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TONLE SAP FISHERIES:
A CASE STUDY ON
FLOODPLAIN GILLNET FISHERIES

by

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PREFACE

The inland fisheries of Cambodia are among the most productive in the world and contribute considerably to national food security. Fish from waters all over the country provide an essential part of the daily diet for millions of people.

The fisheries of the Tonle Sap make up almost two thirds of all inland catches. Together with the forests, they are Cambodia's most important renewable natural resource. Not only does fishery sustain the livelihood of many families, it also provides an essential contribution to the national economy and is a source of foreign currency income.

Nowadays, the bounty of the Tonle Sap is intensively exploited. This seems justified but entails considerable risks. Therefore, sufficient understanding of the natural productivity is required to allow durable exploitation, safeguarding the resource for future generations.

The issues that threaten the existence of the Tonle Sap fisheries as known today are numerous and diverse. The undervaluation of the fisheries risks to contribute to the situation where the sector cannot withstand critical challenges, e.g. from proposed dam construction and the subsequent alterations to the hydrology of the main fishing grounds.

Maintaining the parameters of the complex ecosystem that enable the exceptional production of fish is crucial and possibly the only effective management strategy for the fisheries of the Tonle Sap.

This publication aims at contributing to a better understanding of the Tonle Sap ecosystem and the fisheries and aquaculture sectors. It is written for those who will make the crucial decisions about the future exploitation of the natural richness of the Tonle Sap.

Veravat Hongskul
Secretary
Asia-Pacific Fishery Commission
Bangkok, September 2001

PREPARATION OF THIS DOCUMENT

This document, prepared under Special Service Agreement by Mr. Dirk Lamberts, is a case study on floodplain gillnet fisheries in the Tonle Sap, Siem Reap, Cambodia.

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ABSTRACT

Gillnet fishing makes up a substantial part of the inland fisheries in Cambodia, which are important to food security and to the national economy. The Tonle Sap ecosystem is one of the most productive in the world. Although little studied, its productivity is generally attributed to the pulsed flooding and the specific vegetation of the huge floodplain.

Major habitat types are identified in the floodplain of the Tonle Sap based on macrophyte vegetation and flooding characteristics. These habitats are described in limnological terms and seasonal variation in water quality. This results in the definition of ecologically significant phases of flooding. Their impact on fishes and productivity of the lake are analysed.

The second part describes the fisheries of the Tonle Sap ecosystem and their management. Gillnet fishing in the different habitats of the ecosystem is studied and catches and productivity are compared. Data on biology and ecology of eight fishes of economic importance are presented. The final part describes the aquaculture of the Tonle Sap ecosystem.

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ABBREVIATIONS & ACRONYMS

ASEAN	Association of Southeast Asian Nations
CF_w	Weight-based condition factor (dimensionless)
CPUE	Catch per Unit of Effort
$CPUE_n$	number-based CPUE
$CPUE_w$	weight-based CPUE
DANIDA	Danish International Development Agency
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
Gm^3	Giga (10^9) cubic metres
GIS	Geographic Information System
GPS	Global Positioning System
MAFF	Ministry of Agriculture, Forestry and Fisheries of Cambodia
MRC	Mekong River Commission
NIS	National Institute of Statistics, Ministry of Planning of Cambodia
UNICEF	United Nations Children's Fund
WFP	World Food Programme

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PART I. TONLE SAP ECOSYSTEM

The Tonle Sap ecosystem is defined here as the permanent core area of the Tonle Sap lake and the surrounding natural floodplain, within the boundaries constituted by the upper flood lines. The natural upper flood levels tend to vary from year to year and are not always clear, especially in areas where flood and rainwater retention structures have been built. In most places, human activity is determined by the average expected flood levels and the boundaries of the ecosystem are conspicuous. The ecosystem as defined here also includes the Tonle Sap channel, i.e. the channel between the permanent core area of the Tonle Sap lake to the west and the Mekong river to the east, including its branches and floodplain (Fig. 1.2).

The physical environment

i. Climate

The atmospheric conditions of the Tonle Sap ecosystem are determined by the dry and wet-monsoon climate of the lowland plains of Cambodia. The climate is characterized by a long rainy season determined by the southwest monsoon, beginning in May-July and reaching a peak in precipitation in October. This is followed by the dry period of the northeast monsoon from November to April, which brings generally dry weather over Cambodia and makes December and January the coolest months of the year. The average annual rainfall in Phnom Penh is 1 407 mm. The rainfall across the Cambodian lowland plains increases in a southwest-northeast direction (Mekong Committee 1992). Precipitation for the Tonle Sap lake and an area that stretches about 100 km to the north and the northeast from the lake averages between 1 000 and 1 250 mm per year.

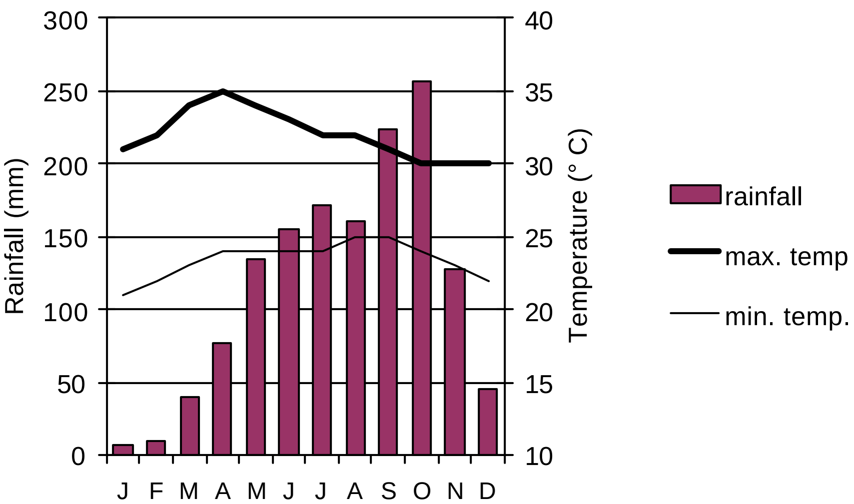

Figure 1.1 Average monthly rainfall and minimum / maximum temperatures for Phnom Penh

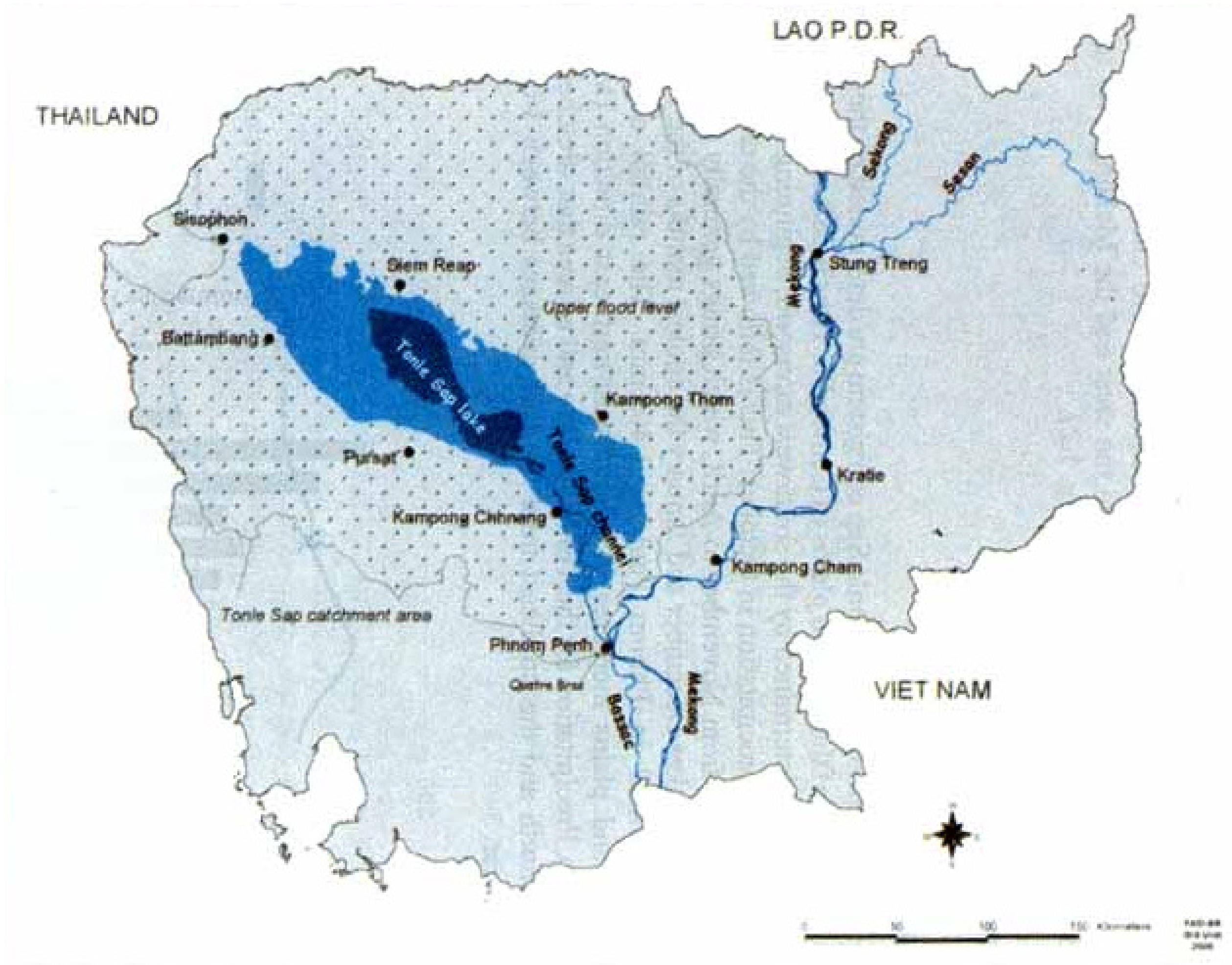

Figure 1.2 Map of Cambodia. The Tonle Sap ecosystem lies within the boundaries of the upper flood area of the Tonle Sap lake and channel.

ii. Geography

Continental Southeast Asia is situated on the Sunda shelf, which is currently exposed as the Indo-Chinese Peninsula and a series of large islands including Sumatra, Java and Borneo. Current sea levels are up to 120 m above the lower parts of the shelf. Several cycles of regression and transgression have repeatedly exposed nearly the entire shelf and again covered large parts of it, including land that is up to 7 m higher than the present sea level. During the periods of exposure, extensive systems of rivers existed which have become disconnected following the transgressions.

The extensive and complex tectonic and volcanic activity of the region has shaped the course of the Mekong, although the present configuration of the river is very recent. Previously, the Mekong debouched into the Gulf of Thailand in Kampot. Many rivers in the region that are discontinuous today were connected in the past, not once but several times. Rainboth (1996) provides an overview of the recent changes of the river basins of the region. Thus, before becoming integrated in the Mekong system, the Tonle Sap channel may have been part of another large river which has disappeared since.

The Tonle Sap lake is situated in the centre of the Cambodian central plain, which has an elevation of 10-30 m above sea level and covers 75 percent of the country. The lake was formed only less than 6 000 years ago when the most recent subsidence of the Cambodian platform took place (Carbonnel, 1963).

iii. Hydrology

The hydrology of the Tonle Sap ecosystem is mostly determined by the over 4 000 km long Mekong river. The lake is connected to the Mekong river through the 100 km long Tonle Sap channel. The channel and the Mekong join at the Quattre Bras near Phnom Penh, after which the river immediately branches into two arms, the larger main Mekong and the smaller Bassac river. Farther downstream these two arms are reconnected to form two equal channels as they start to fan out to form the delta, discharging into the South China Sea.

The Mekong originates in the same area in southeastern Tibet where four other Asia's major rivers (Brahmaputra, Irriwaddy, Salween and the Yangtse) have their origin. The total drainage area of the Mekong is 795 000 km^2 (Mekong Committee, 1992).

The part of the Mekong in Cambodia is 486 km long and drains a total of 156 000 km^2 or 86 percent of the country (Hak and Piseth, 1999). There are two different sections. From the Khone falls at the border with Laos down to Kratie, the river type is that of a fast streaming upland form, with relatively high turbidity and characterized by a succession of rapids, deep pools and sand banks. Gradients are high, currents strong and the inundation zone is localized. The flow ratio between high and low water is very high. In the section downstream from Kratie, the Mekong shows the characteristics of a broad lowland river. The gradients are shallow and seasonal flooding by the river waters covers vast areas.

The discharge of the Mekong reflects the pattern of the rainfall distribution throughout the year and follows the monsoon seasons. Consequently, the flow patterns display predictable cyclical changes. The water level varies accordingly and fluctuations between years in the maximum water levels and discharge volumes are large. However, minimum levels are stable with little variation and do not seem related to the preceding maximum levels (Hak and Piseth, 1999). The maximum water level in the Mekong in Kratie is reached in September-October. The river flow decreases rapidly until December, and then slowly during the dry period, reaching minimum levels in late April. As the rising water level in the Mekong during the following months reaches 7 metres above mean sea level, overland flow begins and the flow in many tributary rivers is reversed.

The high velocity of the water at the beginning of the flood increases the carrying capacity and consequently reduces the clarity of the water by five to ten times compared with the dry season. The sediment load of the Mekong is low compared with other major rivers, and decreases downstream (Mekong Committee, 1992).

Flow reversal also occurs in the Tonle Sap channel. By the end of May, the water level of the Mekong at Quattre Bras reaches sufficient height (9 m) to start pushing water from the Tonle Sap drainage area back in the channel, thus reversing the flow. This results in an accumulation of water from the Mekong and from its proper drainage area in the Tonle Sap lake. Extensive flooding is the result, increasing the surface area of the lake from about 2 500 km^2 to over 10 000 km^2 and, according to some sources, even to almost 16 000 km^2 (Rainboth, 1996). The size of the lake varies between 160 km long and 35 km wide at its widest point during the low water time, and 300 km in length and over 100 km in width in some places at the height of the flooding. Maximum depth is reported to vary between less than 2 m in the dry season and up to 14 m at the peak (Rainboth, 1996; Mekong Committee, 1992; Hak and Piseth, 1999). After about five months, in October, the water level in the Mekong has sufficiently subsided for the flow in the Tonle Sap channel to reverse and the lake and the thousands of square kilometres of floodplain to be drained. Hak and Piseth (1999) estimate the volume of water yearly stored in the Tonle Sap lake at 72 Gm^3. The Tonle Sap drains an area of 85 065 km^2, which is 10.7 percent of the total drainage area for the Mekong. It contributes 6.4 percent of the average annual flow of the Mekong (Mekong Committee, 1992).

Farther downstream, at the border with Viet Nam, the Mekong begins to experience tidal influences, even though the water remains entirely fresh.

Biotic components of the ecosystem

The primary production of the Tonle Sap ecosystem depends on the phytoplankton and the macrophyte vegetation of the floodplain. A Vietnamese study in the late 1980s (Nguyen and Nguyen, 1991) identified 197 species of **phytoplankton** in the Mekong, the Tonle Sap channel and the floodplains. Green algae and diatoms make up almost two thirds (64 percent) of the plankton species, one quarter are blue-green algae and the remainder is composed of Euglenophyta and some Xantophyta, Pyrrophyta and Chrysophyta. Among the diatoms, there are 17 marine species and only about 10 percent of the species are specific to the river or to the floodplain. The largest number of species was found in the main stream of the Mekong. The phytoplankton density varies considerably in the rivers and is about 40 times higher in the dry season than during the high-water period. The density is in general higher in the flooded areas than in the rivers.

The **macrophyte vegetation** is one of the most conspicuous elements determining the structure and nature of the habitats in the ecosystem. McDonald and Veasna (1996) and McDonald *et al.* (1997) provide a detailed study of the macrophyte vegetation of the Tonle Sap ecosystem. The present seasonally inundated vegetation is composed of several distinctive vegetation types that are located exclusively within the boundaries of the fluctuating shorelines. The original macrophyte vegetation of the floodplains of the ecosystem has assumed a variety of forms as a result of a thousand years of human impact and is at different stages of degradation and regeneration.

A number of **cultured crops** make up part of the macrophyte vegetation of the ecosystem nowadays. These include maize, mung bean, lotus, rice and a variety of vegetables. In places, growth of grasses is facilitated for grazing of herded animals (cattle, pigs, ducks).

The **zooplankton** of the Tonle Sap ecosystem is partly described in the study by Nguyen and Nguyen (1991). Half of the 46 species identified are rotifers, about one third are cladocerans and the remaining seven species are copepods. The number of species in the flooded areas is higher than in the river, and the composition of the zooplankton communities varies throughout the year. In the Tonle Sap channel, the zooplankton density increases by a factor of 107 during the dry season. This is attributed to the impact of the water of the Tonle Sap lake but no explanation is given on how this effect is brought about. In the flood season, zooplankton density in the flooded areas is almost one hundred times higher than in the river. The dynamics of plankton communities are complex and considerable variation in species composition and density is likely.

The biomass of the **zoobenthos** does not vary much with the seasons. Nguyen and Nguyen identified 57 species: 15 insects, 8 oligochaete worms, 29 molluscs and 5 crustaceans. Molluscs make up as much as 85 percent of the zoobenthos by weight. Rainboth (1996) terms the rich diversity of molluscs in the Mekong as “striking”.

The **neuston** has been little studied in tropical floodplains but usually makes up a non-negligible part of the aquatic ecosystem. Mosquito larvae, insects (hemiptera and coleoptera) and other invertebrates are common in floodplains, particularly in the sheltered water among the stems of floating or submerged vegetation (Welcomme, 1985).

Of all the vertebrates of the Tonle Sap ecosystem, **fishes** are undoubtedly the largest group, both in number of species as well as in biomass. The precise number of species in the Mekong is not known; the total number recorded or inferred from the known zoogeography of the region includes about 1 200 species (Rainboth, 1996). Welcomme (1985) ranks the Mekong in terms of fish species diversity as the third richest river in the world, after the Amazon and the Zaire, with a total number of known species of fewer than 1 000. Based on the relationship presented by the same author between the basin area of 47 of the world’s largest rivers and the number of fish species they hold ($N = 0.297A^{0.477}$, with N the number of species and A the basin area in km^2), as many as 1 938 species would be expected from the Mekong.

Even though the total number of species from large systems tends to be high, groups of species often are confined to very different parts of the river. The three different parts of the Mekong system in Cambodia (the Tonle Sap lake, the main river and the high estuary) support rather distinct fish assemblages (Rainboth, 1996). These differences are based on the physical characteristics and present ecological parameters of the sections and the differences in historical configurations. The complex geological and climatic history of continental Southeast Asia is largely responsible for the present-day fish diversity. The repetitive physical separation and mixing of species in the extensive river systems of the Sunda shelf has contributed to the high number of species in the Mekong system.

The ecological parameters that determine the different habitats in the Mekong have locally given rise to isolated species, although the degree of endemism is not known. The Tonle Sap ecosystem is expected to lack localized endemism (Rainboth, 1996).

The total number of fish species present in the Tonle Sap is not known either. About 500 species have been described for the Mekong system in Cambodia (including the Tonle Sap ecosystem) but the real number is certainly higher (Rainboth, 1996). Furthermore, there is not much reliable information available about the biogeography of most species inside Cambodia. Available information usually does not allow assessing which species are present in the Tonle Sap ecosystem. The data collected from fishery operations tend to underestimate the number of species considerably. This is due to the uncertainty about most field identifications. Identifications based on local names of fish species are not very useful in this respect since they usually cover more than one, and often many, biological species. The lack of a practical, comprehensive fish species identification guide for use in the field by local data collectors contributes to this uncertainty.

Some of the species found in the Tonle Sap remains there permanently, while many other species use the lake and the floodplain only temporarily and migrate back and forth to the Mekong.

Amphibians and **reptiles** are common in the ecosystem, even though larger species like turtles and crocodiles have become rare or have disappeared altogether as the result of excessive hunting. Aquatic snakes are very common, as are toads and frogs.

The Tonle Sap ecosystem is home to some of the world's rarest and endangered **bird** species including *Pelicanus philippensis* (Spot-billed pelican), *Leptoptilos dubius* (Greater adjutant stork), *Cairina scutulata* (White-winged duck), *Mycteria cinerea* (Milky stork) and *Leptoptilos javanicus* (Lesser adjutant stork). It shelters some of the last viable populations of bird species thought to be extinct elsewhere. The flooded forest hosts the largest breeding water bird colony anywhere in Southeast Asia covering an estimated 875 ha in Battambang province, mostly in Fishing Lot 2 (E. Briggs, personal communication, 2000). Most of the birds species of international conservation significance known to occur in Cambodia are found in habitats that are also present in the Tonle Sap ecosystem (Ministry of Environment, 1998). Bird colonies are large in places and they can locally play an important role as fish predators and in nutrient recycling (Welcomme, 1985).

Orcaella brevirostris, the freshwater dolphin that is found in the Mekong, is occasionally also seen in the Tonle Sap ecosystem. As all larger wild animals in the Tonle Sap ecosystem, it is becoming increasingly rare.

Cultured animals are increasingly becoming a permanent part of the Tonle Sap ecosystem. Inundated forest in the floodplains is cleared using slash-and-burn techniques in order to facilitate the growth of young grasses on which cattle and ducks are grazed.

Productivity of the ecosystem and natural resource use

i. Ecosystem productivity

The Tonle Sap ecosystem is widely believed to be one of the most productive inland waters in the world (e.g., Mekong Committee, 1992; Rainboth, 1996; Ministry of Environment, 1998). This assessment is mainly based on the amount of harvested fish, which will be discussed in more detail later on.

The productivity of the ecosystem is generally attributed to two of its particular characteristics: the flood cycle with extensive, long-lasting floods, and the vegetation of the floodplain usually described as flood or flooded forest. Fig. 1.3 provides a simplified model for the productivity of the Tonle Sap ecosystem. The precise mechanism of the productivity is not yet fully understood but high rates of nutrient cycling and the high biodiversity are key factors (T. Hand, personal communication, 1999; Junk and Furch, 1991).

The input of silt-laden water from the Mekong and from the catchment area of the Tonle Sap ecosystem provides an annual addition of silt that is deposited in the floodplain, particularly where floods have been at their deepest, as in Battambang and Siem Reap (Mekong Committee, 1992).

The migration of many fish species between the Tonle Sap ecosystem and the Mekong is extensive and diverse. Regardless of the precise migration patterns that differ for most species, there is an annual mostly passive migration of large numbers of eggs, fry, juvenile and adult fish into the Tonle Sap as the water of the channel begins to flow towards the lake from the Mekong. The monsoon rainfall in the catchment of the ecosystem proper and the rainwater collected in the Mekong cause the rise in water levels and subsequent flooding. Mekong Committee (1992) provides a model for the hydrological systems of the lower Mekong basin which further clarifies the pathways of the water in this stage.

The productivity model (Fig. 1.3) is based on the parameters that are essential for the productivity of the Tonle Sap ecosystem. The **level and duration of the floods** are essential as they determine the area that becomes part of the aquatic phase of the ecosystem and thereby the amount of terrestrial primary products that can contribute to the aquatic productivity.

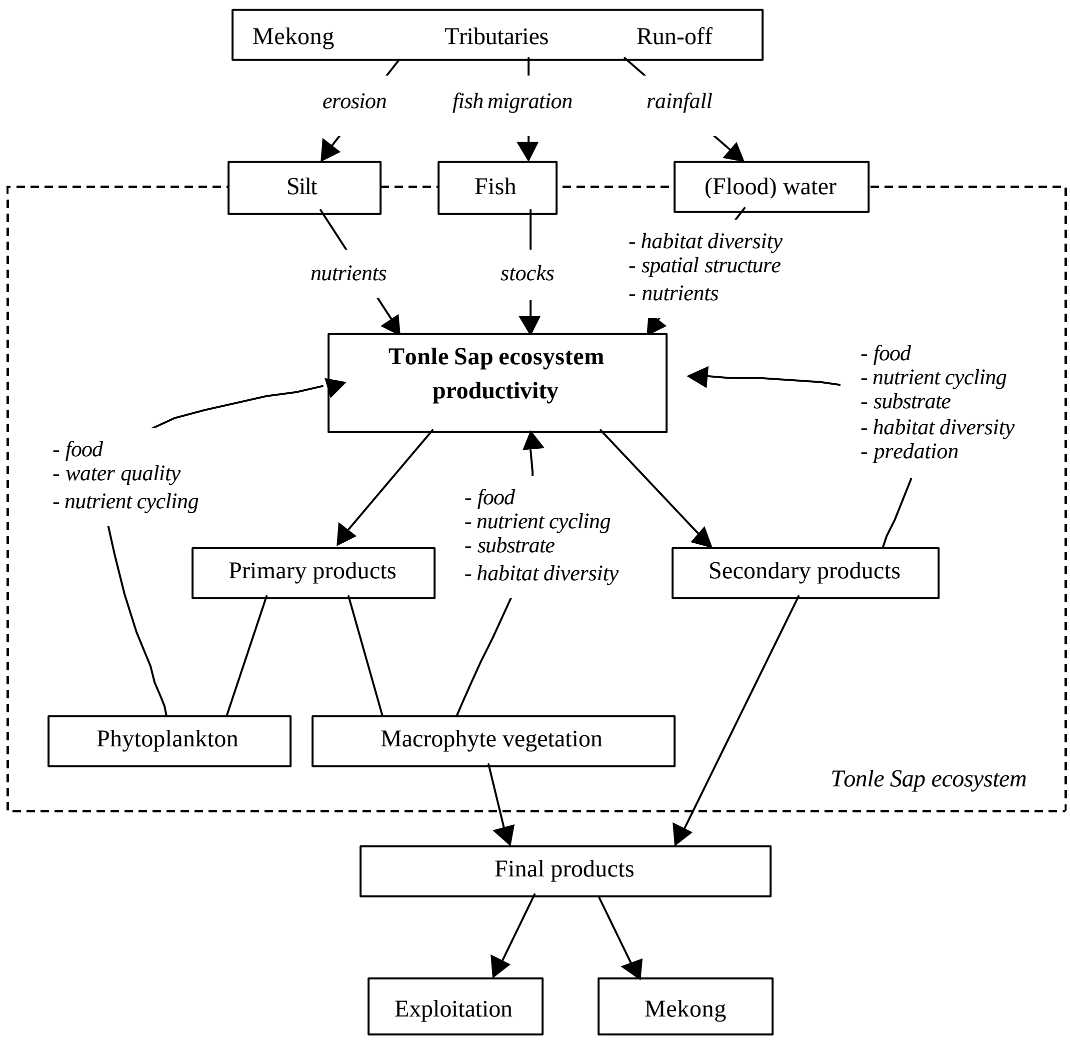

Figure 1.3. Tonle Sap ecosystem productivity model. The dotted line indicates the boundaries of the Tonle Sap ecosystem. Products are considered final as they leave the ecosystem

As substantiated further on in this chapter, the aquatic habitats go through different ecologically significant phases which depend on the duration of flooding. The flooded habitats in the floodplain need time to develop and to perform the role they have in the aquatic production.

The **migration of fish** at different stages of development into the ecosystem at the beginning of the flooding is for many species very important, as it determines the initial stock levels and therefore the potential final production. Migration out of the Tonle Sap ecosystem is essential for many species, e.g. for mere survival away from deteriorating water quality, or for reproduction. Minimum levels of migration of fish in and out of the ecosystem are therefore another essential parameter for its productivity.

With **silt**, a number of **nutrients** enter the production system of the Tonle Sap. It is not known how important this input of nutrients is for productivity. The levels of silt load and subsequent siltation in the Tonle Sap ecosystem are reportedly increasing, reaching levels where the productivity of the lake could be affected (Mekong Committee, 1992). Increased siltation could alter water levels and quality and influence the migration of fish in and out of the ecosystem.

The **flooded macrophyte vegetation** of the floodplain is another essential parameter of the productivity model. The ratio between primary products of the system that originate from phytoplankton and those coming from the macrophyte vegetation is not known. However, aquatic primary productivity is thought to be not as high as is the case in similar tropical lakes (Nguyen and Nguyen, 1991; Boyd, 1990; J. P. Descy, personal communication, 1997). Apart from this energy input, the flooded forest vegetation is important as a spatial structure with multiple functions, particularly that of a substrate, and which defines many different habitat types in the floodplain. The present-day vegetation of the floodplain is becoming more diverse under the impact of human activities but in most cases, this entails a loss of primary products available for the aquatic phase and paradoxically results in a loss of habitat diversity. The ecological functions of the flooded vegetation effectively result in an amplification of the primary productivity by enabling the development of subsequent associated communities of microorganisms, epiphytic algae and their associated communities and so on, all characterised by high turn-over rates of nutrients.

The **high degree of biodiversity** among the fish makes that a maximum of niches are created, making intensive use of the potential of the ecosystem at a maximum time, and that the available resources are used to a high degree.

These are the parameters that determine largely the productivity of the Tonle Sap ecosystem. They are therefore prime points of attention and concern for the management and conservation of the system and the livelihood of the people who are dependent on its rich production.

ii. Natural resource use in the Tonle Sap ecosystem

All elements of the Tonle Sap ecosystem that can be exploited with the mostly low-tech means locally available are being exploited. Most of the collection activities are labour-intensive. Harvesting of products from the ecosystem for subsistence use or for local trade at community or village level is done for nearly all the products; the more valuable items are also exploited on a larger scale, and some even in very large, labour and capital-intensive operations.

The natural floodplain vegetation is used for the collection of a variety of wood and non- wood forest products. This exploitation has been going on to the extent that in large parts of the floodplain the original trees have almost all disappeared and only pruned or regenerated morphs remain. The level of degradation appears to be linked with the accessibility of the area (McDonald and Veasna, 1996). In many places, the original vegetation is entirely cleared.

Wood is collected from the flooded forest for a wide variety of purposes: for domestic use as fuel wood or as charcoal, as construction material, for use in brick kilns, for fish processing (smoking and drying), for the construction of fishing gear, for use as artificial shelter for fish and shrimp in order to facilitate their capture (so-called brush parks), etc.

The flooded forest is also a rich source of non-wood forest products. These include a wide range of plants used as food and for medicinal purposes for man and husbanded animals. Lianas are collected for furniture and fishing gear production. Other plant products include fruits, seeds, resins, tubers, bark and mushrooms. Forest animals and their products that are collected include beeswax and honey, while some larger animals are collected for use as pets (macaques, iguanas, birds) or trade but they often end up as food.

Aquatic plants are collected for human consumption, as feed for farmed animals (pigs, fish) or for further cultivation, as is the case with lotus. Dried water hyacinth (*Eichchornia crassipes*) is sometimes used as fuel, especially in villages where after the recession of the floodwaters, large amounts of the dry plants have accumulated under the houses and create at the same time a considerable fire hazard.

Most macroscopic aquatic animals are used by humans. Several aquatic insects (mainly coleoptera) are collected for consumption. Shrimps are caught and molluscs (mainly snails) collected for food. Frogs are collected from the wild to be further raised in pens for the local food market. All reptiles are sought after. Snakes are hunted for consumption of body parts or for trade, alive or for their skins. Tortoises are collected for exquisite food and for the trade in tortoiseshell. Birds are hunted for food, for use as pets and for trade. Eggs and chicks are collected for consumption, especially in the floating villages where they are one of the few local sources of animal protein other than fish. Suntra (1995) mentions kingfisher feathers as one of the main non-wood forest products during the height of the Angkor era. The largest volume of products of the Tonle Sap ecosystem is fish. Fish are harvested in many ways. They are either consumed directly as such, or processed for added value (smoking) or for preservation (drying, smoking, *prahoc* and fish sauce production). Certain species are traded, some of them alive. Fish, mostly juvenile specimens, collected from the wild form the majority of seed for local aquaculture in the Tonle Sap, mostly in large floating cages and pens. Considerable volumes of the fish harvested are used as a cheap feed source for husbanded animals (crocodiles, pigs, fish).

The water of the Tonle Sap ecosystem forms per se one of the important natural resources. Floodwater is retained in the floodplain for irrigation and for cultivation of flood-recession rice. The rising water levels in the tributaries and in some places the reversed currents are used for irrigation. The Tonle Sap lake and channel form one of the important transportation ways between the centre of the country and the northwest. Thousands of tourists travel between Siem Reap and Phnom Penh each month and large quantities of freight and passengers are transported. A variety of

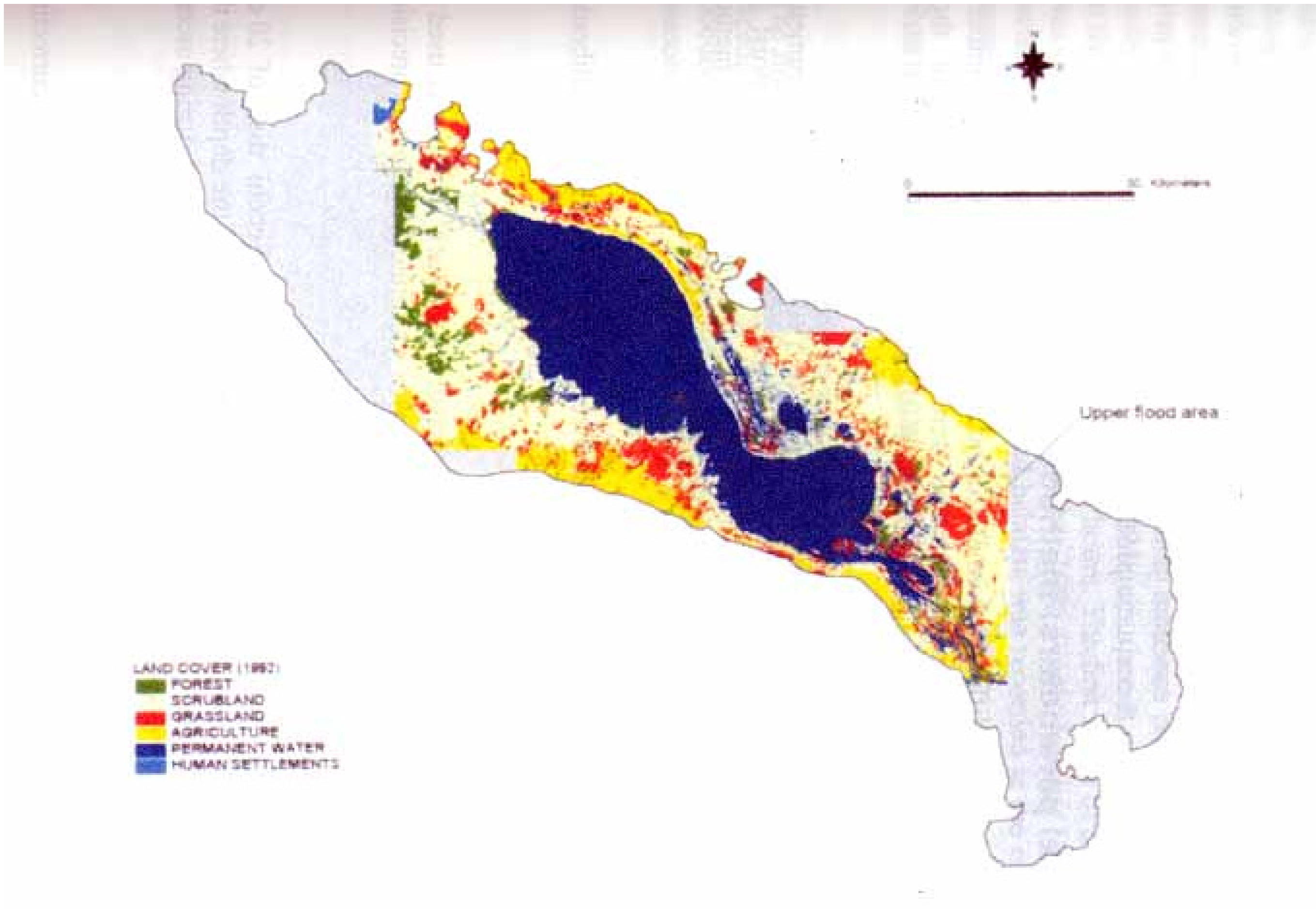

Figure 1.4. Land cover of part of the floodplain of the Tonle Sap lake, 1992

vessels are used for these purposes, and they all have in common to be causing high levels of noise pollution, possibly impacting on (migrating) fish. The water of the lake also provides a living ground for floating villages.

Part of the land in the floodplain is used for agriculture. For this purpose, the original vegetation is removed, usually with the use of fire. Agriculture activities range from herding of cattle, pigs or ducks to the growing of corn and other cash crops like tobacco, watermelon and mung bean. Rice and a variety of vegetables are grown in the floodplain and on the riverbanks after the water has receded. Based on the model presented here, it can be expected that most types of agriculture practised in the floodplain tend to reduce the aquatic productivity of the lake.

Limnological parameters: methods

In order to describe the different habitats of the Tonle Sap ecosystem, a number of basic physico-chemical water parameters were measured, in particular those parameters that have a determining importance in sustaining aquatic life.

- *Dissolved oxygen*

Dissolved oxygen levels were measured using a Yellow Springs Instrument® electronic dissolved oxygen meter. The probe was calibrated against moist air, calibration that had proved satisfactory by comparing it with the Winkler method. Saturation levels were calculated using the reference tables in Boyd (1990).

- *pH*

The pH of samples was measured using an electronic pH meter after calibration against a neutral and an acid buffer.

- *Temperature*

The temperature sensor in the probe of the dissolved oxygen meter was used to measure the temperature of the samples. This was calibrated against a precision mercury thermometer.

- *Secchi depth*

The Secchi depth was measured by lowering a weighted Secchi disk of 20 cm diameter. The Secchi disk depth was calculated as the average of the depth where the disk disappeared during descent and the depth at which it reappeared during ascent. The rope it was attached to was marked with 10 cm intervals.

- *Specific conductivity*

Specific conductivity was measured using an electronic conductivity meter, correcting automatically the measured effective conductivity for that at 25°C.

Water samples were collected using a horizontal Van Dorn bottle of 2.5 litres at regular depth intervals of 1 metre, starting from just below the water surface to, as conditions would allow, near the bottom. The water quality parameters were measured from samples immediately after collection.

The sampling procedure outlined in the introduction was followed for the collection of data to assess seasonal variations in water quality. In addition, another sampling and data collection procedure was followed to determine diurnal fluctuations or patterns.

For the former, sampling and data collection were done, where and when possible, at monthly intervals, together with experimental gillnet fishing. This was repeated for three or four positions per sampling site, coinciding with the number and location of the gillnets. For the diurnal sampling, at two dates, dissolved oxygen concentrations, pH, temperature and specific conductivity of the water in the different habitats were recorded according to depth three times a day. Measurements were made at regular one-metre depth intervals from the surface to near the bottom. The first data were collected at sunrise, between 0500 and 0600 hours, then at noon and the final ones late in the afternoon, between 1700 and 1800 hours. The first series of diurnal change data was collected for all habitats late December 1996 / early January 1997, and a second series of only the permanently flooded habitats was recorded at the end of May 1997, towards the end of the dry season.

Results of the limnological sampling

i. Diurnal changes in water quality

The first data were collected for all the habitats at the time when flood levels begin to recede, at the beginning of January 1997. A second series, only of the permanently flooded habitats, was recorded at the end of May 1997, towards the end of the dry season.

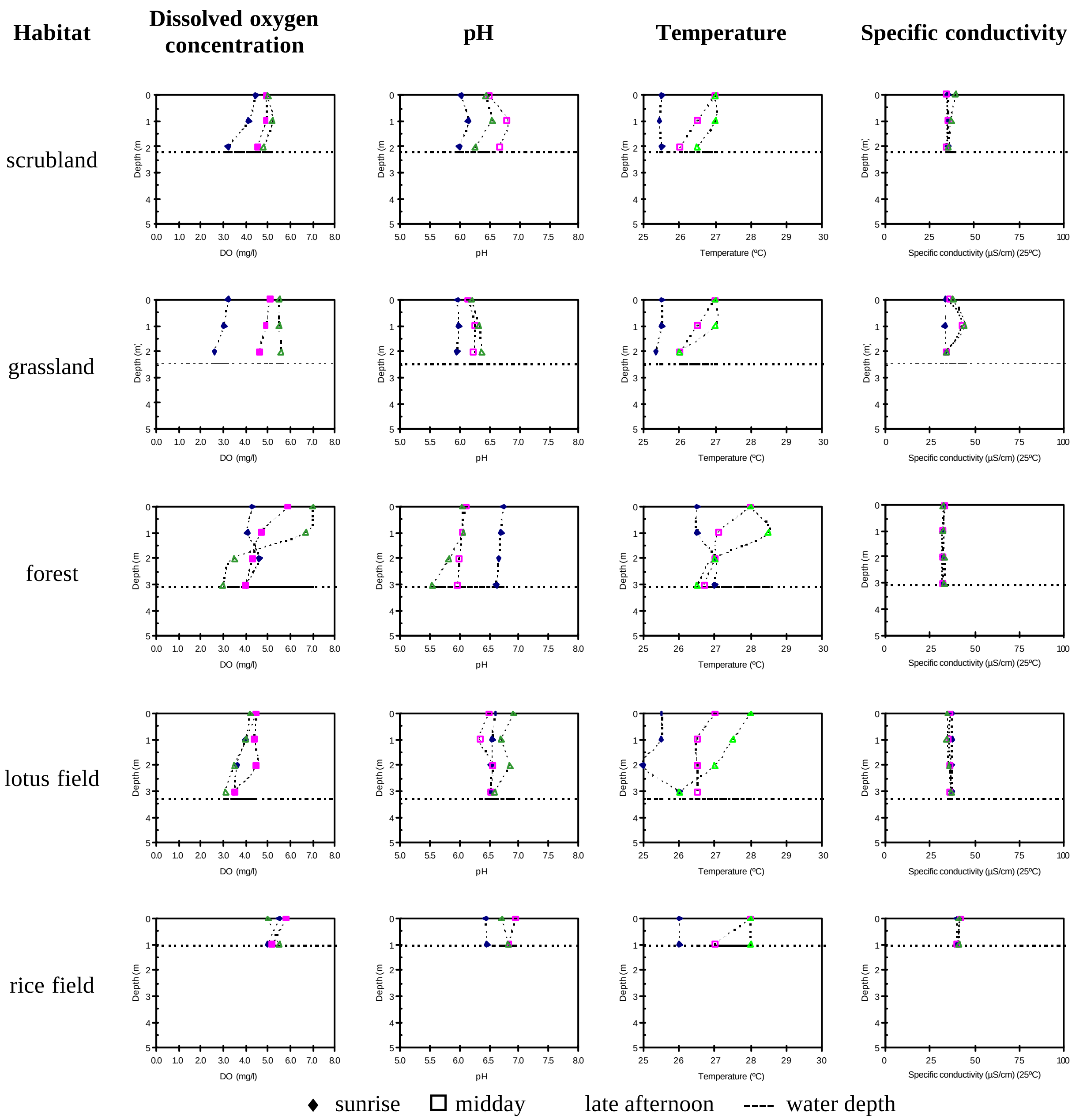

Figure 1.5. Diurnal change of dissolved oxygen concentrations, pH, temperature and specific conductivity at different depths for the *temporarily aquatic habitats* of the floodplain. (The dotted horizontal lines indicate maximum water depth at the time of sampling. Data recorded between 30 December 1996 and 10 January 1997, at the *beginning of flood recession*).

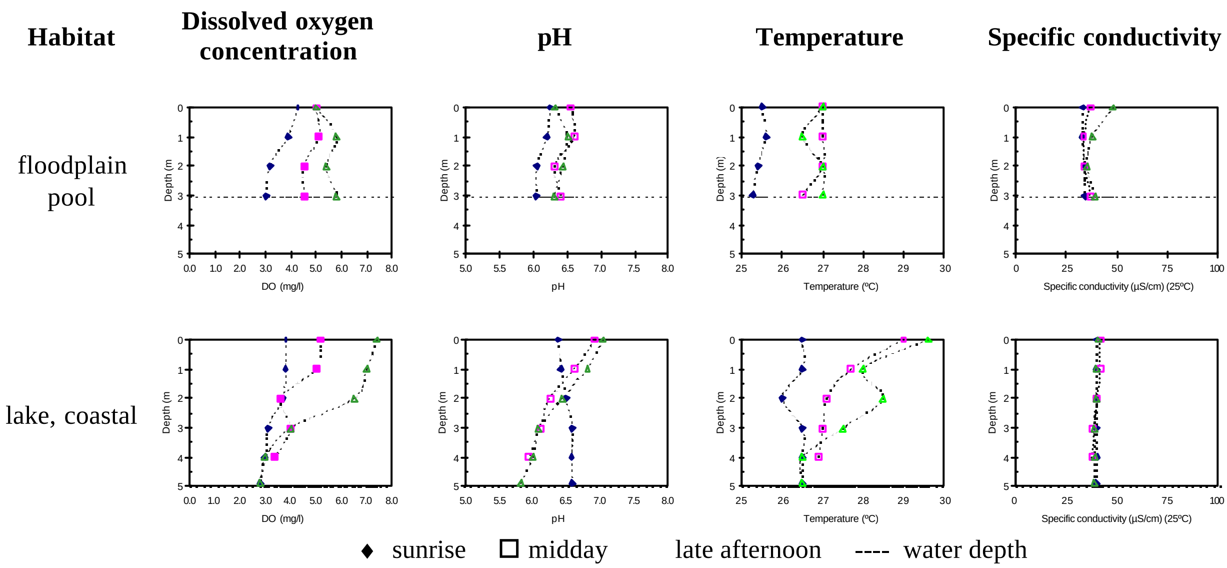

Figure 1.6. Diurnal change of dissolved oxygen concentrations, pH, temperature and specific conductivity at different depths for the *permanently aquatic habitats.* (The dotted horizontal lines indicate maximum water depth at the time of sampling. Data recorded between 30 December 1996 and 10 January 1997, at the *beginning of flood recession*).

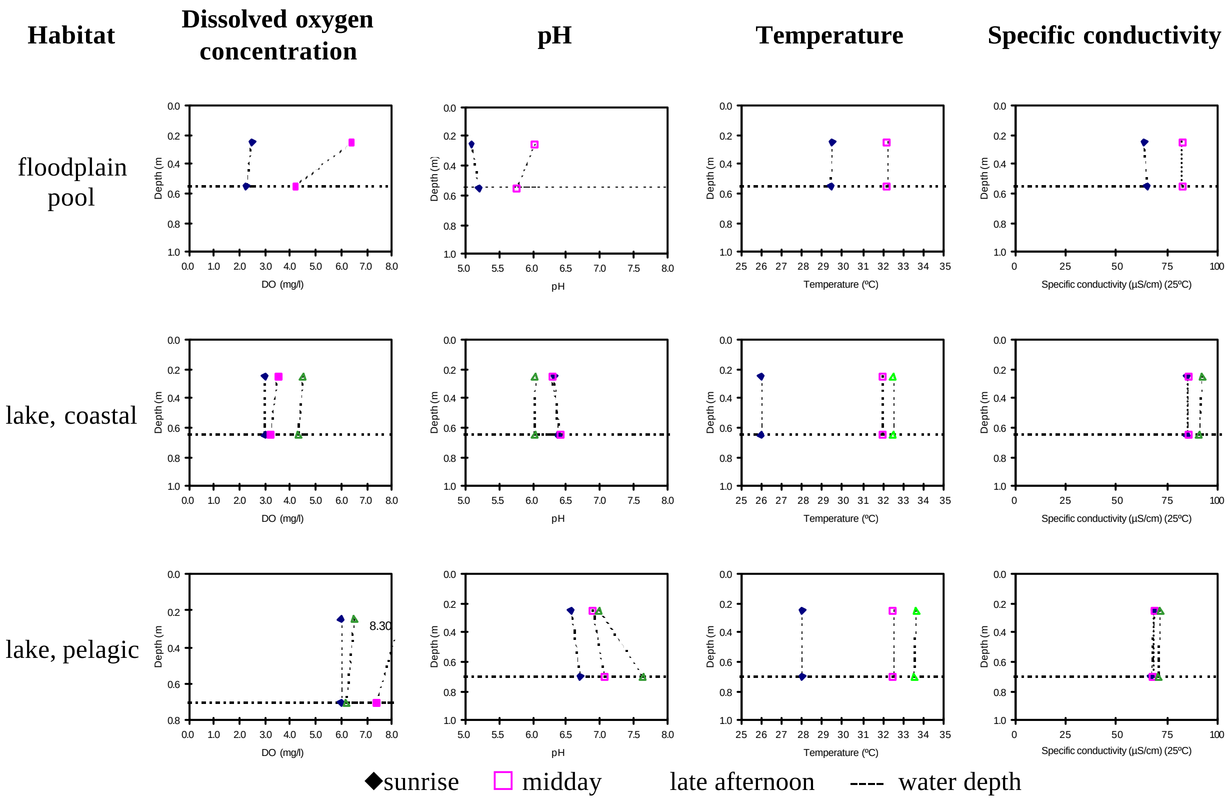

Figure 1.7. Diurnal change of dissolved oxygen concentrations, pH, temperature and specific conductivity at different depths for the permanently aquatic habitats. (The dotted horizontal lines indicate maximum water depth at the time of sampling. Data recorded between 28 May and 2 June 1997, at the *end of the dry season*)

The levels of dissolved oxygen in the samples show an increase during the day, more pronounced in the surface layers of deeper waters, and return to rather homogenous conditions at lower levels throughout the water column in the morning. The levels vary between 1.60 and 8.30 $mg.l^{-1}$, which corresponds at the given temperatures to saturation levels of 20 percent and 115 percent respectively. The variation throughout the day can be as large as 5 $mg.l^{-1}$, which is also the highest difference found at a given time between the dissolved oxygen concentrations throughout the water column. In two habitats (forest and coastal area of the lake), there is a clear diurnal stratification in the dissolved oxygen contents of the water. In the dry season, the floodplain pool shows a strong gradient between the surface and the water near the bottom.

The general pattern of diurnal thermal variation is one of isothermal conditions throughout the water column at dawn, in some cases with a slightly cooler surface region. During the day a temperature gradient builds up, which leads to higher, isothermal conditions in the late afternoon, or to pronounced thermal stratification in places with deeper water. The temperature differences between the surface layer and deeper water are limited, and are less than 4°C at any time in all habitats. The maximum temperatures reached in the shallow habitats at the end of the dry season are considerably higher than those of January. The temperature of water below 3.5 m of depth does not vary much at all. The maximum water temperatures recorded in December-January and May-June were 29.6°C and 33.6°C respectively, the lowest 25.0°C and 26.0°C.

All water samples analysed are neutral to slightly acid. The pH varies usually within half a unit throughout the day. This variation is higher for the two lake habitats (forest and coastal lake), which are also the habitats where the diurnal variation does not occur homogeneously throughout the water column but where there is a considerable drop in pH at larger depths towards the end of the daylight period. The pH reaches more extreme values (between 4.87 and 7.63) in the shallow habitats of the dry season than during high-water time (between 5.55 and 7.04).

Table 1.1. Secchi depths and total water depths for the habitats in December 1996 / January 1997. (Secchi disk readings done at midday).

Habitat	Secchi depth (m)	Total depth (m)
scrubland	1.20	2.30
grassland	1.35	2.60
floodplain pool	1.25	3.10
lotus field	1.10	3.30
rice field	0.70	1.10
forest	0.80	3.00
lake, coastal	0.90	4.10

Throughout the day as between the different depths, there is little or no variation at all in the specific conductivity of the samples. Values are higher for the habitats in the dry season, varying between 52 and 92 $\mu S.cm^{-1}$; December-January samples show values between 32 and 48 $\mu S.cm^{-1}$.

ii. Seasonal changes in water quality

The results of the sampling and data recording for water quality for all eight studied habitat types are presented in the figures below (Fig. 1.9-1.16). All samples were taken around 0530 hours at sunrise. When no values are presented, it means that data are not available. The values shown in the graphs are the averages for three to five measurements that were made at each site for each date and depth. Fig. 1.8 shows as an example the average dissolved oxygen concentrations for the permanent water and the pelagic lake in August 1997 with their standard deviation. This source of variation has been analysed for all data, and, as in case of the example, is in most cases small or nil.

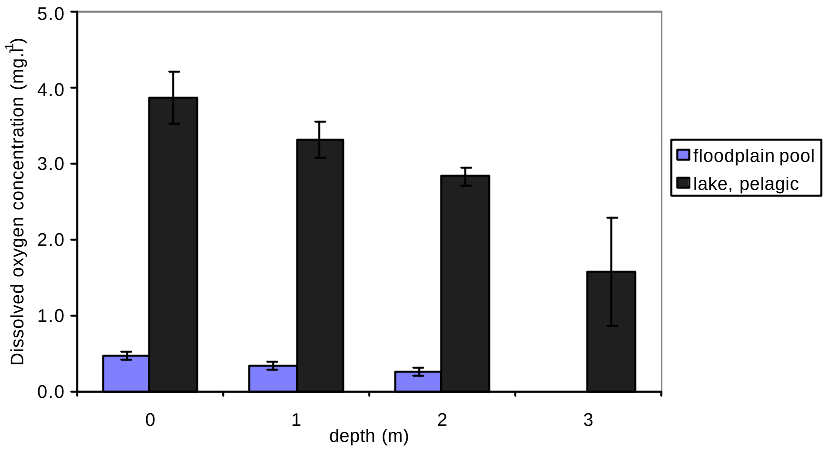

Figure 1.8 Dissolved oxygen concentrations for two habitats. Repetitions as a source of variation. The error bars indicate the standard deviation

Dissolved oxygen concentrations vary between 0.20 and 7.00 $mg.l^{-1}$, corresponding at relevant temperatures with 3 percent and 94 percent saturation respectively. All cases in which surface levels of dissolved oxygen of less than 1 $mg.l^{-1}$ were recorded occurred in August at the onset of the flooding. All but three of the 161 samples from any depth that had oxygen concentrations of less than 1 $mg.l^{-1}$ were collected in August. All samples with oxygen concentrations of more than 5.5 $mg.l^{-1}$ were collected in the three permanently aquatic habitats (floodplain pool, coastal and pelagic areas of the lake). Whereas oxygen levels tend to go down towards the end of the dry season in both areas of the lake, the opposite is true in the floodplain pool. When the pool gets flooded with lake water in August, there is a sharp drop in dissolved oxygen levels.

Except for the strong variations in August, the pH levels follow roughly the same pattern as do the concentrations of dissolved oxygen. The extreme values measured were 4.65 and 7.90. The largest difference in pH recorded at any given time between depths in one habitat was 3.07, in the floodplain pool; the smallest (0.76) was found in the rice field. The pH is usually homogenous throughout the water column, except in cases where there is a pronounced gradient or stratification in the dissolved oxygen concentration.

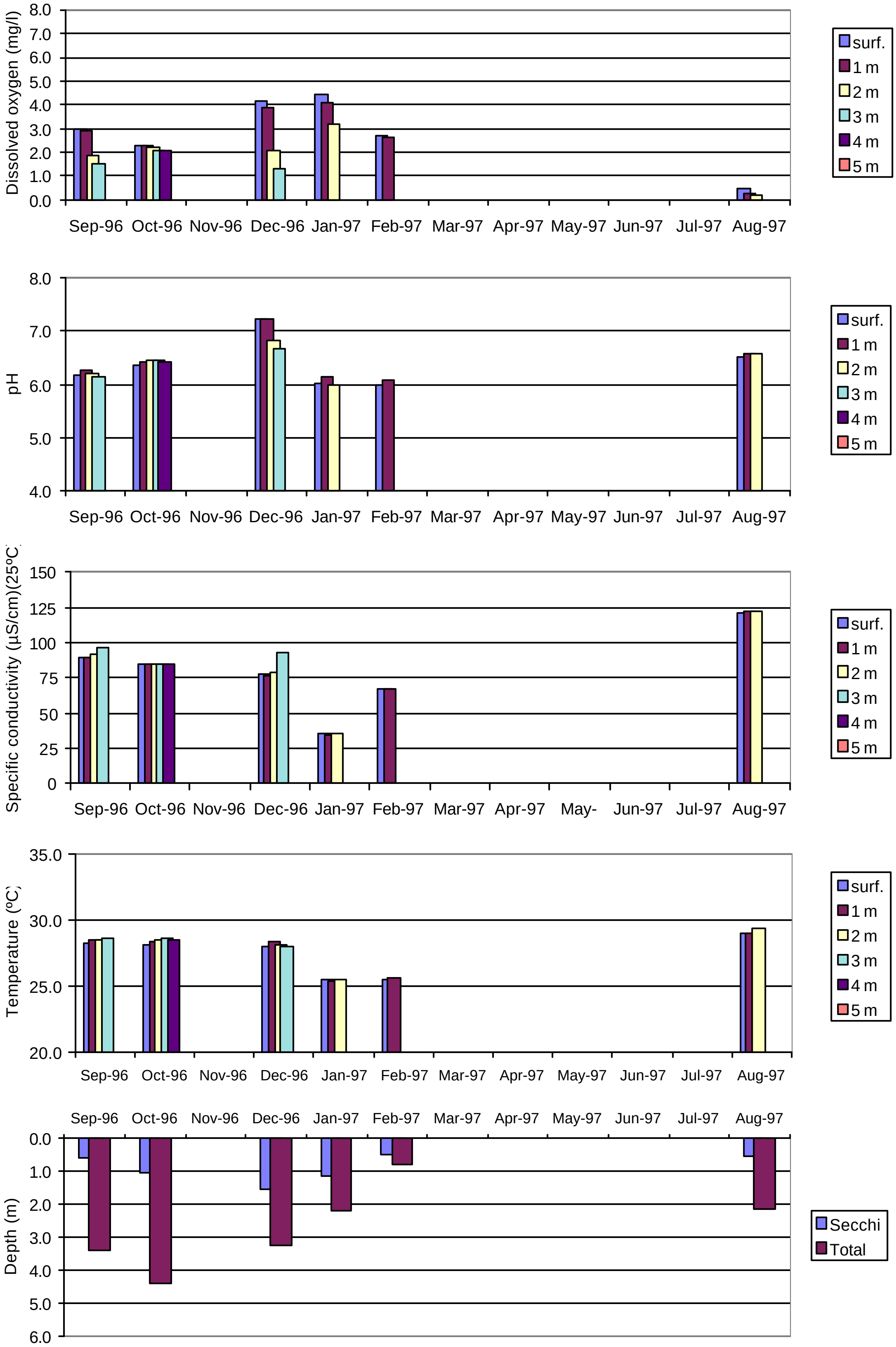

Figure 1.9 Seasonal variations of water quality for the **scrubland** habitat

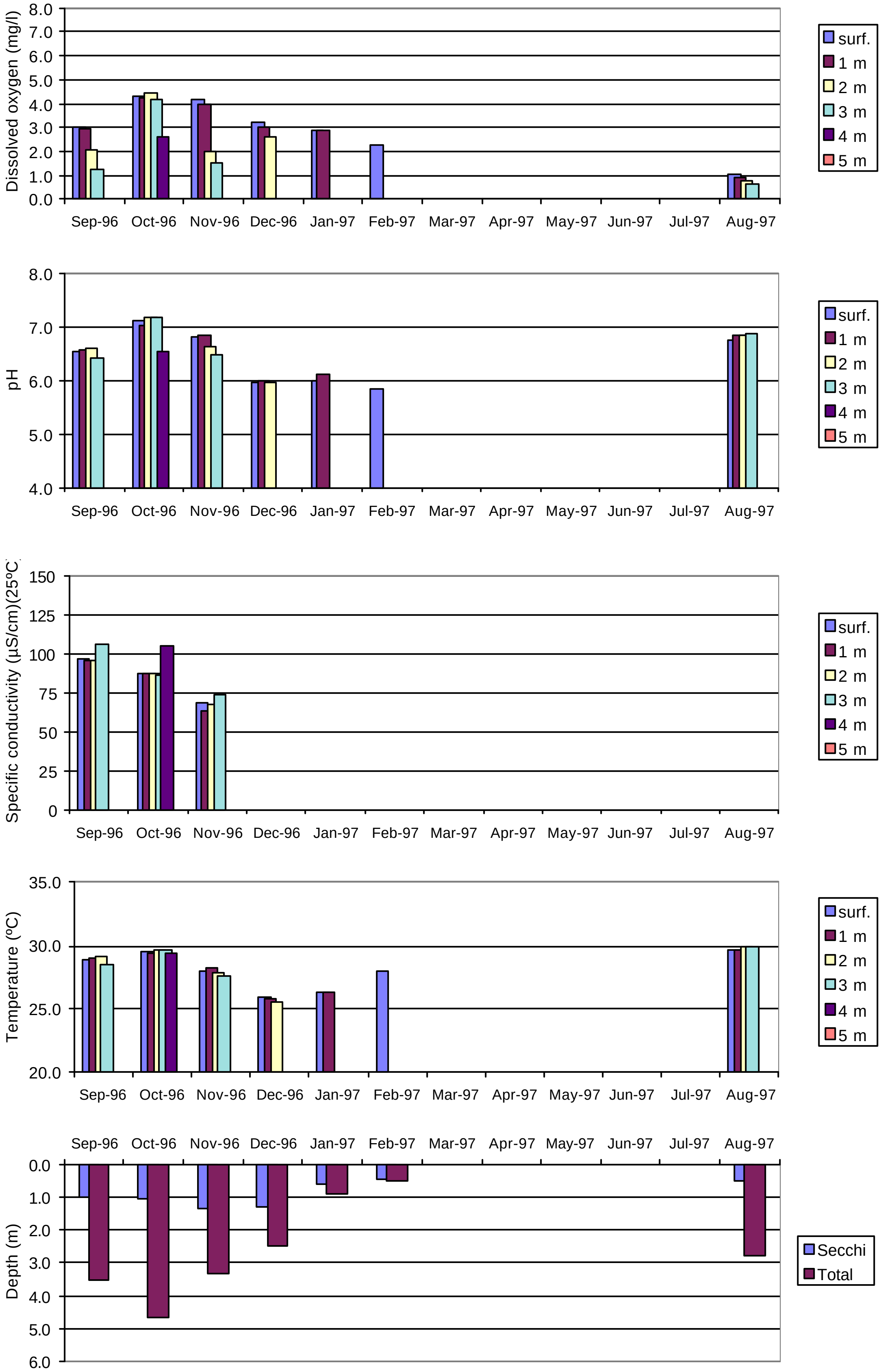

Figure 1.10 Seasonal variations of water quality for the **grassland** habitat

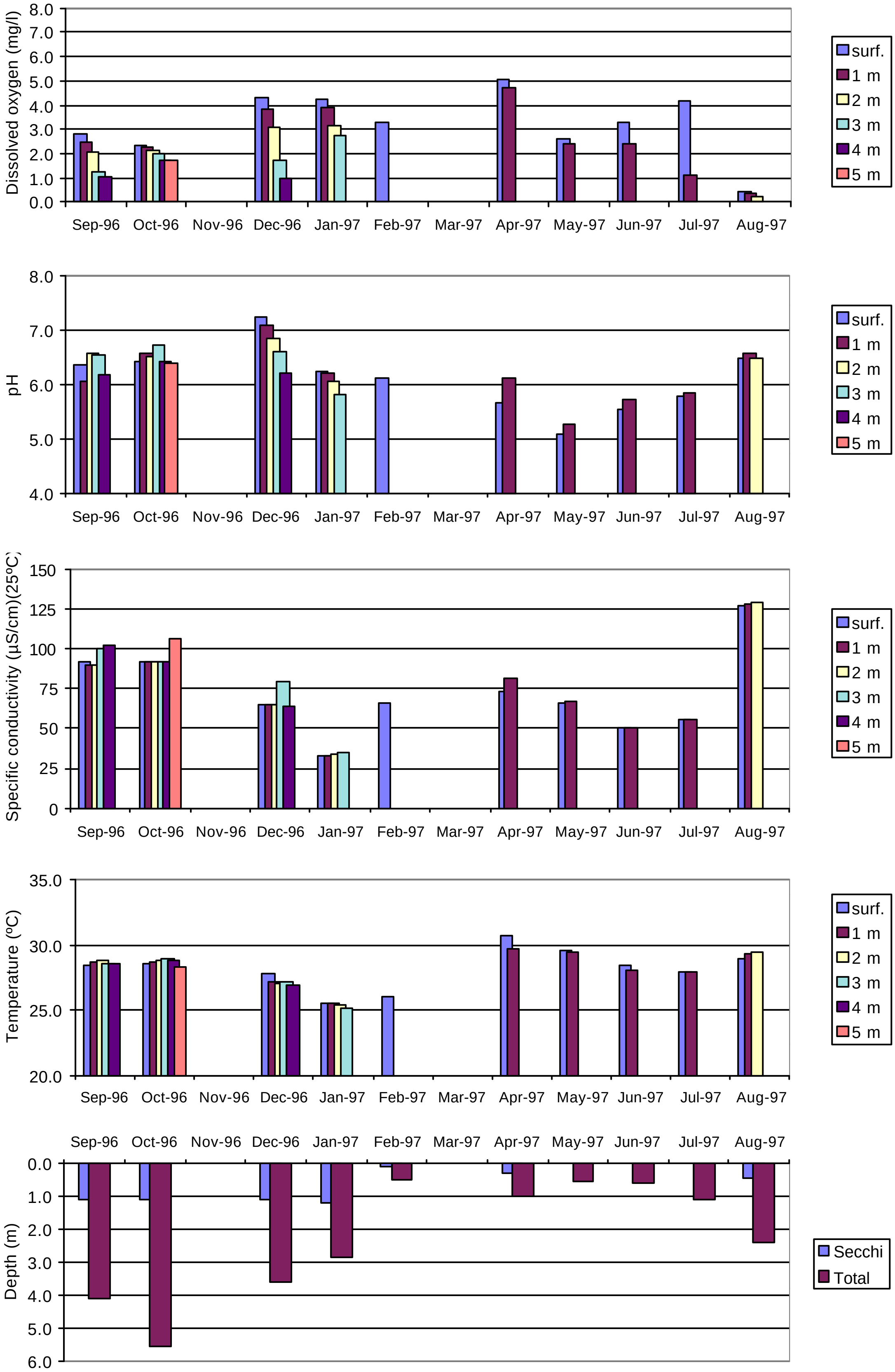

Figure 1.11 Seasonal variations of water quality for the **floodplain pool** habitat

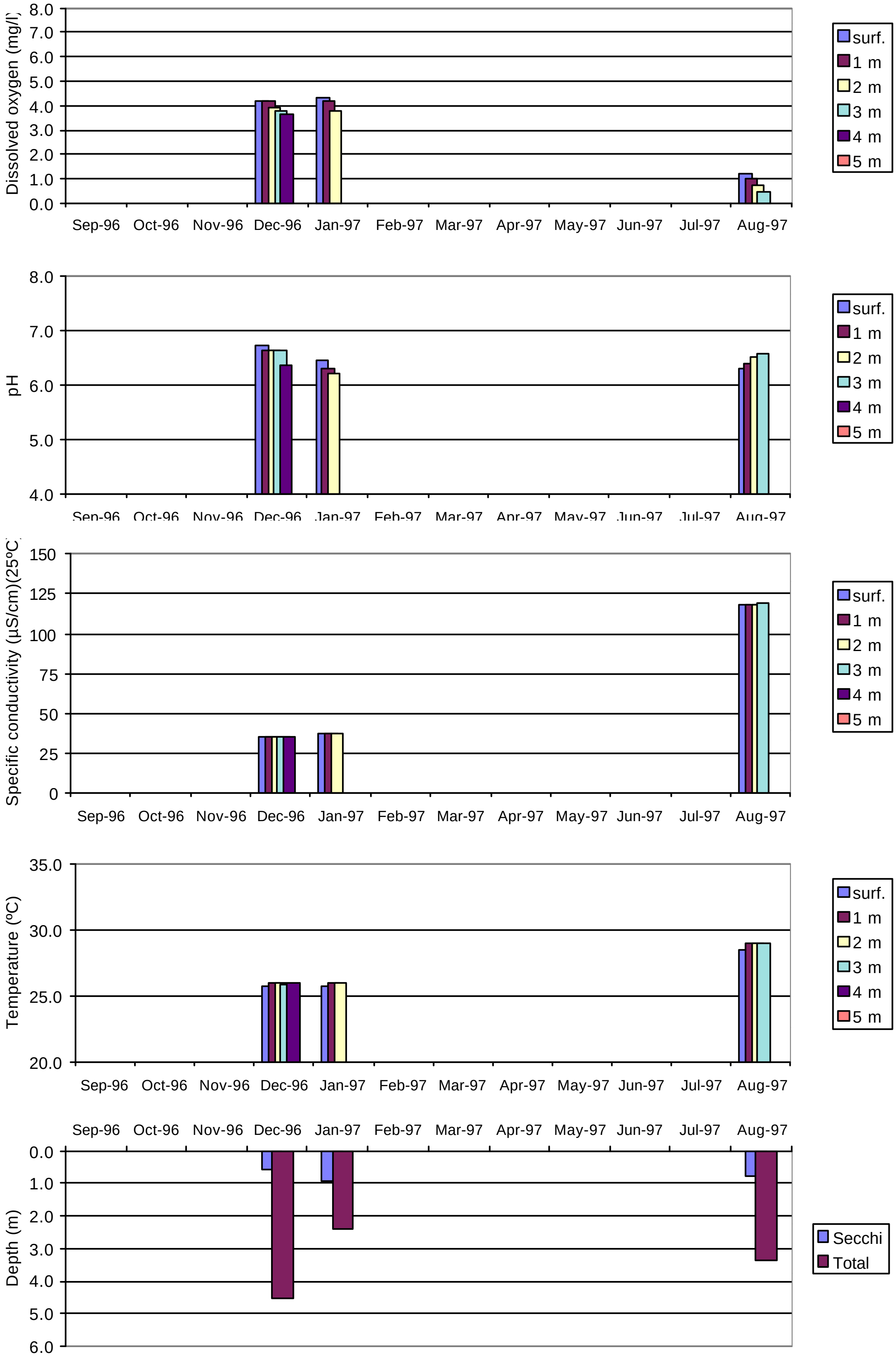

Figure 1.12 Seasonal variations of water quality for the **lotus field** habitat

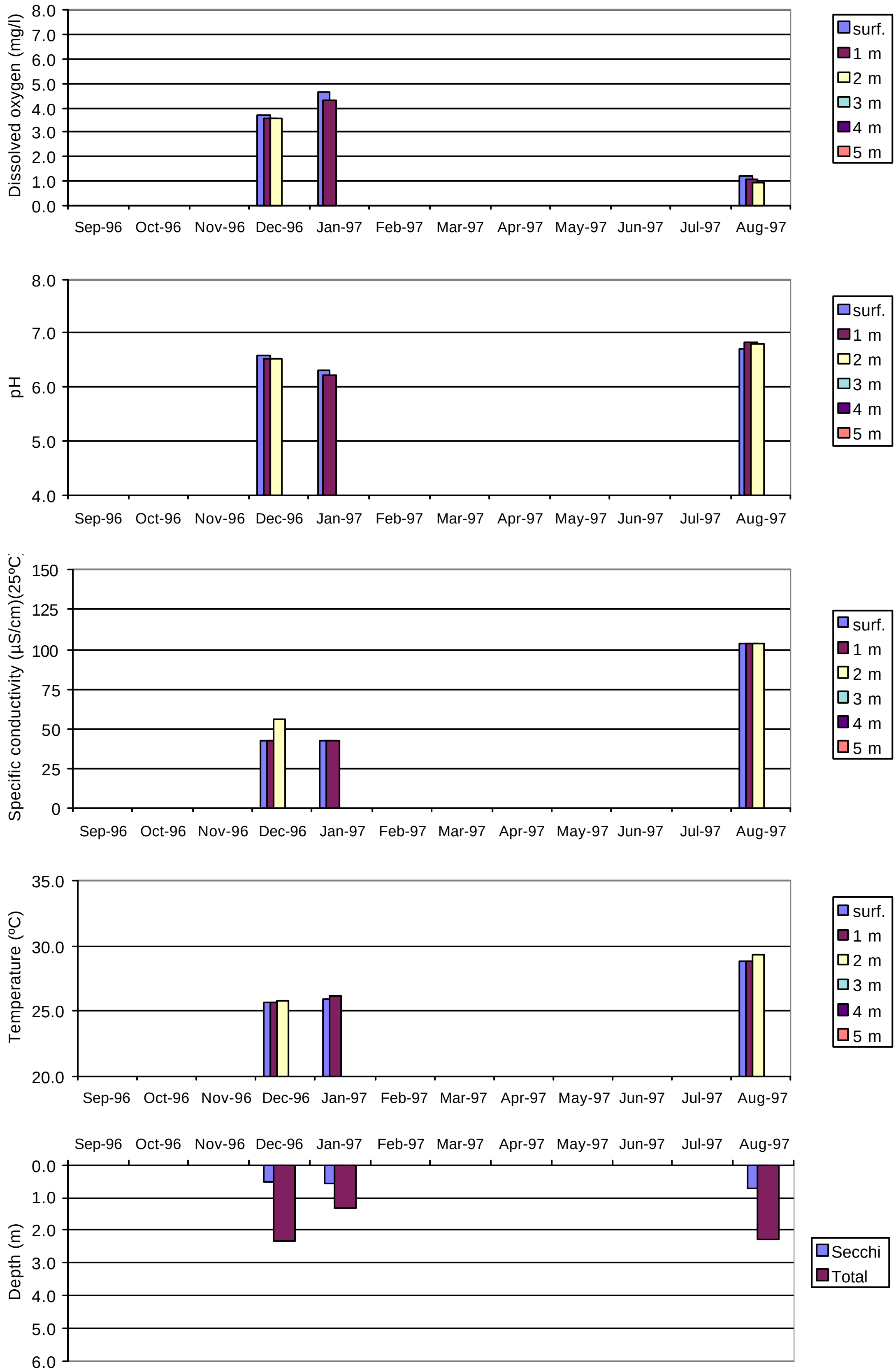

Figure 1.13 Seasonal variations of water quality for the **rice field** habitat

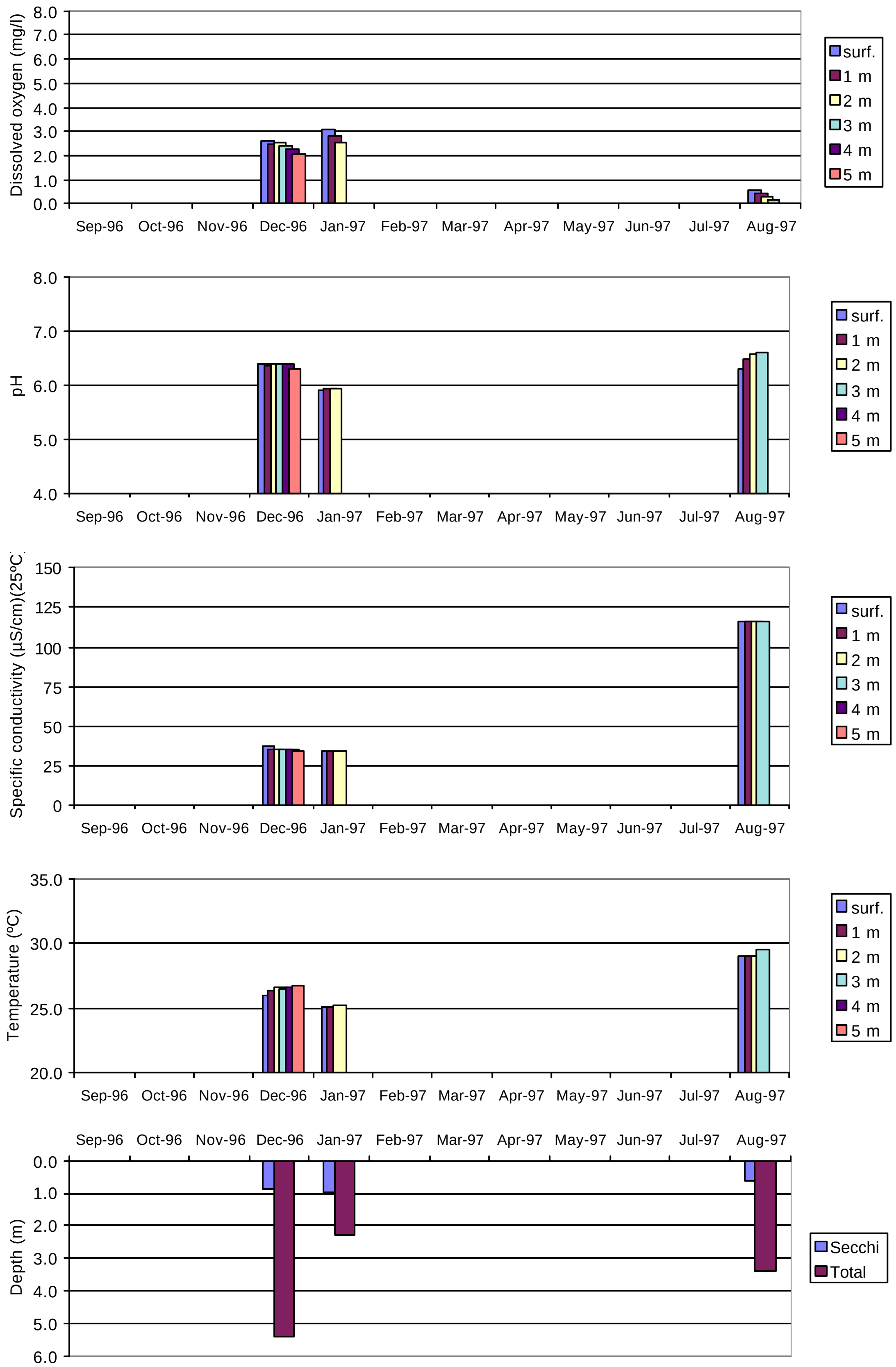

Figure 1.14 Seasonal variations of water quality for the **forest** habitat

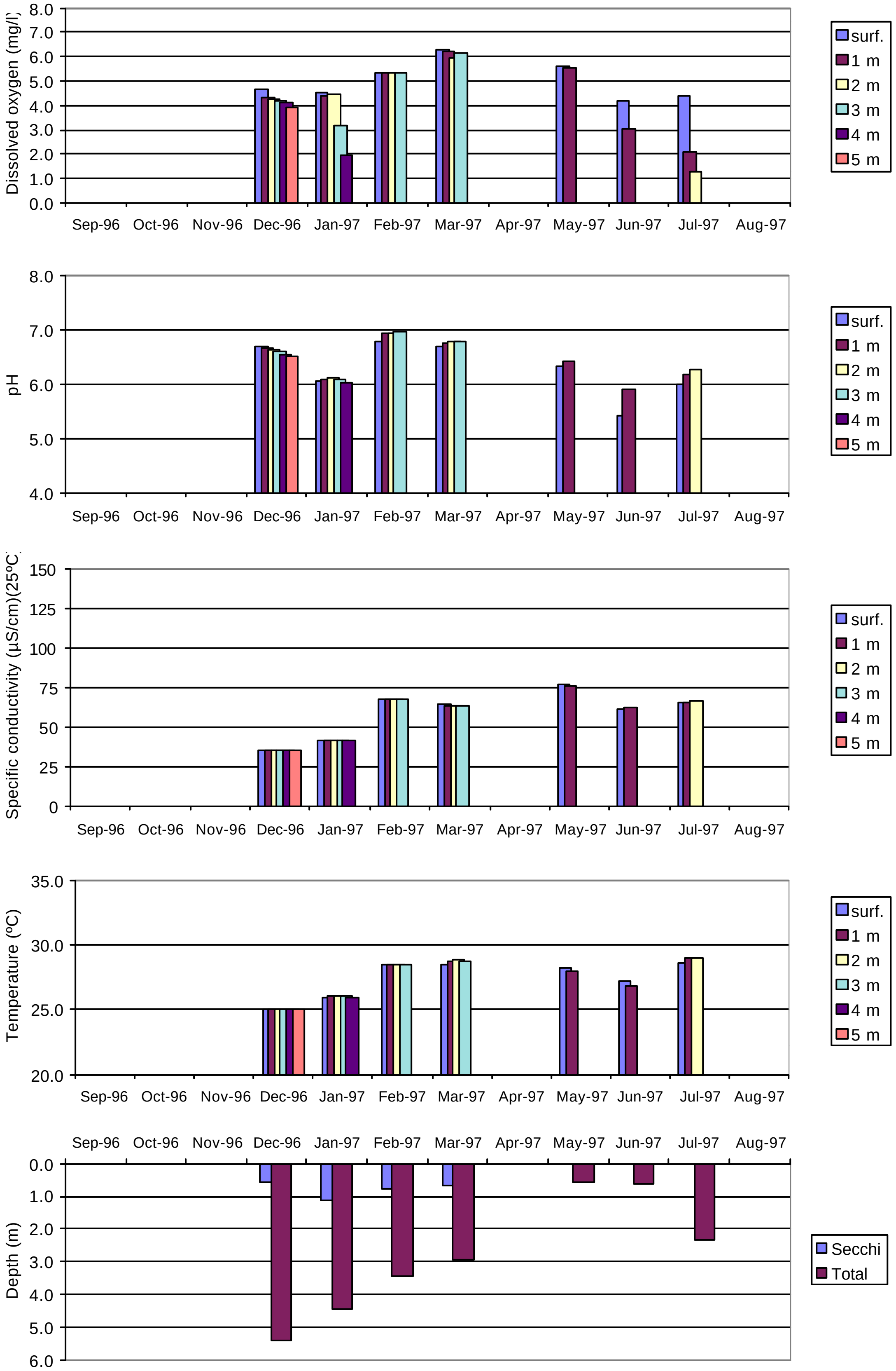

Figure 1.15 Seasonal variations of water quality for the **coastal lake** habitat

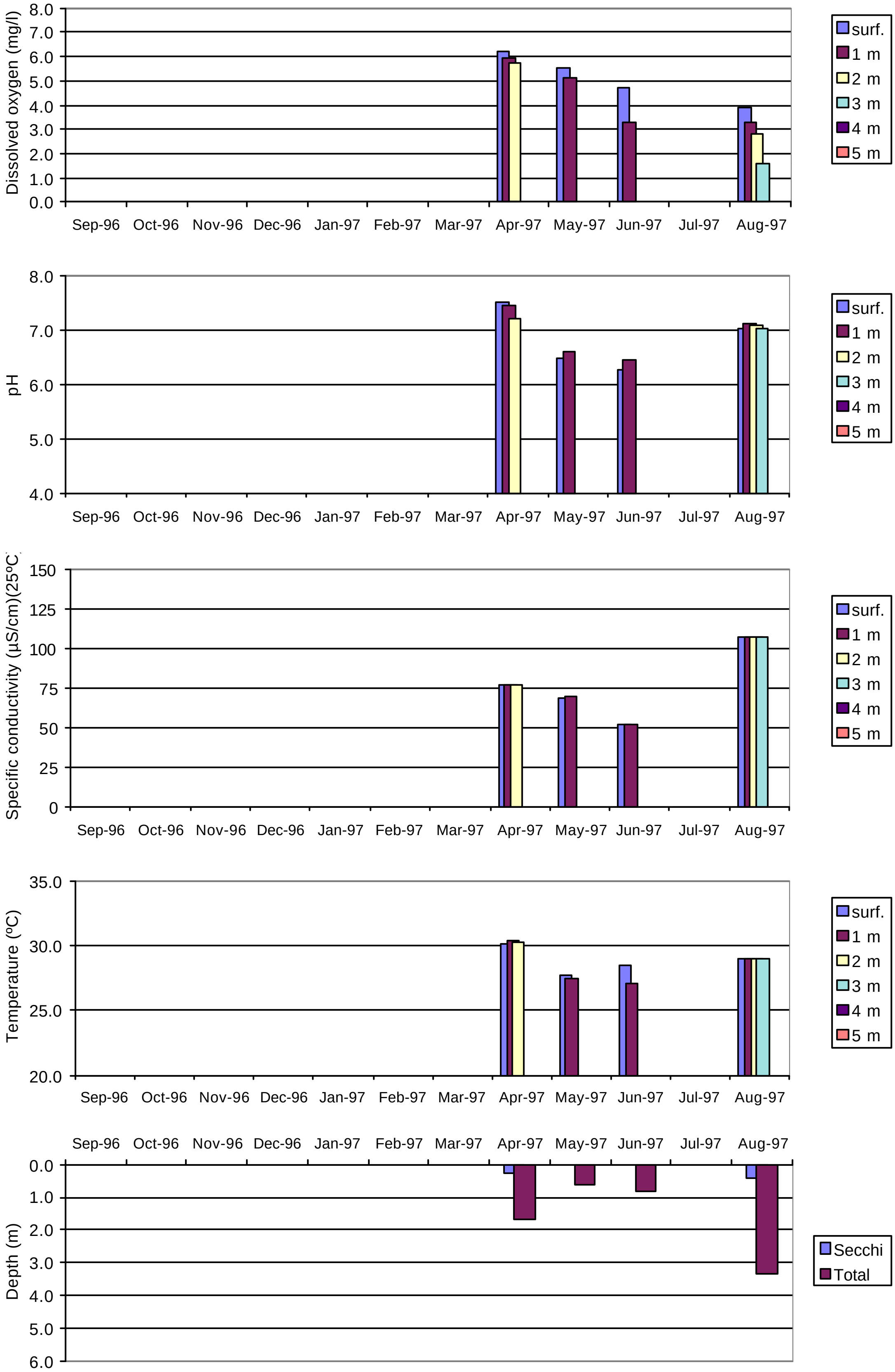

Figure 1.16 Seasonal variations of water quality for the **pelagic lake** habitat

There are two peaks in the temperature of the water. The first one coincides with the warm-season months of April and May, the second one with the onset of the flooding in July-August. Except for the floodplain pool and the pelagic lake where the highest temperature is reached in April, maximum water temperatures occur in July and August for all other habitats. The temperature range recorded for all samples is from 25.0°C to 32.0°C. The highest variation throughout the year within any given habitat is 7.0°C (floodplain pool), the smallest 1.5°C, in the rice field. The temperature is almost always homogenous throughout the water column at dawn, the time when the samples were taken.

The specific conductivity (25°C) for all samples varies between 32.0 and 132.2 µS.cm^{-1}. The largest variation throughout the year was registered in the floodplain pool with a difference of 100 µS.cm^{-1}, the smallest variation (50.9 µS.cm^{-1}) was found in the coastal areas of the lake. However, for this habitat, the data for August 1997 are not available; they were probably considerably higher than those recorded in July, as is the case with all other habitats. Like for temperature, there are two peaks in specific conductivity throughout the year. In Fig. 1.17, the data of all the specific conductivity measurements of all habitats and depths are plotted in function of the time.

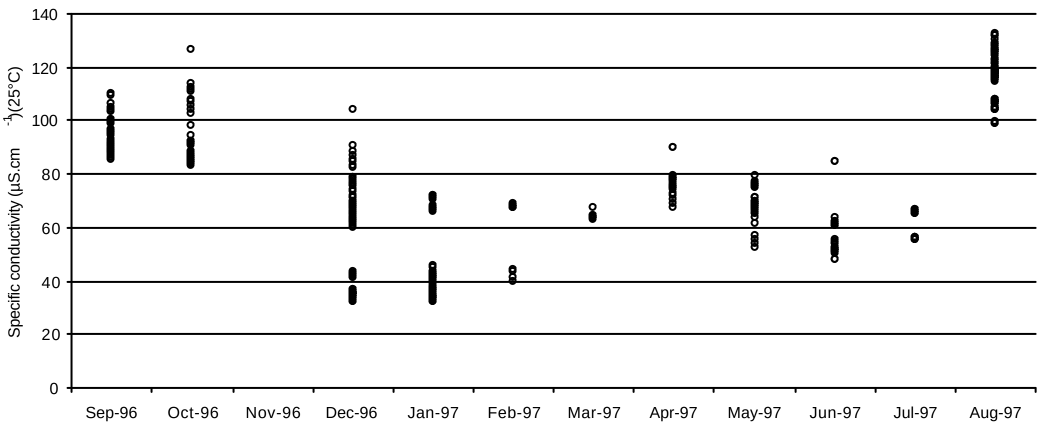

Figure 1.17 Specific conductivity (µS.cm^{-1}) at 25°C. Results of all samples from all habitats combined

The Secchi depth in the shallow murky waters of the dry-season habitats was only a couple of centimetres and could therefore not be accurately measured in these conditions. The maximum Secchi depth measured is 1.55 m (Table 1.1).

Discussion: floodplain habitats ecology

The results of the limnological sampling show the variation and dynamic character of the parameters that characterize the different habitats. The annually recurring event of flooding creates a very large, dynamic inter-phase between the water and the solid fractions of the ecosystem. The quality of the water of the lake and the floodplain is determined by the processes in the inter-phase and consequently varies considerably, reaching extreme values in transition situations. Water quality is one of the most directly determining factors for the temporal and spatial distribution of aquatic organisms in general, and for fish in particular.

i. Diurnal changes and patterns

The diurnal sampling demonstrates the influence of the water level on water quality of the different habitats. Places with high water levels show a temperature-driven diurnal stratification like the one that is typical for shallow tropical lakes. Dissolved oxygen and pH levels vary during the day in a way suggesting that photosynthetic activity plays an important part. Where the water depth is not high, the diurnal variation is not sufficient for clear strata to be formed but there are pronounced gradients throughout the water column. In the shallowest habitats, the changes in water quality occur in a homogenous manner throughout the water column. Regardless of the water level, conditions are homogenous in all floodplain habitats at the end of the night. From the limited number of data, it appears that the stratification in the lake itself does not last but is diurnal as well, at least in the volume of water at the time of the sampling (January). The sampling did not take into consideration gradients that might exist between the very edge of the flood zone and the cooler water offshore. Temperature stratification is likely to occur in any of the habitat types, provided that the water depth is sufficient.

The diurnal variations in water quality parameters are larger, and the extreme values more pronounced in the dry season than during the high-water period. Temperatures below 3.5 m do not appear to be affected by the diurnal changes higher up in the water column. This is the normal situation for stratification due to surface heating (Welcomme, 1985). The subsequent mixing is likely mainly due to density differences and wind action. This diurnal cycle has an effect on the availability of nutrients. These may be recycled at high rates due to the high temperature, and are redistributed daily over the entire water column. In such conditions, nutrient limitation of planktonic production is unlikely (Boyd, 1990).

The mineral content, as approached by pH and specific conductivity, does not vary much throughout the day. Nevertheless there is a significant change of specific conductivity between samples from the floodwater recession period (December-January) and the samples taken at the end of the dry season (May-June). The first period corresponds to a low mineral content, with specific conductivity (25°C) as low as 32 $\mu S.cm^{-1}$, and the second one to higher dissolved solids levels with specific conductivity up to 92 $\mu S.cm^{-1}$. This may be the result of intense mineralizing processes when the terrestrial vegetation gets flooded. The pH variations seem to be mostly the result of short-term biological processes, such as phytoplankton photosynthesis and activity of heterotrophic bacteria in the stratified water column.

The diurnal patterns of water quality variation indicate that dissolved oxygen levels are an important factor in determining the possible distribution of fish in a habitat. Of the parameters studied, dissolved oxygen is the only one to reach values that exclude large groups of fish from these waters. High temperatures also have an excluding role but for a much smaller group of species than the dissolved oxygen.

ii. Seasonal changes and patterns – phases of flooding

Apart from the distinctive diurnal variation of the limnological parameters throughout the water column, all the habitats also exhibit equally important changes in water quality in the course of the year. These variations are closely linked to the process of flooding and the associated mechanisms of decomposition and aquatic primary production.

For the habitats in the floodplain that exist as aquatic habitats only during a part of the year, these variations are extreme; for the permanent waters there are seasonal changes that are linked to the flooding but the amplitude of the variations is somewhat limited. At the beginning of the flooding in August, the levels of dissolved oxygen in the pelagic area of the lake are comparable with those at other times of the year and much higher than any of the levels measured in or near the floodplain at that time. This indicates the presence of processes in the floodplain that increase the oxygen consumption and that reduce the aquatic oxygen production, resulting in very low dissolved oxygen concentrations.

The low levels, and for the permanent aquatic habitats the sharp drop in dissolved oxygen levels during the early flooding, even in habitats with little decomposable matter, indicate that the decomposition process is not localized to the origin of the organic matter. The elevated levels of dissolved oxygen in the floodplain pool before the flooding, and the subsequent sharp drop when the pool gets flooded with lake water, are probably due to increased primary production in the pool, linked to the fact that the pool is somewhat protected from wind and wave action and run-off and therefore has a lower turbidity and less aquatic respiration.

In general, and except for the floodplain pools that are surrounded by scrubland, habitats with little organic matter on or near the soil (grassland, rice field, lotus field), show minimum dissolved oxygen levels that are higher than those of the scrubland. The forest is also one of these habitats as most of the degradable biomass of the trees is situated above the level of flooding at such time.

The seasonal variation in specific conductivity shows the result of a combination of two processes: the decomposition and mineralization of organic matter and the influx of silt-laden water from the Mekong at the onset of the flooding (August) resulting in a sharp increase in conductivity. Later in the flood season, the decomposition process slows down but the evaporation during the dry season and subsequent concentration of ions will result in an increase in conductivity. The first rains of June and July cause a slight dilution of the ions, thus reducing conductivity. The effective conductivity is influenced by temperature, and reaches more extreme values.

Even though the flooding itself, i.e. the extension of the lake water over the land, is a rather steady process, its consequences on the quality of the water, both above the freshly inundated parts as in the permanent lake itself, are far from steady and continuous. The progression of the water onto the land causes important and fast changes in the composition and quality of the lake water, having important consequences for the animal life that can potentially survive in it.

From an ecological point of view, several different phases can be distinguished in the flooding process, each showing important differences in potential for sustaining animal life. To illustrate this, the limnology data for the surface samples from the grassland habitat are plotted together on one relative scale showing the variation of these parameters between their extremes during the flood period (July-February) (Fig. 1.18). A better understanding of the processes associated with the flooding and of their consequences is important for a better understanding of the relationships between the new aquatic habitats that are being formed in the flooded area and the animal populations in them. The characteristics of these habitats and their variations are major factors determining the composition and size of the fish populations and their changes over time.

In the case of the Tonle Sap ecosystem, dissolved oxygen concentration is the water quality parameter that has the greatest impact on accessibility of the newly inundated habitats for fish and many other aquatic organisms as benthos and zooplankton.

In general, the flooding process shows four phases, based on the impact of the flooding on the aquatic habitat formation. In so far as the available data allow to conclude, the processes are similar for all the different types of habitat in the floodplain but the extent of the consequences of the flooding varies somewhat for each habitat. There is, however, a notable difference for the floodplain pools, where a phenomenon occurs which is hybrid between what is typical for the floodplain habitats and what takes place in the permanent core area of the lake. The timing of the onset and the duration of the different phases also depend on the position of the habitat in the floodplain and the time of flooding.

The following phases can be distinguished for the floodplain habitats:

I. Initial phase

The water depths in the newly flooded area are rising but still low. Turbidity is very high due to suspended deposits and to the high turbidity of the inundating lake water. This causes the temperature of the shallow water to rise fast and high during the day. Dissolved oxygen concentrations are very low or decreasing rapidly. Conductivity also rises and reaches maximum levels, indicating high levels of minerals.

There is readily decomposable organic matter available in the dead (plant) material layer on top of the soil, as well as on the standing vegetation. The fast depletion of oxygen and the sharply rising conductivity indicate that aerobic decomposition and mineralization is going on at a high rate. Aquatic primary productivity under these conditions is probably zero; terrestrial primary productivity by (partially) flooded plants diminishes or stops. Overall, during this early phase, highly unfavourable conditions for the development of a diverse fauna are formed. The freshly inundated areas are only accessible for air-breathing fish, capable of surviving almost exclusively on atmospheric oxygen (e.g. *Anabas testudineus*), or using the very thin surface layer that usually is well oxygenated, many of them feeding on exogenous food like flying insects. Towards the end of this first phase, with the diluting effect of the rising water levels, there is a rise in dissolved oxygen concentration and conditions slowly improve.

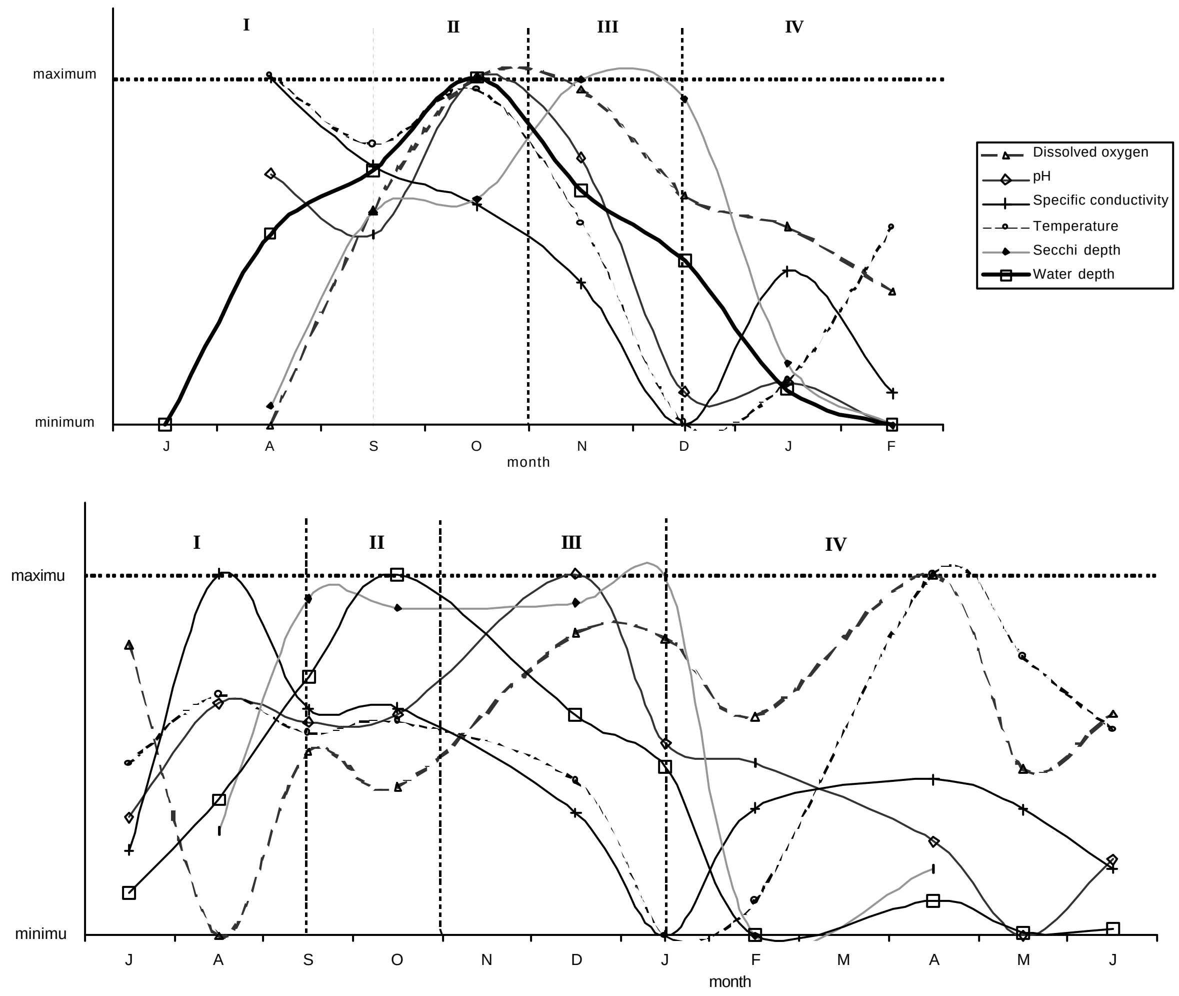

Figure 1.18. Phases of flooding. Seaonally aquatic habitats (top) and floodplain pool (bottom).

II. Transitional phase

Water depths are steadily rising and reach maximum levels. Turbidity is diminishing considerably, due to the settlement of larger suspended particles and to the increased water volume. Higher water levels reduce the suspension of soil particles by wave action. Dissolved oxygen levels are further rising and reach their highest concentrations. This is the result of the increased aquatic primary production. The reduced turbidity has created a deeper euphotic zone. The readily decomposable matter has disappeared and the nutrients contained therein have recycled and become available for aquatic primary production. pH reaches maximum values. The combined effect of reduced respiration and increased photosynthesis contributes to higher dissolved oxygen levels. Terrestrial primary production (in the habitats with standing macrophyte vegetation) is further reduced to a minimum due to increased flood stress. Secondary aquatic communities are developing and provide new feeding opportunities. The habitats are now accessible for most fish species but in the early stages of this phase, mostly fishes with supplementary breathing features such as diverticula of the branchial cavity (e.g., *Channa striata*, *Trichogaster trichopterus*) are found.

III. Proliferation phase

Water depths have peaked and slowly begin to recede. Turbidity is minimal but still considerable. Water temperature drops and reaches minimum values during these months with also the lowest atmospheric temperatures. Dissolved oxygen levels are still high but tend to become lower towards the end of the phase. Water conductivity drops sharply, reaching minimum levels. This could indicate that the aquatic primary productivity has become nutrient limited, which would explain the falling levels of dissolved oxygen. However, oxygen concentrations are still such that most fish species will not experience these as a stress factor and thus limit their distribution. A wide variety and large biomass of feed communities have developed, contributing to a large number of diverse ecological niches.

IV. Terminal phase

Water levels are strongly going down now, leading in the end to total desiccation of the non-permanent aquatic habitats. Whereas turbidity did hardly change during the first half of the water level drop, it now increases sharply, probably because a critical depth has been reached where wave action kicks up considerable quantities of deposited matter. This probably is also the cause for the conductivity to rise again. Dissolved oxygen levels decrease somewhat further but remain relatively elevated. The shallower waters are more easily heated and the temperature rises again considerably towards the end of the flooding. The receding water levels cause many aquatic organisms to die off, sometimes massively. This is the case with much of the floating aquatic vegetation such as *Eichchornia crassipes*. Aerobic decomposition levels are increasing as a consequence. The aquatic primary production is reducing due to increased turbidity and adverse conditions for photosynthesis at shallow water depths. Overall, the conditions in the flooded habitats are turning adverse for aquatic fauna and flora, ending in total desiccation and disappearance of the aquatic habitat. The latter is of course not the case for the habitats that exhibit a permanent stand of water. Less favourable water quality is urging many fish species to migrate into the permanent lake water. This is also the time of the massive migrations out of the lake but it is probably not the reduced levels of dissolved oxygen that trigger the migration from the floodplain habitats. These levels remain relatively high until the very end of the flooding. Fish with supplementary breathing features can remain somewhat longer but are eventually forced to migrate or they die off. Some fish are capable of migrating over land.

This succession of events seems to be similar in all the habitats in the inundated area. The extent of oxygen depletion varies somewhat between the habitats but not as much as could be expected based on the potential amount of aerobic decomposition taking place in the habitats. The oxygen depletion in habitats with relatively low levels of macrophyte biomass such as floodplain pools and lotus fields is similar to that in the habitats like scrubland where there are large quantities of decomposable matter. The patchiness of the inundated area and water movements probably cause a spreading of the suspended organic matter.

The last phase of the flooding is somewhat different in the case of the floodplain pool habitat, which remains aquatic (Fig. 1.18). After the sharp drop in water levels and the related phenomena such as reduced dissolved oxygen, high turbidity and rising temperatures, the pool seems to recover from this degradation in water quality during the terminal phase and to develop according to an own dynamic. Turbidity diminishes, temperatures rise high, and dissolved oxygen levels reach maximum values. This creates a microenvironment in the floodplain that offers favourable conditions for many fish species. The pH, however, reaches unfavourable low values. This microenvironment is abruptly disturbed when the pool gets flooded with the rising lake water as the annual cycle resumes.

Apart from the temporal variation in water quality, there also is a spatial one. This is mainly linked to the elevation of the site and therefore to the flood levels. Higher areas with short flood periods are expected to show similar phases in the flooding as lakeshore sites but the level and time at which the processes reach their local maximum vary.

Some of the scheduled sampling could not be carried out for a variety of reasons. Particularly, data that should have been collected together with the experimental gillnet fishing in the forest habitat are missing. The strong wind and wave action caused the experimental gillnets to become displaced and entangled in the vegetation, or made the nets collapse. Accessibility of the sampling sites varied according to the progression and receding of the floodwater. At some points during the transition, especially after the flooding, access to some sampling sites was impossible.

PART II. TONLE SAP FISHERIES

Historically, rich and diverse fisheries have developed in the Tonle Sap ecosystem, with fishing strategies and techniques based mostly on fish behaviour and the flood regime. A large variety of gear is used, over 150 different types of gear have been inventoried (P. Degen, personal communication, 2000). Many of the techniques and gear used are of the passive type whereby no active effort is involved in the act of capturing the fish. Floodwater recession and migration patterns of fish are exploited in these fisheries.

Catches

The catches from the Tonle Sap make up about 60 percent of the total inland catch of the country (World Bank, 1995; Csavas *et al*., 1994). According to the most recent official catch figures, this corresponds to 138 600 tonnes, though the most recent MRC estimates (van Zalinge *et al*., 1999) put the Tonle Sap catch at between 177 000 and 252 000 tonnes.

Different classification systems are traditionally used to characterize the catch. Biological species are rarely used as a criterion in this. Different classifications were devised for different purposes. Some of the most commonly used systems are described here.

Mekong Secretariat (1992) provides a detailed description and review of a classification system that defines categories of fish based mainly on their water quality requirements and usual distribution patterns. Four categories are widely used:

- **Species associated with the main streams and, to some extent, with the open lake**. This is only a marginal group in the catches of the Tonle Sap ecosystem and includes some secondary freshwater species. This category includes clupeids, sciaenids and soleids.

- **"White" fish**. A group of species that are mainly associated with the main channels and streams, but which also migrate into the floodplains. Many species undertake both lateral (main water–floodplain) and longitudinal (lake–channel–Mekong) migrations. Species usually included are cyprinids (*Cirrhinus microlepis*, *Hampala macrolepidota*, *Barbodes altus*, *Leptobarbus hoeveni*, *Osteochilus melanopleura*, *Morulius chrysophekadion*), several pangasiids species, silurids (*Wallago attu*, *Micronema apogon*) and notopterids (*Notopterus chitala* and *N. notopterus*). Most white fishes have rather high requirements for water quality and behave accordingly (timing of migration etc.).

- **"Black" fish**. This category includes species that are able to survive under less favourable water conditions, and almost all are species that in particular can tolerate low dissolved oxygen levels for at least some time. Most black fish species have specific adaptations for living under such conditions. Species include clariids (*Clarias batrachus*), channids (*Channa micropeltes*, *C. striata*), bagrids (*Mystus* spp.), belontids (*Trichogaster* spp.) and *Anabas testudineus*.

- **“Opportunists”**. These are small, fast-growing and prolific species, able of utilizing the flood period for prolific reproduction and/or growth. The group consists mainly of cyprinids (*Henicorhynchus siamensis*, *Thynnichthys thynnoides*, *Dangila spilopleura*). These fish are mostly used for making *prahoc* and fish sauce or as feed for caged fish.

Csavas *et al.* (1994) provide a description of the classification system used for official statistics which grades fish according to size and species based on local taxonomical knowledge. Freshness also plays a role in the sense that it can downgrade less-fresh fish. Grade 1 fish are 1 kg or more in weight, even though some high-quality smaller fish can be included. Grade 2 fish are between 0.5 and 1 kg, and fish weighing less than half a kilogram are usually classified as Grade 3. This classification system has primarily a commercial use. Generally, the price and utilization of the fish will depend on their grade. First-grade fishes fetch the highest prices, and they are often transported to urban areas or exported. Second-grade fish will be mostly consumed locally, being more affordable for the generally poorer rural population. Fish of the third grade is usually not directly consumed but processed or transformed into *prahoc*, or used as animal feed. Grade 1 fish include notopterids (*Notopterus chitala* and *N. notopterus*), cyprinids (*Balantiocheilos melanopterus*, *Morulius chrysophekadion*, *Cyclocheilichthys enoplos*, *Puntioplites proctozysron*, *Barbodes altus*, *B. schwanefeldi*, *Osteochilus melanopleurus*, *Hypsibarbus lagleri*, *Cirrhinus microlepis*, *Leptobarbus hoeveni*, *Paralaubuca harmandi*), pangasids (*Pangasius sutchi*, *P. larnaudi*), bagrids (*Mystus numerus*), silurids (*Belodontichthys dinema*, *Micronema apogon*) and channids (*Channa micropeltes*).

There are about 120 commercially important species in the lower Mekong (Jensen, 2000a). Ten species make up almost two thirds by weight of the total catch from inland waters in Cambodia and over half of its total value (Table 2.1). Since most of the inland catches originate from the Tonle Sap ecosystem, this is expected to reflect the species composition of the Tonle Sap catches as well.

Catch data have traditionally been collected by the provincial offices of the Department of Fisheries. Only data on the formally licensed (*i.e.*, large and medium-scale) fishing operations are systematically collected. Data collection is based on the mandatory reporting of catches by fishing operators. In these reports, catches are categorized according to the three grades described earlier. There is usually no independent sampling or verification of the data presented to the Department of Fisheries. No information about catch efforts or on species composition or any other biological information is included in this yearly exercise. Even though the quality of these data is generally considered good (Jensen, 2000c), there is only limited use for them. This system of data collection is prone to underreporting by fisheries operators as licence prices are in part determined by the previously reported catches and revenues from the same fishing operation. The permanent presence of data collectors at the large-scale fishing operations has not proven to provide more complete and accurate catch data. As a consequence, the catch and revenue from the inland fisheries have been systematically underreported, to the point where the sector risks to becoming marginalized.

Table 2.1 Ranked relative species composition and value of the 1995/1996 catch (top-ten species only) from different types of large and medium-scale fisheries in Cambodia.

Rank	Species	Khmer name	Percentage of total catch by large and medium-scale fisheries	
			by weight	***by value***
1	*Henicorhynchus*[1] spp.	*trey riel*	21	9
2	*Channa micropeltes*[2]	*trey chhdaur*	9	19
3	*Cyclocheilichthys enoplos*	*trey chhkok*	9	8
4	*Dangila* spp.	*trey khnawng veng*	6	2
5	*Osteochilus melanopleurus*	*trey krum*	4	2
6	*Cirrhinus microlepis*[3]	*trey pruol*	3	4
7	*Pangasius*[4] spp.	*trey pra*	3	3
8	*Barbodes gonionotus*	*trey chhpin*	3	2
9	*Paralaubuca typus*	*trey slak russey*[5]	3	1
10	*Channa striata*	*trey raws*	2	6
Total of 1-10			*63*	*56*

[1] Includes three, possibly five, different species.

[2] It is not clear whether this includes juveniles of this species, for which a different Khmer name (*trey diep*) is used.

[3] It is not clear whether this includes juveniles of this species, for which a different Khmer name (*trey krawlang*) is used.

[4] Includes possibly Pangasianodon hypophthalmus.

5 See note on the identification and use of the Khmer name on page 107.

Source: Deap *et. al.*, 1998

The lack of complete catch data from all segments of the fisheries has caused or contributed to a number of problems. The fact that the reported data are only partial is in most cases neglected when these data are used, resulting in secondary data of poor quality. As mentioned earlier, the contribution of the inland fisheries sector to food security is probably grossly undervalued. The share of the GDP originating from fish, fish products and employment in the fishery sector has never been accurately assessed, resulting in an underestimation of the GDP and underperforming collection of taxes and fees for the national budget. The general impression among Department of Fisheries officials and many fishers about the decline of stocks and catches and the disappearance of larger species is likely to be accurate but cannot be substantiated without comparable data. The undervaluation of the licensed fisheries sector and the non-quantification of the subsistence and small-scale fisheries risk to contribute to the situation where the fisheries sector cannot withstand critical challenges, *e.g.*, from proposed dam construction and subsequent alterations to the hydrology of the main fishing grounds. Other critical issues include land use and natural resource management of the floodplain of the ecosystem. Reasonably good and complete data are essential for the proper management of the fisheries and its preservation as one of the main natural resources of Cambodia.

In the past seven years, there has been a considerable effort by the DANIDA funded MRC project for the management of the freshwater capture fisheries of Cambodia to upgrade the quality and scope of the fisheries catch data. Details on the methods and results can be found in Deap *et al.* (1998) and Sensereivorth *et al.* (1999). The systematic sampling and collection of data has resulted in a more complete and accurate picture of what inland fisheries in Cambodia produce. The collection of data was refined to the level where information is collected for individual genera or species. This will allow the creation of time series of the catches and consequently a substantiated assessment of trends in the catches. It will also contribute to remedy some of the negative consequences of the current problematic data collection and presentation. The most important achievement to date is probably the capacity and awareness that has been built at all levels in the Department of Fisheries.

Consequently, the department has for the first time included figures on the other segments (family and on-farm fishing) in the official fisheries data for 1999. However, the collection of data from the licensed fishery sector has not changed. The recent creation of so-called “research lots” might contribute to an improvement in this part of the sector as well.

There appears to be a consensus in the scientific community studying the inland capture fisheries of Cambodia about the perceived declines in fish stocks and catches (*e.g.*, van Zalinge and Thuok, 1999; Gum, 1998; Loeng, 1999). The human population increase of the last two decades has resulted in an increased fishing effort, overcapitalization and more mouths to be fed from the catches (Csavas *et al.*, 1994; Mekong Secretariat, 1992; NIS, 1999; Ahmed *et al.*, 1998; Demuynck, 1995). Undoubtedly these factors contribute to a trend widely perceived as a decline of the inland fisheries. In addition, a number of indicators do suggest that the fishing effort has reached levels where overfishing is likely, at least for part of the stock. From the anecdotal data and information available, it is evident that the largest species such as Mekong giant catfish (*Pangasianodon gigas*) and giant barb (*Catlocarpio siamensis*) have become less common and those specimens that are caught are generally smaller than in the past (van Zalinge and Thuok, 1999; Rainboth, 1996). Catches of large specimens of these species are headline news nowadays. There are less clear indications for the medium-sized species, although the catches have probably gone down. These include the most valuable species, which are specifically targeted. Some species have become rare or endangered (Rainboth, 1996; Ministry of Environment, 1998). The small species are still very abundant and probably more fish are being caught than ever before in this category. The reproductive biology of these species makes them less vulnerable to overfishing.

The lack of data does not allow to conclude any overall trend in the total inland catch. However, there is concern about the impact of overfishing of part of the stock on the ecosystem as a whole, and the productivity might well be affected by the decline or disappearance of species. Other major threats to the productivity come from impacts on the parameters of the ecosystem that determine its productivity and thereby the potential catch.

Fishing techniques and gear

Based on legal and practical requirements, the inland fisheries of Cambodia have been divided into three categories: large, medium and small-scale fisheries. Apart from a number of general rules that apply to all, each category is subject to specific regulations concerning gear, fishing grounds and timing of fishing and related activities.

i. Large-scale fisheries (fishing lots)

The large-scale fisheries are also referred to as industrial fisheries, even though there is very little industry or mechanization involved in the fishing or subsequent processing of fish. Large-scale fishing is practised in areas for which exclusive access and exploitation rights are acquired. These areas are generally referred to as “fishing lots”, and their acquisition is subject to public auction. The conditions of the lease are specified in a standard-format contract. The information contained therein stipulates the precise location and boundaries of the fishing lot, the timing and kind of fishery activities allowed and additional conditions for the lessee. Typically, a fishing lot is leased for two years, after which the lease of the lot is auctioned again. By leasing the fishing lots, and this particularly applies to the lots covering large areas, the Department of Fisheries *de facto* cedes control over the area of the lot, allowing the lessee to set up his own militia and use force to control access, to detain people who unlawfully enter the lot, to confiscate and destroy unauthorized fishing gear, and to regulate all other fishing activities taking place inside the lot. The fishing season is officially open from 1 October until 31 May; during the closed season, no activities are allowed in the fishing lots. In 1999, there were 239 fishing lots in the country, 139 of which are situated inside the Tonle Sap ecosystem (Table 2.2).

There are three major techniques used in the large-scale fishing operations, depending on their location in the ecosystem. Inside the Tonle Sap lake and the surrounding floodplain, fishing is mainly done by seining. In order to prevent the fish from escaping from the fishing lot exclusive area, the lessees install an extended system of bamboo fences that are being erected when the floodwaters have considerably receded. Subsequently, the fish are systematically chased out of parts of the area and collected in a large fenced holding area. In this area, the main installations of the fishing lot are built. They include a landing platform for the catches, and installations for the loading of the catch onto boats of fish buyers who dock at this platform. Usually a part of the catch is sold directly, while the rest is stocked in large floating cages. These fish are transported to Phnom Penh where generally higher prices are fetched, or they are kept for sale later when the markets are less saturated. This kind of fishing operation targets primarily fish of the first grade, many of which are black fish, like *Channa*, *Pangasius*, *Cirrhinus* and *Kryptopterus*. Juvenile *Pangasius* are sold not for consumption but are used for stocking in cages for further culture. There is little information available about the internal functioning of the fishing lots, but sub-leasing of parts of a lot seems to be common practice. There are reports of social problems related to some fishing lots, in particular with respect to their boundaries and the access of communities to local open-access fishing grounds (*e.g.*, van Zalinge and Thuok, 1999; Demuynck, 1995; Gum, 1998).

Barrage fisheries are the second type of operation used in the large-scale fisheries. This technique is mainly found in the delta formed at the point where the Tonle Sap channel connects to the lake. It targets mainly longitudinally migrating fish. The composition of the catches depends on the precise location in the ecosystem and they usually contain both white and black fish. The barrages are constructed from wooden poles and bamboo fencing and block the entire width of a branch of the channel. Depending on the size of the barrage, one or more catch chambers or long net funnels are attached to openings in the barrage. The barrage operation is combined with seining. Towards the end of the water recession, seine nets are pulled downstream across the channel and the fish are trapped between the net and the barrage.

The third type of large-scale fisheries practised under the lots system is the bag net – locally called *dai* – fishing lots on the Tonle Sap channel. The *dais* are located in the southernmost 30 km of the channel. Large cone-shaped bag nets of about 100 m long and with a mouth diameter of 25 m are suspended from floaters and anchored in the channel, where they are held open by the current. Mesh size is 15 cm at the entrance and 1 cm at the bag (Loeng, 1999). Each net is considered a fishing lot. The nets are connected in series of four to nine in rows across the channel, sometimes leaving only a small opening for navigation. The bag can be winched onto a wooden platform anchored near the net end; there the catch is sorted and transferred onto boats for transport. *Dais* are operated from the end of September until March.

The *dai* fishery specifically targets migrating fish leaving the Tonle Sap lake and floodplain when the water levels begin to recede and in the months after that. There is a pronounced peak in the catches in January. The migration out of the lake towards the Mekong occurs in well-known and regular waves, reaching its highest levels six to three days before full moon (Loeng, 1999; Fily and d'Aubenton, 1966). During these migration peaks, the bags are lifted every 20-25 minutes day and night, and 500 kg of fish may be collected with each lift, to the extent that the handling and transport capacity at the *dai* becomes a limiting factor for the volume caught (H. Hy, personal communication, 1999). Outside these peaks, lift frequency is much lower.

The *dai* catch consists mainly of migrating white fish, with a majority of third-grade fish that is mostly used for the production of *prahoc*. Loeng (1999) reports strongly reduced catches (9 000 tonnes compared with 15 000 tonnes the previous season) from the *dai* fishery in 1998/1999 when the highest flood levels were considerably below normal, possibly as a result of El Niño. This supports the hypothesis that the area that is flooded is determining the productivity of the ecosystem.

Some of the fishing lots have not been leased out but were reserved for research by the Department of Fisheries. In an attempt to improve data collection from the commercial fishing lots, in 1999 some of the leased fishing lots were additionally converted into research lots. In 2000, 70 lots, or about one third of all, have been given this new status. The lot owners have the obligation to maintain the flooded forest, to allow physical demarcation of the lot area, and to allow research on species and catch data within the lot to improve fisheries statistics. However, capacity of the Department of Fisheries to effectively carry out this research is insufficient, and the previous public auction system has been replaced by less transparent direct agreements between the fishing lot lessees and the Department. Under the new status, lots can be assigned for four to six consecutive years (Department of Fisheries; Seilert and Lamberts, 2000). It is not clear what the impact of this policy will be on revenue collection for the government or on the management of the fishing lots.

Table 2.2 Type and number of fishing lots in the Tonle Sap ecosystem per province, 1999 (Department of Fisheries)

Province	Fenced and barrage lots		*Dai*	Total
	Auctioned	*Research*		
Phnom Penh	-	1	25	26
Kampong Chhnang	9	10	-	19
Siem Reap	-	7	-	7
Pursat	-	7	-	7
Battambang	7	5	-	12
Kampong Thom	2	5	-	7
Banteay Meanchey	4	-	-	4
Kandal	2	17	38	57
Total	*24*	*52*	*63*	*139*

Fishing lot operations are generally large and labour-intensive, requiring considerable investment. Especially the fenced fishing operations use large amounts of bamboo and wood, inputs that last only for one or at most two fishing seasons. Operating a fishing lot requires a high level of logistical coordination to ensure the timely mobilization of all inputs like labour, equipment, guarding, actual fishing, marketing, transport and processing of the catch.

ii. Medium-scale fisheries

The open-access areas are shared between the medium-scale fisheries and subsistence fisheries. The medium-scale fisheries are subject to yearly licensing by the Department of Fisheries. The licence restricts the activities in regard to number and kind of fishing gear and area and period of fishing. A large variety of gear is used in the middle-scale fisheries and details of the specifications for each gear type are indicated in the fisheries law. The most important gear types used are large arrow-shaped traps with bamboo fences, gillnets, traps, encircling seines and long lines. As for the large-scale fisheries, fishing is only allowed during the open season. Gillnets make up a large part of the gear used in the middle-scale fisheries; 63 percent of the households in fishing communities use gillnets (Ahmed *et al*., 1998).

The arrow-shaped traps are mostly used in the floodplain of the lake and are moved as the water levels recede. The gear targets fish that are migrating out of the flooded forest area and the catches are dominated by black fish, about one quarter of it giant snakehead (*Channa micropeltes*) (Roth and Sea, 1999). Migrating fish are guided by up to 2-km-long bamboo fences to the arrow-shaped head of the gear where they are gathered in large submerged drum-shaped traps. Although such fence lengths are illegal (the maximum length allowed is 500 m), in places the fences of traps are combined and form a large system with several traps, effectively sealing off a part of the inundated area in a way similar to the system of fences erected around the exclusive-access fishing lots. Traps are operated in the open-access fishing areas with a licence issued by the provincial office of the Department of Fisheries, or inside the fishing lots under agreements with the fishing lot lessee. Recently, there is a trend to replace the bamboo for the fences with much cheaper and more effective nylon netting (Roth and Sea, 1999). This is likely to have a negative impact on the ecosystem as nets are lost in the environment and the fishing pressure is likely to increase.

iii. Subsistence (small-scale) fisheries

The small-scale fisheries are the third main category. All fishing activities not included in the large and medium-scale categories are considered here. Small-scale fishing, which is also referred to as subsistence or family fishing, is allowed throughout the year and in all fishing grounds, except in fishing lots during the open season and in the fish sanctuaries. Most of the fishing in this category is done for subsistence by individuals or at household level, or for cheap complementing and variation of the diet. Some of the fish caught are traded but this is usually not the main objective.

There are no accurate figures available on the importance of the small-scale fisheries in the total inland fisheries catch. One of the few studies that include the small-scale fisheries (Ahmed *et al*., 1998) provides some data on the species composition of the catch, albeit based on interviews with fishers rather than on sampling. One third of the fishing households (*i.e*., households of which at least one member is involved in fishery as a main activity in a commune that has access to a fishing ground and where inhabitants are involved in fishing) reported *trey riel* (*Henicorhynchus* spp.) as the most important species caught. Other important species are black fish. Table 2.3 provides an overview of the results of the same study on small-scale fishing in fishing grounds of the Tonle Sap ecosystem.

Table 2.3 Percentage of households engaged in small-scale fishing during the open (*o*) and closed (*c*) season in various fishing grounds in the Tonle Sap ecosystem by province (1995-1996). n = total number of fishing households questioned in the survey. (based on data from Ahmed *et al*. 1998)

Fishing ground	**Phnom Penh (n = 95)**		**Kampong Chhnang (n = 257)**		**Siem Reap (n = 203)**		**Pursat (n = 238)**		**Battambang (n = 287)**		**Kampong Thom (n = 104)**		**Total (n = 1 184)**	
	o	***c***	***o***	***c***	***o***	***c***	***o***	***c***	***o***	***c***	***o***	***c***	***o***	***c***
Tonle Sap lake	0	0	2	2	16	17	1	2	0	0	6	0	4	4
Tonle Sap channel	14	30	58	53	6	3	0	0	0	0	0	6	15	15
Flooded rice field	22	45	23	30	47	53	7	86	49	39	38	43	31	50
Small river / lake	28	38	48	48	72	46	66	53	85	76	67	69	65	56
Inundated forest	17	28	26	30	40	39	13	14	69	52	28	30	36	34
Others	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.4 Percentage of fishing households engaged in small-scale fisheries by gear type in provinces bordering the Tonle Sap ecosystem, and number of gear in use per household (1995-1996) (based on data from Ahmed *et al*. 1998)

Gear type	**Percentage of all households**		**Average number of gear per household**[1]	
	open season	***closed season***	***open season***	***closed season***
Harpoons	4	4	2.5	2.3
Bamboo / rattan traps	26	29	10.6	9.4
Cast net	32	25	1.1	1.1
Scoop net	2	2	1.4	1.4
Gillnet	50	50	3.2	3.0
Small handled drag net	1	1	5.6	6.6
Single-hook line	15	17	67.3	70.6

[1] Including data from Kandal and Kampong provinces.

Gillnets are the gear type most widely used in small-scale fisheries and half of the fishing households use them in addition to other gear. Gillnets are the most commonly held fishing gear in non-fishing households (Ahmed *et. al*., 1998).

There are reports of widespread illegal fishing operations such as the use of explosives, electro-fishing, poisoning, fishing with unauthorized and oversized but otherwise legal gear, expansion of boundaries, use of brush parks, etc. In part, this reflects the changing reality and requirements of the fisheries and the need for an update of existing legislation and rules. For example the catch per unit effort of gillnets is low (read on) and the legal limitation of 10 m length for gillnets used in small-scale subsistence fisheries is usually too low to make this operation worthwhile. On the other hand, it demonstrates the lack of enforcement capacity of the Department of Fisheries. The continued use of *samrah* or brush park fisheries is an example of this. This small-scale fishing practice has been classified as illegal since 1987. However, in 1998 there were still 165 of these brush parks operating in the Tonle Sap channel. The technique of the brush parks consists of the creation of an artificial habitat for fish in the open water, resembling the nearby inundated forest. To this effect, large amounts of trees and branches are cut in the flooded forest and placed in the stream in December-January, together with bamboo and wooden sticks that mark the boundaries of the brush park. These brush parks have an average area of 400 m^2 (Ho, 1999). Starting in February, when the water level has sufficiently receded, the brush parks are encircled by a seine net and the branches are removed. In this way all the fish present in the artificial forest are caught. The branches are reused for a new *samrah* and the operation is repeated about every two months until the floodwaters come up in the channel. The catch consists of a variety of black and white fish. It is clear that this type of fishing technique has a number of detrimental consequences for the ecosystem. A considerable amount of wood is cut from the flooded forest to form the brush parks. Their presence in the channel slows down the current and increases siltation, and the parks trap floating vegetation coming down from the Tonle Sap lake. Often, navigation in the channel is hampered. Ho (*op. cit*.) states that the lack of enforcement in this case is due to the government ignoring the problem, despite indications of the environmental impact of the brush parks.

Fisheries management

The fisheries of Cambodia are regulated by law, issued by the Council of State on 9 March 1987 (Fiat-Law No. 33 KRO.CHOR on Fisheries Management and Administration) and completed by two additional sub-laws (No. 66 OR.NOR.KROR of 5 November 1988 and No. 26 OR.NOR.KROR of 9 May 1989). The fisheries legislation used to be one of the most developed and extended systems of fisheries regulation found in the world (Mekong Secretariat, 1992). The law applies to all “wild” plants and animals found in the fishery domain. The inland fishery domain as defined by the law includes practically all inland waters except man-made ponds and reservoirs, and includes the areas that are only temporarily aquatic, such as the flooded forests. The fishery domain includes both the fishing lots and the area outside the lots, called the protected fishery domain. The latter includes flooded forest areas and the fish sanctuaries where all fishing is prohibited. In 1999, the World Bank made a number of recommendations for a revision of the fisheries laws (Swan, 1999).

The Department of Fisheries of the Ministry of Agriculture, Forestry and Fisheries is the agency that holds the authority over the fishing domain. The Department of Fisheries is charged with the enforcement of the fisheries law. In 1999, 1 855 cases of illegal inland fishing were taken up by the Department. Almost 150 million Riel or about US$40 000 worth of fines were imposed in a total of 638 cases, while 103 cases were referred to the courts. In 1 227 cases, illegal fishing equipment was confiscated and destroyed (Department of Fisheries).

At the provincial level, the institutional settings tend to weaken the authority of the Department of Fisheries. The provincial offices of the Department are managed under the provincial offices of the Department of Agriculture, resulting in a double hierarchy and at times conflicting interests and policies. This weakens the ability of the Department of Fisheries to implement its management activities.

The objectives of the Department of Fisheries in fisheries management are:

1. to maintain the resource for food security for all rural people;
2. to use additional production for income generation from export; and
3. to assure that fisheries provide substantial input for the national economy.

There is no elaborated overall fisheries management plan apart from the general rules and regulations given in the fisheries law (World Bank, 1995). Reforestation and restoration of the natural inundated forests and development of the aquaculture sector are the two issues that are put forward by the Department as priorities for long-term planning.

The management tools at the disposal of the Department of Fisheries for the enforcement of the law and implementation of the policies are primarily licensing activities for the large and medium-scale commercial fisheries, enforcement of gear and timing regulations and research and data collection.

Table 2.5 Management issues for Cambodian inland fisheries

Issues	Required management tools	Assessment
Objective 1: To maintain the resource (…)		
Exogenous	*Credible data on the value and importance of the inland fisheries sector for use as an argument in relevant national and regional decision making*	*The present data are improving but still fragmentary. There is no accurate valuation of the inland fisheries sector*
▪ Alterations to the hydrology of the Tonle Sap ▪ Development for industrial purposes (e.g. oil / gas) ▪ Pollution ▪ Siltation	Evidence of the importance of the present hydrological cycle for the productivity of the inland fisheries in general, and the vulnerability of the Tonle Sap ecosystem in particular	Increasing amount of supporting data available but still no clear demonstration of the importance of the hydrological cycle. Mechanism of production in the floodplains not demonstrated
	Appropriate forums	ASEAN, MRC
Endogenous	*Effective regulation and enforcement*	*Extensive regulation but weak enforcement*
Threats to the parameters of the inland fisheries ecosystem:		
▪ clearing of flooded forest	Protection and restoration of the flooded forest	Lack of enforcement capacity and insufficient integration with the multiple functions of the flooded forest for local communities
▪ hampering of fish migration	Regulations and enforcement to ensure migration paths remain clear	There is concern in the Department of Fisheries about the collection of large amounts of fry in the Mekong, and about the possible impact of heavy and noisy boat traffic on the migration paths. Use of illegal fishing methods in migration ways (e.g. brush parks) not effectively stopped. Construction of obstructions is forbidden
▪ bad fishing practices	Regulations specifying permitted fishing practices and effective implementation including policing and awareness building among the fishers	Extensive and detailed regulation exists but somewhat outdated; update with recent information and developments required. Problematic enforcement

Table 2.5 (*continued*)

Issues	Required management tools	Assessment
Overfishing of specific stocks	Quota/specification of catch limitations for vulnerable species	No effective limitation or awareness building among fishers. Insufficient data on the condition of most stocks
Loss of biodiversity	Conservation measures like the creation of protected areas Awareness building	Eight fish sanctuaries have been established in deeper sections of the lake where all fishing is forbidden but poaching reported. Their boundaries are reportedly unmarked. Some awareness building efforts ongoing but limited
Objective 1: (…) for food security (…)		
Availability of food	Effective management of the fish stocks in a durable manner and at high levels	Exploitation at high levels but probably not durable for at least part of the fish species
	Data on per-caput fish consumption and availability	Some data available from recent surveys but the inaccurate total production and fish availability figures do not allow assessment of fish consumption
	Data on regional variation in fish consumption	There are considerable variations in fish consumption but no specific data available
Objective 1: (…) for all rural people.		
Access to fishing grounds for subsistence fishers	Demarcation of open-access areas and reservation of fishing rights for subsistence fishing. Mediation and mitigation in case of conflicting interests	Problematic in many areas due to illegal expansion of exclusive fishing areas; open- access areas at times unlawfully occupied for private (commercial) use. Overall weak judicial system, undermining authority of the Department of Fisheries, and powerless fishers and local communities
Access to food / transport and distribution	Facilitation of transport, distribution and processing; improvement of market transparency	Poor but improving infrastructure (roads). Limited distribution to rural areas away from fishing grounds. Processing is widespread but generally of low quality and limited preservation time

Table 2.5 (*continued*)

Issues	Required management tools	Assessment
Objective 2: Use additional production (…)		
Assessment of surplus production	Data on local consumption, production and availability	Insufficient at present
Objective 2: (…) for income generation (…)		
Contribution to the national budget and the operating budget of the Department of Fisheries	Effective collection of export taxes and fees	Incomplete
Contribution to trade balance	Private sector	Well developed
Objective 2: (…) from export.		
Preservation and processing techniques and subsequent food quality.	Food quality control and assurance facilities.	Exports to neighbouring countries ongoing and well organized. Lucrative overseas markets inaccessible because of insufficient food quality control and assurance
Transportation	Infrastructure	Poor road infrastructure limits the amount and quality of fish and fish products for export
Objective 3: (…) provide substantial input (…)		
Establishment and collection of licence and auction fees	Administration	The administration is in place and well functioning. Fees are sub-optimal. One third of the fishing lots are no longer auctioned under the new research lots status
Objective 3: (…) for the national economy.		
Contribution to GDP	Catch data collection and market information	Inadequate catch data, although improving. Large sectors of the inland fisheries are not included in the production data
Contribution to national budget	Reliable catch data and effective tax / fee / fines collection	Inadequate catch data. Collection of moneys inadequate

The objectives of the fisheries management are diverse but coherent. The issuance of licences is the most important management tool used by the Department of Fisheries. In practice though, there are many licensing instances, both formal and informal, some of which are listed in Table 2.6. They all control a part of the fisheries, and each with its own set of objectives. All these licensing agents are operators of a complex fisheries management system, sometimes without being aware of it, and usually without awareness or consideration for what the objectives of the fisheries management at the ecosystem level are.

Table 2.6 Formal and informal licensing agents in the inland fisheries sector

Licensing agent	Nature / description of licence	Licensing / Management objective	Licensees
Central Department of Fisheries, Phnom Penh	Formal. Fishing lots. Licences award exclusive exploitation rights to clearly defined and delineated fishing lots.	▪ Maximizing catch ▪ Access control, although not for catch limitation ▪ Revenue for national (60%, of which 10% for the central Department of Fisheries) and provincial administration (40%, of which 5% for the provincial Department of Fisheries)	Fishing lot lessees
Provincial offices of Department of Fisheries	Formal. Medium-scale gear licences	▪ Access control ▪ Revenue for national (60%, of which 10% for the central Department of Fisheries) and provincial administration (40%, of which 5% for the provincial Department of Fisheries)	Medium-scale gear operators
Fishing lot lessees	Informal. ▪ Subleases for parts of the fishing lots ▪ Subleases for gear	▪ Catch and profit maximization ▪ Investment and risk limitation	▪ Individual subsistence fishers ▪ Local communities for subsistence fishing ▪ Medium-scale gear operators ▪ Local military groups in exchange for protection
Local military authorities	Informal. Fishing rights for certain fishing grounds	▪ Income generation ▪ No fisheries management objective	Mainly subsistence fishers
Village chiefs	Informal. Sub-lease of parts of fishing lots. Subsistence fishing grounds allocation	Access for subsistence fishers	Subsistence fishers

Traditional single-species stock based fisheries management approaches are very difficult to apply to the Tonle Sap fisheries. The fisheries are multi-species, multi-user, multi-gear in nature, and only recently a modest start has been made with a stock assessment. A considerable part of the sector is informal and involves large numbers of users, mainly subsistence and many occasional fishers, and catch data are not adequately recorded. Modern ecosystem-based fisheries management approaches require levels of understanding of the ecosystem that are still beyond what is nowadays known and understood about the Tonle Sap.

In order to achieve the overall fisheries management objectives, the short-term objectives would need to include the following:

- To preserve the capacity of the Tonle Sap to function as a prime fishery resource for future generations. More concretely, this implies immediate attention to conservation of the biodiversity of all life forms that constitute the ecosystem and the maintaining of the original habitats.
- Simultaneously, the ecosystem and its exploitation should be further studied in order to obtain a sufficient understanding that will enable the formulation of concrete medium and long-term management objectives and tools.
- "Always right" management tools, based on the precautionary principle approach, need to be better implemented, specifically regarding the use of destructive gear and fishing practices, protected areas and habitat conservation.

The use of the fishing lots is probably one of the most effective ways of fisheries management. Because of demand (subsistence, commercial) and the common property nature of the fisheries, most developed fisheries are overcapitalized, *i.e.*, the users are not optimizing the use of their gear and efforts. Through the auctioning of the lots, the character of the fisheries shifts from a common property to that of a privately owned property, resulting in an adjustment of the fishing effort to minimize costs and maximize yields and profits (Laevastu, 1996). However, the short duration of the lease (two years) does not provide much incentive to the lessees to maximize yield and profit in a medium or long-term perspective, and investments in habitat conservation and other long-term measures are generally low. Since nearly all the fish catches from the lake do have a market value, the present exploitation is optimized towards as large quantities as possible, regardless of long-term considerations.

From detailed descriptions of fishing lot operations by lessees (*e.g.*, Mekong Secretariat, 1992; Vibolrith, 1999; Loeung, 1999), it appears that these are efficiently run, and that operations are effectively focused on minimizing of costs and maximizing immediate profits.

However, the current implementation of the fishing lots system, particularly in the Tonle Sap lake, gives rise to a large number of conflicts with other, mostly local, users of the common property resources. These conflicts usually arise when the exploitation of the lots is done at the expense of the local community, by affecting its livelihood or even food security. In developing countries, the privatization of a common property resource is expected to generate benefits for the community, at all levels. Unless these issues are adequately dealt with, the lot system is counterproductive and does not contribute to the achievement of the fisheries management objectives.

For the management of the inland fisheries to be effective, action is required at regional, national and local levels. The most urgent issues are found at the local level: equitable access to common property resources, local-level food security, habitat conservation and good fishing practices.

Environmental aspects

The very nature of its productivity, the ecosystem is affected by changes in the wide environment. There are a number of significant environmental developments affecting the fisheries of the lake, events and processes that are both natural and man-made or aggravated by human activities. On the other hand, fishing activities in the Tonle Sap have environmental impacts as well.

- *Siltation*

Siltation of the Tonle Sap is a natural process. The rate of siltation is reported to have considerably increased in the past century, from 2-8 mm per year in 1900 to 40 mm per year recently (Mekong Secretariat, 1992; Csavas *et al.*, 1994). However considerable, there are no differential data available for the areas of the ecosystem that are subject to local sedimentation rates. Sedimentation is more pronounced in places where differences occur in water flow speed such as the junction of the Tonle Sap channel with the Mekong at the Quattre Bras, at the mouth of rivers and canals and in the inland delta formed at the junction of the Tonle Sap channel and the lake.

Clearing of flooded forest and deforestation in the catchment areas of the Mekong and the Tonle Sap have been widely blamed for the rise in siltation. Mining for gems and deforestation have contributed to an increased sediment load of tributaries to the lake (*e.g.*, the Sangkae river in Battambang).

The effects of the presumed increased siltation on the fisheries are mostly indirect. The flow of water to the Tonle Sap from the Mekong is reduced, resulting in a smaller area that gets flooded and therefore reducing the input in the ecosystem by the flooded forest and reducing the habitat area for the fish. A direct consequence of this is a lower productivity of the ecosystem and a reduction in potential fish catch. The average water depth in the lake during the dry season has decreased, and this has probably led to slightly higher water temperatures. The assumption that this has been the cause of reported dry-season mortalities of fish (Mekong Secretariat, 1992; Csavas *et al.*, 1994) is unsubstantiated. Other factors such as reduced transparency would negatively impact on the capacity for planktonic photosynthesis; on the other hand, with the higher silt loads there is an increase in nutrients, and the net outcome of the two effects is unpredictable. The increased deposit of silt at the Quattre Bras and at the inland delta of the Tonle Sap could reduce the flow of fish eggs and larvae into the lake and hamper the migration of fish out back to the Mekong when the water recedes.

Proposals have been made for dredging parts of the ecosystem, particularly at the Quattre Bras junction to improve navigation, enhance the water flow and facilitate fish migration. At this point, there is a lack of understanding both of the sedimentation process in this dynamic area and fish migrations, and any assessment of positive effects of such activity seems premature (Mekong Secretariat, 1992). The dredging process itself would likely cause serious temporary problems.

- *Changes to the hydrology of the ecosystem*

Apart from the natural siltation process, there are a number of human activities which would have an important impact on the hydrology of the Tonle Sap ecosystem. As all other floodplain fisheries, those of the Tonle Sap are particularly sensitive to water regulation. Water regulation in the ecosystem was the subject of some proposals in the past but is nowadays discounted. Changes in the hydrology nowadays would be a secondary effect of other development plans like dams and irrigation schemes.

In the past, proposals were worked out to increase the water depth of the lake and to block the return of the floodwaters to the Mekong for two months by means of dams and a barrage on the Tonle Sap channel to increase the production time of the floodplain (Bardach, 1959; Fily and d'Aubenton, 1966). Nowadays, such proposals seem grotesque and contrary to all understanding and knowledge of the functioning of the ecosystem.

However, plans for upstream dams on the mainstream Mekong and major tributaries still are a reality. The impacts of such constructions would be lower flood levels, less flooded area and higher dry-season flow rates. The timing of the flood cycle would likely be altered, which might result in the loss of the synchronization between the reproductive behaviour of (migratory) fish species and the hydrological events. This could seriously impact on migrations and the distribution of eggs and fry (van Zalinge *et al.*, 1999). Most previous assessments of the impact of dams construction on the fisheries of the Tonle Sap seriously underestimate the consequences. This is mostly due to the way in which these assessments are made but it is also brought about by the persistent underreporting of the inland fisheries production. Furthermore, most of the alterations to the hydrology of the ecosystem would not only affect the fish production but would also have considerable social implications. A reduction of the flooded area not only means lower production and catches but also reduced access for fishers to the stocks. This is particularly relevant for places where the fishing lots take up most of the area of the common property resources. Proposed mitigation for the loss of lake fisheries such as alternative reservoir fisheries are usually not realistic (Mekong Secretariat, 1992).

Downstream water control in the Mekong delta may also affect the Tonle Sap ecosystem, resulting in higher water levels.

- *Irrigation*

The development of irrigated rice culture schemes could reduce wild fisheries production (Mekong Secretariat, 1992). On the other hand, the irrigated rice fields could produce considerable amounts of fish, especially when enhanced stocking of the rice fields is carried out.

- *Agro-chemicals*

Intensification of rice culture and agricultural expansion in parts of the floodplain of the ecosystem lead to an increased use of agro-chemicals such as pesticides and fertilizers. Various unregulated pesticides are used and enter the ecosystem. Apart from an impact on fish production, this forms a threat to public health through the accumulation of pesticides in the fish. There is a continuing reduction of the area in the floodplains that is covered by original vegetation as more land is converted for agriculture purposes. Fertilizers used will partly run off and be taken up in the ecosystem. Given the size and hydrology of the ecosystem, this is likely to have only a limited effect on the fisheries and on productivity.

- *Pollution*

At present, the little-developed industry of Cambodia causes only few pollution problems. However, recent cases of illegal importation of toxic waste show that there is a danger to public health and to the Tonle Sap ecosystem. The potential impact of pollution is large, especially if migration paths were polluted (Mekong Secretariat, 1992). Urban and domestic liquid waste is not treated but directly discharged into water bodies. Especially around centres of human population (Phnom Penh, floating villages), this has an impact on water quality, particularly during the dry season, when the shallow waters are stagnant and temperatures can be high.

- *River transport*

Pollution at ports is a greater risk, as there is more traffic. Oils spills are a real risk and waste oil, sludge and bilge are usually discarded in the water. There is concern about the impact of busy motorized boat traffic along the channel on migration of fish.

PART III. GILLNET FISHERIES: CASE STUDY

METHODS

i. Experimental gillnet fishing

The gear for the experimental gillnet fishing were monofilament nylon gillnets with knot-to-knot mesh sizes of 10, 20, 30, 40, 50, 60, 70, 80 and 100 mm. These nets each had a length of 10 metres and 2 metres hanging depth. On top, they were equipped with a cork line and underneath with a PVC lead line of 1.2 kg/100m. Sets of these gillnets of all the mentioned mesh sizes were assembled, in order of mesh size, to panels of 90 metres total length. Total surface area per panel was thus 180 m^2, with 20 m^2 of surface per mesh size. This definition of a panel is the unit used for the calculation of the catch per unit effort (CPUE) data. Panels that were used for fishing at the bottom were additionally weighed and marked with buoys.

The sampling procedure was to set three panels at the surface, and to sink one panel for bottom catches. In the scrubland, the bottom panel could for obvious reasons usually not be used. Catches in the forest near the lakeshore were often impossible because of the presence of the submerged vegetation and the almost perpetual wave and wind action. The nets were set from a small man-powered boat.

One habitat was sampled at a time, and all panels were placed in that habitat. The panels were placed from around 0500 hours on, shortly before sunrise, and were soaked for three hours. The limnology data were collected after the nets were placed. As the nets were being recovered, the fish caught were taken from the net and per mesh size and panel collected in marked plastic bags. The bags were kept on ice until analysis of the catch.

All specimens from the experimental catches were identified and measured for weight, standard and total length. CPUE was calculated using the panels as defined higher as standard gear, and expressed as $g.panel^{-1}.hour^{-1}$ of soaking time ($CPUE_w$) for a weight- based measurement, and as $panel^{-1}.hour^{-1}$ ($CPUE_n$) for a figure based on the number of specimens.

ii. Additional fish sampling

On a number of occasions, fish were collected from a variety of sources for additional data collection. This was the case with fish sizes or species that were only occasionally caught by the gillnets, or to assess gear characteristics as selectivity. Fish were collected from traps, from additional gillnets or from local markets where fish sold were caught by a variety of gear (traps, harpoons, hooked lines, cast nets, etc.). Data from these fish were used together with those from the experimental gillnet fishing in the calculation of the length-weight relations, for scale collection and for gear selectivity assessment. Unless collected directly from the source, the habitat where the fish originated from was not traced, and no quantification of fishing effort was attempted for any of these additional sources since reliable information was usually not available.

iii. Selected species

Eight species were selected for a more detailed study of the nature of the relationship between the fishes and the different habitats. The criteria for the selection were the economical importance of each species in the catches of Cambodia and their occurrence in the experimental catches. The selected species are *Cirrhinus microlepis*, *Cyclocheilichthys apogon*, *Cyclocheilichthys enoplos*, *Henicorhynchus siamensis*, *Osteochilus melanopleurus*, *Paralaubuca typus*, *Trichogaster microlepis* and *Trichogaster trichopterus*.

iv. Fish identifications

Fish identification based on the FAO species guide for the fishes of the Cambodian Mekong (Rainboth, 1996) and all the scientific and Khmer names used here refer to the names as used in the FAO guide. In a number of cases, the information given on morphology and anatomy for a species did not suffice for certain identification. At that point, other information such as geographical, spatial and temporal distribution as well as data on behaviour and reported feeding habits were taken into consideration. Although this was not a problem in this study, regional variations in the use of the Khmer fish names are a potential source of misidentification.

v. Ichthyological parameters

- *Weight*

All the fish that were analysed in this study were weighed as soon as possible after retrieval of the catch using precision spring balances. When large quantities of one species occurred in the catches, a random sample of 20 specimens were individually weighed and measured; the rest was counted and weighed in bulk.

- *Length*

Total length and, except for some samples collected early in the study, standard length of all the fish caught were measured to the nearest millimetre, using measurement boards.

- *Condition Factor*

In isometrically growing fish, the exponent in the power equation describing the relation between the length of a fish and its weight is three. $W = q.L^3$ describes this relationship between the length L and the weight W. In case of allometry, the exponent b in the more general power equation $W = qL^b$ will differ from three. In these equations, q is a constant to be determined empirically.

The length-weight relationships were analysed for the eight species studied in more detail by using all the length and weight data collected over the whole year (September 1996-August 1997). The length-weight relationship was established by calculating the least squares fit through the data points of each species using the equation $y = qx^b$, where q and b are constants, y the weight and x the standard length. This length-weight equation is given for each species in the chart with the data points.

Once the general length-weight equation is determined for a species, it is possible to calculate the factor q_i for individual fish of known length and weight. The value of the factor q_i can be considered a measure for the condition of the fish, supposing that the weight of a fish is directly linked to its condition or “well-being” (King, 1995). The more a fish weighs at a given length, the greater will be its factor q_i.

The general length-weight relationship established using the data from the whole year can be used to predict a posteriori the weight for a fish of a given length. It can also be used to predict the mean weight for a sample of fish, given the mean length of the fish in that sample. This would allow monthly values of mean weight to be compared with the general predicted value for fish of the same mean length.

A mean weight-based condition factor (CF_w) can be calculated from this:

$$CF_w = (\text{mean weight}).(\text{predicted mean weight})^{-1}$$

The results of this comparison are given for each of the selected species. The condition factors that are thus calculated from monthly samples can allow the detection of monthly variations in the condition of fish. These variations may be related to fluctuations in food availability, reproductive activity of the species, etc. and would need to be completed with additional information for interpretation.

There are some limitations to this technique. The factors in the length-weight equations are estimates of the populations parameters based on a limited sample. For some species, the fit that was found is not very close. The monthly samples of fish are not of the same size, given that they consisted for a large part of the catches of unpredictable sizes of the experimental gillnet fishing. This source of bias was reduced towards the end of the period when every month large samples (more than 100 specimens) of each species were analysed.

- *Scalimetry*

Scales were collected from the same area on the bodies. The area between the rostral insertion of the dorsal fin and the lateral line was used to collect the scales for analysis. After removal, the scales were conserved in paper envelopes. Prior to mounting between two microscope slides, the scales were cleansed by rubbing between the top of two fingers and rinsing with clean water. Three to eight scales were mounted per slide, and these were then coded. Per specimen, one scale was selected for analysis. Regenerated scales were disregarded.

The scales were inspected for selection and analysed using a microfiche reader enlarging them 40 times. The median radius (distance from the focus to the edge of the rostral field along the median axis of the scale) was measured.

Results

i. Composition of the gillnet catches

The species composition and the total number of specimens of all the experimental gillnet fishing together are given in Table 2.7. Based on information from the literature, two other relevant characteristics are listed for each species: their main source of food and the ability of the species to tolerate low levels of dissolved oxygen.

In total, 7 744 specimens of 46 species were caught and identified. Of these, three species could only be identified with certainty to genus level, one species with 11 specimens only by its Khmer name, and two specimens of one species not at all. Nine of the collected species were unique catches with only one specimen, and 16 species could be considered occasional catches with fewer than ten specimens. Between 10 and 100 specimens were caught of each of the ten more common species, while 11 species are abundant in the catches with up to over 2 000 specimens. Two small schooling cyprinids (*Paralaubuca typus* and *Parachela siamensis*) make up over half of the total number of fish in the catch.

Table 2.7 Fish species with number of specimens caught during the experimental gillnet fishing. Codes: P: plankton community, B: benthic community, A: Aufwuchs community, H: plant community, C: prey community, ?: unknown (see text)

Species	Total number caught with gillnets	Percentage of total catch by number	Percentage of total catch by weight	Main food source(s)	Resistance to low dissolved oxygen concentrations
Anabas testudineus	33	0.4	0.9	C	very high[1]
Arius truncatus	1	0.0	0.0	C	low (high?)
Barbodes gonionotus	8	0.1	0.1	H / A	low (high?)
Cirrhinus microlepis	3	0.0	0.8	P / H / C	low
Coilia lindmani	402	5.2	4.3	P	low
Crossocheilus reticulatus	1	0.0	0.0	A / P	low
Cyclocheilichthys apogon	362	4.7	3.4	P	low
Cyclocheilichthys enoplos	9	0.1	1.7	C / B	low
Dangila lineata	32	0.4	0.9	P / A	low
Dangila spilopleura	9	0.1	0.1	P / A	low
Esomus longimanus	12	0.2	0.1	P / C	low
Esomus metallicus	15	0.2	0.2	P / C	low
Hampala dispar	2	0.0	0.2	C	low
Hampala macrolepidota	16	0.2	2.1	C	low
Hemipimelodus borneensis	1	0.0	0.0	B	high
Henicorhynchus siamensis	276	3.6	8.0	H / P / A	low
Hypsibarbus lagleri	12	0.2	0.9	P / B	low

1 Very high=facultative air-breathing.

Species	Total number caught with gillnets	Percentage of total catch by number	Percentage of total catch by weight	Main food source(s)	Resistance to low dissolved oxygen concentrations
Kryptopterus cheveyi	6	0.1	0.1	C	low
Kryptopterus schilbeides	2	0.0	0.0	C	low
Labeo erythropterus	1	0.0	0.1	A / P	low
Luciosoma bleekeri	1	0.0	0.0	C	low
Lycothrissa crocodilus	46	0.6	0.9	C	low
Macrognathus sp.	1	0.0	0.0	B	low
Mystus mysteticus	14	0.2	0.2	A	low
Notopterus notopterus	2	0.0	0.1	C	very high
Osteochilus hasselti	105	1.4	4.2	H / A	low
Osteochilus melanopleurus	8	0.1	1.5	H / P	low
Oxyeleotris marmorata	1	0.0	0.0	C	high
Pangasius sp. (2)	2	0.0	1.6	B	high
Parachela siamensis	2 358	30.4	21.4	P	low
Paralaubuca typus	1 897	24.5	16.3	P	low
Polynemus longipectoralis	17	0.2	0.4	C	low
Pristolepis fasciata	9	0.1	0.2	H	high
Pseudambassis notatus	157	2.0	0.4	C	high
Puntius brevis	563	7.3	4.0	B / H	high
Rasbora aurotaenia	7	0.1	0.1	C	low
Rasbora caudimaculata	2	0.0	0.2	C	low
Rasbora sp.	1	0.0	0.0	P (?)	low
Systomus orphoides	1	0.0	0.0	H	low
Thynnichthys thynnoides	2	0.0	0.1	A / P	low
Trichogaster microlepis	514	6.6	9.2	P / C	very high
Trichogaster pectoralis	2	0.0	0.1	H (?)	very high
Trichogaster trichopterus	454	5.9	4.0	P / C	very high
Undetermined # 1	2	0.0	0.0	?	?
Undetermined # 2	11	0.1	0.1	?	?
Xenentodon cancila	364	4.7	11.1	C	high
Total	*7 744*	*99.7*[2]	*100.0*		

[2] Does not add up to 100 due to rounding.

Information from the literature on specific feeding habits is for most species fragmentary and often contradictory, resulting in a low usability as a factor for characterizing fish catches in different habitats. Only few species seem to have feeding habits limited to one group of organisms or matter. Therefore, the feeding habits of the fish are not approached from their own characteristics but from the main communities in the floodplain ecosystem providing feeding opportunities. Of the categories of direct food sources as listed by Welcomme (1985), five are particularly relevant in floodplains (Table 2.8). Species depending on the five categories are present in the gillnet catches, with emphasis on species hunting for prey and on those feeding on the plankton community.

Table 2.8. Relevant food categories and their composition

Category	Composition
Plankton community	▪ phytoplankton ▪ zooplankton ▪ drift organisms
Benthic community	▪ mud and associated micro-organisms ▪ coarse detritus, decomposing vegetable or animal remains ▪ insects and small crustaceans
Aufwuchs community of epilithic / epiphytic organisms and the periphyton	▪ epiphytic or epilithic algae ▪ associated micro-organisms, insects, crustaceans, etc. ▪ this category includes the root flora and fauna of floating vegetation as well as some detrital aggregate, that slimy coating found on submerged parts of plants or rocks which consists of detritus, bacteria and algae
Plant community	▪ plants including filamentous algae and submerged, floating or emergent vascular plants
Prey community	▪ neuston, surface living insects and larvae at the water / air interface ▪ fish, including eggs, larvae and juveniles ▪ other vertebrates, including amphibians, reptiles, birds and small aquatic mammals

Source: Welcomme, 1985.

The assessment of tolerance for low dissolved oxygen concentrations is made based on the known presence of anatomical or physiological adaptations to use atmospheric oxygen for breathing or of behavioural adaptations to use the better oxygenated surface layers of the water. Unambiguous for those species with clear adaptations of either type, there is a degree of arbitration in the classification of species' resistance of low oxygen conditions as low or high. This classification was based in this case mainly on information on the timing of movements in and out of the flooded areas and the associated changes in overall water quality. Most species encountered are obligate aquatic respirators, and only a small number showed higher tolerance for low dissolved oxygen levels.

ii. Selectivity of gillnets – comparison of experimental gillnet catches with those by other types of gear

On a number of occasions, samples were taken from commercial traps in the same general area as where the experimental gillnet fishing was done (for timing and location see Annex 3). Of the 46 species caught by the experimental gillnets, 27 were also caught by the traps. The average weight for species caught in common by gillnets and traps is given in Table 2.9. Where sufficiently large numbers (> 5) of specimens were available, a Student's *t*-test was done to assess whether the difference in the average weight for fish from the different gear is statistically significant (á = 0.05).

This is the case for half of the species for which a *t*-test could be done (Table 2.9). For only one species (*Osteochilus hasselti*) the average weight in the gillnet catches is significantly higher than that of the trap catches, but only by about 16 percent; in all other cases there is no significant difference or the average weight from the traps is higher than that from the gillnets. There is large variation in the factor by which the significantly different average weights from both gear differ: fish from traps are 1.18 to 25.8 times heavier than same-species fish from the gillnets.

Table 2.9 Species common to the experimental gillnet catches and the samples collected from traps. All habitats, September 1996-August 1997

Species	Total number caught with gillnets	Total number caught with traps	Average weight (g) in gillnets	Average weight (g) in traps	Difference significant ($p < 0.05$)
Anabas testudineus	33	1	19.0	26.0	-
Barbodes gonionotus	8	15	4.4	113.5	yes
Cirrhinus microlepis	3	37	183.3	139.3	-
Coilia lindmani	402	1	7.2	8.8	-
Cyclocheilichthys apogon	362	130	6.2	12.1	yes
Cyclocheilichthys enoplos	9	448	124.1	72.9	no
Dangila lineata	32	207	18.9	16.1	no
Hampala dispar	2	1	61.0	32.0	-
Hampala macrolepidota	16	2	88.8	39.0	-
Henicorhynchus siamensis	276	83	19.2	50.4	yes
Hypsibarbus lagleri	12	120	48.9	97.2	yes
Kryptopterus schilbeides	2	11	6.6	6.4	-
Lycothrissa crocodilus	46	32	12.5	7.4	no
Mystus mysteticus	14	2	8.2	20.5	-
Osteochilus hasselti	105	95	26.7	23.1	yes
Osteochilus melanopleurus	8	76	128.4	130.2	no
Oxyeleotris marmorata	1	4	30.8	80.3	-
Parachela siamensis	2 358	13	6.0	5.7	no
Paralaubuca typus	1 897	251	5.7	6.7	yes
Pristolepis fasciata	9	11	15.8	22.8	no
Pseudambassis notatus	157	1	1.8	1.8	-
Puntius brevis	563	70	4.7	11.0	yes
Rasbora aurotaenia	7	1	6.9	4.2	-
Thynnichthys thynnoides	2	11	34.5	74.8	-
Trichogaster microlepis	514	52	11.9	12.9	no
Trichogaster trichopterus	454	43	5.9	11.6	yes
Xenentodon cancila	364	107	20.2	19.5	no
Total	*7 656*	*1 825*			

The trap catches sampled contained 11 species that were not caught by the experimental gillnets (Fig. 2.1).

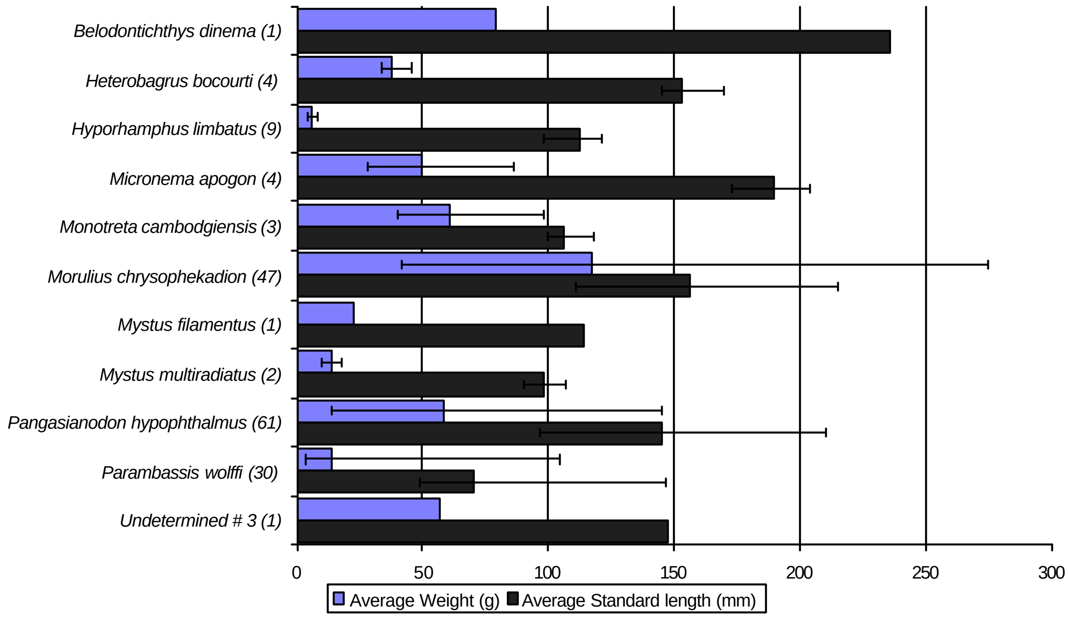

Figure 2.1 Species caught only with traps. Average weights and average standard lengths. Bars indicate minimum and maximum values for each species in the catches

The species caught only by traps are rather large in comparison with the average catch by the experimental gillnets; the average standard length for specimens of all the 11 species is more than 100 mm. None of the species only caught by traps are feeding predominantly on the plankton community. Benthic community feeders are as common as species feeding on prey (Table 2.10).

Table 2.10 Fish species caught exclusively by the traps. Codes: P: plankton community, B: benthic community, A: Aufwuchs community, H: plant community, C: prey community, ?: unknown (see text)

Species	**Total number caught in traps**	**Main food source(s)**	**Resistance to low dissolved oxygen concentrations**
Belodontichthys dinema	1	C	low
Heterobagrus bocourti	4	B	low
Hyporhamphus limbatus	9	C	high
Micronema apogon	4	C	low
Monotreta cambodgiensis	3	B / H	low
Morulius chrysophekadion	47	B / P	low
Mystus filamentus	1	C	low
Mystus multiradiatus	2	A	low
Pangasianodon hypophthalmus	61	C / B / H	low
Parambassis wolffi	30	C / B	high
Undetermined # 3	1	?	?

Table 2.11 Trap catches composition. Number of species for each habitat (*n*) and their percentages by number of specimens (% *n*) and by weight (% *w*) in the traps catches, categorized by their facultative air breathing ability and by food community. Samples taken between 18 December 1996 and 8 January 1997. Percentage totals for the feeding communities do not add to 100, as the categories are not mutually exclusive

	Habitat					
	rice field			forest		
	n	*% n*	*% w*	*n*	*% n*	*% w*
Respiration						
Exclusive aquatic	21	95	97	17	100	100
Facultative air	2	5	3	1	0	0
Feeding community						
Plankton	9	64	53	7	44	50
Benthic	4	10	10	5	78	79
Aufwuchs	3	32	43	6	8	7
Plants	6	19	25	7	28	26
Prey	13	24	27	8	58	53
Total	23			18		

Facultative air breathers make up only a very small part of the trap catches, both in the rice field and the forest habitats. Catches in the forest are dominated by species feeding on the benthic community, while planktivorous species are the most abundant species in the rice field.

The results from the experimental gillnet fishing split between surface panels and bottom panels are given in Table 2.12. The results of fishing with additional local gillnets are presented in the same table.

Table 2.12 Catch composition (numbers) by mesh sizes for surface, bottom and panels of local gillnets

	Surface panels		Bottom panels		Local gillnets	
Mesh size (mm)	**% of catch (n) within the panel**	**% of total exp. gillnets catch (n)**	**% of catch (n) within the panel**	**% of total exp. gillnets catch (n)**	**Number of species**	**% of catch (n) within the panel**
10	91.2	76.8	90.0	14.2	-	-
20	7.7	6.5	9.8	1.6	20	94.5
30	1.1	0.9	0.2	0.0	9	5.5
40	0.0	0.0	0.0	0.0	0	0.0
50	0.0	0.0	0.0	0.0	0	0.0
60	0.0	0.0	0.0	0.0	-	-
70	0.0	0.0	0.0	0.0	-	-
80	0.0	0.0	0.0	0.0	-	-
100	0.0	0.0	0.0	0.0	-	-

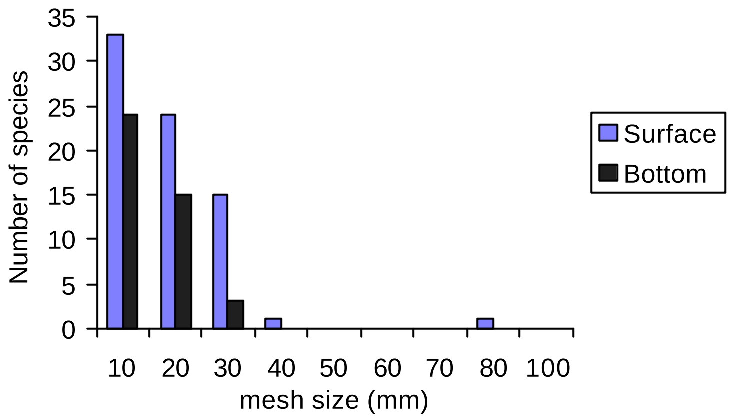

Figure 2.2 Number of species in the experimental gillnets by mesh size and position of the panels

Over three quarters of all fish caught in the experimental gillnet fishing were collected from the smallest mesh size section of the surface panels. Over 90 percent of the fish caught in a panel was found in the smallest mesh size, 10 mm for the experimental gillnets and 20 mm for the local gillnets. No fish were caught in the sections of the panels with mesh sizes between 50 and 70 mm, or in the 100 mm section. The catches in the 40 and 80 mm sections consist both of a single fish.

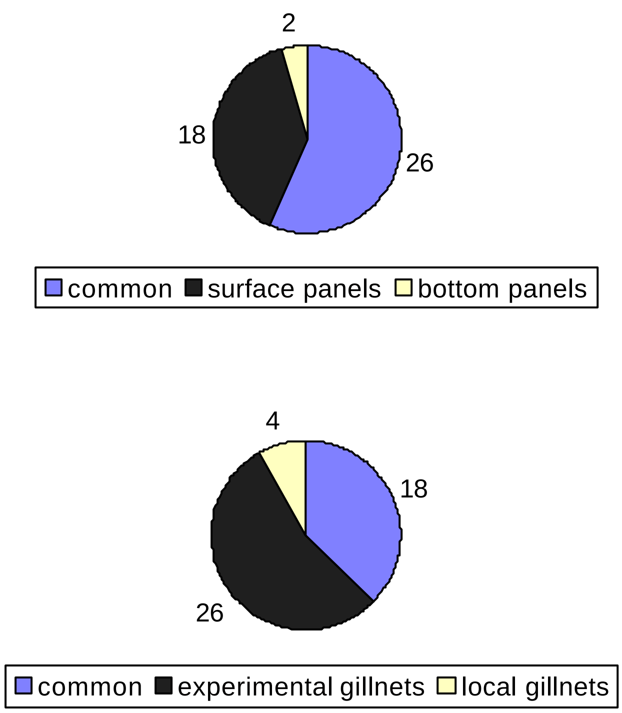

Figure 2.3 Number of species common and specific for the surface and bottom panels in the gillnet catches (upper) and for the surface panels of the experimental gillnets and the local gillnets (lower). The numbers indicate the number of species for each category

Bottom panels caught fewer species than panels at the surface (Fig. 2.2), but mostly they were the same species. The local gillnets produced 22 species, which is less than half of the number of species caught in the experimental gillnets; however, four species were only found in the former.

The fishing effort was not equal for the different panels. Bottom panels were hardly used in certain habitats (scrubland, forest) because they would become entangled in the vegetation. In general, when bottom panels were used, only one panel was sunk to the bottom instead of three as used for the surface. The local gillnet panels were used occasionally, when conditions allowed, one panel at the time, and only on the surface, at a distance away from the experimental panels in the same habitat type.

iii. Habitat-related results of the experimental gillnet fishing

The largest number of species in the experimental gillnet catches was found in the floodplain pool, while scrubland, lotus field and the coastal lake all recorded the lowest number of species. The very low number of the forest is not very representative since it is based on a single sampling. The floodplain pool catches also hold the largest number of facultative air breathing species. The proportion of air breathing species in the total number does not vary much for any of the habitats.

Table 2.13 Number of species (*n*) for each habitat and their percentages by number of specimens (*% n*) and weight (*% w*) in the gillnets catch, categorized by their facultative air breathing ability and by food community.

	Habitat											
	Scrubland			**Grassland**			**Floodplain pool**			**Lotus field**		
	n	***% n***	***% w***	***n***	***% n***	***% w***	***n***	***% n***	***% w***	***n***	***% n***	***% w***
Respiration												
Exclusive aquatic	13	71	76	22	79	87	23	90	89	13	95	92
Facultative air	3	29	24	3	21	13	4	10	11	3	5	8
Feeding community												
Plankton	7	82	67	12	85	69	10	72	60	7	66	46
Benthic	1	5	2	2	1	2	3	18	15	3	8	30
Aufwuchs	4	12	25	6	8	20	5	6	9	2	4	6
Plants	4	16	24	6	9	25	5	23	19	5	13	11
Prey	8	40	48	11	31	39	14	19	33	7	25	29
Total	16			25			27			16		

	Habitat											
	Rice field			**Forest**			**Lake, coastal**			**Lake, pelagic**		
	n	***% n***	***% w***	***n***	***% n***	***% w***	***N***	***% n***	***% w***	***n***	***% n***	***% w***
Respiration												
Exclusive aquatic	23	96	95	0	0	0	14	96	92	21	86	76
Facultative air	3	4	5	3	100	100	2	4	8	3	14	24
Feeding community												
Plankton	13	89	83	1	44	29	9	86	79	12	89	81
Benthic	3	3	4	0			2	8	5	4	4	12
Aufwuchs	6	4	9	0			3	3	12	4	3	9
Plants	5	6	10	1	13	22	4	11	18	5	6	14
Prey	10	9	13	2	88	78	8	8	17	12	21	43
Total	26			3			16			24		

Note: The totals for the feeding communities do not add up to 100 as the categories are not mutually exclusive

Species feeding on plankton communities make up the largest group for all habitats, both by number of specimens as by weight. In some habitats (rice field and the two lake habitats), this dominance is more pronounced than in others. The highest number of prey eating species was found in the catches from the scrubland, with half of the species fitting in this category. Also in the floodplain pool, the benthic community plays a considerable role as a food source. Herbivorous species take up only the third rank in most habitats; they are somewhat more present in the coastal area of the lake and in the floodplain pool. The benthic and Aufwuchs communities are of less importance in most habitats. However, fish feeding on the benthic community make up almost one third of the weight of the fish caught in the lotus field, but these are mostly big fish as their share in the total number is much smaller. In the floodplain pool, they make up 15-18 percent of the catch. Species feeding on the Aufwuchs community make up a quarter and one fifth of the weight of the catch in the scrubland and the grassland respectively.

Some caution is required with the interpretation of these feeding community results. The feeding habits are those reported for the encountered species in a variety of ecosystems, but almost no reports on feeding habits of these species in the studied habitats are available. Their classification as belonging to one or more categories does not imply that this is effectively the case in the habitats of the floodplain, or at all times and stages of their development.

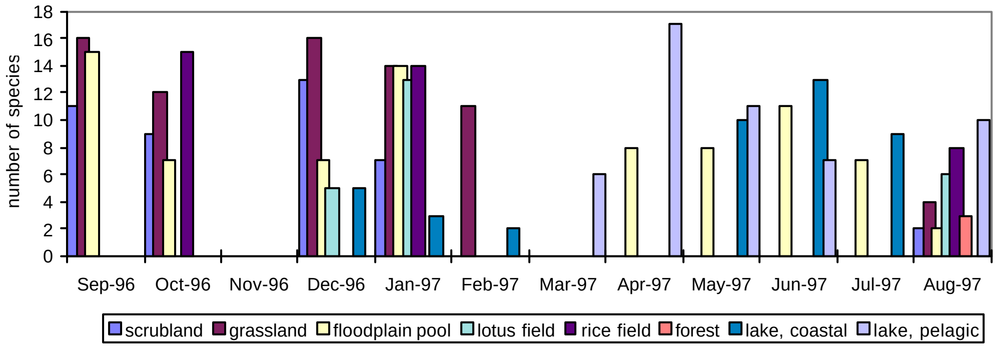

Figure 2.4 Number of species in the experimental gillnet catches per habitat and per month

Species composition of the experimental gillnet fishing per habitat shows considerable fluctuations over time. The pelagic lake has the highest number of species present in the catches at any time but its total number of species is lower than that of e.g. the rice field. (Fig. 2.4).

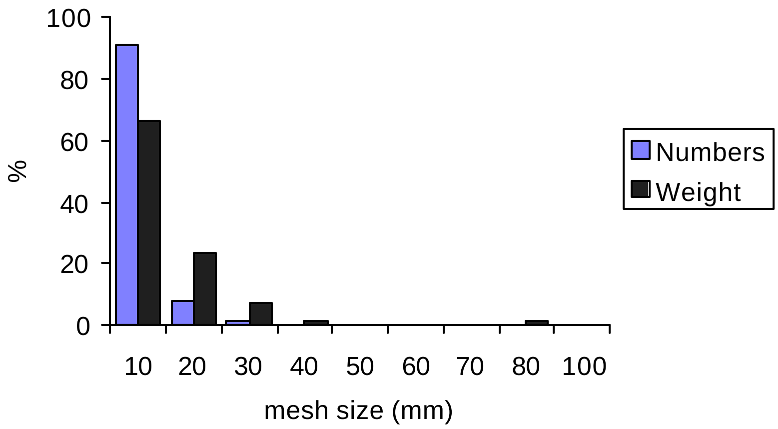

Figure 2.5 Experimental gillnet catches by mesh size as percentage of total catch by numbers and by weight

Over 90 percent of all 7 744 specimens and two thirds of the total ichthyomass of 66.459 kg were caught in the section of the panels with the smallest mesh size. No fish were caught in the 50, 60, 70 or 100 mm mesh size sections, and the catches in the 40 and 80 mm sections consist each of one rather big fish.

The average soaking time for the experimental gillnets was three hours and 18 minutes. On average, and with little variation, the nets were set at 0527 hours and retrieved around 0845 hours.

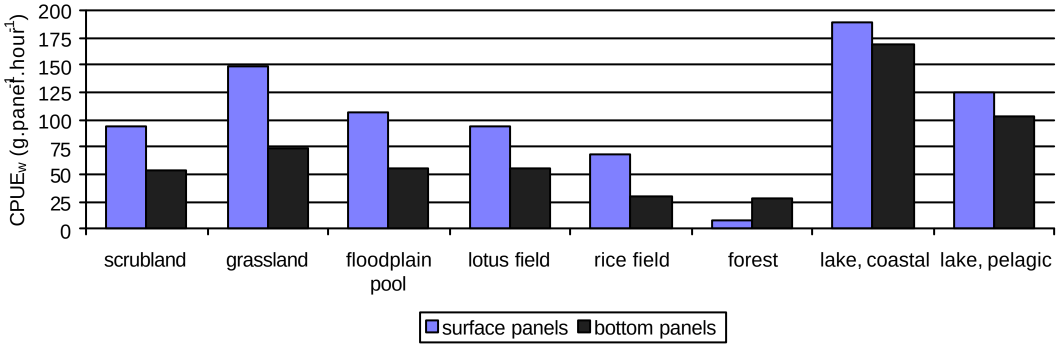

Figure 2.6 Average catch per unit of fishing effort by weight ($CPUE_w$) ($g.panel^{-1}.hour^{-1}$) for all the habitats

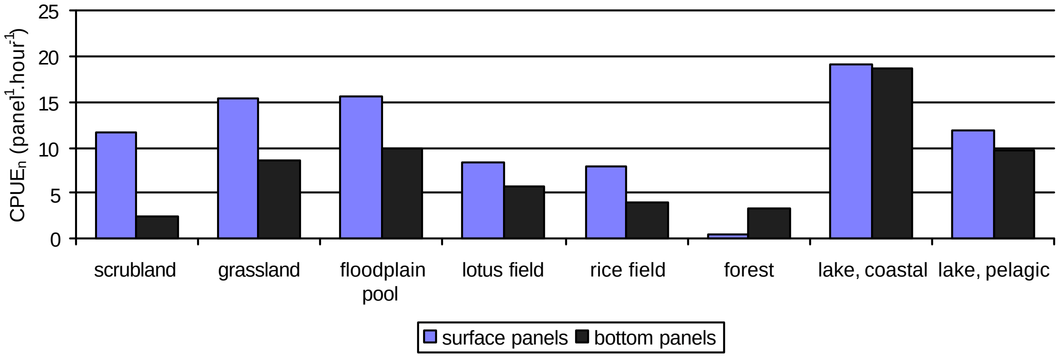

Figure 2.7 Average catch per unit of fishing effort by numbers ($CPUE_n$) ($panel^{-1}.hour^{-1}$) for all the habitats

The average catch per effort results are calculated for each habitat based on all the available data from all experimental gillnet fishing in that habitat. The results, based on both total weight of the catch ($CPUE_w$) and on the number of fish specimens in the catch ($CPUE_n$), are given in Fig. 2.6 and 2.7. In general, there is large variation in CPUE. In Table 2.14, the calculated average CPUE-values are presented, together with the total number of panels used in the sampling (each time a panel was used was counted as a unit) and the extreme values for the CPUE that are found. As remarked earlier, the number of samples is rather small for some habitats, especially for the forest.

Table 2.14 CPUE for the habitats and its variation. Units are $g.panel^{-1}.hour^{-1}$ ($CPUE_w$) and $panel^{-1}.hour^{-1}$ ($CPUE_n$)

	Surface panels						
	$CPUE_w$			$CPUE_n$			Number
Habitat	**mean**	**min.**	**max.**	**mean**	**min.**	**max.**	**of panels**
Scrubland	94.8	21.5	261.1	11.6	1.8	35.8	24
Grassland	148.8	2.7	374.6	15.3	0.5	29.3	24
Floodplain pool	106.4	11.6	218.1	15.5	0.9	29.3	30
Lotus field	93.5	19.0	239.1	8.3	2.4	17.7	9
Rice field	67.3	16.3	129.2	8.0	2.4	12.9	6
Forest	7.7	1.3	12.6	0.5	1.3	0.9	3
Lake, coastal	189.1	5.3	732.9	19.1	1.0	65.0	18
Lake, pelagic	125.9	16.6	351.9	11.9	1.8	32.9	21
	Bottom panels						
	$CPUE_w$			$CPUE_n$			Number
Habitat	**mean**	**min.**	**max.**	**mean**	**min.**	**max.**	**of panels**
Scrubland	53.9	47.4	60.3	2.4	1.6	3.3	2
Grassland	74.0	5.3	208.2	8.6	1.2	26.8	7
Floodplain pool	55.0	0.0	140.6	9.9	0.0	24.9	8
Lotus field	56.4	3.5	149.5	5.6	0.6	14.2	3
Rice field	30.5	17.0	44.0	4.0	1.8	6.2	2
Forest	27.8	-	-	3.3	-	-	1
Lake, coastal	168.0	12.9	544.6	18.7	2.4	58.8	6
Lake, pelagic	102.4	8.0	249.2	9.7	0.3	25.6	7

The results show that the fish caught in the lake, and even moreso in the coastal zone than in the pelagic area, are not only heavier but also more abundantly caught than in the other habitats. Bottom nets are in general less productive than surface panels, except in the lake habitats where the difference is very small. Of the floodplain habitats, the grassland and the floodplain pool were the most productive ones in terms of CPUE. The agriculture lands (rice field and lotus field) had the lowest production, and the scrubland took an intermediate position.

The seasonal variation in CPUE in the floodplain pool follows different patterns depending on the weight or the numbers as basis for calculation. It is clear however that there is a sharp drop in CPUE in August (Fig. 2.8).

Figure 2.8 Seasonal evolution of $CPUE_w$ (top) and $CPUE_n$ (bottom) for the floodplain pool. Mean CPUE-values for each month, based on three surface panels

Discussion: floodplain gillnet fisheries

The experimental gillnet catches were dominated both in terms of numbers as by species by small cyprinids. Most fish were caught in the smallest mesh sizes. Species of all feeding guilds were present in all habitats but there were considerable differences in the importance each group has in the total catch. The largest number of species was found in the floodplain pool; however, it is not clear whether this is due to the special characteristics of this habitat as discussed above, or simply to the fact that this habitat was the most sampled.

The CPUE values of the experimental gillnet panels do not provide a realistic estimate of the productivity of gillnets in these waters. Ninety percent of the numbers were caught in the section of the gillnets with the smallest mesh size of 10 mm, which made up only one ninth of the total surface of the panels. The CPUE of gillnets consisting only of such mesh size would probably be about ten times higher.

The large variation in CPUE within habitats is in part explained by the presence or absence of schooling species. The number of samples and the time between samples did not allow a rigorous analysis of the sources of variation between the CPUEs as recorded in the different habitats. The differences in CPUE also seem related to the degree of diversity within the habitats: the lowest production was found in the habitats where diversity is actively reduced by agricultural activities (rice and lotus fields).

The floodplain pool shows a sharp drop in CPUE for August. This coincides with the flooding of the pool and is probably due to the “dilution” of the fish present in the

pool in the low-in-fish lake water, and to the abrupt change in water quality, which may have resulted in fish mortality.
Gillnets are highly selective fishing gear. The results from the experimental gillnet fishing for numbers of species and CPUE for the different habitats therefore only provide information on the composition of the gillnet catches and the productivity of these gear. They do not allow drawing conclusions about species diversity in the different habitats, or about the potential of such habitats for use of other gear, and about the effects of the conversion of habitat types on catches and biodiversity.

The selectivity of the gillnets as compared with other gear is not only in terms of species but also in terms of size of fish. The composition of the catches based on the feeding communities for the species is shown in Fig. 2.9. Details of the catch composition for all the habitats are discussed in the section on habitats. The two habitats for which the species composition in terms of feeding communities can be compared show considerable differences depending on the gear (Fig. 2.10).

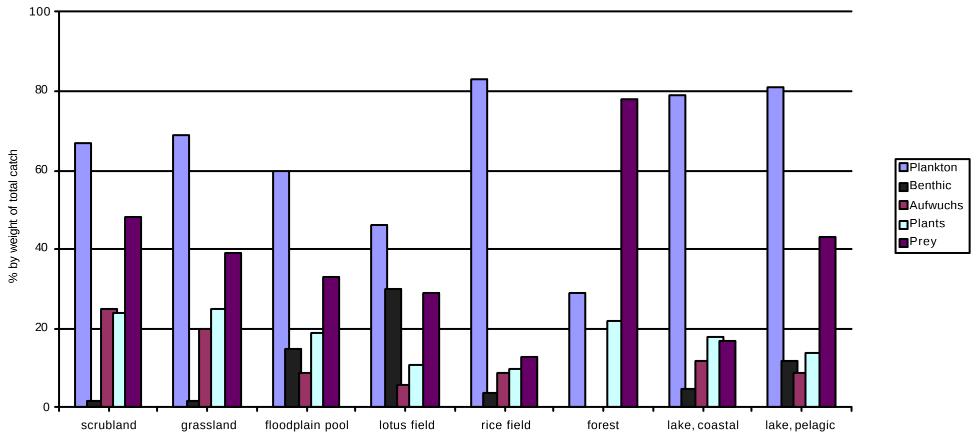

Figure 2.9 Composition of the experimental gillnet catches by main trophic communities, as percentage by weight of the total catch for each habitat. Based on data from Table 2.13

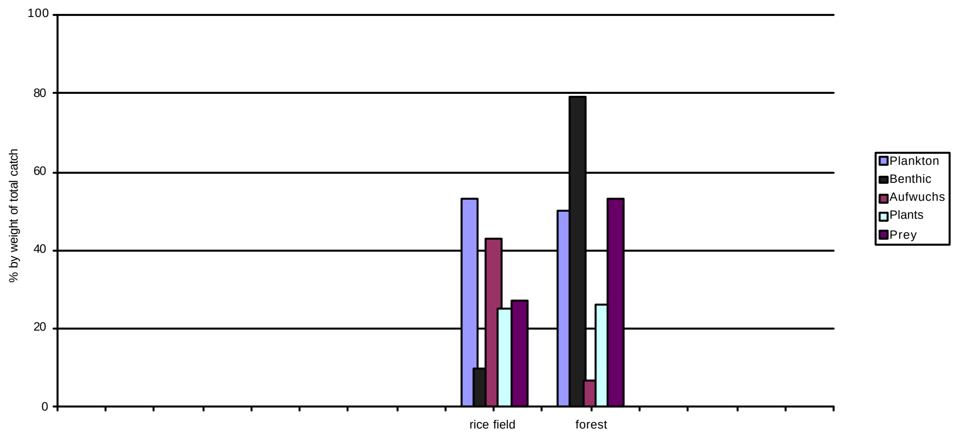

Figure 2.10 Composition of the catches by traps by main trophic communities, for the habitats where traps were sampled. Based on data from Table 2.11

Facultative air breathing species are present in all habitats. The species with higher tolerance to low dissolved oxygen levels and the facultative air breathing species have significant advantages in taking up niches that are created in the freshly flooded floodplain areas. The adaptations to tolerate low levels of dissolved oxygen allow these species to occupy specific niches in the flooded ecosystem that offer particular advantages for reproduction and feeding, opportunities for geographical distribution and protection from predation by less adapted predator fish species (Welcomme 1985, Rainboth 1996, Jobling 1995).

The total number of species encountered in any given habitat is much higher than the number of species found in the same habitat at any given time. There are shifts in the species composition throughout the season, shifts that are closely linked to the water quality in the floodplain habitats and to the migration habits of many species. For the floodplain pool for instance, a total of 27 species was recorded; however, no more than 15 species were found together at any time. The pelagic area of the lake has the highest number of species present in the catches at any time but the total number of species is lower than that of for instance, the rice field. This indicates that the variation in the species composition over time is not the same in all habitats. The difference in species numbers caught with bottom panels and local gillnets is probably attributable to the difference in soaking time of these two gear rather than to specific selective capacity. However, the species composition of the fish population near the bottom may differ from that near the surface.

There is evidence that vegetable detritus is contributing only for a small amount to the growth of at least some groups of detritivorous fish. Most of the carbon constituting these fish originates from phytoplankton (Forsberg *et al*., 1993; Hamilton *et al*., 1992), even if phytoplankton constitutes only a small part of their diet. This has been attributed by some authors to the poor digestibility of the vegetable detritus.

Selected data and information on eight species of economic importance

During the experimental gillnet fishing a substantial amount of data was collected on the biology and the ecology of many species. Mostly, this was an outcome of the activity itself, but in some cases additional specimens were collected for analysis from a variety of sources (local markets, intermediaries, traps, etc.) in Siem Reap. This was done in particular for economically important species that were only occasionally present in the experimental catches.

In this section, the data collected from all sources on fish biology and ecology are presented for the eight species. In addition to the original data, information from the literature is presented, though without the ambition of providing a review of each species. The purpose is rather to provide a fuller picture of these species and on their relationship with the habitats, which are the subject of this study.

The economic importance of the fish in Cambodia has been discussed in the introduction. Table 2.15 gives an overview of the important species of the medium and large-scale fisheries. Three species that are not in this list have been selected to be included here because of their importance in gillnet fisheries.Table 2.15 Medium and large-scale fisheries. Species composition (top-ten species only) and value of the

1995/96 season (after Deap *et al.*, 1998). Species names and Khmer names as given in original document

	Species	Percentage of total catch	
		By weight	By value
1	*Trey riel* (*Henicorhynchus* spp.)	21	9
2	*Trey chadaur* (*Channa micropeltes*)	9	19
3	*Trey chhkauk* (*Cyclocheilichthys enoplos*)	9	8
4	*Trey khnong veng* (*Dangila* spp.)	6	2
5	*Trey krum* (*Osteochilus* spp.)	4	2
6	*Trey proul* (*Cirrhinus microlepis*)	3	4
7	*Trey pra* (*Pangasius* spp.)	3	3
8	*Trey chhpin* (*Barbodes gonionotus*)	3	2
9	*Trey sluk russey* (*Paralaubuca typus*)	3	1
10	*Trey raws* (*Channa striata*)	2	6
	Total	*63*	*56*

The eight species described here are *Cirrhinus microlepis*, *Cyclocheilichthys apogon*, *Cyclocheilichthys enoplos*, *Henicorhynchus siamensis*, *Osteochilus melanopleurus*, *Paralaubuca typus*, *Trichogaster microlepis* and *Trichogaster trichopterus*.

i. *Cirrhinus microlepis* (Sauvage, 1878)

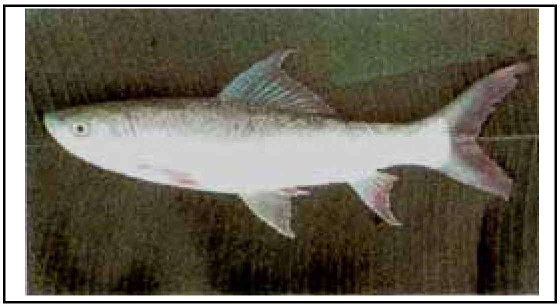

Figure 2.11 *Cirrhinus microlepis* (from Vittayanon, 2000)

Description

Family Cyprinidae, genus *Cirrhinus* (Oken, 1817). This family is the most developed one in Cambodia in terms of numbers of genera, species and number of individuals.

Cirrhinus microlepis is known by two different names in Khmer: *trey krawlang* for juveniles and *trey proul* for adult specimens.

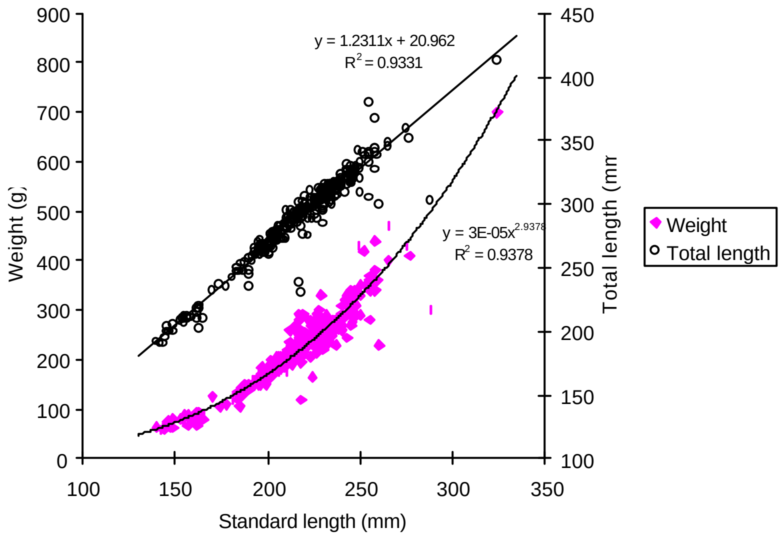

Figure 2.12 *Cirrhinus microlepis*. Length-weight plot and equations for the fish analysed in this study (n = 331)

Almost all 331 fish considered for this analysis came from traps in the lake and the floodplain near Siem Reap. Only two specimens were caught in the experimental gillnet fishing. The least squares power trend line of the standard length-weight plot (Fig. 2.12) shows that the growth of the fish analysed is nearly isometric. Maximum total length for the species is reported to be 65 cm (FishBase, 2000). Fig. 2.13 shows that there is large variation in the median radius of the scales for fish of the same standard length. The lifespan of *Cirrhinus microlepis* is believed not to exceed 11 years (Nguyen and Nguyen, 1991). The species shows slow growth after the seventh year.

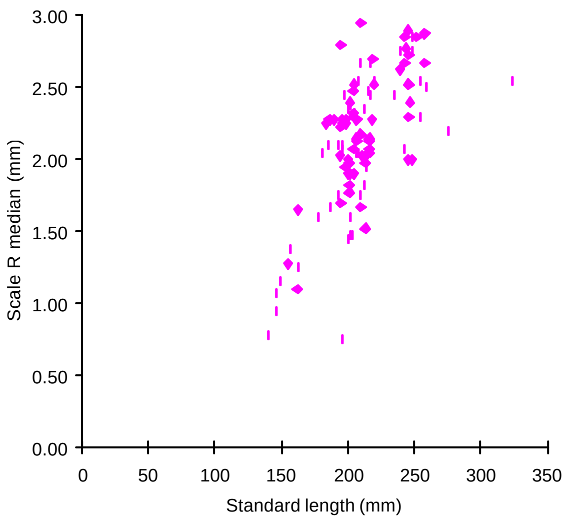

Figure 2.13 *Cirrhinus microlepis*. Body length and scales median radius (n = 109)

Feeding ecology

Cirrhinus microlepis is reported to be essentially vegetarian (leafy plant matter and phytoplankton) but also to eat insects, shrimps and worms. Bardach (1959) classifies the species as microphage, feeding on algae and plant fragments. Its digestive tract shows characteristics that meet the requirements of a herbivorous diet. Nguyen and Nguyen (1991) report that 94-99 percent of gut contents is made up of organic detritus, and the remainder of phytoplankton.

Flooded vegetation provides an important feeding ground for this species. Shifts in its diet composition towards phytoplankton are likely to occur in function of the availability of leafy matter, which is mostly absent during the dry season period.

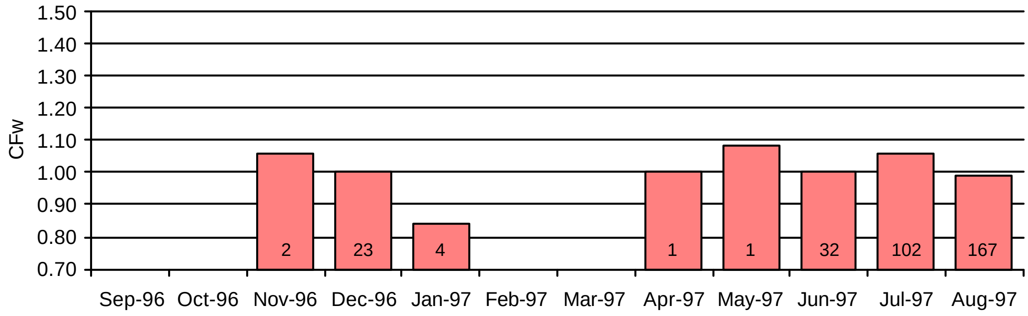

Figure 2.14 *Cirrhinus microlepis*. Monthly condition factor (CF_W). The figure in each column indicates the number of fish involved for that month

The condition factor (Fig. 2.14) does not show much variation throughout the year for the sampled fish, except for the four specimens in January 1997 that were markedly lighter than what could be expected based on their length.

Reproductive ecology

All the fish observed for sexual maturity in the markets of Siem Reap from June to September 1997 were immature and in most cases, sex was indeterminable. *Cirrhinus microlepis* is believed to spawn in the northern Mekong rapids from Sambor to the Khone falls. The fish move with the Mekong floods and re-enter the Tonle Sap mainly for feeding in the rich feeding grounds of the inundated areas. When the water recedes (December to March), they leave the Tonle Sap lake and channel in waves and migrate up the Mekong. Like in the case of many Cambodian migrating fishes, this migration coincides with the waxing moon (Bardach, 1959). There are reports that *Cirrhinus microlepis* shows four-year cycles of abundance. It appears that clearer water and bottoms other than those that can be found in the Tonle Sap are required for their spawning. The age of sexual maturation and first spawning is reported to be the third or forth year (Nguyen and Nguyen, 1991).

Fisheries

This fish is mostly caught with seines, traps and hook and line. It is almost completely absent from the experimental gillnet catches, possibly due to its ability as a fast swimmer, capable of jumping many feet in the air on order to clear obstacles. Its catches are reported to be declining. Most of the catch of *Cirrhinus microlepis* is done in the *dai* fisheries during its spawning migration, and with traps. Fish caught with *dais* or traps are at times kept alive in cages for later sale. They are usually marketed fresh and sometimes dried and salted (FishBase, 2000).

Van Zalinge and Thuok (1999) write that the catch of medium-sized fishes such as *Cirrhinus microlepis* has gone down due to overfishing.

Potential for aquaculture

There is contradictory information from the literature about the ability of *Cirrhinus microlepis* to persist in impoundments. It is not used in aquaculture in Siem Reap, and fish caught in the lake are immediately marketed. It is not mentioned in the list of major aquaculture species in Cambodia (Nam and Thuok, 1999). Recent studies in Lao PDR (Chapman *et al*. 1996) show progress in the induced breeding of this species using brood stock caught from the Mekong. Progress is also reported on the techniques for growing *Cirrhinus microlepis* fry obtained from induced breeding in earthen ponds. The size of this fish, its presumed diet, the fact that it will sexually mature in ponds and the high appreciation of the fish as food make that *Cirrhinus microlepis* has potential for use as an indigenous species in aquaculture.

Importance

This fish is important in the fisheries of Cambodia. *Cirrhinus microlepis* makes up 3 percent of the total catch volume of middle and large-scale fisheries (Deap *et al*., 1998) and as such is the sixth most important species for inland fisheries. It is one of the most popular food fish, much appreciated because of its attractive coloration and graceful lines as well as its food quality (Smith, 1945). *Cirrhinus microlepis* is one of the more expensive fish. It is sold at about 2 500 Riel/kg in markets along the lake. It is available from the lake throughout most of the year, except during the low-water period when most fish have migrated to the Mekong for reproduction.

Conclusion

The importance of the flooded area for *Cirrhinus microlepis* lies in the feeding opportunities it offers. Being primarily detritivorous, habitats with large standing crops of vegetation in the flood area will offer the most opportunities. For this species, preservation of the scrubland and forest vegetation is to be given priority as a management measure at the level of the Tonle Sap lake and canal. The other habitats in the flood area seem to offer less feeding potential for this species. In the floodplain pools and the permanent lake, *Cirrhinus microlepis* has to rely mostly on phytoplankton for feeding. It is probably not among the first fish to enter the inundated areas but does so during the third phase of flooding (see Part I). Unhindered migration up and down the Mekong is essential for its survival as a dominant species in the Tonle Sap.

ii. ***Cyclocheilichthys apogon*** **(Valenciennes, 1842)**

Figure 2.15 *Cyclocheilichthys apogon* (from Vittayanon, 2000)

Description
This cyprinid species belongs to the genus *Cyclocheilichthys* (Bleeker, 1859), which is well represented in the ichthyofauna of Cambodia. Some species in this taxon are abundant and form an important element in the food supply of the people living around the Tonle Sap lake and the channel. *Cyclocheilichthys apogon* can be distinguished from the other species of this genus in Cambodia by the absence of barbels (hence the FAO name "beardless barb"). The Khmer name for it used in Siem Reap is *trey srawka kdam* or *trey kros*.

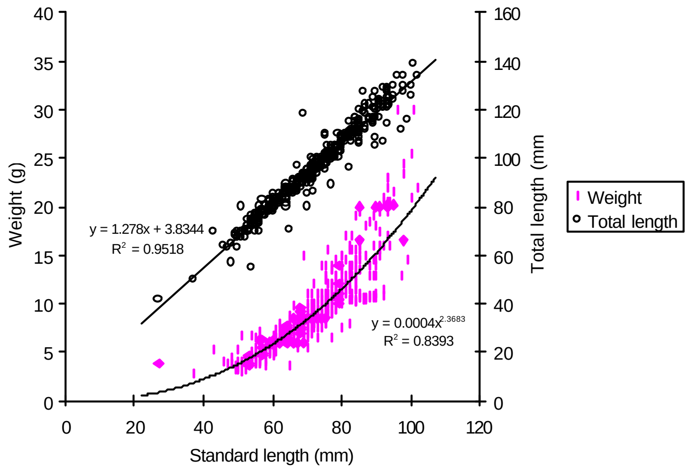

Figure 2.16 *Cyclocheilichthys apogon*. Length-weight plot and equations for the fish analysed in this study (n = 550)

Rainboth (1996) mentions *Cyclocheilichthys apogon* attaining in Cambodia a maximum length of 15 cm, although the species is reported to grow up to 25 cm in Malaysia and India (FishBase, 2000). The standard length of the specimens found in this study varied between 2.7 and 10.2 cm.

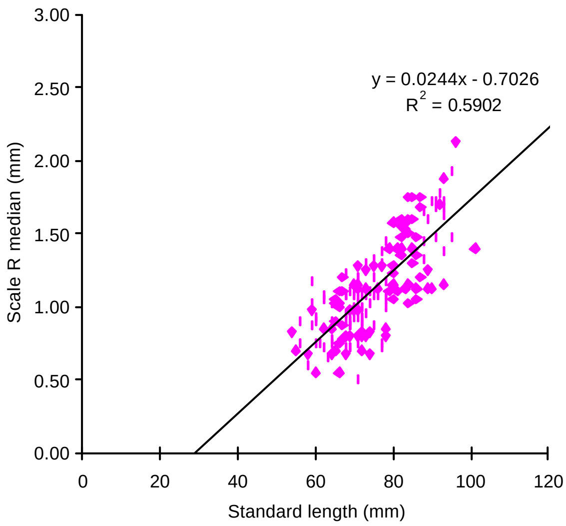

Figure 2.17 *Cyclocheilichthys apogon*. Body length and scales median radius (n = 180)

Feeding ecology

Cyclocheilichthys apogon is reported to be microphage, feeding on plankton, zoobenthos and crustaceans. It is typically found around surfaces, such as plant leaves, branches and roots, where it browses for food.

Reproductive ecology

This species uses the flood area not only for feeding but specifically also for breeding, which occurs late in the high-water season, as water levels peak and begin to decline. Rainboth (1996) speculates that by breeding late in the flooding (September to October), predation by species that move back to permanent water immediately at the onset of water recession, could be avoided.

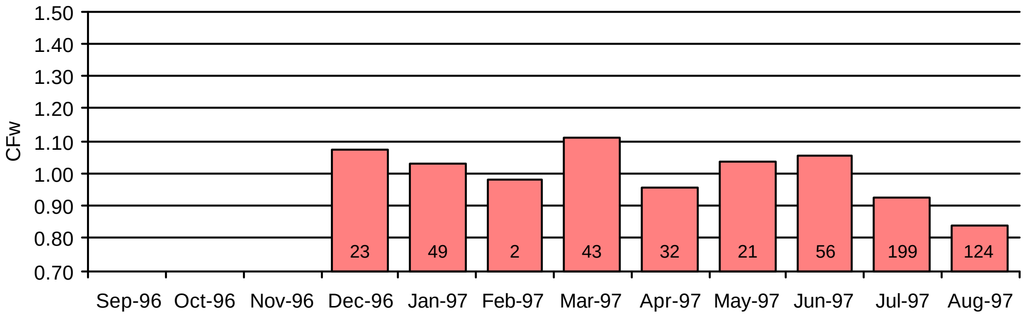

Figure 2.18 *Cyclocheilichthys apogon*. Monthly condition factor (CF_w). The figure in each column indicates the number of fish involved for that month

Fish collected during a period of time that are on average heavier than expected by calculation for the same period from the general length-weight relationship, score CF_w-values of higher than one. The condition factor shows a sharp decrease in July and August (Fig. 2.18). This coincides with and is probably due to the spawning of the females. Gonads make up a large part of their body mass in the weeks before spawning. Fig. 2.19 shows the gonad weights for female fish around that time. Gonads then made up as much as 30 percent of the body mass of female specimens. For all fish in these samples, average sex ratio (m:f) was 1.10.

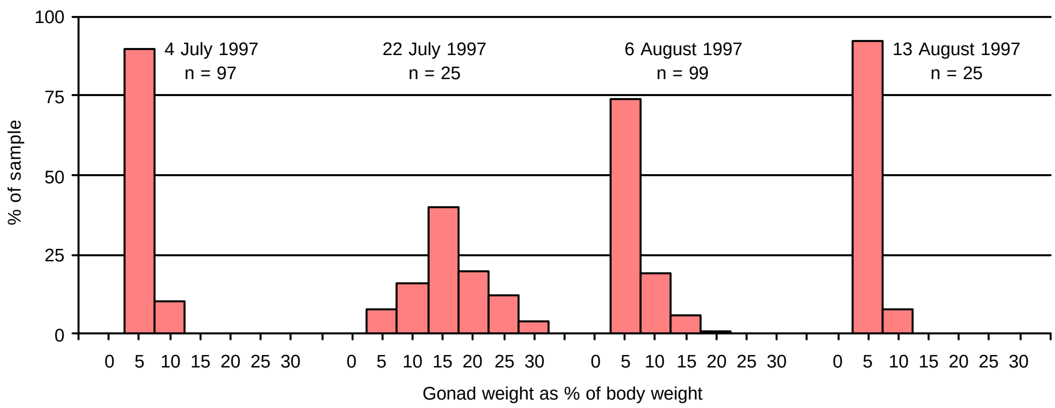

Figure 2.19 *Cyclocheilichthys apogon*. Gonad weight as percentage of body weight for female fish. (n) refers to the number of female fish analysed

Fisheries
Cyclocheilichthys apogon is caught with seines, set nets and traps. The species is abundantly present in the experimental gillnet catches, and is mostly used to make *prahoc* or marketed fresh for direct consumption. *Cyclocheilichthys apogon* is available the whole year round. It performs a lateral migration into the flooded area, into both flooded forest as non forested floodplains (Rainboth, 1996).

Potential for aquaculture
This species is known to survive in impoundments and offers thus possibilities as an indigenous aquaculture species. With about 1000 Riel/kg, it is in the middle-price range.

Importance
The species is indigenous in Cambodia and widely distributed in Southeast Asia. It is an important species in the fisheries of the Tonle Sap, making up about 1 percent by weight of the total catches by middle and large-scale fisheries (Deap *et al.,* 1998).

Conclusion
The available information shows that scrubland and forest are the habitats offering the best opportunities for *Cyclocheilichthys apogon.* Floodplain pools seem to have few features that are particularly attractive to this species. Lotus fields offer potentially much food but they are readily accessible for migrating or foraging species and do not provide much shelter for fry or adults.

iii. *Cyclocheilichthys enoplos* (Bleeker, 1850)

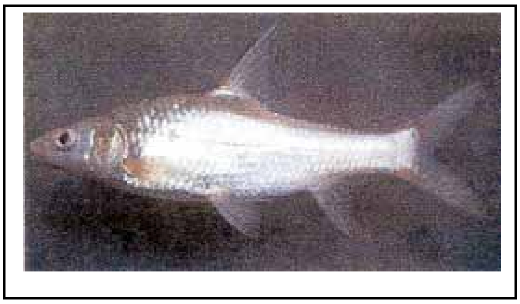

Figure 2.20 *Cyclocheilichthys enoplos* (from Vittayanon 2000)

Description
Cyclocheilichthys enoplos (Cyprinidae) can be distinguished from the other members of this genus in Cambodia by the lateral line with bifurcate or even multifurcate tubules. However, there is considerable variation in this character. The Khmer name used in Siem Reap is *trey chhkok*.

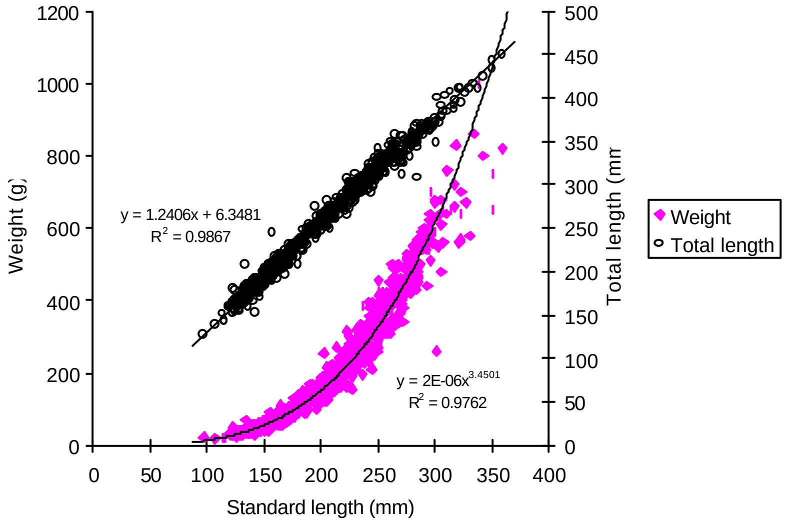

Figure 2.21 *Cyclocheilichthys enoplos*. Length-weight plot and equations for the fish analysed in this study (n = 881)

It is the largest species of the genus. It is reported to reach a total length of 74 cm, but lengths up to 45 cm are most common (Rainboth, 1996).

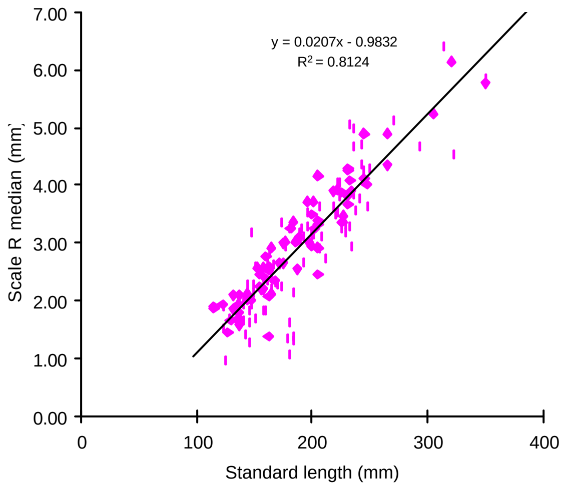

Figure 2.22 *Cyclocheilichthys enoplos* Body length and scales median radius (n = 197)

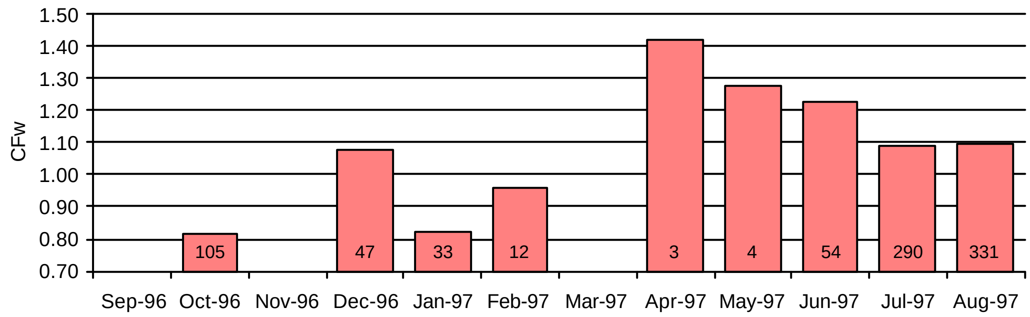

Figure 2.23 *Cyclocheilichthys enoplos*. Monthly condition factor (CF_w). The figure in each column indicates the number of fish involved for that month

Fish dissected in July and August 1997 showed high amounts of body fat, often combined with important parasite infections of the intestinal tract and internal organs.

Feeding ecology

The young of *Cyclocheilichthys enoplos* are reported to feed on zooplankton while the diet of adults includes insect larvae, crustaceans and fish. There are reports of the diet also containing plant roots, bivalves and green algae (FishBase, 2000) and being more that of omnivorous fish. However, Nguyen and Nguyen (1991) report that zoobenthos accounts for up to 95 percent of the food intake.

Reproductive ecology

Rainboth (1996) reports this fish to spawn in the rainy season, without specifying when precisely. There is one report from Thailand (FishBase, 2000) about the presence of mature females of this species from May to August. The main spawning season of the group of anadromously migrating fish for breeding in the Mekong like *Cyclocheilichthys enoplos* is from May to July (Nguyen and Nguyen, 1991).

Fisheries

The fish is caught with different kinds of nets and traps, but only occasionally with gillnets. It is usually marketed fresh and is among the more expensive fish.

Potential for aquaculture

Cyclocheilichthys enoplos is not found in impoundments. Experimental use for aquaculture is reported from Thailand (FishBase, 2000).

Importance

Cyclocheilichthys enoplos is one of the most important species in the fisheries of Cambodia. With 9 percent of the total volume, it is reported to be the third most important species in the catches by middle and large-scale fishing operations (Deap *et al.*, 1998). It is found in benthopelagic habitats in rivers and the lake, and moves into the flooded plains and inundated riparian forests. It is reported to return from there to the permanent waters from October to December. This fish is considered excellent eating and is highly sought after.

Conclusion

Considering its diet and the lack of adaptations for surviving in waters with low dissolved oxygen levels, *Cyclocheilichthys enoplos* will probably not move into the inundated areas until water quality has improved after the beginning of the flooding. Low dissolved oxygen levels limit the area where the fish can comfortably survive. This factor, combined with the lack of well-developed intermediary-level communities (zoobenthos, aquatic insects, zooplankton), limits the distribution of *Cyclocheilichthys enoplos* in the flooded areas during the earlier stages of the flooding. It is one of the first species to return to the permanent water zones as soon as the floodwaters begin to recede.

iv. *Henicorhynchus siamensis* (deBeaufort, 1927)

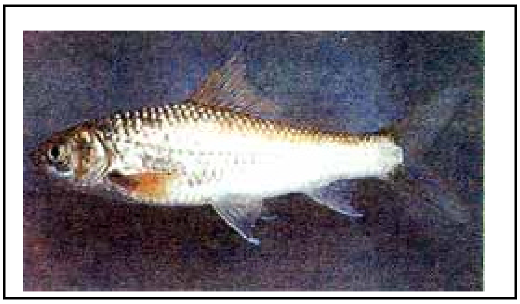

Figure 2.24 *Henicorhynchus siamensis* (from Vittayanon, 2000)

Description

The taxonomic status of *Henicorhynchus siamensis* and of the genus *Henicorhynchus* has been subject to considerable discussion. FishBase (2000) considers the name *Henicorhynchus siamensis* (deBeaufort, 1927) a junior synonym to *Cirrhinus siamensis* (Sauvage, 1881). For consistency, the former is used in this publication. This species is another member of the in Cambodian fresh waters dominantly present family of the Cyprinidae. The Khmer name is *trey riel.*

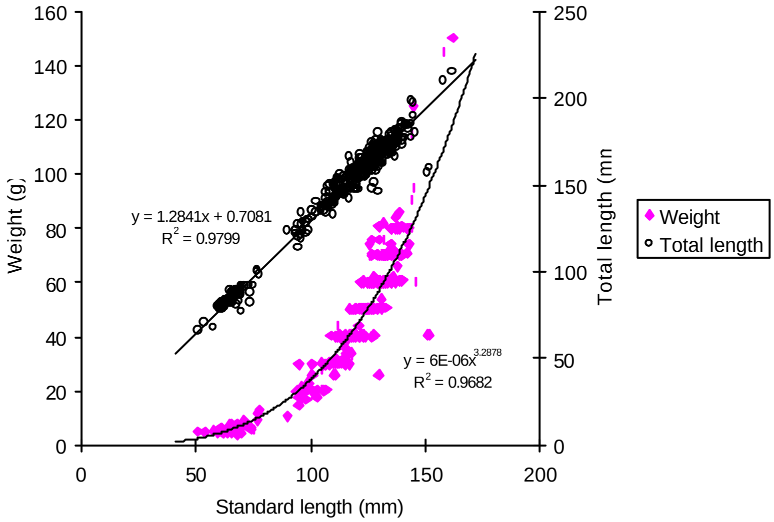

Figure 2.25 *Henicorhynchus siamensis*. Length-weight plot and equations for the fish analysed in this study (n = 510)

There is a gap in the representation of fish of about 80 mm in the fish sampled. The cause for this is not clear. Maximum size reported for this species is 20 cm standard length (Rainboth, 1996).

Feeding ecology

This fish is well known for its annual trophic migrations out to the floodplains in the wet season. It is almost completely absent from the experimental gillnet catches from January until March. This coincides with the period when most of the migration towards the Mekong takes place (Rainboth, 1996). *Henicorhynchus siamensis* is reported to be herbivorous, feeding on algae, periphyton and phytoplankton.

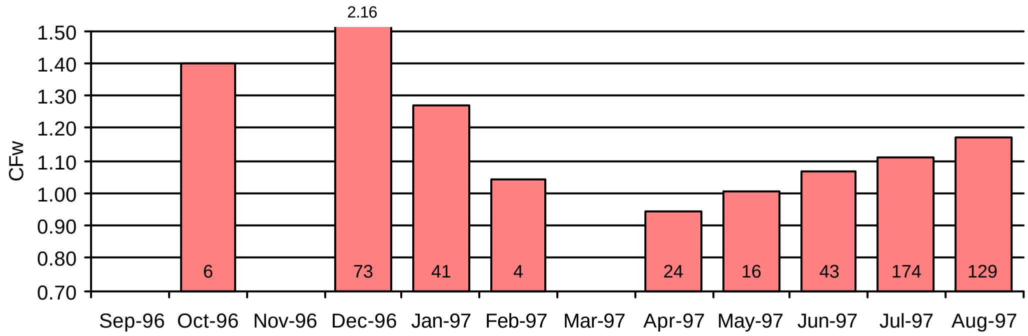

Figure 2.26 Henicorhynchus *siamensis*. Monthly condition factor (CF_w). The figure in each column indicates the number of fish involved for that month

The evolution of the condition factor from April to August appears to confirm the feeding migration into the flooded areas. The first fish entering the inundated habitats (April-May) are rather lean but by the time the floodwaters begin to recede (December), they are about twice as heavy as what can be expected for a fish caught at random throughout the year.

Reproductive ecology

The rise of the condition factor is partly due to the development of gonads in the females (Fig. 2.27). *Henicorhynchus siamensis* is reported to reproduce in flowing water, also in currents in the core of the Tonle Sap lake and in the floodplain (H. Hy, personal communication, 2000).

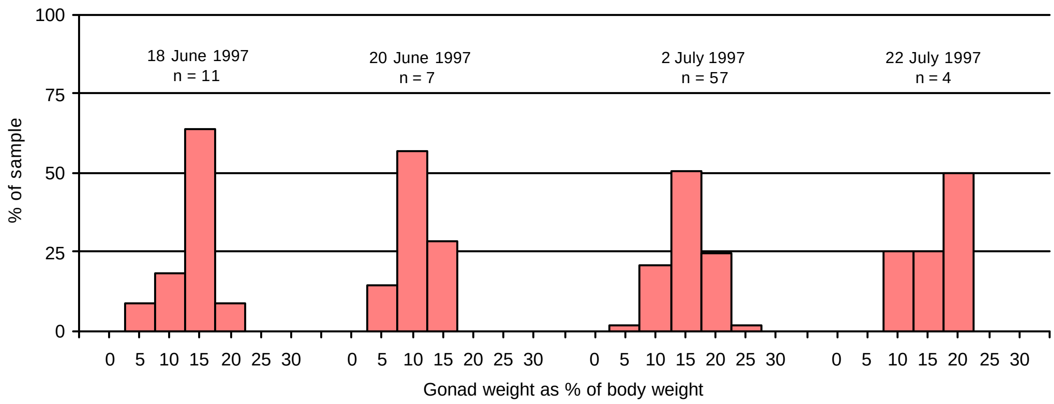

Figure 2.27 *Henicorhynchus siamensis*. Gonad weight as percentage of body weight for female fish. (n) refers to the number of female specimens analysed

Large amounts of body fat were observed in many specimens during the dissections in June and July 1997.

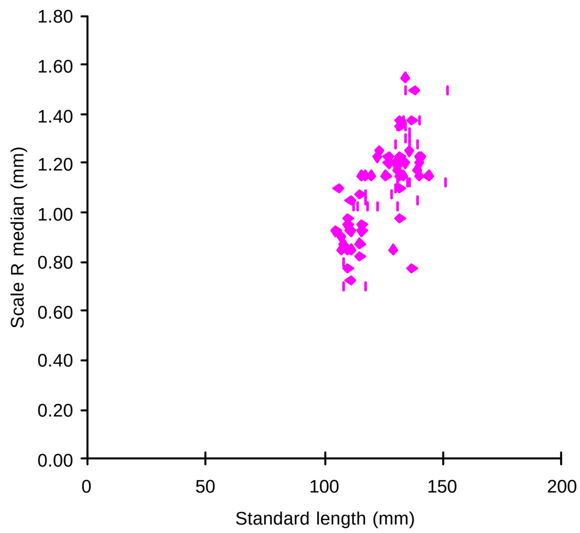

Figure 2.28 *Henicorhynchus siamensis*. Body length and scales median radius (n = 84)

Fisheries
Most of the catches of *Henicorhynchus siamensis* are done with seines, cast nets, traps and set nets. The *dai* fisheries take a large part of the total catch during the annual migration out of the Tonle Sap lake towards the Mekong. The fish is used along the Tonle Sap to make *prahoc*.

Potential for aquaculture
Henicorhynchus siamensis is not known to prosper in impoundments and seems to have limited potential for aquaculture.

Importance
Henicorhynchus siamensis is the backbone of commercial fishing operations in the Tonle Sap lake and channel. It makes up every fifth kilogram of fish produced by these fisheries, and represents almost 10 percent of the total value generated (Deap *et al*., 1998). It is no coincidence that its Khmer name is that of the national currency. Despite heavy fishing pressure, the species is not believed to be overfished at present (van Zalinge and Thuok, 1999).

Conclusion
The main function of the inundated area for this species is feeding. This is supported by the increasing condition factor as the flooding starts and goes on. More body fat is also observed during this period. The spawning function is not clear. Its diet makes it rather independent of the kind of habitat it moves to in the flooded area. Habitats such as scrubland and forest with lots of surface that offer opportunities for the development of epiphytic algae seem to offer advantages. Being a rather small fish, the bushy habitats offer considerable shelter from larger predators.

v. ***Osteochilus melanopleurus* (Bleeker, 1852)**

Figure 2.29 *Osteochilus melanopleurus* (from Vittayanon, 2000)

Description

The cyprinid osteochilids are commonly found in Cambodia, and in some places and at certain times they may be abundant. The Khmer name for *Osteochilus melanopleurus* is *trey krum*.

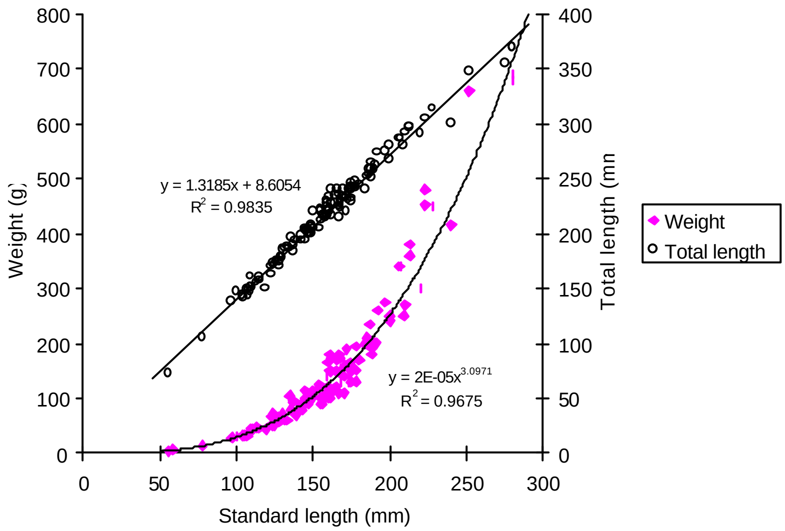

Figure 2.30 *Osteochilus melanopleurus*. Length-weight plot and equations for the fish analysed in this study (n = 127)

Osteochilus melanopleurus is the largest of the local species of the genus. Its maximum standard length is reported to be 40 cm (FishBase, 2000).

Feeding ecology

This species migrates into the seasonally flooded habitats but returns from there to the Mekong as soon as the water begins to recede in October. The migration reaches a maximum in January.