FACTORS AFFECTING TILAPIA PRODUCTION IN CAPRICORN AND VHEMBE DISTRICTS IN LIMPOPO PROVINCE, SOUTH AFRICA

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DEDICATION

I dedicate this dissertation to my family.

DECLARATION

I declare that **FACTORS AFFECTING TILAPIA PRODUCTION IN CAPRICORN AND VHEMBE DISTRICTS IN LIMPOPO PROVINCE, SOUTH AFRICA** is my own work and that all the sources that I have used have been indicated and acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other institution.

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Hlongwane Khathutshelo Cathrine (Ms) **Date**

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ABSTRACT

Tilapia production in South Africa is failing to reach sustainable commercial levels of development, despite the efforts by the government to improve aquaculture production. Limpopo Province has been practicing fish farming since the 1980s, with tilapia being the most widely farmed fish. Currently, tilapia production in Capricorn and Vhembe districts in Limpopo Province remains low. In this study, factors affecting tilapia production in aqua dams, earthen ponds, concrete ponds, and RAS systems in Capricorn and Vhembe districts were explored. Eight different production systems were used to collect field data, four in each district. Water quality parameters in aqua dams, earthen ponds, concrete ponds, and RAS system were determined. The abundance of phytoplankton was determined in three different production systems. And lastly, a questionnaire was used to determine factors critical for successful tilapia production from the farmer's perspective in Capricorn and Vhembe districts.

The levels of ammonium and ammonia were below detection limits in all the production systems in Capricorn and Vhembe districts. The results showed that water temperature, alkalinity (as bicarbonate and carbonate), potassium, total phosphate frequently did not meet the requirement for the culture of tilapia in all the production systems in Capricorn and Vhembe district throughout the study. The concrete ponds, aqua dams, and RAS systems in both districts were mostly affected by these parameters. The phytoplankton abundance varied according to the type of production system and water quality parameters of the production systems. The concrete pond in Olifanshoek, Vhembe district had the highest total phytoplankton composition. An aqua dam in Bungeni had the highest total phytoplankton composition compared to other aqua dams in Capricorn district. The earthen ponds in Vondo in Vhembe district had the lowest tilapia yield and total phytoplankton composition compared to all the production systems in Capricorn and Vhembe districts. Phytoplankton species abundance was not correlated to primary production and tilapia yield, and there was no correlation between primary production and tilapia yield.

Tilapia farmers in Capricorn and Vhembe district both ranked "value chain accessibility", "appropriate technology approach", "market factors", "level of operational integration", and "access to multiple market destination" as the most important socio-economic factors affecting tilapia production in both districts. Tilapia

production in Capricorn and Vhembe districts is not profitable because of low tilapia yields due to low stocking densities and because of low-priced imported tilapia from China and low-priced wild-caught tilapia sold by local fishermen in villages. The study concluded that tilapia production in Capricorn and Vhembe districts is not successful because farmers struggle to maintain optimum water quality and the water temperature was suitable for tilapia farming only for a short period of time. And lastly, tilapia production is failing to succeed in Capricorn and Vhembe district because it is not profitable.

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CHAPTER 1: GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

1.1 Tilapia production

More than 120 million people throughout the world are estimated to depend on aquaculture for income (FAO, 2005; HLPE, 2014; Rabo *et al.*, 2014). Over 80% of the global aquaculture production is from rural aquaculture farms that are commonly owned and managed by families (De Silva & Davy, 2009). The need to boost aquaculture production resulted from the decrease in ocean fisheries supply as a result of over-fishing and pollution (Kelleher & Weber, 2006). Therefore, the rising demand for aquatic products is met by aquaculture (Rana *et al*., 2009). Fish farming has the potential to play a leading role in the fight against food insecurity, malnutrition, and poverty in Africa (Prabu *et al.*, 2019). Egypt has been a major contributor for decades, and it continues to dominate the production of tilapia in Africa (FAO, 2018). However, the problem is that in South Africa, tilapia production has remained low despite numerous interventions by the government (Moyo & Rapatsa, 2021).

Limpopo Province is one of South African's Provinces with great potential for the culture of tilapia because of the high summer temperatures (Moyo & Rapatsa, 2021). Limpopo Province has five districts. Capricorn and Vhembe districts are two of the districts in Limpopo Province that has environmental conditions that represent the entire climate of Limpopo Province because of their geographic locations. Limpopo Province has been practicing fish farming ever since the 1980s when the government discovered that freshwater aquaculture can contribute to economic development and food security in rural areas of South Africa (Rouhani & Britz, 2004). Tilapia is the most widely farmed fish in Limpopo Province (DAFF, 2016; Phosa & Lethoko, 2018). Tilapias are knowns as 'aquatic chickens' due to their high adaptability to a wide range of environmental conditions. They readily reproduce in captivity, feed at the low trophic level, have high growth rates, and tolerate a wide range of water quality parameters (El-Sayed, 2006) and accept artificial feeds immediately after yolk-sac absorption (Pandit & Nakamura, 2010; Osman & El-Khateeb, 2016). The main challenge is that tilapia production is not improving in Limpopo Province, even state-owned projects end in failure. For instance, farmers in Limpopo Province used to receive fingerlings from Turfloop state-owned hatchery since 1982. However, the production started to decline from 2003 and currently the hatchery is no longer operational. It has been observed that most of the production systems in Southern Africa are physically located in areas with unsuitable climates (Moyo & Rapasta, 2021). Therefore, farmers with appropriate production systems located in physically suitable areas both from a climatic and edaphic perspective are more likely to have a successful tilapia production than farmers located in unsuitable areas.

Tilapias are native in Africa (excluding Madagascar) and the Palestine (Jordan valley and coastal rivers), they are found in the Nile river as well as most of African rivers and lakes (Philippart & Ruwet, 1982; Pillay & Kutty, 2005; El-Sayed, 2006). Despite that tilapias are native in Africa, tilapia aquaculture in most parts of Africa as well as in South Africa remains a small-scale activity (DAFF, 2018; FAO, 2020a). Tilapias are widely cultured in a wide range of systems for domestic consumption and export in more than 100 countries around the world (Egna & Boyd, 1997; Pillay & Kutty, 2005; El-Sayed, 2006). Tilapia species that are commonly farmed around the world include *Oreochromis niloticus* (Nile tilapia), *Oreochromis mossambicus* (Mozambique tilapia), *Oreochromis aureus* (Blue tilapia), *Tilapia zillii* (Redbelly tilapia), and *Coptodon rendalli* (Redbreast tilapia). The major determining factor of a fish species to be used in aquaculture is its growth rate. Nile tilapias have better attributes for culture than other tilapia species (Marcel, 1986; Siddiqui & Al-Harbi, 1995; El-Zaeem, 2011; Day *et al.*, 2016). This species is considered to have greater tolerance to adverse environmental conditions, breeds easily, rapid growth rate, ability to convert organic and domestic wastes into high-quality protein efficiently, and good taste (Pullin & Lowe-McConnell, 1982). As a result, Nile tilapia is the most farmed tilapia around the world (Neves *et al.*, 2008). The farming of Nile tilapia is prohibited in Limpopo Province. South African freshwater aquaculture is mostly based on the farming of Mozambique tilapia (DAFF, 2016). Nile tilapia is not widely cultured in South Africa since it is an alien invasive species, and a permit is required to farm Nile tilapia. The department of agriculture, forestry, and fisheries (DAFF) legalised the farming of Nile tilapia in closed systems in 2014 provided that proper permits from the relevant provincial environment authorities are granted (DEA, 2016; DAFF, 2017). However, most farmers in Capricorn and Vhembe districts do not have permits, therefore Mozambique tilapia is the most widely cultured fish in Limpopo Province.

1.2 Environmental requirements for tilapia production

Water quality in fish ponds is affected by the interactions of several parameters. Temperature, pH, salinity, electrical conductivity, turbidity, chemical oxygen demand (COD), potassium, alkalinity, and phosphate are interrelated and can have profound effects on pond productivity, the level of stress and fish health, dissolved oxygen (DO) availability and the toxicity of ammonia as well as that of certain metals (Wurts & Durborow, 1992; El-Sayed, 2006). Temperature is of prime importance and essential to maximizing tilapia growth (Pandit & Nakamura, 2010; Pimolrat *et al.*, 2013; Sriyasak *et al.*, 2013). The temperature affects the growth, physiology, metabolism, and reproduction of fish. Tilapias are thermophilic fish and known to tolerate a wide range of water temperatures (El-Sayed, 2006). For normal development, reproduction, and growth, tilapia requires a temperature between 25 and 30 °C (Chervinski, 1982; Philippart & Ruwet, 1982) which is within the range of Limpopo Province's ambient temperature (Mosase & Ahiablame, 2018). However, tilapia farmers in Limpopo Province are challenged with a low temperature in winter; because the temperature can drop to a minimum of 3 °C in Capricorn district and 7 °C in Vhembe district (FAO, 2004; Kruger & Shongwe, 2004; Mosase & Ahiablame, 2018). Tilapia species can tolerate temperature as low as 7 °C (Chervinski, 1982; Sifa *et al.*, 2002). However, extended exposure to low temperature can lead to an increase in mortality rate and poor feeding response (Jennings, 1991). The study on the effect of temperature in tilapia production is imperative in Limpopo Province because of the province's long and cold temperatures that can lead to loss of fish due to slow growth and mortalities. Tilapia feeding is severely reduced below the temperature of 20 °C (Balarin & Haller, 1982; Chervinski, 1982). They usually stop feeding at around 15 °C, and mortalities can be expected when temperature reaches 12 °C and below (Balarin & Haller, 1982). Fluctuation in water temperature usually results in changes in other water quality parameters in the pond (Wurts & Durborow, 1992; Boyd, 2018).

Good water quality is essential for the health of fish at all stages of development. Poor water quality can result in low profit through fish mortalities and low product quality (El-Otify, 2015). Water quality in a semi-intensive culture system can deteriorate rapidly due to pond fertilization. However, Tilapia tolerates a wide range of environmental conditions (salinity, dissolved oxygen, temperature, pH, and ammonia levels) than most cultured freshwater fish (Mjoun *et al*., 2010). Optimum dissolved oxygen for growth is obtained at concentrations greater than 3 mg/L (Ross, 2000) however, tilapia can tolerate a low dissolved oxygen concentration of 0.1 mg/L (Magid & Babiker, 1975). To maximize tilapia growth in a production system, other parameters such as pH, ammonia, and salinity must be optimal. A pH of 7 to 9 is optimum for tilapia growth and tilapia can tolerate a pH range of 3.7 to 11 (Ross, 2000). The level of pH has a direct effect on the toxicity of ammonia on fish, ammonia-nitrogen has a more toxic form (un-ionized ammonia) at high pH and a less toxic form (ionized ammonia) at low pH (Wurts, 2003). However, there is normally an equilibrium between ionized ammonia and un-ionized ammonia in the water. Ammonia is toxic to tilapia at a concentration of 2.5 mg/L (Stickney, 1979). Ammonia toxicity can also be influenced by the level of salinity in the water, an increase in salinity usually lowers the proportion of unionized ammonia. Tilapia species, except for Nile tilapia, can grow and reproduce at salinity concentrations of up to 36 parts per thousand, but optimal performance measures for reproduction and growth are attained at salinities up to 19 parts per thousand (El-Sayed, 2006). The interaction of water quality parameters is complex and poorly understood by most tilapia farmers in Capricorn and Vhembe districts. Hence, it is vital to investigate the effect of water quality parameters on tilapia production.

Water scarcity causes most farmers to depend on rain to serve as a water source. Capricorn district which is the central region of the province is known to receive more annual rainfall than the northern region (Vhembe district) of the Limpopo Province (Mosase & Ahiablame, 2018). Annual rainfall can serve as a reliable water source for smallholder aquaculture in Limpopo Province. However, in this case, a region that receives more annual rainfall has a lower ambient temperature. Rainfall is a climatic element affecting fish production in the tropics (Olaoye *et al*., 2010). Apart from serving as a reliable source of water for fish farms, rainfall can also increase plankton densities in a pond. Several studies have reported higher densities of plankton, mainly phytoplankton, during the rainy season because rains carry allochthonous nutrients from the drainage basin as well as mixing of the autochthonous material (Naz & Turkemen, 2005; Arimoro *et al*., 2008; Shan *et al.*, 2008; Kunlasak *et al.,* 2013). Rainfall can also alter the concentration of limiting nutrients in water bodies such as phosphorus, nitrogen, and alkalinity (Egna & Boyd, 1997). Parameters such as total phosphorus, nitrogen, total dissolved solids, and electrical conductivity can be used as indicators and predictors of pond productivity (Egna & Boyd, 1997)

1.3 Tilapia feed

Fish feed is the most expensive component in the aquaculture industry, where it represents over 50% of operating costs (El-Sayed, 2006; FAO, 2009; Craig & Helfrich, 2017). Therefore, proper feed management is a necessary tool for successful tilapia culture (Ratafia, 1994). Traditionally, fishmeal has been used as the main dietary protein source in fish diets because of its well-balanced amino acid profile, adequate fatty acids, high levels of essential vitamin and mineral composition, high palatability, and a high digestibility (Nguyen *et al.*, 2009). Incorporating protein in feeds results in an increased growth rate of fish and can allow high stocking densities in a pond (Fitzsimmons *et al.*, 1999). However, a major challenge is that dietary protein is often expensive to incorporate into a diet. As a result, farmers in rural communities usually fertilize the ponds to enhance natural food and supplement using pellets or nonconventional feed (New *et al*., 1994; Hasan *et al.*, 2019). Tilapia farmers in Capricorn and Vhembe districts use nonconventional feed such as maize bran and sorghum.

Nonconventional feed and supplement feed that farmers add to the ponds do not have to be very high in protein. However, the fish get some of their protein requirement from natural food available in earthen ponds (Pandey, 2013; Kuhn, 2017). Protein content in plankton can reach up to 83 percent (Leaves & Sorgeloos, 1996). High levels of different grains fed to tilapia can decrease the growth performance. For instance, the growth performance of tilapia can decrease with the increasing level (25-43%) of maize grain in the diet (Al-Ogaily *et al.,* 1994). Tilapia farmers in Capricorn and Vhembe districts do not produce on-farm feed, they feed maize bran and sorghum directly to the fish. Sorghum based diet can result in good growth performance without any deleterious effect on fish health (Al-Ogaily *et al.,* 1996; Solomon *et al.*, 2007). The feed has a significant impact on the quality and the nutritional value of farmed fish. A wrong choice of feed type would not only produce a lower weight gain but also would increase stress level and thus increase fish's susceptibility to diseases and infections (Garcia & Villarroel, 2009). Feed type can enhance or reduce primary production and plankton abundance in a pond, which in turn can lead to an increase or decrease in tilapia production (Olah *et al.,* 1986). Tilapia can efficiently feed on plankton. Most juvenile tilapia feed on planktons until they are about 5 mm in total length (Lazzaro, 1987; Abdel-Tawwab & Marakby, 2004).

1.4 Socioeconomics factors in tilapia production

Several socio-economic factors affect tilapia production ranging from economic factors to human resource capacity. Aquaculture is deemed unprofitable by most rural communities in South Africa because of the cheaper wild-caught tilapia and Chinese imported tilapia (Moyo & Rapatsa, 2021). The main economic factor that challenges tilapia aquaculture in South Africa is the lack of financial support. This affects fish feed quality and availability along with the acquisition of high-quality fingerlings (Moyo & Rapatsa, 2021). Rural aquaculture farming is regarded as high-risk activity therefore most banks and investors are reluctant to give them loans (Mpandeli & Maponya, 2014; Khapayi & Celliers, 2016; Moyo & Rapatsa, 2021). Thus, most of the fish ponds are run at a family level as a backyard pond (Ansah *et al.*, 2014; Moyo & Rapatsa, 2021). Tilapias from these ponds are usually sold either at the farm gate, to neighbours or in local markets at low prices (Gono *et al.*, 2015; IDC, 2015; Mulokozi *et al*., 2020). However, tilapias have grown in importance from being just a low-cost, high-protein food fish (BFAR, 2006; Fitzsimmons, 2006; FAO, 2010; Prabu *et al.*, 2019). It is the second most important farmed fish species after carps (FAO 2018; Prabu *et al.*, 2019). In 2004, tilapia's economic importance surpassed the salmons, and they are expected to eventually equal the carps (Fitzsimmons, 2006; Prabu *et al.*, 2019).

Aquaculture profitability is determined by the stocking density in a production system, management level and the market value of the farmed fish (Moyo & Rapatsa, 2021). The major expenses in aquaculture are the cost of feed, more than 60% of the cost of running an aquaculture enterprise goes towards fish feed (FAO, 2016b). The pelleted feed is imported at a high cost and locally manufactured feed is usually of poor quality (Shipton & Britz, 2007; IDC, 2015). Another economic challenge faced by farmers is the price of tilapia. The estimated production costs for tilapia are R45/kg and the retail price are estimated to be R38/kg, while the imported tilapia from China cost R17/kg retail price (IDC, 2015). This makes the culture of tilapias unprofitable in South Africa.

Another challenge is that most rural fish farmers enter into aquaculture lacking requisite farming skills for them to successfully run fish farms. These skills include knowledge of water quality, pond design, basic fish husbandry practices, disease identification and treatment, and the development of business plans (Moyo & Rapatsa, 2021). Little work has been done on factors affecting tilapia production in rural communities in South Africa. Thus, it is important to ascertain the extent to which different factors affects tilapia production in Capricorn and Vhembe districts in Limpopo province because tilapia aquaculture is gradually picking up in other African countries (FAO, 2018). The main aim of this study was to determine the key factors that are critical for the failure of tilapia pond production in Capricorn and Vhembe districts of Limpopo Province in South Africa. The specific objectives were to determine:

- Key water quality parameters affecting tilapia production in aqua dams, concrete ponds, earthen ponds, and RAS in Capricorn and Vhembe districts
- Phytoplankton abundance in aqua dams and concrete ponds in Capricorn district.
- Phytoplankton abundance in aqua dams, earthen ponds, and concrete ponds in Vhembe district.
- The most important socio-economic factors critical for successful tilapia production in Capricorn and Vhembe districts.

1.5 Dissertation layout

Key factors affecting tilapia production in Capricorn and Vhembe districts was assessed. This dissertation has been divided into seven chapters, each addressing a step in assessing the factors affecting tilapia culture in Capricorn and Vhembe districts. Chapter 1 identifies the research problem and gives an outline of the background of the study.

Chapter 2

In this chapter, current status on tilapia production and challenges experienced by tilapia farmers developing countries is explored.

Chapter 3

In this chapter, the effect of temperature, dissolved oxygen, alkalinity (bicarbonate and carbonate), turbidity, ammonia, ammonium, pH, salinity, electrical conductivity, chemical oxygen demand, potassium, nitrogen, and phosphate on tilapia production in different production systems is described. Reference is made to the selection of sampling ponds, as well as the description of study sites.

Chapter 4

This chapter focuses on determining the abundance of phytoplankton in aqua dams and concrete ponds in Capricorn district.

Chapter 5

This chapter focuses on determining the abundance of phytoplankton in aqua dams, earthen ponds, and concrete ponds in Vhembe district.

Chapter 6

In this chapter, the key success factors critical for the success or failure of tilapia aquaculture in Capricorn and Vhembe districts are explored.

Chapter 7

This chapter explains the general discussion, recommendations, and conclusion of the study.

CHAPTER 2: LITERATURE REVIEW

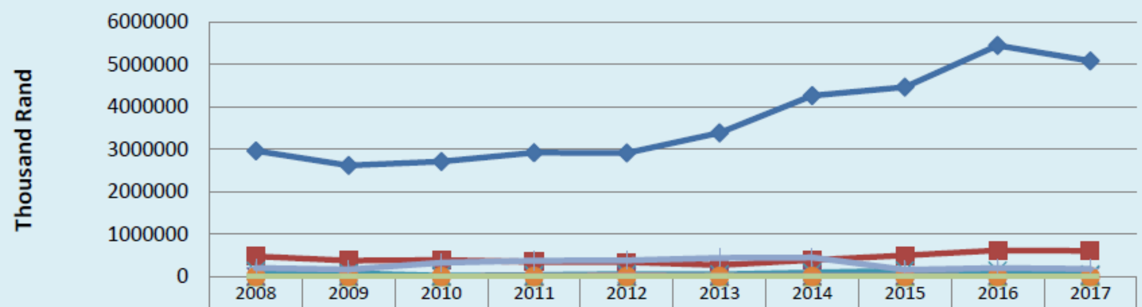
2. LITERATURE REVIEW

2.1 Present status of aquaculture production of tilapia

People in rural areas farm tilapia to support their families financially, provide food security, and improve social standards and livelihood in their communities (Halwart *et al.*, 2003; Gono *et al.,* 2015). Historically and from a social standpoint, tilapia farming was practiced for home consumption, with millions of small-scale fish farmers around the world supplementing their diets with tilapia (Fitzsimmons, 2006; Pradu *et al.*, 2019). Currently, aquaculture accounts for 46 percent of the total world fish production where 52 percent of fish is for human consumption (FAO, 2020b). The contribution of aquaculture to total global fish products (excluding plants) has steadily increased from 4% in 1970 to 36% in 2006 (FAO, 2009). World aquaculture production (fish, crustaceans, and molluscs) excluding plants and non-food products was 66.7 million tons in 2006 (FAO, 2009). In 2010, it came down to 60 million tons with an estimated total value of US$ 119 billion (FAO, 2012). From the total production of 60 million tons, freshwater fishes contributed 33.4 million tons (56.4%) where 24.2 million tons was carp fish. Tilapia and other cichlids only contributed 3.4 million tons, however, 72% (of 3.4 million) of the tilapia was cultured in Asia (particularly in China and Southeast Asia), and only 19% came from Africa (mostly from Egypt) and none came from South Africa. In 2018, the aquaculture production was 82.1 million tonnes (US$ 250.1 billion) excluding aquatic plants (FAO, 2020b). From the 82.1 million tonnes of food fish, inland aquaculture contributed 54.3 million tonnes of finfish where only 10.2% of the finfish production was tilapia (8.3 % was Nile tilapia and 1.9 % was tilapia spp.) species (FAO, 2020b). Major tilapia producers were China, Indonesia, India, Viet Nam, Egypt, Chile, Norway, Ecuador, and Bangladesh (FAO, 2020b).

However, few countries in Africa are steadily improving in aquaculture production. For instance, Zambia is one of the biggest producers of tilapia in the South African Development Community (SADC) (FAO, 2016a). Approximately 20% of the total tilapia produced in Zambia is coming from small-scale tilapia production (FAO, 2016a; Genschick *et al.*, 2017). Nonetheless, South Africa tilapia farming is stagnant (Shipton & Britz, 2007; IDC, 2015; DAFF, 2018). Despise that freshwater aquaculture started around 1896 (FAO, 2010), aquaculture production is still low in South Africa.

Aquaculture particularly tilapia farming is not successful more especially in Limpopo Province (DAFF, 2018). In terms of exports, Western Cape is the only province in South Africa that is successfully producing and exporting aquaculture products unlike Limpopo Province and other provinces (Figure 2.1). Thus, this study will investigate factors affecting tilapia production in Limpopo Province of South Africa, particularly in Capricorn and Vhembe districts.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Western Cape	2967189	2620959	2712531	2919250	2915593	3388876	4270134	4472693	5452805	5090766
Eastern Cape	474670	375990	390303	344519	340540	267961	389837	497075	616038	603391
Northern Cape	0	0	0	28	0	318	545	337	184	165
Free State	732	0	138	0	52	177	17084	18531	19994	20017
KwaZulu-Natal	131575	77318	18928	34933	55675	52828	94962	136082	133506	52566
North West	0	17	4	0	0	0	0	94	283	249
Gauteng	204663	166766	322287	370828	382232	437148	448502	159203	200460	180580
Mpumalanga	650	382	1281	6744	14051	10904	10278	4118	1701	2957
Limpopo	0	87	605	877	2012	3604	484	307	646	2287

Figure 2. 1: Values of fish and aquatic invertebrate exported from South Africa from 2008 to 2017. Source: DAFF, 2018.

Tilapia species that are mostly cultured in South Africa is Mozambique tilapia followed by the Nile tilapia (DAFF, 2016). According to DAFF (2016), tilapia products contributed 325.29 tons (17.90%) to South Africa's national freshwater production in 2015. South Africa's total freshwater aquaculture production in 2015 was 1826.29 tons (Figure 2.2), where trout was the highest contributor with 1497.00 tons. Tilapia contributed 325.29 tons while marron crayfish contributed 4.00 tons (DAFF, 2016). The total freshwater aquaculture contribution to the overall aquaculture production is 34.00% (1826.29 tons) of 5418.00 tons (DAFF, 2018). Tilapia currently produced in South Africa (Figure 2.2), is insufficient to meet the demand for fish thus China is importing tilapia to South Africa (Shipton & Britz, 2007). This highlights that tilapia production is not growing in South Africa.

Sub-sector	Year and production(tons)										Total production (tons)
	2006	2007	2008	2009	2010	2011	2012	2013	2014	**2015	[illegible]
Tilapia	0	0	0	10	10	100	234.17	289.71	289.71	325.29	1258.88
Trout	807	658	943	948.62	950	1199	1428	1497.3	1497.3	1497	11425.22
Catfish	180	180	180	180	180	160	0	0	0	0	1060
Marron crayfish	0.2	0.4	0.4	0.4	0.8	0.8	3.5	5	5	4	20.5
Totals	987.2	838.4	1123.4	1139.02	1140.8	1459.8	1665.67	1816.41	1792.01	1826.29	13764.6

Figure 2. 2: South African's freshwater aquaculture production from 2006 to 2015. Source: DAFF, 2016.

2.2 Challenges facing tilapia aquaculture in developing countries

Rural aquaculture is the production of fish whereby most of the output is sold for profit and some of the output is consumed by the producer (Ridler & Hishamunda, 2001; New, 2003). Rural aquaculture uses low-cost production with extensive and semi-intensive technologies, most appropriate for the limited resource base of small-scale farmers (Edwards, 2000; New, 2003). Aquaculture plays a vital role in food production, economic development, and food security and is increasingly becoming important in many countries (Patrick & Kagiri, 2016). The benefits of aquaculture in rural development related to health and nutrition, employment, reduction of vulnerability and farm sustainability (Mulokozi *et al*., 2020). Most of the global aquaculture production comes from rural aquaculture farming. Rural aquaculture provides high-quality protein at affordable prices for the poor segment of the society (De Silva & Davy, 2009; Allison, 2011). However, the industry faces several challenges, the main one being low tilapia yields

A study by Makori *et al*. (2017) showed that low tilapia yield is caused by poor water quality in the earthen ponds that did not support the optimal growth of tilapia, either because of lack of information or ignorance among the fish farmers. Studies by Caldini *et al*. (2011), Opiyo *et al*. (2018), Setiadi *et al*. (2018) and Mulokozi *et al*. (2020) agrees that poor water quality cause low tilapia yields. For instance, chronically low dissolved oxygen (DO) levels cause stress, poor appetite, disease susceptibility, mortality, reduce growth (Mallya, 2007; Boyd & Hanson, 2010), it limits respiration, and other metabolic activities of fish (Hagras *et al*., 2015). Moreover, low DO levels can be associated to increasing temperature in water. High water temperature results in increased oxygen demand by tilapia due to increased metabolic rate (Franklin *et al*., 1995). Thus, DO level and temperature are the major limiting water quality parameter in aquaculture systems. Normally studies look at the effect of physico-chemical parameters on tilapia in the laboratory. This study will use field data to evaluate the effect of water quality parameters on tilapia production. Limited work has been done on water quality parameters in tilapia farming around Limpopo Province. Thus, this study will investigate the effect of dissolved oxygen, pH, salinity, electrical conductivity, total alkalinity, potassium, total nitrogen, phosphorus, and chemical oxygen demand on tilapia yield in different production systems in Capricorn and Vhembe districts, Limpopo Province. Water quality parameters such as total phosphorus, nitrogen, alkalinity, turbidity, electrical conductivity, and temperature can also be used as indicators and predictors of pond productivity (Onada, 2015). Several studies showed that fluctuation of plankton community in a pond affects fish yield (Bhaumik *et al*., 2006; Attayde & Menezes, 2008; Sipaúba-Tavares *et al*., 2011; Tóth *et al*., 2020). This study will also determine phytoplankton abundance in different fish production systems in Capricorn and Vhembe districts.

Poor tilapia yield in different fish production systems is a result of stunted growth due to a lack of good quality feed. (Olaoye, 2014; Opiyo *et al.*, 2018; Mulokozi *et al*., 2020). Ridha (2006); Shitote *et al.* (2013); Munguti *et al*. (2014) and Gono *et al.* (2015) showed that poor local feed quality and high cost of imported commercial feeds is a major constrain for rural fish farmers. Feed cost is also a hindrance to tilapia development, finding cheaper alternative feed sources such as nonconventional feed can be an effective way to reduce fish production costs. A wrong choice of protein source does not only produce a lower weight gain, but it also influences the susceptibility of fish to diseases (Garcia & Villarroel, 2009). Furuya *et al*. (2003) fed different grain sources to tilapia and reported that sorghum-based diet experienced the largest weight gain. Solomon *et al.* (2007) recorded a good tilapia growth performance in sorghum-based without any deleterious effect on fish health, even at an inclusion level of 57%. A study by Liti *et al.* (2006) showed that tilapia fed maize bran grew significantly faster than those fed rice bran or wheat bran since maize bran has a lower level of fibre. Tilapia farmers in Capricorn and Vhembe district commonly feed with pellets and nonconventional such as sorghum and maize meal.

According to Gono *et al.* (2015), low tilapia yield is caused by extremely high stocking densities (14 fingerlings per square meter) in a pond. Bhujel (2013) also showed that the major drawback to pond culture is the high level of precocious breeding that occurs in mixed-sex tilapia farming because it causes the original stock to become stunted, thus yielding only a small percentage of marketable fish. On the other hand, socio-economic factors such as lack of appropriate and relevant tilapia farming skills can lead to low tilapia yield for rural fish farmers (Ridha, 2006; Munguti *et al*., 2014; Mulokozi *et al*., 2020; Harohau *et al*., 2020). Chirindza (2010) found that low tilapia yield was caused by poor management skills and poor integration of fish farming into the rest of the farming activities. Such studies had not been in Limpopo Province; thus, this study will investigate the most important factors critical for the successful of tilapia production in Capricorn and Vhembe districts. A study by Saidyleigh (2018) and Harohau *et al*. (2020) showed that low total harvest yield was associated with a lack of basic fish husbandry techniques, less functional small hatchery, and inadequate logistics to carry out breeding programmes. Kassam and Dorward (2017) reported that lower production from fish farming is related to lower input, poor management practices and the fact that it is not usually a priority income source. Shitote *et al*. (2013); Munguti *et al*. (2014) and Gono *et al*. (2015) showed that low fish production is due to the fact that policymakers have accorded low priority to fish farming as an economic activity, that policymakers do not see fish farming as an economic activity.

Several studies have shown that socio-economic factors that affect tilapia production and growth. Gupta and Acosta (2004); Bhujel (2013); Hossain *et al.* (2013); Munguti *et al*. (2014); Mpandeli and Maponya (2014); and Amenyogbe *et al.* (2018) reported that tilapia farmers are challenged with disadvantageous product prices in the local market, high production costs because they lack access to knowledge of low-cost and efficient production technology, lack of start-up capital, and lack access to low-interest loan. Other challenges such as poor market infrastructure, and inadequate support from the government, unfriendly investment policies, insufficient land availability to expand production are also found to lower tilapia production in rural areas (Munguti *et al*., 2014; Mpandeli & Maponya, 2014; Das *et al.*, 2018). Another major challenge is the importation of tilapia (Hara *et al*., 2017). The growing importation of Chinese frozen tilapia into the SADC region at prices that wild and farmed tilapia cannot compete with, constrained the tilapia aquaculture growth in the SADC region. As a result, the development of tilapia aquaculture continues to struggle. Another constraint for aquaculture development in the past has been the poor links among farmers, extensionists, and researchers (Gupta, 2019; Harohau *et al*., 2020). Thus, this study seeks to identify key factors critical for the success of rural tilapia farming in Capricorn and Vhembe districts. Rural tilapia farmers are affected by several factors ranging from biological to socio-economic. This study seeks to evaluate biological, physical, and socio-economic factors that affect tilapia production in Capricorn and Vhembe districts.

CHAPTER 3: THE IMPACT OF PHYSICO-CHEMICAL PARAMETERS ON TILAPIA PRODUCTION IN DIFFERENT PRODUCTION SYSTEMS

3 THE IMPACT OF PHYSICO-CHEMICAL PARAMETERS ON TILAPIA PRODUCTION IN DIFFERENT PRODUCTION SYSTEMS

3.1 INTRODUCTION

Water quality is a major determining factor for optimal production of fish in water bodies (Egna & Boyd, 1997). Water quality in fish farming refers to the chemical, physical and biological condition of the water that enables a successful culture of aquatic organisms (Boyd, 1995). Despite the fact that over 100 countries around the world farm tilapia, most farmers in developing countries lack accurate and critical knowledge about tilapia farming (Machena & Moehl, 2001; El-Sayed, 2006), including farmers in Capricorn and Vhembe districts in Limpopo Province. Maximum fish production in production systems is frequently reduced by limited information on water quality requirements for the farmed fish species (Machena & Moehl, 2001). The major challenge is that tilapia farming has not been successful in Capricorn and Vhembe districts in Limpopo Province, despite the countless effort by the government to boost aquaculture production. Little work has been done on the water quality of farmed fish species in Limpopo Province, thus this study seeks to determine the most important water quality parameters affecting tilapia production in fish ponds, aqua dams and RAS in Capricorn and Vhembe districts. The most important parameters to monitor in production systems to maximize fish production is temperature, dissolved oxygen (DO), turbidity, primary productivity, potassium, pH, alkalinity, phosphorus, unionized ammonia, nitrite, nitrate, chemical and biological oxygen demand, and plankton population (Bhatnagar & Devi, 2013; Omer, 2019).

Water quality is affected by the type of production system used to culture tilapia and is also determined by management practices, such as stocking densities, fertilization strategy and supplemental feeding (Egna & Boyd, 1997; Kunlasak *et al*., 2013). In most parts of the world, the production of tilapia is conducted in earthen ponds (Favaro *et al.*, 2015). Effective tilapia production in ponds can be affected by a lack of resources to aerate ponds or to exchange water for the maintenance of good water quality (Favaro *et al.*, 2015). Tilapia farmers in Capricorn and Vhembe districts produce tilapia in concrete ponds, aqua dams (7 000 L plastic containers), earthen ponds and recirculating aquaculture systems (RAS). Production systems can also affect the size of the fish at harvest, tilapia can reach 500 grams in five months depending on the production systems used (Diana *et al*., 1994).

Water quality in production systems is affected by the type of feed used by fish farmers. Tilapia farmers in Capricorn and Vhembe districts feed with formulated pellets and nonconventional food such as maize bran and sorghum. Feeding with nonconventional food is common among small-scale fish farmers (El-Sayed, 2013). The major challenge with the type of feed used is the deterioration of water quality over time. The end product of the digestion of the protein present in the feed is ammonia which is excreted through the gills and faeces. The amount of ammonia excreted by the fish is dependent on the percentage of protein present in the feed, the amount of feed input into the production system and the rate of feeding (Boyd, 2004; Torres-Beristain *et al*., 2004; Mustapha & Akinshola, 2016). Bacterial decomposition of organic matter such as uneaten feed or dead algae can also deteriorate the water quality in production systems (Durborow, *et al*., 1997; Hargreaves & Tucker, 2004). Moyo and Rapatsa (2021) reviewed the factors affecting tilapia production in Southern Africa and identified water quality as one of the critical factors affecting tilapia production. However, there is very little empirical data on water quality in tilapia production systems. This data is important before any water quality management interventions are implemented. This chapter gives monthly data on water quality parameters in different production systems and evaluates the effect of water quality parameters on tilapia yield in different production systems.

3.2 OBJECTIVE

To identify key water quality parameters affecting tilapia production in aqua dams, earthen ponds, concrete ponds and RAS in Capricorn and Vhembe districts

3.3 NULL HYPOTHESIS

Water quality parameters have no effect on tilapia production in aqua dams, earthen ponds, concrete ponds and RAS in Capricorn and Vhembe districts

3.4 MATERIALS AND METHODS

3.4.1 Description of the study site

This study was conducted in Capricorn and Vhembe districts of Limpopo Province. Limpopo Province (Figure 3.1) is the northern province of South Africa (23.4013°S, 29.4179°E) and it covers a geographical area that is predominantly rural (Wisborg *et al*., 2013). A total of 8 tilapia farms were selected in the study, four in each district (Table 3.1). The study was conducted from June 2019 to March 2020. Pictorial images of some production systems used by tilapia farmers are shown from Figure 3.2 to Figure 3.6.

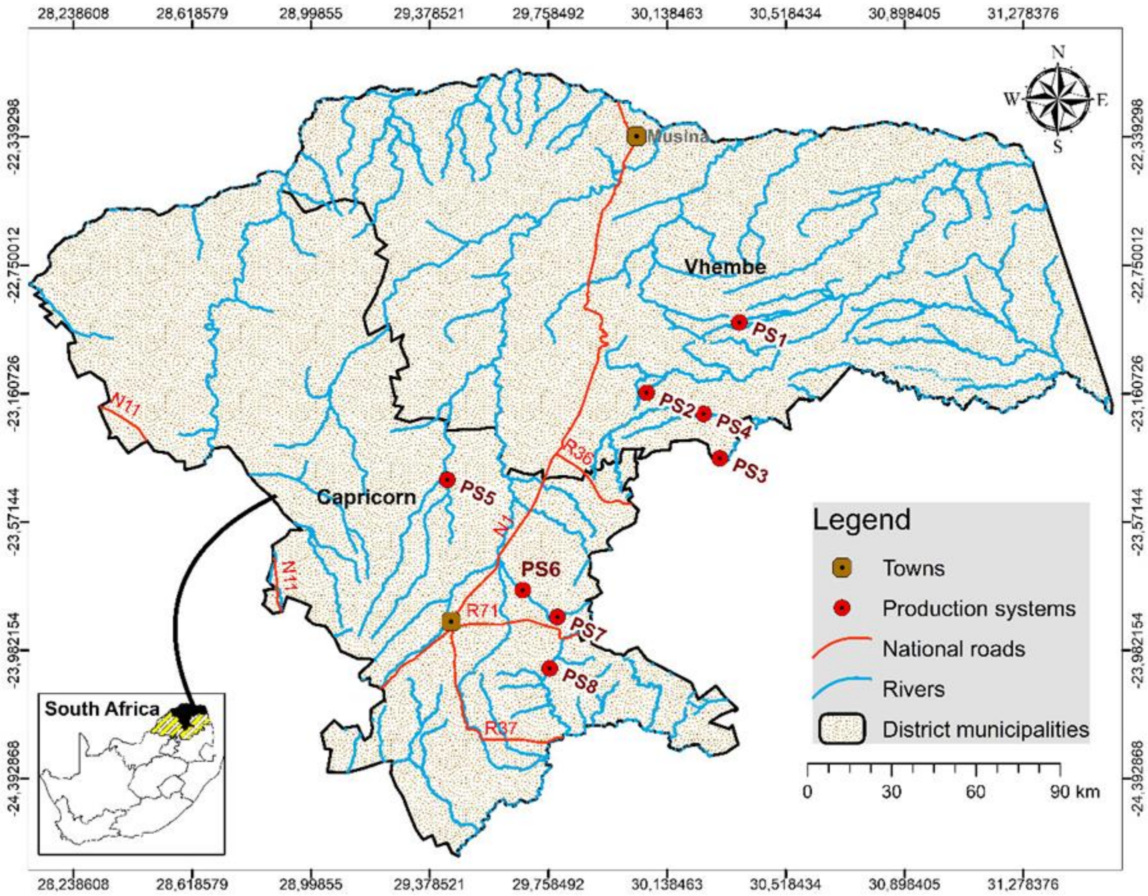


Figure 3. 1:Geographic location of tilapia farmers that participated in Capricorn and Vhembe districts in Limpopo Province

Table 3. 1: Farm’s spatial data

District	Coordinates	Location name	Production system type	Surface Area (m^2)
Capricorn	24°02’57.6”S 29°46’32.3”E	Molepo	Concrete pond	54.977
	23°54'23.5"S 29°53'12.0"E	Veekraal	RAS	40.212
	S23°54.213 E029°48.639	Mahlanhle	Aqua dam	23.562
	S23°52.368 E029°44.545	Mothole	Aqua dam	23.562
Vhembe	22°55’39.9”S 30°22’02.0”E	Vondo	Earthen pond	107.2
	23°09’20.9”S 30°03’30.7”E	Elim	RAS	40.212
	23°19’49.4”S 30°16’45.2”E	Olifanshoek	Concrete pond	45
	23°12’28.2”S 30°13’00.3”E	Bungeni	Aqua dam	23.562

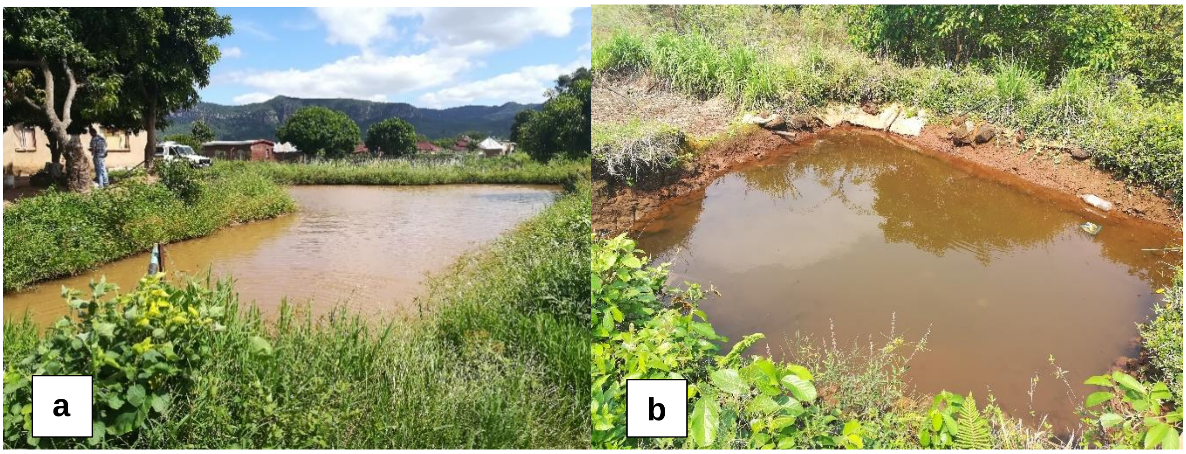


Figure 3. 2: Earthen ponds system used for tilapia farming in Vhembe district

Figure 3. 3: Plastic aqua dams (7000 L) used by tilapia farmers in Capricorn (a) and Vhembe districts (b).

Figure 3. 4: Concrete ponds used for tilapia farming in Capricorn (a) and Vhembe districts (b)

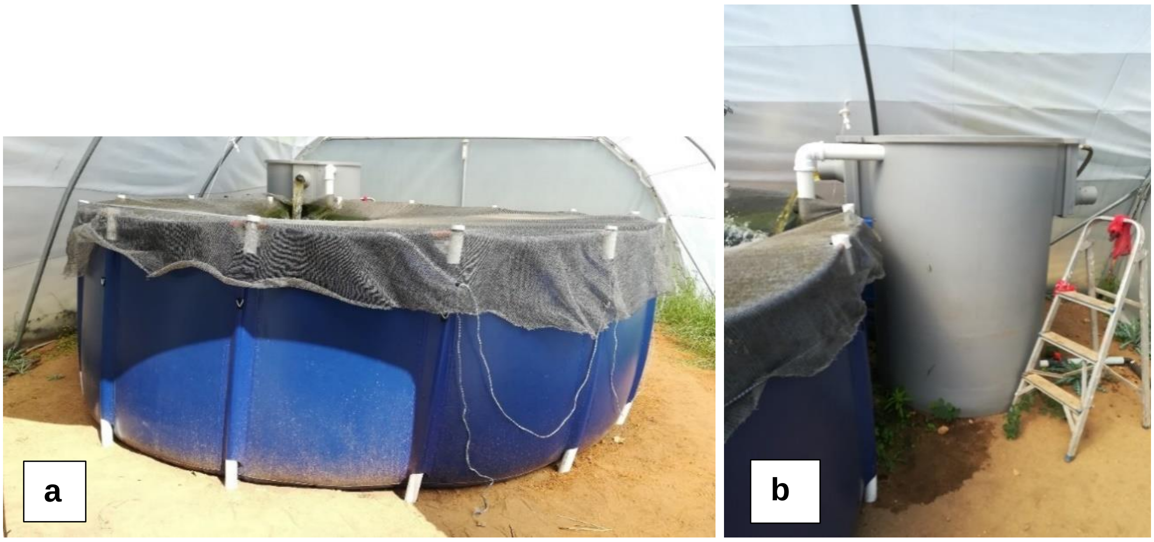


Figure 3. 5: Recirculating Aquaculture System used for tilapia farming in Capricorn district.

Figure 3. 6: Recirculating Aquaculture System for tilapia farming in Vhembe district

3.4.2 Monthly climatic variations in Capricorn and Vhembe districts

Capricorn and Vhembe districts were purposefully chosen for this study because of their geographic locations and their environmental conditions that represent the entire climate of Limpopo Province. Vhembe district is located in the northern part of the Province, and it consists of four local municipalities. Capricorn district is in the central region of the Province, and it also has four local municipalities. Capricorn district is known to have lower ambient temperature throughout the year, while Vhembe district has higher ambient temperature. During the course of the study, Vhembe district had higher minimum and maximum ambient temperature throughout the year compared to

Capricorn district (Figure 3.7). Capricorn district has the lowest minimum average temperature of 6.39 °C in June 2019 and highest maximum average temperature of 29.96 °C in February 2020 (Figure 3.7). In Vhembe district, a minimum average temperature of 11.5 °C was experienced in July 2019 and maximum average temperature of 34.91 °C in November 2019 (Figure 3.7). The annual rainfall amount was higher in Vhembe district, Vhembe district also has higher ambient temperature than Capricorn district (Figure 3.8). The lowest amount of rainfall is received in June 2019 in Vhembe district and the highest amount in January 2020. In Capricorn district, the lowest amount of rain is received in July 2019 and December 2019 received the highest amount of rainfall (Figure 3.8).

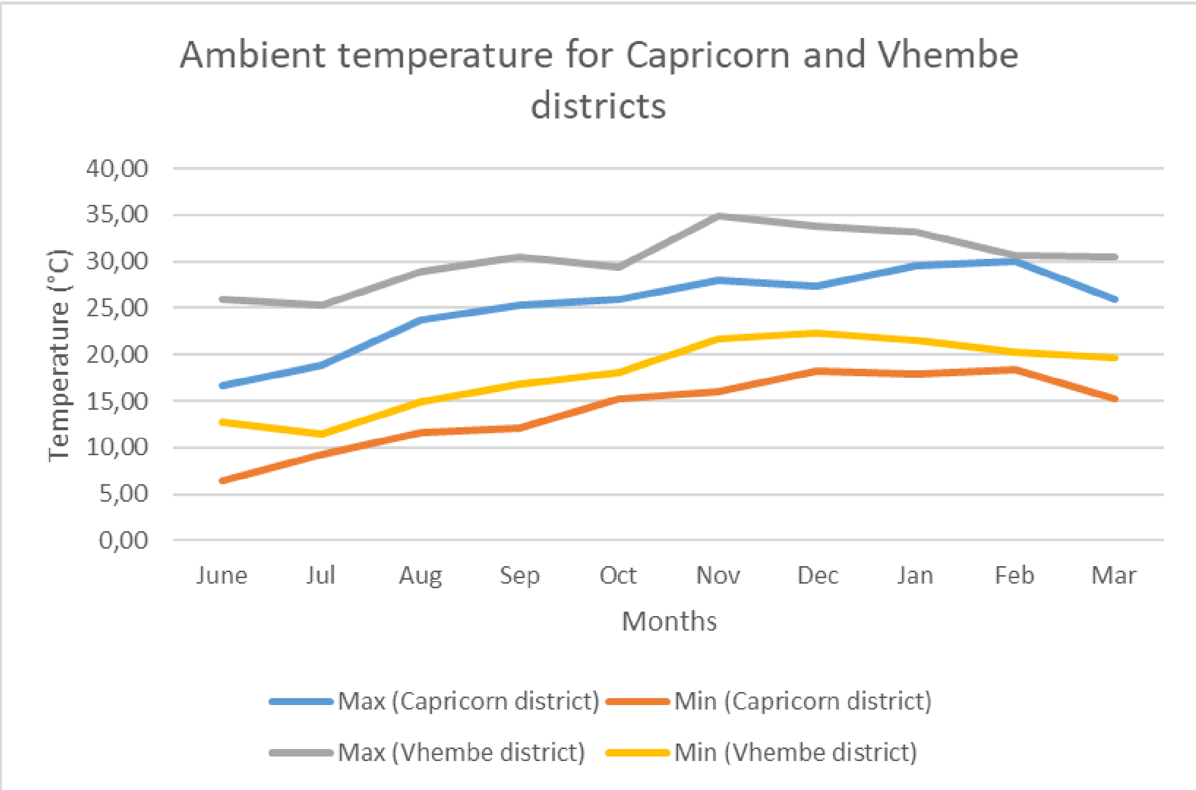


Figure 3. 7 : Average monthly ambient temperature for Capricorn and Vhembe districts from June 2019 to March 2020. Source: Weatherspark, 2020

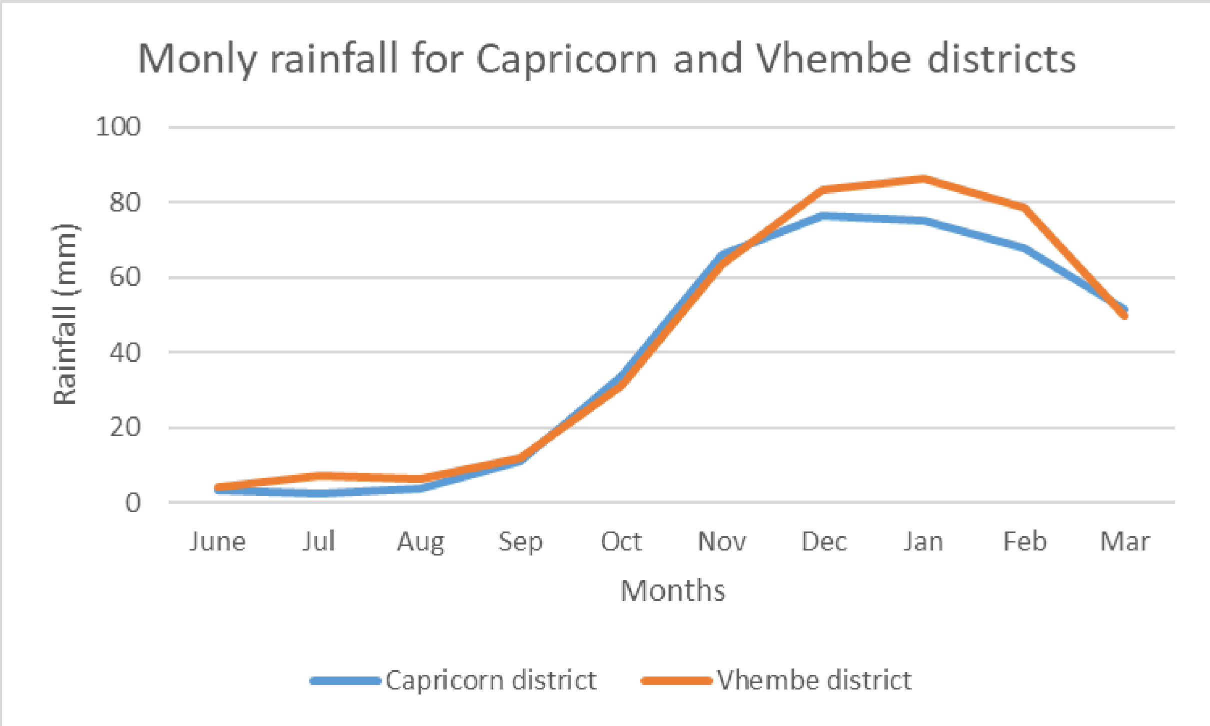


Figure 3. 8: Monthly rainfall for Capricorn and Vhembe districts from June 2019 to March 2020. Source: Weatherspark, 2020

3.4.3 Determination of water quality parameters

Water samples were collected once every two months (June 2019-Feb 2020). Dissolved oxygen (mg/L), pH, and salinity (ppt), electrical conductivity (mS/cm) were measured in situ using YSI multi-probe meter. Turbidity (NTU) was measured using a turbidity meter (Turb 430 IR). Water samples were collected in 1L sample bottles at the surface of the water column for laboratory analysis of alkalinity, potassium, total nitrogen, total phosphorus, and chemical oxygen demand (COD)

Total alkalinity as Bicarbonate (HCO_3^-*) and Carbonate (*CO_3^{2-}*)*

Total alkalinity was determined according to the US Standard Methods 2320 B. This method is based on the principle that hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity thus depends on the end point pH used, 0. 02 N sulfuric acid is titrated to an end point of pH 4.5 using methyl red as an indicator.

Potassium as K

Potassium was determined according to the US Standard Methods 3120 B and EPA method 200.7. The methods involve multi-elemental determinations by inductively coupled plasma ICP-AES using sequential or simultaneous instruments. The instruments measure characteristic atomic-line emission spectra by optical spectrometry.

Total Nitrogen as N

Total nitrogen was determined according to spectroquant nitrogen test 1.14537.0001. In this method, organic and inorganic nitrogen compounds are transformed into nitrate according to Koroleff's method by treatment with an oxidizing agent in a thermoreactor. In concentrated sulfuric acid, this nitrate reacts with a benzoic acid derivative to form a red nitro compound that is determined photometrically.

Ammonia (NH_3) and ammonium (NH_4+)

Ammonia and ammonium were determined according to spectroquant ammonium-test 1.14752.0001/1.14752.0002/1.00683.0001 method. The method is based on the principle that in strongly alkaline solution ammonium nitrogen is almost entirely present as ammonia, which reacts with a chlorinating agent to form monochloramine. This in turn reacts with thymol to form a blue indophenol derivative that was then determined photometrically at 630 nm wavelength. This test measures both ammonium ions and dissolved ammonia. The method is analogous to EPA 350.1, APHA 4500-NH3 F, ISO 7150-1, and DIN 38406-5.

Phosphate as P

Phosphate was determined according to spectroquant 1.14848.0001. In this method, phosphate ions in solution acidified with sulfuric acid, reacts with molybdate ions to form molibdofosforic acid was reduced by ascorbic acid phosphomolybdic blue (PMB) which was determined photometrically. This method is analogous to ISO 6878/1-2005 method and is used to determine orthophosphates and total phosphorus.

Chemical Oxygen Demand (COD)

COD was determined according to spectroquant 1.14848.0001. The water sample was oxidized with a hot sulfuric solution of potassium dichromate, with silver sulfate as the catalyst. Chloride was masked with mercury sulfate. The concentration of green $Cr3^{+}$

ions was then determined photometrically. The method corresponds to DIN ISO 15705 and is analogous to EPA 410.4, APHA 5220 D, and ASTM D1252-06 B.

3.4.4 Determination of tilapia yields in different production system

The following calculation was used to determine the tilapia yield:

- Fish yield (kg m^{-2})= $\frac{total\ fish\ harvest\ (Kg)}{Surface\ area\ (m2)}$

3.4.5 Statistical analysis

Microsoft Excel was used to determine the means and standard deviations on water quality in earthen ponds in Vhembe district. Normality and homogeneity of variance of all water quality parameters was tested using the Shapiro-Wilk normality test. One-way analysis of variance (ANOVA) on the Statistical Package and Service Solutions (SPSS version 20.5) was used to determine any significant difference of water quality parameters in aqua dams, concrete ponds, and RAS production systems in Capricorn and Vhembe districts. Canonical Correspondence Analysis (CCA) (Canoco 4.5) was used to show the effect of water quality parameters on tilapia yield.

3.5 RESULTS

3.5.1 Water quality parameters in different production systems

The temperature in an earthen pond in Vondo in Vhembe district was below the acceptable limits for farming tilapia except in August and October (Table 3.2). Dissolved oxygen (DO) was also below the acceptable limits for farming tilapia except in December and February. Turbidity levels were within the acceptable limits throughout the study period. The pH levels were within the acceptable limits except in February (Table 3.2). The level of alkalinity as bicarbonate was below the acceptable limits for tilapia production except in June. Ammonia, ammonium, and total nitrogen were below detection limits throughout the study period (Table 3.2). Total phosphate was above the acceptable limits except in August.

Table 3. 2: Water quality profile for earthen pond in Vondo in Vhembe district. Mean±sd values of parameters sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb	TWQR
Temperature (°C)	19.33±1.46	25.50±2.96	25.05±2.33	22.85±0.35	22.80±0.00	25-32
Dissolved oxygen (mg/l)	2.96±0.89	1.43±0.03	1.45±0.24	4.03±1.71	4.80±0.65	3-8
pH	7.14±0.07	7.95±0.06	7.71±0.00	7.65±0.01	6.87±0.07	7-9
Salinity (ppt)	0.30±0.00	0.02±0.01	0.02±0.01	0.02±0.01	0.01±0.00	19
EC (ms/sc)	35.38±24.11	0.03±0.03	0.07±0.01	0.04±0.03	0.03±0.01	150-1500
Turbidity (NTU)	8.68±2.71	33.15±35.99	32.80±36.90	17.39±17.69	70.80±48.36	<3000
Alkalinity (Bicarbonate) (mg/l)	25.50±14.84	10.40±3.53	15.00±7.07	10.00±7.07	9.60±3.53	25-100
Alkalinity (Carbonate) (mg/l)	1.00±1.41	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	25-100
Potassium (mg/l)	0.34±0.18	0.52±0.11	0.66±0.03	0.29±0.03	0.84±0.79	1-8
Total Nitrogen (mg/l)	<1.4*	<1.4*	<1.4*	<1.4*	<1.4*	<10
Ammonium as NH_4-N (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.25
Ammonia as NH_3-N (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.30
Total Phosphate (mg/l)	0.78±0.86	<0.05*	0.84±0.79	0.72±0.95	0.74±0.93	0.06-0.2
COD as O_2 (mg/l)	<18*	41.02±57.94	31.63±44.35	9.05±31.78	<18*	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR source: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al.*, 2009; WHO, 2009; Sipaúba-Tavares *et al.*, 2011.

The temperature in Mahlanhle and Mothole in Capricorn district was below the acceptable limits for farming tilapia (Table 3.3). The lowest temperature of 16.00±0.56 °C was recorded in June and the highest in October (23.85±2.47 °C). The levels of DO were within acceptable limits for tilapia production throughout the study period. The pH level was also within the acceptable limits throughout the study period (Table 3.3). Alkalinity as bicarbonate was above acceptable limits for farming tilapia in October, December, and February. It was below the acceptable limits in June and was within the optimum level in August. Turbidity levels were within the acceptable limits. Ammonia and ammonium levels were below the detection limits (Table 3.3). Salinity levels were within the acceptable levels throughout the study period. Total phosphate levels were above the acceptable limits except in June and December. Electrical conductivity (EC) was within acceptable limits for farming tilapia (Table 3.3).

Table 3. 3: Mean±sd of water quality parameters in aqua dams in Mahlanhle and Mothole in Capricorn district against TWQR of tilapia, sampled from June 2019 to February 2020.

	June	**Aug**	**Oct**	**Dec**	**Feb**	**TWQR**
Temperature (°C)	16.00±0.56	17.25±3.11	23.85±2.47	23.75±0.07	19.43±3.85	25-32
DO (mg/l)	5.29±0.67	2.25±0.85	7.20±2.17	7.42±0.98	8.41±1.53	3-8
pH	7.95±0.14	7.78±0.18	6.97±0.04	7.84±0.00	7.35±0.19	7-9
Salinity (ppt)	0.09±0.04	0.08±0.04	0.10±0.08	0.07±0.04	0.08±0.05	19
EC (ms/sc)	0.17±0.07	152.28±107.16	0.21±0.16	153.18±79.58	0.15±0.08	150-1500
Turbidity (NTU)	5.33±0.63	26.70±18.95	39.75±1.20	26.30±3.39	34.70±24.183	<3000
Alkalinity (Bicarbonate) (mg/l)	19.40±13.85	29.20±24.74	79.40±63.92	3750±27.71	79.80±80.46	25-100
Alkalinity (Carbonate) (mg/l)	44.55±30.05	22.90±11.17	4.15±5.86	20.80±10.60	17.10±11.17	25-100
Potassium (mg/l)	3.26±1.25	2.14±0.12	3.79±.46	2.30±0.28	2.04±1.07	1-8
Total Nitrogen (mg/l)	1.60±0.14	2.90±0.28	3.25±1.20	<1.4 *	2.45±1.06	<10
Ammonium (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.25
Ammonia (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.30
Total Phosphate(mg/l)	0.20±0.21	0.66±0.16	0.31±0.07	0.11±0.02	0.76±0.86	0.06-0.2
COD (mg/l)	198.25±122.32	98.00±48.08	183.00±28.28	181.50±144.95	330.50±420.72	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR source: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al*., 2009; WHO, 2009; Sipaúba-Tavares *et al*., 2011.

Water quality parameters in the concrete pond in Molepo in Capricorn district showed that temperature was below the acceptable limits for farming tilapia throughout the study period (Table 3.4). Dissolved oxygen (DO) was within the acceptable limits, it ranged from 4.04±0.96 to 13.66±0.09 mg/l. Turbidity was also within the acceptable limits for farming tilapia throughout the study period (Table 3.4). The levels of alkalinity were above the acceptable limits. Ammonia and ammonium were below detection limits except in August and October. The pH levels were within acceptable limits. Total phosphate levels were above the acceptable limits. The level EC was above the optimum level for farming tilapia except in June and August (Table 3.4).

Table 3. 4: Mean±sd of water quality parameters in concrete pond in Molepo in Capricorn district against TWQR of tilapia, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb	TWQR
Temperature (°C)	15.98±2.29	20.30±4.24	24.20±1.62	24.95±0.84	21.83±1.59	25-32
DO (mg/l)	4.38±0.67	4.04±0.96	10.28±0.36	13.66±0.09	9.65±2.17	3-8
pH	8.24±0.26	7.82±0.06	7.05±0.08	7.73±0.28	7.36±0.49	7-9
Salinity (ppt)	1.00±0.25	1.14±0.65	1.13±0.66	1.57±1.42	1.16±.82	19
EC (ms/sc)	1.74±0.63	679.47±956.75	2195.25±1240.61	2976.75±2610.28	1571.02±571.36	150-1500
Turbidity (NTU)	39.71±49.34	26.55±27.37	46.39±54.46	13.20±768.48	36.90±11.74	<3000
Alkalinity (Bicarbonate) (mg/l)	404.00±77.49	466.45±15.62	431.65±1.20	328.15±65.69	387.73±68.05	25-100
Alkalinity (Carbonate) (mg/l)	171.70±42.42	250.40±354.11	222.10±314.09	487.10±529.76	283.55±309.07	25-100
Potassium (mg/l)	24.77±24.88	31.55±39.18	201.50±278.31	57.86±75.29	78.13±105.53	1-8
Total Nitrogen (mg/l)	5.3±0.42	10.15±5.16	11.95±2.05	6.95±2.05	8.35±1.06	<10
Ammonium (mg/l)	<0.20*	0.4	0.5	<0.20*	<0.20*	<0.25
Ammonia (mg/l)	<0.20*	0.4	0.4	<0.20*	<0.20*	<0.30
Total Phosphate (mg/l)	0.49±0.00	0.54±0.34	0.50±0.57	0.34±0.24	0.65±0.42	0.06-0.2
COD (mg/l)	132.25±149.55	147.00±182.43	263.50±342.94	378.50±474.46	261.34±335.64	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR source: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al*., 2009; WHO, 2009; Sipaúba-Tavares *et al*., 2011.

The mean levels of water quality parameters in Veekraal in the RAS system in Capricorn district showed the temperature was below the acceptable limits for farming tilapia except in December (Table 3.5). The level of DO was within acceptable limits except in August. The pH levels were within the acceptable limits throughout the study period. Alkalinity as bicarbonate was below the acceptable limits except in June (Table 3.5). It was below the detection limits in June. The levels of turbidity were within acceptable limits. Ammonia and ammonium levels were below the detection limits throughout the study period except in June (Table 3.5). Total phosphate levels were above the acceptable limits.

Table 3. 5: Mean±sd of water quality parameters in Veekraal in RAS system in Capricorn district against TWQR of tilapia, sampled from June 2019 to February 2020.

	June	**Aug**	**Oct**	**Dec**	**Feb**	**TWQR**
Temperature (°C)	19.01±0.02	16.90±0.07	24.90±0.63	25.65±0.14	21.45±0.70	25-32
DO (mg/l)	5.43±0.70	2.55±0.69	8.01±0.70	5.36±0.24	6.57±0.38	3-8
pH	7.90±0.02	7.87±0.21	7.12±0.06	7.66±0.23	7.38±0.31	7-9
Salinity (ppt)	0.14±0.06	0.06±0.00	0.07±0.00	0.09±0.00	0.06±0.00	19
EC (ms/sc)	0.28±0.00	122.90±86.26	141.80±0.56	185.30±0.19	0.12±0.06	150-1500
Turbidity (NTU)	88.10±0.70	13.30±0.21	33.70±0.21	43.50±0.34	54.50±0.66	<3000
Alkalinity (Bicarbonate) (mg/l)	<0.5	17.90±0.07	22.10±0.04	13.80±0.09	22.90±0.01	25-100
Alkalinity (Carbonate) (mg/l)	0.00±0.00	19.20±0.12	11.70±0.41	0.00±0.00	5.00±0.24	25-100
Potassium (mg/l)	7.70±0.18	2.59±0.04	4.44±0.03	7.02±0.04	3.73±0.06	1-8
Total Nitrogen (mg/l)	24.6±0.04	7.1±0.06	12.00±0.28	18.00±0.06	8.9±0.02	<10
Ammonium (mg/l)	3.3	<0.20*	<0.20*	<0.20*	<0.20*	<0.25
Ammonia (mg/l)	3.6	<0.20*	<0.20*	<0.20*	<0.20*	<0.30
Total Phosphate (mg/l)	1.92±0.02	1.44±0.28	0.48±0.02	0.56±0.03	0.31±0.00	0.06-0.2
COD (mg/l)	333.25±0.19	103.00±0.54	448.00±0.70	483.00±0.65	299.00±1.41	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR sources: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al*., 2009; WHO, 2009; Sipaúba-Tavares *et al*., 2011.

Water quality parameters in the aqua dam in Bungeni in Vhembe district showed that temperature was below the optimum level for farming tilapia except in December (Table 3.6). The levels of DO were below the acceptable limits except in February. The levels of pH were within the acceptable limits for farming tilapia throughout the study period (Table 3.6). Turbidity was within acceptable limits. Ammonia and ammonium levels were below the detection limits throughout the study period (Table 3.6). Alkalinity as bicarbonate was above acceptable limits for farming tilapia except in February. Total phosphate levels were above the acceptable limits except in August.

Table 3. 6: Mean±sd of water quality parameters in aqua dam in Bungeni in Vhembe district, against TWQR of tilapia, sampled from June 2019 to February 2020.

	June	**Aug**	**Oct**	**Dec**	**Feb**	**TWQR**
Temperature (°C)	18.05±0.07	20.73±0.04	21.27±0.31	27.63±0.04	24.73±0.04	25-32
DO (mg/l)	1.00±0.01	0.80±0.24	1.94±0.04	2.51±0.43	10.54±0.54	3-8
pH	7.64±0.05	7.94±0.04	7.91±0.01	7.45±0.04	7.43±0.01	7-9
Salinity (ppt)	0.80±0.01	0.46±0.03	0.57±0.00	0.47±0.00	0.15±0.02	19
EC (ms/sc)	834.49±0.70	0.94±0.04	1.09±0.02	943.04±0.06	289.34±0.05	150-1500
Turbidity (NTU)	71.90±0.00	44.10±0.00	60.73±0.04	343.50±0.70	7.37±0.43	<3000
Alkalinity (Bicarbonate) (mg/l)	286.44±0.62	414.38±0.31	491.35±0.48	375.04±0.06	40.58±0.25	25-100
Alkalinity (Carbonate) (mg/l)	44.49±0.69	0.00±0.00	0.01±0.02	0.00±0.00	69.10±0.14	25-100
Potassium (mg/l)	14.14±0.00	18.51±0.01	26.60±0.00	11.64±0.00	3.52±0.01	1-8
Total Nitrogen (mg/l)	4.69±0.13	10.27±0.32	10.45±0.48	10.58±0.25	4.14±0.0	<10
Ammonium (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.25
Ammonia (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.30
Total Phosphate (mg/l)	0.28±0.03	0.07	0.54±0.06	1.79±0.12	0.27±0.02	0.06-0.2
COD (mg/l)	421.00±0.53	671.00±0.14	788.00±0.24	905.00±0.00	<18*	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR sources: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al*., 2009; WHO, 2009; Sipaúba-Tavares *et al*., 2011.

Water quality parameters in the concrete pond in Olifanshoek in Vhembe district showed that temperature was below the acceptable limits except in December (Table 3.7). Dissolved oxygen levels were within the acceptable limits except in October. Turbidity was within the acceptable limits for farming tilapia. Alkalinity as bicarbonate was above the acceptable limits for farming tilapia except August (Table 3.7). Ammonia and ammonium levels were below the detection limits throughout the study period. The levels of pH were within acceptable limits. Total phosphate levels were above the acceptable limits except in June and August (Table 3.7).

Table 3. 7: Mean±sd of water quality parameters in concrete pond in Olifanshoek in Vhembe district, against TWQR of tilapia, sampled from June 2019 to February 2020.

	June	**Aug**	**Oct**	**Dec**	**Feb**	**TWQR**
Temperature (°C)	15.45±0.48	23.24±0.06	21.44±0.06	27.45±0.21	23.55±0.35	25-32
DO (mg/l)	4.47±0.24	3.18±0.07	2.20±0.21	11.33±0.42	6.18±0.04	3-8
pH	7.57±0.02	7.90±0.00	7.94±0.02	7.25±0.05	7.09±0.02	7-9
Salinity (ppt)	0.92±0.00	0.65±0.04	0.38±0.00	0.34±0.00	0.21±0.00	19
EC (ms/sc)	702.01±0.01	0.64±0.06	0.75±0.04	704.04±0.06	439.14±0.06	150-1500
Turbidity (NTU)	28.44±0.06	43.50±0.00	52.71±0.01	51.06±0.09	73.07±0.10	<3000
Alkalinity (Bicarbonate) (mg/l)	232.39±0.55	86.34±0.06	145.20±0.27	236.56±0.37	139.24±0.06	25-100
Alkalinity (Carbonate) (mg/l)	88.04±0.07	266.40±0.41	238.37±0.09	80.39±0.55	37.26±0.33	25-100
Potassium (mg/l)	14.88±0.15	17.51±0.56	20.61±0.26	15.46±0.48	12.48±0.38	1-8
Total Nitrogen(mg/l)	3.31±.02121	6.90±0.00	10.52±0.03	6.05±0.07	5.85±0.06	<10
Ammonium (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.25
Ammonia (mg/l)	<0.20*	<0.20*	<0.20*	<0.20*	<0.20*	<0.30
Total Phosphate(mg/l)	0.16±0.03	<0.05*	0.71±0.14	0.28±0.07	0.22±0.12	0.06-0.2
COD (mg/l)	192.43±0.61	262.06±0.08	263.11±0.16	264.43±0.61	265.05±0.07	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR sources: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al*., 2009; WHO, 2009; Sipaúba-Tavares *et al*., 2011.

Water quality parameters in Elim in the RAS system in Vhembe district showed that temperature was below the acceptable limits except in December and February (Table 3.8). Dissolved oxygen was also within acceptable limits except in December and February. The levels of pH were within the acceptable limits throughout the study period. Turbidity was within the acceptable limits for farming tilapia. Alkalinity as bicarbonate was above the acceptable limits (Table 3.8). Ammonia and ammonium were below detection limits. Total phosphate levels were above the acceptable limits except in October.

Table 3. 8: Mean±sd of water quality parameters in Elim in RAS system in Vhembe district, against TWQR of tilapia, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb	TWQR
Temperature (°C)	19.03±0.04	23.11±0.127	23.30±0.00	30.14±0.06	26.42±0.02	25-32
DO (mg/l)	1.84±0.08	0.83±0.35	1.92±0.04	3.25±0.05	3.17±0.10	3-8
pH	7.31±0.02	8.00±0.02	7.85±0.02	7.54±0.04	7.02±0.00	7-9
Salinity (ppt)	0.77±0.00	0.36±0.02	0.35±0.02	0.34±0.02	0.31±0.00	19
EC (ms/sc)	681.50±0.70	44.27±61.55	273.67±386.10	0.82±0.07	671.44±0.62	150-1500
Turbidity (NTU)	2.54±0.04	29.04±0.05	4.25±0.0	4.52±0.04	4.08±0.03	<3000
Alkalinity (Bicarbonate) (mg/l)	198.05±0.07	242.50±0.57	248.54±0.33	209.47±0.39	217.90±0.60	25-100
Alkalinity (Carbonate) (mg/l)	0.00±0.00	0.00±0.00	0.01±0.01	0.50±0.70	0.01±0.01	25-100
Potassium (mg/l)	11.44±0.05	13.26±0.37	8.40±0.35	8.27±0.02	7.57±0.23	1-8
Total Nitrogen (mg/l)	8.24±0.06	14.49±0.57	5.31±0.41	7.24±0.06	3.41±0.55	<10
Ammonium (mg/l)	<0.20*	<0.20*	<0.20*	27.0	<0.20*	<0.25
Ammonia (mg/l)	<0.20*	<0.20*	37.0	<0.20*	<0.20*	<0.30
Total Phosphate (mg/l)	2.30±0.19	1.31±0.02	0.69±0.12	2.51±0.21	1.41±0.48	0.06-0.2
COD (mg/l)	112.05±0.07	205.33±0.47	108.44±0.62	<18	19.06±0.09	<10

* no mean and SD since the data values were below the detection limits, TWQR = Target water quality range. TWQR sources: Boyd & Tucker, 1998; Ardjosoediro & Ramnarine, 2002; El-Sayed, 2006; Francis-Floyd *et al*., 2009; WHO, 2009; Sipaúba-Tavares *et al*., 2011.

3.5.2 Tilapia yields in different production system

Tilapia yield ranged from 0.001194 to 0.5717 kg/m^2 in the different production systems in Capricorn and Vhembe districts (Table 3.9). Five farmers used borehole water and two farmers used natural spring water, only one farmer used municipal water. Six farmers fed with pellets and two farmers fed with maize bran and sorghum (Table 3.9).

Table 3. 9: Tilapia yields of farmers in Capricorn and Vhembe districts.

	Location name	**Systems**	**Water source**	**Feed type**	**Total harvested weight (kg)**	**Total harvested number of fish**	**Fish yield (kgm^{-2})**
Capricorn	Molepo	Concrete pond	Borehole water	Pellets	1.72	492	0.0312
	Veekraal	RAS	Natural spring	Pellets	21.92	373	0.5451
	Mahlanhle	Aqua dam	Borehole water	Pellets	13.47	354	0.5717
	Mothole	Aqua dam	Municipal tab water	Maize bran	2.25	234	0.0954
Vhembe	Vondo	Earthen pond	Natural spring	Maize bran and sorghum	0.12	122	0.001194
	Elim	RAS	Borehole water	Pellets	7.53	301	0.1872
	Olifanshoek	Concrete pond	Borehole water	pellets and sorghum	8.15	215	0.1811
	Bungeni	Aqua dam	Borehole water	pellets	7.34	978	0.3115

Tilapia farmers in Capricorn and Vhembe districts feed with fish pellets and nonconventional food such as sorghum and maize meal (Table 3.10). Maize meal is usually fed to the fish directly or in the form of stiff pap, left-over from the household; and Sorghum is fed directly to the fish.

Table 3. 10: Nutritional value of nonconventional feed and formulated pellets that farmers use to feed tilapia in Capricorn and Vhembe districts.

	Nutritional value per 100 g		
	Maize	Sorghum	Pellets
Energy (kcal)	86	339.0	15%
Protein (g)	3.27	11.3	30%
Fat/lipid (g)	1.35	3.3	15%
Carbohydrates (g)	18.7	74.6	40%
Fibre (g)	2	2.7	8%
Iron (mg)	0.52	4.4	6
Magnesium (mg)	37	0.19	1.2
Phosphorus (mg)	89	287	900
Potassium (mg)	270	350	210- 330
Zinc (mg)	0.46	1.54	3
Vitamin C (mg)	6.8	2	5

Source: El-Sayed, 2006; Weatherspark, 2020

3.5.3 Effect of water quality parameters on the yield of tilapia in different production systems

The first two Axes CCA ordination explained 96.0 % of the variation in water quality parameters in Capricorn district (Table 3.11). Axis 1 explained 73.1 % of the variation in the species-environment biplot. Axis 1 had a strong positive loading for alkalinity as bicarbonate and carbonate, salinity, electrical conductivity (EC), and DO (Table 3.12). The second axis explained 22.9 % of the variation in the species-environment biplot (Table 3.11). It had a strong positive loading for potassium and turbidity (Table 3.12). Negative loadings of factors associated with axis one and axis two suggest that there was an inverse correlation between the axis and the variables and that the direction of the variables was going on a single dimension vector.

Table 3. 11: Eigenvalues of the correlation matrix water quality parameters relation in Capricorn district

Total Variance		
Axes	1	2
Eigenvalues	0.029	0.009
Species-environment correlation	1.00	1.00
Cumulative percentage variance	73.1	96.0

Table 3. 12: The correlation matrix of water quality parameters in Capricorn district.

Correlation Matrix		
	Axes	
	1	2
Temperature	-0.4884	0.5346
DO	0.9575	0.0378
pH	-0.7741	0.2936
Salinity	0.9705	0.2366
Electrical Conductivity	0.9575	0.2688
Turbidity	-0.5765	0.8035
Alkalinity (Bicarbonate)	0.9876	0.1555
Alkalinity (Carbonate)	0.9900	-0.0461
Potassium	0.2716	0.9624
Total Phosphate	-0.7525	0.5151
COD	0.6381	-0.5209
Total Nitrogen	-0.7805	0.1903

Three groups/clusters can be identified from the CCA biplot in Capricorn district (Figure 3.9). The first cluster grouped salinity, EC, DO, bicarbonate, and carbonate together with a concrete pond that had a tilapia yield of 0.0312 kgm^{-2} (Figure 3.9). These parameters were associated with a concrete pond in Capricorn district. The second cluster grouped potassium and total nitrogen together (Figure 3.9). Potassium and total nitrogen were not associated with any production systems. The third cluster grouped turbidity, temperature, total phosphate, pH, and COD together with a RAS system that has a tilapia yield of 0,5451 kgm^{-2} (Figure 3.9). Turbidity and temperature were associated with RAS system. Aqua dams in Mothole tilapia yield of (0.0954 kgm^{-}

^{2}) and in Mahlanhle (0.5717 kgm^{-2}) were not associated with any of the water quality parameters.

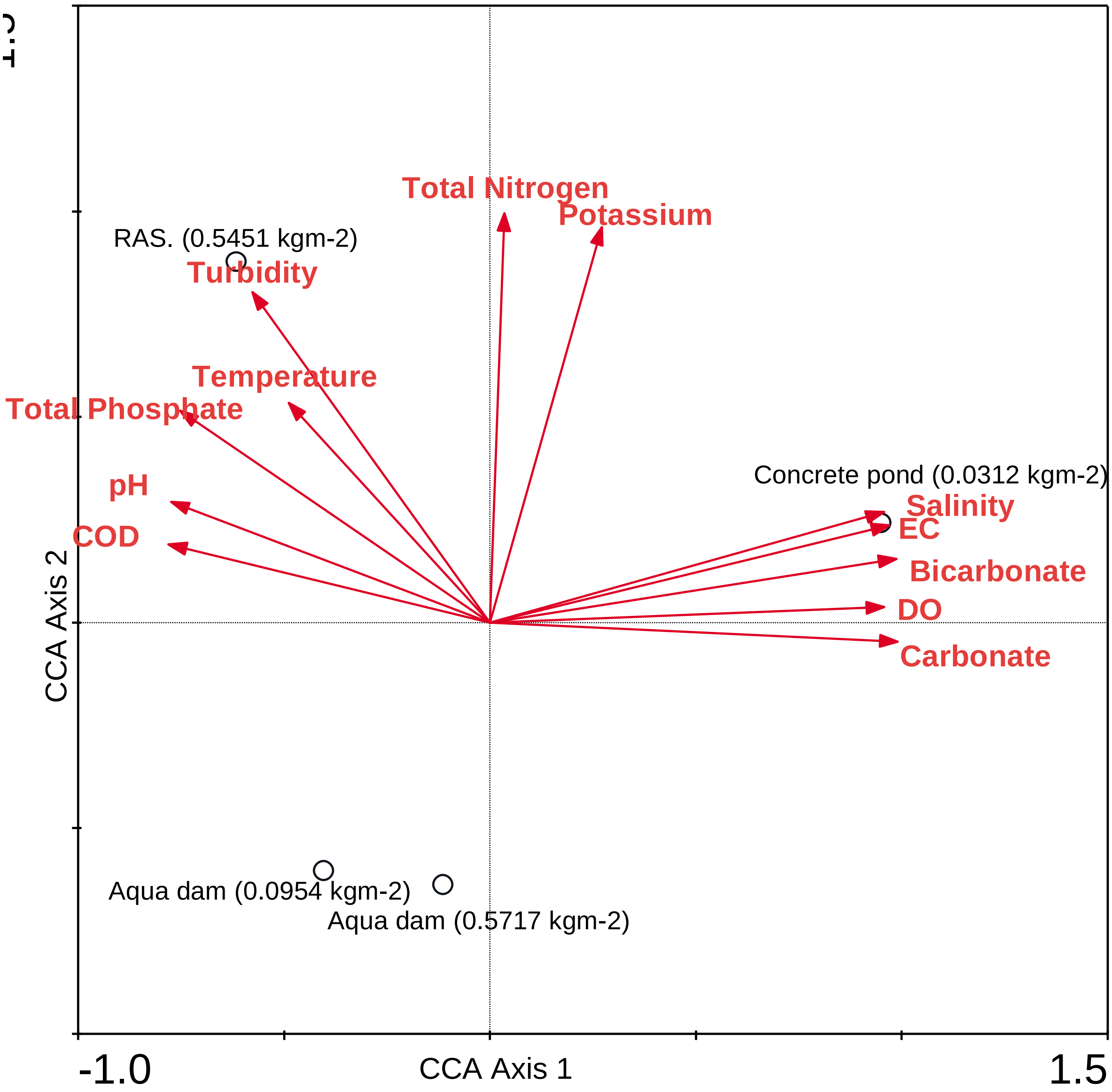


Figure 3. 9: CCA plot of the relationship between tilapia yields and water quality parameters in Capricorn district.

Axis 1 and 2 of the ordination explained 98.0 % of the variation in water quality parameters in Vhembe district (Table 3.13). Axis 1 explained 65.7 % of the variation in the biplot. The first axis had a strong negative loading for salinity, potassium, EC, and total nitrogen (Table 3.14). Axis 2 explained 32. 3 % of the variation in the biplot (Table 3.13). Axis two had a strong positive loading for total phosphate, temperature, and DO (Table 3.14). Negative loadings of factors associated with axis one and axis two suggest that there was an inverse correlation between the axis and the variables and that the direction of the variables was going on a single dimension vector.

Table 3. 13: Eigenvalues of the correlation matrix of water quality parameters relation in Vhembe district

Total Variance		
Axes	1	2
Eigenvalues	0.087	0.043
Site-environment correlation	1.00	1.00
Cumulative percentage variance	65.7	98.0

Table 3. 14: The correlation matrix of water quality parameters in Vhembe district

Correlation Matrix		
	Axes	
	1	2
Temperature	-0.0987	0.9939
DO	-0.5205	-0.7296
pH	-0.5098	0.6705
Salinity	-0.9871	0.1549
Electrical Conductivity	-0.9680	-0.0139
Turbidity	-0.5333	-0.3409
Alkalinity (Bicarbonate)	-0.6918	0.3824
Alkalinity (Carbonate)	-0.5353	-0.6536
Potassium	-0.9805	-0.1923
Total Phosphate	-0.0618	0.9970
COD	-0.5483	-0.1395
Total Nitrogen	-0.8484	0.5007

Temperature and total phosphate were associated with a RAS system that has a tilapia yield of 0.1872 kgm^{-2} (Figure 3.10). Turbidity, carbonate and DO were associated with a concrete pond (0.1811 kgm^{-2}) in Olifanshoek. Potassium, COD, and EC were associated with an aqua dam (0.3115 kgm^{-2}) in Bungeni. Earthen pond (0.001194 kgm^{-2}) in Vondo was not associated with any of the water quality parameters.

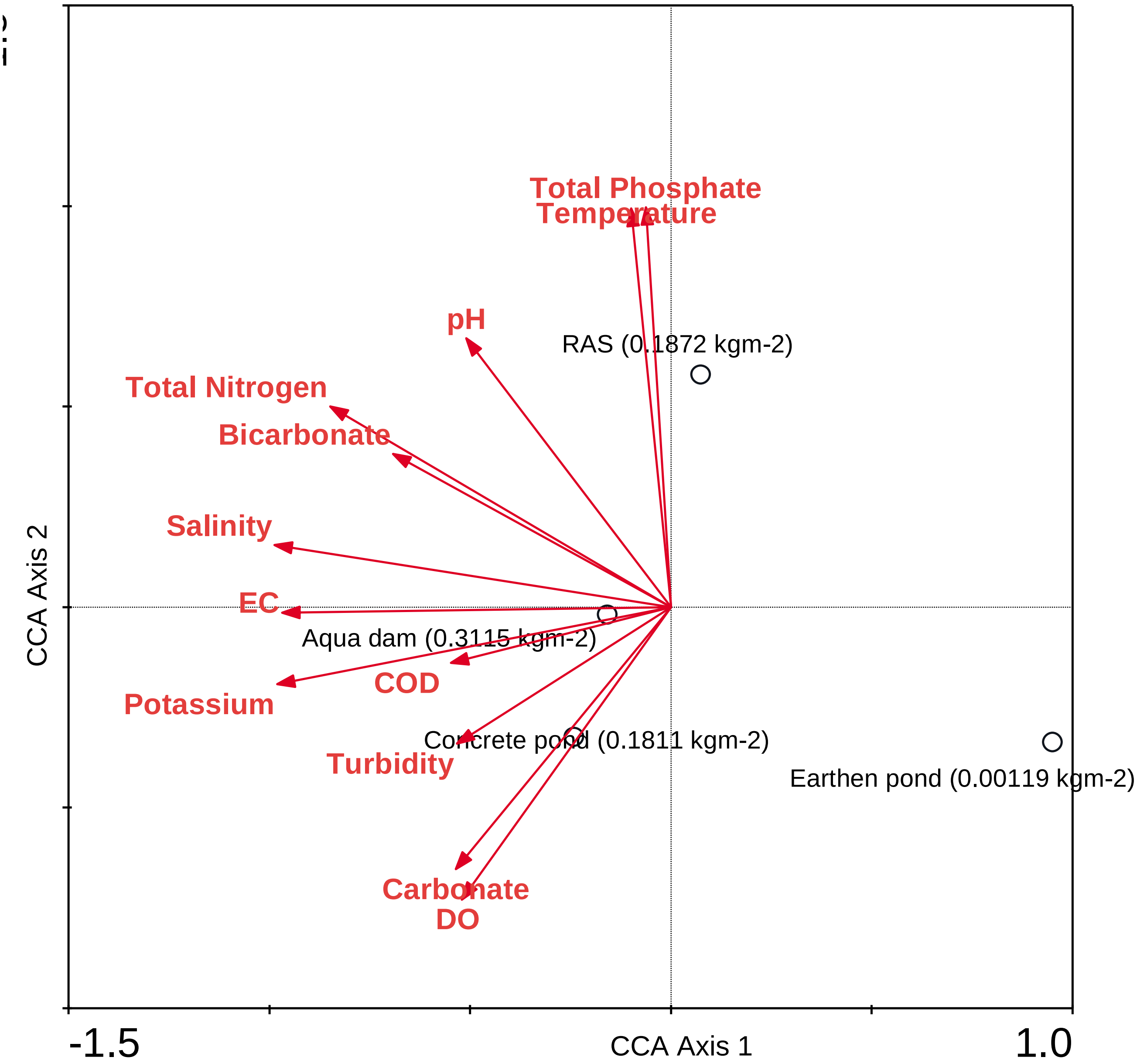


Figure 3. 10: CCA plot of the relationship between tilapia yields and water quality parameters in Vhembe district

3.6 DISCUSSION

Poor water quality affects fish growth and reproduction, it increases fish susceptibility to diseases and can even cause mortality leading to low production, profit, and product quality (Bryan *et al*., 2011; Shoko *et al*., 2014). Therefore, fish farmers are obligated to keep the physical, chemical, and biological parameters optimal to achieve optimal fish growth (Isyiagi *et al*., 2009). Successful management of fish production systems requires an understanding of water quality parameters such as temperature, dissolved oxygen (DO), pH, salinity, electrical conductivity, turbidity, alkalinity, potassium, total nitrogen, chemical biological demand (COD), and total phosphate (Bhatnagar & Devi, 2013). In this study, water quality parameters were analysed in eight production systems because there were few farmers willing to participate.

Water temperature has a profound effect on the growth and survival of fish. The most preferred temperature range for optimal growth of tilapia is between 25 and 32 °C (Boyd, 1998; Halley & Semoli, 2010; Sipaúba-Tavares *et al.*, 2011). The temperature was below the optimum level in aqua dam and concrete pond in Capricorn district, and in the RAS system it was optimum only in the month of December. The temperature in Vhembe district showed that temperature was also below acceptable limits in all the production systems except in December and also in February in the RAS system. The temperature was also within the acceptable limits in August and October in the earthen pond. This is because there are few places in South Africa with suitable temperatures to enable optimum tilapia growth for the whole year (Moyo & Rapatsa, 2021). Even though the temperature was below the acceptable limits, RAS systems in both districts had high water temperature throughout the study period compared to other production systems. This is explained by the fact that RAS systems have a greenhouse structure that helps to maintain the temperature throughout the year. Another major cause of temperature fluctuation in RAS systems in Capricorn and Vhembe district is the poor design of the systems, water heaters were not installed to keep the water temperature stable throughout the farming seasons. Vhembe district had a higher ambient temperature than Capricorn district, as a result all the production systems in Vhembe district had higher water temperature than those in Capricorn district. CCA also shows that temperature had a strong positive loading and was associated with the RAS system in Vhembe district. This means that temperature was an important parameter affecting the farming of tilapia in the RAS system. In Capricorn district, the temperature had a moderate loading, and it was associated with RAS system. RAS system in Vhembe district had higher temperature reading but had lower tilapia yield, while the RAS system in Capricorn had a lower temperature and higher tilapia yield. This is explained by the temperature that was below acceptable limits in most of the months. It can also be explained by the fact that the farmer in Capricorn district was farming same-sex tilapia while in Vhembe district there was mixed-sex tilapia, both farmers were feeding pellets in their RAS system. Mixed-sex tilapia culture in production systems always results in early maturity that leads to uncontrolled reproduction causing overcrowding, stunted growth (Omitoyin *et al*., 2013) and low tilapia yield at harvest (Dagne *et al*., 2013). Same-sex tilapia culture prevents overpopulation, competition for feed and space, thus resulting in increased growth rate and yield at harvest (Celik *et al*., 2011; Budd *et al*., 2015). Fish growth is generally greater in production systems with optimal levels of temperature and dissolved oxygen.

Dissolved oxygen is a critical water quality parameter in freshwater aquaculture production systems. Recommended DO level for optimum growth of tilapia is above 3 mg/L (Ross, 2000; Riche & Garling, 2003; Sipaúba-Tavares *et al*., 2011). The monthly data in Capricorn district showed that DO levels, in all production systems, were within the acceptable limits for optimal tilapia growth except in August. It was below the acceptable limits in the aqua dam and concrete pond in August. CCA also shows that DO had a strong positive loading and was associated with concrete ponds in both districts. This mean DO was an important parameter affecting the farming of tilapia in concrete ponds. The level of DO is explained by the lower temperature observed in the production system in Capricorn district since the demand for DO is correlated to temperature. In Vhembe district, levels of DO were below the acceptable limits except in December and February in the earthen pond, aqua dam, and RAS system. In the concrete pond, it was within the acceptable limits except in October and the overall DO levels were higher than other production systems in Vhembe district. When the temperature is high, the oxygen demand increases due to increased metabolic reactions of the fish (Poxton, 2003). Lower DO levels can also be explained by the lack of mechanical aeration in the production systems. Stagnant water in the aqua dam and concrete pond also contributed to low DO in the production system.

To maximize tilapia growth in a pond, other parameters such as pH, ammonia, total nitrogen, and salinity also need to be optimum. Ideal pH ranges between 7 and 9 is optimum for tilapia growth (Ross, 2000; Crane, 2006; Makori *et al*., 2017). In the current study, the recorded pH levels were within the optimal range in all the production systems throughout the study period except in February in the earthen pond. This indicates a well-buffered condition in the production systems in Capricorn and Vhembe districts. The buffering condition of water in all the production systems can be explained by the high levels of alkalinity throughout the study period. The earthen pond was the only production system with alkalinity levels that were below the acceptable limits except in June. Alkalinity is related to the presence of calcium carbonate in the water (Cavalcante *et al*., 2014), and the quantity of alkalinity is pH dependent. Bicarbonate is dominant in surface waters at pH 6 to 9, while carbon dioxide and carbonate ion play increasingly important roles below pH 6 and above pH 9, respectively. The alkalinity levels in all the production systems in Capricorn and Vhembe districts were fluctuating and mostly above acceptable limits in monthly data. Recommended limits for water used for aquaculture to avoid pH variations is 25–100 mg/l CaCO3 (Boyd, 1990; Wurts & Durborow, 1992; Boyd *et al*., 2016). Low tilapia yields can also be explained by high levels of alkalinity since water with high alkalinity can impair fish growth (Boyd & Lichtkoppler, 1979; Boyd & Tucker, 1998). CCA showed that bicarbonate and carbonate had a strong positive loading, and they were was associated with a concrete pond that had the highest alkalinity levels in Capricorn district. In Vhembe district, CCA showed that alkalinity as bicarbonate was associated with an aqua dam, aqua dam had the highest bicarbonate levels in Vhembe district. High alkalinity in a concrete pond in Capricorn district and aqua dam in Vhembe district might be explained by the source of water used, both systems used borehole water. Borehole water is usually hard and has high alkalinity levels (Grimason *et al*., 2013; Chidya *et al*., 2016; Shigut *et al*., 2017). CCA biplots in both districts showed that alkalinity was one of the important parameters affecting tilapia production in concrete pond and aqua dam systems. A production system with good water quality is likely to produce more and larger fish than a system with poor water quality (Boyd, 1998). Alkalinities between 40–80 mg/l are beneficial in nitrification processes (Biesterfeld *et al.,* 2003).

Ammonia and ammonium levels were below detection limits in Capricorn district. It was also below detection limits in the production system in Vhembe district. However, the RAS system had ammonia and ammonium levels that were above the acceptable limits in October and December. This might be explained by the high temperature reading in the RAS system in Vhembe district and input of nitrogen through pellets. Ammonia can easily accumulate due to the decomposition of uneaten pellets and fish faeces (Dauda *et al*., 2019). Ammonia usually represents 60-80 % of the end product of protein digestion in a production system (Mustapha & Akinshola, 2016). Temperature and pH have a profound effect on ammonia and ammonium (Setiadi *et al*., 2018). The high levels of ammonia and ammonium in RAS systems shows that the systems were poorly designed and the biofilters were not effective. Low tilapia yield in the RAS system in Vhembe district may be explained by the level of ammonia and ammonium which were above the acceptable limits of farming tilapia.

The acceptable limits for turbidity are between 25 and 100 mg/l, that is up to 3000 NTU (Buck, 1956; Ardjosoediro & Ramnarine, 2002). Turbidity in production systems can be caused by algae and suspended organic matter. However, algal turbidity within certain levels is desirable (Boyd, 1982); because algae are eaten by tilapia, adds oxygen through photosynthesis during the day, and also removes toxic parameters such as ammonia, nitrite, and nitrate. However, high turbidity levels in a production system reduce primary productivity, because of decreased light penetration through the water column. As a result, the fish growth rate decreases with increasing turbidity (Buck, 1956; Ardjosoediro & Ramnarine, 2002). Moreover, turbidity can cause gill damage in fish and thus affects ventilation efficiency, which in turn affects growth rates and survivorship (Roberts, 1978; Boyd, 2004). In the current study, the levels of turbidity were within the acceptable limits in all the production systems in Capricorn and Vhembe districts. Mostly tilapia culture is carried out in production systems where turbidity is variable, and tilapia can tolerate high turbidity (Boyd, 2004). CCA shows that turbidity has strong positive loading, and it was associated with a RAS system in Capricorn district that has a tilapia yield of 0.5451 kgm^{-2}. This means turbidity was an important parameter. In Vhembe district, turbidity had weak loading and was associated with a concrete pond that has a tilapia yield of 0.1811 kgm^{-2}. This means low tilapia yield can also be explained by the levels of turbidity in this study. Turbidity levels also explain high levels of EC recorded in this study since EC is directly related to the concentrations of total dissolved solids. CCA showed that EC had a strong loading in both districts, and it was associated with a concrete pond in Capricorn district, while in Vhembe district it was associated with an aqua dam. This means EC is also an important parameter affecting tilapia production in Capricorn and Vhembe districts. Water quality parameters such as turbidity, salinity, and EC are not of major concerns in tilapia production since their effect on fish health is relatively minimal (Bhatnagar & Devi, 2013). In the current study, salinity levels in all the production systems both in Capricorn and Vhembe districts were within the optimal range. CCA showed that salinity had strong loading in both districts. It impacted the farming of tilapia in the concrete pond and aqua dam in Capricorn district and Vhembe district, respectively.

Other parameters that can affect tilapia yield is total phosphate and potassium since they are limiting nutrient for the primary production of algae (Martins *et al.*, 2018). An acceptable limit for phosphate in a production system is between 0.06 to 0.2 mg/l (Hargreaves & Tucker, 2004; Sipaúba-Tavares *et al*., 2011). In this study, the monthly data shows that the level of total phosphate fluctuated in all the production systems and was mostly above the acceptable limits in both districts. This might be caused by the type of feed farmers used in their production systems. Poor feed quality and nonconventional feeds usually leach nutrients from the fish feed into the water (Hardy, 1999; Omitoyin *et al.,* 2017). The excessive disposal of phosphorus in the water causes eutrophication and algal blooms (Hussein, 2012), which later on affect fish growth in production systems.

High tilapia yields were expected from RAS systems in both districts because RAS systems are designed to maximize production by providing optimum environmental condition for fish growth throughout the year. Several studies showed that tilapia yield can range from 768 to 11558 kg/ha within five months of culture under different culture conditions (Diana *et al*., 1991; Aldon, 1998; Diana *et al*., 1994; Mac'Were *et al*., 2006; Neira *et al*., 2009; Elnady *et al*., 2010; Lind *et al*., 2015). However, tilapia yield in the RAS system in both districts was low because the systems were poorly designed and dysfunctional. In Capricorn district, the highest tilapia yield was 0.5717 kgm^{-2} in an aqua dam in Mahlanhle. The highest tilapia yield of 0.3115 kgm^{-2} was also observed in an aqua dam in Bungeni in Vhembe district. The temperature was the overriding factor affecting tilapia production, especially in the RAS system. The temperature was not suitable for farming of tilapia in most months, it was only suitable for a very short period of time. Tilapia yield can also be explained by the fact that farmers do not prioritize tilapia farming. All the farmers who participated in this study had a primary source of income, tilapia farming was a secondary activity and most of the production systems were backyard systems.

In conclusion temperature, alkalinity (as bicarbonate and carbonate), potassium, and total phosphate were key factors that mostly did not meet the requirement for the culture of tilapia in production systems in Capricorn and Vhembe districts. These were the key factors affecting tilapia production with the temperature being a major determining factor for tilapia growth. Therefore, temperature greatly affected tilapia yield because it was suitable for tilapia farming for a short period of time throughout the study. RAS production systems in both districts were dysfunctional and poorly designed since heaters were not installed.

CHAPTER 4: PHYTOPLANKTON ABUNDANCE IN DIFFERENT FISH PRODUCTION SYSTEMS IN CAPRICORN DISTRICT

4. PHYTOPLANKTON ABUNDANCE IN DIFFERENT FISH PRODUCTION SYSTEMS IN CAPRICORN DISTRICT.

4.1 INTRODUCTION

Phytoplankton are single-celled organism of plants which are primary producers in any water body, natural and manmade. The plankton population represents the biological wealth of a water body, constituting a vital link in the food chain (Rahman, 2015). The relative status of plankton communities gives insight into water quality parameters and the possible success or failure of tilapia production in earthen ponds (Mandal *et a*l., 2004). The production of tilapia in developing countries mostly occurs in semi-intensive production systems such as earthen ponds and concrete ponds, where fish largely depend on planktons as the main food source (Hassan, 2011; El-Sayed, 2013). This potentially reduces the cost of feed. Similarly, tilapia farmers in Capricorn district farm tilapia in concrete ponds and aqua dams. Capricorn district is in the central region of the Province and known to have lower ambient temperature throughout the year compared to most parts of the Limpopo Province. Tilapias are omnivorous filter-feeders that largely feed on plankton species, with phytoplankton as the main dietary component (Figueredo & Giani, 2005; Semyalo *et al*., 2011, El-Otify, 2015). The early stages of development tilapia feed on zooplanktons then later change to feed on phytoplankton, macrophyte and detritus (Trewavas, 1982; Egna & Boyd, 1997; Beveridge & McAndrew, 2000).

Phytoplankton biomass and productivity are in direct relation with the water quality parameters (Lungayia *et al.*, 2000). Water quality parameters that are critical for plankton growth include nitrogen, phosphorus, potassium, ammonia, turbidity, salinity, dissolved oxygen, and temperature (Dejen *et al*., 2004; Badsi *et al.,* 2010; Kunlasak *et al.*, 2013; Veronica *et al*., 2014). In the previous chapter, total nitrogen was mostly within the acceptable limits for farming tilapia in concrete ponds and aqua dams. The total phosphorus was mostly above the acceptable limits in all the production systems in Capricorn district. The content of dissolved oxygen (DO) in water typically correlates with phytoplankton density in fish ponds (Kunlasak *et al.*, 2013). In the previous chapter, DO was within the acceptable limits in concrete ponds and aqua dams in Capricorn district. Phytoplankton species can show dramatic changes in population density from day to day due to their short life cycle (Egna & Boyd, 1997). Plankton abundance varies from location to location and pond to pond within the same location, even within similar ecological conditions (Rahman & Hussian, 2008). The relative status of plankton communities gives insight into water quality parameters and the possible success or failure of the culture season (Mandal *et al.*, 2004). This study will determine phytoplankton abundance in aqua dams, and concrete ponds in Capricorn district.

4.2 OBJECTIVE

The primary objective of this chapter is to determine phytoplankton abundance in aqua dams and concrete ponds in Capricorn district in Limpopo Province.

4.3 NULL HYPOTHESIS

There is no difference in the abundance of phytoplankton in aqua dams and concrete ponds in Capricorn district in Limpopo Province.

4.4 MATERIALS AND METHODS

4.4.1 Description of study site.

Refer to chapter three section 3.4.1

4.4.2 Determination of phytoplankton abundance

Water samples for plankton analysis were collected once every two months (June 2019 to Feb 2020). The samples were collected 50 cm below the surface using a truncated cone-shaped, silk bolting cloth plankton net. A 71 µm mesh sizes net was used to collect phytoplankton. Samples were collected by filtering pond water through the plankton net, the collecting net was then rinsed into a 5 L bucket using pond water then decanted into 1L sample bottles. The sample bottles were kept in ice and transported to the Aquaculture Research Unit laboratory of the University of Limpopo, where they were fixed with 4% formalin and stored in a dark cooler room at 4 °C.

The phytoplankton were counted under a light compound microscope (Leica E24) using improved double Neubauer chamber W- Germany, 0.100 mm depth, 0.0025 mm^2. The counting chamber and the coverslip were cleaned with 70% ethanol, then 0.01 ml (10 µl) of the sample was loaded on the loading groove using a micropipette. The plankton cells that touched the upper and left border were counted whilst cells that touched the right and lower border were not counted. The procedure was done in four main squares of the counting chamber. The concentration of cells in 1 µl was estimated by dividing the number of counted cells by the volume of the four main squares, then the value was multiplied by 1000 to get the number of cells in 1 ml. Phytoplankton identification catalogue (Prescott, 1954; Botes, 2003; Vuuren *et al*., 2006; Bellinger & Sigee, 2010,) was used to identify phytoplankton.

4.4.3 Determination of primary production different production systems

Primary productivity was determined using the light and dark bottle method. Water samples were collected 25 cm below the surface using 1L bottles in all production systems. Four samples were collected once every two months. Two samples were left clear (light bottle samples), and the other two dark sets (dark bottle samples) was covered with an aluminium foil to exclude light. All samples were incubated for 24 hrs, the clear samples were incubated outdoors where they received sufficient sunlight. The dark bottles, covered with aluminium foil, were further covered with a black plastic bag. They were then placed inside the cardboard box before incubation inside a laboratory cabinet unit. Dissolved oxygen was measured using YSI meter before and after incubation. The carbon values were obtained from the O_2 values by multiplying with 0.375 (Sreenivasan, 1964).

Gross primary production (GPP) calculation:

- Gross Primary Productivity (O_2 mg/l/hr) = (Dl - Dd) /hr × 0.375 = gC/m^2/ hr

Where: Dl - Dissolved Oxygen in the light bottle in mg/l

Dd - Dissolved Oxygen in the dark bottle in mg/l

hr - Duration of exposure in hours

4.4.4 Determination of tilapia yields in different production system

Refer to chapter three section 3.4.4

4.4.5 Statistical analyses

Relative abundance was calculated using Microsoft Excel (2013). The pie charts were plotted using Origin 2021 software. Statistical Package for Social Sciences (SPSS, version 26) was used to run a linear regression. Canonical Correspondence Analysis

(Canoco version 4.5) was used to determine the association of phytoplankton abundance with tilapia yield in different production systems in Capricorn district.

4.5 RESULTS

4.5.1 Phytoplankton composition in different production systems

Nine phyla and 34 genera were identified from the concrete pond in Molepo in Capricorn district (Table 4.1). The concrete pond in Molepo had more phytoplankton genera compared to aqua dams in Mothole and Mahlanhle. The highest number of phytoplankton species was recorded in February (Table 4.1). *Pinnularia* sp. and *Navicula* sp. were the most predominant phytoplankton genera throughout the course of the study. Numerically. Bacillariophyta phylum dominated the phytoplankton flora (Figure 4.1).

Table 4. 1: Composition (no./ml) of phytoplankton species in concrete pond in Molepo in Capricorn district, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb
Bacillariophyta					
Amphipleura sp	0	5.94	0.62	0	0
Gymnodinium sp	0	1.72	0	0	0
Pinnularia sp	13.88	5.38	10.88	8.06	24.7
Synedra sp	0	0	0	16.5	12.78
Navicula sp	7.58	0.34	7.12	2.86	0.82
Nitzschia sp	1.04	0	5.86	5.08	1.5
Chlorophyta					
Ankistrodesmus sp	0	0	0	1.9	0
Chroococcus sp	0	0.26	0.34	3.46	4.54
Chlorella sp	5.28	0.5	1.2	0	0.04
Cosmarium sp	0.56	0	0.12	1.04	0.16
Crucigenia sp	0	0	0	0	2.38
Dictyosphaerium sp	0	1.26	3.7	0	12.72
Kirchneriella	0	0	0	1.56	4.06
Merismopedia elegans	0	0	1.34	0	0
Micractinium sp	0	0	0	0	0.1
Pediastrum sp	0.06	0	0.06	0.04	0.06
Pediastrum simplex	2.8	0	0	0	0
Rhizoclonium sp	0.14	0	0	0	0
S. quadricuada	0	0	0	5.78	0.06
Scenedesmus sp	0	0	0.1	3.88	0
Selenastrum sp	0	0	0	0	0.88
Tetraedron sp	0	0	0	2.48	0
Westella sp	0	1.2	3.5	0	0
Charophyta					
Mougeotia sp	0	0	0.28	0	0
Cryptophyta					
Cryptomonas sp	0	2.58	0.38	0.82	0
Cyanophyta					
Aphanocapsa sp	1.8	0.56	0	20.54	16.24
Oscillatoria sp	0	0	0	0.08	0
Merismopedia sp	0.32	0	1.34	0	0
Microcystis sp	1.06	1.14	0	4.92	6.48
Spirulina sp	0	0	0	0.04	0
Dinoflagellata					
Peridinium sp	2.8	0	0.36	0	0.1
Euglenophyta					
Trachelomonas	0.72	0	0	0	0
Euglenozoa					

Peranema sp	0	0.24	0	0	0
Ochrophyta					
Mallomonas sp	0	0	0	0	1.62
Total	**38.04**	**21.12**	**37.2**	**79.04**	**89.24**

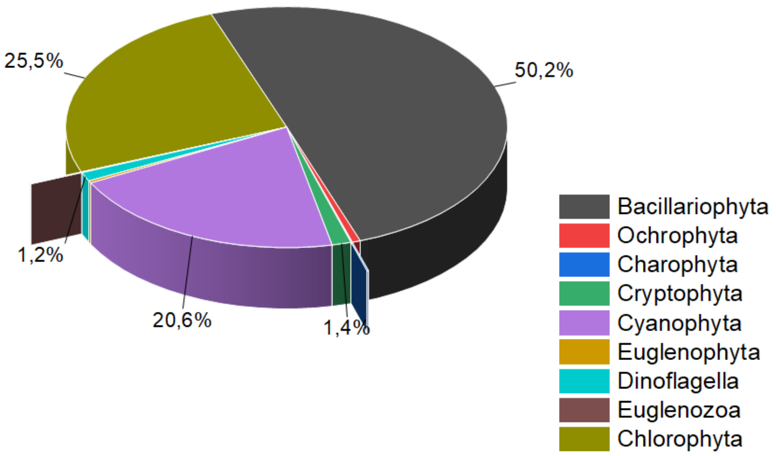


Figure 4. 1: Relative abundance of phytoplankton species in concrete pond in Molepo in Capricorn district

Seven phyla and 22 genera were identified from the aqua dam in Mahlanhle in Capricorn district (Table 4.2). Although concrete pond in Molepo had more total number of genera identified, an aqua dam in Mahlanhle had the highest total phytoplankton flora compared to all the production systems in Capricorn district. The highest number of phytoplankton species was recorded in December followed by February (Table 4.2). *Scenedesmus* sp. and *S. quadricuada* were the most dominant genera throughout the study. Numerically, Chlorophyta dominated the phytoplankton flora (Figure 4.2).

Table 4. 2: Composition (no./ml) of phytoplankton species in aqua dam water in Mahlanhle in Capricorn district, sampled from June 2019 to February 2020

	June	**Aug**	**Oct**	**Dec**	**Feb**
Bacillariophyta					
Pinnularia sp	3.52	0	0	11.4	0.04
Navicula	6.56	0	1.42	4.64	0.06
Nitzschia sp	0	1.12	0	0	0
Chlorophyta					

Ankistrodesmus sp	0.36	0	2.02	0	0
Chlorella sp	3.06	0	0	1.8	0.16
Closteruim sp	0.24	0	0.8	0	0
Coelastrum sp	0	0	7.44	10.82	0
Cosmarium sp	1.04	4.08	8.76	0.4	0
Gonium sp	0	0	0	4.86	0
Lagerheimia sp	0	0	7.08	5.72	0.12
Micractinium sp	0	0	2.58	8	7.34
Monoraphidium sp	0	22.3	0	0	0
Pandorina sp	11.54	0	0	0	18.32
S. quadricuada	8.74	9.48	21.9	36.52	28.36
Scenedesmus sp	0.62	6.34	14.28	4.4	13.22
Sphaerocystis sp	0	0	0	0	12.44
Charophyta					
Mougeotia sp	0.08	0.38	0.32	0	0
Staurastrum sp	13.76	0	0	0	0
Cryptophyta					
Cryptomonas sp	4.02	1.22	0	0.12	0.02
Cyanophyta					
Microcystis sp	3.72	0	0	1.26	0
Euglenophyta					
Trachelomonas	0	5.26	0	0	0.26
Euglenozoa					
Peranema sp	0	1.06	0	0	0
Total	**57.26**	**51.24**	**66.6**	**89.94**	**80.34**

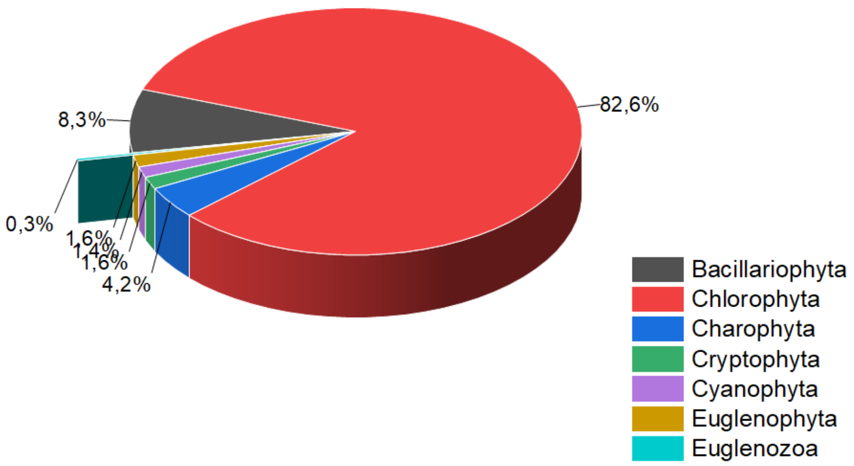


Figure 4. 2: Relative abundance of phytoplankton species in aqua dam in Mahlanhle in Capricorn district.

In another aqua dam in Mothole, 27 phytoplankton genera from eight phyla were identified (Table 4.3). The total number of phyla and genera identified in an aqua dam in Mothole were higher in comparison to aqua dams in Mahlanhle. However, an aqua dam in Mothole had the lowest total phytoplankton flora compared to the aqua dam and the concrete pond in Capricorn district. The highest number of phytoplankton species was recorded in June (Table 4.3). *S. quadricuada* was the most dominant species throughout the study Chlorophyta dominated the phytoplankton flora (Figure 4.3).

Table 4. 3: Composition (no./ml) of phytoplankton species in aqua dam in Mothole in Capricorn district, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb
Bacillariophyta					
Pinnularia sp	0	0	0	0	11.74
Synedra sp	0	0	0	0.12	0
Surirella sp	0	0	0	0	0.36
Navicula sp	0	0	0	0	8.62
Nitzschia sp	0	4.78	0	0	1.1
Chlorophyta					
Ankistrodesmus sp	0	0	0.74	0.34	0
Chroococcus sp	1.38	0	0	0	0
Chlorella sp	9.22	0.96	0	1.6	0
Closteruim sp	11.92	0	0	0	0
Coelastrum sp	12.68	0	0	12.2	0
Cosmarium sp	0	2.62	7.64	0	0
Dictyosphaerium sp	0	0	0	0.84	3.24
Franceia sp	0.28	0	0	0	0
Gonium sp	0	0	0	6.08	0
Micractinium sp	0	2.74	0	0	0
Monoraphidium sp	0	7.14	0	0	0
Pandorina sp	3.7	6.32	13.06	0	4.66
S. quadricuada	11.44	6.88	8.7	6	3.76
Scenedesmus sp	3.14	0	8.62	2.54	5.82
Charophyta					
Mougeotia sp	0	0.08	0	0	0
Staurastrum sp	0	0	0.3	1.36	0
Cryptophyta					
Cryptomonas sp	6.9	1.4	0	4.06	0
Cyanophyta					
Microcystis sp	0	0	0.72	0	0.68
Euglenophyta					
Trachelomonas	0.76	4.42	0.08	0	0
Euglenozoa					
Peranema sp	0.2	0	1.22	0	0
Ochrophyta					
Actinosphaerium sp	0	0.44	0	0	0
Melosira sp	0.04		0	0	0
Ophiocytium sp	0	0	0	1.82	0
Total	**61.66**	**37.78**	**41.08**	**36.96**	**39.98**

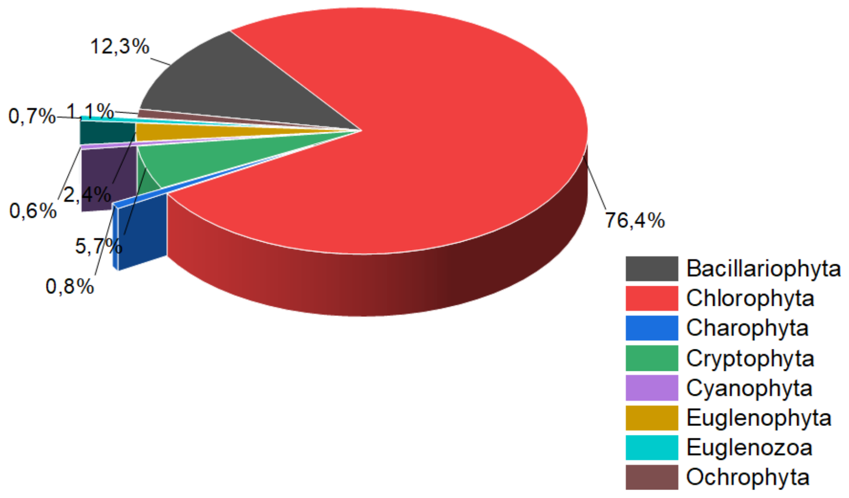


Figure 4. 3: Relative abundance in phytoplankton species identified from an aqua dam in Mothole in Capricorn district.

4.5.2 The relationship of primary production, phytoplankton abundance and tilapia yield

The highest primary production value in Capricorn district was recorded in October in concrete pond in Molepo (Table 4.4). Primary production was at its lowest in June in aqua dam in Mahlanhle. Primary production values were higher in concrete pond compared to the aqua dams (Table 4.4).

Table 4. 4: Mean of gross primary production (gC/m2/yr) in production systems in Capricorn district, sampled from June 2019 to Feb 2020.

Location name	Production system	June	Aug	Oct	Dec	Feb
Molepo	Concrete pond	4.34	13.53	91.76	13.47	7.73
Mahlanhle	Aqua dam	1.45	14.01	23.45	6.65	34.84
Mothole	Aqua dam	3.87	13.89	11.87	4.52	10.07

Linear regression of primary production and phytoplankton abundance produced a Pearson correlation value of -0.131, therefore they were no correlation (Figure 4.4). Only 1.7 % (R^2=0.017) of variability in phytoplankton abundance can be accounted for by primary production. There was no correlation between primary production and phytoplankton abundance in production systems in Capricorn district, the values were scattered as shown in Figure 4.4. Moreover, the correlation of primary production and phytoplankton abundance was not statistically different (p>0.05).

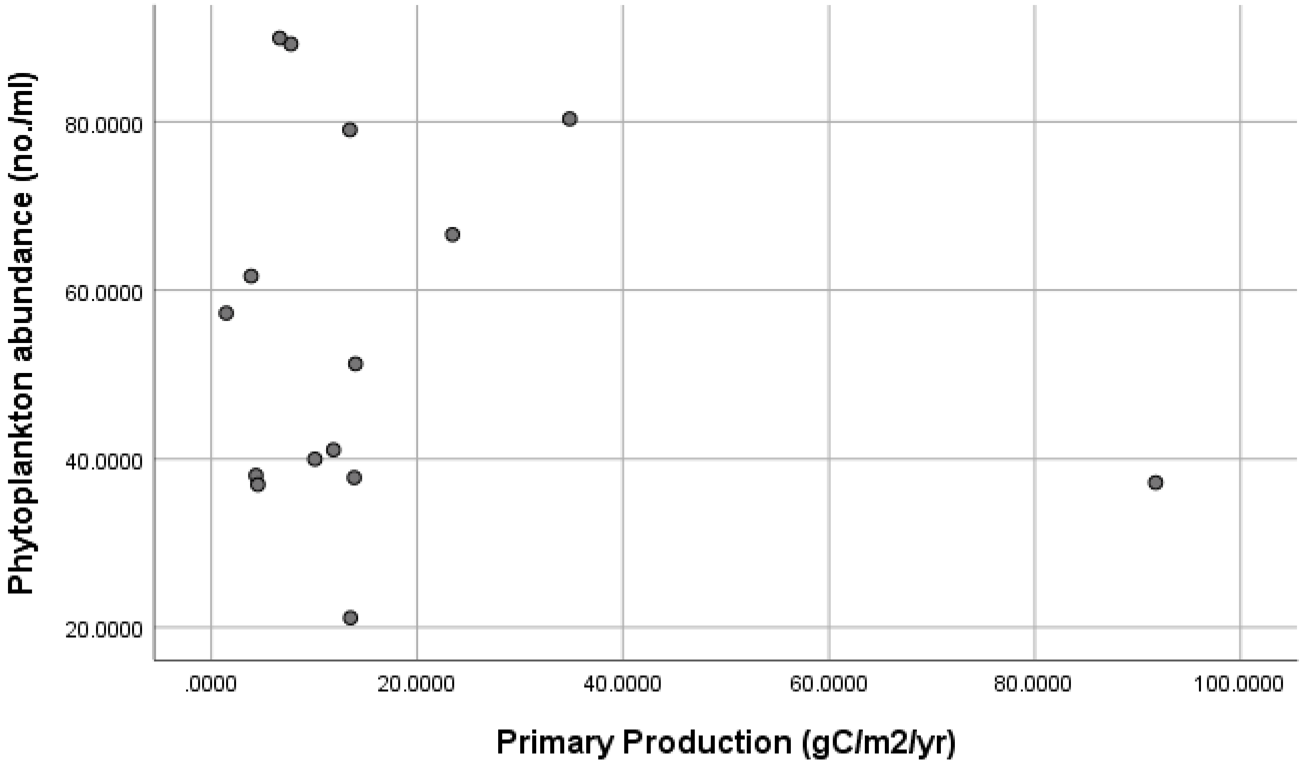


Figure 4. 4: The relationship of primary production and phytoplankton abundance in fish production systems in Capricorn district.

Linear regression of primary production and tilapia yield produced an R^2 value of 0.025 and a Pearson correlation value of 0.157, therefore they were no correlation (Figure 4.5). The correlation of primary production and tilapia yield was not significantly different (p>0.05).

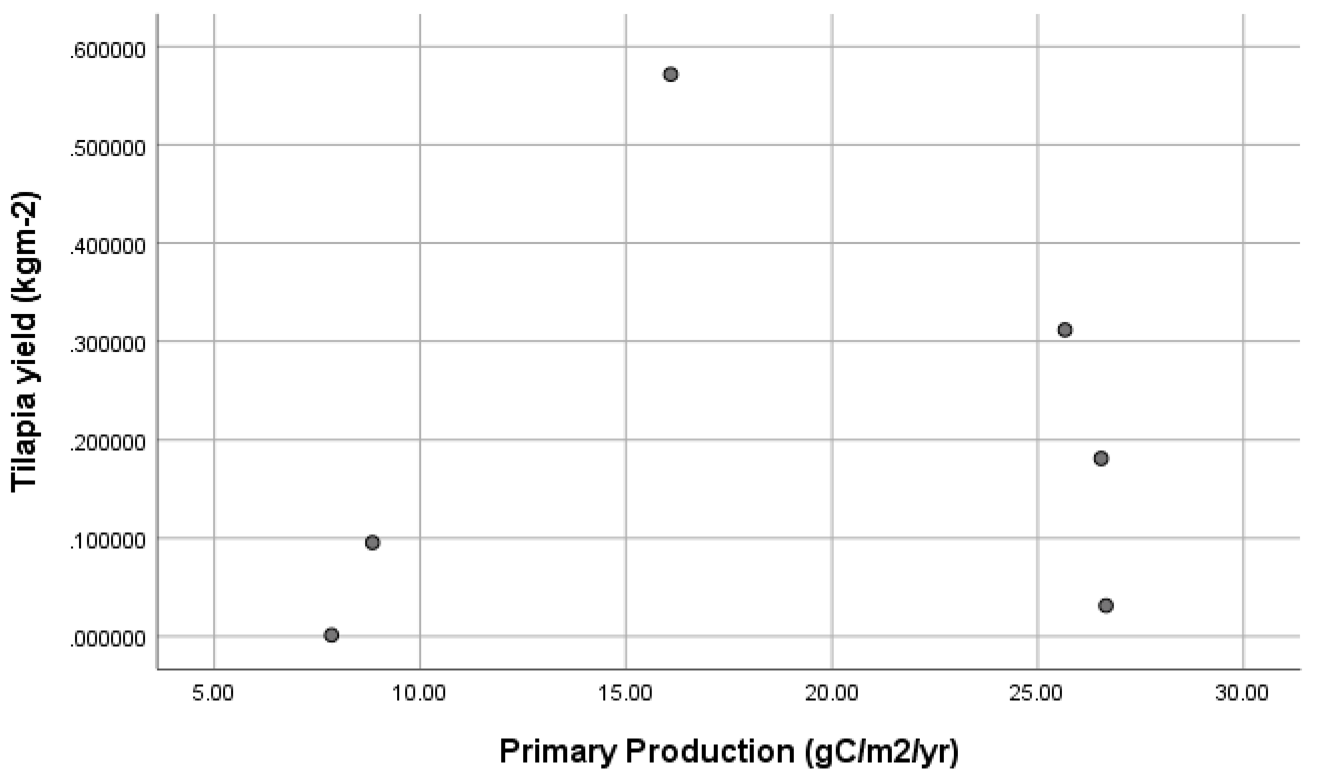


Figure 4. 5: The relationship of tilapia yield and primary production in Capricorn and Vhembe districts.

Linear regression showed no correlation between phytoplankton abundance and tilapia yield in production systems in Capricorn and Vhembe districts (Figure 4.6). The correlation produced an R^2 value of 0.253, the phytoplankton and tilapia yield values were scattered as shown in Figure 4.6. The correlation of phytoplankton abundance and tilapia yield was not significantly different (p>0.05).

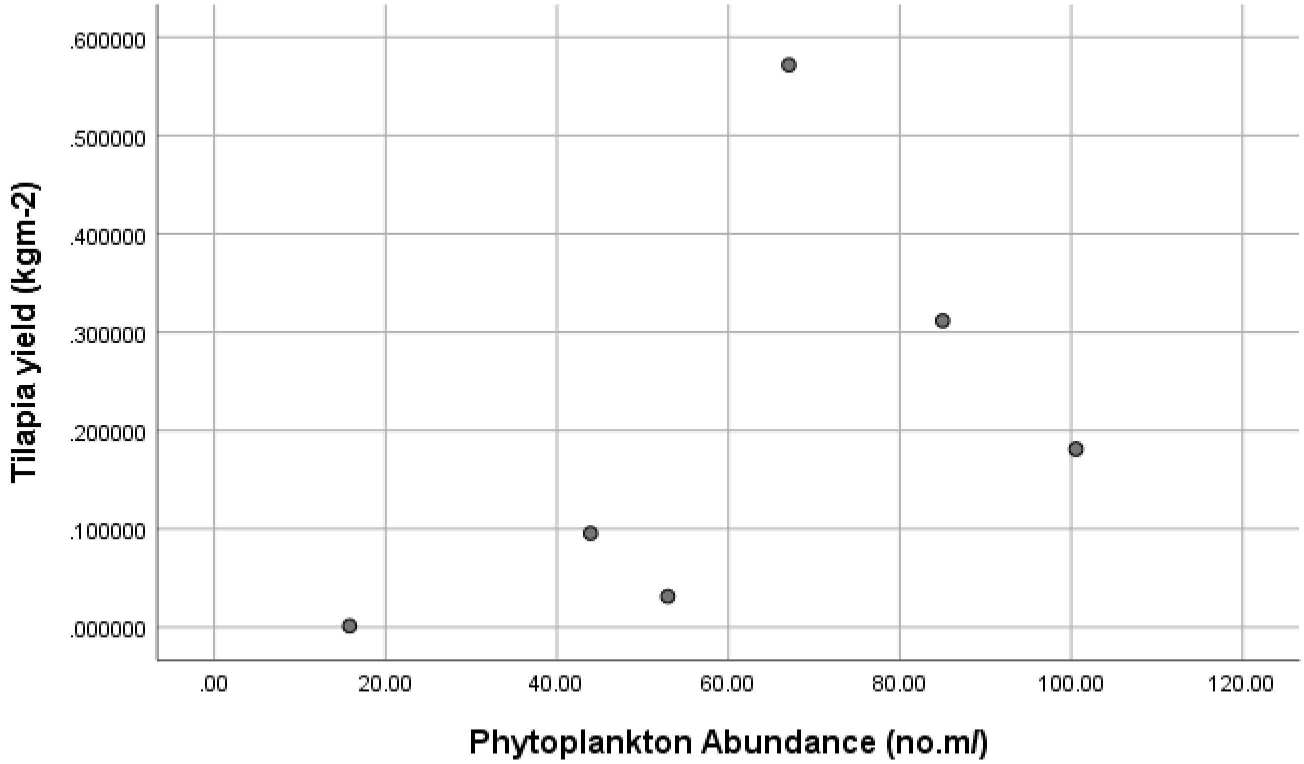


Figure 4. 6: The relationship of tilapia yield and phytoplankton abundance in Capricorn and Vhembe districts.

4.5.3 The effect of phytoplankton abundance on tilapia yield in different production systems

The eigenvalues of the correlation matrix of phytoplankton abundance and production systems with different tilapia yields showed that axis 1 explained 78.2 % of the variation and axis two explained 21.8 % of the variation (Table 4.5). The sum of all eigenvalues was 0.684.

Table 4. 5: Eigenvalues of the correlation matrix of phytoplankton genera and production systems in Capricorn district.

Total Variance		
Axes	1	2
Eigenvalues	0.535	0.149
Species-environment correlations	1.00	1.00
Cumulative percentage variance	78.2	100.0
Sum of all eigenvalues		0.684

The CCA plot showed that the concrete pond in Molepo in Capricorn district was associated with more phytoplankton species compared to other production systems in Capricorn district (Figure 4.7). A concrete pond in Molepo (0.0312 kgm^{-2}) was associated with *Westella* sp., *Kirchneriella* sp., *Aphanocapsa* sp., *Synedra* sp., *Amphipleura* sp., *Chroococcus* sp., and *Crucigenia* sp. (Figure 4.7). An aqua dam in Mothole (0.0954 kgm^{-2}) was associated with *Closterium sp.* and an aqua dam in Mahlanhle (0.5717 kgm^{-2}) was associated with *Sphaerocystis* sp., *Staurastrum* sp., and *Lagerheimia* sp. (Figure 4.7). Aqua dams in Capricorn district were associated fewer phytoplankton species compared to a concrete pond.

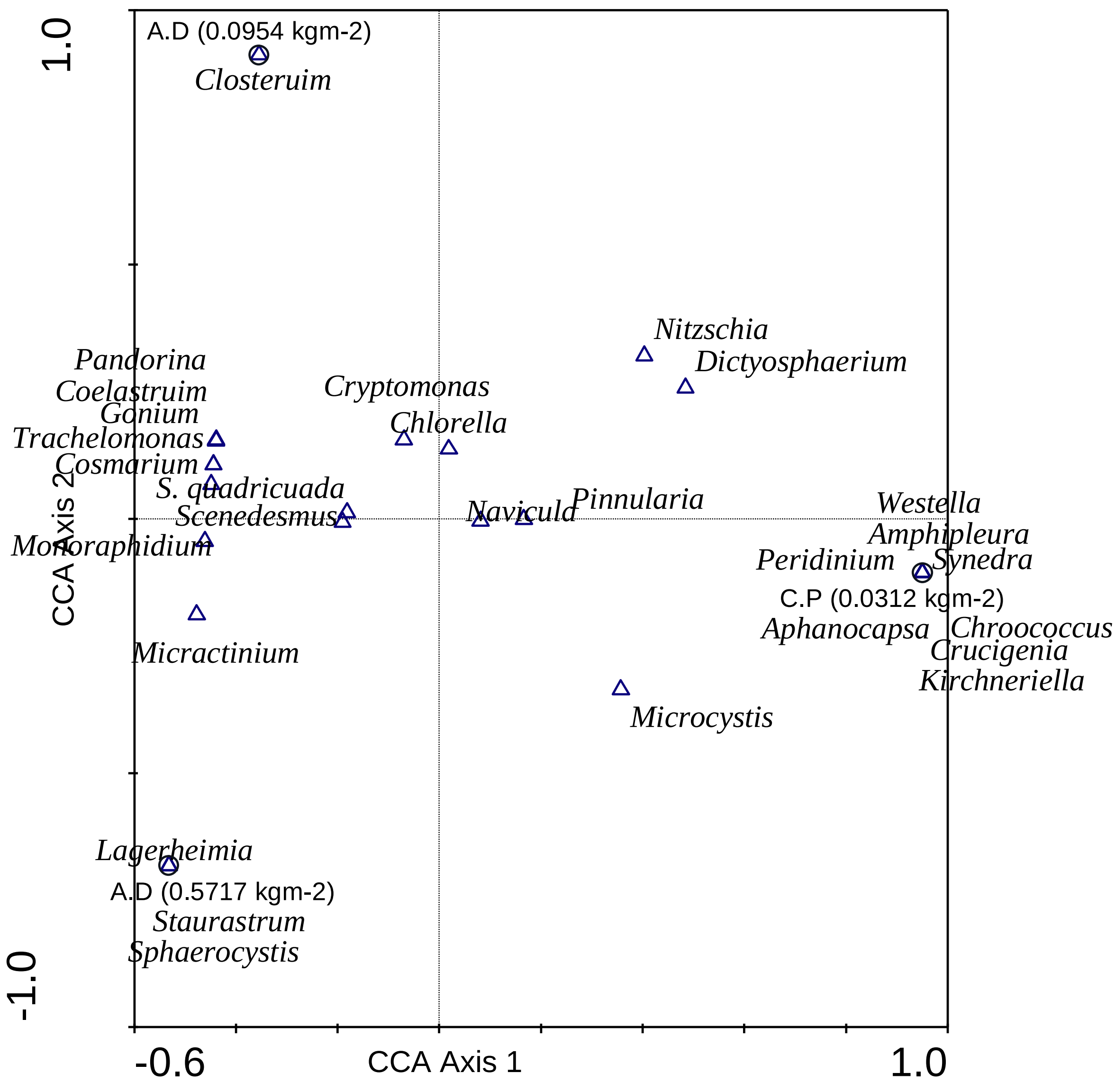


Figure 4. 7: CCA plot of the association of phytoplankton abundance with tilapia yields in production systems in Capricorn district (A.D -aqua dam; and C.P -concrete pond)

4.6 DISCUSSION

This study showed that the concrete pond in Molepo in Capricorn district was dominated by phytoplankton genera belonging to Bacillariophyta, Chlorophyta and Cyanophyta phyla. *Pinnularia* sp. and *Navicula* sp. were most predominant throughout the course of the study. CCA showed that concrete pond in Molepo was associated with *Westella* sp., *Kirchneriella* sp., *Aphanocapsa* sp., *Synedra* sp., *Amphipleura* sp., *Chroococcus* sp., and *Crucigenia* sp. These genera were most abundant in the concrete pond in Molepo. The concrete pond in Molepo was associated with more phytoplankton species compared to aqua dams. This might be explained by the material used to build the concrete pond, it acts as a better substrate to support phytoplankton growth unlike the plastic material of aqua dams. Moreover, nutrients were accumulating in the pond because there was no incoming water into the pond therefore could not lose fertility. Species belonging to *Pinnularia* sp. genus common benthic genus living on stones and sediment mainly in freshwater. *Amphipleura* sp., species are widely distributed in sediment habitats of standing or slow-flowing waters (Janse van Vuuren *et al*., 2006). *Crucigenia* sp. species can even be found on moist terrestrial surfaces because of their ability to survive in a variety of freshwater ecosystems such as ponds, lakes, and rivers (Janse van Vuuren *et al*., 2006). Their abundance in the concrete pond can be explained by untreated borehole water used by the farmer.

Aqua dams in Mahlanhle and Mothole were both dominated by genera belonging to Chlorophyta phylum. However, an aqua dam in Mahlanhle had the highest total phytoplankton flora compared to all the production systems in Capricorn district. *Scenedesmus* sp. and *S. quadricuada* were the most dominant in aqua dams, and they occurred throughout the study period. CCA showed that aqua dam in Mahlanhle was associated with *Sphaerocystis* sp. and *Staurastrum* sp. The aqua dam in Mothole was associated with *Lagerheimia* sp. and *Closterium* sp. Both aqua dams had no constant incoming water, therefore nutrients accumulated in the tanks. *Scenedesmus* sp. and *Lagerheimia* sp species are common genera found in the plankton of freshwater ponds, lakes, and rivers. *Staurastrum* sp. species are widespread and extremely diverse, most commonly found in the sediments or periphyton of oligotrophic lakes, ponds, and swamps (Janse van Vuuren *et al*., 2006). High total phytoplankton flora in an aqua dam in Mahlanhle may be explained high nutrient accumulation compared to the aqua dam in Mothole.

Bacillariophyta, Chlorophyta, Cyanophyta, and Euglenophyta are common phytoplankton groups found in freshwater ponds (Grubach, 2010; Salazar *et al*., 2016; Sipaúba-Tavares *et al*., 2011; Das *et al*., 2018; Mohamed *et al.,* 2019). In this study, Bacillariophyta, Chlorophyta, and Cyanophyta were the most abundant phyla in all the production systems; Euglenophyta, Euglenozoa and Ochrophyta were the least abundant. A study by Figueredo and Giani (2005) showed that tilapia selectively feed on large algae such as cyanobacteria and diatoms by filtration, which leads to the proliferation of chlorophytes. The preference of large phytoplankton by tilapia was also proved by Turker *et al*. (2003) who observed a decrease in green algae and cyanobacteria in the presence of tilapia. Other studies by Elhigzi *et al*. (1995); Beveridge and Baird (2000); Attayde and Menezes (2008); and Mbonde *et al*. (2017) also supports that tilapia feed on larger phytoplankton such as Bacillariophyta species. A study by Rini (2013) showed that the abundance of *Nitzchia* sp. in fish ponds shows the potency of its utilization as natural food for tilapia fish. Tilapia is known to ingest phytoplankton phyla such as Bacillariophyta, Euglenophyta and Cyanophyta in large quantities (Danaher *et al*., 2007; Kunlasak *et al*., 2013; Ikpi *et al*., 2013). However, the analysis on the stomach and gut content proved that not all the phytoplankton species ingested by tilapia are digested and assimilated. Digestion of phytoplankton species by tilapia involves grinding of phytoplankton cells and lyses of algal cell walls by the stomach acidic pH which is below 1.5 (Xie *et al*., 2001; Komarkova & Tavera, 2003). Tilapia is among the very few fish species which are capable of digesting Cyanophyta species because of their stomach pH (Turker *et al*. 2003; Salazar *et al*., 2016; Osti *et al*., 2018). Several studies have shown that tilapia has a high ingestion rate and digestion efficiencies for Cyanophyta and Euglenophyta species (Abdel-Tawwab & El Marakby, 2004; Menezes *et al.,* 2010; Salazar *et al*., 2016; Mohamed *et al.,* 2019). A study by Mohamed *et al*. (2019) showed that tilapias are able to digest phytoplankton species belonging to Cyanophyta, Chlorophyta, Dinoflagellata and Euglenophyta, but not able to digest Bacillariophyta species. Tilapia can easily ingest Bacillariophyta species but unable to digest them because diatoms are more resistant to digestion in the fish gut than other phytoplankton groups (Mohamed *et al*., 2019). Seventy-seven percent of the ingested Bacillariophyta species were found in the faeces (Ping &

Jiankang, 1994; Grubach, 2010). Therefore, the abundance of phytoplankton species, especially Bacillariophyta, in production systems in Capricorn and Vhembe districts does not mean they were digested and assimilated by tilapia.

Phytoplankton abundance in production systems was not correlated with primary production. Primary production was also not correlated to tilapia yield. In this study, primary production ranged from 1.45 to 91.76 gC/m2/yr in all the production systems. Tilapia yields observed in this study were below those found in published literature for other similar production systems. Other studies showed that primary production levels can range from 301.1 to 2053.1 gC/m2/yr (López-Archilla *et al*., 2004; Christensen *et al*., 2013; Solomon *et al*., 2013; Hornbach *et al*., 2017 & 2020). Low stocking densities and early reproduction of tilapia can also explain the low tilapia yields observed in this study. Other studies showed that tilapia yield can range between 768 and 11558 kg/ha within five average months of culture under different culture conditions (Olih *et al*., 1986; Diana *et al*., 1991; Diana *et al*., 1994; Mac'Were *et al*., 2006; Neira *et al*., 2009; Elnady *et al*., 2010; Lind *et al*., 2015).

In conclusion, the results of this study suggest that concrete ponds and aqua dams in Capricorn district have different phytoplankton abundance. The abundance of phytoplankton species in fish production systems is not always correlated to primary production, as primary production is not always correlated to tilapia yield. Phytoplankton abundance was also not correlated to tilapia yield in Capricorn and Vhembe districts. The high abundance of plankton species in a production system does not always result in high tilapia yield, because phytoplankton ingestion by the fish does not mean they were digested and assimilated by fish.

CHAPTER 5: PHYTOPLANKTON ABUNDANCE IN DIFFERENT FISH PRODUCTION SYSTEMS IN VHEMBE DISTRICT

5. PHYTOPLANKTON ABUNDANCE IN DIFFERENT FISH PRODUCTION SYSTEMS IN VHEMBE DISTRICT.

5.1 INTRODUCTION

Phytoplankton are microscopic plants that live in all water bodies including natural freshwater ponds, lakes, and man-made ponds. Phytoplankton plays an important role in nutrient recycling and primary production in all aquatic systems (Akunga *et al*., 2018). Thus, they play an essential task in the maintenance of the water quality and serves as an indicator for the productivity of water bodies (Akunga *et al*., 2018). Phytoplankton are important food items of most aquatic organisms including tilapia fish. Tilapia is traditionally farmed in earthen ponds (Favaro *et al*., 2015), where fish largely depend on planktons as the main food source. Similarly, tilapia farmers in Vhembe district farm tilapia in earthen ponds, concrete ponds, and aqua dams. Plankton composition, distribution, and abundance in semi-intensive production systems is affected by biotic and abiotic factors (Mbonde *et al*., 2017). Abiotic factors include water quality parameters, sunlight, and nutrients availability; and biotic factors include grazing and excretion and ingestion by the fish species (Drenner *et al*., 1984; Bhavimani & Puttaiah, 2014; Roy *et al*., 2014).

Fish yield in earthen fish ponds is usually correlated with phytoplankton abundance (Hepher, 1962). It has also been shown that the fish yields of finfish such as tilapia in reservoirs and lakes are correlated with phytoplankton and primary production (McConnell *et al.*, 1977; Behrends *et al*., 1985; Downing *et al.*, 1990; Hiroki *et al*., 2020). Measurements of primary production can be used to improve the assessment of fish yield from tropical and temperate lakes and reservoirs (Biro & Voros, 1982). Primary production has been shown to be a better predictor of fish yield in lakes than other suggested relationships between yield and environmental variables (Melack, 1976; Liang *et al*., 1981). It is thus important to determine both phytoplankton and primary production in different production systems, both these parameters can be used to estimate fish yield.

Natural food contributes between 300 and 500 g/kg of growth when tilapia is supplemented with formulated diets (Hepher, 1988; Schroeder *et al*., 1990; Gatlin, 2010). The protein content of natural food ranges between 550 and 700 g /kg on a dry matter basis (Hepher, 1988; Gatlin, 2010). Moreover, the survival is also significantly higher in fish fed live food than in fish fed with formulated diets (Hassan, 2011). Rural tilapia farmers utilize locally available ingredients rather than relying completely on imported formulated feeds (Shoko *et al*., 2011). Similarly, farmers in Vhembe district feed with formulated pellets and nonconventional food such as maize bran and sorghum. Any feed that favours plankton growth will result in high fish yield in a production system (Jha *et al.,* 2004). This study will determine phytoplankton abundance in earthen ponds, concrete ponds, and aqua dams in Vhembe district.

5.2 OBJECTIVES

The primary objective of this chapter is to determine phytoplankton abundance in aqua dams, earthen ponds, and concrete ponds in Vhembe district in Limpopo Province.

5.3 NULL HYPOTHESIS

There is no difference in the abundance of phytoplankton in aqua dams, earthen ponds, and concrete ponds in Vhembe district in Limpopo Province.

5.4 MATERIALS AND METHODS

5.4.1 Description of study site.

Refer to chapter three section 3.4.1

5.4.2 Determination of phytoplankton abundance

Refer to chapter three section 4.4.2

5.4.3 Determination of primary production in different production systems

Refer to chapter three section 4.4.3

5.4.4 Determination of tilapia yields in different production systems

Refer to chapter three section 3.4.4

5.4.5 Statistical analysis

Relative abundance was calculated by Microsoft Excel (2013). The pie charts were plotted using Origin 2021 software. Statistical Package for Social Sciences (SPSS, version 26) was used to run Regression. Canonical Correspondence Analysis

(Canoco version 4.5) was used to determine the association of phytoplankton abundance with tilapia yield in different production systems in Vhembe district.

5.5 RESULTS

5.5.1 Phytoplankton composition in different production systems

Eight phyla and 21 genera were identified from the earthen pond in Vondo in Vhembe district (Table 5.1). The highest number of phytoplankton species was recorded in October. *Pinnularia* sp., *Synedra* sp., and *Cosmarium* sp. were the most predominant genera throughout the course of the study. The lowest number of phytoplankton species (per ml) was counted in an earthen pond in composition compared to other production systems in Vhembe district (Table 5.1). Numerically, Bacillariophyta followed by Chlorophyta dominated phytoplankton flora (Figure 5.1).

Table 5. 1: Composition (no./ml) of phytoplankton species in earthen pond in Vondo in Vhembe district, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb
Bacillariophyta					
Amphipleura sp	0	0.12	0	0	0
Gymnodinium sp	0	0.9	0	5.34	0
Pinnularia sp	2.6	4.46	10.76	1.38	8.38
Navicula sp	0	0.24	5.86	0	1.4
Nitzschia sp	0	0	1.08	0	0
Synedra sp	0.18	3.28	0.5	1.44	0.08
Chlorophyta					
Ankyra sp	0	0	0	0	0.02
Chlorella sp	0	0	0	0.38	0.82
Closterium moniliferum	0.16	0	0	0	0
Cosmarium sp	2.18	4.54	7.94	0.78	0.04
Dictyosphaerium sp	0	0	0	0.84	0
Pediastrum sp	0	0	0	0.04	0
S. quadricuada	0.1	0.36	0	2.28	1.18
Scenedesmus sp	0	0.08	0.22	0.26	1.6
Selenastrum sp	0	0	0	0	0.16
Charophyta					
Euastrum sp	0	0.68	1.22	0.26	0
Cryptophyta					
Cryptomonas sp	0.46	0.16	0.64	0.1	0.84
Cyanophyta					
Anabaena sp	0	0	0	0	0.04
Microcystis sp	0	0	0	0.08	0
Dinoflagellata					
Peridinium sp	0.86	0	0.2	0.18	0
Euglenophyta					
Phacus sp	0	0	0	0.26	0
Trachelomonas sp	0.08	0	0.2	0	0.38

Ochrophyta					
Actinosphaerium sp	0.32	0	0	0	0.06
Total	**6.94**	**14.82**	**28.62**	**13.62**	**15**

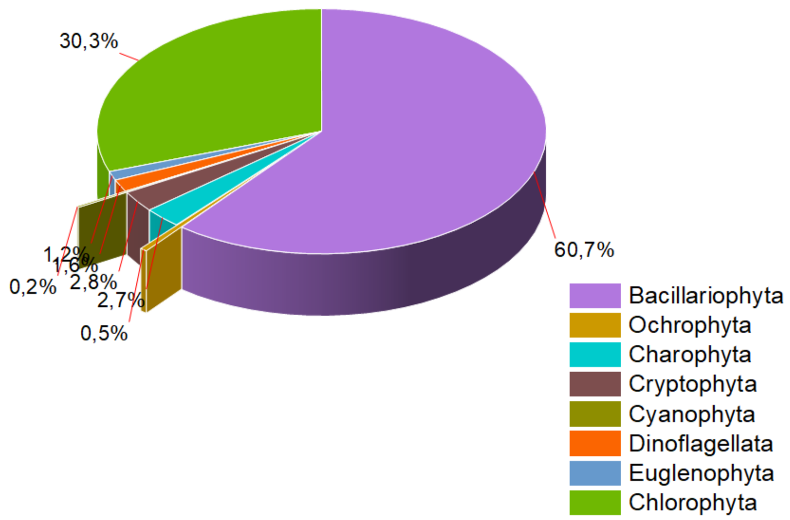


Figure 5. 1: Relative abundance of phytoplankton species in earthen pond in Vondo in Vhembe district.

An aqua dam in Bungeni recorded seven phytoplankton phyla and 22 genera (Table 5.2). More phytoplankton species (per ml) were counted in aqua dam in Bungeni compared to an earthen pond in Vondo. The highest number of phytoplankton species was recorded in June (Table 5. 2). *S. quadricuada*, *Scenedesmus* sp., and *Microcystis* sp. occurred throughout the whole study. Chlorophyta dominated the phytoplankton flora (Figure 5. 2).

Table 5. 2: Composition (no./ml) of phytoplankton species in aqua dam in Bungeni in Vhembe district, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb
Bacillariophyta					
Amphipleura sp	0	0	0	8.22	0
Pinnularia sp	0.92	0.16	0	0	0.16
Navicula sp	8.64	0.64	0	4.44	0
Nitzschia sp	0	0	11.38	0	0
Chlorophyta					
Ankyra sp	0	0	0	0	0.04
Chroococcus sp	4.66	0	0	0	0
Chlorella sp	16.2	27.96	13.42	0	1.86

Closteruim sp	5.14	0	0	0	0
Cosmarium sp	16.5	0	10.14	0	0
Kirchneriella	0	4.74	0	0	0
Micractinium sp	16.72	10.22	13.08	0	1.12
Pandorina sp	11.08	6.78	8.44	0	8.16
Pediastrum sp	3.38	0	0	0	0
S. quadricuada	15	0.96	12.22	9.44	0.82
Scenedesmus sp	19.22	3.92	14.64	25.14	2.2
Selenastrum sp	18.98	0	0	0	0
Tetraedron sp	0	0	0	4.98	3.58
Cryptophyta					
Cryptomonas sp	0.54	6.42	11.42	0	0
Cyanophyta					
Merismopedia elegans	0	0.32	0	0	0
Microcystis sp	26.64	10.22	13.14	4.16	0
Euglenophyta					
Trachelomonas sp	4.36	0	0	0	0
Euglenozoa					
Peranema sp	0	1.68	0	0	0
Ochrophyta					
Mallomonas sp	0	0	0.84	0	0
Total	**167.98**	**74.02**	**108.72**	**56.38**	**17.94**

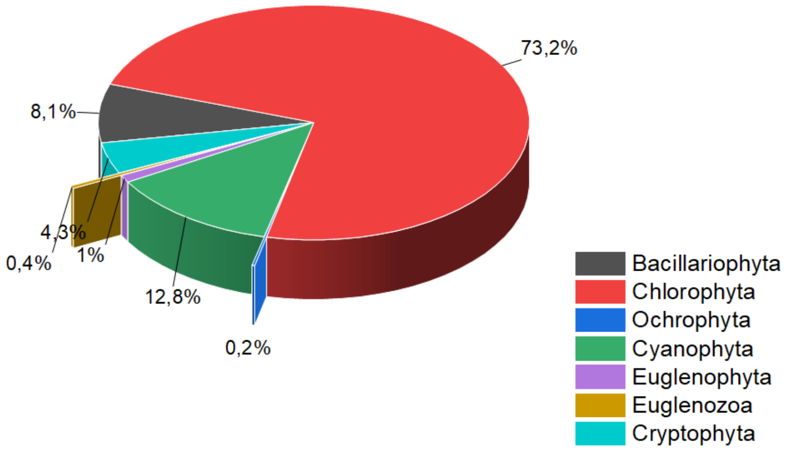


Figure 5. 2: Relative abundance of phytoplankton species identified from aqua dam in Bungeni in Vhembe district.

Six phyla and 25 genera were recorded in the concrete pond in Olifanshoek (Table 5. 3). The concrete pond in Olifanshoek recorded fewer phytoplankton phyla compared to other production systems in Vhembe district (Table 5.3). However, the highest number of phytoplankton species (per ml) was counted in concrete pond in

Olifanshoek compared to the earthen pond and aqua dam in Vhembe district. The highest number of phytoplankton species was recorded in October (Table 5. 3). *Chlorella* sp., *S. quadricuada*, and *Scenedesmus* sp., these three were the most dominant genera occurring throughout the course of the study. Numerically, Chlorophyta dominated the phytoplankton flora (Figure 5.3). Bacillariophyta only contributed 1 % to the phytoplankton composition in the concrete pond in Vhembe district.

Table 5. 3: Composition (no./ml) of phytoplankton species in concrete pond in Olifanshoek in Vhembe district, sampled from June 2019 to February 2020.

	June	Aug	Oct	Dec	Feb
Bacillariophyta					
Pinnularia sp	1.26	0.64	0.36	0.26	0
Navicula sp	1.38	0.3	0.44	0	0
Synedra sp	0	0	0	0.16	0
Chlorophyta					
Actinastrum sp	0	0	0.3	0	0
Chroococcus sp	3.44	2.54	0	0	0
Chlorella sp	20	23.64	48.34	27.64	9.06
Closteruim sp	4.4	15.46	0	0	0
Coelastrum sp	0	0	47.7	0	0
Cosmarium sp	5.1	0.8	2.22	0	0.08
Dictyosphaerium sp	0	0	0.9	1.94	0
Gonium pectrorale	0	0	0	8.28	0
Lagerheimia sp	10.24	0	1.28	0	0
Micractinium sp	8.12	0	0	0	0
Pandorina sp	13.84	6.5	0	1.36	3.62
Pediastrum sp	0	0	0.46	0	0
S. quadricuada	19.36	14.72	28.08	2.1	1.6
Scenedesmus sp	4.06	14.68	31.88	3.06	2.76
Selenastrum sp	3.38	0	0	0	0
Tetraedron sp	0.94	0	0	8.06	8.28
Cryptophyta					
Cryptomonas sp	0	5.68	8.24	1.24	2.24
Cyanophyta					
Aphanocapsa sp	0.78	0	0	0	0
Merismopedia elegans	2.68	1.56	27.04	28.38	0
Microcystis sp	3.56	0	0	0.2	0
Euglenophyta					
Phacus sp	0	0	0	0.1	0
Trachelomonas sp	3.18	0	0	0	0.04
Euglenozoa					
Peranema sp	0	2.58	0	0.24	0.06

Total		105.72	89.1	197.24	83.02	27.74

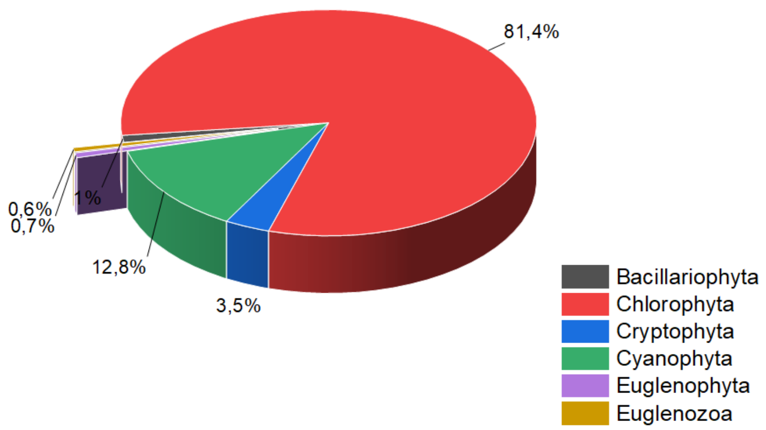


Figure 5. 3: Relative abundance of phytoplankton species in concrete pond in Olifanshoek in Vhembe district.

5.5.2 The relationship of primary production, phytoplankton abundance and tilapia yield

The highest primary production values in all the production systems in Vhembe district was recorded in December in an aqua dam in Bungeni (Table 5.4). The lowest primary production values were recorded in June and October in an earthen pond in Vondo. The highest value in a concrete pond in Olifanshoek was recorded in February (Table 5.4).

Table 5. 4: Mean of gross primary production (gC/m2/yr) in production systems in Vhembe district, sampled from June 2019 to Feb 2020.

Location name	Production system	June	Aug	Oct	Dec	Feb
Vondo	Earthen pond	0.73	1.41	0.62	19.49	16.99
Bungeni	Aqua dam	15.52	25.68	6.08	73.30	7.73
Olifanshoek	Concrete pond	9.36	12.79	9.25	49.71	51.60

Linear regression of primary production and phytoplankton abundance produced a Pearson correlation value of -0.036 and an R^2 value of 0.001, therefore they were no correlation (Figure 5.4). Moreover, the correlation of primary production and phytoplankton abundance was not statistically different (p>0.05).

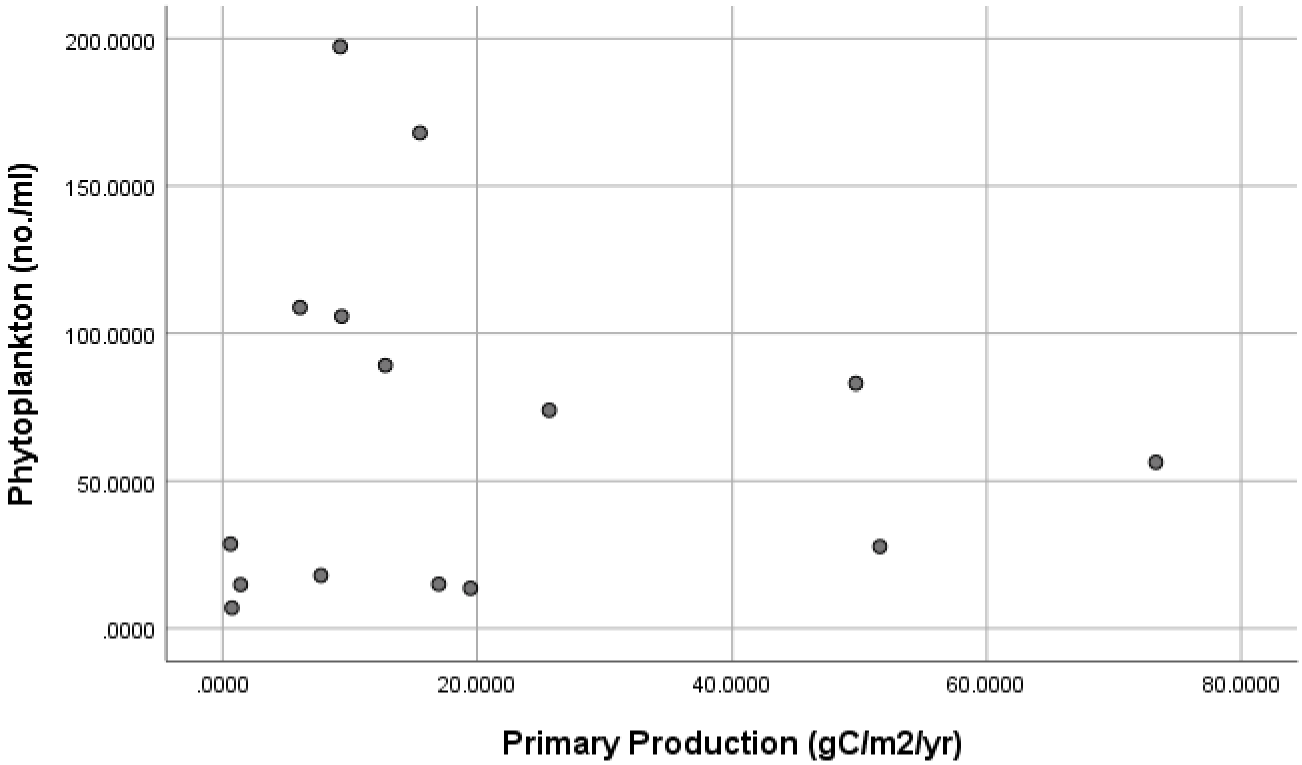


Figure 5. 4: The correlation of primary production and phytoplankton abundance in fish production systems in Vhembe district

5.5.3 The effect of phytoplankton abundance on tilapia yield in different production systems

The eigenvalues of the correlation matrix of phytoplankton genera and production systems in Vhembe district showed that axis one explained 64.4 % of the variation and axis two explained 35.6 % of the variation. The sum of all eigenvalues was 0.695 (Table 5.5).

Table 5. 5: Eigenvalues of the correlation matrix of phytoplankton genera and production systems in Vhembe district.

Total Variance		
Axes	1	2
Eigenvalues	0.447	0.248
Species-environment correlation	1.00	1.00

Cumulative percentage variance	64.4	100.0
Total variation		0.695

CCA plot showed that an earthen pond in Vondo, that has a tilapia yield of 0.00119 kgm^{-2}, was associated with *Pinnularia* sp., *Gymnodinium* sp., and *Synedra* sp. (Figure 5. 6). Aqua dam in Bungeni was associated with *Pediastrum* sp., *Amphipleura* sp., and *Kirchneriella* sp. An aqua dam in Bungeni had a tilapia yield of 0.3115 kgm^{-2}. The concrete pond (0.1811 kgm^{-2}) in Olifanshoek was associated with more phytoplankton genera compared to an aqua dam and earthen pond. Concrete pond in Olifanshoek was associated with *Lagerheimia* sp., *Peranema* sp., *Dictyosphaerium* sp., *Merismopedia* sp., *Coelastrum* sp., and *Gonium* sp. (Figure 5. 5).

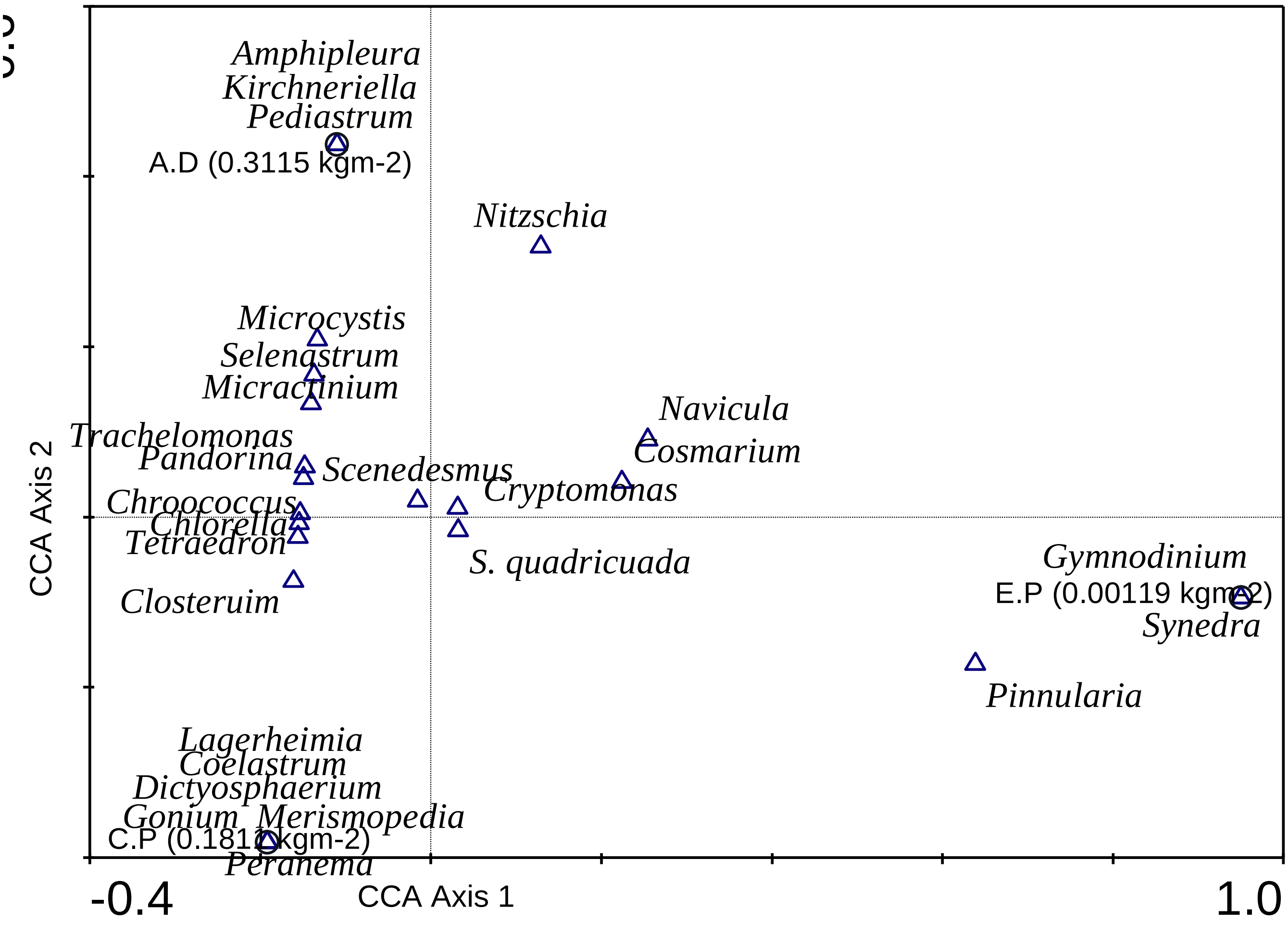


Figure 5. 5: CCA plot of the association of phytoplankton genera and production systems in Vhembe district (A.D -aqua dam; C.P -concrete pond; and E.P -earthen pond).

5.6 DISCUSSION

Earthen pond in Vhembe district was dominated by phytoplankton flora belonging to Bacillariophyta and Chlorophyta. *Pinnularia* sp., *Synedra* sp., and *Cosmarium* sp. were the most occurring genera throughout the study period. CCA showed that earthen pond in Vondo was associated with *Gymnodinuim* sp., *Pinnularia* sp., and *Synedra* sp. Moreover, the earthen pond had the lowest flora compared to aqua dams and concrete ponds. This is because an earthen pond had constant incoming spring water into the pond throughout the course of the study. Possibly the rate of incoming water flushed the phytoplankton out of the pond, or the fish were feeding on most of the phytoplankton in the pond. The abundance of *Pinnularia* sp. is because of the earthen pond bottom sediment, *Pinnularia* sp. are a common benthic genus living on stones and sediment (Janse van Vuuren *et al*., 2006). The abundance of *Synedra* sp. is explained by the constant incoming water because they are a free-living genus usually found in open waters such as lakes, dams, and rivers (Janse van Vuuren *et al*., 2006). Species belonging to Chlorophyta are tolerant to a variety of conditions and they usually do well as long as they are exposed to sunlight (Mette *et al.*, 2011). *Cosmarium* sp. are extremely widespread and common worldwide and are mostly free-floating in lakes, reservoirs, ponds (Janse van Vuuren *et al*., 2006).

The concrete pond in Olifanshoek, Vhembe district was dominated by Chlorophyta and Cyanophyta phyla. The highest number of phytoplankton species was recorded in October. *Chlorella sp., S. quadricuada,* and *Scenedesmus* sp., predominated throughout the whole study period. CCA showed it was associated with *Lagerheimia* sp., *Peranema* sp*., Dictyosphaerium* sp., *Merismopedia* sp., *Coelastrum* sp., and *Gonium* sp. These were the most abundant genera in the concrete pond in Olifanshoek. The concrete pond in Olifanshoek has more phytoplankton flora than an earthen pond and aqua dam in Vhembe district. The rough surface of concrete ponds acts as a better substrate to support phytoplankton species growth, unlike the plastic material of aqua dams. The high abundance of phytoplankton may be explained by the accumulation of nutrients in a pond because there was no incoming water into the pond. The abundance of genera such as *Chlorella* sp. and *Scenedesmus* sp. can be accounted for by the accumulation of nutrients in the pond. These genera are widespread and common, free-living in all climates (Janse van Vuuren *et al*., 2006). The abundance of Cyanophyta can be explained by their robustness and ability to outcompete most algal species because they are resilient and can form larger colonies that can rise to the surface more quickly and benefit from harnessing available light (Sitoki *et al.,* 2012; Rumisha & Nehemia, 2013). There was no consistency in the association of phytoplankton abundance and production systems, the concrete ponds in Capricorn and Vhembe district are associated with different phytoplankton genera.

Aqua dam in Bungeni was dominated by Chlorophyta and Cyanophyta. *S. quadricuada*, *Scenedesmus* sp., and *Microcystis* sp. occurred throughout the whole study period. It was associated with *Pediastrum* sp., *Amphipleura* sp., and *Kirchneriella* sp. The abundance of these phytoplankton may be explained by the fact that the aqua dam in Bungeni had no constant incoming water therefore could not lose fertility in the water flowing out of the tank as compared to the earthen pond which had incoming water. Species belong to *Pediastrum* sp. are widespread and common in most standing and slow-flowing freshwaters such as swamps, bogs, ditches, and ponds (Janse van Vuuren *et al*., 2006). The presence of Chlorophyta species is an indication that the aqua dams had sufficient nutrient concentrations for the growth of phytoplankton species. Species belong to *Microcystis* sp., and *Scenedesmus* sp. are commonly found in eutrophic conditions and also hypereutrophic waters (Yilmaz *et al*., 2018). *S. quadricuada*, and *Scenedesmus* sp. were abundant in the concrete pond and aqua dam because they both did not have incoming water into the system. The aqua dams in Capricorn and Vhembe district are associated with different phytoplankton genera meaning there was no consistency in the association of phytoplankton abundance and production systems.

Different production systems promote the growth of different phytoplankton systems because of the material of the system. However, Bacillariophyta, Chlorophyta and Cyanophyta were the most abundant phyla in all the production systems. As mentioned in the previous chapter, the abundance of phytoplankton species, specially Bacillariophyta, in production systems does not mean they were digested and assimilated by tilapia. This study showed that phytoplankton species may be abundant in production systems but not correlated with primary production level. Primary production and tilapia yield were also not correlated. This might be explained by the type of feed the farmers were feeding. Factors such as plankton species composition, fish stocking density, nature of fertilization and feeding intensity have an influence on the correlation of primary production and fish yields in a production system (Olih *et al*., 1986). Primary production in production systems in Vhembe district ranged from 0.62 to 73.30 gC/m2/yr. The range of these values was below those found in published literature for other ponds. When converted to carbon values and calculated per year, primary production in a study by Geertz-Hansen *et al*. (2011) ranged from 123.18 to 1245.56 gC/m2/yr and it ranged from 492.75 to 971.81 gC/m2/yr in a study by Klotz (2013). In the previous chapter, published literature showed that primary production can range from 301.1 to 2053.1 gC/m2/yr. Low primary production values may be explained by the fact that the productive potential of these production systems is often not utilized to the maximum due to extreme low stocking densities (Olih *et al*., 1986).

Similar to other studies, Bacillariophyta, Chlorophyta, Cyanophyta, and Euglenophyta were common phytoplankton phyla identified (Grubach, 2010; Salazar *et al*., 2016; Sipaúba-Tavares *et al*., 2011; Das *et al*., 2018; Mohamed *et al.,* 2019). As mentioned in the previous chapter, the similarity in plankton composition in aqua dams and concrete ponds might be explained by the existence of similar concentrations of nutrients, and water quality in the production systems. Although light intensity was not measured in the present study, all production systems were free from aquatic vegetation and were well exposed to sunlight, thus had equal access to light.

In conclusion, the results of this chapter were similar to the previous chapter. The earthen ponds, concrete ponds, and aqua dams in Vhembe districts have different phytoplankton abundance. The concrete pond in Olifanshoek had the highest total plankton composition compared to all the production. The earthen pond in Vondo had the lowest flora compared to all the production systems. The abundance of phytoplankton species in fish production systems is not always correlated to primary production. As mentioned in the previous chapter, primary production was correlated to tilapia yield and phytoplankton abundance. Phytoplankton abundance was also not correlated to tilapia yield in production systems in Capricorn and Vhembe districts. The high abundance of phytoplankton species in a production system does not always result in high tilapia yield, since phytoplankton ingestion by the fish does not mean they were digested and assimilated by fish.

CHAPTER 6: SOCIO-ECONOMIC FACTORS AFFECTING TILAPIA PRODUCTION IN CAPRICORN AND VHEMBE DISTRICTS.

6. SOCIO-ECONOMIC FACTORS AFFECTING TILAPIA PRODUCTION IN CAPRICORN AND VHEMBE DISTRICTS.

6.1 INTRODUCTION

Most fish farmers in rural areas around the world have been involved in tilapia farming because of its profitability (Hossain *et al*., 2013; Toma *et al*., 2015; Ferdoushi *et al*., 2019). In places like Bangladesh, tilapia farming has been proved to be a more profitable business than rice cultivation (Islam *et al*., 2002; Hossain *et al*., 2013). Tilapia farmers can get a minimum of two yields in a year since tilapia can reach a marketable size of 100 to 150 grams within four months of its culture period (Hussain *et al*., 2004; Rahma *et al*., 2012; Toma *et al*., 2015; Ferdoushi *et al.,* 2019). But tilapia farmers in Limpopo Province, particularly in Capricorn and Vhembe districts, culture tilapia for a year without the fish reaching a marketable size. The increase in tilapia production levels in Africa (FAO, 2018), is evidence that highlights tilapia market potential in the aquaculture industry including in Limpopo Province. Although there are several tilapia producers in Capricorn and Vhembe districts of Limpopo Province, the major challenge is that most of them do not produce efficiently. The failure to farm tilapia to reach a marketable size to attract buyers prevents them from obtaining a competitive price for their product. Tilapia produced by these rural farmers is sold to the neighbours and consumed by the family (Coche & Muir, 1998; El-Sayed, 2006). Moreover, due to poor marketing and the lack of coordination among farmers in marketing their products, locally produced tilapia is not able to compete with the imported fresh and frozen tilapia (Ridha, 2006; Moyo & Rapatsa, 2021).

Tilapia production might be affected by external factors that cannot be controlled such as tilapia demand in the market and increasing production costs (Yuan *et al*., 2017). But that does not mean tilapia have no potential in the market. As much as the cost of production in aquaculture varies with local environmental and economic conditions (Shang, 1985), rural farmers around the world find it to be a profitable business (Toma *et al*., 2015). Profitable aquaculture operations are achieved through a better understanding of biological, physical, and economic factors as well as their interrelationships in the entire production process (Shang, 1985). Yet, no appreciable study has been done on such factors in tilapia production in Limpopo Province.

Fundamentally, the popularity of farming tilapia is associated not only with its potential as a source of food but also as an attractive investment activity (Sevilleja, 2002). However, most tilapia farmers in Capricorn and Vhembe districts are performing poorly (DAFF, 2018). Low competitiveness or comparative advantage of products combined with inappropriate productive factors that lead to lack of cost-effectiveness can result in poor economic performance (Barroso *et al*., 2019). Thus, it's vital to determine socio-economic factors and the market performance of tilapia in rural communities of Limpopo Province.

6.2 OBJECTIVE

To identify the most important socio-economic factors critical for the success of tilapia production in Capricorn and Vhembe districts.

6.3 NULL HYPOTHESIS

There are no important socio-economic factors critical for the successful tilapia production in Capricorn and Vhembe districts.

6.4 MATERIALS AND METHODS

6.4.1 Description of the study site

Refer to chapter three section 3.4.1

6.4.2 Data collection

Primary data was collected using a structured questionnaire. The study was conducted in accordance with the University of Limpopo's ethical committee regulations. Tilapia farmers in Capricorn and Vhembe districts were interviewed face to face in the comfort of their homes, and the questions were simplified and translated to their level of understanding. Capricorn and Vhembe districts were selected for this study because they have different environmental conditions due to their geographic locations. Capricorn district has a total of six tilapia farmers and Vhembe district has fifty-four tilapia farmers. The questionnaires were distributed to farmers who were willing to participate in the study. Twenty tilapia farmers were interviewed, fifteen in Vhembe district and five in Capricorn district because few farmers were willing to participate in the study. Personal interviews allowed the researcher to clarify, explain and probe for information from the farmers. The questionnaire contained five sections (Appendix A). These were: general information, the relative importance of key success factors in aquaculture, factors relating to industry attractiveness, factors relating to cost advantage, factors relating to differentiation advantage. The farmers were to rank and rate the factors in order of importance when answering the questions. Key success factors in aquaculture were ranked from 1 to 8, where 1 is the least important through to 8 being the most important. Factors relating to sector attractiveness were ranked from 1 to 6, where 1 is the least important and 6 the most important. The factors relating to cost advantage were ranked from 1 to 10, where 1 is the least important and 10 most important. Factors relating to differentiation advantage were also ranked from 1 to 10, where 1 is the least important and 10 most important.

6.4.3 Determination of tilapia yields

Refer to chapter three section 3.4.4 for tilapia yield

6.4.4 Statistical analyses

Microsoft Excel 2013 was used to rank the relative importance of factors. It ranked factors from largest to smallest (according to values given by farmers when ranking), giving the value one to factors which were ranked very/most important. Microsoft Excel 2013 was also used to plot graphs. Canoco (4.5) was used to run Principal Component Analysis (PCA). PCA was used to determine the most important socio-economic factors affecting tilapia production in Capricorn and Vhembe district.

6.5 RESULTS

6.5.1 The relative importance of factors

KEY SUCCESS FACTORS FOR TILAPIA PRODUCTION

Farmers in Capricorn district ranked “value chain accessibility” and “appropriate technology approach” as the most important key factors followed by “financial consideration” (Figure 6.1). Farmers in Vhembe district ranked “financial consideration” and “human resources” as the most important factors followed by “appropriate technological approach”. Tilapia farmers in both districts ranked “site location” and “biological factors” as the least important factors (Figure 6.1).

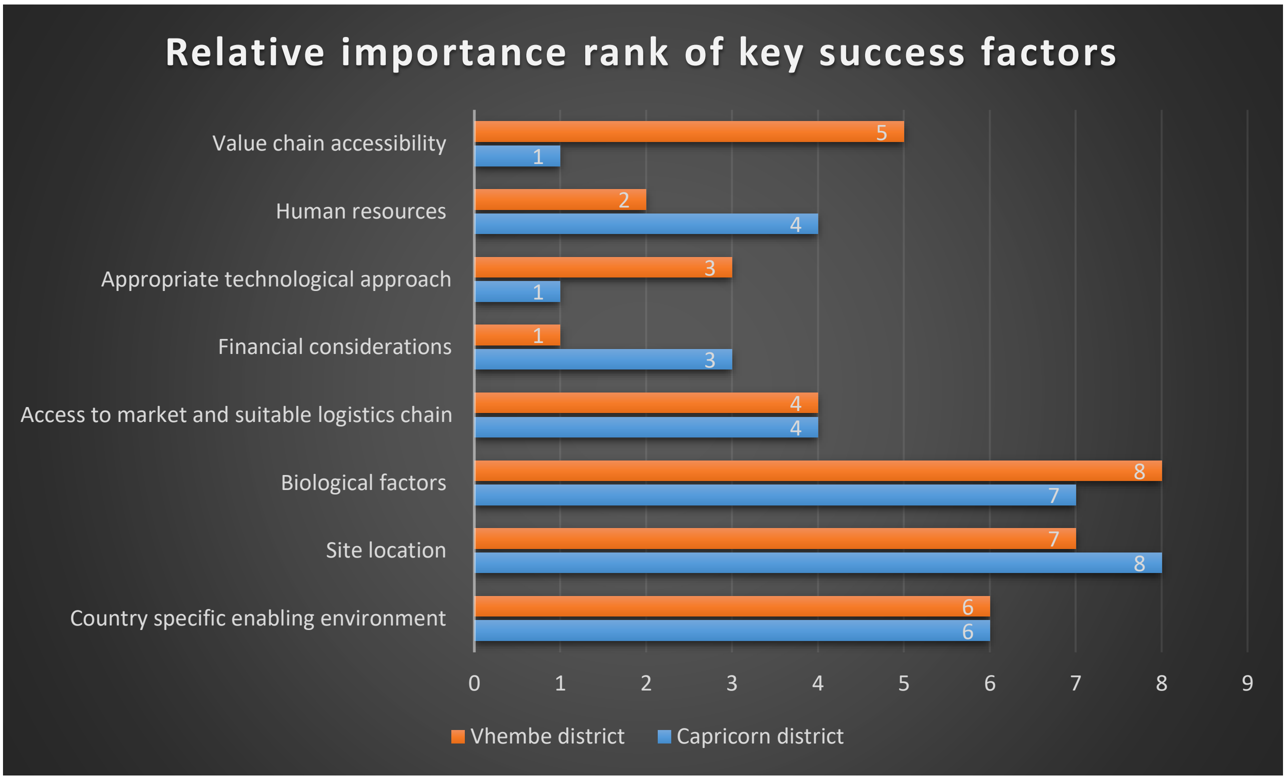


Figure 6. 1: Ranking of relative importance of key success factors for aquaculture in Capricorn and Vhembe districts.

FACTORS INFLUENCING INDUSTRY ATTRACTIVENESS

Farmers in both districts ranked “market factors” as the most important factor” (Figure 6.2). In Capricorn district, “natural strategic advantage” and “barriers to entry” were ranked as the second most important factors. Vhembe district farmers ranked “sector structure” as the second most important factor (Figure 6.2). Vertical bargaining power was ranked as the least important factor in both districts.

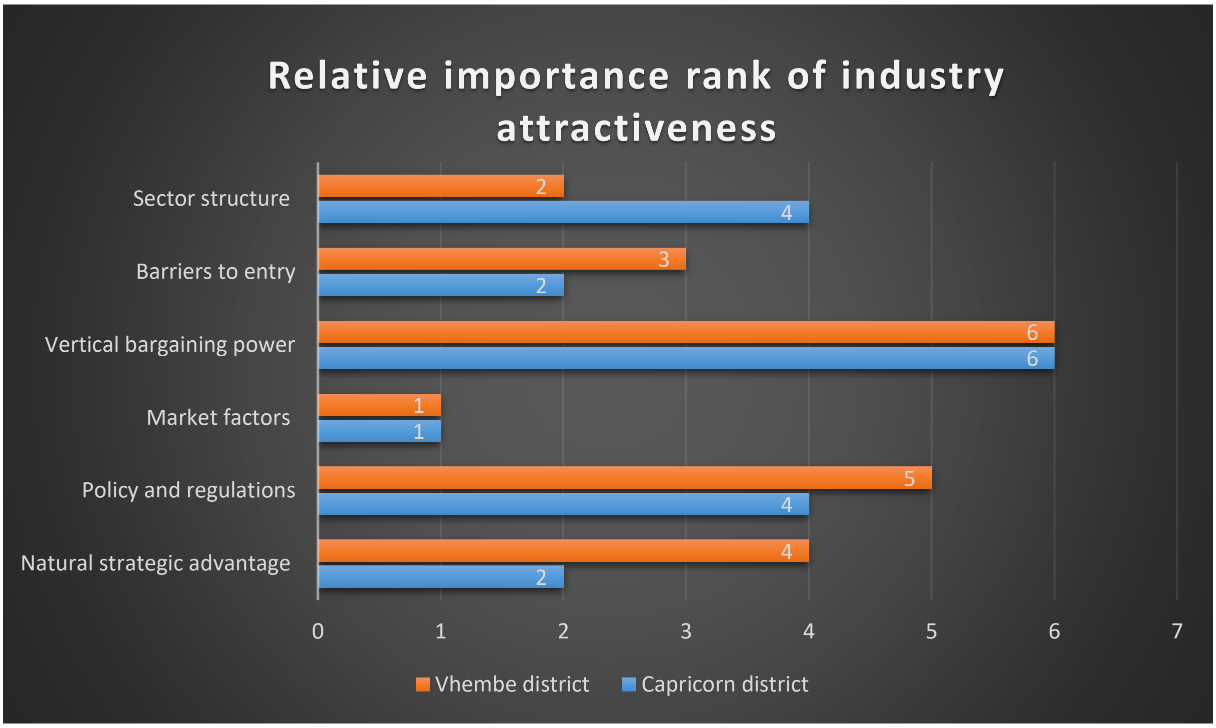


Figure 6. 2: Ranking of factors influencing tilapia aquaculture industry attractiveness in Capricorn and Vhembe districts

FACTORS INFLUENCING COMPETITIVE ADVANTAGE

Competitive advantage is made up of two separate components, namely cost advantage and differentiation advantage. Each component has factors used to identify an industry competitive advantage. In terms of the relative importance of cost advantage measures, “access to investment funding” followed by “ability to access input” were ranked as the most influential factors by farmers in Vhembe district (Figure 6.3). Farmers in Capricorn district ranked “level of operational integration” as the most important factor. Ability to access input, “access to technology for culture & processing”, “scale economies”, “access to investment funding” and “technological approach” were ranked the second most important factors (Figure 6.3). Both districts ranked “exchange rate hedging instruments” and “absence of duties and taxes on input” as the least influential factors.

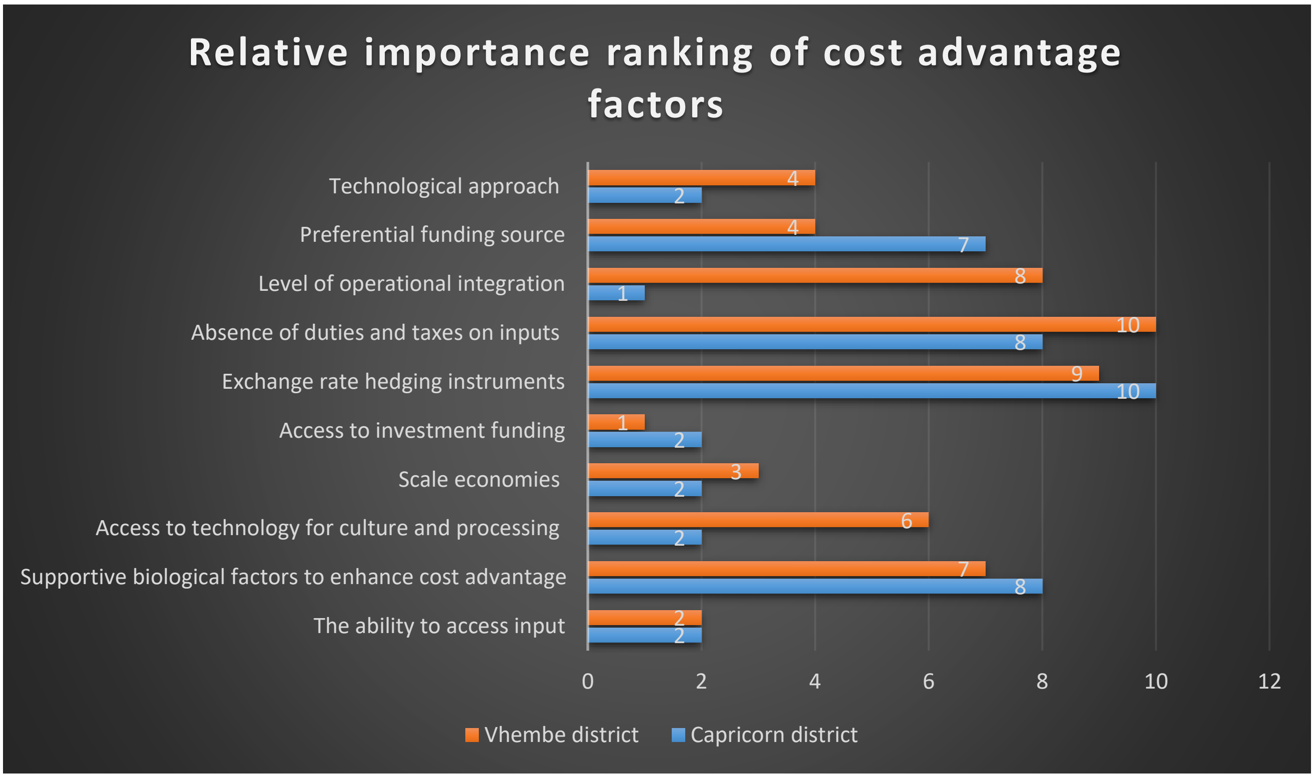


Figure 6. 3: Ranking of factors influencing cost advantage of tilapia aquaculture in Capricorn and Vhembe district

In terms of the relative importance of differentiation advantage measures, “access to multiple market destinations” was ranked as the most influential factors in both districts (Figure 6.4). The ability to export products was ranked as the second most influential in by farmers Capricorn district (Figure 6.4). Farmers in Vhembe district ranked “ability to direct market” as the second most important factor. Farmers in Capricorn district ranked “level of product innovation” as the least important factor and Farmers in Vhembe district ranked “duties and tariffs in target markets” as the least important factor (Figure 6.4).

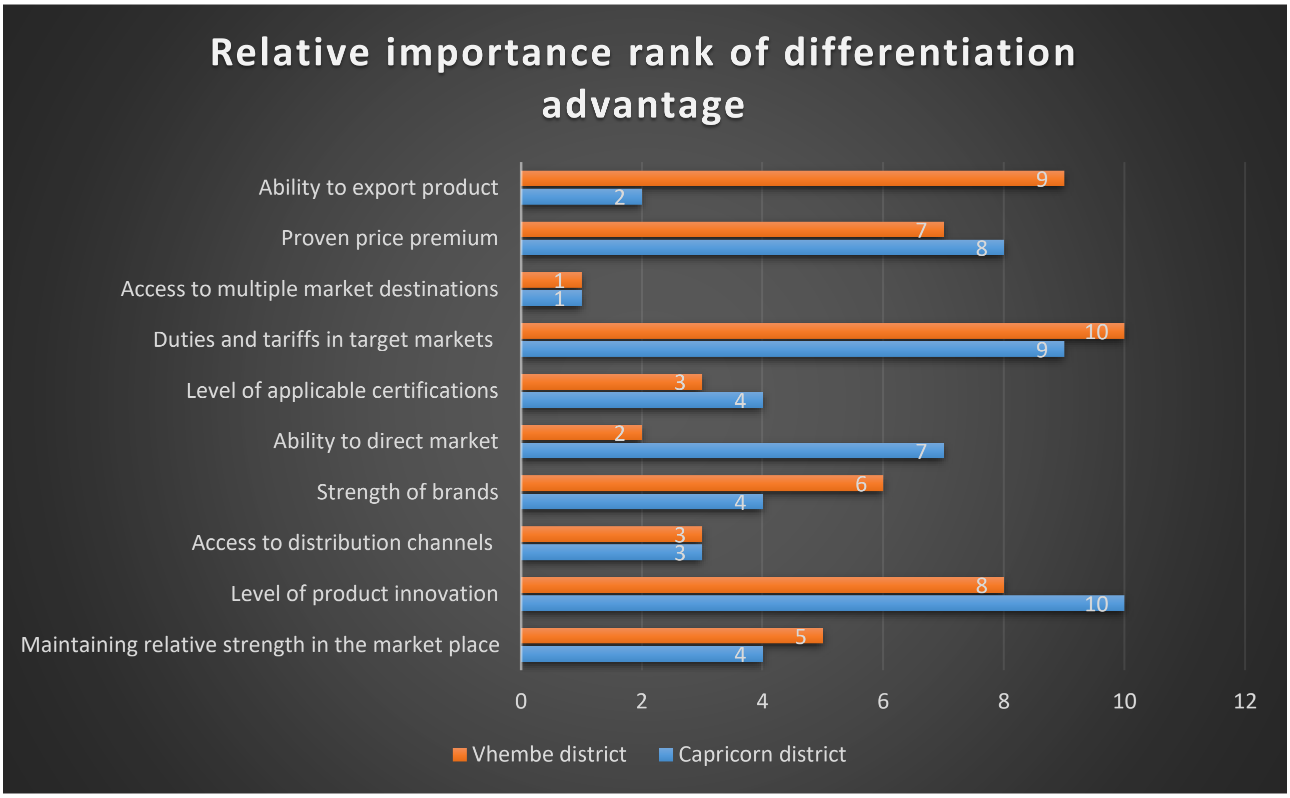


Figure 6. 4: Ranking of factors influencing differentiation advantage in Capricorn and Vhembe districts.

6.5.2 Most influential factors in Capricorn and Vhembe district.

FACTORS INFLUENCING PRODUCTION IN CAPRICORN DISTRICT.

All the extracted communalities are high and acceptable (p >0.5). All extracted factors in both districts have the value of one (Table 6.1), thus one table represents the communalities for Capricorn and Vhembe district. Eigenvalues showed that the first two principal components are the most significant in Capricorn district. Principal component (PC) 1 explained 67.3 % of the total variance and PC 2 explained 21.8 % variance of socio-economic factors affecting tilapia farming in Capricorn district (Table 6.2).

Table 6. 1: Communalities of socio-economic factors affecting tilapia production in Capricorn and Vhembe district.

Communalities		
	Initial	Extraction
Financial considerations	1.000	1.000
Appropriate technological approach	1.000	1.000
HR	1.000	1.000
Value chain accessibility	1.000	1.000
Natural strategic advantage	1.000	1.000
Market factors	1.000	1.000
Barriers to entry	1.000	1.000
Sector structure	1.000	1.000
Ability to access input	1.000	1.000
Access to technology for culture	1.000	1.000
Scale economies	1.000	1.000
Access to investment funding	1.000	1.000
Level of operational integration	1.000	1.000
Preferential funding source	1.000	1.000
Technological approach	1.000	1.000
Access to distribution channels	1.000	1.000
Ability to direct market	1.000	1.000
Level of applicable certifications	1.000	1.000
Access to multiple market	1.000	1.000
Ability to export product	1.000	1.000

Table 6. 2: Eigenvalues of socio-economic factors affecting tilapia production in Capricorn district.

Total Variance			
Principal Components	1	2	3
Eigenvalues	0.673	0.218	0.109
Cumulative percentage variance	67.3	89.1	100

PC 1 had a strong loading of “barriers to entry”, “level of operational integration”, “technological approach (RAS)”, “access to distribution channels”, “ability to direct market”, “access to multiple market destinations”, “scale economies”, “ability to access input”, “market factors”, and “HR” (Table 6.3). PC 2 had a strong loading “sector structure”, “access to investment funding”, “level of applicable certifications”, “financial considerations”, and “ability to export product” (Table 6.3). Negative loadings of factors associated with PC1 and PC 2 suggest that there was an existence of inverse correlation between the principal component and the variables and that the direction of the variables in the PC was going on a single dimension vector.

Table 6. 3: Correlation matrix of socio-economic factors affecting tilapia production in Capricorn district.

Component Matrix		
	1	2
Financial considerations	-0.3486	-0.7632
Appropriate technological approach	-0.6449	0.0799
Human Resources (HR)	-0.8234	-0.4917
Value chain accessibility	-0.6449	0.0799
Natural strategic advantage	0.6449	-0.0799
Market factors	0.8234	0.4917
Barriers to entry	-0.9959	-0.0397
Sector structure	0.0290	-0.9912
Ability to access input	-0.8581	0.3571
Access to technology for culture and processing (technology for culture)	-0.2512	-0.1321
Scale economies	-0.8581	0.3571
Access to investment funding	-0.1064	-0.9143
Level of operational integration	-0.9959	-0.0397
Preferential funding source	0.0596	0.3865
Technological approach (RAS)	-0.9959	-0.0397
Access to distribution channels	-0.9959	-0.0397
Ability to direct market	-0.9959	-0.0397
Level of applicable certifications	0.3960	-0.8555
Access to multiple market destination	-0.9959	-0.0397
Ability to export products	-0.5606	0.6265

A concrete pond in Molepo that has a tilapia yield of 0.0312 kgm^{-2} was associated with “HR”, and “technology for culture” (Figure 6.5). A RAS system, 0.5451 kgm^{-2}, in Veekraal was associated with the “ability to exports products”. Aqua dam (0.5751 kgm^{-}

²) in Mahlahle was associated with “natural strategic advantage” and “market factors” (Figure 6.5). An aqua dam that has a tilapia yield of 0.0954 kgm^{-2} in Mothole was associated with “access to investment funding”, and “financial consideration” (Figure 6.5).

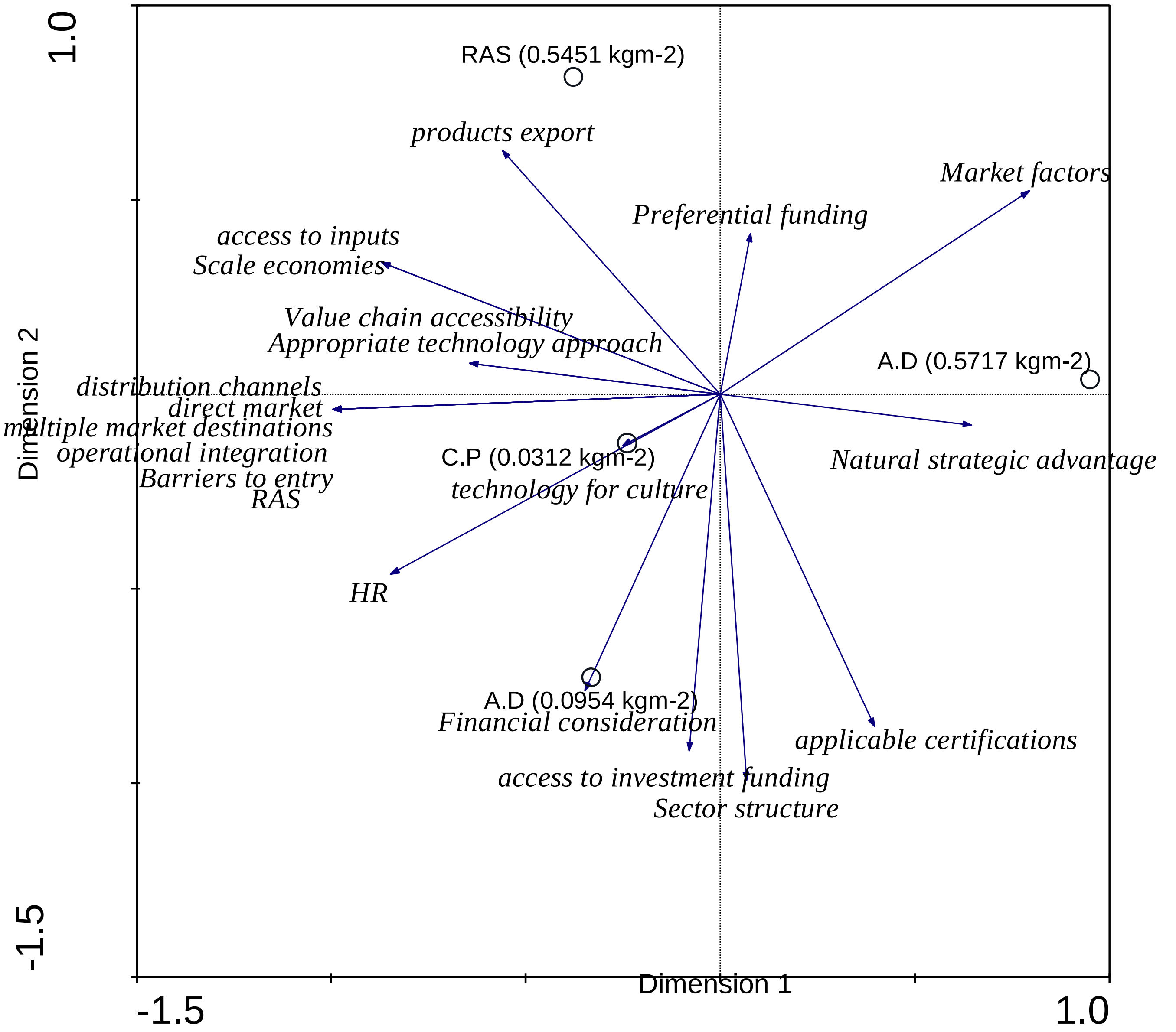


Figure 6. 5: PCA biplot distribution of socio-economic factors affecting production in tilapia farming in Capricorn district, in respect to component 1 and 2. (A.D -aqua dam; C.P -concrete pond; and RAS- aquaculture recirculating system).

FACTORS INFLUENCING PRODUCTION IN VHEMBE DISTRICT

The first two principal components explained 96.6 % of the total variance in Vhembe district (Table 6.4). PC 1 explained 80.4 and PC 2 explained 16.2 % of the total variance of socio-economic factors affecting tilapia production in Vhembe district.

Table 6. 4: Eigenvalues of socio-economic factors affecting tilapia production in Vhembe district.

Total Variance			
Principal Components	1	2	3
Eigenvalues	0.804	0.162	0.032
Cumulative percentage variance	80.4	96.6	100

PC 1 had a strong loading of “access to technology for culture and processing”, “access to investment funding”, “preferential funding source”, “level of operational integration”, “ability to direct market”, “access to multiple market destination”, “value chain accessibility”, “sector structure”, and “access to distribution channels” (Table 6.5). PC 2 had strong loading of “market factors”, “ability to export product”, “appropriate technological approach”, “barriers to entry”, and “natural strategic advantage” (Table 6.5). Negative loadings of factors associated with PC1 and PC 2 suggest that there was an existence of inverse correlation between the principal component and the variables and that the direction of the variables in the PC was going on a single dimension vector.

Table 6. 5: Correlation matrix of socio-economic factors affecting tilapia production in Vhembe district.

Component Matrix		
	1	2
Financial considerations	0.1653	-0.6867
Appropriate technological approach	0.4406	-0.8747
Human Resources (HR)	-0.1245	-0.2824
Value chain accessibility	-0.9398	0.0454
Natural strategic advantage	-0.4796	-0.8681
Market factors	0.2016	-0.9764
Barriers to entry	0.4406	-0.8747
Sector structure	-0.9398	0.0454
Ability to access input	0.1239	-0.6976
Access to technology for culture and processing (technology for culture)	-0.9851	-0.0798
Scale economies	-0.6206	-0.2825
Access to investment funding	-0.9851	-0.0798
Level of operational integration	-0.9845	0.0025
Preferential funding source	-0.9851	-0.0798
Technological approach (RAS)	-0.1673	0.2334
Access to distribution channels	-0.9370	-0.1160
Ability to direct market	-0.9832	-0.1512
Level of applicable certifications	0.1239	-0.6976
Access to multiple market destination	-0.9750	-0.1636
Ability to export product	0.3036	-0.9427

The concrete pond (0.1811 kgm^{-2}) in Olifanshoek was not associated with any of the socio-economic factors affecting tilapia production in Vhembe district (Figure 6.6). The RAS system (0.1872 kgm^{-2}) in Elim was associated with a “technological approach (RAS)”. An aqua dam (0.3115 kgm^{-2}) in Bungeni was associated with “natural strategic advantage” and an earthen pond (0.001194 kgm^{-2}) in Vondo was associated with “HR” (Figure 6.6).

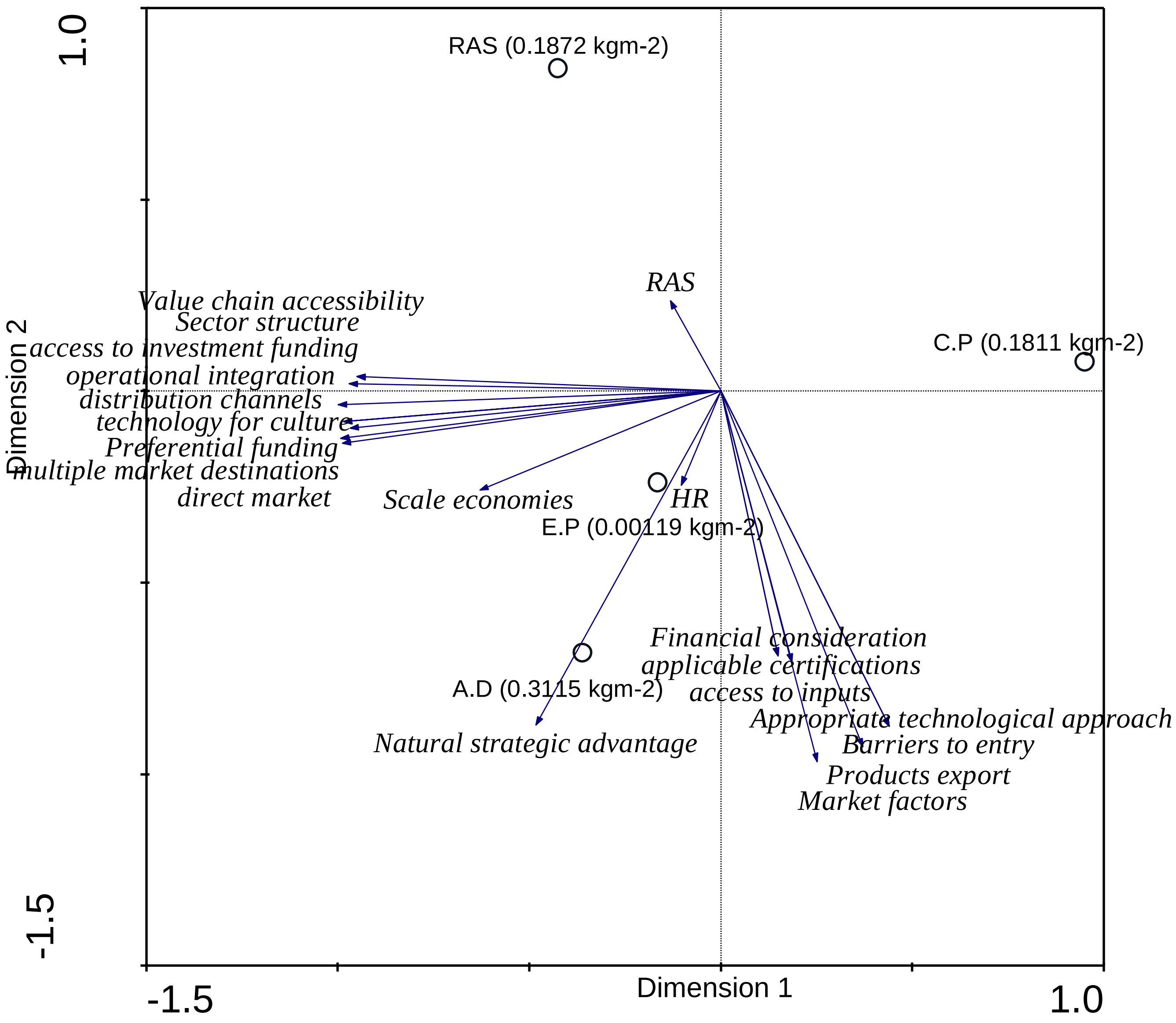


Figure 6. 6: Component biplot distribution for socio-economic factors affecting production in tilapia farming in Vhembe district, in respect to component 1 and 2. (A.D -aqua dam; C.P -concrete pond; E.P -earthen pond; and RAS- aquaculture recirculating system)

6.6 DISCUSSION

Value chain accessibility and “appropriate technology approach” were ranked as the most important factors influencing the production of tilapia in Capricorn district. PC 1 also showed that “value chain accessibility” had strong loading thus causing variation. This might be explained by the lack of operational hatchery and veterinary services in Limpopo Province (Rouhani & Britz, 2004). The lack of operational hatchery and veterinary services can lead to poor fingerlings quality which in the long run it affects tilapia production as a result of stunted growth in ponds (Shitote *et al*., 2013; Olaoye *et al*., 2014; Amenyogbe *et al*., 2018; Opiyo *et al*., 2018; Mulokozi *et al*., 2020). Moreover, no value chain studies has been done in Limpopo Province. Value chain accessibility and “appropriate technological approach” also caused variation in Vhembe district, and it had a strong loading proving that both districts are affected by these factors. Vhembe district ranked “financial consideration” and “human resources” as the most important factors influencing the production of tilapia. PC 1 also showed that “financial consideration” and “human resources” had a strong loading. Human resources were associated with an earthen pond (0.001194 kgm^{-2}) in Vondo. Human resources deal with requisite farming skills, manpower and experience in tilapia farming while financial consideration focuses on access to funding by farmers. Farmers ranked these factors as the most important factors because access to funding and services is necessary to create, maintain, expand, increase efficiency, and meet seasonal operating cash flow in aquaculture (Hishamunda & Manning, 2002). According to Dasgupta and Durborow (2009), small-scale productions has higher per-unit production costs and higher break-even prices than large-scale operations. Thus, making products of small-scale aquaculture less competitive and difficult to market (Osawe & Salman, 2016). Capricorn district also had strong loading on financial consideration, and it was associated with an aqua dam in Mothole with a tilapia yield of 0.0954 kgm^{-2}, proving that it has a negative effect on tilapia farming on both districts. Access to funding in the form of loans is important since most tilapia farmers lack their own equity as result, they depend on external funding to start and grow aquaculture business (Mpandeli & Maponya, 2014; Khapayi & Celliers, 2016). Tilapia farming requires adequate capital and farmers need loans to meet farm fixed financial obligations, more especial in the first production cycle. The lack of capital remains one of the biggest barriers to aquaculture development in South Africa because most banks are reluctant to give loans to rural aquaculture farmers because they are regarded as a high-risk group (Moyo & Rapatsa, 2021). Human resources were also ranked as the most important factor. It is well known that aquaculture can be highly technical. Farmers need knowledge and skills to culture the fish (monitor and control the physical environmental and biological parameter to optimize growth). Its strong loading may be explained by the fact that most farmers come into the aquaculture industry without any knowledge or skills related to aquaculture (FAO, 2010; AgriSETA, 2020). Factors such as "site location" and "country specific enabling environment" were ranked as the least important factors in both districts. As much as species (biological factors) and site location through environmental suitability are important factors, farmers in Capricorn and Vhembe districts do not consider them important since the environment mostly allow tilapia farming in ponds and similar impoundments such as aqua dams.

Factors relating to industry (tilapia production) attractiveness shows how one industry compares to alternative industries in terms of its potential to deliver profitable returns. Farmers in Capricorn and Vhembe districts, under the industry attractiveness section, ranked "market factors" as the most important factor affecting tilapia production. PC 1 also showed that "market factors" together with "barriers to entry" and "natural strategic advantage" had strong loading in Capricorn district. Natural strategic advantage and "market factors" were associated with an aqua dam in Mahlanhle (0.5717 kgm^{-2}) while "barriers to entry" was associated with a concrete pond Molepo (0.0312 kgm^{-2} tilapia yield). Market factors include factors such as market size, growth potential and levels of product innovation. These factors are the important driving force influencing aquaculture development in developing economies. Barriers to entry include factors such as licences and access to infrastructure. Farmers in Limpopo Province lack operational hatchery (Rouhani & Britz, 2004). Therefore, the lack of brood-stocks together with poor fingerling's production management results in a high rate of inbreeding. Moreover, the lack of diversified strains and Genetically Improves Farmed Tilapia (GIFT) strains (due to licences) that easily adapt to different environmental conditions is one of the bottlenecks hindering tilapia farming. Genetic improvement (product innovations) is one of the most powerful and least expensive means of increasing the efficiency of aquaculture (Ponzoni *et al.*, 2007), and technological innovations in farming equipment's can reduce the complications and efforts in fish farming (Barroso *et al*., 2019). Market factors are important since the success of tilapia culture depends on the marketability of the products and the efficient use of the available resources to maximize production (Matlala *et al.*, 2013). The tilapia market is growing because of the wider acceptance of the species at the international markets (Zhao, 2011). However, the local market is less rewarding and yet developing (Matlala *et al.,* 2013). Currently, most of the fish ponds are run at a family level because tilapia aquaculture is not seen as a profitable enterprise by most rural communities (Moyo & Rapatsa, 2021). Identifying market opportunities will help farmers to develop a market-based production plan and also marketing plans (Dasgupta & Durborow, 2009).

The level of operational integration is one of the factors influencing cost advantage, and Capricorn district ranked it as the most important factor affecting tilapia production. PC 1 showed that the “level of operational integration” together with “technological approach (RAS)” had a strong loading and caused variation in Capricorn district. Preferential funding source and “access to technology for culture and processing” are also cost advantage factors that had strong loading on PC 2 in Capricorn district. The integration of tilapia farming with livestock production and crops is important, and it is economically and environmentally sound. For instance, fish ponds silt is an excellent fertilizer for land crops and is commonly used by farmers (FAO, 1979). Since there is water scarcity in most of Africa (WWF, 2002), pond water may also be used for irrigating crops. The commune members can also be considered as an element in this type of integration and recycling, as they eat fish and other farm products and human and animal wastes are used to fertilize ponds and cropland (FAO, 1979). Considering the economic conditions of Limpopo Province (Kongolo, 2009), integration serves the major purpose of providing cheap feedstuffs and organic manure for the fish ponds. Thus, reducing the cost and need for providing compounded fish feeds and chemical fertilizers, by reducing the cost of fertilizers and feedstuffs the overall cost of fish production is reduced and profits increased. (FAO, 1979; Little & Edwards. 2003; El-Sayed, 2006; Soliman & Yocout, 2016). In Vhembe district, PC 1 showed that “level of operational integration”, “access to technology for culture and processing”, and “preferential funding source” also had a strong loading together with “access to investment funding”, and “scale economies”. Funding is critically important in the aquaculture industry to help develop the sector and reduce imports of tilapia from China. This sector needs to be targeted interventions, especially geared at supporting and improving tilapia farming to boost production and meet market demand. For instance, the operating costs of fish farming represent more than 95% of the total production cost, the remaining 5% representing the construction and equipment. Depreciation feed cost can represent 75-90% of the operating costs based on the farming system adopted (El-Sayed, 2004). Such large operating expenses typical require access to investment funding, more especially when they are located in poor Limpopo Province (Kongolo, 2009). The challenge is that most financial institutions do no offer credit services to fish farmers, though the minority of commercial lenders do because they believe fish farming is a high-risk or unprofitable activity (Halley & Semoli, 2010). Lack of knowledge concerning aquaculture, and the perception that fish farming is a marginal and risky investment, have contributed to the absence of investments in this sector (Ngugi & Manyala 2004). As much as the government provided grants and soft loans for crucial start-up funding (DAFF, 2013), the government must be careful that funding encourages communities to run aquaculture as investment-based businesses, not social programmes. Moreover, community enterprises must be able to transit into financially viable and sustainable business arrangements, without constant government bailouts. Several studies (Gupta & Acosta, 2004; Li *et al.*, 2011; Cai *et al.*, 2017; Hara *et al*., 2016; Das *et al*., 2018) showed that marketing and investment funding is an important factor that can limit production.

Access to multiple market destination was ranked as the most important factor in both districts. Principal Component Analyses showed that “access to multiple market destination” is an important factor influencing tilapia production. In Capricorn district, PC 1 showed that “access to multiple market destination” and “access to distribution channels”, “ability to direct market”, and “ability to export products” had a strong loading. Vhembe district biplot showed that “ability to direct market” and “access to multiple market destination” also had a strong loading. PC 2 showed that “ability to export products”, “access to distribution channels” and “level of applicable certifications” had a strong loading in Vhembe district. This might be explained by the fact that factors such as “access to multiple market destination”, “ability to direct market”, “ability to export products” and “access to distribution channels” are important drivers of the aquaculture market, whether for smallholders or larger commercial farms. These factors increase production, further intensification and competition resulting in reduced product prices and further market penetration (Webber & Labaste, 2010). Multiple and large retail chains have had a profound influence on agri-food market chains in the developed parts of the world. Supplying several supermarkets presents potentially large opportunities for aquaculture producers to the cater the increasing population and growing middle class (Subasinghe *et al*., 2001). However, the challenge is that local tilapia farmers are failing to secure a market in the local community because of the cheap imported tilapia from China and wild-caught tilapia prices (Moyo & Rapatsa, 2021).

In conclusion, the result of this chapter showed tilapia production in Capricorn district is affected by different socio-economic factors affecting tilapia production in Vhembe district. However, “value chain accessibility, “appropriate technology approach”, “market factors”, “level of operational integration”, and “access to multiple market destination” affected tilapia production in both districts. Moreover, tilapia production is not profitable in Capricorn and Vhembe district due to the imported tilapia from China and wild-caught tilapia prices.

CHAPTER 7: GENERAL DISCUSSION, RECOMMENDATIONS, AND CONCLUSION

7. GENERAL DISCUSSION, RECOMMENDATIONS, AND CONCLUSION

Tilapia production in Capricorn and Vhembe districts, Limpopo Province has failed to reach a sustainable commercial level of development despite the efforts by the government to improve aquaculture production. Selected villagers received aqua dams and *O. mossambicus* fingerlings as an initiative to increase tilapia production and profitability by the government through the Department of Agriculture, Forestry and Fisheries Strategic Plan 2011–2015 and the National Aquaculture Strategic Framework. The government continued to show efforts by developing National Aquaculture Framework supported National Aquaculture Strategy and Action Plan aiming to double aquaculture production by 2020 (DEFF, 2019). However, tilapia farming is still at its lowest in Capricorn and Vhembe districts. Limpopo Province has been practicing fish farming ever since the 1980s (Rouhani & Britz, 2004), tilapia being the most widely farmed fish (DAFF, 2016; Phosa & Lethoko, 2018). Currently, tilapia culture in Capricorn and Vhembe districts, Limpopo Province has not realized its full potential. Thus, this study aimed to evaluate factors affecting tilapia production in different production systems in Capricorn and Vhembe districts. Both Capricorn and Vhembe districts have the potential to farm tilapia because of its high summer temperature, provided the farmer chose the right production system.

Several studies have been looking at the effect of water quality parameters on tilapia in the laboratory. This study used field data to evaluate the effect of dissolved oxygen (DO), temperature, pH, salinity, electrical conductivity (EC), turbidity, alkalinity (as bicarbonate and carbonate), potassium, total nitrogen, ammonium, ammonia, total phosphate, and chemical oxygen demand (COD) on tilapia production in aqua dams, earthen ponds, concrete ponds and RAS in Capricorn and Vhembe districts (Chapter 3). The study also determined phytoplankton abundance in aqua dams, earthen ponds, and concrete ponds in Capricorn (Chapter 4) and Vhembe (Chapter 5) districts. And lastly, it identified the most important socio-economic factors critical for the success of tilapia production using questionnaire data (Chapter 6). The results of this study showed that there are several factors affecting tilapia production in aqua dams, earthen ponds, concrete ponds and RAS systems in Capricorn and Vhembe districts.

Water quality problems are usually prevalent in earthen ponds. Parameters in earthen ponds are usually above the acceptable limits for farming tilapia because the water is stagnant. However, this study showed that water quality parameters in earthen ponds were mostly below the acceptable limits for farming tilapia compared to concrete ponds, aqua dams. This is explained by the continuous incoming water into the ponds that prevented the accumulation of nutrients in the pond. Therefore, temperature, dissolved oxygen (DO), electrical conductivity (EC), alkalinity as bicarbonate, and potassium were mostly below the acceptable limits for farming tilapia in an earthen pond in Vhembe district. Temperature, alkalinity (as bicarbonate and carbonate), potassium, and total phosphate mostly did not meet the requirement for the culture of tilapia in all the production systems in Capricorn and Vhembe districts. These were the key factors affecting tilapia production with the temperature being a major determining factor for tilapia growth. These water quality parameters mostly did not meet the requirement for the culture of tilapia in a concrete pond in Molepo and RAS system in Veekraal, Capricorn district. In Vhembe district, these parameters mostly affected a concrete pond in Olifanshoek, a RAS system in Elim and an aqua dam in Bungeni. Optimal temperature is a determinant factor for successful tilapia culture, and it was only suitable for farming tilapia for a short period in production systems in Capricorn and Vhembe districts. Tilapia production in Capricorn and Vhembe districts is not successful because farmers are unable to manage and keep the water quality optimum for tilapia production.

Tilapia is traditionally farmed in earthen ponds and concrete ponds where fish largely depend on phytoplankton as the main food source. Thus, the abundance of phytoplankton in production systems potentially reduces the cost of feed. The high abundance of phytoplankton species in production systems results in high tilapia yields. Fish yields in ponds are usually correlated with phytoplankton abundance (Hepher, 1962; Hiroki *et al*., 2020). However, in this study, phytoplankton abundance was not correlated to tilapia yield in production systems in Capricorn and Vhembe districts. Low tilapia yields observed in this study can be explained by low stocking densities, mixed-sex culture, feed quality, and the quantity of feed. The feed given to fish had a low amount of nitrogen and protein content because the concentration of ammonia and ammonium were below detection limits throughout the study period. Tilapia farmers in Capricorn and Vhembe districts feed with pellets and with non-conventional foods such as sorghum and maize meal. Moreover, the quality of fish feed produced locally are usually of poor quality (Shipton & Britz, 2007; IDC/Urban-

Econ, 2015), or too expensive for rural tilapia farmers to afford. The type of feed and the quality of pellets is a major factor deterring the success of tilapia production in rural communities. Tilapia yields in RAS systems can also be explained by the fact that fish in the RAS system requires a complete diet, which is normally too expensive, therefore farmers do not always feed the fish to satiation.

This study also determined socio-economic factors affecting tilapia production in Capricorn and Vhembe district. Socio-economic factors include human resources capacity, economic factors, and governance and legal framework (Moyo & Rapatsa, 2021). The results of this study showed that farmers in Capricorn and Vhembe districts ranked “value chain accessibility”, “appropriate technological approach”, “market factors”, “level of operational integration”, and “access to multiple market destination” as the most important socio-economic factors affecting tilapia production. Most rural tilapia farmers run fish ponds at the family level because aquaculture is seen as an unprofitable initiative (Moyo & Rapatsa, 2021). Similarly, tilapia production in Capricorn and Vhembe district is cultured at the family level. Thus, ranking “access to multiple market destination” and “market factors” as important factors affecting tilapia production is nonsignificant because none of them is producing at a commercial level. Ranking “value chain accessibility” as an important factor was also nonsignificant because value chain accessibility studies have not been done in Limpopo Province. However, farmers in Capricorn and Vhembe districts are affected by the “level of operational integration” since they are not able to integrate fish farming with livestock production and crops due to water scarcity. Most farmers in Capricorn and Vhembe district are using aqua dams, concrete ponds, and earthen ponds, thus they are affected by an “appropriate technological approach”. Recirculating aquaculture systems (RAS) technology is water efficient and would be appropriate because of climatic and edaphic perspective (Moyo & Rapatsa, 2021). Moreover, having farming equipment’s such as water quality meters, scoping nets, handling and grading equipment, the automatic feeder can reduce the complications and efforts in fish farming. The production of tilapia in Capricorn and Vhembe districts is not profitable because of low tilapia yields due to low stocking densities. Tilapia production is also not profitable because of low-priced imported tilapia from China and low-priced wild-caught tilapia sold by local fishermen in villages.

Conclusion

Temperature, alkalinity (as bicarbonate and carbonate), potassium, and total phosphate affected tilapia production in all the production systems in Capricorn and Vhembe districts. Phytoplankton abundance was not correlated to tilapia yield in all production systems in Capricorn and Vhembe districts. Value chain accessibility, "appropriate technological approach", "market factors", "level of operational integration", and "access to multiple market destination" are the most important socio-economic factors affecting tilapia production in Capricorn and Vhembe districts. Based on the results, tilapia production in Capricorn and Vhembe districts is affected by biological, physical, and socio-economic factors.

Recommendations:

- Earthen pond in Vondo had low dissolved oxygen throughout the study period. This study recommends that farmers challenged with low dissolved oxygen should install wind-powered aerators in the pond.
- The water temperature was suitable for tilapia farming only for a short period of time, this study recommends that tilapia farmers already using aqua dams, concrete ponds, and earthen ponds should install greenhouse structures around the production systems to help maintain an optimal temperature for farming tilapia throughout the year. Moreover, this study encourages aspiring tilapia farmers who seek to embark on this venture to use RAS systems since it is better and more efficient production systems to farm tilapia districts because of its ability to maintain a constant temperature throughout the year.
- Farmers in Veekraal and Elim should install water heaters in the RAS systems to keep the water temperature optimum throughout the year.
- Tilapia farmers using concrete ponds had no incoming water into the ponds, as a results nutrient accumulated into the ponds. This study supports the suggestion by Moyo and Rapatsa (2021) of Biofishency installation in ponds, to improve the water quality and increase the carrying capacity of the pond.
- The focus of this study was on mixed-sex *Oreochromis mossambicus* (Mozambique tilapia), and its failure to grow proves that it is not the best species of culture. This study recommends the use of YY male tilapia and Genetically Improved Farmed Tilapia (GIFT).

- This study recommends the government build functional hatcheries where farmers can get same-sex tilapia or GIFT fingerlings that will reach maximum yields in record time.
- Tilapia farmers have limited skills and knowledge to manage and maintain optimal water quality in production systems. This study also recommends that farmers should receive practical training on water quality management. The government and institutions should find a new approach in the training based on the FAO field school approach (AFS) be adopted.
- The aqua dams used by farmers in Capricorn and Vhembe districts were received from the government. The government should find new improved ways to promote tilapia farming in the rural community rather than giving farmers aqua dams and once fingerlings without enough support from extension officers.
- Some tilapia farmers in Capricorn and Vhembe districts were feeding with sorghum and maize meal because feed is expensive. This study supports the use of locally available ingredients to replace the expensive fishmeal to lower the cost of fish feed (Moyo & Rapatsa, 2021).
- This study monitored water quality parameters during the day only. This recommends that a further study with 24 hours monitoring cycle, for improved perspective since water quality parameters changes during the night, should be done. Moreover, further studies should be done to evaluate factors affecting tilapia production in all five districts in Limpopo Province and in South Africa as a whole should be explored. This study also recommends that a study should be done on value chain analyses for tilapia production in Limpopo Province.

CHAPTER 8: REFERENCES

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APPENDIX A

APPENDIX A: Aquaculture Questionnaire

Aquaculture Questionnaire Survey

General information

Nature of enterprise:

Location:

Species cultured:

Name of respondent:

Gender:

Position of the respondent on the farm:

Year established:

Average current annual production (tonnes/annum):

Maximum capacity (tonnes/annum):

Number of employees:

Brief description of production system used for culture:

Questionnaire

The questions below relate to factors that influence aquaculture. When answering these questions, you are requested to assess the factors in terms of what makes the sector in which you operate from an investor perspective.

Relative importance of key success factors in aquaculture

Please rank the following factors which are dominant in determining the success of an aquaculture enterprise in order of importance from 1-8, where 1 is the least important through to 8 being the most important.

1. Country specific enabling environment
2. Site location (environmental suitability, infrastructure development, access to labour)
3. Biological factors (species, bio-security)
4. Access to market and suitable logistics chain
5. Financial considerations (access to funding, price)
6. Appropriate technological approach
7. Human resources (requisite skills, man power, experience)
8. Value chain accessibility (hatcheries, veterinary services)

Factors relating to industry attractiveness

Please rate the importance of the following factors relating to attractiveness of the sector in which you operate. Please chose only one option between: (i) Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

1. Natural strategic advantage (Environmental suitability, socio-political environment), is environmental suitability an important factor in establishing an aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

2. Policy and regulations (regulatory environment for aquaculture and accommodating development policies), do government policy and regulations affect the operations of your aquaculture enterprise?

(i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

3. Market factors (market size, growth potential, levels of product innovation); are market factors important in your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

4. Vertical bargaining power (existence of local and regional suppliers, levels of supplier competition), do local and regional suppliers play a role in your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

5. Barriers to entry (licenses, access to infrastructure), how important is obtaining a license for your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

6. Sector structure (sector profitability, intensity of competition, emerging opportunities), how importance is competition and emerging opportunities in an aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

Relative importance of sector attractiveness

Please rank the following which are important in determining sector attractiveness in order of important from 1-6, where 1 is the least important and 6 the most in important.

1. Natural strategic advantage
2. Policy and regulations
3. Market factors
4. Vertical bargaining power
5. Barriers to entry
6. Sector structure

Factors relating to cost advantage

Please rate the importance of the following factors relating to cost advantage in the development of a competitive advantage to your aquaculture enterprise. Choose one option for each question between: (i) Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

1. The ability to access inputs, how important is access to input in your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

2. Supportive biological factors to enhance cost advantage, how important are biological factors in enhancing cost advantage?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

3. Access to technology for culture and processing, is access to technology an important factor in culturing and processing at your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

4. Scale economies, are economies of scale important?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

5. Access to investment funding, is access to funding an important factor in your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

6. Exchange rate hedging instruments, do the fluctuations in the Rand affect your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

7. Absence of duties and taxes on inputs, are duties and taxes on input affecting your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

8. Level of operational integration, how important is integrated fish farming to you?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

9. Preferential funding sources, is it important to access preferential funding for aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

10. Technological approach (Recirculating Aquaculture Systems), is technology an important factor in your aquaculture enterprise?
    (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

Relative importance of cost advantage

Please rank the following factors that are dominant in determining cost advantage of an aquaculture enterprise as a function of competitive strength in order of importance from 1- 10, where 1 is the least important and 10 most important.

1. The ability to access input
2. Supportive biological factors to enhance cost advantage
3. Access to technology for culture and processing
4. Scale economies
5. Access to investment funding
6. Exchange rate hedging instruments
7. Absence of duties and taxes on inputs
8. Level of operational integration
9. Preferential funding source
10. Technological approach (Recirculating Aquaculture Systems)

Factors relating to differentiation advantage

Please rate the importance of the following factors relating to differentiation advantage of the sectors in which you operate. Please choose only one option.

1. Maintaining relative strength in the market place, is maintaining relative strength in the market place for your aquaculture enterprise important?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

2. Level of product innovation, how important is product innovation in your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

3. Access to distribution channels, is access to distribution channels important?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

4. Strength of brands, is branding an important factors in your aquaculture enterprise?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

5. Ability to direct market, is direct access to a market important?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

6. Level of application certifications, would certification give you a competitive advantage?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

7. Duties and tariffs in target markets; do duties and tariffs in the targent market affect your enterprise?

(i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

8. Access to multiple market destinations, how important is access to multiple market destination?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

9. Proven price premium, is achieving a premium price on your product an important factor?
   (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

10. Ability to export product, is exporting your product and important factor?
    (i)Not important (ii) slightly important (iii) important (iv) fairly important (v) very important

Relative important of differentiation advantage

Please rank the following factors which are dominant in determining differentiation advantage of an aquaculture enterprise as a function of competitive strength in order of importance from 1 -10, where 1 is the least important and 10 the most important.

1. Maintaining relative strength in the market place
2. Level of product innovation
3. Access to distribution channels
4. Strength of brands
5. Ability to direct market
6. Level of applicable certifications
7. Duties and tariffs in target markets
8. Access to multiple market destinations
9. Proven price premium
10. Ability to export product

<u>**Missing factors and information in the questionnaire**</u>

Do you feel there are any factors or issues that are not addressed in this questionnaire, that are important considerations when determining the success of an aquaculture enterprise? Please specify

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Thank you very much for filling in this questionnaire, and for your time.