UPTEC W07 028
Examensarbete 20 p
December 2007

Primary production in freshwater reservoirs in Mauritius

Primärproduktion i sötvattenreservoarer på Mauritius

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ABSTRACT

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The first measurements ever of primary production in freshwater reservoirs in Mauritius resulted in surprisingly low primary production and chlorophyll *a* concentration. The primary production was measured with the oxygen method once a week during a four week long sampling period in January and February 2007. Supporting data included chlorophyll *a*, counting of the most abundant phytoplankton, water temperature, pH, water depth and water transparency. The two measured reservoirs La Nicolière and Piton du Milieu are quite small with surface areas; 1.02 km^2 and 0.76 km^2 respectively.

The mean Net primary production was 0.97 $gC/m^2/d$ for the euthrophic La Nicolière and 0.16 $gC/m^2/d$ for Piton du Milieu that is mesotrophic. These results place the two reservoirs in the lower interval of primary production of tropical lakes and reservoirs. The biomass, expressed as chlorophyll *a*, reaches a mean of 2.50 µg/l and 1.83 respectively for La Nicolière and Piton du Milieu, which is very low for tropical reservoirs. But when both primary production and chlorophyll *a* content is low the specific primary production get higher; 383 gC/gChla/d in La Nicolière and 89 gC/gChla/d in Piton du Milieu. La Nicolière is in the normal range for tropical reservoirs but Piton du Milieu has a very low specific primary production. When counting the most abundant phytoplankton, it counts up to a biomass of around 2500 µg/l in La Nicolière and 650 µg/l in Piton du Milieu. For La Nicolière the groups are cyanophyta, bacillariophyceae and in Piton du Milieu dinophyceae, chlorophyta and some conjugatophyceae.

This thesis was a continuation of a 2 year long project about La Nicolière and Piton du Milieu. The low primary production and chlorophyll *a* content is surprising for reservoirs in a tropical country like Mauritius and further investigations of primary production in Mauritius are recommended.

Keywords: primary production, phytoplankton, tropical reservoirs, Mauritius

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REFERAT

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Den första mätningen någonsin av primärproduktion i sötvattenreserveroarer på Mauritius visade låga värden av både primärproduktion och klorofyll a. Primärproduktionen mättes med syrgasmetoden en gång i veckan under fyra veckor i januari och februari 2007. Understödjande parametrar som också mättes var klorofyll, räkning av de mest förekommande fytoplankton, vattentemperatur, pH, vattendjup och secchi-djup. De två undersökta reservoarerna La Nicolière och Piton du Milieu är ganska små med ytareorna; 1.02 km^2 respektive 0.76 km^2 (Berg. 2004).

Medelnettoprimärproduktionen var 0.97 $gC/m^2/d$ för den eutrofa La Nicolière och 0.16 $gC/m^2/d$ för Piton du Milieu som är mesotrof. Det placerar reservoarerna i det lägre intervallet av primärproduktion för tropiska sjöar och reservoarer. Biomassan, uttryckt som klorofyll a nådde ett medel på 2.50 µg/l och 1.83 µg/l för La Nicolière respektive Piton du Milieu, vilket är väldigt lågt för tropiska reservoarer. Men när både primärproduktion och klorofyll a är låga blir den specifika primärproduktionen högre; 383 gC/gChla/d i La Nicolière och 89 gC/gChla/d i Piton du Milieu. La Nicolière ligger inom det normala intervallet för tropiska reservoarer medan Piton du Milieu har en väldigt låg specifik primärproduktion. Vid räkning av de mest förekommande fytoplanktonen ger det en biomassa av ca 2500 µg/l i La Nicolière och 650 µg/l i Piton du Milieu. De vanligaste grupperna i La Nicolière var cyanophyta och bacillariophyta och i Piton du Milieu: dinophyceae, chlorophyceae och en del conjugatophyceae.

Studien var en komplettering på ett två år långt projekt om La Nicolière och Piton du Milieu. Då produktionen var låg jämfört med andra tropiska länder rekommenderas fortsatta undersökningar av primärproduktion på Mauritius.

Nyckelord: primärproduktion, fytoplankton, tropiska reservoarer, Mauritius

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PREFACE

This study was carried out as a 20 week long Master Thesis for the education program in aquatic and environmental Engineering at Uppsala University. The thesis was carried out at the faculty of Science at University of Mauritius within an exchange program between The Department of Limnology at Uppsala University. The coordinators are Drs. Anna Brunberg at Uppsala University and Professor Deolall Daby at University of Mauritius.

The exchange between Uppsala University and University of Mauritius has been going on since 2002 and includes exchange for both teachers and students. The Linneaus-Palme program that is the sponsor of this program has as its main purpose to widen the knowledge about living conditions in different parts of the world. This Linneaus-Palme project is called "Integrated Water Resources Management" and its purpose is to emphasize on the value of the drainage area for water resource planning and water environmental control and follows the ideas with EUs water directive.

ACKNOWLEDGEMENTS

I would like to thank all my supervisors that have guided me through the whole project. Especially my supervisor and subject reviser in Sweden; Drs. Anna Brunberg and Dr Anders Broberg, who though the long distance been present in my work. Also a great thank to my supervisor at the University of Mauritius; Professor Deolall Daby for the practical arrangements. Danishta Dumur has been a super help through all my stay in Mauritius, with the work but also to show me where the good food is.

A big thanks to all the technicians, at the department for biosciences, for all their practical help and especially their heroic work with collecting water samples in air boats without air and trying to fish lost bottles.

And thanks to Annick for making my stay in Mauritius unforgettable and to my family and friends in Sweden who has cheered me up when being away from home.

UPTEC W07 028, ISSN 1401-5765
Printed at the Department of Earth Sciences, Geotryckeriet, Uppsala University, Uppsala, 2007.

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1 INTRODUCTION

Mauritius is a small island in the middle of the Indian Ocean populated by 1.25 million people. The country's economy is on the rise and it is developing fast in many industries. One goal is to become an "IT-Island" in a near future. When inhabitants are increasing and economy is rising, freshwater is one of the most important sources affecting further development. Groundwater and eleven man made reservoirs supports the requirements of freshwater for domestic and industrial use, irrigation, and hydro-electric power.

Research in primary production is wide spread in both aquatic and terrestrial environments, but mostly concentrated towards temperate waters. Research in the tropical world is not as frequent as in temperate water, but has started to increase. The characteristics of tropical and temperate systems are different in many ways. That it is why results from one part of the world can not be applied to another. Some of the results are comparable but you always have to be extra careful when comparing water sheds from different parts of the world with each other.

Phytoplankton is an important part of the freshwater system in the beginning of the food web. Their short generation time; works over days and weeks, also makes them respond very quickly to changes in the environment. This makes them a good model of general ecological principles (Harris 1986). Phytoplankton's primary producing ability is an important ecosystem parameter, to a large extent controlling the available carbon supply in the rest of the food web. The level of primary production constitutes the conditions for secondary production.

1.1 AIMS

My study was performed in two reservoirs in Mauritius; La Nicolière and Piton du Milieu to examine the photic zone, regarding the primary production (PP), chlorophyll and other pigments and the most abundant phytoplankton groups. This study provided an estimation of the primary production because of the short sampling period. As a part of the project goal I also looked for factors affecting primary production and biomass such as temperature, water depth, water transparency and pH. Especially I compared my results with the earlier set classification and characteristics of the reservoirs.

1.2 THEORY

1.2.1 The difference between tropical and temperate reservoirs and lakes

Apart from the most obvious difference, temperature, there are more things that vary between tropical and temperate reservoirs and lakes. First of all there are far more temperate lakes and reservoirs than tropical ones in the world so most primary production research is made on temperate waters (Wetzel, 2001). Temperature is not only higher in tropical areas but it also does not change as much as for temperate areas. Solar radiation also differs between temperate and tropical regions and just as for temperature; the variation is greater in temperate areas between winter and summer than in tropical areas. In tropical areas instead the light penetration into the water vary more and is more dependent of factors like turbidity and nutrient inflow from connected rivers

(Henry, 2006).

The gross primary production is higher in tropical lakes than in temperate lakes because of the meteorological differences but there are also other reasons for the more efficient tropical lakes. Many tropical reservoirs surrounded by nutrient buffering wetlands and river inflow all year around sets a higher and more stable biomass of phytoplankton and PP than in temperate lakes (Wetzel, 2001). The PP is twice as high per nutrient load in tropical reservoirs as in temperate reservoirs because of the higher stability. Also the higher mean temperature, greater stability of solar radiation during the year, Coriolis Effect (the same wind force will have less effect in high latitudes than in low latitudes), intra seasonal deep mixing leads to more efficient nutrient cycling that give rise to the PP (Lewis, 1987). The recycling of nutrients is one of the greatest causes to the big differences in PP.

There are also some similarities between the two climate zones and that is the species diversity, which is expected to increase with increased temperature as in terrestrial ecosystems. But there are no large differences between the diversity in temperate and tropical lakes (Lewis, 1987).

1.2.2 Phytoplankton

Primary production in the pelagial zone is performed by phytoplankton so the abundance of phytoplankton sets the conditions for primary production. Phytoplankton is a group of small plants that are freely floating or suspended in water, planktonic stands for unicellular floating. The size varies from prokaryotic and eukaryotic single cells to organisms seen by the naked eye. Most phytoplankton is microscopic algae but some bacteria are also included in the group. There are three groups in the microbiological world: eubacteria, archaebacteria and protists. The two first groups are prokaryotic cells and the protists are eukaryotic cells. The protests include the algae, protozoa and fungi. The algae consist of motile flagellates and non-motile desmids and diatoms. Non-motile algae are often the bigger ones which are more dependent of mixing while the one that have the ability to move are smaller. If a lake is not mixed then the small algae are more abundant than larger ones.

For measurement of phytoplankton biomass, the most correct method is counting in a microscope. This gives a thorough result but takes time. An easier method is to measure the chlorophyll *a* and assume that it is correlated to biomass. However the concentration of chlorophyll *a* may vary substantially between different species and with varying environmental conditions. However, the method is widely used, as a reasonable estimate of phytoplankton biomass. Other methods can be to measure the transparency (secchi depth), which is inversely proportional to the chlorophyll *a* concentration (Branco & Senna 1996).

The biomass, when measured as Chlorophyll *a*, has been measured as high as 2000 mg/m^3 in an Ethiopian lake with a euphotic zone as shallow as 0.6 m. This gave an aerial biomass of 180-325 mg/m^2 and the largest to occur in nature have been estimated to 180-450 mg/m^2 (Wetzel 2001).

1.2.2.1 Diversity of phytoplankton

In oligotrophic lakes there is a dominance of small algae and the more eutrophic lake the more of larger algae (Calijuri 2000). In oligotrophic lakes the size also differs between the seasons. During the winter the microorganisms were dominating and in the summer species smaller than 20 µm were more abundant. Common species in tropical lakes are: dinoflagellates, diatoms and cyanobacteria (Laiz Averhoff & Blomqvist 1988). Unexpected, the number of species in tropical waters have the same diversity as temperate lakes. This is different from terrestrial ecosystem where tropical areas have much more diversity. But the diversity do instead differ with the biomass of the water; the more oligotrophic the higher diversity (Wetzel, 2001).

Abundances of phytoplankton species vary with the retention time. With a short retention time green algae and planktonic diatoms are dominating, this occurs during summer. When the retention time is longer, in the dry winter, the cyanobacteria is more common (Wetzel, 2001). If the reservoir is having a low retention-time in case of a big outdraw from the reservoir, this can cause washout of the phytoplankton. It can wash out whole populations of phytoplankton.

The diversity of phytoplankton can be used as an indicator of degree of eutrophication and pollution of an ecosystem instead of chemical indicators. This has been used and investigated in several articles. Overestimation of species has to be taken into consideration since some species may originate from the sediments (Fathi, 2005). Difficulties when using this method for estimating the level of eutrophication also includes that, biological indicators are more complex, species that is only supposed to survive in one environment can adapt, and when identifying species the skills of the taxonomists may vary rather than the ecosystem (Kalff and Knoechel, 1978).

If the concentration of carotenoids are high relative to Chlorophyll *a* then this can indicate the abundance of Botryococcus but there is also a possibility that the synthesis of carotenoids has been introduced to other populations. (Kebede 1987)

1.2.2.2 Variation of phytoplankton

The conditions for phytoplankton change with the seasons and with the dry and rainy periods. The maximum of phytoplankton biomass often occurs during the dry winter. The concentrations of different nutrients and the plankton community differ between the winter and summer. The phytoplankton biomass can change five times from the warmest to the coldest time of the year (Wetzel, 2001). Except from physical and chemical factors regulations of phytoplankton are also restricted by top down effects by grazing from zooplankton (Henry 2006).

The biomass of phytoplankton both varies with depth and position in the reservoir. The depth variation depends on time of the day and some plankton species move vertically during different times of the day. During evenings and nights they are sinking or working actively downwards and during the morning they are moving towards the surface (Naturvårdsverket 2004), stated for temperate lakes. In a reservoir different zones have different concentrations of phytoplankton and production. When looking at a reservoir from a length perspective there are three zones, the riverine zone comes first just after the river inflow. The transitional zone is in the middle and just before the dam wall there is a lacustrine zone. The primary production was higher in the riverine zone and the transitional zone. The riverine zone is fed with nutrients from the connected river and in the transitional zone a high production can emerge due to the tranquility (Comerma et al., 2003).

1.2.3 Primary production

Primary production is the transformation of inorganic carbon to organic matter, which can be used as food for other organisms. When carbon is present in its inorganic form no other than the primary producers can use it. A primary producing organism can use the photosynthesis or the chemosynthesis for this conversion. Photosynthesis is far more common than chemosynthesis. Primary producers can be planktons, bacteria, macrophytes, terrestrial plants etc. In the pelagic zone of a freshwater ecosystem you only have plankton and bacteria that can perform primary production.

The term "primary production" has caused a lot of debates in the past and still has various definitions. I have chosen to follow Ahlgren (2000) that has the following explanation:
"the real production of organic substances by photosynthesis (or chemosynthesis), which can be used as food."

The photosynthesis is explained as follows by Wetzel (2001): "Cell carbon is obtained by reduction of carbon dioxide to carbohydrates from transformation in which light energy obtained by light-receptor pigment systems is converted to chemical energy."

The reaction for photosynthesis is described by the chemical equation in eq. 1. Inorganic carbon and water becomes organic material and oxygen. The reduction of carbon to organic material results in a binding of energy which can be released and used for other metabolic processes when the produced organic material is oxidised. Oxygen is a rest product at primary production, which is very important for surrounding water.

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2 + energy \qquad \text{(eq. 1)}$$

Light radiation is one of the most important factors for the primary production and a study made by Calijurii (2001) in a tropical reservoir comparable to the two in this study also came to this conclusion. The radiation that affects the photosynthesis is Photosynthetic Active Radiation (PAR) and includes the wavelengths between 400 and 700 nm. In water photosynthesis has a maximum depth and it varies with the transparency of the water which is a function of concentration of particulate and dissolved organic compounds and the biological turbidity. Hence, large biomass of phytoplankton in a lake doesn't mean that the primary production is larger there, it may instead restrict the PP since turbidity lowers the PP; self-shading occurs (Wetzel, 2001).

Primary production can be distinguished as net (NPP) or gross (GPP) primary production (eq. 2 and 3) where NPP accounts for losses such as respiration and excretion while GPP includes the total amount of fixed carbon. Further the excretion from the phytoplankton can be used by bacteria. This takes the excreted carbon into the microbial loop as food. The definition of net production is the biomass that can be used as food, thus leads to that the excretion is no loss out of the system. Also the respiration can in some cases be disregarded which means that NPP equals GPP. However this only happens when respiration is very small e.g. in temperate eutrophic systems and not for tropical systems were the respiration generally is high. Primary production may also be calculated as specific primary production (SPP), which is the primary production per unit biomass (eq. 3), the latter often expressed as chlorophyll *a*.

$$Gross\ primary\ production = Net\ primary\ production + respiration \qquad \text{(eq. 2)}$$

$$Specific\ primary\ production = net\ or\ gross primary production / biomass \qquad \text{(eq. 3)}$$

When comparing different ecosystems with each other the NPP is used because it doesn't include the respiration that differs a lot for different systems. But when comparing a system internally annually then the gross primary production may also be used.

Several studies have been made where primary production has been measured as one of many parameters, which has resulted in several correlations for PP. As in the study performed by Calijurii (2001) the primary production correlated almost perfect with chlorophyll *a* (r=0.99) and very good with inorganic phosphate, total dissolved phosphate, reactive silicate, theoretical water retention time, Zmax/Zeu[1] and outflow from the reservoir. Also Bannister (1974) concluded that primary production and biomass increased linearly from the zero-zero intercept. Branco & Senna (1996) also found a correlation between PP and biomass but the effect is delayed in both directions and not in direct phase as PP and solar radiation.

Despite that the productivity of phytoplankton can be high it is very low if you compare with other photosynthetic organisms in a limnic system. The upper limits for photosynthetic capacity is about 2.8 gC/m2/h (Robarts, 1992) but the productivity varies between 4 gC/m2/year in the most oligotrophic lakes and 500-700 gC/m2/year in the most eutrophic lakes (Kalff and Knoechel, 1978). In a comparative study, using data from 30 tropical and 30 temperate reservoirs, Bandu Amarasinghe & Vijverberg (2002) found that PP was 3 times higher in the tropical reservoirs during summer, and 6 times higher if calculated on annual basis.

The photosynthesis is performed in limnological systems by plants as macrophytes, microphytobenthos, phytoplankton and periphyton. Of these, all except the phytoplankton lives and performs PP exclusively in the littoral zone. An African reservoir contained during normal conditions 6.4 tons carbon. This biomass consisted of 55% of littoral macrophytes, 19% of microphytobenthos, phytoplankton was 25% and the periphyton

[1] Zmax = maximum depth and Zeu = depth of euphotic zone

<1%. The proportions differed when the drought started and the volume decreased, then the macrophytes in the littoral zone were left up on land and most of the primary producing biomass then consisted of microphytobenthos (around 60%) and the rest was phytoplankton (Thomas et al. 2000).

1.2.3.1 Pigments

To perform photosynthesis the primary organisms must be equipped with pigments. The most common pigments for oxygen producing organisms are Chlorophyll *a, b* and *c*, of which the most common is chlorophyll *a*. When working it leads to fluorescence and excitation of chlorophyll *a* molecule. It operates in the wavelengths around 430 and 660 nm. Chlorophyll *b* has a different mechanism; it is a transferor of absorbed light energy to Chlorophyll *a*. It is more common in higher plants but can also be found in green algae, euglenophytes and it operates in the range of 435 and 645 nm. Chlorophyll *c* is a bit different from the two resent while it probably is an accessory pigment to photosystem II (Wetzel 2001), it operates in the wavelengths 630-635 (maximal), 583-586 and 442-452 nm. Further more there is Chlorophyll *d* and *e* which are very rare and rarely accounted for.

Other pigments are carotenes that include alfa-carotene and beta-carotene. Beta is the most common but alpha replaces it in green algae and Cryptophyceaes. The carotenes are unsaturated hydrocarbons and works just as Chlorophyll *b*, transferring absorbed light energy to Chlorophyll *a*, which then goes on working.

Different algal groups contains a mixture of different pigments and the most common groups in freshwater can be seen in table 1.

Table 1 Pigments in algal groups that are common in freshwater (modified from table 1.1, Harris, 1986).

Group	Pigments
Cyanophyceae Blue-green algae	Chlorophyll *a*, C-phycocyanin, allophycocyanin, C-phycoerythrin, B-carotene, xanthophylls
Chlorophyceae Green algae	Chlorophyll *a* and *b*, A- and B-carotenes, several xanthophylls
Euglenophyceae euglenoids	Chlorophyll *a* and *b*, B-carotenes, several xanthophylls
Chrysophyceae Golden and yellow-green algae including diatoms	Chlorophyll *a* and *c*, carotenes, several xanthophylls, fucoaxanthin
Pyrrophyceae dinoflagellates	Chlorophyll *a* and *c*; B-carotenes, several xanthophylls, peridinin
Cryptophyceae cryptomonads	Chlorophyll *a* and *c*, carotenes, distinctive xanthophylls, phycobilins

1.2.3.2 Variation in Primary Production

Two important factors affecting the primary production are the light availability and the nutrient content (Henry 2006). The solar radiation is crucial for the photosynthesis and thus always a limiting factor. The role of nutrients has been more debated. The primary production of a plankton society that is not nutrient limited can not be restricted by nutrients (Joniak 2003). Kalff and Knoechel (1978) investigated the influence of nutrients on the specific production of phytoplankton in oligotrophic and eutrophic lake ecosystems. They found that the SPP was equal, only the biomass differed between the two kinds of trophic state. They concluded that the nutrient limitation only controlled the biomass and not the production per biomass. On the other hand Lewis (1987) found that a decrease in nutrient inflow to a tropical system could supersede the effects of temperature and solar radiation on primary production.

PP varies with depth, since the light availability decreases with depth so does the primary production. Approximately primary production occurs in the photic zone. The photic zone (or euphotic) stretches down to where 1% of the sun radiation at the surface is left. But the primary production is also regulated by the depth of the mixed zone. A well mixed euphotic zone generates a larger biomass produced by the phytoplankton. If $Z_{mix}>Z_{eu}$, which occurs during winter, the plankton sometimes is transported out from the euphotic zone and no primary production can occur. This is a limiting factor. But when $Z_{mix}<Z_{eu}$ the planktons are constantly in the euphotic zone.

If primary production is too high and the phytoplankton biomass increases alarmingly biomanipulation can be used to limit the phytoplankton as well as primary production. Biomanipulation with input of predatory fish was used by Janiok (2003) in a reservoir in Poland and led to a decrease in primary production and increasing the specific primary production directly after the experiment. After a while the PP showed its old value as before the experiment but the SPP was still high during the summer months and indicated zooplankton pressure. Janiok (2003) found a different result than Kalff and Knoechel (1978) did, where they declared that the SPP were independent of the biomass. This presents the great difficulties of using found correlations and dependencies from one ecosystem in another.

1.2.4 Measurement of primary production

The two most common techniques for measuring primary production are the O_2 method and the C^{14} method. The oxygen method is the oldest and easiest technique and measures the oxygen production. It involves bottles at different depths that are incubated during a period of time and afterwards the oxygen content in them are compared to the initial oxygen content. It has through history been the most used but now the C^{14} method is more common since it has a lower detection limit. The detection limit for the O_2 method is about 20mg C/m^3d and for the C^{14} method it lies around 0.1-1 mg C/m^3d (Ahlgren 2006).

None of the methods are totally free from problems, both of them can have problems like algae that break during mixing/shaking, the photorespiration can't be measured and the enclosure in the bottles is a non-natural situation. For deep samples the algae can have a light shock when lifted to the surface.

With the O_2 method the primary production is measured as oxygen production and for transformation to carbon there is first a conversion factor to use for mass conversion from oxygen to carbon, which is 0.375. Then the photosynthetic quotient, $PQ=O_2/CO_2$ is difficult to decide, it depends on what chemical substances are being produced and which are the accessible nitrogen sources. PQ varies between 0.5 and 3.5 (Ahlgren, 2000). When measuring dissolved oxygen (DO) it can not be allowed to become saturated then the sampling is ruined because the time when it reached total saturation is not known then. In tropical reservoirs where the sun radiation is stronger than in temperate areas the DO will reach saturation faster. To be sure to capture the maximum of primary production which occurs in the upper part of the euphotic zone, the distance between the bottles is tighter there and along the vertical line the distance is always doubled downwards. The deepest light bottle is placed at the triple distance of the secchi depth for being sure of catching the whole euphotic zone (Alhgren, 2006).

The primary production can be calculated per volume of lake water as well as on areal basis. Most of the studies handle the areal primary production, some of them use both types of calculations for comparison. To calculate the areal primary production the ratio between the maximum volumetric primary production and the coefficient of vertical extinction of light is used. But since the biomass varies with depth; the biomass in the euphotic zone is a poor prediction of the total aerial primary production (Ahlgren 2006) but easiest to use when comparing different lakes and reservoirs.

1.3 HYPOTHESIS

Since the Mauritian reservoirs are tropical the primary production should be quite high and expected between 7 and 18 $gO_2/m^2/d$ (table 10). La Nicolière is an eutrophic reservoir and Piton du Milieu a mesotrophic, this should result in different levels of chlorophyll *a* and Net and Gross Primary production, with the larger chlorophyll *a* content and PP in La Nicolière. The PP should also vary with solar radiation and correlate with chlorophyll *a* according to theory. Based on earlier investigations (Dumur, 2007), the most abundant phytoplankton was expected to be cyanophyta and bacillariophyceae/diatoms in La Nicolière and chlorophyceae, dinophyceae and some conjugatophyceae in Piton du Milieu.

2 BACKGROUND

2.1 MAURITIUS

Mauritius is situated in the Pacific Ocean, 800 km east of Madagascar, at latitude 20º15´ S and longitude 57º35´ E. The size of this tropical island is 1,865 km^2 and the whole republic, including the outer islands: Rodrigues, Agalega, St. Brandon, Tromelin and some small islets, is 2,040 km^2 (figure 1). The whole country holds 1.25 million inhabitants and the population is increasing with 0.8% annually. This is a large population for such a small area and the country is one of the most densely populated in the world with 614 persons per km^2 (CSO, 2005).

Figure 1 Map of Mauritius and position in the Indian Ocean (modified from Philip's, 2002).

Mauritius is a volcanic island, originally created 10 million years ago, later modified by further volcanic eruptions. The bedrock consists mostly of basaltic rocks and some carbonate along the coastlines (Petersson, 2005). The land is mostly covered by cultivated areas, 46%, of which the largest part is sugar plantations. Since most of the soils originate from basalt, which gives nutrient poor soils, and because of the large amount of area under plantation, fertilizers are spread all over Mauritius. Forest, scrubs and grazing lands cover 31% of the land area and built-up area is 20%. The forest has been cut down to give space to sugar cane fields ever since the Dutch claimed the Island in 1598. Now the sugar canes are covering 38% (CSO 2005) of the island but the area has decreased since the 70es. The large decrease of forested areas has lead to erosion all over the island, clearly visible around the coastline where sand has started to erode on the beaches. Trees have been planted around the coastline to hold back the erosion but still the landmasses are moving.

Some years ago the Mauritian economy depended almost completely on the sugar production but after a drop in the sugar value and import restrictions from EU the country has been forced to develop other businesses. Adjusting to the new conditions has developed its tourist industry, clothes industry and other industries. In all these areas the development is increasing and processing for making their economy stronger. Mauritius belongs to the group SIDS - Small Island developing states, a collection name for low-lying states struggling sustainable development challenges classified by UN (UN, 2007).

Along the development of a country the water demand also increases. For Mauritius the demand increased by 32.8% between 1995 and 2003 (CWA, 2003) which will, by all mean, continue to increase with the economic and demographic development of the country. For domestic use 98.7% of the population had water within their premises and 85% inside their houses in 2000 (CSO, 2005). The distribution system for water has great losses, up to 50% of the totally distributed water (Berg, 2004).

2.2 CLIMATE

Mauritius is a tropical country, the definition for that is a yearly average air temperature above +18°C. A year consists of two periods; the dry winter and the wet summer and for tropical countries it is more appropriate to name them dry and wet period than winter and summer (figure 2). The dry period stretches from September to November and the wet from December to April. A hydrological year in Mauritius starts at 1st of November in the end of the dry period and ends at 31st of October. The mean annual precipitation is 2100 mm/year over Mauritius but there are great differences in the amount of rain depending on where on the island you are, most rains fall on the central plateau and the driest area is the west coast (figure 3). The sugar canes are mostly situated in the lowland, with less rain than the central plateau, which obliges to irrigation; most common is overhead irrigation.

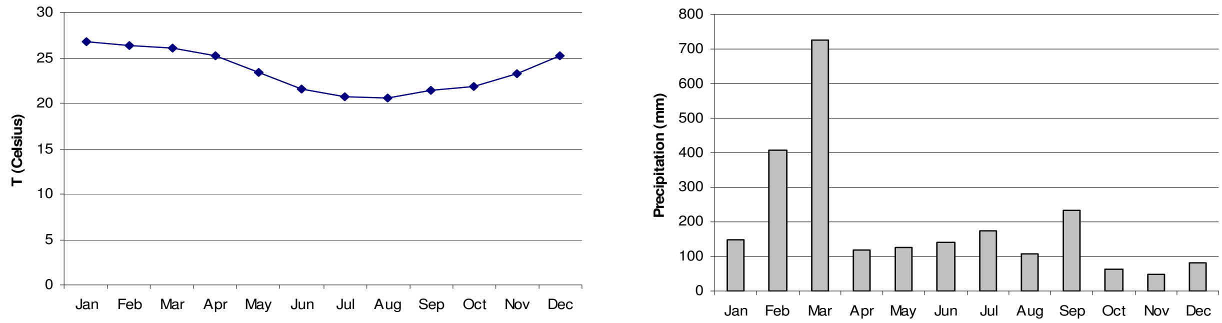

Figure 2 Temperature and precipitation for Mauritius for 2005.

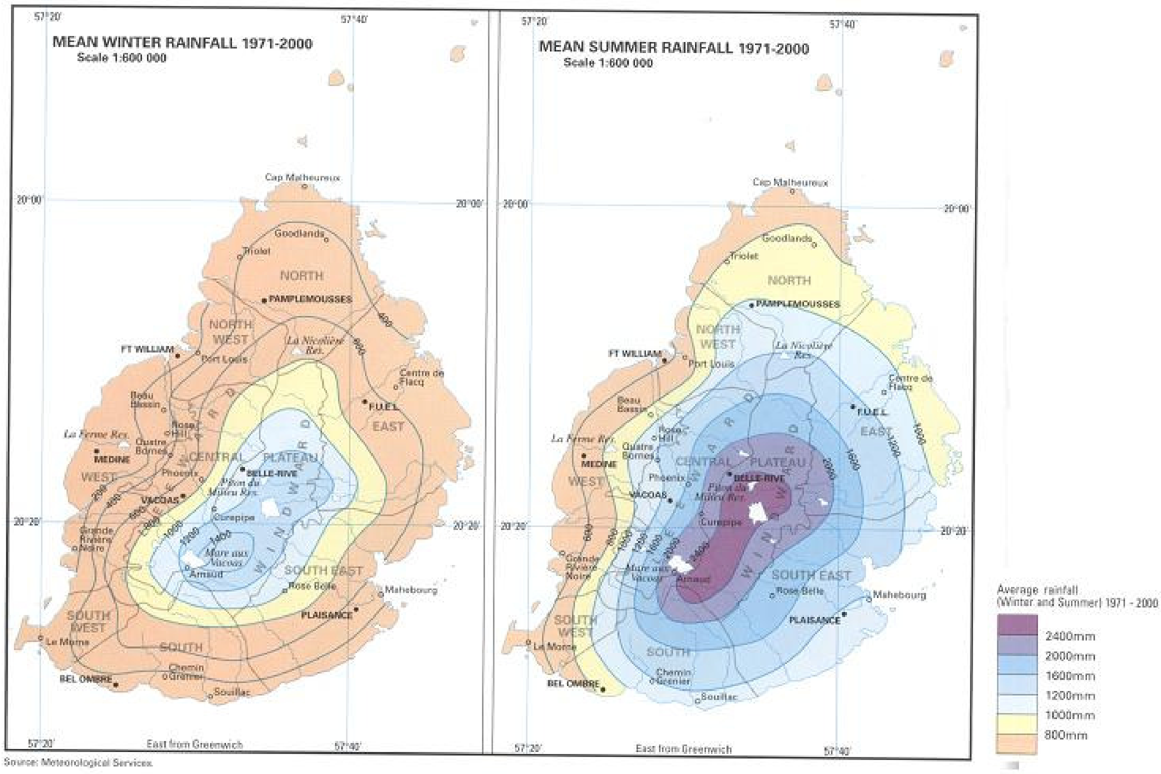

Figure 3 Winter and summer rainfall over Mauritius (modified from Philip, 2002).

Situated in the Indian Ocean, Mauritius now and then suffers from cyclones during the late summer months which can increase the annual rainfall substantially. The last cyclone Gamede, which forced Mauritius to warning class 1 in 22.02.07 and passed the island in 25.02.07, gained around 300 mm to the central plateau for a period of one week. The heavy rainfall causes water cuts since the inflow to the water treatment plants is closed, otherwise the great water masses will clog the filters in a short time.

The solar radiation varies with season and during summer (October to December) the solar radiation is at least 25% more than in the winter (April to August). The measuring is based on hours of bright sunshine (Berg, 2004).

2.3 RESERVOIRS

When natural water supplies not are enough; reservoirs are built to fulfill the water requirement all year around or to create a steady flow for hydro-power. The most common way to build a man made reservoir is by damming a river valley. Reservoirs are something between lakes and rivers regarding hydrological, morphological and nutrient conditions. The environmental conditions are very special for example because of manual regulation of water volume. Macrophytes are very few since the regulations create an almost non-existing littoral zone. The primary production is higher than in lakes despite the higher turbidity and this is because reservoirs are more often connected to larger streams and water volume from runoff is larger and this gives a higher nutrient load (Wetzel, 2001).

2.3.1 Reservoirs in Mauritius

There are 11 man made freshwater reservoirs in Mauritius (table 2) with a total capacity of 90 Mm^3 and they feed the island with 305 Mm^3 water per year (Berg, 2004). They are providing the people with water for domestic use, irrigation, hydro-power and industrial use. More than 50% of the available water is used for irrigation in the agricultural sector (Berg 2004). Since the rain spread of the island is uneven the reservoirs are mostly placed at the central plateau (figure 4) where most rain falls. Reservoirs are the most important water supplies for Mauritius over the year, groundwater supplies are more important during the dry period (May-October) when the reservoirs are low on water.

Table 2 Reservoirs in Mauritius (modified from Berg, 2004).

Reservoir	Capacity (Mm3)	Maximum surface area (km2)	Purpose
Mare aux Vacoas	25.89	5.60	Domestic
Midlands Dam	25.50	3.84	Domestic, irrigation
Mare Longue	6.28	1.05	Hydropower, irrigation
La Ferme	11.52	2.28	Irrigation
Piton du Milieu	2.99	0.76	Domestic
La Nicoliere	5.26	1.02	Domestic, irrigation
Tamarin Falls	2.30	1.68	Hydro-power, irrigation
Eau Bleue	4.10	0.75	Hydro-power
Diamamouve	4.30	0.43	Hydro-power
Dagotiere	0.60	-	Sugar-mill, irrigation
Valetta	2.00	-	Sugar-mill, irrigation

Figure 4 Location of the 11 man made reservoirs in Mauritius (Berg 2004).

The pressure on the reservoirs is increasing since the island is developing and especially the industries are growing. Hence, good quality of the water in all reservoirs is crucial, especially in the summer when the reservoirs are sometimes half full and all available water is important. The depth in the reservoirs is varying some meters between winter and summer. During the summer 2006/2007 most of Mauritius' reservoirs were half full or less because of lack of rain, La Nicolière only had around 35% of its full capacity. The small amount of water in the reservoirs caused problems for the Mauritian people, the water supply was cut during day time and warnings were announced in the news several times. (MBC news, 2006)

For administration of questions concerning water; Mauritius has the Central Water Authority (CWA). This is a government department operating under the aegis of the ministry of Public Utilities (Mau. Gov., 2007). They handle the supply of water for domestic, commercial and industrial purposes throughout Mauritius. The Water Resources Unit (WRU) handles the reservoirs and has the responsibility to ensure a healthy water use for the whole island. Their work mostly concerns water supply and hydrology.

2.4 THE STUDY AREA

Before the investigations of Dumur (2007), none of the Mauritian reservoirs had been under such a thorough study. The choice of study sites ended up on La Nicolière and Piton du Milieu for they were used as drinking water but also because of their small size. Reservoirs that are used for drinking water have higher demand on good water quality than the ones used for irrigation and hydro-power. Both of the studied reservoirs are more than 50 years old (Berg, 2004).

2.4.1 La Nicolière

This reservoir is the only one situated in the northern part of the country, which makes it important for the northern people, both for domestic and irrigation purposes. Until some years ago it was the only reservoir feeding the north for their needs. However, recently the Midlands dam was built 27 km south of La Nicolière and now this larger reservoir supplies La Nicolière with water through a feeder canal. Total capacity of La Nicolière is 5.26 Mm^3 and it has a maximum depth of 10 m (WRU, 1999).
According to WRU (1999) La Nicolière is containing a large amount of substrate but is still oligotrophic. On the other hand, Dumur (2007) 4 years later classified the reservoir as eutrophic (Dumur, 2007). It is well mixed with a few indications of short events of stratification. The secchi depth is about 0.6 m because of the amount of substrate (Dumur, 2007).

La Nicolière gets its water from Du Rempart River and the feeder canal from Midlands dam. The catchment area mostly consists of forest-covered mountains but a small part on the northern side has fields of sugar cane (figure 5). The reservoir was built in 1929.

The local climate here ranges in the humid zone with precipitation between 2000 and 2500 mm per year. The mean temperature is 24 °C, the sun shines 7-8 hours per day and the mean humidity in the air is 77% (Dumur, 2007).

Figure 5 View over La Nicolière from the north.

2.4.2 Piton du Milieu

Piton du Milieu reservoir is situated in the centre of the island and is only used for domestic purposes. Total capacity of the reservoir is 3.2 Mm^3 and it is one of the smallest reservoirs at the island but also the deepest with 15 meter as maximum depth (WRU, 1999). During the dry period it can decrease the water level with as much as 3.5 meter. It has small summer stratification but is fairly well mixed in the euphotic zone and the secchi depth is about 1.2 meter. The system has been classified as oligotrophic (WRU, 1999) or mesotrophic (Dumur, 2007).

The catchments area is mostly covered by sugar canes (66%) and the rest is forest. Piton du Milieu is a reservoir constructed by damming Vacoas River with an 825 m long dam wall (figure 6). Except from Vacoas River it also gains water from some small rivulets. Small amounts of water are added to the reservoir from excess water from high altitude rivers flowing parallel. The reservoir was built in 1952.

The climate here is wetter than at La Nicolière since Piton du Milieu is situated at the central plateau. The annual precipitation is 3400-3600 mm, which makes this a super-humid area. It has a mean annual temperature of 20.5 °C, sunshine; 6.5 hours per day and 82% humidity (Dumur, 2007).

Figure 6 The bridge at Piton du Milieu with view over the dam wall while sampling.

2.5 PREVIOUS STUDIES IN THE RESERVOIRS

The responsibility for all the reservoirs of Mauritius belongs to WRU. For quality control of the reservoirs they measure standardized parameters for drinking water. The tests include several biological, chemical and physical parameters although measured only in surface water but the hydrology of the reservoirs is much more examined. Since water is scarce in the dry period of the year, a lot of effort has been put to understand the hydrology for being able to provide water to the Mauritian people all year around.

"Water resources and water management of Mauritius" is an earlier study within this exchange program by Per Berg (2004). Mauritius' natural resources and how the country handles their management were investigated. The study included some work on reservoirs but also on groundwater. Municipal water originates to 58% from groundwater and the rest is surface water. Further the total need of water for Mauritius is 975 Mm^3.

The reservoirs in Mauritius have during the last years for the first time been examined regarding their limnic ecosystem. The work started when the MPhil student Danishta Dumur began her investigations in 2004. The study included physical parameters, (temperature, pH, turbidity, conductivity, water transparency and dissolved oxygen) chemical parameters, (Inorganic Phosphorus, Total Phosphorus, Nitrate-Nitrogen, Ammonium-Nitrogen, Nitrite-Nitrogen and soluble Reactive Silica) and biological parameters, (Chlorophyll *a*, phytoplankton biomass and zooplankton density) for classifying two reservoir systems. These examinations resulted in the report "Limnological studies in two reservoir systems of Mauritius: La Nicolière and Piton du Milieu reservoirs" (2007).

The result of those investigations shows different characteristics than earlier classification of the reservoir made in 1999 concerning several factors. La Nicolière should now be considered a eutrophic system and Piton du Milieu a mesotrophic system when looking to Vollenweider's classification but also regarding physical parameters as water transparency and pH. Stratification is an important factor influencing lake ecosystems, in tropical areas lakes mostly are polymictic or warm monomictic. Dumur (2007) showed that La Nicolière is a polymictic system with weak stratification which was explained by the strong wind and discharge rate in the feeder canal. For Piton du Milieu the stratification was significant during the wet period and the oxygen level decreased considerably down the water column. Even anoxic conditions were recorded at the bottom during one of the two stratification periods that were recorded.

The biomass of phytoplankton (wet weight) was high in La Nicolière and low in Piton du Milieu. La Nicolière had a total mean biomass during the dry period of 16110 μgl^{-1} and 7803 μgl^{-1} during the wet period and was dominated by cyanophytes, diatoms and conjugatophytes. In Piton du Milieu conjugatophytes were most abundant and the biomass had a mean of 6300 μgl^{-1} in the wet period and 4672 μgl^{-1} during the dry period.

Dumur (2007) recommended further studies of Mauritian limnology and on the reservoirs, this project being one of those.

3 METHOD

3.1 SAMPLING

The planned sampling was performed under a period of four weeks in January and February 2007 and before that a test sampling occurred in December (table 3). Water from the euphotic zone was collected from the sampling spot at the side of the bridge and put in a bucket (figure 7).

Table 3 Dates of sampling.

	La Nicolière	Piton du Milieu
Test sampling	06-12-06	
Sampling from boat	07-01-23	
Sampling 1	07-01-29	07-01-25
Sampling 2	07-02-07	07-01-31
Sampling 3	07-02-13	07-02-08
Sampling 4	07-02-20	07-02-15

Figure 7 a) Sampling spot where the red arrow points in La Nicolière (the bottles hung on the back of the bridge) **b)** Sampling spot in Piton du Milieu.

3.1.1 Primary production

The oxygen method was used for measuring primary production. Since both reservoirs are used as drinking water the C^{14} method is not allowed by the CWA. The oxygen method is performed by measuring dissolved oxygen and a modification of the Winkler method (1888) was used. From a bucket, water was filled to 9 100 ml bottles; 1 bottle for initial measurement of oxygen, 1 bottle for dark incubation and 7 bottles for light incubation. To the initial bottle was immediately the two oxygen reagents (Manganese-solution and Hydroxide/Iodine-solution) added and then put in an isotherm box. The other bottles were put on a vertical line (figure 8) to be incubated for 2 hours at 0, 0.1, 0.2, 0.4, 0.8, 1.6 and 3.2 m depth. The dark bottle was wrapped in aluminum foil and attached to the rope under the deepest bottle. Every sampling was performed in duplicates, where two bottles at the same depth contributed to every value for oxygen content for each depth.

Figure 8 The line with light bottles are taken up after incubation in La Nicolière.

3.1.2 Chlorophyll and other pigments

A half liter plastic bottle was filled with well mixed water from the bucket. For stabilization of the water 3 ml Magnesium carbonate solution per liter sample water was added. The stabilization is made in order to prevent the chlorophyll being transformed to phaeophytine. Then the bottle was put in a dark and cold place (isotherm box) until analysis.

3.1.3 Phytoplankton biomass

A 300 ml glass bottle was filled with water from the bucket. 0.1 ml Lugols solution was added per 100 ml water. The bottle was directly put in the dark until analysis.

3.2 LABORATORY WORK

The laboratory work was performed at the biology department, Faculty of Science at the University of Mauritius (figure 9).

Figure 9 The lab work bench. The filtering equipment with pump is seen to the left and to the right is the spectrophotometer with a collection of sample bottles next to it.

3.2.1 Primary production

Back at the laboratory, 1 ml concentrated phosphoric acid per 100 ml sample was added and when this had dissolved, after about 5 minutes, the absorbance at 450 nm was measured with a spectrophotometer (Spectronic 21D Milton Roy).

The oxygen concentration in the different bottles was calculated from the absorbance according to Broberg (2003).

$$Oxygen\ conc. = Absorbance \cdot 11.92 \quad \text{(eq. 4)}$$

The depth distribution of net and gross primary production along with respiration was calculated according to Ahlgren (2006).

$$Net\ oxygen\ production = oxygen\ conc.(light\ bottle) - oxygen\ conc.(initial\ bottle) \quad \text{(eq. 5)}$$

$$Gross\ oxygen\ production = Net\ oxygen\ production + respiration \quad \text{(eq. 6)}$$

$$\mathrm{Re}\,spiration = oxygen\ conc.(initial\ bottle) - oxygen\ conc.(dark\ bottle) \quad \text{(eq. 7)}$$

For primary production per unit surface area, in $gO_2/m^2/d$, the graphical integral of the depth-production-curve (=I) was calculated. For transformation from O_2 to CO_2, the conversion factor 0.375 and PQ 1.5 was used (since the dominating N source is NO_3 (Ahlgren, 2000)).

$$Primary\ production\left[\frac{gC}{m^2 \cdot h}\right] = \frac{I \cdot conversion\ factor}{incubation\ hours \cdot PQ} \quad \text{(eq. 8)}$$

3.2.2 Chlorophyll and other pigments

The water was poured and pumped through a glass fiber filter (45µm pore size and 47 mm diameter). The volume was measured before filtration. The whole filter was then put in a glass beaker and 10 ml 90% acetone was added. The beaker was then placed in the fridge over the night and the absorbance was measured at 750, 665, 645, 630 and 480 nm with a spectrophotometer (Spectronic 21D Milton Roy) the next morning. Finally one drop of HCl was added in the cuvette and the absorbance was measured at 665 and 750 nm after 1 minute. For calculations of the different pigments equations 9-15 were used. Chlorophyll *a, b* and *c* and Caretonoids were calculated according to Parsons T.R. & J.D.H. Strickland, 1963 and the pheo pigments according to Lorenzen C.J, 1967.

$$Chlorophyll\ a\ (\mu g/l) = K\frac{(11.6D_{665} - 0.14D_{630} - 1.31D_{645})}{V}$$

eq. 9

$$Chlorophyll\ b\ (\mu g/l) = K\frac{(20.7D_{645} - 4.34D_{665} - 4.42D_{630})}{V} \quad \text{eq. 10}$$

$$Chlorophyll\ c\ (\mu g/l) = K\frac{(55.0D_{630} - 16.3D_{645} - 4.64D_{665})}{V}$$

eq. 11

$$Pheo\ pigments\ (\mu g/l) = K\frac{26.7(1.7D'_{665} - D_{665})}{V} \quad \text{eq. 12}$$

$$Corr.Chlorophyll\ a\ (\mu g/l) = K\frac{26.7(D'_{665} - D_{665})}{V} \quad \text{eq. 13}$$

$$Caretonoids\ (\mu g/l) = K \cdot T\frac{\left[(A_{480} - A_{480(Aceton)}) - 3(A_{750} - A_{750(Aceton)})\right]}{V} \quad \text{eq. 14}$$

$$D_{lambda} = (A_{lambda} - A_{lambda(Aceton)}) - (A_{750} - A_{750(Aceton)}) \quad \text{eq. 15}$$

$D'_{lambda} = D_{lambda}$ after sour
A_{lambda}=Absorbance at wave length lambda
K = extract volume(ml)/cuvette length(cm)
V = filtrated volume of sample water (L)
T = 4 when greenalgae or cyanobacteria dominate
T = 10 when chrysophytes or pyrrophytes dominate

The value of K was 2, based on extract volume 10ml and cuvette length 5cm. As green algae and cyanobacteria were more abundant than chrysophytes or pyrrofytes, T=4 was chosen.

3.2.3 Phytoplankton biomass

The samples were put in a sedimentation chamber for 24 hours; 1 ml chamber for La Nicolière and a 10 ml chamber for Piton du Milieu. This was recommendations from Dumur based on the results she received two years back. After 24 hours a glass plate were put over the sedimented part and put under an inverted microscope. The most abundant phytoplankton groups were counted and the biomass of these was calculated with conversion factors received from Dumur which she calculated in 2005.

3.3 ENVIRONMENTAL VARIABLES

Various environmental conditions were measured at each sampling occasion; max water depth, secchi disc depth, temperature and pH.

Meteorological data were received from Mauritius Meteorological Services. For each reservoir a mean from two nearby weather stations was calculated. For La Nicolière these were Nouvelle Découverte and Pamplemousses and for Piton du Milieu; Belle Rive and Rosalie. Weather data were received for 2006 and for the period when the sampling was performed.

Hydrological data were received from WRU, these data were discharge in the largest rivers feeding the reservoirs and the daily storage volume for the reservoirs. The rivers feeding La Nicolière would then be Du Rempart River and a Feeder Canal from Midlands dam and for Piton du Milieu; Bateau River and Vacoas River.

4 RESULTS

4.1 PRIMARY PRODUCTION

In La Nicolière there was a negative net primary production in the last four samplings (figure 11), which is not possible so these were later stated as zero primary production. Piton du Milieu had negative net primary production 070125 and 070215, so these were also set to zero (figure 12). The Gross primary production was zero in la Nicolière at 070207 and negative once for Piton du Milieu in 070215. A negative net primary production means that the respiration is larger than the production and no production can occur. In gross primary production respiration is accounted for and production still being zero shows for production being non-existing. The first sampling in La Nicolière in December, which is the only one before the rains, showed a lower rate of photosynthesis than in January and February when the rains had started (when disregarding 070207 as primary production being zero).

Photo inhibition occurred in La Nicolière for the two first samplings when the clouds were fewer and the sun was stronger than in the other samplings. In Piton du Milieu photo inhibition occurred but not as distinct as in La Nicolière even though the observed sun radiation was stronger there. In the cases when no photo inhibition occurred the photosynthesis at the surface was among the strongest from the depth profile. Especially in Piton du Milieu 070215 the photosynthesis was much stronger at the surface than in any other point in the depth profile. This indicates a perfect sun radiation, not too strong for photo inhibition to occur and then the sun radiation decreases with increasing depth.

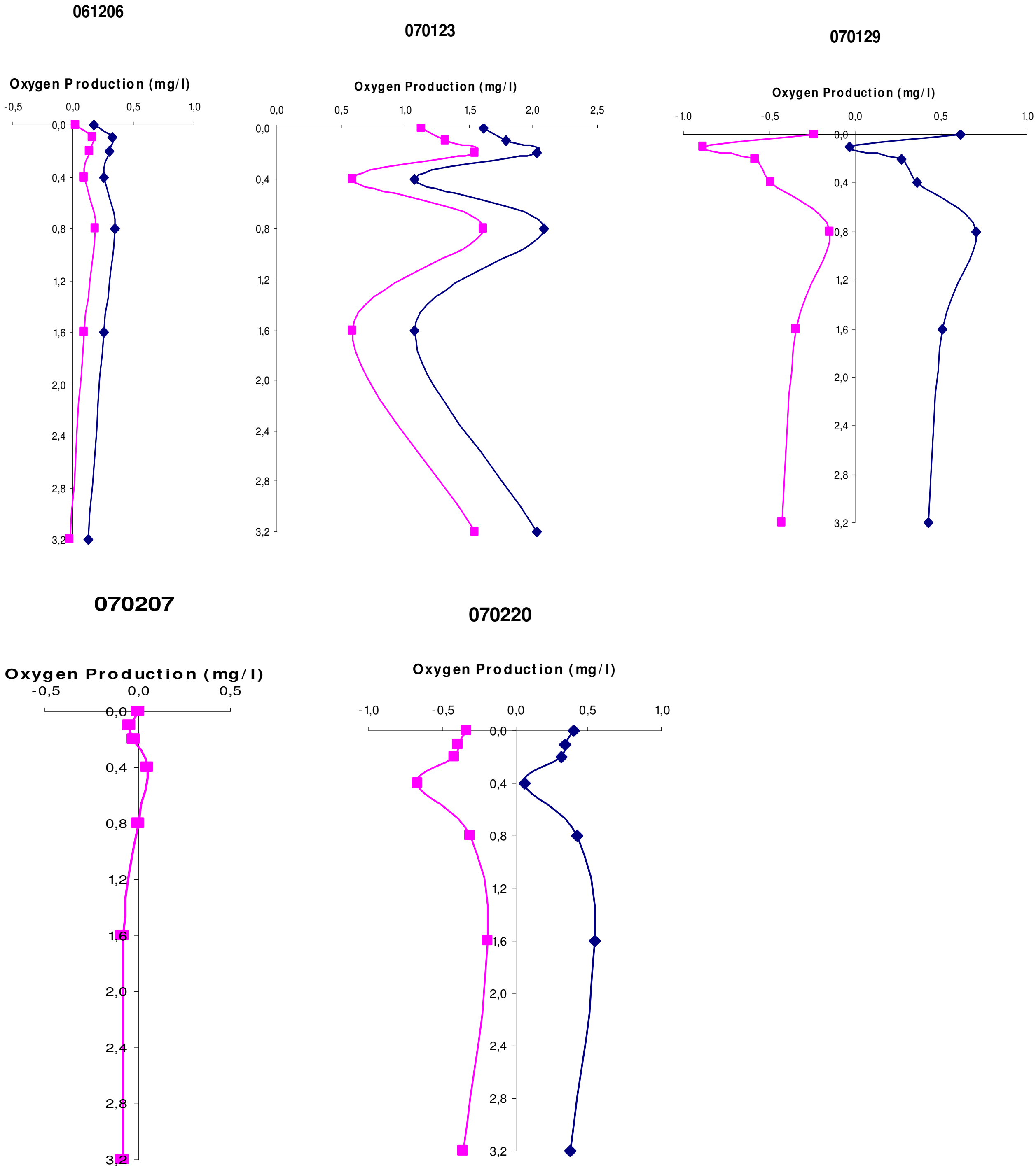

Figure 11 Depth (m) distribution of Net (light) and Gross (dark) primary production (mg/l) in La Nicolière.

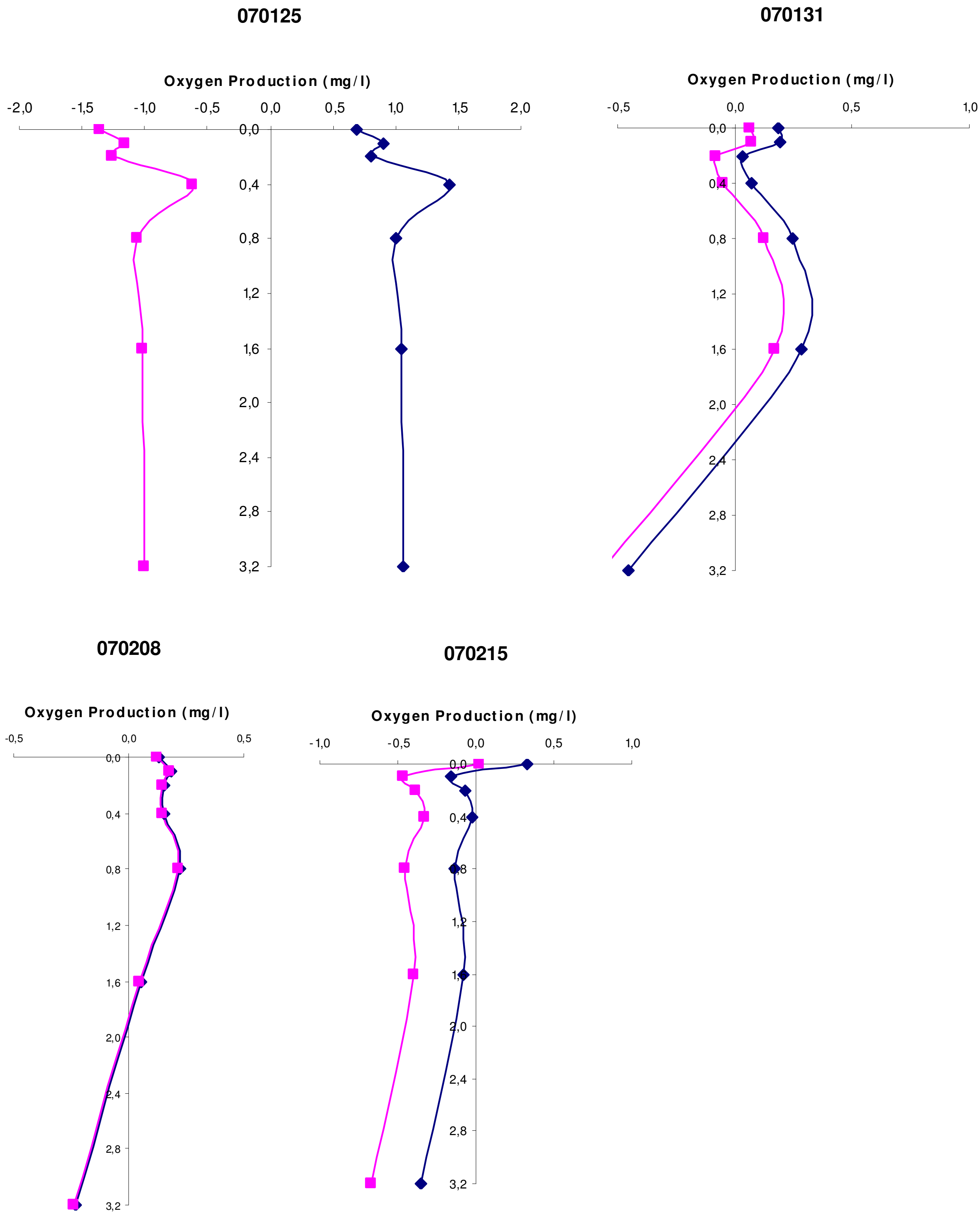

Figure 12 Depth (m) distribution of Net (light) and Gross (dark) primary production (mg/l) in Piton du Milieu.

Graphical integrals were calculated from figure 11 and 12 to receive the net and gross primary production per unit surface area (Table 4, 5, 6 and 7). The daily primary production was received by multiplying the hourly PP with that specific day's sunshine hours received from MMS. The net and gross primary production were higher in La Nicolière than in Piton du Milieu, as expected, but also the specific primary production was higher except for the first sampling in Piton du Milieu when the production was exceptionally high. For La Nicolière the highest GPP occurred on the 23 of January and the lowest on 7 February. For Piton du Milieu the maximum were spectacular high and occurred on 25 of January and the minimum on 15 February.

Table 4 Net Primary Production in La Nicolière.

Datum	NPP (gO2/m2/h)	NPP (gO2/m2/d)	NPP (gC/m2/h)	NPP (gC/m2/d)	SPP (gC/gChla/d)
2006-12-06	0.11	0.81	0.03	0.20	134
2007-01-23	1.66	6.95	0.41	1.74	632
2007-01-29	0.00	0.00	0.00	0.00	0.00
2007-02-07	0.00	0.00	0.00	0.00	0.00
2007-02-13	0.00	0.00	0.00	0.00	0.00
2007-02-20	0.00	0.00	0.00	0.00	0.00

Table 5 Net Primary production in Piton du Milieu

Datum	NPP (gO2/m2/h)	NPP (gO2/m2/d)	NPP (gC/m2/h)	NPP (gC/m2/d)	SPP (gC/gChla/d)
2007-01-25	0.00	0.00	0.00	0.00	0.00
2007-01-31	0.11	0.44	0.03	0.11	43
2007-02-08	0.12	0.82	0.03	0.21	136
2007-02-15	0.00	0.00	0.00	0.00	0.00

Table 6 Gross Primary Production in La Nicolière

Datum	GPP (gO2/m2/h)	GPP (gO2/m2/d)	GPP (gC/m2/h)	GPP (gC/m2/d)	SPP (gC/gChla/d)
2006-12-06	0.31	2.30	0.08	0.57	379
2007-01-23	2.42	10.15	0.60	2.54	924
2007-01-29	0.63	2.90	0.16	0.72	326
2007-02-07	0.00	0.00	0.00	0.00	0.00
2007-02-13	0.42	3.32	0.10	0.83	359
2007-02-20	0.69	2.98	0.17	0.74	211

Table 7 Gross Primary production in Piton du Milieu

Datum	GPP (gO2/m2/h)	GPP (gO2/m2/d)	GPP (gC/m2/h)	GPP (gC/m2/d)	SPP (gC/gChla/d)
2007-01-25	1.69	14.03	0.42	3.51	2980
2007-01-31	0.31	1.24	0.08	0.31	122
2007-02-08	0.13	0.89	0.03	0.22	147
2007-02-15	0.01	0.01	0.00	0.00	0.81

4.2 CHLOROPHYLL AND OTHER PIGMENTS

The most important pigment chlorophyll *a* also had the highest concentration of the measured pigments (table 8 and 9), as expected. In La Nicolière Chlorophyll c was quite high and also Carotenoids, this doesn't indicate in high concentration on a specific group since they exist in almost all the common phytoplankton in freshwater systems from table 1. For Chlorophyll *a* the mean for La Nicolière was 2.50 µg/l and Piton du Milieu was a bit lower with 1.83 µg/l. This supports the results from earlier works, where La Nicolière is stated to be the most nutrient rich. Both the reservoirs have a very low concentration of chlorophyll *a* compared to other reservoirs in the tropical part of the world. For La Nicolière chlorophyll *a* was increasing throughout the measured period, this meaning the more rain that fell and the fuller the reservoir was, the higher concentration of biomass. For Piton du Milieu a tendency like that could not be seen.

Table 8 Pigment concentrations for La Nicolière

Samplingdate	06-12-06	07-01-23	07-01-29	07-02-07	07-02-13	07-02-20
Chlorophyll *a* (µg/l)	1.51	2.75	2.22	2.68	2.31	3.52
Chlorophyll *b* (µg/l)	0.21	0.07	0.04	0.21	0.12	0.33
Chlorophyll *c* (µg/l)	0.29	1.08	0.49	0.94	0.60	1.48
Pheo pigments (µg/l)	0.31	0.13	0	0.45	0	0
Corr. Chlorophyll *a* (µg/l)	1.31	2.62	2.20	2.37	2.67	3.79
Carotenoids (µg/l)	0.51	1.83	1.30	1.63	1.05	1.70

Table 9 Pigment concentrations for Piton du Milieu

Samplingdate	07-01-25	07-01-31	07-02-08	07-02-15
Chlorophyll *a* (µg/l)	1.18	2.55	1.51	2.08
Chlorophyll *b* (µg/l)	0.13	0.34	0.12	0.22
Chlorophyll *c* (µg/l)	0.41	0.67	0.18	0.36
Pheo pigments (µg/l)	0	0.19	0	0
Corr. Chlorophyll *a* (µg/l)	1.21	2.40	1.70	2.18
Carotenoids (µg/l)	0.65	1.37	0.75	1.29

4.3 BIOMASS

The most abundant phytoplankton groups differed between the two reservoirs (figure 13 and 14). In La Nicolière which is eutrophic and has the largest biomass, most of the biomass consisted of diatoms followed by cyanophytes. The mean during the sampling was around 2500 µg/l and the maximum occurred at the first and last sampling; beginning of December and February. For the mesotrophic reservoir Piton du Milieu the most abundant phytoplankton amounted up to around 650 µg/l. In Piton du Milieu the phytoplankton did not vary as much as in La Nicolière instead they slowly increased until the reservoir is full at the 8 of February when they reached a maximum and stayed there for the last sampling too. La Nicolière on the other hand had three peaks with two deep dips in-between but when looking at the different groups almost only the diatoms contributed to the variation in the biomass. Diatoms are quite heavy and can have sunk in the two samplings when they were very infrequent; 070123 and 070213, this gives very quick variations for the diatoms and doesn't say much about the biomass since they will be resuspended by mixing, hence La Nicolière being mixed most of the time.

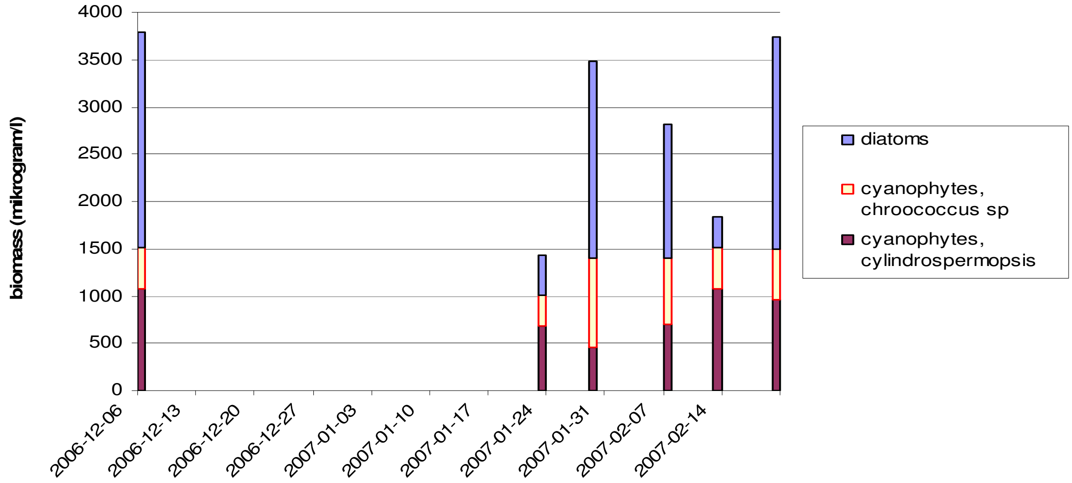

Figure 13 The most abundant species in La Nicolière.

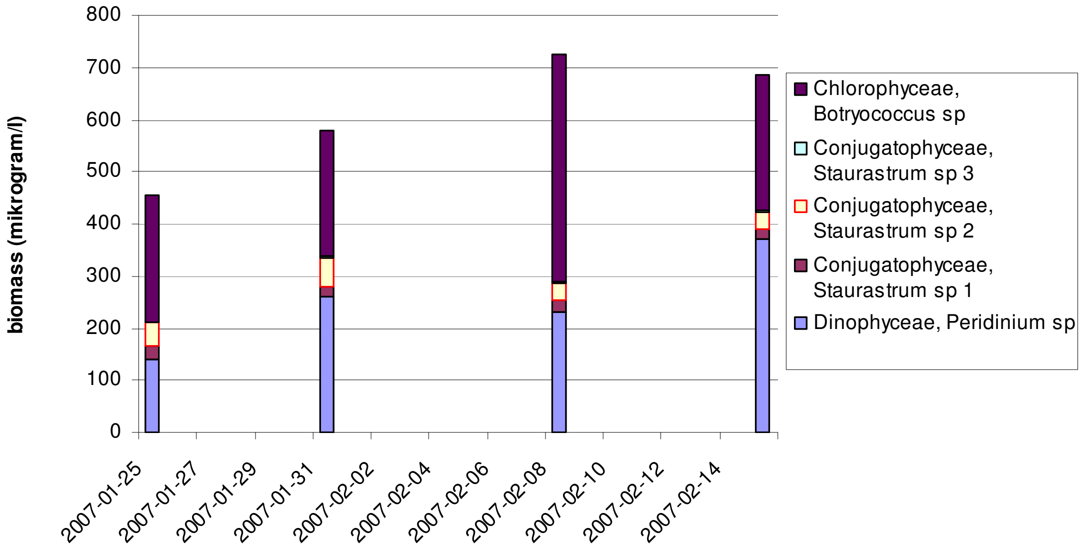

Figure 14 The most abundant counted species in Piton du Milieu.

4.4 ENVIRONMENTAL VARIABLES

For temperature, pH, depth and water transparency, these results can bee seen together with the primary production and DO (figure 15 and 16). In La Nicolière a small trend connected to the primary production can be seen for all the variables except for transparency. In Piton du Milieu it is harder to see correlations but there was a large water level increase in Piton du Milieu when the reservoir started to get full, between 070125 and 070131, when the temperature and pH decreased.

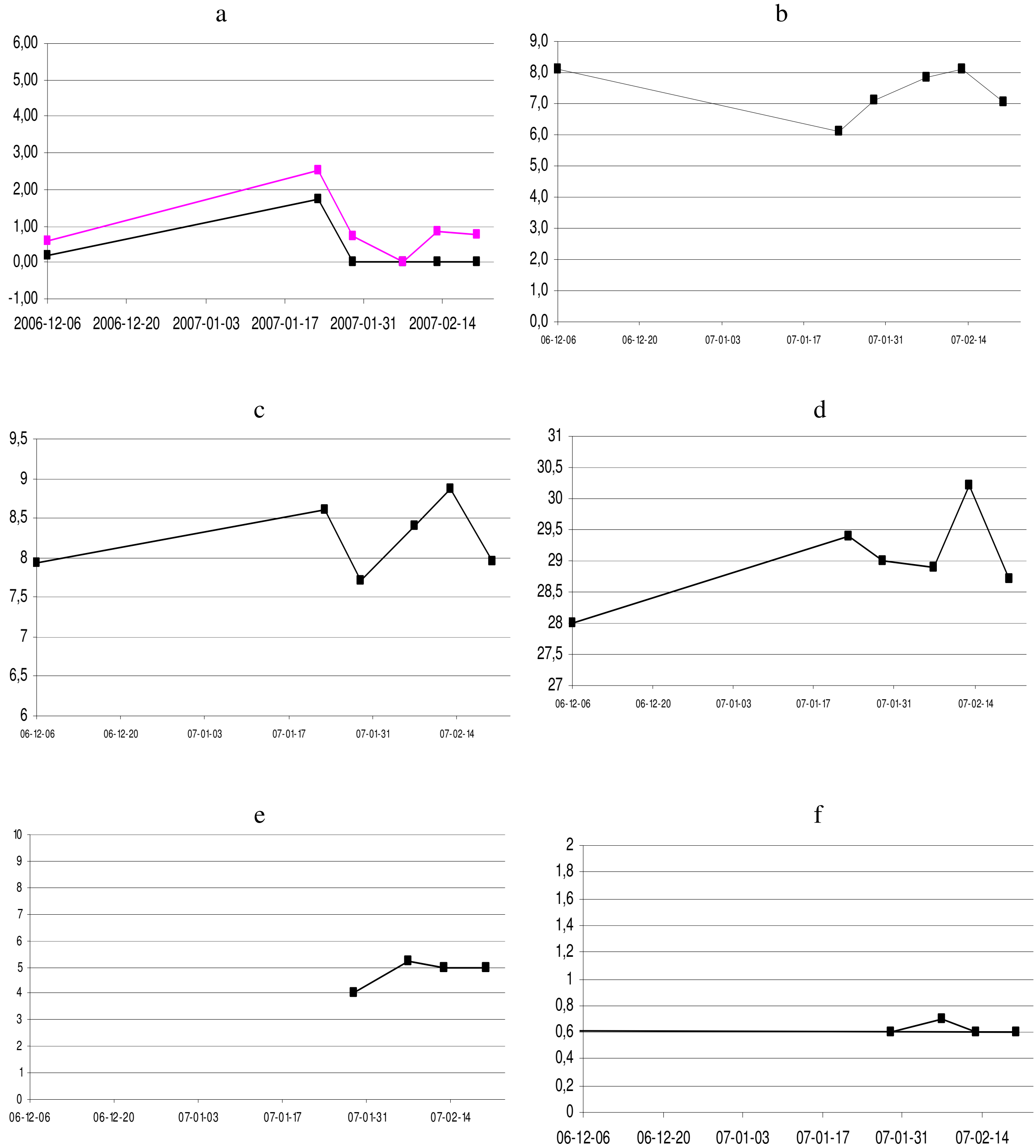

Figure 15 Parameters for La Nicolière a) Net (dark) and gross (light) primary production (gC/m2/d). b) Dissolved oxygen (mg/l). c) pH. d) Temperature (°C). e) Depth of reservoir (m). f) Transparency (Secchi depth (m)).

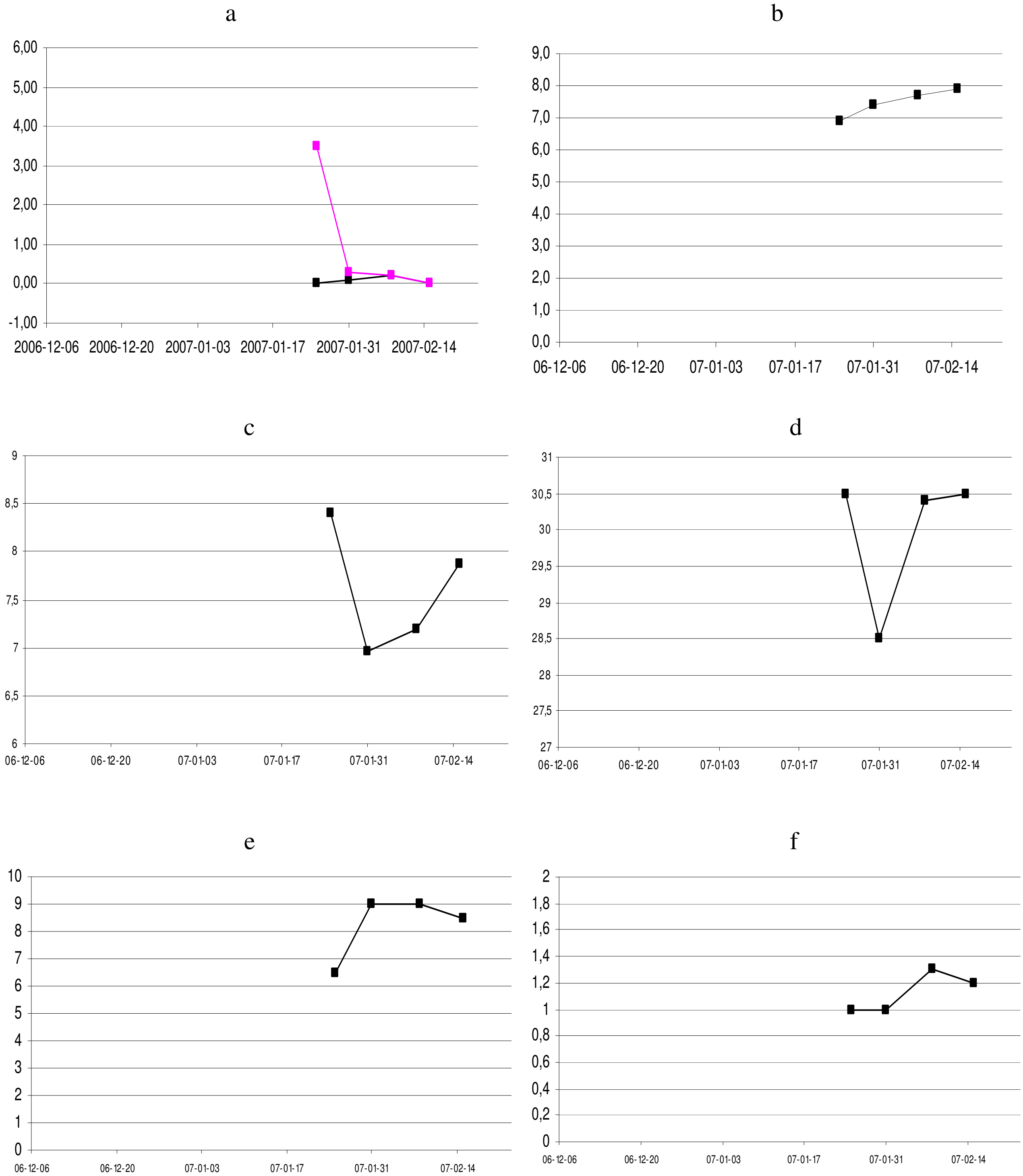

Figure 16 Parameters for Piton du Milieu a) Net (dark) and gross (light) primary production (gC/m2/d). b) Dissolved oxygen (mg/l). c) pH. d) Temperature (°C). e) Depth of reservoir (m). f) Transparency (Secchi depth (m)).

4.4 METEOROLOGICAL AND HYDROLOGICAL DATA

For precipitation, air temperature and evaporation one year of data (060301-070228) is shown graphically, including the sampling period in the end (figure 17-20).

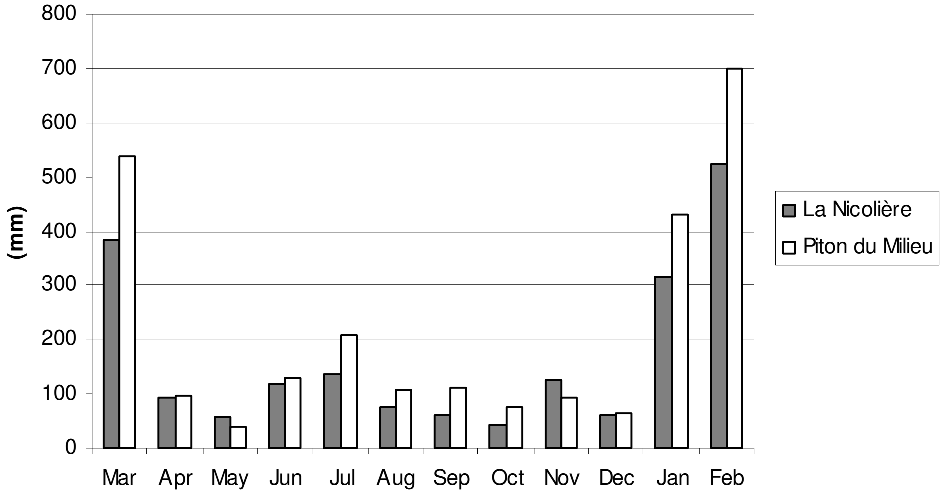

Figure 17 Precipitation over La Nicolière and Piton du Milieu for 2006/2007, this gives the total precipitation 2000 mm respectively 2593 mm for one year.

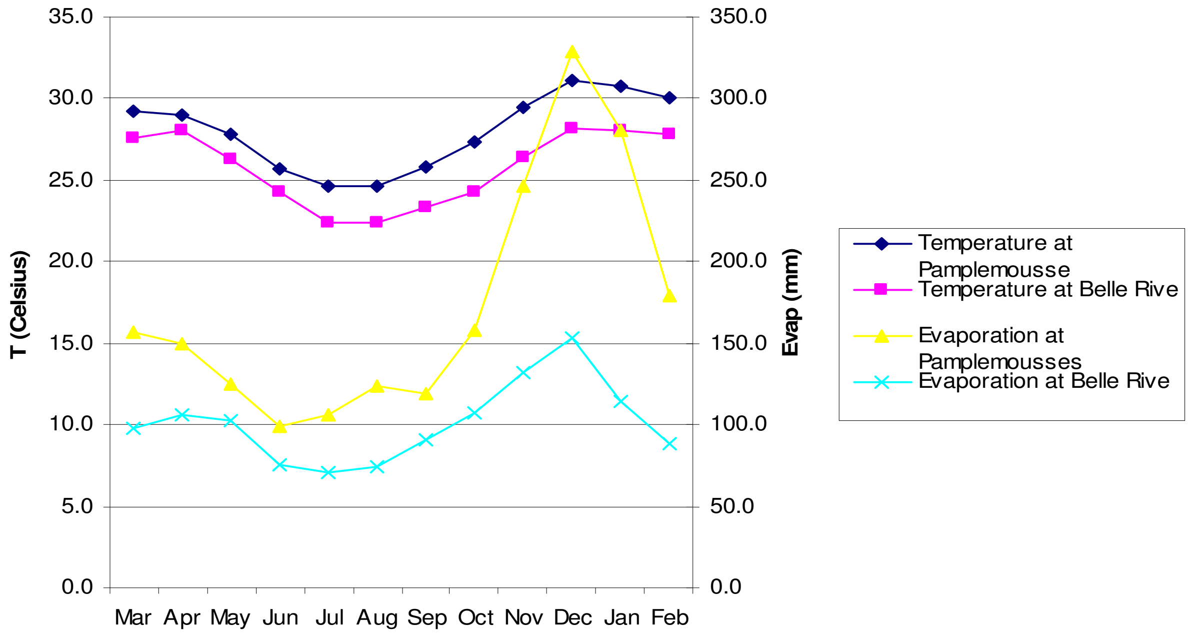

Figure 18 Monthly max temperatures for the nearest station to La Nicolière (Pamplemousses) respectively Piton du Milieu (Belle Rive).

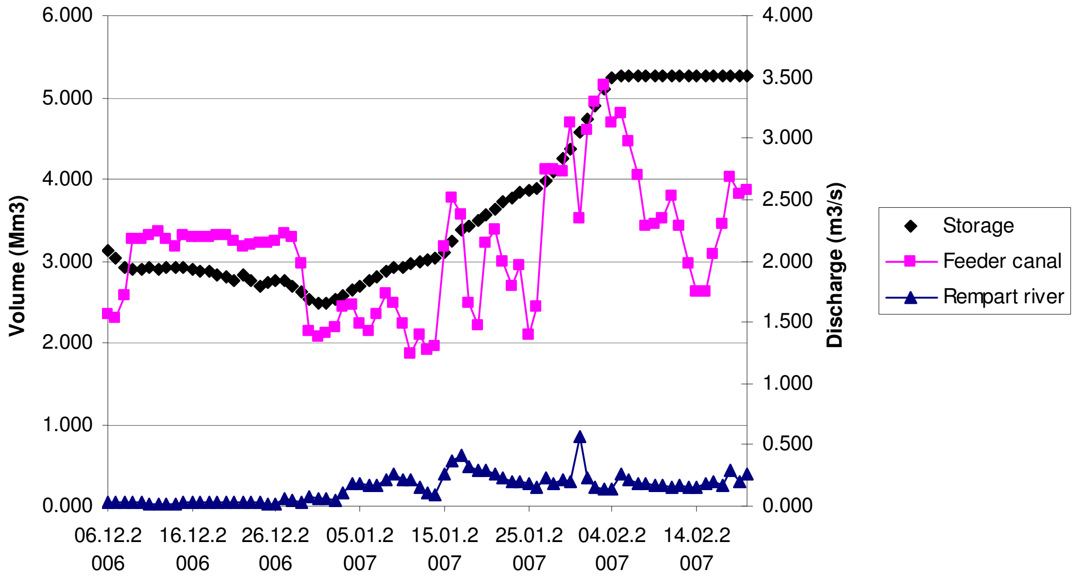

Figure 19 Volume of La Nicolière and the discharge in the feeder canal from Midlands dam and Rempart River that are feeding the reservoir.

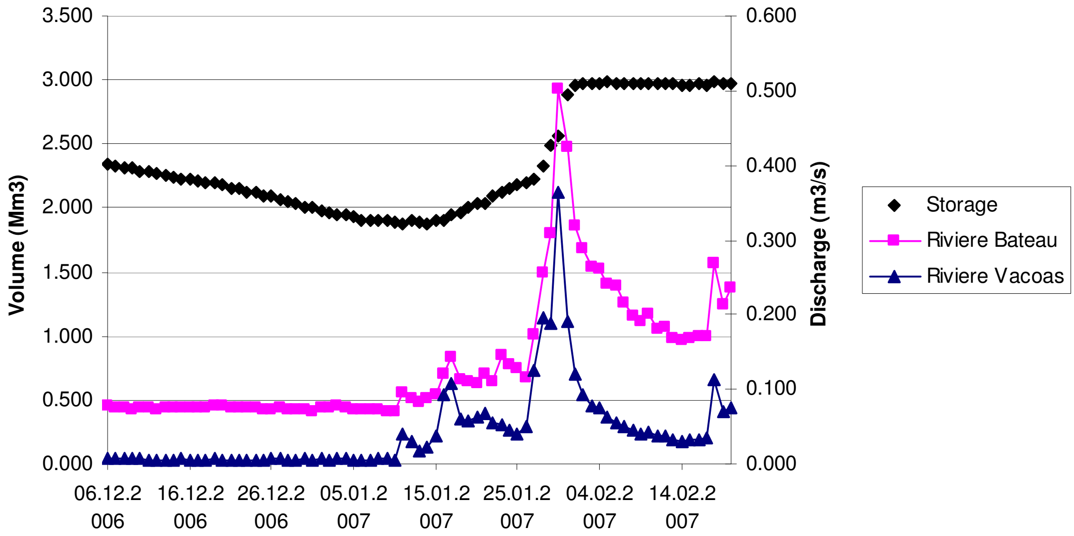

Figure 20 The variations in Piton du Milieu during the sampling period for volume in the reservoir and the discharge for the two main rivers feeding the reservoir.

5 DISCUSSION

Summarizing the main results of this study, the primary production was low in both reservoirs when comparing to other tropical lakes and reservoirs. Also the Chlorophyll *a* content was low and not correlated with the counted biomass of phytoplankton. However, low values of primary production and chlorophyll *a* content together resulted in a normal level of specific primary production compared to other tropical reservoirs.

The primary production was higher in La Nicolière than in Piton du Milieu at all occasions except one (070125). The difference in primary production between the two reservoirs can be explained by the different nutrient content (Henry 2006). The sampling in Piton du Milieu on 070125 resulted in remarkably high values of primary production compared to the measurements performed later. The environmental conditions, with high pH and temperature and a much lower depth, support these results. The other observations of PP in Piton du Milieu gave lower values than those of La Nicolière, but this single result contributes to a higher mean of specific primary production than for La Nicolière. On 31 of January the discharge in the rivers feeding Piton du Milieu were extremely high. This could support a higher nutrient content and thereby a higher phytoplankton biomass and primary production, but this was not the case. It could be that the decrease in temperature and pH cancel out these effects.

The primary production is in theory strongly correlated to solar radiation but since no radiation data were available, it was not possible to make such a comparison.. Visual weather observations (appendix IV) were made during sampling but no relations could be found from these observations.

The primary production curves (figure 11 and 12) are dichotomous but since the values are very small and also the bottles hung from a concrete bridge and did not follow the fluctuations in the water level this can be disregarded and probably there is only one maximum. Interesting is that during the samplings when the bottles hung from a boat, i.e., the two first samplings in La Nicolière, the largest photo inhibition occurred.

This survey only included 4 samplings during the wet summer period, which makes it difficult to compare the results with mean annual figures from the literature. On the other hand, in tropical reservoirs the PP doesn't vary very much within the year. It can be expected that the mean value of this study is a bit higher than the annual mean since this study was made during summer. The mean values of this study are, however, uncertain since they are based on few data with large variations. For NPP both reservoirs only had two values each above zero from where the mean was calculated, which yields a large uncertainty in the mean. The euphotic zone is thicker in winter than in summer, which can in somehow compensate the lower volumetric primary production and yield a more similar areal primary production. When comparing to other tropical lakes (table 10), La Nicolière and Piton du Milieu have a very low net and gross primary production. Though, the specific primary production is large when comparing to one other lake, meaning that the two reservoirs have a high efficiency when looking at the gross production. For the net production the efficiency is a bit different since some of the results were zero. Net

SPP was 383 gC/gChla/d and 89 gC/gChla/d respectively for La Nicolière and Piton du Milieu.

Table 10 Comparison for primary production between this study and other tropical reservoirs and lakes and the Swedish temperate lake Erken.

Lake/reservoir	GPP (gO2/m2/d)	NPP (gC/m2/d)	SPP (gC/gChla/d)	Reference
La Nicolière reservoir	4.33	0.97	439.94	this study
Piton du Milieu reservoir	4.04	0.16	1082.29	this study
Tissawewa reservoir	7.2	-	253.56	(Bandu Amarasinghe & Vijverberg 2002)
Lake Erken		0.28	-	(Lewis 1974)
Lake Lanao		1.7	-	(Lewis 1974)
Lake Victoria	13.9	-	-	(Bandu Amarasinghe & Vijverberg 2002)
Lake Xolotlán	18	-	-	(Eriksson 1998)

The chlorophyll content was very low, in La Nicolière the concentration was 2.50 µg/l and Piton du Milieu had 1.83 µg/l. In other tropical reservoirs and lakes the chlorophyll contrations were around 30µg/l from Bandu (2002) and 27.3 µg/l (Thomas et al, 2000). The chlorophyll *a* content is more similar to an eutrophic reservoirs in Portugal (Geraldes & Boavida, 2003) where the annual mean was around 2 µg/l. For other pigments you can see a larger fraction of chlorophyll *b* in Piton du Milieu, provided by the greater amount of chlorophyta there. As for the rest of the pigments it is hard to see correlations because a specific phytoplankton group contains many pigments.

Both the primary production and chlorophyll *a* is much lower than in other tropical lakes and reservoirs but since these are the only one measured at Mauritius we have to assume this is normal for the island. On the other hand most of the examined reservoirs and lakes in the world are eutrophic and have high nutrient content. La Nicolière and Piton du Milieu, which both had low nutrient concentration, Piton du Milieu was even extremely low in nutrients, can then be hard to compare with other catchments. Other parameters as temperature and pH lie in a normal interval. By using the bottle technique for in situ experiment the productivity is underestimated since the phytoplanktons can become photoinhibited. When the planktons are free floating they move in and out from high irradiation. But this isn't something that explains the large differences from other tropical reservoirs since the same methods with bottle incubations are generally used. One thing explaining the small primary production can also be a high respiration. The high temperature and low chlorophyll *a* content supports this explanation.

The most abundant phytoplankton account for half of the biomass in La Nicolière and three fourths in Piton du Milieu. The biomass was larger than 2 years ago when looking at the counting of the most abundant groups. This can have something to do with the lower water depths in the reservoirs in the beginning of the sampling since less water gives higher concentrations of nutrients. The water scarcity in the reservoirs during this summer could have caused a change in the limnic systems. For example the macrophytes

are decreasing since they end up at land instead of under water which can lead to changes in the reservoirs. It can also depend on an increase in nutrients, this we didn't measure but it is one of the most important factors controlling phytoplankton.
The largest aerial density of phytoplankton occurs in the euphotic zone and then the biomass decreases with increased depth (R. Eriksson 1998). Since measurements took place in the euphotic zone the highest occurring biomass in the reservoir is there. La Nicolière had a large biomass of cyanophyceae and they were more abundant in the dry period than after the rain had started (*cf.* Wetzel, 2001).

The primary production should correlate with chlorophyll *a* and phytoplankton biomass (Calijuri 2001). In this study the phytoplankton biomass have an inverted correlation with PP in both reservoirs, when phytoplankton increases the primary production decreases. Between chlorophyll *a* and PP there is no found correlation. This can depend on the few samplings in this survey but a big difference from many other tropical reservoirs is the low nutrient content in La Nicolière and Piton du Milieu.

Regarding the oxygen saturation high values were expected but not super saturated, which were the results. Since the water was saturated from start the over-saturation could not be used as an indication for too long incubation time. This is not something unusual for tropical lakes; in a Brazilian eutrophic lake, 140% of oxygen saturation was reached (Arcifa et al., 1990). The maximum oxygen saturation in this investigation was 108%, in La Nicolière. But also Piton du Milieu was oversaturated in half of the samplings and that reservoir is not a eutrophic ecosystem.

When comparing DO from this study with the previous study made by Dumur (2007) it gave more similarities for La Nicolière than for Piton du Milieu. This can depend on that La Nicolière is more vertically mixed than Piton du Milieu in the euphotic zone. This leads to a more homogenate system in La Nicolière because Dumur (2007) results were from integrated samples from the whole reservoir and this study had from location in each reservoir. In figure 15b and 16b the initial oxygen concentration for La Nicolière and Piton du Milieu can be seen. When comparing to the result received two years back you also see more variation in the surface water for La Nicolière as here. The concentration levels for La Nicolière are more similar between the two studies and for Piton du Milieu this study shows a bit less DO. Even though the nutrient content isn't that high the mixing makes recycling easier and can raise the primary production.

The measuring of secchi depth didn't gain anything to the survey since it did not correlate with any other parameter. A weakness in the measurements of transparency was the high insecurity in the result since the person measuring stood two meters above the surface, at the bridge and not at the surface. When comparing to Dumur (2007) my results are at the lower end especially when regarding it is summer and the transparency is at its higher scale (Henry, 2006). The lowest transparency occurs in the beginning of the dry season.

Zooplankton were not counted or looked for, from Dumur I got the information that the zooplankton didn't control the phytoplankton, since the most abundant phytoplankton were zooplankton resistant in the reservoirs.

5.1. SOURCES OF ERROR

The sampling was planned to occur once before the rain started in December. But since the boat broke during the first test sampling in La Nicolière no more samplings could be done during December. This sampling comes from only one set of bottles since it was suppose to be a test but when being the only sampling before the rain started it has been incorporated to the results. The first real sampling was then performed in January. This was a disappointment for the project since it had been good to have values before the rain started in the dry period and then after. A sampling frequency and period according to the original plans of sampling would have given more reliable results for this kind of short term survey. Now the sampling had to bee compromised for being able to finish the project in time. The sampling in both reservoirs was to be carried out at the deepest part like standard procedure for this kind of measurements but since the boat broke again during the second sampling in La Nicolière we were not able to reach that spot any more. Both of the reservoirs had a bridge were the samples were taken instead, this spot was 2-3 m shallower. On 7 February; one set of bottles were lost to the bottom so these are also from only one set. In the other samplings the two sets often differed a great deal (appendix III).

The higher detection limit for the oxygen method compared to C14 is manageable since this is just a first control of the primary production in the euphotic zone. Since only four samplings occurred, the sampling only showed the primary production under a very short period of time. Primary production is often measured throughout 2 years for a total annual check. In a study like that you get the seasonal variations and when measuring two years you get a mean from two years, in case one year is deviant.

After reading the method manual by Blomqvist (2001) a lot of sources of error have been thought about. Two mentioned and taking extra time to avoid have been: dirt to bottles under transport in car and boat and keeping track of different bottles. The bridge, where the bottles hung down in the water, was constructed with concrete all the way down to the bottom and restricted scattered light from that direction to reach the bottles. And we also had to be cautious and think about the suns path in the sky so the bottles didn’t end up in the shade during any part of the incubation time.

When putting the bottles down in the water and when taking them up there is some waiting time, which also differs for different bottles. But most concerning is the light chock that especially deeper bottles get when they reach the surface. This was avoided by trying to place the bottles in the shadow and using an umbrella for protection against the sun.

6 CONCLUSIONS

Primary production measured during the wet period at Mauritius gained a mean net/gross primary production of 0.97/1.08 gC/m2/d for La Nicolière and 0.16/1.35 gC/m2/d for Piton du Milieu. For the specific primary production there was also surprisingly a difference between the two reservoirs. La Nicolière had a SPP of 383 gC/gChla/d and 89 gC/gChla/d for Piton du Milieu. When making this comparison it should be noted that Piton du Milieu only once had higher PP than La Nicolière and this value was extremely high. When ignoring the extreme value the values agree with the theory that a more nutrient rich system has a higher primary production, hence La Nicolière being eutrophic and Piton du Milieu mesotrophic.

The chlorophyll *a* content is low for this latitude, with La Nicolière containing 2.50 µg/l and Piton du Milieu 1.83 µg/l, but still following the different nutrient content in the two reservoirs.

The phytoplankton biomass gained from counting of the most abundant groups led to a biomass of around 2500 µg/l and 600 µg/l for La Nicolière and Piton du Milieu respectively. La Nicolière's phytoplankton biomass mostly consisted of diatoms and the cyanophyte *Cylindrospermopsis*. Phytoplankton in Piton du Milieu is composed by equal shares of Chlorophyceae and Dinophyceae.

The measured primary production is low for being in a tropical ecosystem. The PP varies a lot between different days but following the environmental conditions: DO, pH, water temperature and depth. The low PP can be explained by a high respiration, this theory is also supported by high temperature and low chlorophyll *a* content. The chlorophyll *a* content is extremely low for being tropical reservoirs;, they are more similar to a Mediterranean lake. The different primary production and chlorophyll *a* content in the two reservoirs is probably a result of the low nutrient content in the two reservoirs compared to many other investigated lakes and reservoirs in the world. But further and longer investigations are recommended for mapping of primary production in Mauritius and such investigations should extend at least over one full year.

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7.2. INTERNET SOURCES

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7.3. PERSONAL COMMUNICATION

Ahlgren Gunnel and Ingemar, Department of Limnology, Uppsala University Sweden, November 6, 2006

Broberg, Anders och Brunberg, Anna. Department of Limnology, Uppsala University Sweden, November 2, 2006

Brunberg, Anna. Department of Limnology, Uppsala University Sweden, Mars 6, 2007

7.4. OTHER

MBC (Mauritius broadcasting) news, 15 December 2006

APPENDIX I

ABBREVIATIONS

CWA – Central Water Authority of Mauritius

GPP – Gross Primary Production

MMS – Mauritius Meteorological Services

NPP – Net Primary Production

PP – Primary Production

SPP – Specific Primary Production

WRU – Water Resources Unit of Mauritius

APPENDIX II

CHEMICAL SOLUTIONS

Lugols solution
done 061130

100g KI
50g I2 (cover with tinfoil as light sensitive and can evaporate)

The chemicals were mixed with 900ml ionized water (super Q) under a fume hood. 100 ml Glacial Acetic Acid was added and theb the bottle closed. The bottle was mixed by turning it upside down several times.

Mn+-solution
done 061204

150g MnCl2 was dissolved in about 150ml deionized water and diluted to 250ml with more water.

OH- - I- - N3- - solution
done 061205

160g NaOH is carefully dissolved in 150ml deionized water. (coolen before continuing)
300g NaI is dissolved in 200ml deionized water
6 g NaN3 is dissolved in 50 ml deionized water

The three solutions were mixed and the volume adjusted to 500 ml.

Aceton (90%)
Done 061205

50ml deionized water was poured into a 500ml measure colve, Aceton was added until the colve was filled. The solution was kept in a dark cupboard.

Magnesiumcarbonate (1%)
done 061205

1g MgCO3 was dissolved in 50 ml deionized water in a 100ml measure colve. Then it was filled up to 100 ml with water.

Hydro chloride acid (4M)
done 061205

35 ml deionized water was poured in a 50 ml measure colve and 15 ml concentrated HCl was added.

APPENDIX III

SAMPLING RESULTS

Sampling data for dissolved oxygen for La Nicolière, absorbance.

Date	***06-12-06***	***07-01-23***			***07-01-29***		
Comments	*Test, 50 ml*	*From boat*			*From bridge*		
w. temp	28	29,4			29		
PH	7,94	8,6			7,7		
Depth	5,7	6,2			4		
Secchi depth	0,6	0,7			0,6		
Time	11.20-13.50	11.50-13.55			10.30-13.00		
Bottle/depth	*Serie 3*	*Serie 1*	*Serie 2*	*Mean*	*Serie 1*	*Serie 2*	*Mean*
Initial	**0,680**	0,420	0,600	**0,510**	0,601	0,590	**0,596**
Dark	**0,667**	0,450	0,490	**0,470**	0,429	0,619	**0,524**
0,0	**0,682**	0,740	0,470	**0,605**	0,630	0,521	**0,576**
0,1	**0,694**	0,740	0,500	**0,620**	0,455	0,587	**0,521**
0,2	**0,692**	0,720	0,560	**0,640**	0,559	0,535	**0,547**
0,4	**0,688**	0,550	0,570	**0,560**	0,591	0,518	**0,555**
0,8	**0,696**	0,820	0,470	**0,645**	0,646	0,520	**0,583**
1,6	**0,688**	0,610	0,510	**0,560**	0,600	0,533	**0,567**
3,2	**0,678**	0,740	0,540	**0,640**	0,626	0,494	**0,560**

Date	***07-02-07***			***07-02-13***			***07-02-20***		
Comments	*From bridge*			*From bridge*			*From bridge*		
w. temp	28,9			30,2			*28,7*		
PH	8,4			8,86			*7,96*		
Depth	5,2			5			*5*		
Secchi depth	0,6			0,9			*0,6*		
Time	10.30-12-30			10.35-12.35			*10.25-11.25*		
Bottle/depth	*Serie 2*	*Serie 1*	*Mean*	*Serie 2*	*Serie 4*	*Mean*	*Serie 2*	*Serie 4*	*Mean*
Initial	0,654	0,662	**0,658**	0,704	0,656	**0,680**	0,617	0,569	**0,593**
Dark	0,670	-	**0,670**	0,637	0,615	**0,626**	0,549	0,514	**0,532**
0,0	0,659	-	**0,659**	0,671	0,628	**0,650**	0,561	0,570	**0,566**
0,1	0,654	-	**0,654**	0,683	0,586	**0,635**	0,541	0,579	**0,560**
0,2	0,656	-	**0,656**	0,672	0,587	**0,630**	0,545	0,572	**0,559**
0,4	0,663	-	**0,663**	0,692	0,594	**0,643**	0,502	0,573	**0,538**
0,8	0,658	-	**0,658**	0,649	0,619	**0,634**	0,543	0,591	**0,567**
1,6	0,651	-	**0,651**	0,677	0,629	**0,653**	0,561	0,593	**0,577**
3,2	0,651	-	**0,651**	0,658	0,643	**0,651**	0,568	0,559	**0,564**

Sampling data for dissolved oxygen for Piton du Milieu, absorbance.

Date	***07-01-25***			***07-01-31***		
w. temp	30,5			28,5		
PH	8,4			6,96		
Depth	6,5			9		
Secchi depth	1			1		
Time	11.15-13.15			10.45-12.45		
Bottle/depth	*Serie 1*	*Serie 2*	*Mean*	*Serie 1*	*Serie 2*	*Mean*
Initial	0,609	0,548	**0,579**	0,610	0,633	**0,622**
Dark	0,338	0,473	**0,406**	0,621	0,602	**0,612**
0,0	0,404	0,524	**0,464**	0,622	0,632	**0,627**
0,1	0,458	0,505	**0,482**	0,623	0,632	**0,628**
0,2	0,424	0,522	**0,473**	0,621	0,608	**0,615**
0,4	0,504	0,548	**0,526**	0,630	0,605	**0,618**
0,8	0,432	0,547	**0,490**	0,624	0,640	**0,632**
1,6	0,431	0,555	**0,493**	0,628	0,643	**0,636**
3,2	0,492	0,496	**0,494**	0,529	0,618	**0,574**

Date	***07-02-08***			***07-02-15***		
w. temp	30,4			30,5		
PH	7,2			7,88		
Depth	9			8,5		
Secchi depth	1,3			1,2		
Time	10.50-12.50			10.40-12.40		
Bottle/depth	*Serie 2*	*Serie 4*	*Mean*	*Serie 2*	*Serie 4*	*Mean*
Initial	0,654	0,642	**0,648**	0,660	0,662	**0,661**
Dark	0,640	0,655	**0,648**	0,656	0,613	**0,635**
0,0	0,661	0,656	**0,659**	0,672	0,653	**0,663**
0,1	0,664	0,662	**0,663**	0,648	0,595	**0,622**
0,2	0,664	0,657	**0,661**	0,635	0,623	**0,629**
0,4	0,664	0,657	**0,661**	0,658	0,608	**0,633**
0,8	0,669	0,663	**0,666**	0,614	0,632	**0,623**
1,6	0,656	0,648	**0,652**	0,621	0,635	**0,628**
3,2	0,646	0,610	**0,628**	0,608	0,601	**0,605**

Chlorophyll and other pigments

Sampling data for La Nicolière, absorbance.

Samplingdate	**06-12-06**	**07-01-23**	**07-01-29**	**07-02-07**	**07-02-07**	**07-02-13**	**07-02-13**	**07-02-20**	**07-02-20**
Analyze date	**06-12-14**	**07-01-24**	**07-01-30**	**07-02-08**	**07-02-08**	**07-02-14**	**07-02-14**	**07-02-21**	**07-02-21**
Volym (L)	0,530	0,530	0,535	0,525	0,460	0,440	0,480	0,410	0,450
Wave length (nm)									
750	0,006	0,017	0,002	0,001	0,002	0,003	0,003	0,000	0,040
665	0,042	0,082	0,055	0,062	0,059	0,047	0,054	0,063	0,113
645	0,018	0,035	0,016	0,020	0,019	0,016	0,017	0,019	0,064
630	0,014	0,033	0,013	0,016	0,016	0,013	0,014	0,014	0,062
480	0,052	0,172	0,093	0,110	0,100	0,116	0,018	0,107	0,194
750 (+ Hcl)	0,003	0,016	0,003	-0,008	0,004	0,005	0,004	0,002	0,007
665 (+ Hcl)	0,026	0,055	0,034	0,036	0,035	0,027	0,031	0,036	0,048

Sampling data for Piton du Milieu, absorbance.

Samplingdate	**07-01-25**	**07-01-31**	**07-01-31**	**07-02-08**	**07-02-08**	**07-02-15**	**07-02-15**
Analyze date	**07-01-26**	**07-02-02**	**07-02-05**	**07-02-09**	**07-02-09**	**07-02-19**	**07-02-20**
Volyme (L)	0,530	0,250	0,200	0,380	0,375	0,420	0,440
Wave length (nm)							
750	0,002	-0,002	-0,001	0,004	0,004	0,003	0,004
665	0,030	0,024	0,024	0,033	0,026	0,045	0,042
645	0,011	0,007	0,007	0,013	0,010	0,016	0,016
630	0,009	0,004	0,005	0,010	0,008	0,012	0,012
480	0,049	0,037	0,031	0,053	0,042	0,085	0,074
750 (+ Hcl)	0,003	-0,001	0,000	0,005	0,004	0,004	0,005
665 (+ Hcl)	0,019	0,015	0,015	0,021	0,015	0,028	0,026

APPENDIX IV

WEATHER OBSERVATIONS

La Nicolière

06-12-06
Big white clouds, sun shining through sometimes, calm wind

07-01-23
Sunny and cloudy

07-01-29
weak sun for 15 min then very cloudy and rain the last 15 minutes.

07-02-07
Very sunny with small white clouds, bigger white clouds later
The vault was open and the reservoir full

07-02-13
Thin white clouds 80% of sky, strong sun
Big waves over the reservoir and a current path near the bottles

07-02-20
Gray thick clouds, rain for 5 min in the start, Big white fluffy clouds with blue sky coming in the end. Very windy and the vault was open.

Piton du Milieu

07-01-25
Sunny with clouds, after one hour very sunny

07-01-31
Heavy grey sky then sun and rain shifting

07-02-08
Sunny with big white clouds and in the end thick clouds

07-02-15
Heavy grey clouds just 100 meters up, rainy but with strong sun sometimes for 5 minutes.