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THE EFFECT OF INCREASED SEDIMENTATION FROM GOLD MINING ON FISH POPULATIONS OF A LARGE TROPICAL RIVER

A comparison of the fish populations of the Marowijne and Corantijn rivers, Suriname

by

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A thesis submitted to the Anton de Kom University of Suriname, Faculty of Technology, Suriname, in fulfillment of the requirements for the degree of Master of Science (MSc) in Sustainable Management of Natural Resources

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PREFACE

I hope that this thesis can contribute to the improvement of the health of Suriname's large river ecosystems and the well-being of the communities that depend on these ecosystems for their subsistence and that this thesis can be used for further research. I learned a lot during the fieldwork, which was done in cooperation with the Ichthyology Department of the Royal Ontario Museum/University of Toronto. I will cherish the experiences and the friendships that were created during this research forever.

This thesis is the result of the contribution and hard work of many people.

I want to start thanking my supervisors Prof. Dr. Jan Mol who guided and encouraged me through the process of the research and writing of the thesis and Karen Alofs Ph.D. who guided me during the field data collection. Special thanks to Dr. Hernán López-Fernández, who is the curator of Ichthyology in the Department of Natural History at the ROM, for sharing his expertise and his dedicated students who made the fieldwork a success. The field data collection would not be possible without the expertise and support from the boat men from Snesie Kondre and Apoera and the drivers of the bus that brought the research group to the different sampling locations. I want to thank Kenneth Wan Tong You, who passionately supported the field data collection. I am also grateful for the guidance by Drs. Frank L. van der Lugt during the writing of the thesis. I want to thank everyone else who contributed to this thesis.

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Furthermore, I would like to extend my gratitude to Conservation International Suriname for allowing me to study during business hours.

At last I want to thank my friends and family for the support, sacrifices and encouraging words during the whole process. I dedicate this accomplishment to my grandparents.

Krisna Gajapersad

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LIST OF ABBREVIATIONS

ABS	Algemeen Bureau voor de Statistiek in Suriname
DO	Dissolved oxygen
FAO	Food and Agriculture Organization of the United Nations
FNU	Formazin Nephelometric Unit
g	gram
H	Species diversity
J	Evenness
km	kilometer
m	meter
mm	millimeter
ONFI	Office National des Forêts International
pH	Potential of hydrogen; measure of acidity
pi	Number of individuals of species i/total number of samples
S	Number of species or species richness
UN-Water	United Nations Water

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EXECUTIVE SUMMARY

The Marowijne River is the largest river in Suriname and is also one of the most impacted by small-scale gold mining. The impacts of these activities on the Marowijne River are mercury pollution, habitat destruction and anthropogenic sedimentation which increase the turbidity and habitat degradation. Mercury pollution has been studied on several occasions and increased levels of mercury in fish have been reported, but the effects of increased sediments have only been studied for a small stream in Suriname. The purpose of this study was to determine if an increase of the concentration of sediments has an effect on biological characteristics of large rivers. This was done by comparing fish populations of the Marowijne River with that of the Corantijn River with respectively a high and very low anthropogenic sediments inflow. Data on water quality, turbidity and habitat structure were collected at the sampling points and standardized and non-standardized fishing techniques were used to collect fish at the sampling points. The data from the standardized fishing was used to compare fish population characteristics statistically. The turbidity of the Marowijne River is significantly higher than that of the Corantijn River. The calculated habitat diversity of the sampling points in Marowijne River is higher than that of the Corantijn River. No significant difference between the species diversity (H), species richness (S), evenness (J) and mass (M) of the fish populations of the Marowijne and Corantijn rivers were found. Even though the difference of the species richness (S) between the two rivers is statistically not significant, the number of fish species collected in the Marowijne River was higher than the number of species collected in the Corantijn River, which correlates with the habitat diversity indices calculated. A clear difference of the fish species composition of the two rivers was found. The relative abundance of fish that are adapted to low light conditions is five times higher in the Marowijne than in the Corantijn, further the relative abundance of important food fish that depend on vision is almost four times lower in the Marowijne River.

1 INTRODUCTION

1.1 Background information

Globally the availability of freshwater is put under pressure by population growth, economic growth, urbanization and pollution (FAO, 2012). With current rates of development, it is estimated that 1.8 billion people on earth will be living in a country or region with absolute water scarcity (less than 500 cubic meters per capita per year) and two-thirds of the world population will be affected by other types of water scarcity by 2025 (UN-Water, 2006). Suriname has one of the highest volumes of fresh water per capita in the world (FAO, 2016). Suriname also has a high forest cover of 94.7% of which mostly tropical rain forest (ONFI, 2014). A study by Saenz (2014), shows that the highest parts of Suriname have the highest rainfall. The Marowijne River catchment (figure 1.1) has the highest water production of all the river catchments in Suriname with 2500-2800 mm per year per ha (Saenz, 2014). This high water production is caused by high rainfall inputs and relative low evapotranspiration (Saenz, 2014). Rainfall data of the period 1961-1985 shows that the mean annual rainfall varies from 1358 mm in northwest Suriname (Coronie, Nw Nickerie) to 2850 mm in central Suriname (Tafelberg) (Naipal & Nurmohamed, 2004). Approximately 67% of the rainfall in Suriname originates from evapotranspiration of the rainforest and the remaining 33% originates from the Atlantic Ocean (Amatali, 1993). Suriname is drained by seven rivers that flow towards the Atlantic Ocean, from east to west, the Marowijne, Commewijne, Suriname, Saramacca, Coppename, Nickerie and Corantijn rivers (see table 1.1). The largest rivers are the Marowijne River with a drainage area of 68,700 km² and the Corantijn River with a drainage area of 67,600 km² (Amatali, 1993). The Marowijne River has the largest discharge rate 1785 $m^3\ s^{-1}$ followed by the Corantijn River with 1572 $m^3\ s^{-1}$ (Amatali, 1993).

Amazonian rivers are classified following the Sioli (1950) classification which is mainly based on the optical characteristics. The classification has three types of rivers: white-water rivers with high turbidity caused by both dissolved and suspended solids, black-water rivers with high humic and fulvic acid contents and clear-water rivers which are not turbid and are not colored by humic compound (Mol J. H., 2012). The undisturbed rivers draining the interior of Suriname with low natural erosion of the weathered Precambian Guiana Shield are clear water rivers. There may be some suspended sediment in the water for a few days after heavy rains. It is expected that increase of suspended sediments for longer periods in these clear water rivers will have a significant effect on these river ecosystems. Rivers and creeks impacted by human activities, often small-scale gold mining, contain large amounts of suspended sediment and thus high turbidity throughout the year (Mol & Ouboter, 2004; Mol J. H., 2012). Biological productivity is the rate at which all living organisms are produced by organisms and ecosystems. The biological productivity of large rivers is very high and supports large numbers of plants and animals. Large river ecosystems are one of the most productive aquatic ecosystems (Johnson et al., 1995) and together with the water itself provide crucial ecosystem services for human societies worldwide.

Table 1.1: Hydrological characteristics of the seven main Surinamese rivers (data from Amatali, 1993).

Variable	Corantijn	Nickerie	Coppename	Saramacca	Suriname	Commewijne	Marowijne
Catchment area (km^2)	67,600	10,100	21,700	9,000	16,500	6,600	68,700
Mean discharge at outfall (m^3 s-1)	1,572	178	500	225	426	120	1,785
Maximum limit of salt intrusion (300 mg Cl L -1) during low flow in the dry season	Km 82	Km 110	Km 83	Km 89	Km 90	Km 150	Km 59
Minimum limit of salt intrusion (300 mg L-1) during peak flow in the rainy season	Km 40	Km 28	Km 31	Km 37	Km 54	Km 55	Km 37
Location of the first major rapid complex	Km 235	Km 240	Km 170	Km 285	Km 194	-	Km 115
Tidal range at outfall (m)	2	2	2	-	1.8	1.9	2
Tidal volume (1,000,000 m^3)	300	10	75	50	125	40	200
Maximum depth along the thalweg (m)	30(km 112)	17 (km 73)	22 (km 82)	24 (km 145)	17 (km 95)	31 (km 71)	21 (km 47)
Silt content (g L-1) upstream of the minimum limit of salt intrusion	0.02-4	0.03-45	0.02-1.3	0.003-1.3	0.001-1.5	0.07-20	0.01-0.08
Sediment discharge (1,000,000 ton year -1)	1.2	0.1	0.25	0.13	0.25	0.06	1.3
Note: Since the construction of a dam at Afobaka (km 194) in 1964 the Suriname River is a regulated river and discharge and salt intrusion depend on the discharge at Afobaka. Distances along the length of a river are measured along the thalweg in kilometers from its mouth: river Km number begin at zero, designated as the river mouth at the 15 m depth contour at low-water spring tide, and increase further upstream.							

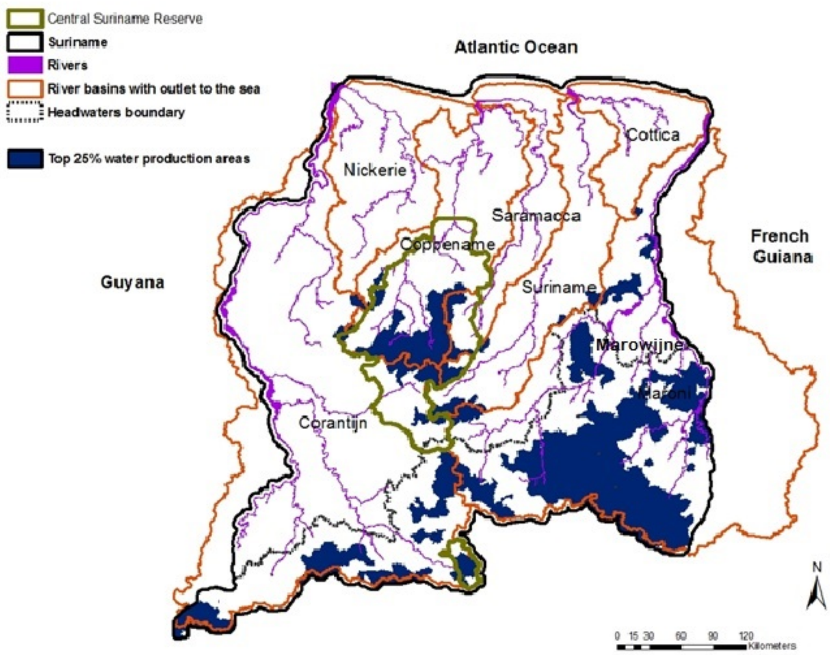

Figure 1.1: An overview of the top 25% water production areas of Suriname (Saenz, 2014).

1.2 Human use of rivers

Many people use polluted and contaminated water for consumption without treatment and in developing countries hundreds of millions of people collect drinking and domestic water directly from aquatic ecosystems (Arthington et al., 2010). Rivers in Suriname are of high importance, especially for the people who live in the interior who daily use the water of the river for their households, fishing, boat transportation and recreation. In 2012, 7550 households were using rivers and creeks as the main drinking water source, which is 5.6% of the total households in Suriname (ABS, 2014). The rivers are also important for Suriname as a nation, because they serve as important source of freshwater and can potentially be exploited for fresh water exports in the future (Saenz, 2014). There are many villages along the Marowijne River and its tributaries and it is estimated that 26,500 people live in these villages. These people are from three Maroon groups (Ndyuka, Paramakka and the Aluku) and one group of Indigenous peoples (Wayana) (ACT-Suriname, 2007). These villages are mostly dependent on their surrounding area for their subsistence and livelihood. Traditional agriculture, hunting and fishing are the main sources of food for these communities. Fish from the river are an important source of protein for these communities.

1.3 Impact of gold mining

The increasing global demand and price of gold stimulates gold mining activities globally, including areas where mining was previously not profitable, because of the high costs for extracting low-grade deposits (Alvarez-Berrios & Aide, 2015). Small-scale gold mining started increasing the last 20 years in Suriname. In Suriname, small-scale gold mining is concentrated in the interior, especially in the Greenstone Belt (Ouboter et al., 2007). It is estimated that between 48 km² and 96 km² of old-growth forest is cleared by gold miners every year in Suriname (Alvarez-Berrios & Aide, 2015). Suriname also has the longest network of waterways (4989.1 km) of the Guiana's, which have direct contact with gold mining activities (Rahm et al., 2015). The largest part of the Marowijne River is located in the Greenstone belt and thus impacted by small-scale gold mining. Gold mining activities cause several negative impacts on the surrounding environment, such as degradation of both aquatic and terrestrial habitat, mercury pollution of air and water and increased sediment influx into the rivers, which also causes habitat degradation (Alvarez-Berrios & Aide, 2015; Ouboter et al., 2012). Soil erosion by gold mining generates two main disturbances: increase of suspended solids (sedimentation) in the water, which causes high water turbidity, deposition of fine sediments, and release of heavy metals (Tudesque et al., 2011; Mol & Ouboter, 2004). Much of the small-scale mining is occurring in the Marowijne river drainage, especially the Merian and Toematoe creeks. The increased sediments and other pollutants from the mining activities are transported to the Marowijne River by the creeks. The Marowijne River is the largest river in Suriname and many people depend on the river as a food and water resource. The effects of the gold mining activities are visible (e.g. muddy creeks, loss of riparian forest) and presumably these have impacts on the physical, chemical and biological characteristics of the Marowijne River. A change of the physical and chemical characteristics of the river, such as increased turbidity, deposition of fine sediments and increased concentration of mercury will likely change the biological characteristics of the river, such as structure and composition of fish and aquatic plant communities and phytoplankton concentration. The effects of increased sediment inflow on biological characteristics of large rivers have not been studied in Suriname. Understanding of the biological effects of an increased sediment input will make it possible to plan for and implement better mitigation methods to prevent further damage to the river ecosystem and biodiversity and to be able to secure river ecosystem services for the people living in the area and Suriname.

1.4 Problem statement

The rivers in Suriname have low anorganic suspended sediment concentrations, because they drain the geologically aged and weathered Guiana Shield and are classified as clear water rivers (Sioli, 1950). Increased sedimentation from anthropogenic sources will have an significant impact on the rivers, because the biodiversity in these rivers is structured to thrive in a clear water river ecosystem. Rivers and creeks which are impacted by small-scale gold mining have high amounts of sediment and high turbidity throughout the year (Mol, 2012; Mol & Ouboter, 2004). The increased sedimentation has several adverse effects on fish diversity, young fishes and causes a change in the assemblage structure with many fishes adapted to low light conditions (Mol & Ouboter, 2004). Increased sedimentation also has negative impacts on the biological productivity of aquatic ecosystems (Waters, 1995).

1.5 Purpose and specific objectives

The purpose of this study was to determine if increased concentration of sediments have an effect on biological characteristics of large rivers by comparing fish populations of the Marowijne River with high anthropogenic sediment inflow with the fish populations of the Corantijn River with very low anthropogenic sediment inflow. The objective was to determine crucial water quality parameters, habitat characteristics, fish species richness, fish species diversity, evenness and fish species composition in the disturbed Marowijne River and to compare these with those of the pristine Corantijn River. The goal is to determine the following:

- If there is a significant difference between the turbidity of the Marowijne River and the Corantijn River over the two sampling periods
- If there is a correlation between physical/chemical characteristics and biological characteristics of the Marowijne and Corantijn rivers
- If there is loss/gain of biological production of the Marowijne River due to sedimentation by anthropogenic activities compared to the Corantijn River
- If there is a difference between the species richness, evenness and fish species composition of the fish populations of the Marowijne and the Corantijn rivers

1.6 Significance of the study

The effect of sedimentation by anthropogenic sources on the biological productivity of large rivers in Suriname has not been studied yet. The Marowijne River is the largest river in Suriname (Table 1) and is situated in the Greenstone Belt, a geological formation where most of the small-scale gold mining activities are taking place (Ouboter et al., 2012). The impacts of these activities on the Marowijne River are mercury pollution, habitat destruction and anthropogenic sedimentation which increase the turbidity and cause habitat degradation. Mercury pollution has been studied on several occasions and increased levels of mercury in fish have been reported (Ouboter et al., 2012), but the effects of increased sediment inflow on fishes have only been studied for a small stream in Suriname (Mol & Ouboter, 2004). This study also gives an overview of the species richness, evenness and the fish species composition of the Marowijne and Corantijn rivers, because there was intensive fish sampling during two periods in both rivers. The data collected for this study can be used for future comparative studies or as baseline data. The present study can also be used to determine the status of the fish populations in the Marowijne and Corantijn rivers, which is important, because many people depend on fish in the Marowijne River ecosystem as a protein source.

1.7 Limitations of the study

One of the most important limitations of this study is that there is very limited historical water quality and fish community data of the Marowijne River, which makes it difficult to compare current conditions with historical conditions before the increased anthropogenic sedimentation. Because of the lack of historical data, the choice was made to compare fish populations of the Marowijne River with the similarly sized Corantijn River, which has relatively very low anthropogenic sedimentation and no gold mining activities. For this study, the Corantijn River is used as the source of baseline water quality and fish population data. The limitation is that the parts of the rivers that were sampled during this study, although situated at equi-distance from the river mouth, had different characteristics; the most important differences include the tidal influence and the absence of rapids in the Corantijn River study area. In addition, the water of the Corantijn River is very clear, which made catching fish with the used methods (seine nets) more difficult, because the fish could see the nets, especially during the day. The East-West Guiana Current generates differences in sedimentation between these two large rivers. This current transports sediment from the Amazon River and the heavier sand particles are deposited in the east (Marowijne River) and the smaller and lighter clay particles are deposited in the west (Corantijn River), thus a broader coastal plain in the west and more suspended sediment is expected in the Corantijn River than in the Marowijne River, but the goldmining in the Marowijne River causes higher concentration of suspended sediments. There are 319 fish species known for the Marowijne River and 278 fish species for the Corantijn River (Mol J. H., 2012). The sampled area of the Marowijne River is located between km 120 - 175 from the river mouth and the sampled area of the Corantijn River was located between km 140 - 200 from the river mouth.

2 EFFECTS OF INCREASED ANTHROPOGENIC SEDIMENTATION ON FISH POPULATIONS IN LARGE RIVERS

2.1 Small-scale gold mining

The current gold rush in Suriname started in 1993 and the Geological and Mining Service of Suriname (GMD) estimated that there are between 25,000 and 35,000 people working in the small-scale gold mining sector (Ouboter et al., 2012; Mol et al., 2001). The livelihood of more than 60,000 people in Suriname is supported by gold mining (Alvarez-Berrios & Aide, 2015). The small-scale gold miners also known as the porknokkers, use the placer mining method where streambeds deposits are mined using open pits. For this the porknokkers use large equipment such as excavators and high-pressure water pumps (Mol & Lugt, 2012) to extract the gold deposits from the soil. First the forest at the mining area is cleared and the trees are burned. The cleared areas are about 80 x 80 m (Peterson & Heemskerk, 2001). Strong water jets are used to remove the topsoil and sludge the soil of creek bottoms and shores, so it can be pumped to sluice boxes (Wantzen & Mol, 2013). Then the gold is recovered from the sludge in the sluice boxes by using mercury which amalgamates with the gold and separates it from the sediment. The gold miners do not use tailing ponds and the sludge from the sluice boxes flows into the creeks (Ouboter et al., 2012). It is estimated that for each kilogram of gold that is produced one kilogram of mercury finds its way to the environment (Veiga, 1997). There are also gold mining operations in the rivers where suction dredges are used to suck up the river bottom with an intake pipe after which the material goes through a sluice box where the dense particles including gold are trapped. The rest of the material is released into the river and creates piles of sediments and tailings (Harvey & Lisle, 1998). In at least one tributuary of the Mindrinetie River the species diversity and the fish community assemblage was changed by increased sedimentation (Mol & Ouboter, 2004).

2.2 Sedimentation of streams

One of the most obvious characteristics of creeks and rivers is the presence of sediment. Sediments have different sources and forms. Fine inorganic particles that flow with the current or are deposited on the bottom cause most problems for aquatic life. Increased turbidity and loss of benthic productivity and fish habitat are results of sedimentation. Erosion of uplands, lateral movement of channels into stream banks and down-cutting of streambeds are the main sources of inorganic sediment (Waters, 1995). Natural erosion of hills, riverbanks and other geological features by wind and water causes small sediment inputs. These small amounts of sediments can be incorporated by the stream processes and do not damage the aquatic ecosystems biological components. They may even increase habitat diversity (Waters, 1995). Anthropogenic erosion causes high sediment input and damages the biological components, because these are not adapted to excessive sediment concentrations (Wantzen & Mol, 2013). Obvious effects of excessive sediment are loss of agricultural soils, decreased water-retention capacity of forest lands, increased flood frequency and rapid filling of reservoirs. Effects on biological components are for example reduction of fish diversity and other animal communities and decrease of the biological productivity of aquatic populations (Waters, 1995).

2.3 Fish ecosystem services and the effect of increased sedimentation on fish

Fish are an integral part of aquatic ecosystems and healthy fish populations deliver fundamental and demand-derived ecosystem services (Holmlund & Hammer, 1999). Fundamental ecosystem services are necessary for the ecosystem to function and to be resilient and are essential for human existence. Fundamental ecosystem services provided by fish populations can be divided into regulating services and linking services. Some examples of regulating services are regulation of food web dynamics, recycling of nutrients, regulation of ecosystem resilience and maintenance of genetic species and ecosystem biodiversity. Some examples of linking services are linkage within aquatic ecosystems, linkage between aquatic and terrestrial ecosystems, transport of nutrients, carbon, minerals and energy and acting as ecological memory. Demand-derived ecosystem services are formed by human needs and are not fundamental for the functioning of the ecosystem. These demand-derived services can be divided into cultural services and information services. Some examples of cultural services are production of food, aquaculture production, control of hazardous diseases and algae and macrophytes, reduction of waste, supply of aesthetic values and recreation. Some examples of information services are assessment of ecosystem stress and resilience, revealing evolutionary tracks, provision of historical, scientific and educational information (Holmlund & Hammer, 1999).

The annotated checklist of the freshwater fishes of Suriname by Mol et al. (2012) shows that 481 species of fish live in the fresh and brackish inland waters of Suriname, with 394 of these restricted to fresh waters. These 481 species represent 16 orders and 64 families (Mol, Vari, Covain, Willink, & Fisch-Muller, 2012). Popular food fish for people in the interior of Suriname are piranhas and pacus (*Serrasalmus, Tometes, Mylesinus* and some *Myleus* species), Moroko (*Brycon falcatus*), Kurimata (the prochilodontids, *Prochilodus rubrotaeniatus* and *Semaprochilodus varii*), *Chaleus macrolepidotus* (Alampiya), Anyumara (*Hoplias aimara*), large catfish species (Pimelodidae), fresh water croakers or Kubi's (*Plagioscion* species) and the larger species of the family Cichlidae (Tukunari *Cichla* spp, Krobia (e.g. *Krobia guianensis* and *Cichlasoma bimaculatum*), Datra-fisi *Crenicichla* spp, (Mol J. H., 2012). Many of these fishes are primarily visual predators and high turbidity levels affect their predation efficiency and consequently growth rates. Because of the lowered foraging ability and higher physiological stress of visual fish predators in turbid waters, they tend to avoid these waters (Wantzen & Mol, 2013). Fishes with good sensory adaptations to turbidity and low light, such as knife fishes and catfishes are often more dominant in water with high turbidity. The lowered abundance of predators in turbid waters reduces predator avoidance behavior and the energy used to avoid predators is invested in foraging for food, which causes increased feeding, growth and migratory activity. This suggests that decreased visual range of fishes caused by inorganic turbidity has important consequences on the structure and functioning of fish assemblages but also for the prey populations depending on size, contrast and behavior of prey (Donohue & Molinos, 2009).

Increased sediment loads have numerous direct and indirect effects on fish including (Donohue & Molinos, 2009):

- Reduced survival of eggs and larvae
- Gill damage and increased gill-flaring
- Reduced individual growth rates, decreased maximum size and reduced length at sexual maturity
- Increased mortality
- Emigration form affected areas
- Impaired feeding activity
- Induced color changes
- Instigation of stress response such as increased blood sugar levels
- Increased susceptibility to toxicants
- Disrupted migration patterns through avoidance

- Altered territorial behavior
- Altered dynamics and functional characteristics of communities
- Altered breeding behavior
- Increased incidence of infection
- Increased risk of injury through increases in aggressive interactions among fish
- Clogging of interstices and interference with oxygen availability
- Decreased connectivity among appropriate habitat patches
- Alterations to habitat structure and reduced habitat heterogeneity.
- Decrease of places where fish can drop their eggs, including holes in the bottom substrate and woody debris and other locations
- Decrease of aquatic macrophytes (food for several fish species) by deposition of sediments on the leaves

3 METHODOLOGY

3.1 Study sites

This study covers two study areas, the Marowijne River in the east of Suriname and the Corantijn River in the west of Suriname (see figure 3.1). The distance between the two study sites is more than 300 km. The Marowijne and Corantijn rivers are the two largest rivers in Suriname (Table 1.1).

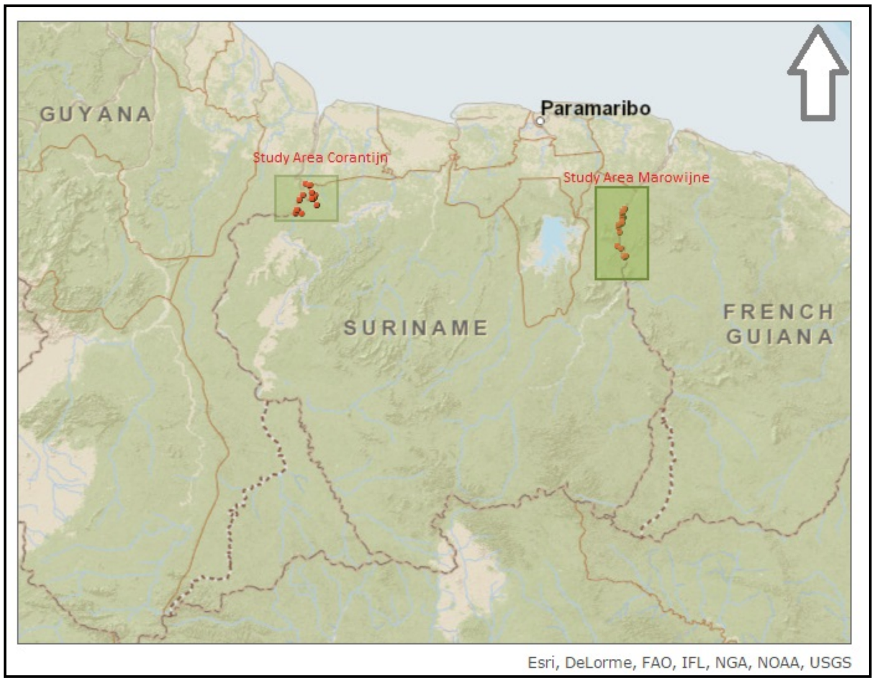

Figure 3.1: Overview of the study sites

3.1.1 Marowijne River

A stretch of 55 km of the Marowijne River was sampled during this study. From the Sisibi sula (km 175) down to Tamara Island (km 120) the Marowijne River contains freshwater and is not under tidal influence (see figure 3.2). There are a number of large creeks which were also partially sampled. A total of 36 points were sampled over the two study periods in this study area. In October 2014, there were 13 standardized sampling points and in March 2015 there were 23 standardized sampling points. Most sampling points from March 2015 were different from the sampling points in October 2014. The Toemati Creek and the Gran Creek are the largest creeks and both creeks were impacted by mining activities. Different types of habitat such as sandy beaches, mud banks, pools, forest creeks, rapids, islands, rocks, forested riverbanks and sand and cobble tailings from suction dredges were encountered and sampled at the Marowijne River during this study. Most sampled sites were not natural habitats, but sites recently disturbed by gold mining activities. In the sampled river stretch at least 10 suction dredges of different sizes were encountered. The Marowijne River and its tributaries are largely located in the Greenstone Belt which is the area in Suriname where most of the gold deposits are found and this makes the Marowijne Basin the main gold mining area of Suriname. The Marowijne River is the border river between Suriname and French Guiana and is equally divided by the two territories. For the part of the river between the northern point of Stoelman's Island (Suriname) and the southern point of Portal Island (French) the country border is marked by a line in the middle of the river (Donovan, 2004). There are many maroon villages along the river in the study area. During the sampling in October 2014 the village Langetabbetje was used as base station and in March 2015 the base station was located at Snesie kondre. The study area is accessible by car, following the east-west road and then the Patamacca road to Snesie kondre.

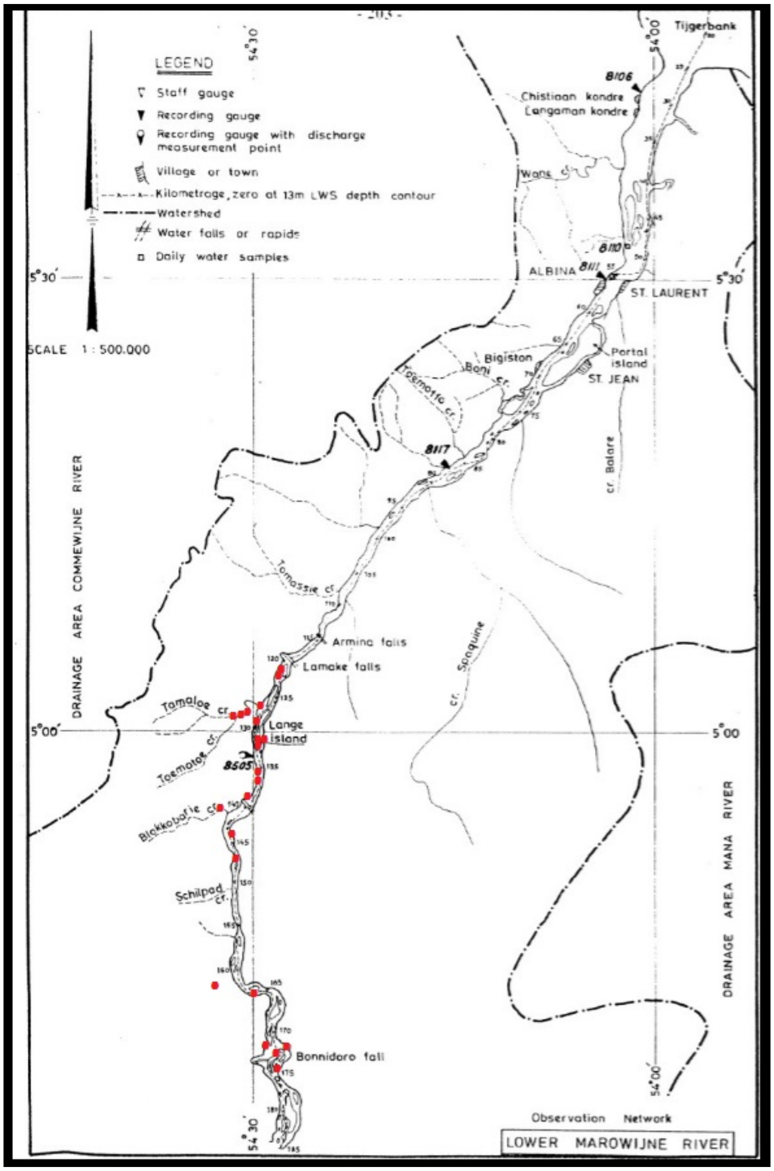

Figure 3.2: The location of the study area at the Marowijne River with the sampling points (red points in the map)

3.1.2 Corantijn River

A stretch of 60 km of the Corantijn River between the mouth of the Kabalebo River (km 200) to the start of the Corantijn kanaal (km 140) was sampled during this study (see figure 3.3). A total of 25 points were sampled over the two study periods in this study area. In October 2014 there were 14 sampling points and in March 2015 there were 11 sampling points. Most sampling points from March 2015 were different from the sampling points in October 2014. The sampled part of the river contains freshwater and is under tidal influence with daily variations in water level. In this part of the river habitat types such as sandy beaches, island, mudflats, creeks, pools, forested river banks and some rocks were encountered and sampled. The only villages along the river in the study area are Apoera, Washabo and Section, mainly inhabited by indigenous people. The water is very clear and it seems that there are no mining activities in or upstream of the study area. Apart from the villages themselves the area seems undisturbed and habitat degradation is low. In the stretch of the river that was studied, there are no rapids. The first rapids (when starting from the estuary), the Cow falls (km 235) are situated approximately 100 km upstream from the most southern sampling point.

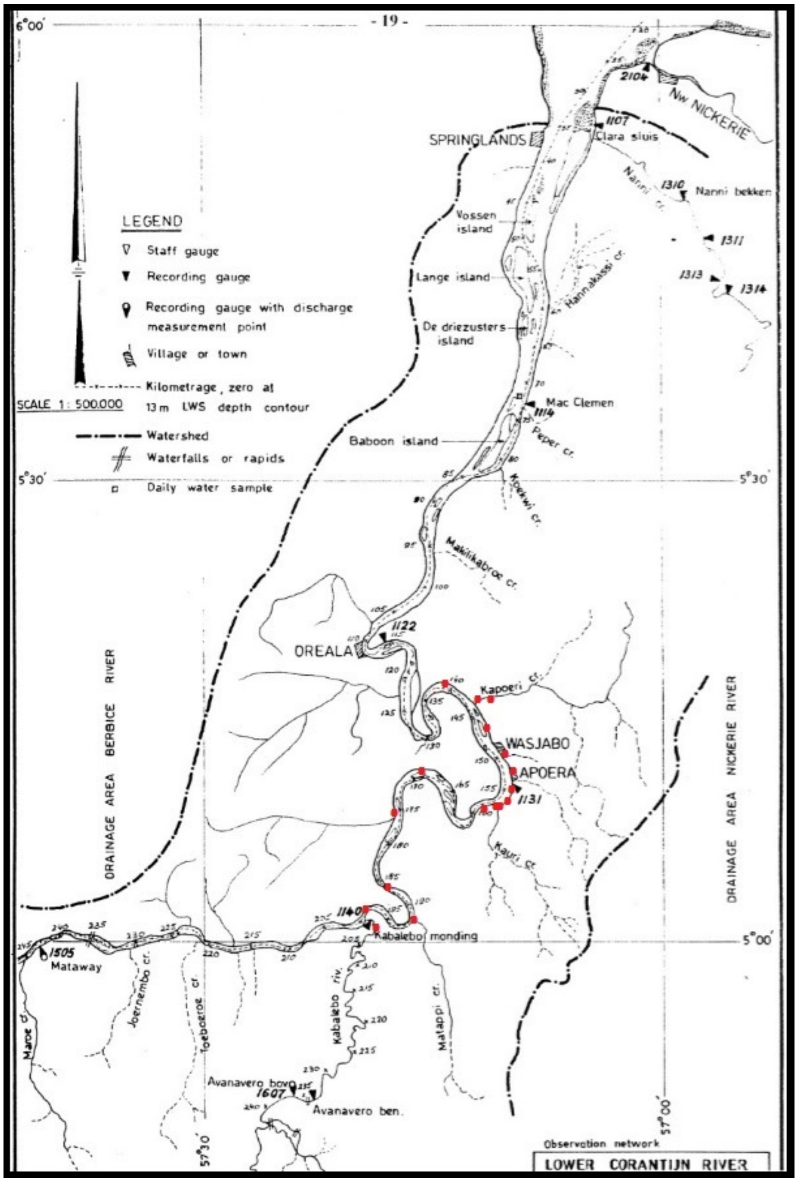

Figure 3.3: The location of the study area at the Corantijn River and the sampling points

3.2 Sampling design

In order to compare the different ecological parameters of fish communities of the Marowijne and the Corantijn rivers it was important to eliminate bias from differences in fishing methods and effort. To do this a standardized fishing method was used for this study, so the samples could be statistically analyzed and tested against each other. It was also important to have sampling points that are similar in habitat type for the Marowijne and the Corantijn rivers.

Sampling took place in two periods, October and March, in which it was expected that the water level of the Marowijne and Corantijn rivers would be low based on the dry season in these periods (Amatali, 1993). For standardized fishing with seine nets it is best to fish when the water level in the river is low, because beach seines are normally only used in water depths that are less than one half or two thirds the depth of the seine, so that the lead line remains on the bottom and the float line remains at the surface as the net is pulled forward. The rivers were sampled in October 2014 which was the large dry season and in March 2015 which was expected to be the small dry season. The Marowijne River was sampled in the period 2nd -7th of October 2014 and 3rd – 8th of March 2015. In October the water level of the Marowijne River was much lower than in March 2015 and there was very little rainfall in the October period compared to the field visit in March 2015. The Corantijn River was sampled in the period 9th – 12th of October 2014 and 10th – 13th of March 2015 and the water levels of the river were not significantly different between the two sampling periods. There was tidal influence during both sampling periods in the Corantijn study area.

Sampling points were selected based on the possibility to use seine nets. Sandy beaches with vegetation, sand and mud banks, creek mouths with shallow river banks, shallow pools and creeks are some examples of sampled sites. The samples were taken in a variety of major river ecosystem habitats, such as river banks, rapids, sandy beaches, pools, sand banks in the middle of the river and also in artificial habitat, such as sand tailing islands in the Marowijne River. There were also some sampling points in a few tributaries of both rivers, not more than 500 m upstream of the confluence with the river. The sampling points were not planned ahead of the field visit, because the selection of a suitable sampling point is strongly dependent on the habitat and the water level of the river. It was important to sample all habitat types occurring in the rivers and to sample as evenly across the span of the study area as much as possible during the field visits. At each sampling site GPS-coordinates, water quality parameters, habitat type and other ecological data were recorded. At each sampling point fishes were collected using both standardized and non-standardized fishing methods. In addition phytoplankton samples were collected at a subset of sampling points.

3.3 Field method and materials

The location of the sampling site was recorded with a GARMIN GPS 60Csx unit. Each sampling site was measured and divided in two or three transects, running from shore in the direction to the middle of the river, depending on the length of the site. Transects were used to measure the depth and current speed for the site at several distances from the shore. The following water quality parameters were measured and recorded: pH, temperature, dissolved oxygen (DO), turbidity, secchi depth and water color. For this pH, DO and turbidity meter (LaMotte 2020we Turbidity meter) and a secchi disk were used. For each transect the percentage of riparian vegetation cover, vegetation type and human disturbance at the river bank were recorded. The percentage of riparian closure was measured with a spherical densiometer. The percentage of aquatic macrophytes, leaf litter, rocks, woody debris, siltation and the structure of the bottom substrate were estimated and recorded for each transect. In addition, the width of the river or creek and the transect length were recorded for each transect. Water depth and current speed were measured and recorded at three points of each transect. These data were collected to calculate the habitat diversity index (H) of the sampled points of the study sites.

After the physic-chemical parameters were recorded, fish were collected at the site. Fish were collected by following the standardized fishing method using a seine net with a horizontal opening of ca. 3 m and a vertical opening of ca. 1.5 m and a mesh size of 3mm with a buoyant line on top and a lead line at the bottom. The ends of both the buoyant and the lead line were tied to sticks to make hauling easier and to decrease the chance for fish to escape from the sides of the net. A single deployment and retrieval of a beach seine is referred to as a haul. During a haul two people, one on each end of the seine, walk in parallel through the water with the seine forming a U-shape behind them. Hauling took place into different directions depending on the habitat at the sampling point. In the standardized fishing method, the number of hauls per sampling point is different, because the number of hauls per site was determined by the number of new species caught in each haul. The hauling went on until there were five consecutive hauls without new species for that sampling point. Each sampling point had a standardized fishing effort of at least five hauls. Non-standardized fishing was done with longer beach seines, gill nets, a casting net and hook and line. The standardized fishing took between 15 and 60 minutes per sampling point, depending on the habitat and the number of hauls.

Beach seines are normally only used in water depths that are less than one half or two thirds the depth of the seine, so that the lead line remains on the bottom and the float line remains at the surface as the net is pulled forward. Deployment and retrieval is easiest over smooth bottoms with no debris or obstructions. Seine nets can become snagged on rocks, logs, etc., and often can only be freed by pulling the net backward, off the object. Where debris is present it is useful to have a third person follow the net who can free it when it becomes snagged. Often the lead line is raised off the bottom when the net is snagged, and this, in combination with the un-snagging process, can allow fish to escape. Seining is a simple method of sampling a large area in a relatively short time. It generally cannot be used among dense and robust macrophytes in habitats with abundant stumps or logs, in fast current, or in deep water. Efficiency varies widely among habitats and species. Benthic species are less catchable than mid-water species. Smaller individuals are more susceptible than large individuals. Very small individuals and fragile species may suffer significant mortality, but for robust species survival is high.

The collected fish were kept alive in a separate bucket during the field work and were processed for identification and DNA sampling as soon as possible. The fish were killed as humanely as possible by pouring clove oil in the bucket. After the fish were dead, DNA samples were taken of selected individuals. For each site the fish were pre-determined to family and where possible to species after which they were stored in 4% formaldehyde in separate Ziploc bags or buckets depending on the amount of fish collected at respective sampling site.

In the laboratory fish specimens were transferred to 70 % alcohol, sorted into morphospecies, identified to species with keys in Mol (2012) and Planquette et al (1996), counted and weighed to the nearest 1 g. Weighing the mass of the fishes collected in the sampling period March 2015 was intended to see if there was a difference between the mass of the fishes caught in the Marowijne and the Corantijn River. This was not ideal, because the specimens were already preserved when weighed. The mass of the fishes was only measured for the March 2015 sampling period. In order to distinguish between individuals of similar species a Human HumaScope Stereo WF10X microscope was used. Identified fish specimens were packed and shipped to the Royal Ontario Museum in Toronto, Canada, for long-term storage.

3.4 Data analysis

From all the water quality data that was collected, the turbidity and secchi depth were used for this study, because a study of the chemical and physical characteristics of the Marowijne and Corantijn rivers was being conducted parallel with this study. A two-way ANOVA with the factors period and river was used to determine if there is a significant difference of turbidity between the two rivers during the different periods (October 2014 and March 2015).

The ecological data that was collected at the sampling points was used to calculate the habitat diversity index of the Corantijn and Marowijne rivers. The habitat diversity index for each river was calculated by calculating the Shannon-Wiener diversity index of each habitat variable and then for the combination of the different habitat variables.

For each study area the fish which were collected, listed and systematically ranked following Nelson (2006). To characterize the species diversity the Shannon-Wiener diversity index (H) was calculated. This index is based on the information theory and measures the order (disorder) of the fish community (Krebs, 2014). The evenness (J) was measured to quantify how equal the fish community was. For all the standardized sampling points the Shannon-Wiener diversity index (H) (Krebs, 1989) and evenness (J) were calculated using the following formulas (Krebs, 1989):

$$\boldsymbol{H = -\sum_{i=1}^{s} (P_i)(lnP_i)}$$

Where,

Pi = Number of individuals of species i/total number of samples

$$\boldsymbol{J = \ Evenness = \frac{H}{\mathrm{H}_{max}}}$$

Where,

H_{max} = Maximum diversity possible = S

S = Number of species or species richness

The two-way ANOVA was used to determine if there was a significant difference between the fish species richness, diversity and evenness of the Marowijne and the Corantijn rivers for each sampling period (October 2014 and March 2015). For this comparison only the standardized samples were included to avoid bias from difference in sampling effort and sampling method. The program R (R Core Team, 2015) was used to conduct the two-way ANOVA and a significant difference was accepted when $p < 0.05$.

4 RESULTS

4.1 Comparison of turbidity between study periods and study areas

The turbidity of the sampling points in the Marowijne and the Corantijn rivers over the two sampling periods (October 2014 and March 2015) was compared in order to know if the fish samples should be analyzed separately for each period or if the samples from each river could be grouped together and then tested for differences between the two rivers. The turbidity and secchi depth were measured at 36 sampling points (13 sampling points in October 2014 and 23 sampling points in March 2015) in the Marowijne River and 25 sampling points (14 sampling points in October 2014 and 11 sampling points in March 2015) in the Corantijn River. Secchi depth ranged from 0.065 m to 1.15 m in the Marowijne River and from 0.65 m to 1.66 m in the Corantijn River. The turbidity of the sampling points in the Marowijne River ranged from 5 to 343 FNU (Formazin Nephelometric Unit) and the turbidity of the sampling points in the Corantijn River ranged from 1.26 to 14.70 FNU.

Significant differences were found between the turbidity of the Corantijn River and Marowijne River (two-way ANOVA; F value: 16.37; p: 0.0001).

The effect of the variable period on turbidity is statistically not significant (two-way ANOVA; F value: *0.48*; p: *0.49*) *(p value> 0.05)*, which means that there is no significant difference of the turbidity between the different sampling periods (October 2014 and March 2015).

The effect of the variable period on river is statistically not significant (two-way ANOVA; F value: *3.51*; p: *0.066*) *(p value> 0.05)*, which indicates that the relationship between "period" and "turbidity" does not depend on "rivers". There is no interaction between "river" and "period".

The difference between the turbidity of the points of the Marowijne River sampled in October 2014 and March 2015 is statistically not significant mainly due to the high variance of the values, but it is clear that the turbidity was much higher in March 2015 (rainy) than in October 2014 (dry season) (see figure 4.1a).

During the sampling in the Marowijne River, there were also visual observations of oil on the surface of at least one creek (Toematie creek; pictures 4.1 and 4.2) and the oil could also be smelled. This oil probably originates from the machines that are used for gold mining in the area.

Picture 4.1: Layer of oil in the Toematie creek (Marowijne River) with high turbidity. (© K. Gajapersad)

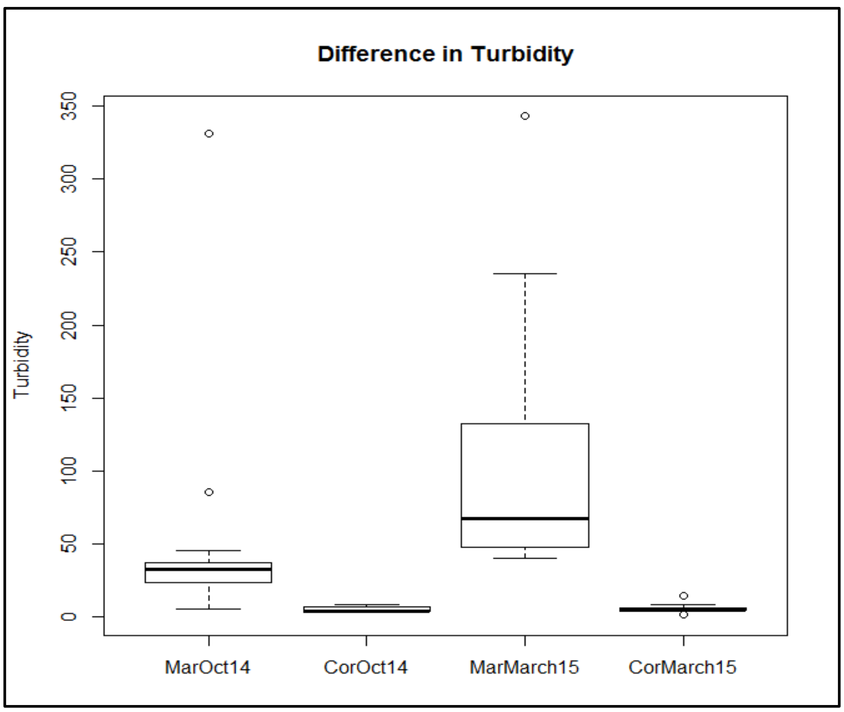

Figure 4.1a: Box plot of the data that was used in the two-way ANOVA showing turbidity in the Marowijne (Mar) and Corantijn (Cor) rivers during the sampling periods October 2014 (Oct14) and March 2015 (Mar15)

Picture 4.2: On the left the clear Matapi creek (Corantijn) and on the right the turbid Toematie creek (Marowijne) (© K. Gajapersad)

4.2 Habitat diversity index of the sampling points in the Marowijne and Corantijn rivers

The habitat diversity index of the variables water depth, current speed, substrate type, riparian closure and vegetation type were computed for the Marowijne and Corantijn rivers. The sampled points in the Marowijne River have higher habitat diversity than the sampled points in the Corantijn River for four variables (water depth, current speed, substrate type, riparian closure), but lower habitat diversity for the variable vegetation type (See table 4.1). The habitat diversity index of the combination of the five variables for the Marowijne River is 6.77 and that of the Corantijn is 5.23. The sampling points in the Marowijne River consisted of natural and artificial habitats. Diverse artificial habitats, such as small islands, sandy beaches, pebble beaches, deep and shallow pools were created by the mining (dredging) activities in the river. Different sizes of rapids were present in the sampled area of the Marowijne River, but absent in the sampled area of the Corantijn River. The human disturbance was visually much higher at the Marowijne than at the Corantijn River, where there was almost no human disturbance at most sampling points.

Table 4.1: Habitat structure of the Marowijne River (n = 34 standardized point samples) affected by small-scale gold mining and the Corantijn River (n = 19 standardized point samples) where there is no gold mining.

Variable/category	*Marowijne*		*Corantijn*	
	Pi	H	Pi	H
Water depth (cm)		0.96		0.88
0 - 25	0.0303		0.0000	
26 - 50	0.2424		0.2632	
51 - 100	0.6364		0.6316	
> 100	0.0909		0.1053	
Current speed (cm/s)		1.45		0.69
< 5	0.3939		0.2105	
5-10	0.1818		0.2105	
11 - 20	0.1212		1.5000	
21 - 30	0.0606		0.2632	
> 30	0.2424		0.1579	
Substrate type		1.85		1.33
macrophytes	0.0754		0.0447	
leaf litter	0.0848		0.0739	
woody debris	0.0577		0.0342	
silt	0.2079		0.4401	
sand	0.3356		0.3557	
pebble	0.1153		0.0511	
cobble	0.0751		0.0000	
rocks	0.0482		0.0003	
Riparian closure (%)		1.30		1.02
0 - 25	0.3333		0.4211	
26 - 50	0.1212		0.1579	
51 - 75	0.1818		0.0000	
76 - 100	0.3636		0.4211	
Vegetation type		1.22		1.31
trees	0.2420		0.2075	
shrubs	0.1556		0.3511	
grass	0.1068		0.3204	
human disturbed	0.4956		0.1211	
Water depth x Current x Substrate type x Riparian closure x Vegetation type		6.77		5.23

4.3 Analysis of standardized samples: number of fish specimens, fish species richness, diversity, evenness and mass

The results of the analysis (two-way ANOVA) of the different fish community characteristics (number of fish specimens, fish species richness (S), diversity (H), evenness (J)) and the result from the t-test of the comparison between the mass of fishes from both rivers collected at the standardized sampling points are presented in table 4.2.

Table 4.2: The results of the analysis (two-way ANOVA) of the different fish community characteristics (number of fish specimens, fish species richness (S), diversity (H), evenness (J)) and the result from the t-test of the comparison between the mass of fishes from both rivers collected at the standardized sampling points.

	Marowijne and Corantijn Rivers			***October 2014 and March 2015***		***Interaction river and period***	
	F value	P		F value	p	F value	p
Number of fish specimens	2.46	0.12		5.47	0.02	5.79	0.02
Significance	Not significant			Significant		Significant	
Species richness (S)	0.23	0.64		0.12	0.73	1.40	0.24
Significance	Not significant			Not significant		Not significant	
Species diversity	0.05	0.83		7.92	0.007	0.58	0.45
Significance of difference	Not significant			Significant		Not significant	
Evenness	3.26	0.08		0.04	0.83	1.43	0.24
Significance	Not significant			Not significant		Not significant	
	t	df	P				
Mass	-0.69	13.71	0.50				
Significance	Not significant						

The number of individual fishes collected across standardized sampling points did not differ between the Marowijne and Corantijn rivers. However, the mean of the number of collected individual fishes was significantly higher in March compared to October 2014 (see figure 4.2). Further, there was a significant interaction between rivers and sampling periods such that the difference in the number of fishes between periods was greater in the Marowijne than Corantijn.

The mean number of collected fish species (S) per standardized sampling point were not significantly different for the Marowijne and Corantijn rivers. The mean fish species per standardized sampling point were also not significantly different for October 2014 and March 2015 (see figure 4.3). The results further indicate that the difference between rivers did not change with period.

The species diversity (H) of the standardized sampling points were not significantly differerent for the Marowijne and Corantijn rivers. Species diversity of standardized sampling points, however, was significantly greater in October 2014 than in March 2015 (see figure 4.4) and the difference between rivers did not change with period.

The eveness (J) of the standardized sampling points were not significantly different for the Marowijne and Corantijn rivers and the eveness of the standardized sampling points were also not significantly different for October 2014 and March 2015 (see figure 4.5). The results also indicate that the difference between rivers did not change with period.

The mass of the individuals collected per sampling point of the Marowijne and the Corantijn were not significantly different (see figure 4.6).

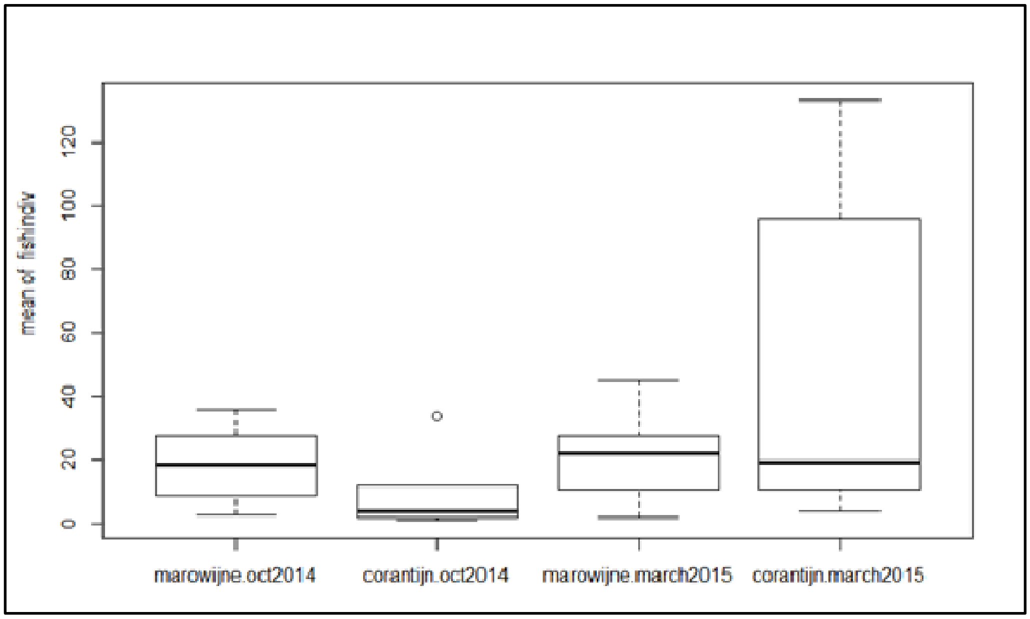

Figure 4.2: Number of individual fishes per standardized sample in the Marowijne and Corantijn rivers

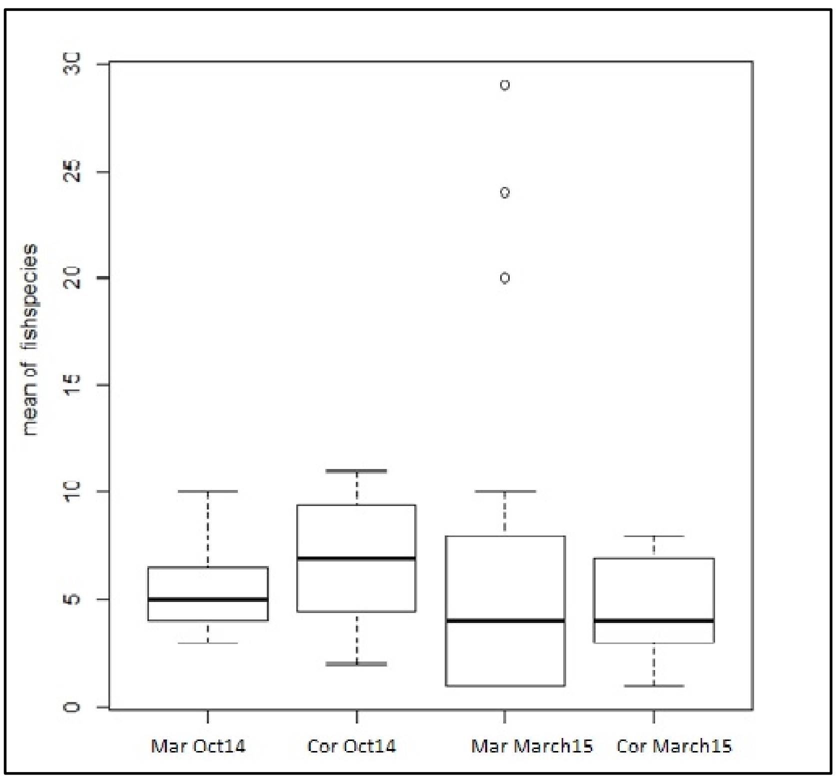

Figure 4.3: Number of species caught per sampling point per site

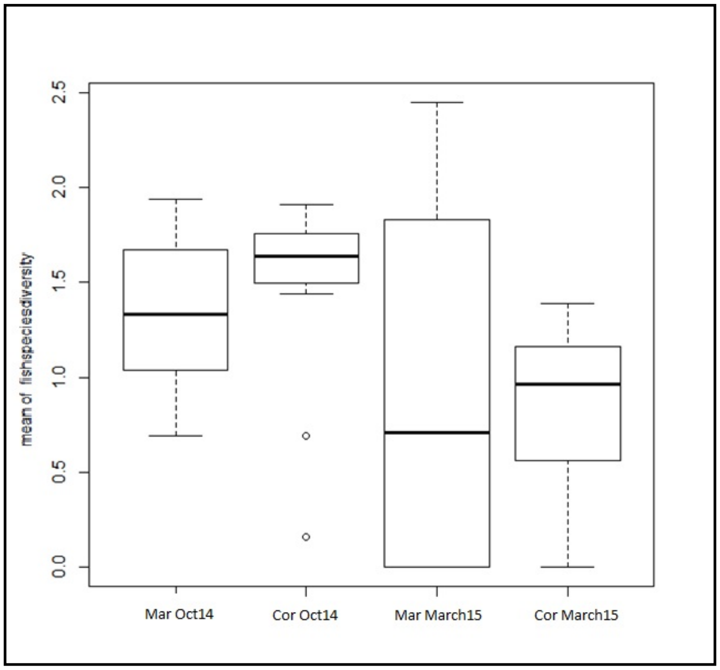

Figure 4.4: Boxplot of the difference in species diversity of the samping points per site

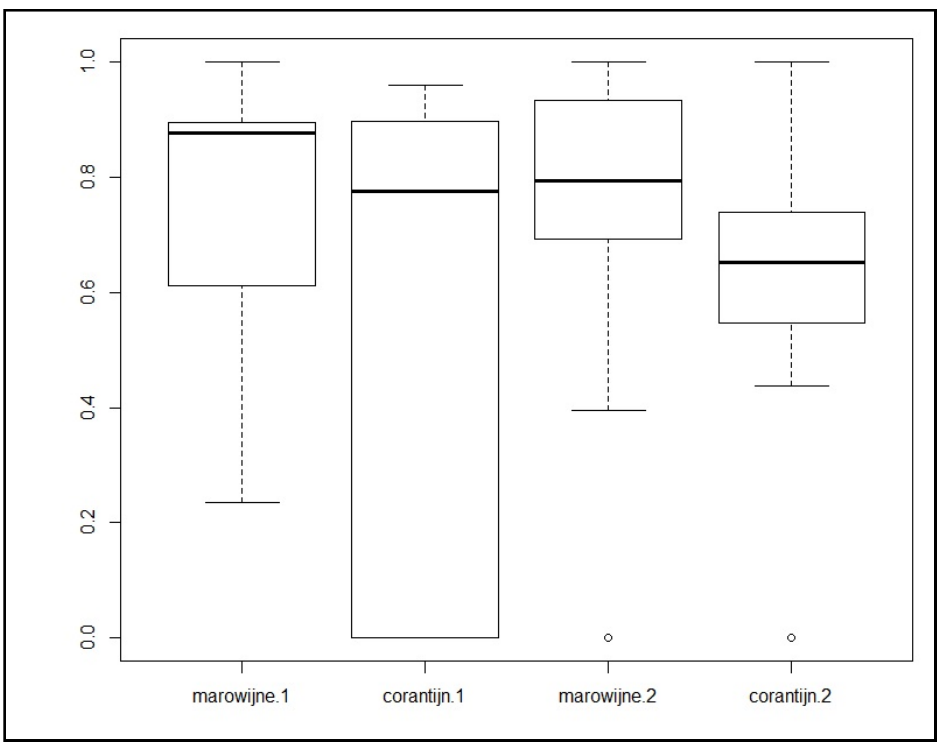

Figure 4.5: Evenness (J) of sampling points of the Marowijne and Corantijn rivers

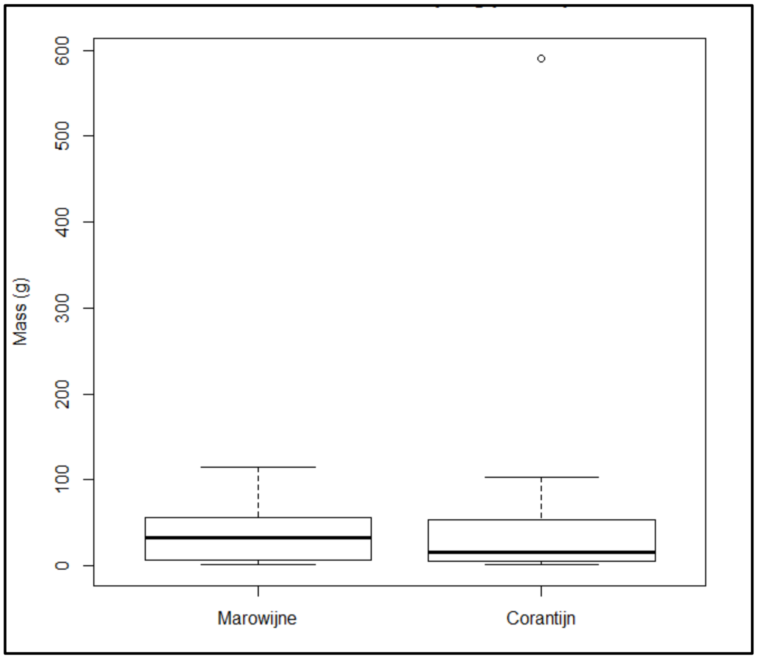

Figure 4.6: The mass in grams of the individuals collected of the sampling points per site

4.4 Fish fauna and species composition of the Marowijne and Corantijn rivers

During the two sampling periods, 1320 fishes were collected from the Marowijne River and 1795 fishes were collected from the Corantijn River, including standardized and non-standardized samples (see detailed species list in annex). The number of species (101) and species diversity (H = 3.30; computed for 53 sampling points over the two periods) for the Marowijne River are higher than in the Corantijn River with 63 species and a species diversity of H = 2.89 (computed for 43 sampling points over the two periods). The species evenness (J = 0.72) of the Marowijne is equal with the evenness (J= 0.72) of the Corantijn.

The Characiformes are the most specious group in both rivers (52% of species in Marowijne and 46% of species in Corantijn) and also the group with the highest number of collected specimens in both the Marowijne and Corantijn rivers, with respectively 66% and 34% (see figures 4.7-10). The relative abundance of catfishes (Siluriformes) and knife fish (Gymnotiformes) which are mainly nocturnal species (Mol & Ouboter, 2004) is five times higher in the Marowijne (15% of catch) than in the Corantijn River (3% of catch). The miscellaneous group including Perciformes (excluding the family Ciclidae), Myliobatiformes (sting rays), Clupeiformes, Beloniformes (needlefish), Gasterosteiformes (pipefish) and Pleuronectiformes has higher relative abundances in the Corantijn (34% of catch) compared to the Marowijne (2% of catch), which indicates that the different fish groups are better represented in the Corantijn than in the turbid Marowijne River. The relative abundance of selected food fishes (*Curimata cyprinoides, Prochilodus rubrotaeniatus, Brycon falcatus, Serrasalmus rhombeus, Hoplias aimara, Cichla ocellaris, Krobia guianensis, Pachypops fourcroi and Plagioscion squamosissimus)* in the Corantijn river (15.8% of catch) is almost four times higher than in the Marowijne river (4.5% of catch).

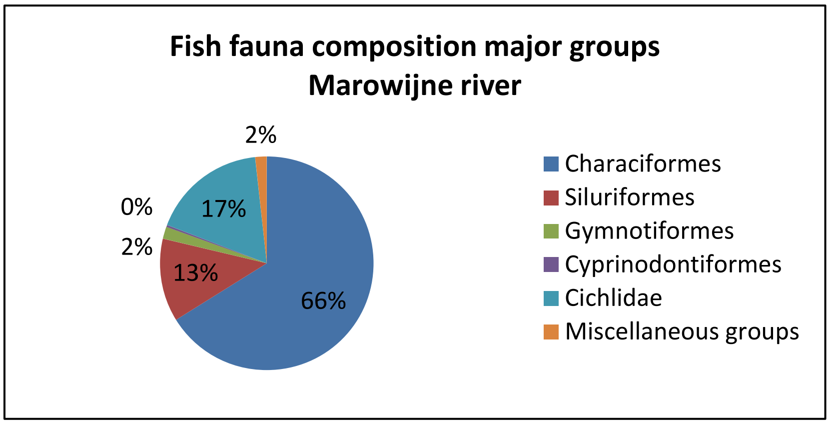

Figure 4.7: Fish fauna composition of the Marowijne River based on the number of specimens in major groups

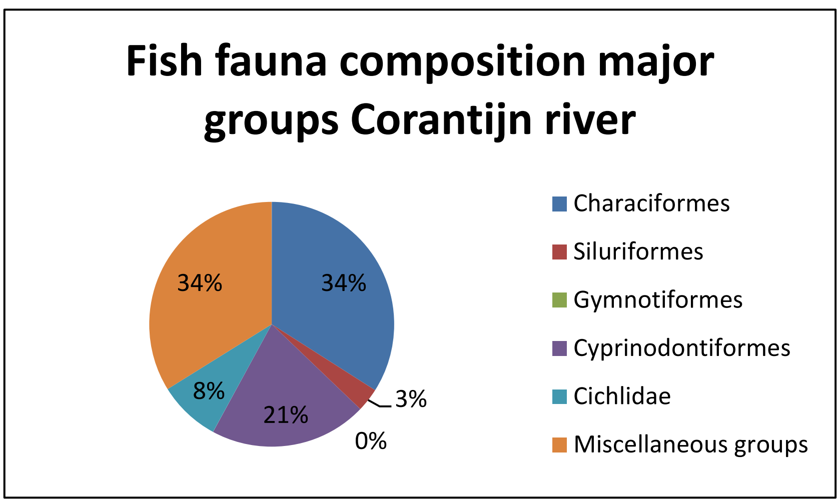

Figure 4.8: Corantijn River fish fauna composition based on the number of specimens in major groups

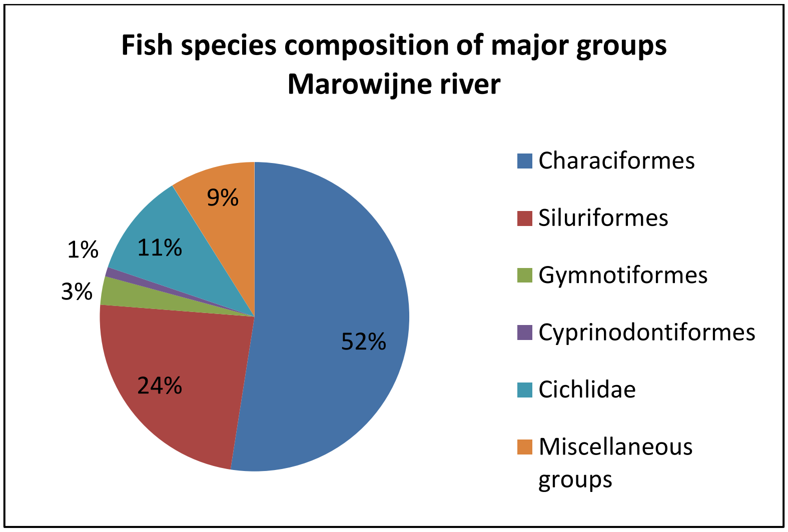

Figure 4.9: Marowijne River fish fauna composition based on the number of species in major groups

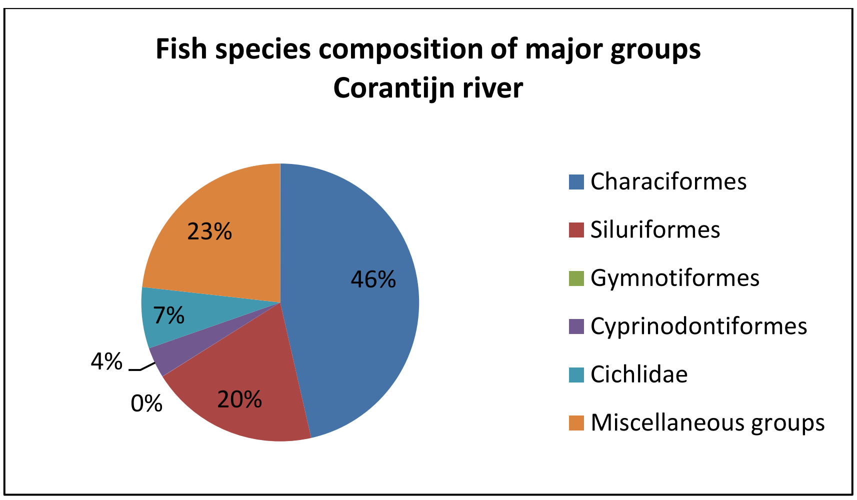

Figure 4.10: Corantijn River fish fauna composition based on the number of specimens in major groups

5 DISCUSSION

This study aimed to understand the effects of the anthropogenic sedimentation of large rivers, in this case the Marowijne River, on fish populations. Since there was not enough historical data on fish populations in the Marowijne River from before the increased gold mining in the area, the fish populations of the Corantijn River were used as baseline.

The turbidity of the Marowijne is significantly higher than of the Corantijn River which corresponds with at least one study (Ouboter et al., 2007) that shows that rivers in gold mining sites have high turbidity exceeding international standards for turbidity. The standard of streams in the United States (US) is a maximum turbidity of 50 FNU (DEQ, 2010). The mean value of the measured turbidity over the two periods of the Marowijne river is 80 FNU, exceeding the standards for the US with 60%. This high turbidity is directly caused by the gold mining activities and also by erosion caused by the deforestation (Peterson & Heemskerk, 2001) which is part of the gold mining activities. The measurements also showed that the turbidity of the Marowijne River was higher in March 2015 than in October 2014 when it was the long dry season. It is possible that there is less sedimentation in the dry season, because there is not enough water in the smaller creeks for gold mining activities and there is less erosion by rain during the dry season. Another possibility is that the lower current speeds in the dry season cause the sediments to settle on the bottom and decrease the turbidity. Deposition of sediments cause loss of habitat, such as shelter and places for egg deposition when sediment is closing holes on the bottom substrate, woody debris and other locations.

The calculated habitat diversity index of the Marowijne River (6.77) was higher than that of the Corantijn River (5.23). Mining activities (dredging) in the Marowijne River may increase habitat diversity by creating artificial habitats, such as deep and shallow pools, sandy beaches, pebble beaches and other habitat types that would not be there without the mining activities. A study by Harvey and Lisle (1998) suggests that there is a high mortality rate of fish eggs of fishes that spawn on unstable tailings. Further the study suggests that the absence of large roughness elements, such as coarse woody debris and large boulders in these tailings negatively affect fish densities, because these large roughness elements have an important role in ecological processes and conditions of streams (microhabitat for different species). In the sampled stretch of the

Marowijne River there were also rapids of different sizes present in contrast to the sampled stretch of the Corantijn River where rapids were absent.

The results of the analysis of different fish community characteristics (number of fish specimens, fish species richness, diversity, evenness and mass) from the standardized samples indicate that there are no significant differences between the Marowijne and the Corantijn rivers. The number of fish specimens caught was significantly higher in March 2015 compared to October 2014, which correlates with the number of points sampled in October 2014 (22) and in March 2015 (31). The fish species diversity (H) calculated for the sampling period October 2014 was significantly higher than that of the period March 2015. A reason for this can be the increased accessibility to micro habitat for fish during the standardized fishing, due to lower water levels in the sampling period October 2014 (long dry season). A study by Mol & Ouboter (2004) showed that less species were caught in the gold impacted Mamanari creek than in the Maykabuka creeks, which are both tributaries of the Mindrineti River. Even though the differences were not statistically significant, the number of species caught in the turbid Marowijne River was higher than in the Corantijn River, which was not expected. The species diversity (based on standardized samples) computed for the Marowijne was also higher than species diversity of the Corantijn River. At least one study by Merigoux & Ponton (1999) correlates habitat diversity with fish species diversity. The higher fish species diversity of the Marowijne River can be explained by the calculated habitat diversity index, which was higher in the Marowijne than in the Corantijn River.

It should be taken into account that the standardized fishing was not as effective in the Corantijn as in the Marowijne River and that this can be a reason for the lower species diversity of the Corantijn River found during this study. Also, there are more species that are known from the Marowijne than the Corantijn River. Of the known fishes in respective rivers, 32% was caught in the Marowijne and 23% was caught in the Corantijn River. Further there were more sampling points (standardized and non-standardized combined) in the Marowijne (53) compared to the Corantijn (43), meaning there was 1.2 times more fishing effort for the Marowijne River. The difference between the percentages of known species caught is less if the numbers are scaled by the effort, namely 32% for the Marowijne and 28% for the Corantijn River.

The relative abundance of fish species that are adapted to low light conditions (catfishes and knifefishes) was higher in the Marowijne than in the Corantijn River. The results of studies done by Rodriguez and Lewis (1997) and by Mol and Ouboter (2004) showed that species adapted to low light conditions dominated over species that rely on vision such as characiforms and cichlids in turbid lakes and turbid creeks, but this this is not the case in the Marowijne River. The characiforms dominate over the siluriforms and gymnotiforms, but the relative abundance of the siluriforms and gymnotiforms is 5 times higher in the Marowijne than in the Corantijn River, which indicates that the fish community structure is becoming more dominated by species that are adapted to low light conditions.

Several studies show that the fish species composition in creeks and lakes changes with increased sedimentation (Mol & Ouboter 2004; Henley et al 2000; Rodriquez & Lewis 1997) and this study confirms that, because there is a clear difference between the fish species composition of the turbid Marowijne River and the clear Corantijn River.

Recent sampling of the Palumeu River, a medium-sized river in the Marowijne River system, resulted in collecting 94 species (Mol & Wan Tong You, 2013). Sampling took place from 9 – 25 March 2012 in different parts of the river without anthropogenic sedimentation. Compared to the 94 species collected in the Palumeu River (Upper Marowijne Basin, upstream of gold mining activities) over a 16 day sampling period, the Marowijne river still has a high number of species with 101 species collected in the Marowijne river during the two sampling periods of in total 12 days at 53 sampling points. The 101 species include the most important food fish and piscivorous predators, such as *Hoplias aimara*, *Serrasalmus rhombeus* and *Cichla ocellaris*. This indicates that the species richness is still high and that there is a good chance of recovery of the fish populations and community structures if the increased sedimentation influx from anthropogenic sources stops in the short term.

A study on the relation between mercury pollution by gold mining and fish consumption showed that there is a link between fish consumption and high mercury concentrations in the body of people that consume fish from the rivers in or near gold mining sites (Cordier et al., 1998). The livelihoods of the local communities for whom fish from the Marowijne River is an important protein source, are also impacted by increased sedimentation, because the relative abundance of popular food fish is almost four times lower than in the clear Corantijn River. It is expected that with the changing fish community the abundance of food fish will decrease in the Marowijne river.

The comparison between the Marowijne River and the Corantijn River is not ideal for understanding the impacts of sedimentation related to mining because the factors that influence the fish community structure, such as hydrological characteristics, weather patterns, tidal influence, habitat types, human activity and other factors are different for the two rivers. Further the fish communities of the Marowijne River and the Corantijn River are independent from each other and each has its own fish species composition. The results were also influenced by the collecting methods. The standardized fishing method was not as effective in the clear Corantijn River as in the turbid Marowijne River. In the Corantijn River the fish could be seen, but not be caught with the seine, because the fishes could see the net and often fled before the fishing started.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The measurements of the turbidity confirm that the turbidity of the Marowijne River were significantly higher than that of the Corantijn River. Secchi depth measurements also confirm that the turbidity of the Marowijne was higher that that of the Corantijn River. Comparison of the species richness (S), species diversity (H) and evenness(J) calculated from the standardized collection data indicate that the species richness (S), species diversity (H) and eveness (J) of the Marowijne River are not significantly different from that of the Corantijn River. From these results it can not be concluded that the increased sedimentation has adverse effects on fish populations of the Marowijne River.

Non-standardized fishing in the Corantijn River was more successful than the standardized fishing methods. More effort was necessary to catch fish in the Corantijn River than in the Marowijne River, because the fish could detect the nets more easily in the clear Corantijn River. During the non-standardized fishing more effort was put into catching the fish with larger nets. From the results it was not possible to determine if there is a change in the biological production caused by increased sedimentation. A clear difference of the fish species composition of the two rivers was found. The relative abundance of fish that are adapted to low light conditions is five times higher in the Marowijne than in the Corantijn, further the relative abundance of important food fish that depend on vision is almost four times lower in the Marowijne River. This impacts the livelihoods and health of local communities living in the Marowijne River area. It can be concluded that there is an adverse effect of increased sedimentation on the fish species composition of the Marowijne River.

6.2 Recommendations

To get better insight of the effects of increased sedimentation of large rivers on fish populations the following is recommended:

- Development of protocols for standardizing the different fishing techniques. This way the different fishing techniques can be implemented in the different habitat types and make fish collecting for comparison reasons more effective.
- Selection of one study area in the areas with increased anthropogenic sedimentation and one study area upstream of the sedimentation sources in the same river or river system to study the effect of increased sedimentation of rivers. This would eliminate the differences of the river characteristics that influence fish populations.
- Phytoplankton studies to determine changes of the primary production of the Marowijne River.
- Long term annual monitoring of the fish populations, phytoplankton concentrations and water quality in the Marowijne River to trace trends in changes of the fish populations.
- Precise measurement of the deposited sediment layers on the bottom substrate, to measure the effect of habitat degradation (less shelter and less suitable places for fish to drop eggs) on fish populations.
- Quantification of sediment input in the Marowijne River by anthropogenic activities.

It is also recommended to study the possibilities of effective measurements to decrease the sedimentation influx from gold mining with low costs. The use of abandonded mine pits as tailing ponds where sediments are allowed to be deposited before the water flows into the natural ecosystem, should be studied. Furthermore it is recommended to study the possibility of using the abandonded mining pits as breeding ponds of local food fish. If this is possible, the local people could have a guaranteed source of protein in their area and an alternative source of income. This would also lower the existing fishing pressure on the fish populations and increase the chance of survival of the species in the Marowijne River with increased sedimentation.

REFERENCES

ABS. (2014). Environmental Statistics. Paramaribo: Algemeen Bureau voor de Statistiek ism Conservation International Suriname.

ACT-Suriname. (2007). Wayana Baseline Study:
A sustainable livelihoods perspective on the Wayana Indigenous Peoples living in and around Puleowime (Apetina), Palumeu, and Kawemhakan (Anapaike) in Southeast Suriname.
Paramaribo: Stichting Amazon Conservation Team Suriname.

Alvarez-Berrios, N. L. & Aide, T. M. (2015). Global demand for gold is another threat for tropical forests. Environmental Research Letters , 1-11.

Amatali M. A. (1993). Climate and surface water hydrology. In P. E. Ouboter, Freshwater Ecosystems of Suriname (pp. 29-51). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Arthington, A. H., Naiman, R. J., McClain, M. E. & Nilsson, C. (2010). Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. Freshwater Biology, 55, 1-16.

Cordier S., Grasmick C., Paquier-Passelaigue M., Mandereau L., Weber J.P. & Jouan M. (1998). Mercury exposure in French Guiana: levels and determinants. Arch Environ Health, 53, 299-303.

DEQ. (2010). Turbidity Technical Review: Summary of Sources, Effects, and Issues Related to Revising the Statewide Water Quality Standard for Turbidity. Portland: Oregon Department of Environmental Quality.

Donohue, I. & Molinos, J. G. (2009). Impacts of increased sediment loads on the ecology of lakes. Biological Reviews , 1-15.

Donovan, T. W. (2004). The Marouini River Tract And Its Colonial Legacy in South America. Chicago-Kent | Journal of International and Comparative Law .

FAO. (2012). Coping with water scarcity: An action framework for agriculture and food security. Water reports 38. Rome: Food and Agriculture Organization of the United Nations.

FAO. (2016). AQUASTAT website. Food and Agriculture Organization of the United Nations (FAO). Website accessed on [2017/03/07].

Harvey, B. C. & Lisle, T. E. (1998). Effects of Suction Dredging on Streams: a Reviewand an Evaluation Strategy. Fisheries, 23 (8), 8-17.

Henley, W. E., Patterson, M. A. & Neves, L. A. (2000). Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Ntural Resource Managers. Reviews in Fisheries Science , 125-139.

Holmlund, C. M. & Hammer, M. (1999). Ecosystem services provided by fish populations. Ecological Economics, 29, 253-268.

Johnson, B. L., Richardson, W. B. & Naimo, T. J. (1995). Past, present and future concepts in large river ecology. Bioscience, 43, 134-141.

Krebs, C. J. (1989). Ecological Methodology. New York: HarperCollins Publishers, Inc.

Lewis, M. A. (1997). Structure of fish assemblages along environmental gradients in floodplain lakes of the Orinoco River. Ecological Monographs, 109-128.

Merigoux, S. & Ponton, D. (1999). Spatio-temporal distribution of young fish in tributaries of natural and flow-regulated sections of a Neotropical river in French Guiana. Freshwater Biology, 42, 177 -198.

Mol, J. H. (2012). The Freshwater Fishes of Suriname. Leiden, The Netherlands: Koninklijke Brill NV.

Mol, J. H. & Lugt van der, F. L. (2012). Assessment of the Merian Gold project, Suriname, with special reference to fish, macro-invertebrate and phytoplankton communities: November/December 2011 and February 2012 surveys.

Mol, J. H. & Ouboter, P. E. (2004). Downstream Effects of Erosion by Small-Scale Gold Mining on the Instream Habitat and Fish Community of a Small Neotropical Rainforest Stream. Conservation Biology, 18 (1), 201-214.

Mol, J. H. & Wan Tong You, K. (2013). Fishes of the Palumeu River, Suriname. In L. E. Alonso, & T. H. Larsen, A Rapid Biological Assessment of the Upper Palumeu River Watershed (Grensgebergte and Kasikasima) of Southeastern Suriname. RAP Bulletin of Biological Assessment 67. Arlington, VA: Conservation International, 119-130.

Mol, J. H., Vari, R. P., Covain, R., Willink, P. W. & Fisch-Muller, S. (2012). Annotated Checklist of the Freshwater Fishes of Suriname. Cybium, 263-292.

Naipal, S. & Nurmohamed, R. (2004). Trends And Variation In Monthly Rainfall And Temperature In Suriname. BALWOIS Conference on Water Observation and Information System for Decision Support. Ohrid, FY Republic of Macedonia: BALWOIS, 1-11.

Nelson, J. S. (2006). Fishes of the World -- 4th ed. New Jersey: John Wiley & Sons.

ONF International. (2014). Suriname National Plan for Forest Cover Monitoring (FCM plan). Paramaribo: Amazon Cooperation Treaty Organization (ACTO).

Ouboter, P. E., Landburg, G. A., Quik, J. H., Mol, J. H. & Lugt van der, F. (2012). Mercury Levels in Pristineand Gold Mining Impacted Aquatic Ecosystems of Suriname, South America. Royal Swedish Academy of Sciences, 873-882.

Ouboter, P., Landburg, G., White, C., Mol, J., Lugt van der, F. & Quik, J. (2007). Mercury pollution in the Greenstone Belt. Paramaribo: World Wildlife Fund Guianas Regional Program.

Peterson, G. D. & Heemskerk, M. (2001). Deforestation and forest regeneration following small-scale gold mining in the Amazon: the case of Suriname. Environmental Conservation , 117-126.

Rahm M., Jullian B., Lauger A., de Carvalho R., Vale L., Totaram J., Cort K.A., Djojodikromo M., Hardjoprajitno M., Neri S., Vieira R., Watanabe E., do Carmo Brito M., Miranda P., Paloeng C., Moe Soe Let V., Crabbe S., Calmel M. (2015). Monitoring the Impact of Gold Mining on the Forest Cover and Freshwater in the Guiana Shield. Reference year 2014. REDD+ for the Guiana Shield Project and WWF Guianas. pp.60

Saenz, L. (2014). Suriname's headwaters Importance for country wide water security. Virginia: Conservation International.

Schemel, L. E., Sommer, T. R., Muller-Solger, A. B. & Harrell, W. C. (2004). Hydrological variability, water chemistry and phytoplankton biomass in a large floodplain of the Sacramento River, CA, USA. Hydrobiologica, 129-139.

R Development Core Team. (2015). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Tudesque, L., Grenouillet, G., Gevrey, M., Khazraie, K. & Brosse, S. (2011). Influence of small-scale gold mining on French Guiana streams: Are diatom assemblages valid disturbance sensors? Ecological Indicators, 14, 100-106.

UN-Water. (2006). Coping with Water Scarcity: A strategic issue and priority for system-wide action. Geneve: UN-Water initiative.

Veiga, M. (1997). Introducing new technologies for abatementnof global mercury pollution in Latin America. Rio de Janeiro: UNIDO/University of British Columbia/Center for Mineral Technology.

Wantzen, K. M. & Mol, J. H. (2013). Soil Erosion from Agriculture and Mining: A Threat to Tropical Stream Ecosystems. Agriculture 2013, 3, 660-683.

Waters, T. F. (1995). Sediment in Streams: Sources, Biological Effects and Control. Maryland, USA: American Fisheries Society Monograph 7.

APPENDICES

Appendix A: Non-standardized data

The data from the non-standardized collections were also analysed to see if there is a difference in the results.

Number of individuals

The means of the number of individuals of the sampling points of the Marowijne and the Corantijn rivers do not significantly differ from each other (t-test, t = -1.2207, df = 24.324, p-value = 0.2339). See figure A.1. The mean of number of individuals per sampling point of the Marowijne is 34.2 and the mean of the number of individuals per sampling point of the Corantijn is 55.7.

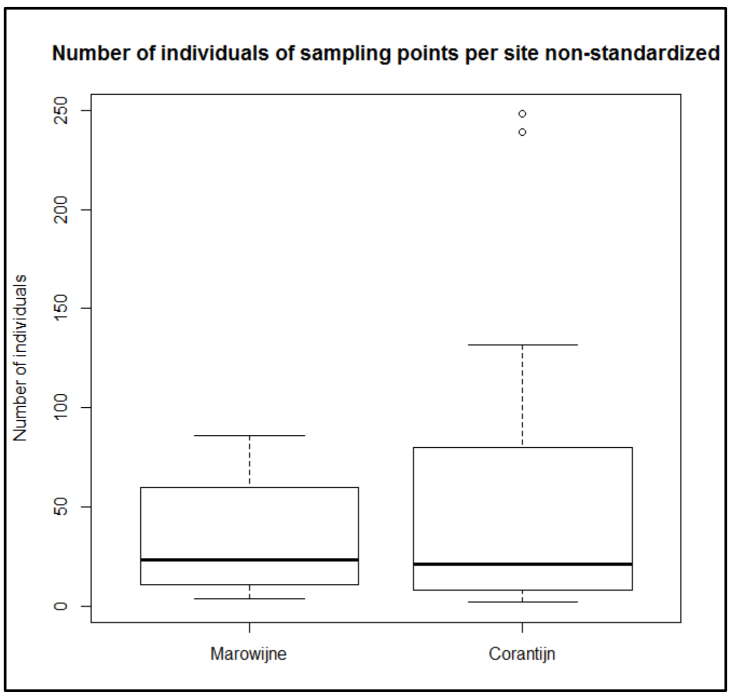

Figure A.1: The number of individuals of the sampling points of the Marowijne and the Corantijn by non-standardized sampling

Number of species

The number of species or species richness (S) is not significantly different between the sampling points of the Marowijne and Corantijn (t-test, t = 1.9508, df = 35.83, p-value = 0.05893) with a mean of 9.2 for Marowijne and 6.0 for Corantijn. See figure A.2.

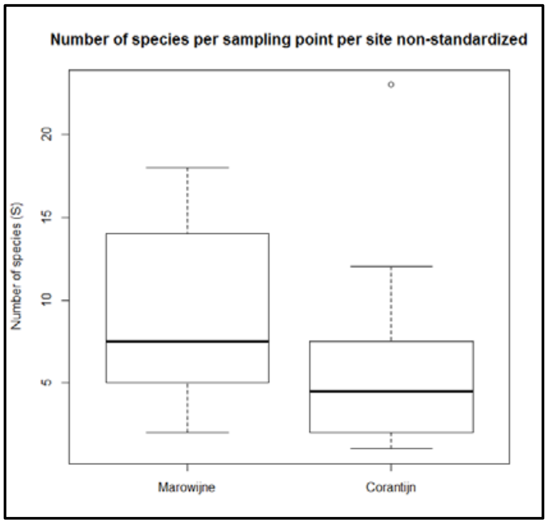

Figure A.2: Number of species (S)

Species diversity

The species diversity (H) of the sampling points of the Marowijne and the Corantijn rivers do not significantly differ from each other (t-test, t = 2.0273, df = 33.98, p-value = 0.05054) with a mean of 1.62 for the Marowijne and a mean of 1.25 for the Corantijn river. See figure A.3.

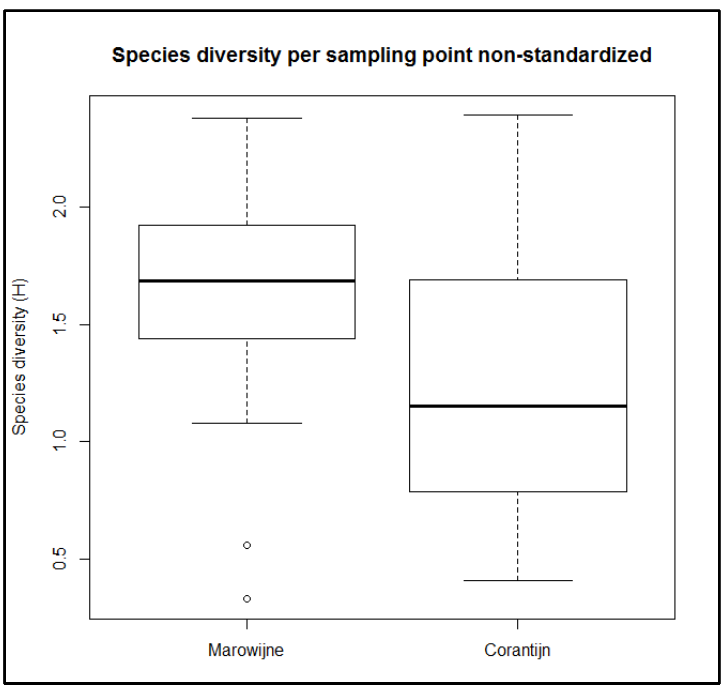

Figure A.3: Species diversity

Evenness

The evenness (J) of the sampling points of the Marowijne and Corantijn are not significantly different (t-test, t = 0.01036, df = 33.587, p-value = 0.9918) with almost equal means. Mean of the evenness of the Marowijne is 0.782 and that of the Corantijn is 0.781. See figure A.4.

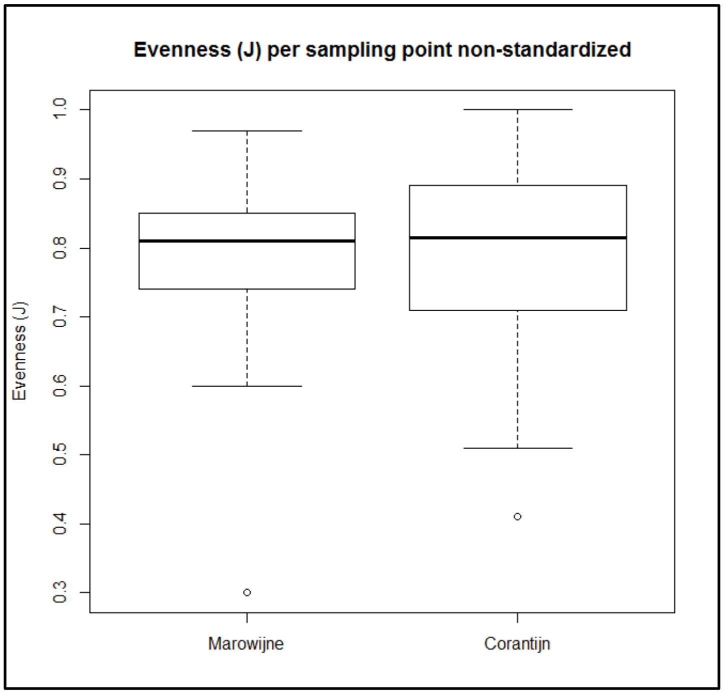

Figure A.4: Evenness (J)

Mass

The mass of the collected individuals of the sampling points of the Marowijne and the Corantijn do not differ significantly (t-test, t = -0.13179, df = 19.901, p-value = 0.8965) with mean of 909 g for Marowijne and a mean of 982 g for Corantijn. See figure A.5.

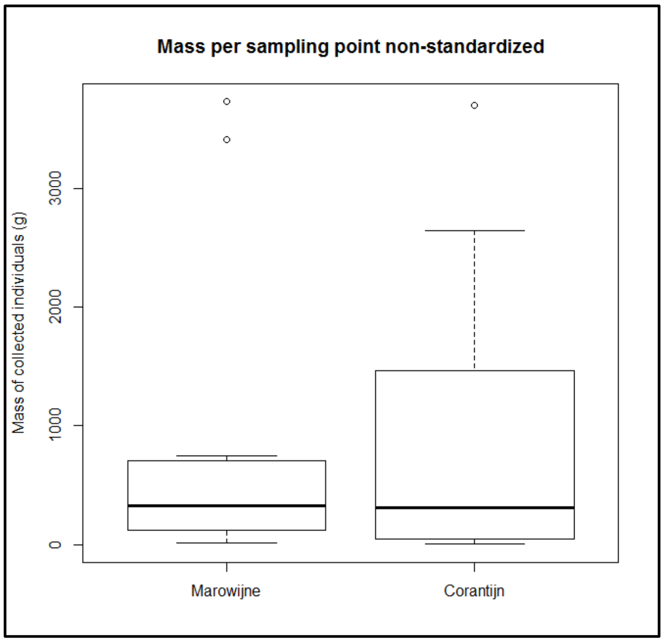

Figure A.5: Mass of collected individuals of sampling point

Appendix B: Phytoplankton

Phytoplankton are the small plants that are mostly free floating with the currents in streams (Mol J. H., 2012). High phytoplankton (open-water algae) concentrations are an indicator of high rates of primary productivity. Phytoplankton are the microscopic, drifting, often unicellular plants that comprise the base of the aquatic food chain (Schemel, Sommer, Muller-Solger, & Harrell, 2004) (Schemel et al. 2004). The increase of inorganic turbidity decreases the amount of light which is absorbed by photosynthesizing phytoplankton. This decrease of light absorption by phytoplankton causes considerable reduction of the density, growth rates and production of phytoplankton. Increased inorganic turbidity also causes shifts in phytoplankton assemblage structure, where the more motile flagellates increase and the less motile filamentous blue-greens decrease. Another problem caused by inorganic turbidity is the adhesion of clay particles onto algal cells, which causes increased rates of algal sinking. This algal sinking reduces phytoplankton densities significantly (Donohue & Molinos, 2009). A study by Tudesque et al. in 2011 showed that diatom assemblages, a type of phytoplankton, are sensitive to gold mining disturbance. The study measured the response of diatom assemblages to gold mining in ten sites with different gold mining intensity and the results showed that taxonomic and functional structure of the diatom assemblages were influenced by the intensity of the gold mining activity. The study also showed that there is a significant relationship between soil erosion and diatom motility.

Collection of phytoplankton samples

Phytoplankton samples were collected at selected sampling sites. In total 30 samples were taken during the two field trips at sites that represent the variety of habitats. Samples were taken by filling up a one-liter bottle for 95% at a depth of 30 cm below the water surface. To preserve the phytoplankton sample ca. 20 ml of 40% formal was added to the bottle. The samples were stored in a container protected against sunlight.

It was decided not to include the phytoplankton analysis in this study, because the analysis could not take place within the time frame of the study.

Appendix C: Results turbidity

Results for the measured turbidity (FNU) and secchi depth (m) in the Marowijne and Corantijn rivers during the two sampling periods

Field number	Date	Locality	Turbidity (FNU)	Secchi depth (m)
HLF-14-18-s	3/10/2014	Marowijne river	23.9	0.56
HLF-14-19-s	3/10/2014	Marowijne river	37.4	0.56
HLF-14-24-s	4/10/2014	Marowijne river	29.3	0.33
HLF-14-25-s	4/10/2014	Marowijne river	32.4	0.34
HLF-14-32-s	4/10/2014	Marowijne river	32.9	0.41
HLF-14-27-s	5/10/2014	Marowijne river tributary	5.2	0.68
HLF-14-28-s	5/10/2014	Marowijne river tributary	8.55	0.94
HLF-14-26-s	5/10/2014	Marowijne river	29.8	0.34
HLF-14-29-s	6/10/2014	Marowijne river-mouth of creek	85.6	
HLF-14-30-s	6/10/2014	Marowijne river main	32.7	0.37
HLF-14-31-s	6/10/2014	Marowijne river	12.2	0.69
HLF-14-W1	6/10/2014	Marowijne river-Toematoe creek	331	0.065
HLF-14-W3	6/10/2014	Marowijne river-mouth of creek	45.2	0.23
HLF-15-01	4/3/2015	Marowijne river -creek	81.9	0.36
HLF-15-02	4/3/2015	Marowijne river -island	96.3	0.16
HLF-15-03	4/3/2015	Marowijne river-artificial beach	128	0.13
HLF-15-04	4/3/2015	Marowijne river	98.7	0.16
HLF-15-05	5/3/2015	Marowijne river-Toematoe creek	235	0.11
HLF-15-06	5/3/2015	Marowijne river-Toematoe creek	199	0.09

HLF-15-07	5/3/2015	Marowijne river	47	0.1
HLF-15-08	5/3/2015	Marowijne river	137	0.14
HLF-15-09	5/3/2015	Marowijne river	152	0.15
HLF-15-10	5/3/2015	Marowijne river	83.9	0.26
HLF-15-11	5/3/2015	Marowijne river	67.5	0.19
HLF-15-12	6/3/2015	Marowijne river	44.7	0.33
HLF-15-13	6/3/2015	Marowijne river	56.2	0.26
HLF-15-14	6/3/2015	Marowijne river	47.9	0.245
HLF-15-15	6/3/2015	Marowijne river	40.2	0.51
HLF-15-16	6/3/2015	Marowijne river	47.2	0.3
HLF-15-17	6/3/2015	Marowijne river	51	0.26
HLF-15-18	6/3/2015	Marowijne river-Grancreek	343	0.08
HLF-15-19	7/3/2015	Marowijne river-creek	151	0.12
HLF-15-21	7/3/2015	Marowijne river-creek	64.1	0.25
HLF-15-22	7/3/2015	Marowijne river	45.1	0.28
HLF-15-23	7/3/2015	Marowijne river	45	0.33
HLF-15-24	7/3/2015	Marowijne river-creek	9.07	1.15
HLF-15-25	7/3/2015	Marowijne river-creek	9.48	1.04
HLF-15-26	7/3/2015	Marowijne river-creek	54.1	0.22

Field number	**Date**	**Locality**	**Turbidity (FNU)**	**Secchi depth (m)**
HLF14-33s	9/10/2014	Corantijn River	7.7	0.65
HLF14-34s	9/10/2014	Corantijn River	8.35	1.25
HLF14-35s	9/10/2014	Corantijn River	3.74	1.42
HLF14-36s	10/10/2014	Corantijn River	3.85	1.25
HLF14-37s	10/10/2014	Corantijn River	4.47	1.66
HLF14-38s	10/10/2014	Corantijn River	4.24	
HLF14-39s	10/10/2014	Corantijn River	2.98	1.55
HLF14-43	11/10/2014	Corantijn River	4.25	too shallow
HLF14-44	11/10/2014	Corantijn River	6.73	too shallow
HLF14-45	11/10/2014	Corantijn River	3.85	1.27
HLF14-46	11/10/2014	Corantijn River -creek along road	162	0.13
HLF14-47	11/10/2014	Corantijn River -creek along road	115	0.13
HLF14-48	11/10/2014	Corantijn River -creek along road	48.9	0.17
HLF14-49	12/10/2014	Corantijn River	4.27	1.64

Field number	Date	Locality	Turbidity (FNU)	Secchi depth (m)
HLF-15-33	10/3/2015	Corantijn River	5.69	1.17
HLF-15-34	10/3/2015	Corantijn River	7.46	too shallow
HLF-15-35	10/3/2015	Corantijn River	4.35	1.22
HLF-15-36	10/3/2015	Corantijn River	4.88	1.23
HLF-15-37	11/3/2015	Corantijn River	14.7	1.46
HLF-15-38	11/3/2015	Corantijn River	6.48	>1.40 (not deep enough)
HLF-15-39	11/3/2015	Corantijn River	4.56	1.3
HLF-15-40	11/3/2015	Corantijn River	4.57	1.2
HLF-15-41	11/3/2015	Corantijn River	3.7	1.21
HLF-15-42	11/3/2015	Corantijn River	4.3	too shallow
HLF-15-45	12/3/2015	Corantijn River	8.52	0.94
HLF-15-46	12/3/2015	Corantijn River-Kaboericreek	1.26	0.92
HLF-15-47	12/3/2015	Corantijn River-Kaboericreek	1.29	1.21
HLF-15-48	13/3/2015	Corantijn River	5.27	1.18
HLF-15-49	13/3/15	Corantijn River	4.69	1.47

Appendix D: List of fish collected

The following list summarizes the fish collected in the Marowijne and Corantijn rivers during the two sampling periods October 2014 and March 2015.

Totals Fish list		**Marowijne**			**Corantijn**		
(Sub) Family	**Species**	**2014**	**2015**	**Total**	**2014**	**2015**	**Total**
Curimatidae	*Curimata cyprinoides*	1		1	3	10	13
Curimatidae	*Curimatopsis sp.*	1		1			0
Curimatidae	*Cyphocharax microcephalus*	5	4	9		2	2
Curimatidae	*Cyphocharax spilurus*	5	58	63	12		12
Prochilodontidae	*Prochilodus rubrotaeniatus*	1	4	5	11	2	13
Anostomidae	*Leporinus apollo*			0	2		2
Anostomidae	*Leporinus fasciatus*		6	6	2		2
Anostomidae	*Leporinus friderici*		11	11	3		3
Anostomidae	*Schizodon fasciatus*	1		1		1	1
Crenuchidae	*Characidium sp.*		1	1			0
Hemiodontidae	*Bivibranchia bimaculata*	20	22	42			0
Hemiodontidae	*Hemiodus unimaculatus*	24	4	28	71	4	75
Gasteropelecidae	*Gasteropelecus sternicla*		5	5			0
Characidae Genera incerta sedis	*Astyanax bimaculatus*		2	2			0
Characidae Genera incerta sedis	*Bryconops affinis*	2		2			0
Characidae Genera incerta sedis	*Bryconops caudomaculatus*	3		3			0
Characidae Genera incerta sedis	*Bryconops melanurus*	7	24	31	22	160	182
Characidae Genera incerta sedis	*Bryconops sp.*	2		2	3		3
Characidae Genera incerta sedis	*Hemigrammus boesemani*		13	13			0
Characidae Genera incerta sedis	*Jupiaba ocellata*			0	142		142
Characidae Genera incerta sedis	*Jupiaba polylepis*		2	2	45	10	55
Characidae Genera incerta sedis	*Moenkhausia lepidura*		3	3			0
Characidae Genera incerta sedis	*Moenkhausia browni*	1		1			0
Characidae Genera incerta sedis	*Moenkhausia grandisquamis*	61	30	91		64	64
Characidae Genera incerta sedis	*Moenkhausia hemigrammoides*		1	1			0
Characidae Genera incerta sedis	*Moenkhausia inrai*		2	2			0
Characidae Genera incerta sedis	*Moenkhausia intermedia*	8	79	87			0
Characidae Genera incerta sedis	*Moenkhausia moisae*		2	2			0
Characidae Genera incerta sedis	*Moenkhausia oligolepis*		2	2			0
Characidae Genera incerta sedis	*Moenkkhausia sp 'yellow fins'*			0	4		4
Characidae Genera incerta sedis	*Pristella maxillaris*		7	7		1	1
Characidae Genera incerta sedis	*Thayeria ifati*	1		1			0
Characidae Bryconinae	*Brycon falcatus*			0		3	3
Characidae Bryconinae	*Brycon pesu*	17	40	57	8		8
Characidae Bryconinae	*Triportheus brachipomus*		7	7			0
Characidae Serrasalminae	*Acnodon oligacanthus*	5	6	11			0

Characidae Serrasalminae	*Myloplus planquetii*		2	2			0
Characidae Serrasalminae	*Myloplus rhomboidalis*	2	26	28	1	1	2
Characidae Serrasalminae	*Myloplus rubripinnis*	2		2			0
Characidae Serrasalminae	*Myloplus ternetzi*	1		1			0
Characidae Serrasalminae	*Pristobrycon cf. eigenmanni (vertical stripes, see pictures)*	2	2		7	7	
Characidae Serrasalminae	*Pristobrycon striolatus*		1	1			0
Characidae Serrasalminae	*Serrasalmidae black stripes*		1	1			0
Characidae Serrasalminae	*Serrasalmidae juv.*	6	11	17			0
Characidae Serrasalminae	*Serrasalmus rhombeus*	1	1	2	3	8	11
Characidae Serrasalminae	*Tometes lebaili*		1	1			0
Characidae Characinae	*Characidae sp.*			0		1	1
Characidae Characinae	*Charax gibbosus*	2	1	3			0
Characidae Characinae	*Cynopotamus essequibensis*			0	1		1
Characidae Characinae	*Roeboexodon guyanensis*		1	1			0
Characidae Stethaprioninae	*Bryconamericus aff. Hyphesson*	38	257	295			0
Characidae Stethaprioninae	*Poptella longipinnis*	5		5			0
Acestrorhynchidae	*Acestrorhynchus falcatus*	1	1	2			0
Acestrorhynchidae	*Acestrorhynchus microlepis*		1	1	2		2
Erythrinidae	*Hoplerythrinus unitaeniatus*		2	2			0
Erythrinidae	*Hoplias aimara*	1	1	2	2		2
Erythrinidae	*Hoplias curupira*		2	2			0
Erythrinidae	*Hoplias juv.*		1	1			0
Erythrinidae	*Hoplias malabaricus*	2		2			0
Aspredinidae	*Bunnocephalus verrrucosus*			0	2		2
Auchenipteridae	*Auchenipterus dentatus*		13	13		1	1
Auchenipteridae	*Auchenipterus nuchalis*	2		2	4		4
Auchenipteridae	*Trachelyopterus galeatus*	1	2	3			0
Doradidae	*Doras carinatus*		1	1			0
Doradidae	*Doras micropoeus*	20		20	2	7	9
Doradidae	*Platydoras helicophilus (shallow scutes)*	3	1	4			0
Heptapteridae	*Pimelodella cristata*	6		6			0
Heptapteridae	*Pimelodella geryi*		8	8			0
Heptapteridae	*Pimelodella megalops*		2	2			0
Heptapteridae	*Pimelodella sp.*	7		7			0
Heptapteridae	*Rhamdia quelen*			0	2		2
Heptapteridae	*Rhamdia sp.*	1		1			0
Loricariidae Hypoptopomatinae	*Parotocinclus sp.*		4	4			0
Loricariidae Hypoptopomatinae	*Pseudancistrus barbatus*	25		25			0
Loricariidae Hypostominae	*Hemiancistrus medians*	1		1			0
Loricariidae Hypostominae	*Hypostomus gymnorhynchus*	1	4	5			0
Loricariidae Hypostominae	*Hypostomus plecostomus*			0		2	2
Loricariidae Hypostominae	*Hypostomus taphorni*			0		1	1

Loricariidae Loricariinae	*Loricaria cataphracta*		26	26		2	2
Loricariidae Loricariinae	*Loricaria nickeriensis*			0		7	7
Loricariidae Loricariinae	*Loricariichthys maculatus*			0		13	13
Loricariidae Loricariinae	*Loricariidae juv.*		1	1		1	1
Loricariidae Loricariinae	*Metaloricaria paucidens*	3		3			0
Loricariidae Loricariinae	*Rineloricaria aff. Stewarti*	19		19	2		2
Loricariidae Loricariinae	*Rineloricaria fallax*			0	106		106
Pimelodidae	*Hemisorubim platyrhyngos*	1		1			0
Pimelodidae	*Pimelodus albofasciatus*			0		2	2
Pimelodidae	*Pimelodus blochi*	2	8	10	9	3	12
Pimelodidae	*Pimelodus ornatus*		2	2			0
Pimelodidae	*Pseudoplatystoma fasciatum*		1	1			0
Trichomycteridae	*Ochmacanthus sp*	1		1			0
Apteronotidae	*Porotergus gymnotus*		4	4			0
Sternopygidae	*Eigenmannia sp.2*		17	17			0
Sternopygidae	*Eigenmannia virescens*			0	10		10
Sternopygidae	*Sternopygus macrurus*		3	3			0
Cichlidae	*Aequidens tetramerus*			0	25		25
Cichlidae	*Cichla ocellaris*		1	1	1	13	14
Cichlidae	*Cichlasoma bimaculatum*		2	2			0
Cichlidae	*Cleithracara maronii*			0	10		10
Cichlidae	*Crenichicla albopunctata*	1		1			0
Cichlidae	*Crenichicla saxatilis*	1		1		1	1
Cichlidae	*Crenicichla multispinosa*		2	2			0
Cichlidae	*Geophagus brachybranchus*			0	55	58	113
Cichlidae	*Geophagus harreri*	18	4	22			0
Cichlidae	*Geophagus surinamensis*	56	91	147			0
Cichlidae	*Guianacara owroewefi*	7	15	22			0
Cichlidae	*Krobia guianensis*		14	14		19	19
Cichlidae	*Krobia itanyi*	15	2	17			0
Cichlidae	*Nannacara anomala*	1		1			0
Poeciliidae	*Tomeurus gracilis*			0	9	116	125
Poeciliidae	*Poecilia reticulata*			0	248		248
Rivulidae	*Laimosemion sp.*	4		4			0
Eleotridae	*Eleotris pisonis*			0	4	3	7
Gobiidae	*Awaous flavus*		4	4	2	262	264
Gobiidae	*Evorthodus lyricus*			0		12	12
Nandidae	*Polycentrus schomburgkii*			0	2		2
Sciaenidae	*Pachypops fourcroi*		3	3		131	131
Sciaenidae	*Plagioscion sp.*			0		1	1
Sciaenidae	*Plagioscion squamosissimus*	1	2	3	71	4	75
Potamotrygonidae	*Potamotrygon cf. orbignyi*			0		1	1

Potamotrygonidae	*Potamotrygon marinae*	1		1			0
Engraulidae	*Anchovia clupeoides*		1	1			0
Engraulidae	*Anchoviella guianensis*		7	7			0
Engraulidae	*Engraulidae sp (juveniles)*	1		1		77	77
Engraulidae	*Pterengraulis atherinoides*		1	1			0
Mugilidae	*Mugil cephalus*			0		1	1
Belonidae	*Pseudotylosurus microps*		2	2		1	1
Hemiramphidae	*Hyporhamphus roberti*			0		33	33
Syngnathidae	*Pseudophallus aff. Brasiliensis*			0		4	4
Achiridae	*Achirus sp*			0		1	1
	Total		101 sp	1320		63 sp	1795