ZOOPLANKTON COMMUNITY STRUCTURE IN PENGKALAN CHEPA RIVER BASIN

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By

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LIST OF ABBREVIATIONS

Abbreviations	**Description**
PCR	Pengkalan Chepa River
DO	Dissolved oxygen
TSS	Total Suspended Solids
SS	Suspended Solids
AN	Ammoniacal Nitrogen
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
WQI	Water Quality Index
SIBOD	Sub Index BOD
SISS	Sub Index SS
TDS	Total Dissolved Solids
pH	Power of Hydrogen
CCA	Canonical Correspondence Analysis
DOE	Department of Environment
EQR	Environmental Quality Report
APHA	American Public Health
sp.	Species

LIST OF SYMBOLS

Symbols	Description
^oC	Degree celsius
%	Percentage
ml/L	Mililitre per Litre
mg/L	Miligram per Litre
mS/cm	Metresiemens per centimetre
g/L	Gram per Litre
ppt	Parts per Trillion
NTU	Nephelometric Turbidity Unit
cm	Centimetre
m/S	Meter per Second
ind/L	Individual per Litre
m	Meter

STRUKTUR KOMUNITI ZOOPLANKTON DI LEMBANGAN SUNGAI PENGKALAN CHEPA

ABSTRAK

Kajian telah dijalankan ke atas komposisi dan kepelbagaian zooplankton di lima stesen berbeza dalam Lembangan Sungai Pengkalan Chepa. Kajian ini telah dilaksanakan bermula dari bulan Mei 2010 sehingga Februari 2011 yang merangkumi kedua-dua musim kering (Mei 2010 sehingga Ogos 2010) dan musim hujan (November 2010 sehingga Febuari 2011) menggunakan Wisconsin net dengan diameter 20 cm dan 63 micron meter (µm) mata jaringan. Kajian ini bertujuan utuk menyenaraikan spesis zooplankton dan menggunakan komuniti zooplankton untuk menilai kualiti air menggunakan komposisi dan struktur zooplankton ini. Sejumlah 157 spesis zooplankton daripada 32 famili telah dikenal pasti. Susunan kumpulan zooplankton dalam jujukan menurun adalah: Rotifera (99 spesis) > kopepoda (38 spesis) > kladocera (22 spesis). Rotifera telah mendominasi komuniti zooplankton dalam kajian dengan menyumbang 62% daripada keseluruhan kepadatan populasi zooplankton, diikuti oleh kopepoda (24%) dan kladosera (14%). *Brachionus urceolaris* (53.51%) merupakan spesis dominan bagi keseluruhan populasi zooplankton. Kopepod air masin juga telah dikenal pasti disebabkan oleh campur tangan air masin (air laut) ke dalam kawasan kajian yang berdekatan., Hasil kajian mendapati Sungai Pengkalan Chepa mempunyai spesis rentan pencemaran berprofil tinggi seperti *Brachionus* sp., *Anuraeopsis fissa, Moina micrura,* dan *Rotaria rotatoria.* Ini menunjukkan kesihatan sungai kurang memuaskan dan terdapatnya pencemaran.

ZOOPLANKTON COMMUNITY STRUCTURE IN PENGKALAN CHEPA RIVER BASIN

ABSTRACT

A study was conducted on zooplankton composition and physico-chemical parameters at five different stations within Pengkalan Chepa River Basin, Kelantan. The study was carried out starting from May 2010 until February 2011 covering both dry (May 2010 till August 2010) and rainy seasons (November 2010 till February 2011) using Wisconsin net of 20 cm in diameter and mesh size of 63 micron meter (µm). The study was aimed to document the zooplankton community and evaluate the water quality of the river using this zooplankton compositions and structure. Approximately 157 species of zooplankton identified, consisting of 32 families from three major groups. The order of zooplankton groups that are dominating the rivers, in descending order were: rotifers (99 species) > copepods (38 species) > cladocerans (22 species). Rotifers was the most dominant group contributing to about 62% of all zooplankton densities, followed by copepods (24%) and cladocerans (14%). *Brachionus urceolaris* which accounts for 53.51% of all zooplankton population was the most dominant zooplankton species. Marine copepods were also observed due the intrusion of seawater from the nearby estuary into the nearest sampling station. The study found that Pengkalan Chepa River Basin was inhabited by a few high profile pollution-tolerant species such as *Brachionus* sp., *Anuraeopsis fissa, Moina micrura,* and *Rotaria rotatoria.* The existence of these types of plankton species alongside the variations of physico-chemical conditions during the study indicated moderate to poor river health that was contaminated.

CHAPTER 1

INTRODUCTION

1.1 Study Background

There are about 189 river basin systems consisting of approximately 1,500 rivers in Malaysia with an estimated overall total length of 57,300 km (River Ranger Squad, 2008). In Peninsular Malaysia, there are about 89 river basins that are mostly originating from the central mountain range, the Titiwangsa Range. The longest rivers recorded include the Pahang River (470 km long), the Kelantan River (about 400 km long) and the Perak River (about 240 km long) (River Ranger Squad, 2008).

Like other regions, rivers as well as estuaries in Malaysia have a very important value to the locals ever since the ancient time; historically, economically and even spiritually. It is well known that the civilization of human being all around the world started near the rivers (Hays *et al.*, 2005; Latip, 2011). This is because rivers and their estuaries also serve as the main source of water that is crucial and have been a catalyst for socioeconomic development of the country (Zaharaton, 2004), such as transportation, communication, ecotourism, aquaculture that are important for the growth of local economy as well as settlements and towns. Similarly in Malaysia, rivers and estuaries have been the starting points of civilization and the first settlement of human being that led to great historical values (Chan, 2005). In the older days, river estuaries have been the transit centre to many foreign merchant ships on their way from the east to the west and vice versa. Thus, it created great historical moments and being recognized worldwide at the time; e.g.

Malacca river estuary for the Kesultanan Melayu Melaka. Rivers were also once used for naming of the new settlement built. For example, the name Kuala Lumpur was derived from a river, Lumpur River which is now known as Gombak River (Latip, 2011). Many of the urban and crowded settlements and industrialization in Malaysia were situated alongside the river such as in Kuala Lumpur, Selangor, Penang and Johor. Rivers also have been used as the borderline between states in Malaysia such as Bernam River that separates Perak and Selangor, Endau River that separates Pahang and Johor and Golok River that bounds Malaysia from Thailand. In Malaysia, several of its rivers have been used in hydroelectric power generation such as Bakun Hydroelectric Plant in Sarawak and Temenggor Dam in Perak which in total contribute to about 11% of all electricity sources (TNB, 2004).

Despite all the importance of the rivers, many of Malaysian urban rivers, which are commonly located near or at the downstream, are heavily polluted with all kinds of chemicals, organic and solid wastes. The disturbances and contamination of this pollution will eventually flow down to the estuaries and accumulate before getting into the sea. In 2010, 1,055 monitoring stations were set up by the Department of Environment (DOE) to monitor water quality in Malaysia, 50% (527 stations) of the stations were found clean, 40% (417 stations) were slightly polluted and 10% (111 stations) of them were polluted (DOE, 2010). The number of clean rivers decreased from 306 in 2009 to 293 in 2010, as well as slightly polluted from 217 in 2009 to 203 in 2010 with an increment in polluted river to 74 from 54 in 2009 (DOE, 2010). Figure 1.1 depicts water quality index trend of Malaysian rivers for the five year periods reported by DOE Malaysia. The decline in clean rivers is due to the rise in the number of polluting sources such as sewage treatment plants and agro-based industries as well as commercial industrialization and human population near the river bank.

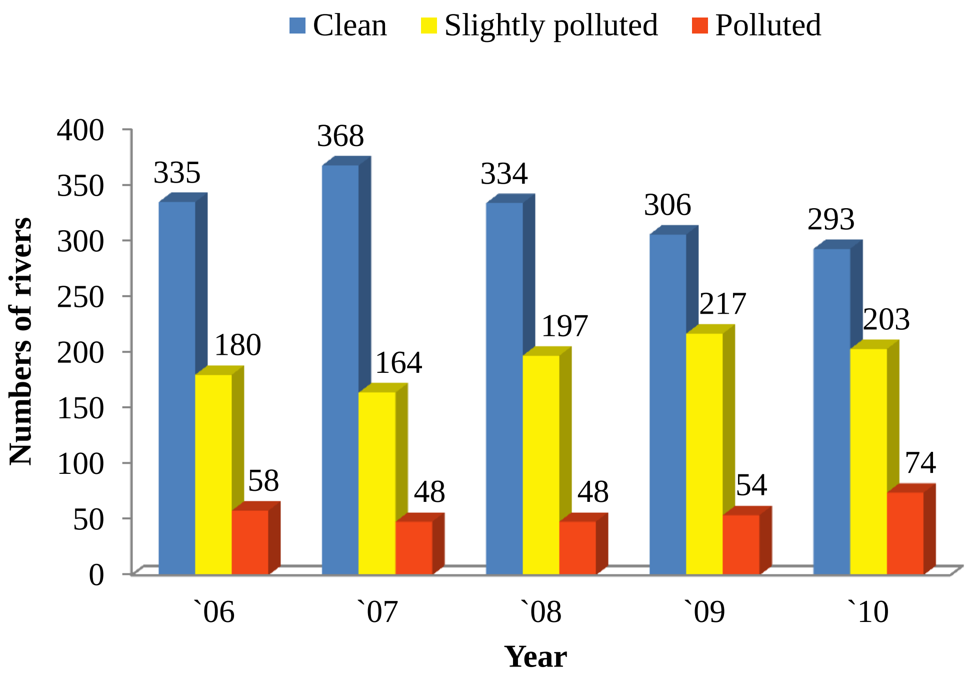


Figure 1.1: Water Quality Index (WQI) trend in Kelantan River for 5 years period.

[Source: Annual Environmental Quality Report from 2006 to 2010 by Department of Environment Malaysia]

According to the Environment Quality Report, EQR (2010), Biological Oxygen Demand (BOD), Nitrogen Ammonia (NH_4-N) and total suspended solid (TSS) were always to be the major pollutants in Malaysian rivers. High BOD can result from the untreated or partially treated sewage and the discharges from agro-based and manufacturing industries. Whereas NH_4-N mainly came from livestock farming and domestic sewage, and SS were from earthworks and land clearing activities. By using the water quality classification based on Water Quality Index (WQI) guideline (Table 1.1), based on BOD level, 211 rivers out of 1,055 water quality monitoring stations has been categorized as polluted, 255 rivers as slightly polluted and 104 rivers as clean. Meanwhile, based on the NH_4-N level, 218 rivers found to be heavily polluted, while 205 rivers were included in the slightly polluted by NH_4-N and 147 rivers were identified as clean. In addition, 156 rivers were recorded to be polluted by SS, 80 rivers as slightly polluted and 334 were clean from TSS pollution.

Table 1.1: Water quality classification based on Water Quality Index (WQI).

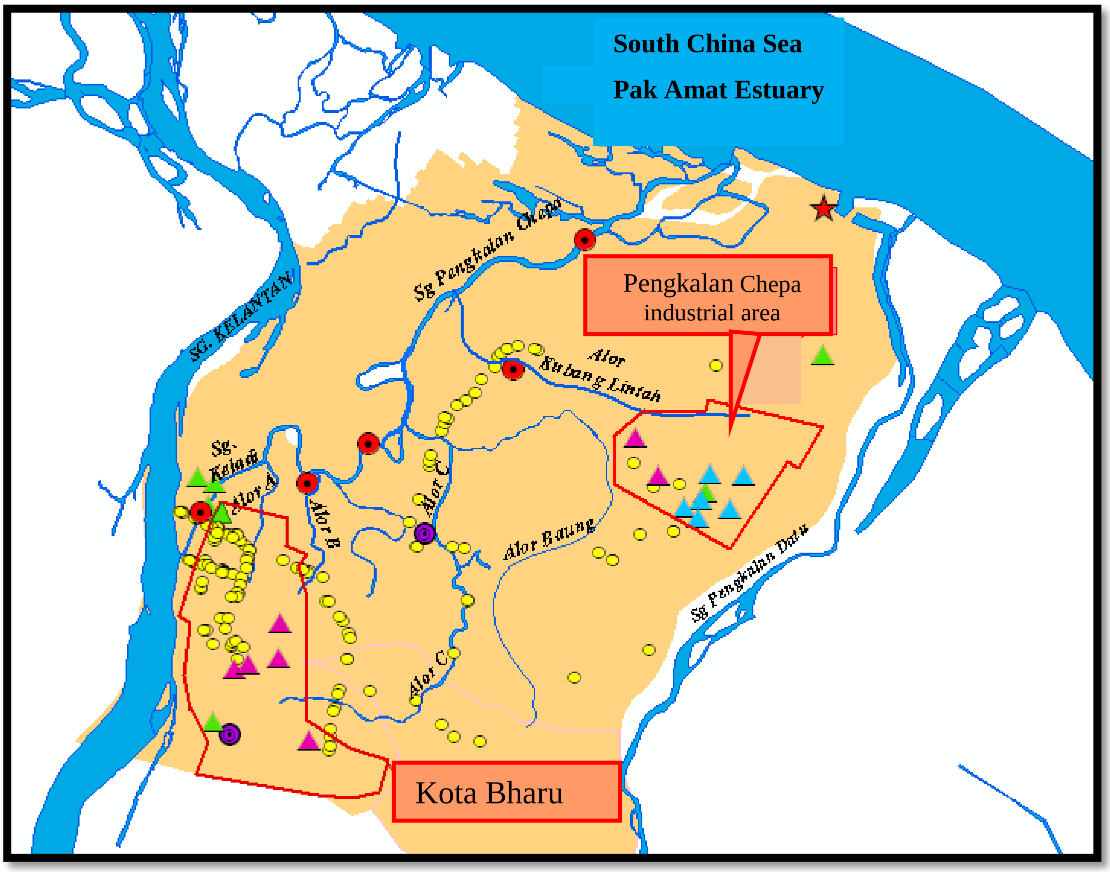
Sub Index & Water Quality Index	Index range		
	Clean	Slightly polluted	Polluted
Biochemical Oxygen Demand (BOD)	91-100	80-90	0-79
Ammoniacal Nitrogen (NH_4-N)	92-100	71-91	0-70
Suspended Solids (SS)	76-100	70-75	0-69
Water Quality Index (WQI)	**81-100**	**60-80**	**0-59**

[Source: Environmental Quality Report 2009]

In many developing countries, the appropriate waste water systems are provided to only some parts of the country, particularly in the urban area, while for majority of the other parts of the population, such facilities are still inadequate. As a result, all kinds of domestic and industrial wastes, as well as raw sewage are dumped and drained into the nearby water bodies. In Malaysia for instance, domestic sewage currently contributes to almost half of the organic pollutant load in the aquatic environment. Domestic sewage contributed to about 46.1% of the total pollution, 43% being from manufacturing wastes and the remaining 10.9% being from agro based activities (Zulkifli, 2003).

There are seven river basins in Kelantan State of Peninsular Malaysia including Kelantan River Basin (KRB). Kelantan River which feeds KRB is the largest and the second largest river in Kelantan and in Peninsular Malaysia, respectively (Ahmad *et al.*, 2009). Kelantan River is about 450 km long (Ahmad *et al.*, 2009) with a catchment area of about 12,000 km^2 (Rohasliney, 2010) and produces average run off of 500 m^3/s (Ahmad *et al.*, 2009). The river drains through several district such as Galas, Kuala Krai and Kota Bharu (Ahmad *et al.*, 2009) and flows northwards into the South China Sea. There is a main and actual estuary that directly originates from Kelantan River delta towards the South China Sea known as Kuala Besar, approximately 15.5 km from the capital city, Kota Bharu (Syazwani Mohd Yusop *et al.*, 2011). Other estuaries from other river basins in Kelantan include Kuala Semut Api, Kuala Sungai Besar, Kuala Pak Amat, Kuala Kemasin, Kuala Melawai and Kuala Semerak (Raj *et al.*, 2007).

Pengkalan Chepa River (PCR) is one of the seven major river basins in Kelantan State of Peninsular Malaysia (Rohasliney, 2011). It originates from Kelantan River through Keladi River and flows over about 12 kilometres into South China Sea through Kuala Pak Amat estuary and affected by the nearby seawater. Pengkalan Chepa River is divided by three stream flows namely Keladi River, Pengkalan Chepa River and Tok Sadang River and feeds six furrows, including Alor A, B, C, D, Alor Kok Pasir and Alor Lintah. It drains through the most urbanized area in Kelantan, Kota Bharu, the city centre of Kelantan and the most industrialized area, Pengkalan Chepa (Figure 1.2).



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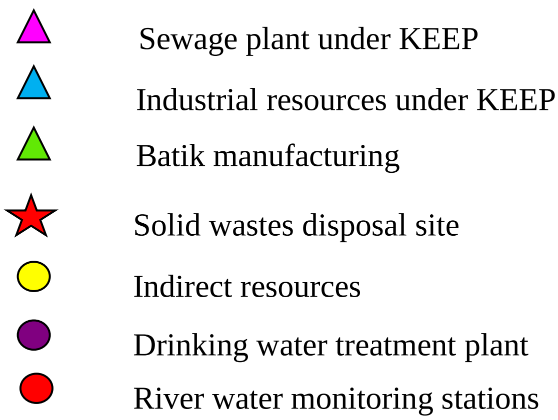


Figure 1.2: Illustration map of land use and pollution sources within Pengkalan Chepa River Basin.
KEEP = Kumbahan dan Efluen-Efluen Industri (Sewage and Industrial Effluents)

[Source: Kelantan Department of Environment Annual Report, 2009]

Pengkalan Chepa River has been categorized as the most polluted stream in Kelantan State and was adopted under the River Pollution Prevention and Water Quality Improvement Program by the DOE since 2005 (DOE, 2009). Based on the Annual Report by Kelantan Department of Environment 2011, even though there is no exact figure on the pollution sources in Pengkalan Chepa River, the main sources of pollution in Pengkalan Chepa River were basically from non-point sources, such as domestic waste from nearby residential and settlement area, restaurant or food stalls, workshops, and urbanization activities. Rubbish, livestock waste and many other wastes were dumped directly into the river particularly in the urban and sub-urban part of the rivers (Rohasliney, 2010). Basically, domestic pollution contributed 60% of total pollution, while 35% was from industrial wastes and the remaining 5% was from solid wastes (Qian *et al.*, 2000). In addition, tidal effect also contributed to the pollution in PCR. During low tide, water from Kelantan River would flow into PCR and sandbars at the estuary prevented the water from flowing into the sea. Thus, all the pollution discharged from the river would accumulate at the bottom of the river. Other than that, leachate from the nearby landfill in Teluk Kitang would overflow during rainy season and flow out into PCR and polluted the affected area (River Ranger Squad, 2010).

Figure 1.3 illustrates water quality index in five different stream tributaries within Pengkalan Chepa River for a period of five years, from 2006 to 2010 as reported by DOE Malaysia. The figure shows discrete variations in pattern among each other. However, Alor Lintah (AL) shows the worst water quality followed by Alor B (AB). Majority of the stream tributaries show decrement in 2010 compared to 2009, especially AL.

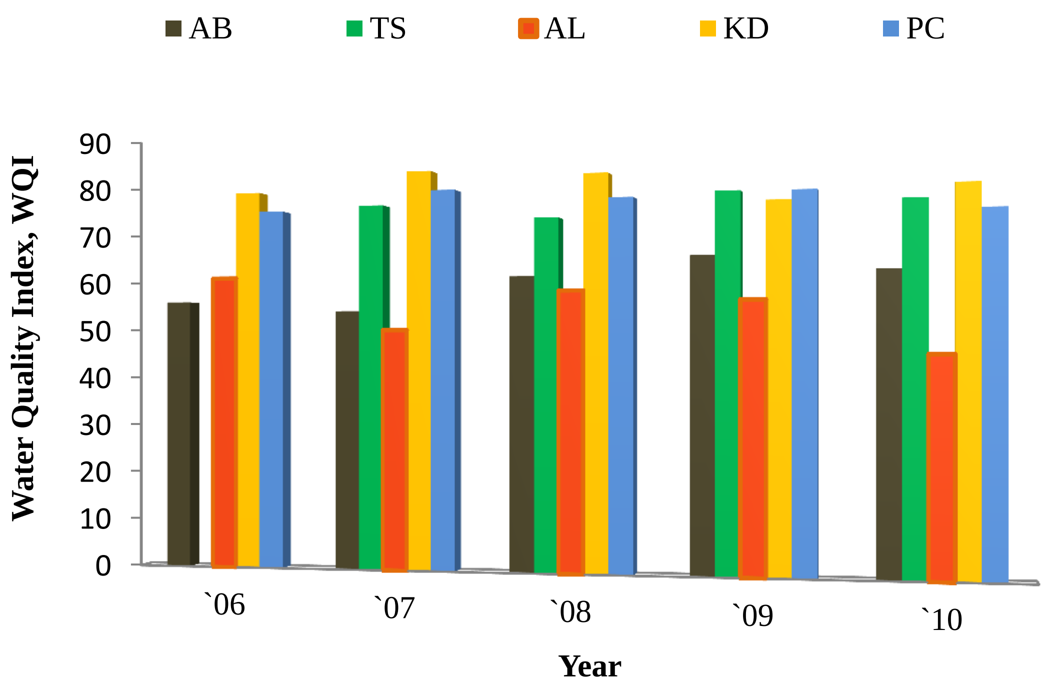


Figure 1.3: Water Quality Index pattern of five sampling stations for five years period (2005–2010). AB = Alor B, TS = Tok Sadang, AL = Alor Lintah, KD = Keladi and PC = Pengkalan Chepa station.

[Source: Annual Environmental Quality Report from 2006 to 2010 by Kelantan Department of Environment]

Bio-monitoring is the use of biological response to assess the changes in the environment more effectively, generally due to anthropogenic causes (Karr, 1987; Ramakrishnan, 2003). It involves the use of indicator; indicator species or indicator communities, generally benthic macro-invertebrates, fish and algae (Ramakrishnan, 2003). Other than that, certain species of aquatic plants and plankton (both phytoplankton and zooplankton) also have been used as indicators in assessing water quality (Arora, 1966; Sládeček, 1983; Duggan *et al.*, 2001; Barros *et al.*, 2007; Lazo *et al.*, 2009; Tasevska *et al.*, 2010). Using plankton as river health indicators is an advantage because plankton normally has rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts. The use of both physico-chemical and biological parameters can provide more accurate information needed for assessing the water quality for appropriate water management (Karr, 1987).

In Malaysia, bio-monitoring of aquatic health was developed recently although water chemistry and toxicity testing have been dominating water-quality programs for decades. Application of physico-chemical variables to assess the water quality of aquatic ecosystems may be inadequate (Arimoro and Oganah, 2010). This is because the biological communities in an aquatic ecosystem could also reflect to the quality of the environment and integrate the environment effect of water chemistry (Sharma and Bhardwaj, 2011). Many of the bio-monitoring studies in Malaysia are basically based on some aquatic organisms as indicators in determining water quality such as benthic macro-invertebrate (Shabdin and Abang, 1999; Yap *et al.*, 2003; Azrina *et al.*, 2006; Al-Shami *et al.*, 2010; Al-Shami *et al.*, 2011; Aweng *et al.*, 2012), phytoplankton (Nather Khan, 1991; Wan Maznah and Mansor, 2002; Wan Maznah, 2010) and molluscs (Ismail and Ramli, 1997; Ali *et al.*, 2002; Ismail and Safahieh, 2005). However, studies exploring zooplankton community as indicators of water quality in Malaysia is still inadequate. So far, studies that involved zooplankton were restricted to ecological distribution, taxonomical identification and morphological study (i.e Fernando and P-Zankai, 1981; Lim and Fernando, 1985) and many of them were from marine community (Fernando and P-Zankai, 1981; Rezai *et al.*, 2003; Rezai *et al.*, 2005; Nakajima *et al.*, 2008; Zaleha *et al.*, 2008). There were also some studies carried out in freshwater such reservoirs, lakes, rivers and streams as well as paddy fields (Ali, 1990; Amir Shah Ruddin *et al.*, 2008; Amir Shah Ruddin *et al.*, 2012).

Routine monitoring of biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic pollution, either chemically or by toxicity tests (Ohio Environmental Protection Agency (OHIO EPA), 1987). In fact, the lack of biological assessment of ecological quality prevents the effective management of these natural resources (Al-Saboonchi *et al.*, 2012) and reduces the effectiveness of control and mitigation programs for the rivers. Therefore, bio-monitoring of aquatic ecosystem is crucial for determining the health of aquatic ecosystem.

1.2 Importance of the study

Pengkalan Chepa River (PCR) has been affected by the rapid and large scale of urbanization and industrialization surrounding, which has caused massive water pollution of the area and thus been abused and neglected. This study can be considered to be the first extensive zooplankton study ever conducted in the PCR Basin. Studies on plankton community of polluted stream in Kelantan, particularly in PCR have not yet been done before. Considering such condition, the present study is aimed to investigate and document the zooplankton community in the PCR Basin and provide some basic ecological information about the river health. The information could be used in determining the quality status of the river in order to conserve the river and to assess the impact of the surrounding activities to the river. Apart from that, the study also helps to increase the knowledge of the potentiality of zooplankton as bio-indicator of water quality in this region. It is also hoped that this study can provide information on the community of zooplankton in PCR with the intention to further enhance the river fisheries and fish production.

1.3 Objectives

1. To determine and document zooplankton community as bio-indicators in the Pengkalan Chepa River Basin, Kelantan.

2. To evaluate the water quality of the river using zooplankton compositions and community structure.

Hypotheses of the study are as follows:

H_o: The composition of plankton communities in PCR is not affected significantly by physico-chemical status of the station, spatially and seasonally.

H_a: The composition of plankton communities in PCR is affected significantly by physico-chemical status of the station, spatially and seasonally.

CHAPTER 2

LITERATURE REVIEW

2.1 Plankton

Planktons are tiny microscopic organisms in open water both marine and freshwater that include plants, animals and bacteria. Plankton includes any floating microorganisms that inhabit the water environment, either the pelagic zone of the ocean or in the freshwater bodies. The term *plankton* comes from a Greek term, which means 'wandering' or 'drifting' and has been first used by Hansen in 1887 to describe any form of microscopic organisms that are floating in the water column (Ismail & Mohamad, 1995). Plankton is usually moved via convection or wind induced water current. Due to their very restricted mobility, the distributions of plankton are largely effected by the movement of water body (Ismail & Mohamad, 1995).

Plankton can be subdivided into different categories based on their taxonomic range. Firstly, within plankton, holoplanktons are organisms that spend their entire life as plankton, such as algae while meroplanktons, such as crustaceans and fish larvae, are those organisms that only their life as plankton on some part of their life (Wickstead, 1965). Other than that, plankton can also be distinguished based on their habitat and abundance in the different aquatic environments; lakes and deep reservoirs plankton (limnoplankton), ponds plankton (heleoplankton), marine plankton (haliplankton) and flowing waters such as rivers plankton (reoplankton or also known as potamoplankton) (Ismail & Mohamad, 1995; Shiel, 1995). These types of plankton usually have their very own element and characteristics that can be used to differentiate among them and it is generally dependent on the environment conditions and their adaptation to the environment. Besides that, plankton can be described in terms of size (Omori and Ikeda, 1992) (Table 2.1).

Table 2.1: Groups of plankton according to size description based on Omori and Ikeda (1992) classification.

Groups	Size
Megaplankton	20 mm and above
Macroplankton	2-20mm
Mesoplankton (also known as netplankton)	0.2-2 mm
Microplankton	20-200 µm
Nanoplankton	2-20 µm

2.1.1 Zooplankton

Zooplankton is the animal part of the plankton and also known as the heterorophic plankton. They generally consume their other counterpart, phytoplankton, since they have no photosynthesis pigment to photosynthesize in order to obtain their energy. Zooplankton is referred as microscopic aquatic organisms which are non-motile and drift in the water column (Rissik and Suthers, 2009). They can be found inhabiting in any forms of water bodies; marine and freshwater, including lakes, reservoirs, ponds, rice-field, irrigation canals and even ground water and temporary water body. Generally, zooplankton can be divided into five groups; microcrustacea, rotifers, coelenterates, ctenophores, annelids and mollusc. Some of the zooplankton exist as plankton only in some part of their life cycle, usually in larval stage and are known as meroplankton. Some examples of this kind of zooplankton are such as crustaceans and most fishes. Some zooplankton spend their entire life cycle as planktonic organisms and are known as holoplankton. Unlike phytoplankton, some zooplankton can move by means of cilia, flagella, jointed appendages or tailed larvae, as the fish larvae.

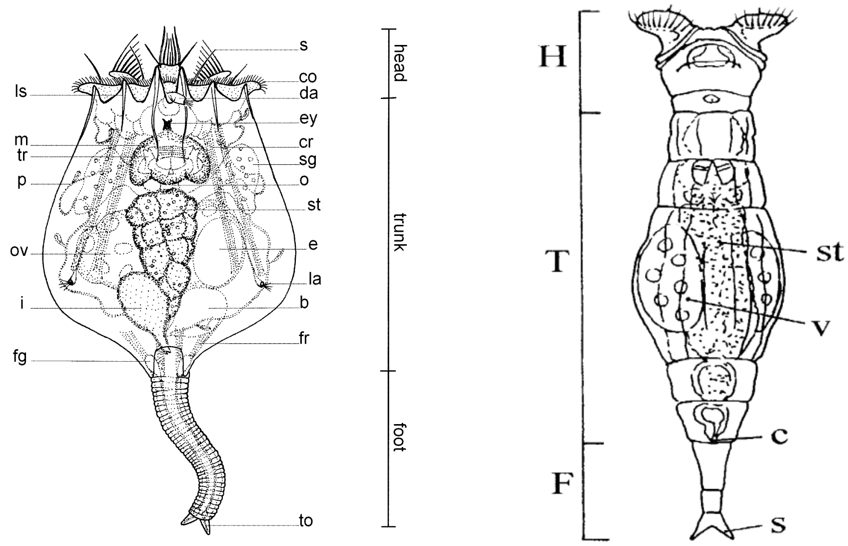
Zooplankton forms a continuous size distribution from tiny flagellates, a few µm in length to giant jellyfish of 2 m in diameter (Chew, 2012). The smallest zooplankton known as picoplankton, which mostly includes bacteria with the size range of about 0.2-2.0 µm. Nanoplankton with the size ranges between 2-20 µm consist of mostly protozoa and heterotrophic nanoflagellates that fed on bacteria. Rotifers and juveniles of micro-crutacean are some of zooplankton that are classified as microplankton. This microplankton ranges between 20 to 200 µm in size. The larger zooplankton group is macroplankton (range size >200µm), commonly consists of some rotifers and most of micro-crustaceans (Shiel, 1995). This zooplankton group also includes hydromedusae, siphonophores, scyphomedusae, ctenophores, mysids and amphipods (Chew, 2012). The largest zooplankton are known as megaplankton (20-200 cm), which includes large jellyfish, such as siphonophore and scyphozoans, as well as pelagic tunicates (Chew, 2012).

In freshwater community, zooplankton dominantly consist of rotifers, micro-crustaceans (cladocerans and copepods, which are mainly in the form of juveniles), protozoan and juveniles of various macro-invertebrates (Ismail & Mohamad, 1995; Shiel, 1995; Case *et al.*, 2008; Ferraz *et al.*, 2009) and are basically larger than phytoplankton in size. Generally, among all basic zooplankton groups occurring in freshwater, rotifers form the most diversified community.

2.1.1.1 Rotifera

Among the important groups of zooplankton are the rotifers. Rotifers are often the most abundant metazoans in inland waters, both in the number of individuals and in terms of species numbers. Rotifers, also known as Rotatoria or wheel animalcules are generally characterized by the appearance of *corona* (Figure 2.2), a ciliated area or a funnel-shaped structure at the anterior end and a *mastax*, a specialized pharynx (Edmondson, 1959). They are characterised by the highly muscular pharynx containing jaws (trophi) used for grasping, crushing or grinding their prey or attaching to a host and by the toes with adhesive glands (Pechenik, 2005). These rotifers are the assemblages of diverse pseudocoelomate, primary bilaterally symmetrical worm, that traditionally include three groups, freshwater Monogononta and Bdelloidea (Figure 2.1), marine epizoic Seisonacea and parasitic Acanthocephala (Segers, 2004). Monogononta is the largest amongst the groups which comprises of about 1450 species, distributed over 29 families and 106 genera worldwide (Segers, 2004).

Rotifers are mostly filter feeders and largely depend on detritus, bacteria and small particles as their diet which are collected through coronal cilia (Karunakaran and Johnson, 1978). Many of the rotifers are considered as active predators, although there are some that feed on large algae (Segers, 2004).



(a) (b)

Figure 2.1: (a) Scheme of the anatomy of a monogonont rotifer, *Brachionus rubens* Ehrenberg in dorsal view. b, bladder; co, corona; cr, corona retractor; da, dorsal antenna; e, egg; ey, eye; fg, foot gland; fr, foot retractor; i, intestine; la, lateral antenna; ls, lorica spine; m, mastax; o, oesophagus; ov, ovary; p, protonephridium; s, sensory cirrus; sg, stomach gland; st, stomach, to, toe; tr, trophy (After Segers (2004)); (b) General anatomy of bdelloid rotifer (dorsal view). H, head; T, trunk; F, foot; c, cloaca; st, stomach; u, uncus; v, vitellarium. (After Ricci and Melone (1984)).

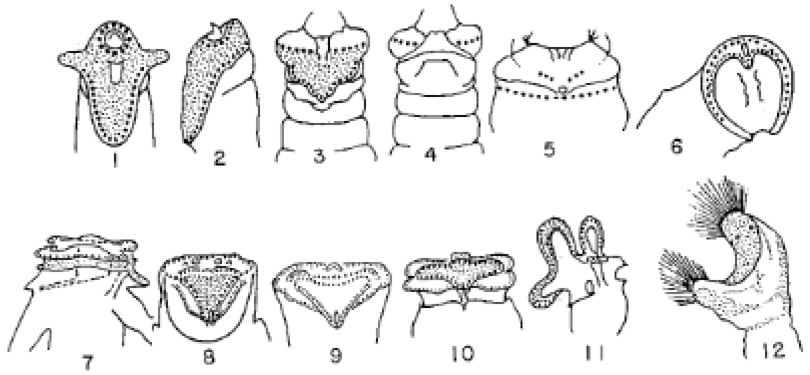


Figure 2.2: Rotifer coronae. 1/2, Notommata, ventral/lateral; 3/4, Macrotrachella (Bdelloidea) ventral/dorsal; 5, Asplanchna, ventral; 6, Conochillus, ventral; 7, Hexarthra, lateral; 8, Euchlanis, ventral; 9, Epiphanes, ventral; 10, Brachionus, ventral; 11, Floscularia, lateral; 12, Collotheca, lateral. Large dots, trochus; medium dots, cingulum; small dots, ciliationof the cicumapical band. (various authors, Koste (1978) as been reviewed by Shiel (1995)).

2.1.1.2 Cladocera

Other common group of zooplankton in freshwater ecosystem is cladocerans. These cladocerans are commonly known as 'water flea'. They are recognized by the unclear segmented body which consist of two main parts, the head and trunk by which most of them are 0.2-3.0 mm long (Figure 2.3). The head bears two pairs of antennae which act as their locomotion organs while the trunk is covered by a bivalve carapace (Silva-Briano and Mirabdullayev, 2004). The bivalve carapace is a fold of the cuticle, which extends backward and downward from the dorsal side of the head (Edmodson, 1959). One special characteristic of cladocerans is that they are able to produce their off-spring without the needs of male to fertilize the eggs, through the process called parthenogenesis (Wickstead, 1965). Majority of cladoceran inhabit freshwater, but there are number of them occur in brackish and saline habitat as well as acid environment such as peat swamp (Silva-Briano and Mirabdullayev, 2004). They are one of the important element in the aquatic micro-faunal food webs (Shiel, 1995) and are the main food of choice of almost all young freshwater fishes as well as other macro-invertebrates (Shiel, 1995).

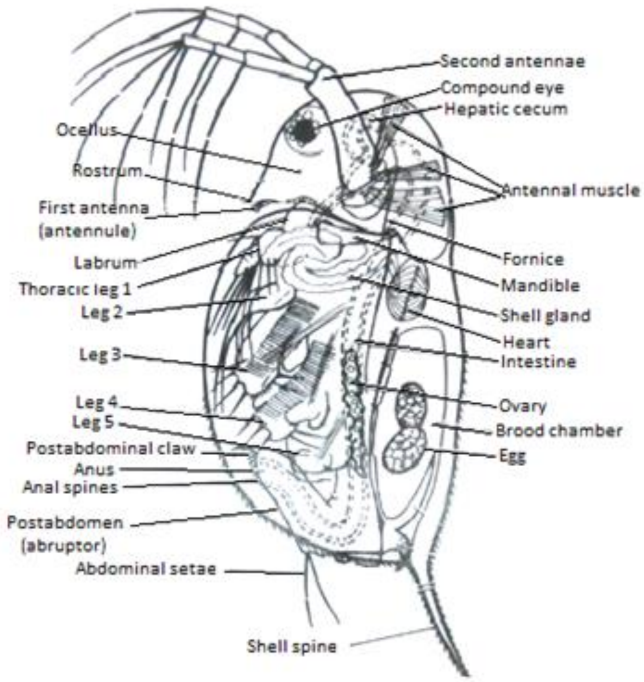


Figure 2.3: Lateral view of female *Daphnia similis* showing the features important in cladoceran taxonomy (modified from Claus by Edmondson (1959)).

2.1.1.3 Copepoda

Copepods are one of the largest class of crustacean that consist of three main suborders; Cyclopoida, Calanoida and Harpaticoida (Figure 2.4). The word ‘‘copepod’’ derives from the Greek *kope* meaning oar and *podos* meaning ‘foot’ and literally means ‘oar-footed’ (Johan, 2005) and refers to their paddle-like paired swimming legs.

Copepods dominate the zooplanktonic community in both freshwater and marine ecosystems (Boxshall and Halsey, 2004). Generally, copepod form a major component (about 50%) of zooplanktonic community and are the essential food source to many primary carnivores, including fishes (Ismail & Mohamad, 1995; Pechenik, 2005). Evidently, quite a large number of marine copepod species are parasites, particularly on fishes (Shiel, 1995; Johan, 2005). Among all the three copepods groups, cyclopoida is found to be more carnivorous than other zooplankton. The large cyclopoida individuals mainly feed on rotifers and crustaceans, insect larvae and other small aquatic organisms (Mirabdullayev, 2004). The calanoids are mainly herbivorous and the harpacticoids are mainly omnivorous.

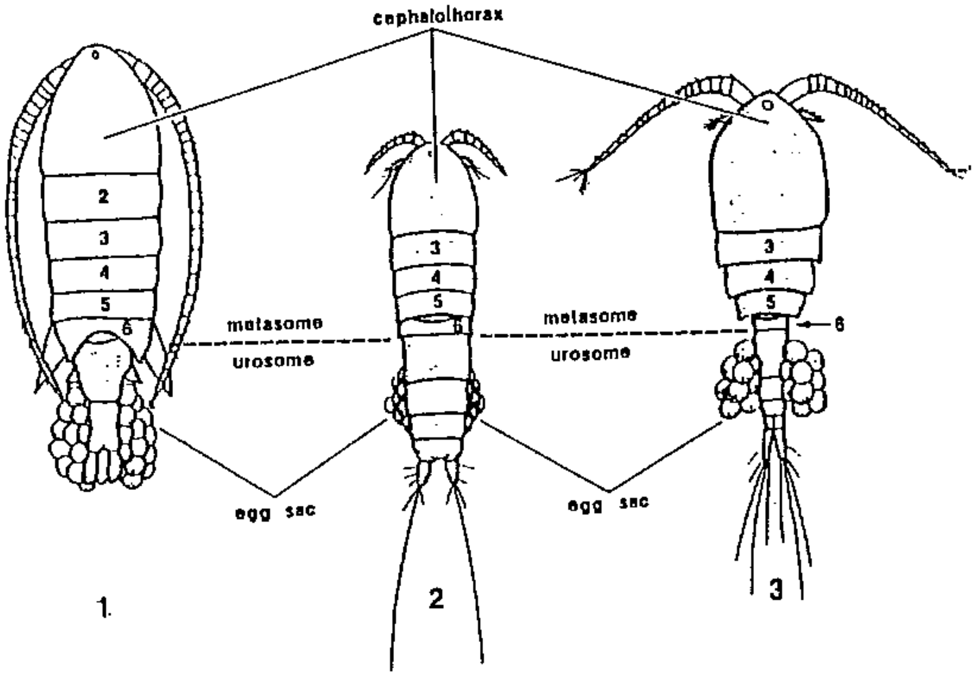


Figure 2.4: General morphology of copepods; 1, Calanoida, 2, Harpaticoida, 3, Cyclopoida (after Williams (1980) as been reviewed by Sheil (1995)).

2.2 Role of Plankton in the Environment

Plankton play an important role as the primer producer and are the essential to the entire aquatic food chain (Muller-Feuga, 2000). They assemble the largest element of the world’s biomass, employing a very important influence on aquatic life and forming most probably the most important basis of aquatic food element of the water bodies, seas or rivers food webs (Tang *et al.*, 2006; Rumengan and Ohji, 2009). Zooplankton plays an important key role in the aquatic food web as primary grazers of phytoplankton and as a food to higher trophic organisms (Johan *et al.*, 2012). In nature, zooplankton are essential in supplying nutrients to fish larvae (Treece and Davis, 2000). There are numerous studies that have shown that small zooplankton (e.g. copepods, tintinnids, cladocerans, larval molluscs) are important component of larval fish food (Agasild and Nõges, 2005).

Other than that, many species of zooplankton, particularly rotifers are the essentials in lacustrine food webs due to their rapid turnover rate and metabolism (Segers, 2004). In addition, calanoids have been known to be important consumers of phytoplankton and provide food for predatory invertebrates and fish, contributing to the energetic of aquatic ecosystems (Lim and Chaw, 2004). Cladocera are an important element of freshwater ecosystems, often being the dominant part of the zooplankton. They are the main food of almost all young freshwater fishes. Harvested and dried or frozen Cladocera are used in aquaculture as food for shrimps and fishes. Cladocera are also used in monitoring of water quality (Silva-Briano and Mirabdullayev, 2004b).

In most of fish species larviculture, rotifers are the important live food (Arimoro, 2006) and are considered as living food capsules for transferring nutrients to fish larvae (Lubzens *et al.*, 1989). Rotifers have extensively been used in fish and shrimp hatcheries worldwide. For instance, *Brachionus plicatilis* and *B. calyciflorus* are two rotifers that are commonly cultured to feed freshwater and marine fish larvae in hatcheries around the world (Treece and Davis, 2000; Arimoro, 2006). As for habitat type preferences, even though pelagic zooplankton provide a relatively lesser food supply compared to the zooplankton littoral region, they serve as the first food source for the post-larval fish and have been the main food source for some fish species, such as riverine sardine, *Clupeichthys aesarnensis* (Fernando, 1994). Pelagic ecosystem is very important where majority of fish species have a pelagic larval phase, including commercial fishes (Van Ginderdeuren *et al.*, 2012).

Other than that, zooplankton also take part in stabilizing the growth or populated filamentous algae or microbial community which lead to eutrophication to occur, where algae form a part of the diet of many zooplankton species. Rotifers have been found to be the dominant grazers in other ecosystems, including freshwater estuaries elsewhere (Kim *et al.*, 2000). Additionally, zooplankton are dominant grazers of phytoplankton, which indirectly can play a large role in water clarity (Ng, 2013).

Moreover, many studies recently have demonstrated that zooplankton communities with large cladocerans, particularly Daphniidae, can strongly impudence the entire microbial community (bacteria, autotrophic picoplankton, heterotrophic nanoflagellates (HNF), ciliates), by both direct and indirect consumption (Silva-Briano and Mirabdullayev, 2004). According to Marten *et al.* (1994), there were some of free-living copepods, especially cyclopoid that are also the enemies of mosquito larvae and can reduce the numbers of these insects in aquaculture, thus, indirectly could lessen the malaria from spreading out. In addition, there were also many laboratory experiments have been conducted for copepod predation on mosquito larvae (Marten and Reid, 2007).

Zooplankton also took part in the P and N cycling in the aquatic environment. Zooplankton can contribute to N removal directly by consuming phytoplankton and indirectly by eating microorganisms, but on the other hand, zooplankton can also contribute directly to N release by excretion of ammonia and urea and slopping feeding (Bode *et al.*, 2004). A study by Bode *et al.* (2004) in the upwelling ecosystem of A Coruna, Northwest Spain, has found that the rates of demand for regenerated ammonium by phytoplankton was closely matched with the regeneration rates of microplankton. Other than that, zooplankton can promote P limitation for phytoplankton by fixing a large fraction of the P in the system into their own mass and recycling a substantial amount of the N to a dissolved form (Urabe *et al.*, 1995).

Plankton community in the marine ecosystem have recently been used in assessing the global climate change. Hays *et al.* (2005) mentioned that plankton are particularly good indicators in the marine environment due to some criteria. Firstly, only few species of plankton are commercially exploited compared to any other marine species, such as fish and many intertidal organisms. Therefore, any long term change can be attributed to climate change. Secondly, the close relationship portrayed between environmental changes and plankton dynamics is due to their short-lived and the population are less influenced by the existence of the previous individuals from the previous years. Other than that, due to the free floating characteristics, plankton can respond easily to the changes of temperature and oceanic current systems and show dramatic changes in their distribution, by expanding or contracting their ranges. Finally, compare to the other environmental variables, plankton are more sensitive to the changes that occur. This is because biological communities respond to the slightest environmental changes.

Unfortunately, despite all the advantages of this zooplankton community, they also could give harm to other animals, especially fish, as well as to human being. Zooplankton has been known to be micropredators to the early stage of fish larvae.

Fish larvae (e.g. carp) are attacked by adults copepods (e.g. *Acanthocyclops robustus*) and by more-advanced copepodit stages and resulted in serious lesions of the fins, head and the gills of fish (Piasecki *et al.*, 2004). Other than that, copepod species such as *Lernaea cyprinacea*, *Ergasilus sieboldi* (and related species), *Salmincola californiensis*, *S. edwardsii*, *Achtheres percarum*, *Tracheliastes maculatus*, and *Caligus lacustris* have been found to be fish parasites (Abdelhalim *et al.*, 1991; Ho, 1998; Johnson *et al.*, 2004; Piasecki *et al.*, 2004). These copepod parasites were also known as 'sea lice'. This 'sea lice' have been found to be the most damaging parasite to the salmonoid farming industry in the Europe and the America (Costello, 2009). The most important human diseases that linked copepods are cholera. Copepods served as the intermediate hosts and vectors for parasites that infect human and the association of *Vibrio cholerae*, the causative agent of cholera, and its copepod host has been under study for more than 25 yr (Piasecki *et al.*, 2004). It is now well documented that *V. cholera* is autochthonous to aquatic environments and closely associated with copepods (*Ibid*).

2.3 Plankton as bio-indicator in evaluating water quality

Plankton has been used to be an indicator to the aquatic environment's health and water quality due to their sensitivity and short life span. Plankton community composition and abundance have long and widely been used in determining aquatic environmental changes resulting either from natural toxicity or anthropogenic pollutant. Plankton can be used as biological indicators to eutrophication and pollution in aquatic environment because of its sensitivity and ability of rapidly respond to the changes of the aquatic environment, nutrient enrichment as well as water quality and different levels of pollution (Tang *et al.*, 2006; Case *et al.*, 2008;

Arimoro and Oganah, 2010). The abundance and variety in plankton species diversity could reflect the conditions of water column (Burford, 1997; Primavera, 1998).

Numerous studies from all over the world have been conducted based on these amazing tiny organisms particularly in assessing the aquatic environmental changes and water quality (Arora, 1966; Evans, 1984; McCormick' and Cairns, 1994; Wan Maznah and Mansor, 2002; Garcia *et al.*, 2009; Lazo *et al.*, 2009; Tasevska *et al.*, 2010). Indices such as diversity, evenness, dominance and species richness are among ecological parameters that have been used by the researchers to monitor and discuss the level of water quality, pollution and disturbances of the stream and estuary and then to identify the indicator species (Arora, 1966; Sládeček, 1983; Duggan *et al.*, 2001; Lazo *et al.*, 2009; Tasevska *et al.*, 2010). For instance, Neumann-Leitão *et al.*, (1992) found that, Ipojuca River, Brazil had a significant high population of rotifers due to high levels of toxic substances loaded from the factories, textile mills and domestic sewage.

Dominance of one species in an aquatic environment evidently relates with the number of species (Green, 1993). The higher the dominance of certain species is the lower number of species (Green and Mengestou, 1991; Green, 1993). A study conducted in West India Dork and Barbican Pool showed that the number of the rotifer species was low while the dominance of the stations was disproportionally high (Green, 1993).

Many species of zooplankton have been identified as good bio-indicator species. According to Zannatul Ferdous and Muktadir (2009), *Brachionus*