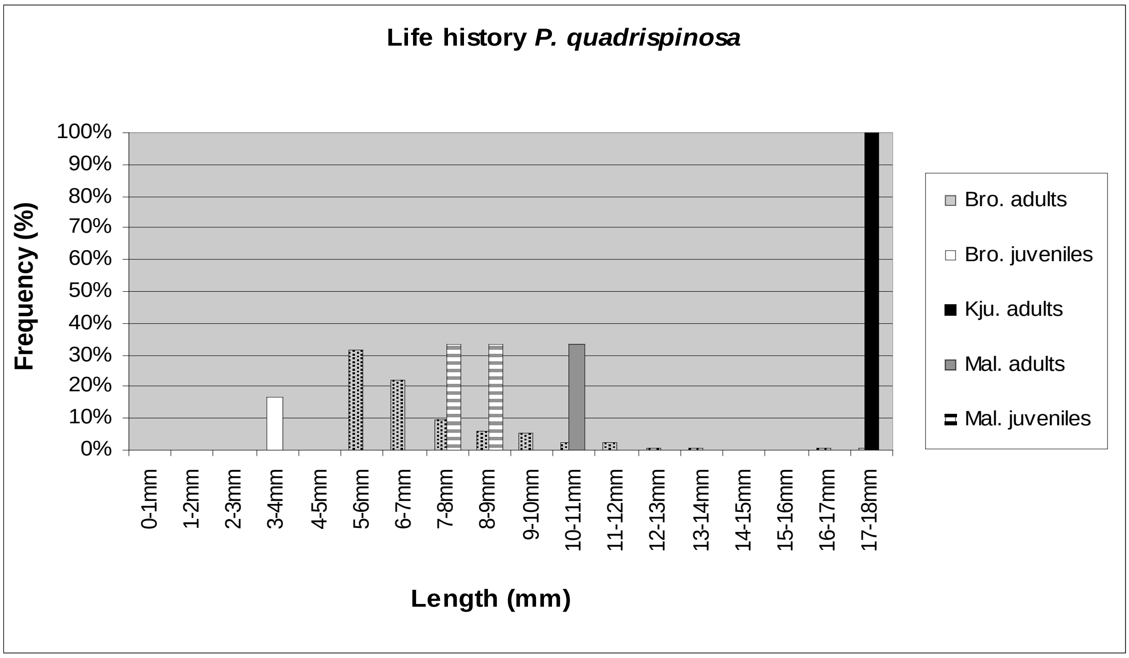



Figure 38. Length distribution of *P. quadrispinosa* at station Bromölla, Kjuge & Malte in July 2006

# 9.0 Discussion

## 9.1 The chemical analysis

The oxygen saturation was quite good in the beginning of the summer. Station Kjuge showed low oxygen content in July (Figure 19-20). A follow up on this matter should according to my opinion be done at this station in the future to discover eventual changes in the oxygen status. The reason for oxygen saturation with a value at over 100% at the surface of the lake is caused by the phytoplankton production (Figure 14). In August the oxygen saturation declined at station Alsterberg (Figure 14) and station 65 (Figure 12). The deep hauls differ when it comes to depth, geographical distribution and size. These parameters are influencing the status of the deep hauls, in combination with summer stagnation and autumn circulation. Station Bromölla is for instance situated at an exposed location, less protected from wind than station Alsterberg and station 65. These stations lie sheltered between the islands of Ivö and Enö, which might explain why many mysids were caught here.

## 9.2 Distribution and composition of relict crustaceans

Hakala (1978) has shown that *M. relicta* has a diurnal vertical migration pattern, why it is important to know at what depths in the water column you are catching them. The migration takes place during night time when they move upwards in the water column to eat protected by the dark (Viherluoto, 2001). In the morning they swim back to the bottom as the morning light is approaching (Hakala, 1978). In this study the trawling was carried out on the bottom of the lake during daylight and the mysids in Swedish lakes are known to stay here at this time of the day (Fürst et al., 1984) and therefore no *M. relicta* should be caught further up in the water column, when pulling up the sledge. Further, the sledge is constructed in such a way that the animals have problems entering the sledge when it is pulled up. No *P. affinis* or *P. quadrispinosa* should either be caught, because they too, stay at the bottom and in the sediment during daytime (Fürst et al., 1984).

At station Bromölla the sledge went deep into the bottom sediment and the sampling bottle was filled up with sediment that seemed to consist of much clay. In the clay a lot of *P. quadrispinosa* and *P. affinis* were seen swimming around, but there were not many *M. relicta.* This could explain the high numbers at station Bromölla (Figure 30). The sledge showed no tendency to go this deep into the bottom sediment at the other stations and the reason for this is probably not only because of the differences in bottom material and behaviour of the sledge, but also because of the amount of rope let out when trawling as a result of the human factor. The reason for catching the highest number of individuals at station Alsterberg might be because it is positioned in the greatest basin of this lake and is in a way a sheltered station between the islands of Enö and Ivö. Why station Malte, which also is situated in the same basin as station Alsterberg, but a little bit more to the south, and of which has the greatest depth of all stations, did not have that many individuals caught is quite strange. Station Malte has the greatest depth (50 m) and is the hardest station to find, since the deep haul is more narrow and elongated so the sledge might have been outside the deep haul a couple of times which might explain the lack of many individuals caught. Maybe it is just a coincidence but to be sure of this, further inventories with the sledge should be done here.

At station Kjuge, which is 20 m deep, only one *P. quadrispinosa* was found, while most animals caught were *M. relicta*. No *P. affinis* were found at this station and the reason for this is probably the lack of oxygen in summer and the animals preferring greater depths where the water is colder and thereby also more oxygen-rich (ALcontrol, 2005) than this station can offer. However, the shallower areas does not always have to be negative, since observations have shown that, when coexisting with other mysid species, they have been common at shallower waters than 20 m (Väinölä, 1998). The mysids move when they find the oxygen content to be too low (Holmquist, 1959), but despite the low oxygen content the mysids have stayed at station Kjuge. The question is if they remain here through the seasons or if this station only serves as a nursery home for juveniles and the ones too old to breed?

### 9.2.1 *Mysis relicta*

Studies on cohorts within populations have been done before. Holmquist (1959) made several studies on the mysids, were the length was measured and compared between different sampling sites and populations of Lake Ivösjön and other places. She found some length differences between and within the sexes from different populations, which she explained as a result of food supply and environmental conditions. Hakala (1978) has also made such studies for instance in Lake Pääjärvi in Finland, but he looked at the weight frequency of the population instead of the length. By weighing the cohorts he revealed one cohort consisting of two sub-cohorts made up of females from different breeding years. In this study the figures 31-35 show some interesting peaks, which might reflect the number of cohorts represented within the mysid population. At all stations but Kjuge (Figure 33) it seems as if two distinct cohorts are present, one cohort of juveniles to the left and one cohort of adults to the right. At station Kjuge it looks as if even a third cohort is present. The females of greater length probably comes from a second year breeder or maybe they have not been breeding at all (Hakala, 1978).

The result of Holmquist from 1955 (Table 5) also seems to show a third cohort in the population, when looking at the separation of individuals in the different gender groups. The lengths of the juveniles and the adults overlap as if they were representing cohorts from different breeding years. The adults are representing two different cohorts where the older one, i.e. mysids with greater length, might be a second year cohort while the others are the first year cohort. The mysids from table 5 were caught at station Alsterberg and Holmquist has not made any other statistics from the other stations that she visited. Firstly, to compare results between stations might not be that interesting since the mysids represented in Lake Ivösjön probably is one single population (pers. comment Audzijonyté). Secondly, since the mysids can not swim upstream they are not remaining still at a specific site their whole life, but drift away to other places by the currents of the lake (Holmquist, 1963a).

According to the one-tailed distribution test (Table 5a,b-6a,b) the length distribution of *M. relicta* shows both highly significant difference between the females (Table 6a-6b) and significant difference between the juveniles (Table 5a-5b) when comparing 1955 and 2006, indicating that the mysids have changed in size over the last 50 years. The lake was sampled for mysids at two occasions and the females from June had a P-value of 0.02 (Table 6a) while they in July had $P < 0.005$ (Table 6b) compared to the results of Holmquist. The variance was big in June which might be explained as the difference in observations between the years. The P-value for juveniles differed between June ($P=0.05$) and July ($P<0.005$) 2006 as well. The number of observations from 1955 is not satisfying since an unbalance like this can contribute to a result with low P-values.

At station Kjuge some females were greater than 20mm in length and when observing them under the stereo-microscope, they had small marsupiums in contribution to their length. According to Holmquist (1959) females that have released their offspring shed their skin and after this they get a medium size or smaller marsupium than before. This probably explains my observation. The change in size within the females of today might be explained as a result of the natural evolving process where the bigger size answers to the cost of the number of eggs/embryos of the same female mysid. Of course, food supply and/or environmental differences can influence the growing process of the relict crustacean as well, just like Holmquist (1959) explained in her observations. Holmquist (1959) also talked about that the length of a mature female is about 15 mm in freshwaters and this is confirmed by my results too since most females having a breeding pouch was about 15 mm in length at all stations. The average size of females carrying embryos was 13.5 mm in June though and the shortest female carrying embryo was only 11mm in length. Could this be a change in the breeding of the mysids or just a coincidence? Most females caught had open pouches and had probably already released their offspring and they had greater lengths too. However, I have not made a long- term study on their life history, which should be done to be sure of their life cycle and breeding patterns. Further is the number of observations differing from 1955 compared to 2006, which can influence the outcome. This is also an assumption before using them in different monitoring programmes (Johnson et al., 1993). Further have I not studied as many females as Holmquist did, which of course can change the result.

### 9.2.2 *Pallasea quadrispinosa*

The life cycle of *P. quadrispinosa* has not been studied in Lake Ivösjön before. As seen in figure 36 no juveniles were caught in May, only in June and July (Figures 37, 38). Station Alsterberg had most juveniles in June while station 65 had most in July. The highest number of juveniles was found at station 65 and the highest number of adults was found at station Alsterberg. It seems to be a two cohort population with juveniles as one cohort and the adults representing the other.

As mentioned before, these stations are sheltered between the islands of Enö and Ivö with station Alsterberg on the border to the open water. Further, the stations have optimal habitats that should be in favour for juveniles' i.e. good bottom oxygen content and different depths regenerating different habitats and food supply etc. When females release their offspring, they tend to visit shallower waters where the offspring can hide from fish and still have access to food (Hill, 1988). Further, studies in German lakes has shown that the adults migrate to the colder and deeper parts of a lake in summer (Hill, 1988), which my results also indicate since most of them seemed to prefer station Alsterberg in the summer months. The great decline in number of adults in July compared with June at station Alsterberg might be explained by death of females after releasing their hatchlings, which most females do (Hill, 1978). The reason for not catching as many adults in May at station 65 in this study might depend on the amphipods being at other depths. The water temperature was quite low in the whole water column at this time, with below 10°C in the thermocline (Figure 23). Adults of *P. quadrispinosa* only tend to avoid temperatures above 10°C (Hill, 1978) and were probably at other depths at the time of the trawling at the bottom. In July the amount of individuals was even fewer and they had probably died off after releasing their hatchlings (Figure 37).

### 9.2.3 *Pontoporeia affinis*

This amphipod has been and still is studied a great deal as it is used in different monitoring programmes for instance in Lake Vättern in the middle of Sweden (Sundelin & Eriksson, 1995). The reason for not finding any *P. affinis* in May/June (Table 1) compared to July (Table 2) might be a result of the sledge not going as deep into the bottom sediment as it did at station Bromölla in July. The low values at station 65 and the total absence at station Kjuge (Figure 30) could be explained by the specific requirements that *P. affinis* have on its environment to survive, which these stations can not offer. In summer time they are seen at greater depths where the oxygen content is higher and the temperatures are low (Hill, 1978, Holmquist, 1963b). Therefore it is strange that station Malte which is 50 m deep have low numbers of *P. affinis* (Table 2). Perhaps it is due to less food supply i.e. detritus since the oxygen concentration is quite good and the temperatures are low. Both at station Alsterberg and station Bromölla there are great amounts of food (pers. comment Brodde Almer). Leaf from the surroundings at station Alsterberg for example, contributes to the supply of detritus for the *P. affinis*.

Sundelin et al. (1995) has studied the fecundity of female *P. affinis* at low oxygen concentrations in laboratory experiments. They found that the females exposed to long term, low concentrations of oxygen (2-4.5 mg $O_2$ /l) carried greater amount dead embryos than those who were exposed to higher oxygen concentrations. Similar affects was also seen when exposed to higher temperatures (by 3-5°C) than they normally were used to. In Lake Ivösjön Almer found *P. affinis* at low oxygen concentrations, but the fecundity was not measured. However, the number of individuals caught were quite low compared with my findings during time with higher oxygen concentrations, which once again support the result of Sundelin et al. (1995).

### 9.2.4 *Limnocalanus macrurus*

Station Alsterberg and station 65 were chosen to represent the whole lake in further studies made of the abundance of the relict's distribution in the water column, as well as at what intervals in the water column they prefer to attend at.

The initial study of *L. macrurus* was to see if it existed in Lake Ivösjön. The results were to be as accurate as possible and therefore a one medium- deep site that showed low presence of individuals, station 65, and one site that was deep with high presence of individuals, station Alsterberg was selected. The stations should also be within easy reach. Station 65 is already a test fishing station today why it is interesting to look for the copepod here as well.

It is said that *L. macrurus* is a stenotherm species preferring depths of colder water temperatures and oxygen levels above 5.1 mg/l (Balcer et al., 1984). Little is known about the sensitivity of *L. macrurus* to light though. According to Ekman (1922) they show no tendency to be sensitive to light, but rather to high temperatures, where he talked about a maximum temperature of 14-17˚C in inland lakes and Carter (1969) of 7˚C at daytime. Holmquist (1963a) on the other hand did not have any information on *L. macrurus* being sensitive to light or not and she did not agree of *L. macrurus* being a stenotherm species either. A study on the swimming behaviour of *L. macrurus* has been observed by Balcer et al. (1984) in the Great Lakes, which might support the theory of the copepod being sensitive to light exposure since they applied diurnal vertical migration. By midnight 25% were found at water surface while 75% did not swim above the thermocline (Balcer et al., 1984).

According to my results from station 65, neither of the above discussion fits. Almost as many *L. macrurus* were obtained between 7-9 m as between 25-31.5 m at 8.30 in the morning (Figure 29), why I have reason to suspect that they might not be as sensitive to light as mentioned above. Nor is *L. macrurus* suppressed by the maximum temperature intervals described above, since the temperature in Lake Ivösjön was about 18-19˚C between 7-9 m. The oxygen level at 10 m was 5.5 mg/l, which according to Balcer et al. (1984), should be the limit for the copepod (appendix 5). The secci-depth was 5 m and the light probably reached a depth of about 10 m (Wetzel, 2001), which suggests copepods not being sensitive to light if can visit these depths. A similar observations have been seen in Norwegian lakes, where adult *L. macrurus* survived long-term exposure to temperatures between 14-20°C (Elgmorks´, 1964). I can only speculate why they are found at this depth, since I have not found any studies or literature on the swimming behaviour or sensitivity to light exposure of *L. macrurus* in Lake Ivösjön that can support my result. I have therefore listed some theories below.

- *Limnocalanus macrurus* might have been up in the water column while feeding upon algae and bacteria (Central Michigan University, 2006). During the sampling the water was green-yellow from algae, which support the theory of them being up in the water column to eat. *L. macrurus* also eats other copepods that they pursue.

- Mysids feed upon *L. macrurus* in oligotrophic lakes (Lasenby, 1981) and maybe they were escaping getting eaten by mysids.

- Maybe they have developed eyes that they are not that sensitive to light. Males of *P. affinis* have more developed eyes than females and maybe it is the same for males of *L. macrurus* and thereby the reason for their presence here.

It is not known if the copepods found here were females or males.
To understand why the copepod was obtained above the thermocline, further studies need to be done in Lake Ivösjön and especially more long-term studies and over the whole season. Regarding the *L. macrurus* found at station Alsterberg almost all were caught below the thermocline and at the greatest depth where the temperature was about 7 °C and the oxygen level 7 mg/l (appendix 3), which follows the observations made by Balcer et al. (1984).

## 9.3 Studies of Holmquist in 1955

The study done by Holmquist on Lake Ivösjön goes back to 1953 and 1955 when she visited the lake on several occasions. I have focused on the results from 1955 since there is most information and statistics published from this time. At station Alsterberg the water temperature was 7.5°C at a depth of 45m and at water surface it reached 13.5°C in June 1955. A thermocline was present between 10-15 m and the oxygen content was good throughout the water column and the oxygen concentration was about 12 mg/l at the bottom (Holmquist, 1959). Holmquist made an inventory of *M. relicta,* which she divided into small and large individuals, but she also took notes on whether the other relict crustaceans, *P. affinis* and *P. quadrispinosa* were present or not (+/-) as well. In June 1955 she found a total of 648 mysids at station Alsterberg after trawling and 613 of these were small individuals (juveniles) whereas 35 were adults. Out of these she studied 52 individuals and measured them from rostrum to telson. The length per gender has been extracted from the figures (Holmquist, 1959) and is shown in table 5.

Table 5. Length distribution of *M. relicta* in June 1955 at station Alsterberg (Data from Holmquist 1959).

| *M. relicta* | 22. VI. 1955 | Station Alsterberg | |
|---|---|---|---|
| | Juveniles | Adults | |
| Length (mm) | | ♀ | ♂ |
| 5 | 1 | - | - |
| 6 | 12 | - | - |
| 7 | 15 | 2 | 1 |
| 8 | 5 | - | 1 |
| 9 | - | - | 1 |
| 17 | - | 1 | - |
| 18 | - | 12 | - |
| 19 | - | 3 | - |
| Total sum (N=52): | **33** | **19** | **3** |

The result from the one-tailed distribution test showed highly significant difference in length between both females and juveniles when comparing the results from 1955 with those from 2006. The results point in a direction of females and juveniles having become shorter over the last 50 years.

In September 1955 Holmquist made a new trip to Lake Ivösjön and she found a total of 192 mysids within the same deep haul, but there is unfortunately not any information on the development stages among these mysids or any statistics documented. At both occasions both *P. affinis* and *P. quadrispinosa* were present at station Alsterberg.

## 9.4 Former studies from 1969

In October 1969 Almer was trawling for the relicts at station Alsterberg (Table 6) (Almer, 1971). The actual depth from where the relicts were taken was 47.5 m and the length of trawling was about 50 m. The result shows that the relict crustaceans had survived though the oxygen level at the time was quite low.

Table 6. Distribution of the relict crustaceans at station Alsterberg in October 1969. (Data from Almer 1971).

| | Amount of individuals per species | | | |
|---|---|---|---|---|
| Day | *Mysis relicta* | *Pallasea quadrispinosa* | *Pontoporeia affinis* | Oxygen (mg/l) |
| 1 | 125 | 481 | 14 | 2,35 |
| 2 | 23 | 87 | 7 | 2,09 |
| 3 | 22 | 1 | 27 | 1,49 |
| Total: | 170 | 569 | 48 | |

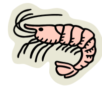
## 9.5 Monitoring

"The cause and effect relation is never easy to confirm without good research". The phrase is taken from Spellerberg (2005) which explains the difficulty in approaching monitoring in a short and concise manner. Monitoring programmes are long-term processes of studies on one or several specific subjects chosen. The use of different methods and techniques depends on what you are monitoring (Spellerberg, 2005).

### 9.5.1 Freshwater biological monitoring

Freshwater biological monitoring includes different techniques like toxic tests, classification systems and many different biological indices. When monitoring freshwater, one can and should use, both biological and chemical monitoring. They complete each other when providing information about the status of the aquatic system **(**Spellerberg, 2005). Some species can work as so called *detectors* of pollutants, since the effect of the pollutant is shown as changes in behaviour, mortality, age-class structure, and defects in eggs and embryos**.** Other species are known as *accumulators* due to their ability to accumulate pollutants like heavy metals to a quantity that is big enough to be measured **(**Spellerberg, 2005).

### 9.5.2 How to monitor the relict crustaceans from trawling



The species *M. relicta, P. quadrispinosa* and *P. affinis* are members of the benthic fauna. They are staying at the bottom of the lake hiding from warm temperatures and light during daytime, so they should be collected at daylight. In Lake Ivösjön they are preferably collected by a bottom sledge as this study has shown.

To get good future series of the *M. relicta* status of the lake, sampling should take place twice a year with one occasion in the fall when the males are present and the mating season started and one occasion in spring when the females are carrying their offspring and about to release them. The length and gender should be determined and compared with former results. Further should all females be studied in more detail i.e. eggs and embryos and unborn mysids should be counted. *Pallasea quadrispinosa* and *P. affinis* should also be studied the same way as *M. relicta*. Further it is preferably to sample the relict crustaceans within a before hand chosen area on the lake for future monitoring program.

### 9.5.3 How to monitor the relict zooplankton

When collecting *Limnocalanus macrurus* a qualitative sampling with either plankton net (100µm) or with water collector is to prefer. The collecting should take place over the greatest depth of the lake. Temperature and oxygen measurements should be done, since changes in temperature can effect the zooplankton population (Albertsson, 1998). The sampling series of *L. macrurus* should be done one time in spring (April) and one time in the fall (August) so that both females and males are included in the monitoring program. When studying them in the microscope the focus should be in counting the number of individuals per litre (Naturvårdsverket, 2003a).

### 9.5.4 Where to monitor?

Station Alsterberg is a good station to use when monitoring the relict crustaceans, since all the species are represented here. It could be interesting to use other stations as well like station 65 and/or station Kjuge. Due to the rareness of *L. macrurus* a comparison between two stations can be too much because one has to go through counting many more specimens than one would with the other relict crustaceans. Therefore station Alsterberg is a good station to use since it can represent the whole lake.

## 10.0 Conclusion

Overall, the relict crustaceans of Lake Ivösjön still seem to have stable populations, even if the population of *P. affinis* was a little bit poor in individuals when comparing with the result of Almer (1971) for instance. The presence of mysids at station Kjuge is very interesting since these animals seems to live here despite their sensitivity to low oxygen content, light and temperature which this deep haul represents. If the mysids only were here temporary or if it is their all year around home, is something that needs longer studies to answer. Also inventories on *L. macrurus* should be done here as well, to distinguish if it is present here or not. A suggestion is that these relict crustaceans should be included in future monitoring programs.

The statistics of the monitoring process should be eased by using one and the same chosen area on the lake when inventorying the lake for the relict crustaceans instead of dredging the deep hauls in before hand chosen directions as was done in this study.

Hopefully this study has contributed to a greater knowledge and concern of the relict crustaceans of Lake Ivösjön and that this study only is the beginning of the future studies that will take place here.

# 11.0 Acknowledgements

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**The Investigation**
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*[www.arkive.org/species/GES/birds/Larus_relictus/more_info.html] [2008-03-26]
** Artdatabanken, SLU 2005. Faktablad: *Salvelinus umbla* – storröding (sydsvenska bestånd). Hammar, J. 1988.
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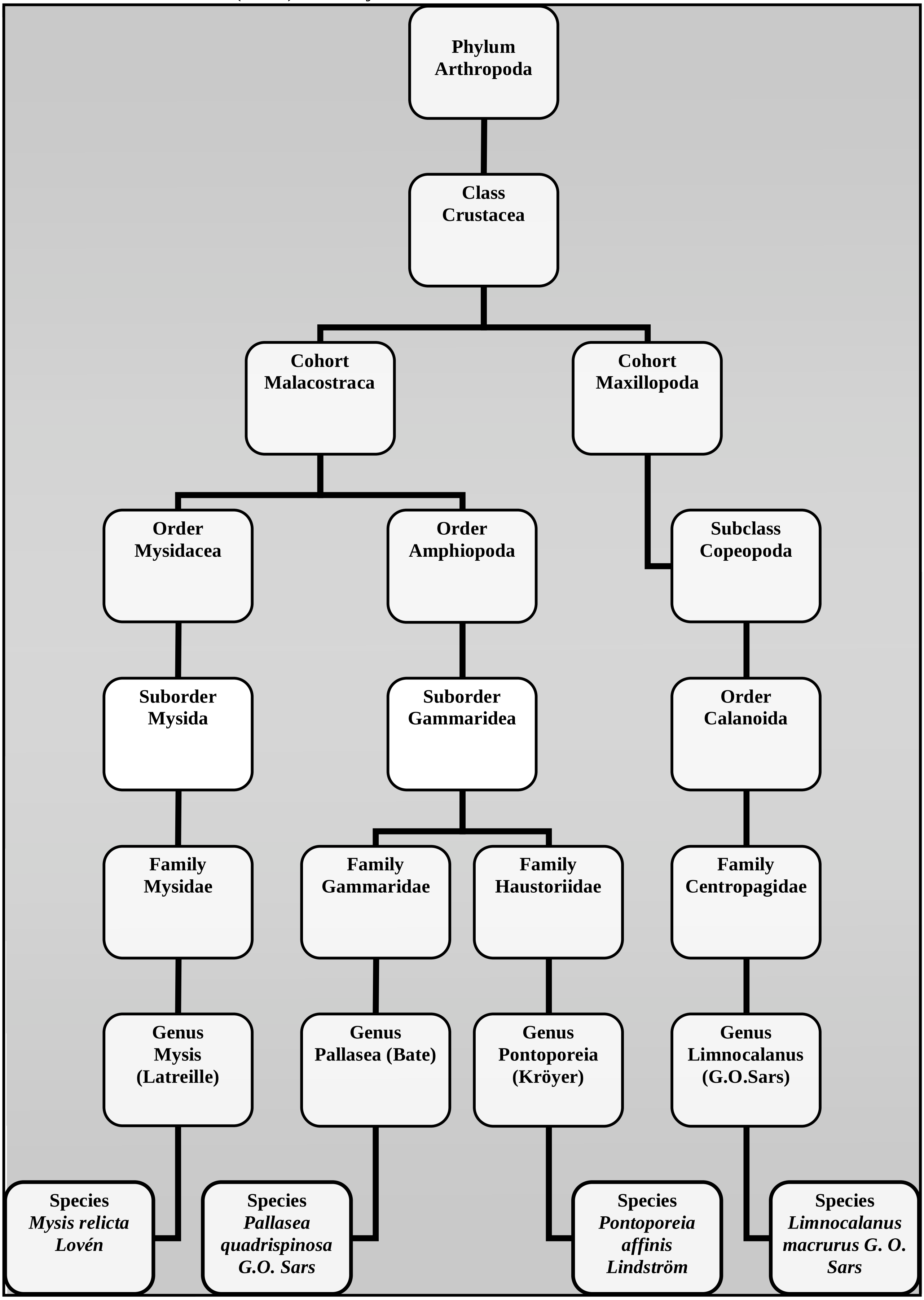
Appendix 1. Classification of the relict crustaceans found in Lake Ivösjön.
Source: Enckell, P. H. (1980). Kräftdjur



Appendix 2. Water measurements at station Alsterberg.

| 27.5.2006 | Stn: "Alsterberg" | 56° 06.478 N | 014°26.578 Ö | | 7.45 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 11,3 | 108 | 12 | | |
| 2,5 | 10,7 | 102 | 11,9 | | |
| 5 | 9,87 | 90 | 11,7 | 4,1 | - |
| 7,5 | 10,6 | 96,9 | 11,6 | | |
| 10 | 10,36 | 95,5 | 11,6 | | |
| 12,5 | 10,12 | 92 | 11,4 | | |
| 15 | 10,03 | 91,2 | 10,7 | | |
| 17,5 | 10,71 | 89 | 7,2 | | |
| 20 | 10,64 | 86 | 7,1 | | |
| 22,5 | 11,49 | 93,8 | 7 | | |
| 25 | 10,72 | 91,6 | 6,5 | | |
| 27,5 | 11 | 88,6 | 6 | | |
| 30 | 11,27 | 92,4 | 5,8 | | |
| 32,5 | 10,45 | 84 | 6,1 | | |
| 35 | 10,55 | 88,4 | 6,3 | | |
| 37,5 | 10,76 | 85,3 | 5,6 | | |
| 40 | 10,53 | 83,6 | 6 | | |
| 42,5 | 10,13 | 81,8 | 6,1 | | |
| 44 | 10,75 | 89,4 | 6 | | |
| 45 | - | - | - | | |

| 1.7.2006 | Stn: "Alsterberg" | 56° 06.476 N | 014°26.445 Ö | | 7.20 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 8,14 | 90,7 | 18,5 | | |
| 5 | 8,57 | 83,6 | 18,2 | | |
| 10 | 8,42 | 90,4 | 14,1 | 3,5 | 15 |
| 15 | 10,29 | 89 | 11,3 | | |
| 17,5 | 9,74 | 93,2 | 9,7 | | |
| 20 | 10,93 | 91,1 | 8,7 | | |
| 22,5 | 10,61 | 93,3 | 8,9 | | |
| 25 | 10,79 | 87 | 8,4 | | |
| 30 | 10,24 | 91,2 | 8,4 | | |
| 35 | 9,95 | 89,1 | 8,6 | | |
| 40 | 11,24 | 89,8 | 6,8 | | |
| 45 | 10,7 | 90,1 | 7,9 | | |
| 45,5 | 10,01 | 89,3 | 8,7 | | |
| 46 | - | - | - | | |

Appendix 3. Water measurements at station Alsterberg and station Malte.

| 25.8.2006 | Stn Alsterberg | 56°06.478 N | 014°26.578 Ö | | 14.15 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen (mg/l) | Oxygen (%) | Temp. (°C) | Secci-depth (m) | Lake-colour |
| 0,5 | 7,54 | 86,2 | 22 | | |
| 5 | 7,2 | 80,8 | 21,2 | | |
| 7,5 | 7,73 | 84 | 19,5 | 5,5 | green-yellow |
| 10 | 7,32 | 74,3 | 16 | | |
| 12,5 | 6,63 | 61,4 | 12 | | |
| 15 | 7,18 | 63,5 | 10 | | |
| 20 | 8,48 | 71,6 | 8 | | |
| 25 | 8,24 | 67,8 | 7 | | |
| 30 | 8,25 | 67,9 | 7 | | |
| 35 | 7,53 | 62 | 7 | | |
| 40 | 8,41 | 69,2 | 7 | | |
| 45 | 6,99 | 57,3 | 6,8 | | |
| 45,5 | - | - | - | | |

| 27.5.2006 | Stn Malte | 56°05.498 N | 014°27.203 Ö | | 12.00 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 10,18 | 97,8 | 13,5 | | |
| 2,5 | 9,5 | 86,6 | 12,5 | | |
| 5 | 9,3 | 87 | 12,1 | 4,3 | - |
| 7,5 | 9,46 | 88,3 | 11,8 | | |
| 10 | 9,7 | 91,3 | 11,3 | | |
| 12,5 | 9,74 | 89,1 | 11,2 | | |
| 15 | 10,24 | 92,1 | 10,8 | | |
| 17,5 | 11,3 | 95,3 | 7,1 | | |
| 20 | 11,11 | 91 | 6,7 | | |
| 22,5 | 11,37 | 90,9 | 6,3 | | |
| 25 | 11,75 | 93,1 | 6,1 | | |
| 27,5 | 11,55 | 90,5 | 5,7 | | |
| 30 | 11,12 | 90,5 | 6 | | |
| 32,5 | 11,6 | 92,3 | 5,3 | | |
| 35 | 11,58 | 92,2 | 5,7 | | |
| 37,5 | 11,39 | 89,6 | 5,6 | | |
| 40 | 11,33 | 91,3 | 5,7 | | |
| 42,5 | 11 | 86 | 5,9 | | |
| 45 | 10,98 | 86,8 | 5,8 | | |
| 47,5 | 10,97 | 88,6 | 5,9 | | |
| 48 | - | - | - | | |

Appendix 4. Water measurements of station Malte and station 65.

| 1.7.2006 | Stn Malte | 56°05.532 N | 014°27.145 Ö | | 11.30 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 8 | 94,5 | 20,7 | | |
| 5 | 9,05 | 87,8 | 18,2 | | |
| 10 | 8,91 | 93 | 14 | 4,5 | 15 |
| 15 | 10,18 | 85,3 | 10,9 | | |
| 20 | 10,14 | 91,8 | 9,6 | | |
| 22,5 | 10,65 | 90,6 | 9,2 | | |
| 25 | 10,79 | 92,1 | 8,5 | | |
| 30 | 9,91 | 88,4 | 8,8 | | |
| 35 | 10,85 | 90,8 | 8,1 | | |
| 40 | 10,26 | 88,2 | 8,8 | | |
| 45 | 10,64 | 91,6 | 9,2 | | |
| 47,5 | 10,58 | 92,3 | 8,4 | | |
| 48 | - | - | - | | |

| 27.5.2006 | Stn: 65 | 56°07.777 N | 014°26.657 Ö | | 8.15 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 9,92 | 94,6 | 13 | | |
| 2,5 | 9,93 | 93,7 | 12,5 | | |
| 5 | 9,82 | 92,6 | 12,2 | 4,3 | - |
| 7,5 | 9,72 | 90,1 | 11,5 | | |
| 10 | 10,6 | 94 | 11,3 | | |
| 12,5 | 10 | 96 | 9,8 | | |
| 15 | 11,14 | 95,7 | 8,7 | | |
| 17,5 | 11,71 | 97,4 | 7,3 | | |
| 20 | 11,7 | 96 | 6,6 | | |
| 22,5 | 12,12 | 97,3 | 6 | | |
| 25 | 12,07 | 96,6 | 5,7 | | |
| 27,5 | 12,06 | 96 | 5,7 | | |
| 30 | 11,81 | 93,8 | 5,7 | | |
| 32,5 | 11,26 | 89,8 | 5,8 | | |
| 33 | - | - | - | | |

Appendix 5. Water measurements at station 65

| 4.7.2006 | Stn: 65 | 56° 07.734 N | 014° 26.614 Ö | | 7.00 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 7,79 | 93,8 | 20,6 | | |
| 5 | 9,49 | 93,1 | 19,6 | | |
| 10 | 8,25 | 91,4 | 14,5 | 4,4 | 15 |
| 15 | 9,72 | 89 | 10,2 | | |
| 20 | 10,68 | 90,7 | 8,2 | | |
| 25 | 10,39 | 91,4 | 8,2 | | |
| 30 | 10,25 | 88,8 | 8,2 | | |
| 31,5 | 10,44 | 90 | 8,1 | | |
| 32 | - | - | - | | |

| 25.8.2006 | Stn 65 | 56° 07.734 N | 014° 26.614 Ö | | 8.30 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen (mg/l) | Oxygen (%) | Temp. (°C) | Secci-depth (m) | Lake-colour |
| 0,5 | 6,56 | 72,1 | 19,9 | | |
| 5 | 8,17 | 88,8 | 19,7 | | |
| 7,5 | 8,59 | 93,5 | 19 | 5,6 | green-yellow |
| 10 | 5,51 | 58,3 | 17,9 | | |
| 12,5 | 7,49 | 74,2 | 15,3 | | |
| 15 | 7,93 | 74 | 12,2 | | |
| 17,5 | 9,1 | 82,7 | 10,9 | | |
| 20 | 8,54 | 74,6 | 8,5 | | |
| 25 | 9,43 | 79,6 | 9,1 | | |
| 30 | 9,31 | 79,9 | 8,7 | | |
| 32 | 7 | 57,9 | 7,4 | | |
| 32,5 | 7 | 58,4 | 7,6 | | |
| 33 | - | - | - | | |

Appendix 6. Water measurements at station Bromölla and station Kjuge.

| 2.6.2006 | Stn: Bromölla | 56° 04.707 N | 014° 27.211 Ö | | 13.35 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 10,23 | 99 | 14,2 | - | - |
| 2,5 | 9,9 | 96,3 | 14 | | |
| 5 | 10,5 | 100 | 13 | | |
| 7,5 | 10,02 | 96,9 | 12,6 | | |
| 10 | 10,25 | 95,2 | 11,6 | | |
| 12,5 | 10,73 | 97,3 | 11,1 | | |
| 15 | 10,68 | 96 | 10,7 | | |
| 17,5 | 10,89 | 96,5 | 10,1 | | |
| 20 | 10,6 | 92,4 | 9,2 | | |
| 22,5 | 10,82 | 94 | 8,9 | | |
| 25 | 11,24 | 93,5 | 7 | | |
| 27,5 | 12,04 | 97,4 | 6,1 | | |
| 30 | 11,93 | 96,7 | 6,3 | | |
| 32,5 | 12,13 | 97,4 | 5,8 | | |
| 35 | 12,24 | 97,8 | 5,7 | | |
| 37,5 | 12,05 | 97 | 5,8 | | |
| 40 | 11,77 | 95,3 | 6,1 | | |
| 42,5 | 12,15 | 97,6 | 5,9 | | |
| 43 | - | - | - | | |

| 1.7.2006 | Stn: Bromölla | 56° 04.705 N | 014° 27.202 Ö | | 7.30 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 7,99 | 91,5 | 17,9 | 4 | 15 |
| 5 | 9,56 | 82 | 17,7 | | |
| 10 | 8,39 | 93,6 | 14,6 | | |
| 15 | 10,33 | 91,7 | 11,6 | | |
| 20 | 10,69 | 95,9 | 9,1 | | |
| 22,5 | 11,17 | 90,8 | 8,1 | | |
| 25 | 10,53 | 94,9 | 7,7 | | |
| 27,5 | 11,56 | 91,7 | 7,2 | | |
| 30 | 10,87 | 93,5 | 7,7 | | |
| 35 | 10,9 | 91,8 | 7,1 | | |
| 40 | 10,72 | 94,1 | 7,5 | | |
| 40,5 | - | - | - | | |

| 4.7.2006 | Stn: Kjuge | 56° 05.495 N | 014° 22.093 Ö | | 14.00 |
|---|---|---|---|---|---|
| Depth (m) | Oxygen mg/l | Oxygen % | Temp. °C | Secci-depth (m) | Water-coulor (mgPt/L) |
| 0,5 | 7,71 | 91,8 | 22,4 | 4,95 | 15 |
| 5 | 8,18 | 88,7 | 20,7 | | |
| 10 | 7,56 | 88,5 | 17,4 | | |
| 15 | 8,63 | 81,1 | 13,6 | | |
| 20 | 7,52 | 81,3 | 12,2 | | |
| 21,5 | 7,79 | 65,7 | 11,6 | | |
| 22 | - | - | - | | |

Appendix 7. Data and calculations of plankton net inventories of *L.macrurus*.

Inventory at specific depth positions in the water column at station Alsterberg in August 2006.

| **Station Alsterberg** | | | | |
|---|---|---|---|---|
| Deep-levels (m) | Total amount Copeopods | Number of *L. macrurus* | Number of *L. m* ♀ | Number of *L. m* ♂ |
| 0-5 | 579 | 0 | 0 | 0 |
| 0-6,5 | 830 | 1 | 1 | 0 |
| 0-17,5 | 718 | 3 | 2 | 1 |
| 0-31,5 | 598 | 1 | 0 | 1 |
| 0-45 | 1024 | 106 | 71 | 35 |
| **Total:** | **3749** | **111** | **74** | **37** |

Inventory at specific depth positions in the water column at station 65 in August 2006.

| **Station 65** | | | | |
|---|---|---|---|---|
| Deep-levels (m) | Total amount Copeopods | Number of *L. macrurus* | Number of *L. m* ♀ | Number of *L. m* ♂ |
| 0-5 | 287 | 5 | 2 | 3 |
| 0-7 | 564 | 0 | 0 | 0 |
| 0-9 | 564 | 6 | 4 | 3 |
| 0-20 | 490 | 7 | 3 | 4 |
| 0-25 | 348 | 3 | 1 | 2 |
| 0-31,5 | 410 | 24 | 14 | 10 |
| **Total:** | **2663** | **45** | **24** | **22** |

Appendix 8. Data and calculations of plankton net inventories of *L. macrurus*.

Number of copepods per litre in the water column (1) and in the strata (2) at station Alsterberg in August 2006.

| Date: 25.8 2006 | Station Alsterberg | | | |
|---|---|---|---|---|
| Net opening diam (cm): | 20 | | | |
| Net opening area (cm2): | 314 | | | |
| 1. | | | | |
| Depth from surface (m) | Filtered Vol/L | Tot Cop/ 60ml | Tot Cop/ 200ml | Column Nb. Cop /L |
| 5 | 157,1 | 0 | 0 | 0 |
| 6,5 | 204,1 | 1 | 3,3 | 0,016 |
| 17,5 | 549,5 | 3 | 10,0 | 0,018 |
| 31,5 | 989,1 | 1 | 3,3 | 0,003 |
| 45 | 1413,7 | 106 | 353,3 | 0,25 |
| 2. | | | | |
| Strata (m) | Filtered Vol/L | Tot Cop. /60ml | Tot. Cop. /200ml | Strata Nb. Cop /L |
| 0-5m | 157 | 0 | 0 | 0 |
| 5-6,5m | 47,0 | 1 | 3,3 | 0,07 |
| 6,5-17,5m | 345,4 | 2 | 6,7 | 0,02 |
| 17,5-31,5m | 439,6 | 0 | 0 | 0 |
| 31,5-45m | 424,6 | 105 | 350,0 | 0,82 |

Number of copepods per litre in the water column (1) and in the strata (2) at station 65 in August 2006.

| Date: 25.8 2006 | Station 65 | | | |
|---|---|---|---|---|
| Net opening diam (cm) | 20 | | | |
| Net opening area (cm2) | 314 | | | |
| 1. | | | | |
| Depth from surface (m) | Filtered Vol/L | Tot Cop/ 60ml | Tot Cop/ 200ml | Column Nb. Cop /L |
| 5 | 157,0 | 5 | 17 | 0,11 |
| 7 | 219,8 | 0 | 0 | 0,00 |
| 9 | 282,6 | 6 | 20 | 0,07 |
| 20 | 628,0 | 7 | 23 | 0,04 |
| 25 | 785,0 | 3 | 10 | 0,01 |
| 31,5 | 989,1 | 24 | 80 | 0,08 |
| 2. | | | | |
| Strata (m) | Filtered Vol/L | Tot Cop/ 60ml | Tot Cop/ 200ml | Strata Nb. Cop /L |
| 0-5m | 157 | 17 | 17 | 0,11 |
| 5-7m | 62,8 | 0 | 0 | 0,00 |
| 7-9m | 62,8 | 6 | 20 | 0,32 |
| 9-20m | 345,4 | 1 | 3 | 0,01 |
| 20-25m | 157,0 | 0 | 0 | 0,00 |
| 25-31,5m | 204,1 | 21 | 70 | 0,34 |

Appendix 9. Data on the length distribution of *M. relicta* at all stations.

Als: Alsterberg, Brom: Bromölla
No/N.: Number of, juv.: juveniles, F: females, ind: individuals,tot: total

| *M. relicta* | Als 2.6 | | Als 1.7 | | 65 31.5 | | 65 4.7 | | Brom 1.7 | | Kjuge 4.7 | | Malte 1.7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length (mm) | No.F | No. Juv | No.F | No. Juv | No.F | No. Juv | No.F | No. Juv | No.F | No. Juv | No.F | No. Juv | No.F | No. Juv |
| 0-1mm | | | | | | | | | | | | | | |
| 1-2mm | | | | | | | | | | | | | | |
| 2-3mm | | **4** | | **1** | | | | | | | | | | **3** |
| 3-4mm | | | | **24** | | | | **41** | | **8** | | **4** | | **3** |
| 4-5mm | | | | **109** | | | | **95** | | **11** | | **4** | | **3** |
| 5-6mm | | | | **33** | | | | **41** | | **15** | | **17** | | **5** |
| 6-7mm | | | | **10** | | | | **15** | | **19** | | **30** | | **6** |
| 7-8mm | | | | **3** | | | | **10** | | **7** | | **26** | | |
| 8-9mm | | **1** | | **1** | | | | **4** | | **3** | | **14** | | |
| 9-10mm | | | | | | | | **3** | | | | **8** | | |
| 10-11mm | **1** | | | | **1** | | | | | | | **3** | | |
| 11-12mm | **7** | | **1** | | | | | | | | | | | |
| 12-13mm | **9** | | **2** | | **1** | | **1** | | | | | | | |
| 13-14mm | **29** | | **5** | | **3** | | **1** | | **1** | | **2** | | | |
| 14-15mm | **36** | | **10** | | **6** | | **14** | | **1** | | **2** | | | |
| 15-16mm | **18** | | **23** | | **3** | | **20** | | **3** | | **1** | | **4** | |
| 16-17mm | **5** | | **6** | | | | **21** | | **3** | | **2** | | | |
| 17-18mm | **1** | | **3** | | | | **3** | | **3** | | | | | |
| 18-19mm | | | **2** | | | | | | | | | | | |
| 19-20mm | **1** | | | | | | | | | | | | | |
| 20-21mm | | | | | | | | | | | **2** | | | |
| 21-22mm | | | | | | | | | | | **1** | | | |
| N (ind./sex) | **107** | **5** | **52** | **181** | **14** | **0** | **60** | **210** | **11** | **63** | **10** | **106** | **4** | **20** |
| N (ind./stn) | | 112 | | 233 | | 14 | | 270 | | 74 | | 116 | | 24 |
| N (females) | **258** | | | | | | | | | | | | | |
| N (juveniles) | **585** | | | | | | | | | | | | | |
| Tot. ind. | **843** | | | | | | | | | | | | | |

Appendix 10. Data on the length distribution of *P. quadrispinosa* at all stations.

Als:Alsterberg, Brom:Bromölla
N/No:number of, juv: juveniles, ind: individuals, stn:station, tot:total.

| *P. quadrispinosa* | Als 2.6 | | Als 1.7 | | 65 31.5 | | 65 4.7 | | Brom 1.7 | | Kjuge 4.7 | | Malte 1.7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length (mm) | No adults | No Juv | No Adults | No Juv | No Adults | No Juv | No Adults | No Juv | No Adults | No Juv | No Adults | No Juv | No Adults | No Juv |
| 0-1mm | | | | | | | | | | | | | | |
| 1-2mm | | | | | | | | | | | | | | |
| 2-3mm | | | | | | | | | | | | | | |
| 3-4mm | | **11** | | **2** | | | | | | **19** | | | | |
| 4-5mm | | | | | | | | **28** | | | | | | |
| 5-6mm | | | **6** | | | | | | **36** | | | | | |
| 6-7mm | **1** | | **6** | | | | **1** | | **25** | | | | | |
| 7-8mm | | | **5** | | **1** | | **4** | | **11** | | | | **1** | |
| 8-9mm | **32** | | **7** | | **3** | | **1** | | **7** | | | | **1** | |
| 9-10mm | **27** | | **3** | | **4** | | | | **6** | | | | | |
| 10-11mm | **22** | | **1** | | **2** | | **1** | | **3** | | | | **1** | |
| 11-12mm | **6** | | **2** | | | | **1** | | **3** | | | | | |
| 12-13mm | | | **1** | | **1** | | **1** | | **1** | | | | | |
| 13-14mm | **2** | | | | | | **1** | | **1** | | | | | |
| 14-15mm | | | | | | | | | | | | | | |
| 15-16mm | | | | | **1** | | | | | | | | | |
| 16-17mm | | | **1** | | | | | | **1** | | | | | |
| 17-18mm | | | | | | | | | **1** | | **1** | | | |
| N (ind/sex) | **90** | **11** | **32** | **2** | **12** | **0** | **10** | **28** | **95** | **19** | **1** | **0** | **3** | **0** |
| N (ind/stn) | | 101 | | 34 | | 12 | | 38 | | 114 | | 1 | | 3 |
| N (adults) | **243** | | | | | | | | | | | | | |
| N (juveniles) | **60** | | | | | | | | | | | | | |
| Tot ind. | **303** | | | | | | | | | | | | | |