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Conservation of freshwater fishes in Saudi Arabia

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Dedication

Nothing in the whole world can describe the love in mother & father hearts. I dedicate this work to my mother; I ask my God to have mercy on her. She died nine years ago and my heart shattered since then. I cannot forget all moments with her. She dreamed of seeing me reaching this stage and I am hoping to be. I am here because of you, this is for your sacrifice and for all that you have been given to me and to my siblings.

I also dedicate this work to my dear father. He did a lot, cares a lot, and he still doing no matter how old he becomes, his heart is the biggest I know.

I dedicate this work to my two uncles and my aunt who died during my time in the United Kingdom, and I did not know about them until after the funeral. My family were hiding their death for fear that my study would be affected by this. What an attitude made me lose the ability of speak.

To my brothers and my sisters, they are best close friends.

To my relatives, they always keep me in their prayers and surrounding me with positivity.

Last for the special in my life, to my soulmate, she is my remedies, she is my companion in this life, she is the only one who was so jealous in a good way from the fish when I spent some time working on them, to my beloved wife, Mastourah.

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Abstract

This study aims to gain fundamental knowledge to underpin the formulation of practical solutions to ensure the protection and conservation of Saudi Arabian fishes threatened by anthropogenic activities, whilst taking into account all users and stakeholders.

Multivariate analysis, based on species presence/absence data in different water bodies in different regions collected from the literature and this study, was used to determine the biogeographical distribution of fish species in Saudi Arabia. Freshwater fish are mainly located within drainages in the south-west of the Kingdom, both in lowlands (western drainage systems) and highlands (eastern drainage systems) of the Sarawat Mountain Range. Importantly, this study recorded the presence of non-native fish species in the dams located in Al Baha Region, Abha and Rabigh, which means both western and eastern drainage systems are being invaded by non-native species such as *Oreochromis* spp. and *Carassius* spp.

The ecology of three native (*Carasobarbus apoensis*, *Cyprinion mhalensis*, *Garra buettikeri*) and four non-native (*Oreochromis niloticus*, *Poecilia latipinna*, *Carassius carassius* and *Gambusia affinis*) species were studied in eight water bodies (five dams, two wadis and one lake) considered representative of the habitats occupied by freshwater fish in Saudi Arabia. Fish were caught by a variety of sampling methods (gill nets, traps and angling) in three seasons (spring [post floods], summer [extreme temperatures and drought conditions] and winter) and examined for age and growth, feeding ecology and reproductive characteristics. The growth of each species was found to vary between sites and was related mostly to habitat type and the quality of the environment.

The dietary studies provided valuable information about the feeding habits of native and non-native fish species in Saudi Arabia and the how foods consumed varied between species, habitat types, size/age of fish species and with season. All species were found to be omnivorous, with varying degrees of specialism towards planktivorous, herbivorous or detritivorous diets, with the exception of *Garra buettikeri*, which is a planktivorous/benthivorous species. Differences in diets were found between locations and seasons for the three native species, and these were concluded to be related to variability in environmental conditions and approximation to the preferred habitat type of the species. Ontogenetic shifts in diet were found among the three native species examined, but the small individual sizes of two of the non-native species, *Poecilia latipinna* and *Gambusia affinis*, and small sample sizes of other non-natives precluded such an analysis. Little overlap was found between the food items consumed by native and non-native species, and where it was observed it was largely food items in abundant supply, such as detritus and benthic algae.

Carasobarbus apoensis and *Cyprinion mahalensis* spawned exclusively in spring during the rainy seasons. *Garra buettikeri* is as batch spawner, and was reproductively active throughout the year. *Oreochromis niloticus* is reproductively throughout the year, and *Poecilia latipinna* and *Gambusia affinis* are viviparous species with two main periods of spawning in spring and autumn. Spawning appears to be driven by rainfall and increased productivity associated with high water events.

The findings of this study were used to formulate a Saudi freshwater fish management plan targeting mainly conservation issues. The plan provides an overview of the status of the fisheries, threats, exploitation pressures and governance structures. Options for management of the fisheries are provided and the integration of freshwater fisheries in water resource management plans is stressed as an affirmative action.

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Chapter 1 General Introduction

1.1 Arabian freshwater fishes

Saudi Arabia is generally considered arid, dry and desert, but there is a diversity of ecosystems and biodiversity. Coral reefs, coastal areas, mountains, deserts and wetlands are examples of diversity in biological and ecological systems. In these environments, many animal and plant species live harmoniously to form sustainable ecosystems with intricate food webs and complex ecological functioning. In general, research on the ecology, species diversity and their environments in Saudi is limited, especially for freshwater fishes.

Freshwater fishes are an important pillar of wetland diversity in Saudi Arabia and the studies that have been carried out on Saudi freshwater fishes are limited, which, by itself, is problematic. The lack of information, the potential risks they face, the level of threats, the extent of exploitation, and depth of ecological and biological information, are all problematic if the resources are to be managed in a sustainable manner. This is of concern given Saudi Arabia is signatory to major international conventions on biodiversity and conservation, such as the Convention of Biological Diversity and RAMSAR. Conducting research to fill these gaps is necessary to improve understanding for protection and management of the resources.

Most of the previous studies conducted on Saudi freshwater fishes were on identification and distribution. However, the surveys were simply exploratory and provide little that can be used for conservation and management plans.

Playfair (1870) was the first person to report on freshwater fishes from Arabia, recording the presence of *Discognathus lamus* (Hamilton) in Yemen (Krupp, 1983). Banister & Clarke (1977) published a comprehensive study on Arabian freshwater fishes, in which a new species, *Carasobarbus apoensis* (Banister & Clarke), was also described. Krupp (1983) described the freshwater fishes of the Arabian Peninsula with their distribution based on a sample consisting of 4500 specimens, but did not include introduced species of his review. Additionally, Krupp provided a distinctive historical sequence about discoveries and descriptions of freshwater fishes in the Arabian Peninsula between 1870 and 1977. These are summarised in Appendix A to identify freshwater fishes in the Arabian Peninsula, of which Saudi Arabia comprises the biggest part. Krupp (1983) categorised the freshwater fishes in the Arabian Peninsula into three ichthyogeographical territories: 1) the Oman mountains with three species closely related to or conspecific with Iranian Cyprinidae; 2) the Red Sea and Gulf of Aden drainage systems with a remarkably uniform fish fauna of seven endemic species; and 3) the western part of the Rub' al-Khali drainage with three species of Cyprinidae. For other parts of the Arabian Peninsula, Krupp assumed there were no primary freshwater fishes.

Al-Kahem & Behnke (1983) described a new species *Cyprinion mhalensis* (Al-Kahem & Behnke) and recorded for the first time the genus *Acanthobrama hadiyahensis* (Coad, Al-Kahem & Behnke). Additionally, they noted there is variability in the characteristics of specimens of *Garra*, *Barbus* and *Cyprinion* that may signify the presence of additional undescribed species.

Al-Ghamdi & Abu-Zinadah (1998) studied freshwater fishes from eight localities in the lowlands and highlands, and found fishes are mostly limited to higher altitudes where rainfall is greater than in the lowlands. They attributed the lack of freshwater fishes in Arabia to the arid climate.

The Environment and Protected Areas Authority (EPAA) hosted a series of annual workshops in the United Arab Emirates between 2000 and 2009. The EPAA workshops in 2002 and 2003 had four working groups, one group was tasked to discuss and evaluate the current situation of freshwater fishes of Arabia. The freshwater fish group recommended several conservation actions, such as standardisation of field techniques; legislation for freshwater habitats and fish, and captive breeding programmes (EPAA, 2002, 2003). These recommendations were ambitious but were based on historical data. The lack of new field data was a major limitation of the EPAA reports, although the working group recommended field studies should be carried as soon as possible.

Hamidan & Shobrak (2019) surveyed the freshwater fishes of Saudi Arabia from April to May 2013 in 22 different locations based on the known published historical distributions, in addition to new places they visited. They confirmed the presence of all previously recorded species except *Carasobarbus apoensis*. *Acanthobrama hadiyahensis* was first recorded after its description around thirty years ago. They concluded that *Acanthobrama hadiyahensis* is a critically endangered species and that *Garra buettikeri* is rated as vulnerable, while all other species are considered as least-concern.

1.2 Research gaps

Freshwater fishes have received little attention in scientific research or assessment studies across Arabia, and Saudi Arabia in particular. Little is known about their distribution, abundance, exploitation or the threats they face. There is a huge gap due to the lack of biological and ecological information about Saudi fishes (such as age/growth, feeding habits, reproductive strategies); vulnerability or multi-users of fishes in the various environments, and the absence of any comprehensive management plan that addresses the diverse impacts and multiplicity of risks to Saudi's freshwater fishes. Understanding the distribution, abundance, exploitation patterns and threats to freshwater fishes in Saudi is critical if the country is to meet its obligations under the Convention of Biological Diversity and other international conventions and regulations.

1.3 Research objectives

The overall aim of the present study was to gain fundamental knowledge to underpin formulation of practical solutions that ensure the protection and conservation of Saudi Arabain fishes threatened by anthropogenic activities, whilst taking into account all users and stockholders. The information will be used to support development of management actions, conservation strategies and future regulations. The specific objectives were:

- To investigate age/growth, feeding habits, reproductive strategies and potential threats to the fish populations.
- To develop a fisheries management plan, which may help to achieve a balance between sustainable exploitation of wetland environmental services and conserving wetland biodiversity (especially fish) from overexploitation, threats and habitat deterioration.
- To provide the necessary data for decision-makers to establish legislation, laws, regulations, financial support for conservation of the fish and standards to ensure the protection of these fishes from extirpation in Saudi Arabia.

1.4 Research contribution

This project provides the first assessment of fundamental information about Saudi Arabian freshwater fishes, such as age/growth, feeding, reproduction and threats to cover some of the huge gaps in this area. This thesis also provides a framework for a conservation management plan for these species based on the information gathered and provides practical solutions for their conservation. As a result, decision-makers can establish legislation, laws, regulations and standards to ensure the protection of these fish from extirpation and ensure human activities are practised in a sustainable and environmentally friendly manner. The strategic plan will promote improvement, monitoring and conservation work on Arabian freshwater fishes to improve their status into the future.

1.5 Thesis chapters

The thesis consists of nine chapters, each with specific objectives to improve understanding of the distribution and ecology of the freshwater fish species found in Saudi Arabia, against which a conservation management plan can be developed.

1- General introduction

The general introduction provides an overview of the current issues facing freshwater fishes in Arabia, and identifies project objectives and links them to the thesis structure.

2- Introduction to Saudi freshwater fishes

This chapter provides an overview of the paleogeography of the Arabian Peninsula and why the Arabian Peninsula is considered to be poor of freshwater fishes. It describes the geomorphology and current status of Saudi wetlands, their diversity and environmental importance, and threats to freshwater fishes based on observations made during field trips or mentioned in previous studies. Descriptions of Saudi freshwater fishes and the conservation status are provided. A summary of fish production in Saudi Arabia, including from marine fisheries or from aquaculture sectors, is provided.

3- Overview of study sites (features, environmental parameter, conditions)

To build a basic understanding of the study sites and potential threats to fish, this chapter describes the basic features of the study sites and their general characteristics, then explores the potential threats to fish at these locations. Physicochemical characteristics, rainfall data and water levels are also examined so they can be related to the ecological characteristics of Saudi Arabian freshwater fishes.

4- **General methodology**

Each chapter has its own specific methodology section, but this chapter provides a description of the basic sampling methods and strategy used for the current study of freshwater fish and fisheries in Saudi Arabia.

5- Fish species distribution

The purpose of this chapter is to determine the past and current distribution of Saudi Arabian freshwater fishes, including non-native species, based on records of presence in different water bodies reported in peer review and grey literature, and relative abundance based on field surveys in this study. The provision of such information, distribution maps that can be updated from time to time will contribute to the understanding the potential risks to endemic freshwater fishes, and formulation of conservation activities.

6- Fish age and growth

This part of the research explores differences between habitats/wadis by determining the age of caught fish and how growth differs among those sites. The potential causes of different growth rates between sites are also predicted. Moreover, some factors have also been tested, such as condition factor, the relationship between length-weight to investigate fishes situation in their habitat. Von Bertalanffy as another parallel growth model was calculated for more understanding.

7- **Feeding ecology of Saudi freshwater fishes**

The goal of this chapter is to provide information on the feeding ecology of some Saudi freshwater fish and understand shifts in diet with size of fish, between seasons and between locations. Moreover, dietary overlaps between different species, including with non-native fish species, was assessed to determine if there is competition between species.

8- **Reproductive aspects**

The aim of this chapter is to examine aspects of the reproductive biology of some Saudi freshwater fishes (*Carasobarbus apoensis, Cyprinion mhalensis*, *Garra buettikeri, Oreochromis niloticus, Poecilia latipinna* and *Gambusia affinis*). The research examines the size at maturity, gonadosomatic index as an indicator of spawning season, fecundity, and its relationships with weight and length, and reproductive strategies. These results are expected to contribute to formulating management actions to conserve the endemic fish stock, especially to regulate fishing activities and to protect fishes against miscellaneous threats.

9- **Saudi freshwater fisheries management plan (SFFMP)**

The aim of this chapter is to formulate a conservation management plan for Saudi freshwater fishes. The other socioeconomic purposes that species can provide will not be negligent. The management of the fish assemblages, fishery and fishes environment approaches also considered. The omission of services provided by wetlands and their vital components for conservation purposes only would increase the frequency of conflict over these resources, where a balanced plan was made to reduce expected conflict.

Chapter 2 Introduction to Saudi Arabian Freshwater Fishes

Freshwater fishes are an essential component of the wetland diversity in Saudi Arabia (SWA, 2008). One of the main constraints facing environmental management practitioners is the availability of information about these species. The lack of knowledge, whether in terms of threats or their biological and ecological characteristics, is frustrating. For the vast majority of Arabia, published data are inadequate or historical. From a global perspective, the freshwater fish fauna of the Arabian Peninsula is incredibly depauperate (Freyhof et al., 2015). Thus, this part of the research focuses on a general introduction to freshwater fishes in Saudi Arabia. It gives an overview of the Arabian Peninsula in ancient times and why the Arabian Peninsula is considered to be poor of freshwater fish. It then describes Saudi wetlands, their diversity and environmental importance, threats to freshwater fishes, based on field trips or mentioned in previous studies and the current status of Saudi Arabia fresh waters is reviewed. Finally, a summary of the extent of fish production, including from the marine fisheries and aquaculture sectors, is provided.

2.1 Paleogeography

According to Islamic culture, the Arabian Peninsula was covered by rivers and meadows, and it will come back as it was in the future. Research carried out by the University of Oxford into human evolutionary heritage and supported by the Saudi Commission for Tourism and National Heritage (SCTH) and the European Research Council (ERC) suggested the Arabian Peninsula had an ancient network of rivers and lakes (physorg, 2012, 2014). Moreover, the discovery of fossils of extinct species such as the Palaeoloxodon elephant suggests a different climate in the Arabian Peninsula in the past, which was greener and wetter. Furthermore, projects near Tayma (a Saudi city), have found fossils of tortoise, fish, elephant, horse, hippo, camel, giant buffalo and oryx (see Climate Change and Human Evolution in the Arabian Desert website: palaeodeserts.com). Accordingly, the possibility of fish fossils in Saudi needs to receive more investigations. Conversely, Krupp (1983) and Al-Kahem & Behnke (1983) surmised that the Arabian Peninsula is poor in freshwater fishes. They provided a geo-historical analysis based on the split of the Arabian Plate from Africa in the west and the Arabian Gulf in the east through different eons. The successive events after this separation had a role in the current distribution of freshwater fishes (Al-Kahem & Behnke, 1983; Krupp, 1983). These, and other interpretations, however, remain inconclusive and require further investigation to support a better understanding of the paleoecology of Saudi freshwater fishes.

2.2 Saudi wetlands (natural and man-made)

The Kingdom of Saudi Arabia is famous for its dry arid region and its vast expanses of sandy deserts. They include rare plant species and unique wild animals, such as the Arabian oryx, Ghazal Al-Reem, Houbara and some predatory birds that inhabit mountains. The Kingdom also has wetland areas that provide important economic and social services. Wetlands are areas permanently covered by water throughout the year or seasonal water bodies, whether stagnant water or flowing, salty, fresh or brackish. Such habitats include swamps, marshes, ponds, shallow water bodies, reservoirs, springs, wells, wadis, streams artificial lakes. They also include coastal marine environments like sandy coasts, mudflats, estuaries, Sabkha (Arabic word = erratically flooded salt flat), mangroves, tidal zones and sea lagoons. In the definition of wetlands in the Ramsar Convention, the area of coastal marine environments less than 6-metre deep is also classed as wetland (Mitsch et al., 1998).

Eight wetlands systems were recognized and described in Saudi Arabia by Scott (1995):

1. Coastal systems: including freshwater marshes, mangroves, coral islands, and mudflats
2. Dunfield: water that runs through sand dunes, including minor aquifer seeps and major wetlands in Empty Quarter desert.
3. Sabkha: any form of salt flat, including continental lagoons or salt lakes.
4. Karst: which are aquifer-fed karst crater lakelets.
5. Mountain: including various seeps, pools, small wetlands, ponded pockets and marshes in volcanic areas
6. Geothermal: very limited wetlands restricted to southern Tihamah
7. Wadis (Saudi word of river valley): including intermittent streams and perennial rivers, important wadi drainages to Saudi Arabian freshwater fish are mapped in Chapter 4.
8. Human-made systems: including reservoirs and dams, in addition to urban discharges from sewage treatment plants.

According to Scott (1995) there are 30 important wetlands in Saudi Arabia (Figure 2.1). These sites need to be re-evaluated, as some sites dried up, for example Uyun Layla (No 14 in Figure 2.1).

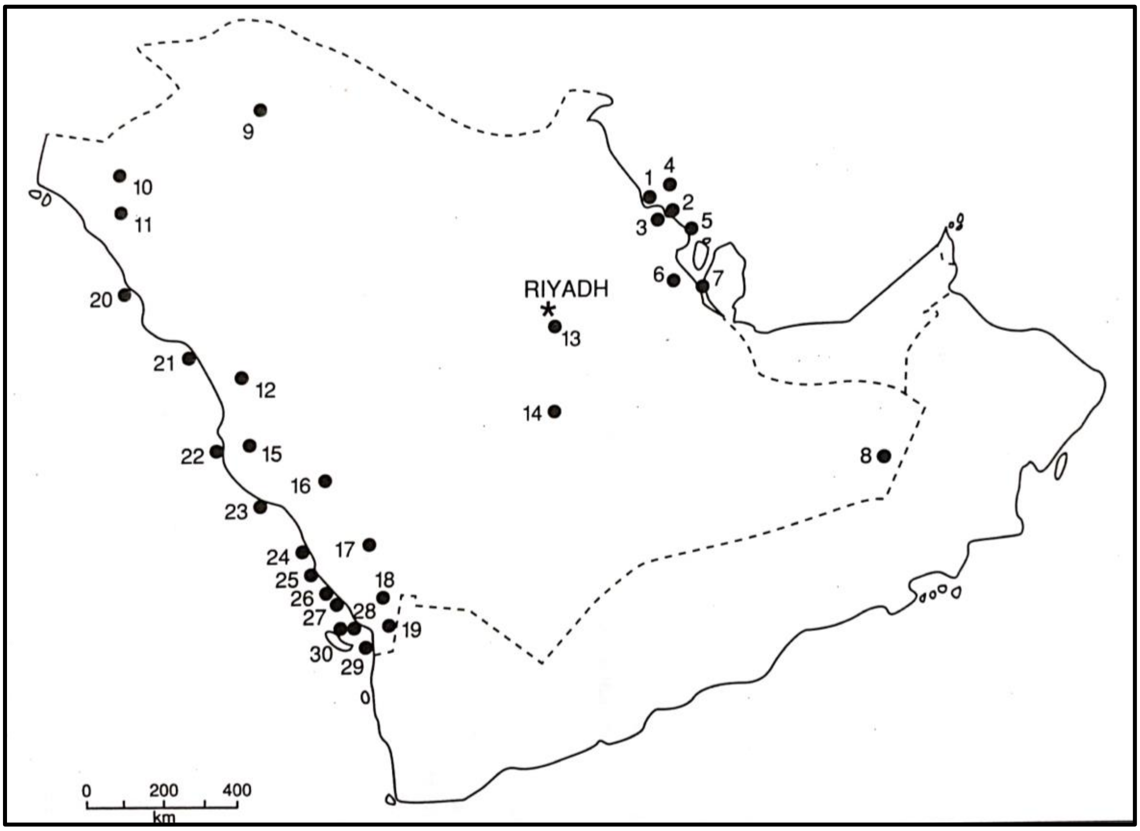

Figure 2.1. Some of important Saudi Arabian Wetlands (Scott ,1995):
(1) Dawhat ad-Dafi and Dawhat al-Musallamiya (coastal systems); (2) Abu Ali; (3) Sabkhat al-Fasl Lagoons (Sabkha); (4) Gulf Coral Islands (coastal systems); (5) Tarut Bay (coastal systems); (6) Al-Hasa Lagoons (human-made systems, Dunfield and Sabkha); (7) Gulf of Salwah (coastal systems); (8) Uruq al-Mutaridah (Dunfield); (9) Dawmat al-Jandl (coastal and human-made systems); (10) Tabuk sttling lagoons (human-made systems); (11) Qaraqir Mountain (mountain streams); (12) Wadi Rabigh Springs (wadis system); (13) Al-Hair (human-made systems); (14) `Uyun Layla (Karst); (15) Makkah Wastewater Stream (human-made systems); (16) Wadi Turabah (wadis system); (17) Shallal ad-Dahna (mountain streams); (18) Wadi Lajb (wadis system); (19) Malaki Dam (human-made systems); (20) Al-Wajh Bank (coastal systems); (21) Yanbu Royal Commission Zone (coastal systems); (22) Jeddah South Cornich and Central (coastal systems); (23) Qishran Bay (coastal systems); (24) Umm al-Qamari (coastal systems); (25) Khawr `Amiq (coastal systems); (26) Kutambil Island (coastal systems); (27) Shqaq Mangrove (coastal systems); (28) Jizan Bay (coastal systems) ; (29) Khawr Wahlan (coastal systems); (30) Farasan Islands (coastal systems), Map by Scott (1995).

Wetlands are critical for their contribution in terms of their biological diversity and renewable natural resources (many species of flora and fauna). They are also a major water resource. The value of wetlands varies according to their biological, ecological, historical, cultural and economic importance, and the extent to which humans benefit from them. Wetlands are natural filters that degrade chemical pollutants, especially organic wastes, and thus improve water conditions (Dordio et al., 2008). Wetlands play an important role in flood control (EPA, 2018) and soil erosion reduction (Vermont, 2018). Wetlands are also the most productive natural ecosystems (EPA, 2018). Two main types of wetlands are found in Saudi Arabia:

- **Seasonal wetlands**: These are more prevalent in the Kingdom than permanent wetlands (perennials) and are found all over the Kingdom. Rain is the main water source to feed them. The amount and duration of rain determine the permanence of this form of wetland. The most common types of seasonal wetlands are swamps and temporary raised water tables that are formed in some wadis.

- **Permanent wetlands:** Include mountain springs, ponds and waterfalls, runoff wadis and hot springs. For example, Tunomah waterfalls, Wadi Qaraqir, Wadi Turbah and Al-Leth hot spring, where water remains throughout the year. However, they may sometimes face drought conditions that put them under considerable stress.

In Saudi Arabia, many people still live in rural regions and small towns near water sources, which provide water for potable supply, agriculture, grazing, tourism and hunting. Coastal areas are also under great pressure due to population overcrowding, beach development, excavation and reclamation operations, which affect these sensitive environments. These wetlands are crucial for society but are equally impacted by man’s activities (Figure 2.2). The wetlands strategy adopted by the Saudi Wildlife Authority (SWA) focuses on the most important wetlands and evaluated them according to Ramsar Convention[1] standard assessments (Paris et al., 2003). Wadi Turbah and Al-Hsa Oasis (two of this project’s study sites) were mentioned as important wetlands in this strategy. Scott (1995) also mentioned the most significant wetlands sites in his book “A Directory of Wetlands in the Middle East”, in which he described 30 central wetlands in Saudi Arabia; Wadi Turbah and Alhsa Oasis are also described briefly. Al-Obaid et al. (2017) overviewed Saudi Arabia's wetlands and focused on their biodiversity, their threats and the development of these biological systems in arid Arabian Peninsula. They stated that human activities should be adapted to make sure these wetlands habitats continue to function effectively.

There is still a need for further research, especially with regard to managing the multiple uses of resources in wetlands by managing droughts and sustainable water use, balancing the human needs for water with biodiversity needs. Achieving this balance is more challenging and tougher in arid climatic conditions.

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[1] Ramsar (www.ramsar.org) is an international framework convention for wetlands to unify efforts around the world to protect these vulnerable ecosystems.

Figure 2.2. Images on the left illustrate some forms of biodiversity in Saudi wetlands, and images on the right illustrate some forms of water withdrawal from wadi streams or through underground artesian wells

2.3 Problems and threats related to Saudi freshwater fishes

There are numerous threats to freshwater fishes in Saudi Arabia, from both high and low impact activities. These threats, however, should be evaluated through specific scientific frameworks to determine their effects and mechanisms to tackle or reduce potential or actual impacts and help formulate an effective management plan for freshwater fishes in Saudi. Figure 2.3 shows the potential risks and pressures that were observed during data collection trips to wadis and dams in Saudi Arabia. The remainder of this sub-section provides more details about some of the key pressures and their impacts. Several other references likewise discuss threats relate to Saudi freshwater fishes, including Al-Ghamdi & Abu-Zinadah (1998), EPAA (2002), Al-Kahem (2004), Hamidan & Aloufi (2014) and Freyhof et al. (2015).

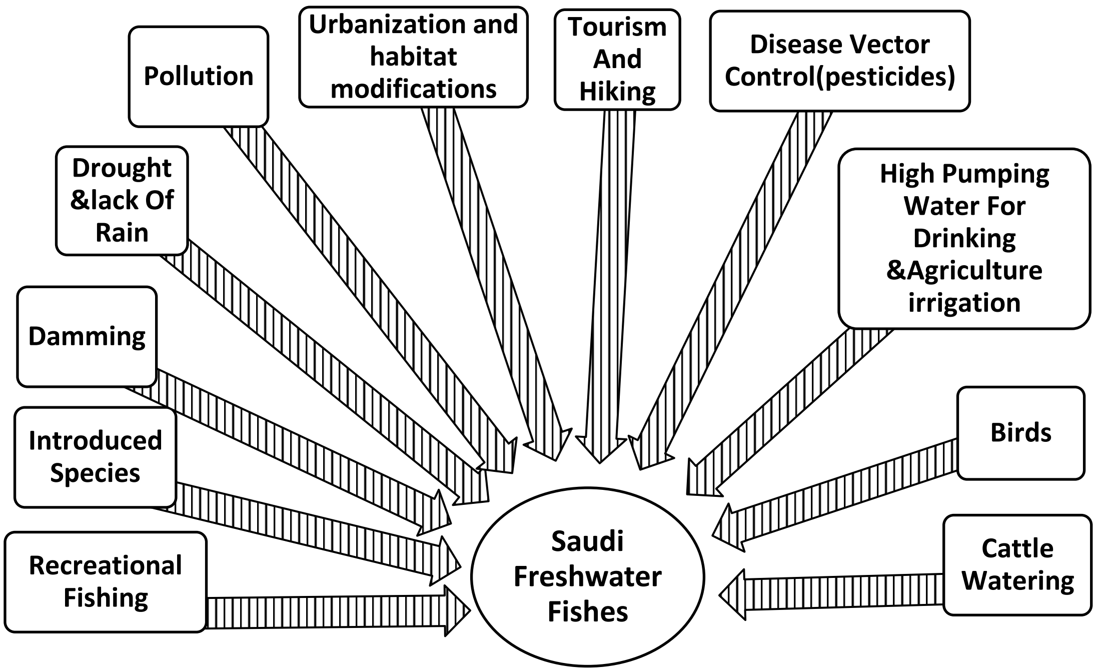


Figure 2.3. Potential risks to freshwater fishes observed during surveys to Saudi wetlands (pers. obs.).

2.3.1 Recreational and subsistence fishing

Fishing was commonly observed during visits to the various water bodies surveyed during this study. Fishing can be described as unlicensed, unmanaged, recreational and sometimes subsistence, with some fishermen and people relying on fish as the source of protein for their diet.

Social-cultural background may play a role in whether fish are exploited and eaten. Not all indigenous people in Saudi Arabia like to eat fish, especially the older generation, and this varies depending on the diversity of eating habits between regions. However, it seems that those who fished in the sites visited were residents who fish for work or people spend holidays in villages or towns near wadis. The situation may differ in wadis that flow towards the Red Sea coast, where fishing is culturally a commonly practised activity. Also, in the eastern coastal areas, where the culture is more closely associated with marine fishing, they practice freshwater fishing in oases and springs.

The greatest fishing pressure appears to target *Arabibarbus arabicus* and *Carasobarbus apoensis* because they reach larger sizes, although medium and small sized fish are also caught. *Cyprinion mhalensis* is, for example, a small sized fish species but are used for cooking in clay ovens. This also applies to *Aphanius dispar dispar* in the eastern region of the Kingdom because, despite their very small size, people still catch them to make a popular traditional dish called Harrseen. *Garra* species are less likely to be targeted because of their appearance and poor taste.

The fishing method most widely used in dams is angling. However, use of gillnetting is becoming common. Some fishermen use local traditional ways for fishing, especially children. They block the water flow with rocks so fish cannot pass (Figure 2.5), or use plastic bags. The presence of these obstacles will affect fish migration between wadis and dam areas.

The small size of the watercourses and the ponds associated with wadis makes them prone to overfishing, especially since some of these ponds serve as shelters for these fishes during drought periods. In 2009, some fisherman were found using gill nets to capture freshwater fish from some ponds in Wadi Turbah (Alharthi, 2009). Because of the size of the stream they are simply able to wade through the stream and capture most big fish using this net (Figure 2.4).

In some dams, like Al-Sadr and Medhaas, people catch fish for aquarium purposes, especially for their children. They catch small fish of all species. In the central region, where dam lakes are surrounded by public parks, people catch fish for their aquaria that have been introduced for biological control operations in the park, like *Poecilia latipinna*. Moreover, some people in the eastern province fish in man-made lakes constructed to collect agricultural wastewater and where the fish are unfit for human consumption.

People like to see the flood waters around wadis after the rain stops. Sometimes the flows are not strong and carry fish, which may be vulnerable to unplanned fishing by locals (Figure 2.6).

In this regard, it is clear that fishing operations take place where major freshwater fishes are present. The problem with these operations is that they are uncontrolled due to the lack of regulations and may lead to declines in the size of the fish population, affecting annual recruitment of these species. Further, the presence of other pressures and paucity of information concerning reproductive seasons and size at maturity could exacerbate these stresses and disrupt natural recruitment potential. In addition, many fishermen throw lots of bread and dough into the water to attract fish, which may affect fish feeding behaviour and reduce water quality. The establishment of fisheries management strategies for the wadis and reservoirs will be discussed in the conservation management plan (Chapter 9).

Figure 2.4. Fishing with gill nets in Wadi Turbah (Alharthi, 2010).

Figure 2.5. Fishing exponents line up stones in streams to block fish movements to catch fish. Arrow shows a dead fish.

Figure 2.6. People catch fish transported by floods following rain, the Saudi endemic species *Carasobarbus apoensis* is shown

2.3.2 Non-native fish species introductions

There are many reasons for introducing fish in Saudi, but aquaculture, biological control and ornamental fishes are the main drivers. Table 2.1 shows the main fish species introduced into

Saudi Arabia. Non-native species are widely found in man-made systems like irrigation channels, sewage drainages and lakes.

Chapter 5 on geographical distribution of fishes in Saudi Arabia illustrates the known distribution of some alien freshwater fish species, especially species that have been imported for biological control that have been observed in artificial lakes. Ornamental fishes are not included in Table 2.1 due to their large numbers and these species were not observed in wadis up to the time of this study. Moreover, there is a fish farm especially for ornamental fish located in the central region, far from the main endemic fish distribution areas.

Table 2.1. Freshwater fish species introduced to Saudi (Al-Kahem, 2004; Younis et al., 2015; fishbase.org, 2018).

Family	Species / group	Purpose	Ref
Poeciliidae	*Gambusia affinis* (Baird & Girard, 1853)	Biological control	(Al-Kahem, 2004)
	Poecilia latipinna (Lesueur, 1821)		(Al-Kahem et al., 2007)
	Poecilia reticulata Peters, 1859		(Al-Kahem, 2004)
	Xiphophorus maculatus (Günther, 1866)		(Al-Kahem, 2004)
Cichlidae	*Oreochromis aureus* (Steindachner, 1864)	Aquaculture	(Al-Kahem, 2004)
	Oreochromis mossambicus (Peters, 1852)	Aquaculture	
	Oreochromis niloticus (Linnaeus, 1758)	Aquaculture Biological control	
	Oreochromis spilurus (Günther, 1894)	Aquaculture &research	FAO country fact sheet
Clariidae	*Clarias gariepinus* (Burchell, 1822)	Aquaculture Biological control	(Al-Kahem, 2004)
Cyprinidae	*Carassius auratus* (Linnaeus, 1758)	-	
	Ornamental fish	*Pet purposes*	
Acipenseridae	*Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833	Aquaculture (Caviar)	
	Acipenser baerii Brandt, 1869		
Cyprinidae	*Ctenopharyngodon idella* (Valenciennes, 1844)	Biological control (weed control)	(Younis et al., 2015)
Cyprinidae	*Cyprinus carpio* Linnaeus, 1758	Biological control& research & aquaculture	

The sources of these non-native fishes are numerous. Firstly, fish farming: fish farms are found in most parts of the Kingdom. After heavy rains, fish may escape from farms to open waters and cause problems for the endemic fish. Some videos (youtube.com/watch?v=WLpYvPslpmE) have been spread on social media about fish from fish farms being found in ponds in the middle of the desert, in very stressful natural conditions. Some alien species endured the extreme desert climate and have established in wadis. Environmental conditions in wadis, being natural water bodies, are good compared with man-made lakes, especially in the south-west region: and the presence of non-native fishes could impact of endemic species. Additionally, fish farms may transmit diseases to fish in natural water bodies (Scarfe et al., 2008).

Secondly, fish have been introduced for biological control (weed control, regulating phytoplankton blooms, snails, mosquitos) or unintentionally (Welcomme, 1988; Coad, 1996; Cowx, 1999; Innal, 2012). Some species introduced for biological control purposes did not meet the goal of the introduction. For example, *Gambusia affinis* introduced to control mosquitoes has had no effect on mosquitos and may be harmful to native fishes (Kottelat and Whitten, 1996). The introduction of alien fishes for biological control purposes in locations where Saudi endemic fish are distributed may be harmful, but the risks to endemic fishes has not been considered before introductions have taken place.

Thirdly, ornamental fish trade. The impacts of introducing fish through the aquarium trade are largely unknown. Some people throw aquarium fish into nearby waters, especially during vacation time, when there is nobody to take care of them. There are about 600 aquarium species sold in pet markets according to import shipment lists. *Carassius* sp. has entered some dams, but data in this regard are still limited.

Studies on the impact of non-native, invasive species on endemic and native species in natural aquatic environments in Saudi Arabia is limited. This study may contribute to evaluating some of these effects, such as competition for food, or whether the reason for the introductions has been successful.

2.3.3 Damming

The main objectives of building dams in the Kingdom according to the Ministry of Water and Electricity (mowe.gov.sa) are: (1) support underground water around dam's area and feeding wells of water; (2) for water drinking purposes through purification stations built on or near the dams; (3) securing irrigation water for agricultural purposes and (4) protect towns and villages from the dangers of floods. There are more than 500 dams within the country of different sizes and types (mowe.gov.sa open database) and the number has increased dramatically in recent years (Table 2.2; also see Chapter 5 on relation between fish distribution and dams).

Table 2.2. Increase in the construction of dams in the Kingdom (numbers, storage capacity in thousand cubic meters) (source: MEWA, 2016).

Purpose	2011		2012		2013		2014		2015		2016	
	N	Capcity	N	Capcity	N	Capcity	N	Capcity	N	Capcity	N	Capcity
control	74	878,446	77	880,302	80	882,162	92	892,434	95	961,848	99	1,042,573
irrigation	2	51,500	2	51,500	2	51,500	2	51,500	2	51,500	2	51,500
Recoup	273	604,151	293	612,903	310	630,291	329	683,719	343	690,273	344	692,237
Drinking	45	392,801	50	422,681	57	452,947	59	456,219	62	463,593	63	463,696
Total	394	1,926,899	422	1,967,386	449	2,016,900	482	2,083,872	502	2,167,215	508	2,250,043

The World Commission on Dams stated that large dams have many mostly negative impacts on ecosystems. Positively, dams hold a vast amount of water in the reservoir that would reduce water evaporation compared with small ponds in wadis, which means water in dams could remain long time, enabling fish to complete their lifecycle if there is an appropriate substrate or conditions. Additionally, dams support many economic sectors such as agriculture, water and tourism. On the other hand, dams degrade habitat and block fish migration routes and fragment habitats (Roberts & Garboczi, 2001; Hall et al., 2011; Liermann et al., 2012). Moreover, dams inundate terrestrial ecosystems (Nilsson et al., 2005). Dams eliminate turbulent river segments and form still water bodies, consequently disturbing, for instance, current and temperature regimes, sediment dynamics and species populations (Liermann et al., 2012). Therefore, the forms of running water in the wadis are completely different from reservoirs in many ways including depth, flow of water and changes in the composition of chemical and physical characteristics. Given the need to build these dams in Saudi Arabia and their potential impacts, it is necessary to have a management plan that minimizes these impacts on the living and non-living ecosystem components.

Some of the negative impacts that were observed during sampling include:

- When dams overflow during heavy rains, dam gates are opened to discharge large volumes of water an avoid dam collapse. This has resulted in fish mortalities as fish pass through the gates. For example, many fish were found decapitated near the gate of Al-Sadr Dam. Further, some of the dams have sluicing system through large pipe at the bottom of the dam wall and when water is released it creates high water pressure may cause damages to fish, especially during periods of ovulation.
- Dam design takes no account of fish migration, either upstream or downstream. If the rains are poor fish have little opportunity to bypass the dams and thus they cannot

complete their life cycle. For example, individuals of the genus *Garra* were seen trying to climb the dam wall at Thrrad Dam during the third sampling trip when the reservoir was overtopping, but they were unsuccessful. It is noteworthy that the species uses a modified buccal disc and pectoral fins as suckers to help it climb, it was not in a position to climb back because of the power of the water flow and the height of the dam wall. A mechanism that enables fish to return to the dam reservoir is also important but missing.

- Flood transports silt, tree debris, pollutants and garbage that altogether aggregate upstream of the dam, causing physical and chemical changes. Additionally, farms and villages close to dams are potential problem because of run-off agricultural fertilizers and organic compounds into the dam water, especially during heavy rain, and can lead to eutrophication.
- Some dams lack shallow areas that are suitable for plant growth, especially marsh areas, which act as spawning, nursery and feeding areas for fish. However, this requires attention, so that such places are available to protect fish during periods of drawdown in the reservoirs.
- On several visits there was a rotting smell around the water possibly suggesting organic pollution from nearby cities; this affects water quality, which will impact on fish, their food and other organisms.
- The presence of barriers and concrete channels and ponds to disperse floods and protect farms and houses downstream of some dams was noted. These structures are unsuitable environments for fish and fish may be trapped and subsequently die.
- The construction of many dams in the same wadi basin results in disconnectivity and fragmentation of the system, disrupting fish migration and resulting in population isolation.
- Dams have attracted tourism, and residues and litter are common around the reservoir and floating on the water. Fishing (angling) is also more widely practiced on the reservoirs.
- Flows downstream of ten dams are also depleted, creating isolated ponds, whilst during floods flow velocities are elevated and violent destabilising the banks. Dams exacerbate the problems associated with droughts below the dam, likely (needs more investigations) impacting on the biodiversity in the altered environment.
- Many trees have been inundated in the impoundment and are decomposing causing oxygen depletion.

2.3.4 Lack of rain and prolonged droughts

"The Arab region's low and variable rainfall, high evaporation rates and frequent droughts contribute to low water resource reliability and availability" (RBAS, 2013). Saudi Arabia has a desert climate, regarded as high heat through the day and sudden drops in temperature at night (Kagan-Zur & Akyuz, 2014). Freshwater fishes in the Kingdom mainly depend on seasonal rains that are scarce (see Section 3.4, page 58, for rainfall data analysis). Prolonged droughts have serious repercussions on the various ecosystems in Saudi Arabia. If there is no rain, the groundwater level fall considerably, causing wetland habitats to dry up. As a result, there is a drastic change in vegetation cover, affecting the infiltration rate, leading to an increase in runoff resulting in soil erosion and a decline in groundwater recharge. Wildlife will consequently be affected by changing and degraded habitats. Natural ecosystems identified as being at risk in Saudi Arabia include wadis, because of droughts (PME, 2005). EPAA (2002) itemized the main threats to freshwater fish that involved drought. Some native species populations have begun to decline rapidly, such as *Aphanius dispar*, as a result of dry springs, affecting ponds (Al-Ghanim, 2005). Drought is an inherent characteristic of the Saudi Arabia environment. Drought management is an important science that enables us to deal with its existence, as it cannot be completely changed. Any programmes for wildlife protection in wetlands should consider this issue, but also make efforts to reduce degradation of ecosystems. Some human activities, such as pumping water for drinking, agriculture goals, building dams and timber cutting, have played a role in exacerbating this problem in living conditions, and require management intervention.

Information relates to resilience and resistance in wetlands habitats and how fish behave and react to drought in Saudi Arabia is inadequate. There is a possibility that fish might survive during low rainfall periods because of drought refugia (McNeil et al., 2013) or migrate upstream to permanent headwaters in the wadi. The latter is a preliminary view and needs to be proven through tracking, for example. Biological and ecological information from this project should contribute to understanding of the impact of lack of rain and drought on fish and what can be done to reduce this impact. It is important to protect the refuges of fish and other aquatic organisms during droughts, by knowing their locations and monitor their condition, especially in times of extreme drought. See Chapter 9 for more about drought and water management for fish and freshwater conservation objectives.

2.3.5 Water quality

Water pollution impacts aquatic organisms, including fish, in numerous ways (Hellawell, 2012). Water quality affects all aspects of fish feeding, growth and reproduction in fish, thus it is important to understand any potential impacts address such issues in the fisheries management plan.

The most prominent issues related to water quality that were observed during fieldwork and likely to have severe consequences for fish were: agricultural waste; organic sewage materials; eutrophication; littering (Figure 2.7. Section 3.3, page 50). Wadis and dams near cities appear more vulnerable to urban discharges from sewage treatment plants and a man-made lake for dumping waste was observed, Wadi Haneefah, Wadi Al-Hair and Nemar Dam as an example. There are strict laws about deliberate discharge of harmful materials via channels or ditches into wadis and dams and attract fines up to £10,000 (National Water Company - NWC.com.sa. Section 3.3 will discuss some of the water characteristics which are important indicators of water quality for fish.

Figure 2.7. 1) Fertiliser seepage from crop farms located next wadis; 2) Fully or partly treated waste water from palm plantations passing through irrigation channels and discharging into Al-Asfer Lake; 3and 8) Plastic littering water bodies; 4) Algal bloom in Al-Aqiq Dam; 5 and 6) Algal bloom arising from eutrophication in Al-Asfer Lake; 7) Dead fish exposed to high temperatures because vegetation in marshes blocks fish migration when water recedes.

The following issues need further investigation as they related to water quality.

- How can agricultural drainage and irrigation channels and lakes for dumping agricultural wastewater be developed, especially since the fish in them are not suitable for human consumption. It may be possible to develop these fisheries for tourism and sport fishing if the costs of improving water quality are known and realistic.
- There are two main factors when talking about the use of wadis as water drainage channels from cities: Does the wadi have permanent flow or is it a dry old wadi; and how contaminated the water that is discharged into the wadi?.

2.3.6 Urbanization and rural areas development

There has been mass movement of people from rural areas to urban centres seeking employment in the last five decades. This has put pressure on major cities in the Kingdom, which that led to construction of amenities to support resettlement or rural communities. These improvements have indirectly impacted on fish. For example, roads block fish migratory routes because no bypass facilities are provided through culverts. Furthermore, digging and rock breaking in the mountains and wadis for road construction may can alter the physical and chemical characteristics of the water body, if sediment erodes to the waterway during excavation. Also, flows in the wadis may be altered by road construction (Figure 2.8). The increases in urban populations has increased pressure on already scarce water resources, resulting in deterioration of some habitats (Section 2.3.9). Discharge of wastewater from urban areas into channel or through arid wadis has resulting in the need to introduce fish species for biological control of mosquitos and snail vectors; Wadi Haneefah near Riyadh is an example.

Figure 2.8. Left: Al-Janabeen Wadi (green line) intersected by a road (red line). Right: Wadi Thrrad upstream of Thrrad reservoir as an example of digging in the mountains and wadis for road construction.

2.3.7 Pastoralists and Hikers

The pastoralists and hikers, who live temporally next to streams impact fish in two main ways. Vehicular access to wadis in remote, rugged areas is by unpaved roads or paths. These paths may block fish migration, especially when they use stones from the banks to make and mark these paths. Some access routes in the wadi inevitable cross the stream, which causes further blockage to migration, disrupts feeding and breeding areas, and vehicles leak oils into the stream and create dust that will be washed into the stream.

Pastoralists also abstract water from streams for watering cattle or their herds can drink directly from brooks. Organic matter from the cattle remains in the wadi and act as organic fertilizers when the river flows re-establish, causing eutrophication problems in pools. There is a need to understand the number of livestock owners, size of herds and rate of abstraction to water cattle to determine the extent of water consumption and organic loadings develop a balanced management plan involving all stakeholders.

2.3.8 Tropical diseases vector control (pesticides)

People living near open waters can be affected by the presence of mosquitoes and other tropical disease pathogens, like Schistosoma which has molluscs such as *Biomphalaria arabica*, *Bulinus beccari* and *Bulinus wright* as their vectors (EPAA, 2002). Research is still ongoing in different parts of the world to find a solution to tackle these diseases, as well as ensuring the safety of the environment. Chemicals are usually using to control these pests and their hosts, but this can have negative effects on non-target organisms, mainly fish. Fish contaminated by the pesticides are caught and consumed and may lead to human health issues (Rozendaal, 1997). During trips, it was noted that the Saudi Health Authority used SHIELD 70% WP as a molluscicide to defeat bilharzia, but this kills fish.

Human health is a priority. Nevertheless, there is also something that can be done to reduce the effects of disease control on fish. The following are some general points that should be taken into account to minimize the impact of control actions against tropical diseases on fish:

- Some *Carasobarbus apoensis* individuals were found to have stomachs full of the bilharzia snail, thus the species may be suitable for biological control. However, this characteristic needs further study to see how these fish are related to these parasites, the location of snails, and feeding preference for snails in the presence of other favoured abundant food.

- Some Saudi fish species eat a variety of mosquito larvae (see Chapter 7), so again it is important to determine if they can be used to control or reduce mosquitoes associated with several tropical diseases, such as malaria.
- Carry out cost benefit analysis of rescuing fish during vector control operations to determine if it is a viable solution to protect fish.
- In cooperation with the Health Authority, the location of the control operations should be identified and mapped so that they can be linked to the distribution of fish and appropriate rescue actions can then be prepared.

2.3.9 Extensive pumping of water for domestic supply and agriculture

Arab States count on both conventional water resources (surface water and groundwater) and non-conventional (desalinated water, treated wastewater, irrigation drainage water, water harvesting and cloud seeding; RBAS, 2013). Saudi Arabia is classified as arid, with no rivers or lakes, and no more than 60 mm rain average per year, making groundwater the most important source of water. These resources have been depleted over the past years with significant challenges in meeting the demand for water for both municipal or agricultural purposes due to a growing population and economic growth (MEWA, 2016). Desalinated seawater contributes the largest proportion of water for drinking – some 3129 MCUM in 2016, which is only about one sixth of the water used for agriculture purposes (19,612 MCUM in 2014). Further pressure is put on water resources because Saudi Arabia is the third highest per capita consumer of water at about 256 litters per day (DeNicola et al., 2015). The scarcity of water coupled with intense use will lead to the degradation of wetlands and exacerbate drought problems, and put aquatic organisms under high pressure. Continued pumping of non-renewable underground resources will endanger freshwater flora and fauna (SWA, 2008), thus a balanced approach to water usage is needed to mitigate the effects on fishes.

During data collections trips, it has been noticed that there are two forms of water withdrawal near sample sites.

- **Water withdrawal by individuals:** People residing near wadis commonly draw water for watering their herds of domestic animals or watering fruits or vegetables under cultivation. These crops consume large volumes of water. It is easy for farmers to pump water directly from the pools that appear in many places within wadi Figure 2.9). Moreover, some livestock owners live temporally with their cattle next to the watercourse or stream until the water in the wadi dries up. This sort of water use should be considered when formulating a management plan for freshwater fish because it has an impact on fish present in wadi streams.

- **Water withdrawal by domestic water supply**: Drinking water is actively abstracted from groundwater aquifers artesian wells and dams to supply some villages and towns. This can result in water depletion and fish are at risk from disappearance of connected surface waters, especially during long periods of drought and delayed rains. For example, Wadi Turbah is considered an important wetland hotspot for freshwater fish. There are, however, many wells spread through the wadi pumping water for supply. This is exacerbated by construction of an upstream dam which has increased the drought risk and isolated the habitats for fish in the wadi. Abstracting water from the dam can also disrupted the breeding of fish in the reservoir, which look to lay eggs on stable substrate that may be exposed when the level is drawn down. For example, Al-Aqiq dam (a data collection site) feeds groundwater wells and also for supplies domestic water. A pumping station below the dam pumps water to a treatment plant, but when the dam was drawndown because of pumping and lack of rain, tons of fish died in the reservoir causing health issues (Figure 2.10). This situation should be considered when formulating a management plan to conserve these fishes because of the need to balance human water needs and requirements for aquatic biota.

Figure 2.9. Pumping water from an Al-Ghadeer (= stream) in Wadi Turbah.

Figure 2.10. Dead fish in Al-Aqiq Dam during its drying up (MZMZ, 2018). Each of the pictures shows different fish species.

2.3.10 Other unclassified

- **Siltation and inundation**: The accumulation of silt and inundation of riverine habitat in reservoirs will change the benthic structure and alter the food composition for fish. Fish that prefer riffle habitat will disappear (Berkman & Rabeni, 1987). Furthermore, prey species may change, as some plants and insects will no longer be able to breed in the altered environment.
- **Flow regime:** alteration of the flow regime (flow and flood behaviour, timing, duration and seasonality of flows) downstream of dams can affect fish and other aquatic organisms (Nielsen et al., 2000; Bolland, 2008; Smith, 2012). Those study and many others, therefore, show that organisms in the aquatic habitat respond according to the flow regime, fish growth and foraging, for instance, may be affected. Knowledge about this impact in relation to Saudi freshwater fishes is almost non-existent and further studies are needed.
- **Channelization:** The drainage channels around Al-Ahsa Oasis, for example, are routinely cleared of vegetation, including trees, by mechanical means or burning, which have serious implications for fish and turtles. In addition, grass carp *Ctenopharyngodon idella* were introduced for weed control purposes (SIO,2019). The results were positive but the grass carp came under pressure from angling that reduced the efficiency of this approach.

2.4 Saudi freshwater fish species

There are 16 primary freshwater fish species in the Arabian Peninsula: *Barbus exulatus* (Yemen), *Cyprinion acinaces acinaces* (Yemen), *Cyprinion microphthalmum muscatensis* (Oman), *Garra longipinnis* (Oman), *Garra barreimiae barreimiae* (Oman), *Garra dunsirei* (Oman), *Garra* *barreimiae shawkahensis* (Oman), *Garra mamshuga* (Yemen), *Garra sahilia sahilia* (Yemen), *Garra ghorensis* (Jordan), *Arabibarbus arabicus* (Yemen + Saudi Arabia), *Garra tibanica tibanica* (Yemen + Saudi Arabia). The following are found only in Saudi: *Carasobarbus apoensis*, *Cyprinion mhalensis*, *Cyprinion acinaces hijazi*, *Garra buettikeri*, *Garra sahilia gharbia*, *Acanthobrama hadiyahensis*.

There are also some secondary freshwater fishes: *Aphanius dispar dispar* (widespread, Saudi Arabia, Egypt to Somalia, Red Sea, Dead Sea, Arabian Gulf, Iran), *Aphanius dispar richardsoni* and *Aphanius sirbani* (Jordan). Furthermore, in Saudi Arabia, some marine fishes occasionally enter freshwater bodies such as *Mugil cephalus* and *Bathygobius fuscus.*

The following section summarises the current information about Saudi freshwater fish species. The information includes descriptions, distribution and the current status. Introduced fish species are described previously (Section 2.3.2, page 13).

2.4.1 *Carasobarbus apoensis* Banister & Clark, 1977

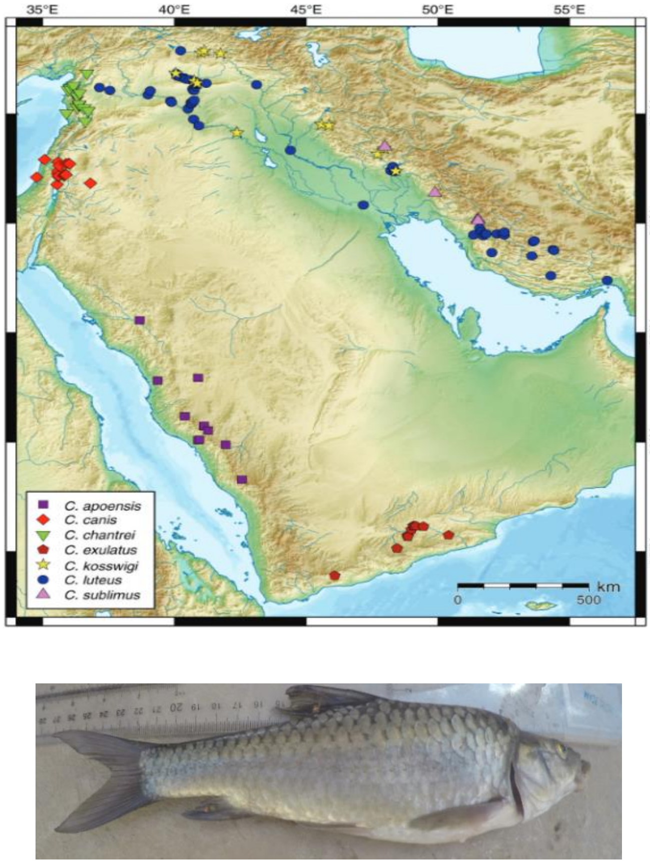


Figure 2.11. Distribution of *C. apoensis* in Saudi Arabia along with other members of the same genus *C. canis, C. chantrei, C. exulatus, C. kosswigi, C. luteus*, and *C. sublimus* in adjacent regions (Borkenhagen & Krupp, 2013). Picture of *C. apoensis* taken during sampling (28 cm).

Taxonomy. Previous scientific name: *Barbus apoensis*. Family Cyprinidae - minnows or carps.

Diagnosis. The species was described by Krupp (1983) and Borkenhagen & Krupp (2013): mouth terminal; one dorsal fin with 4 unbranched rays, 10 branched rays; one pair of barbels 2.3-5.6 % of standard length; no teeth in jaws; no horny sheath on lower lip; anal fin with 6 branched rays and 3 unbranched; the lateral line scales number 27-32.

Distribution. Endemic to Saudi Arabia (Krupp, 1983; Borkenhagen & Krupp, 2013), and occurs in south-western, Saudi Arabian inland drainages (Figure 2.11).

Niche. Habitat: Upper reaches of wadis in fresh water, Dams located in south-western.

Current situation. EPAA (2002) indicated the habitats of *C. apoensis* as fragmented, reduced and the populations have declined by 20% over 5 years at time of study. It is in the IUCN Red List as endangered (EN). This species is a game fish.

2.4.2 *Arabibarbus arabicus* Trewavas, 1941

Figure 2.12 Distribution of *Arabibarbus arabicus* in the Arabian Peninsula (EPAA, 2002). Picture of A. *arabicus* screen-captured from YouTube Video = DogqO_jJkjY.

Taxonomy. Previous scientific name: *Barbus arabicus*. Family Cyprinidae - minnows or carps.

Diagnosis. The species was described by Krupp (1983): one dorsal fin; less than three pairs of barbels; no teeth in jaws; no mental disc; no horny sheath on lower lip; less than 7 branched anal rays; anal fin with 5 branched rays 3 unbranched, the lateral line scales number 29-38.

Distribution. It is native to Saudi Arabia and Yemen. Resides in extreme south-western Saudi Arabia within Red Sea drainage (Figure 2.12).

Niche. Upper and lower reaches of wadis.

Current situation. EPAA (2002) indicated the habitats of *A. arabicus* as fragmented, population size decreasing over 5 years of study. It is in IUCN Red List as least concern (LC). This species is a game fish.

2.4.3 *Acanthobrama hadiyahensis* Coad, Al-Kahem & Behnke, 1983

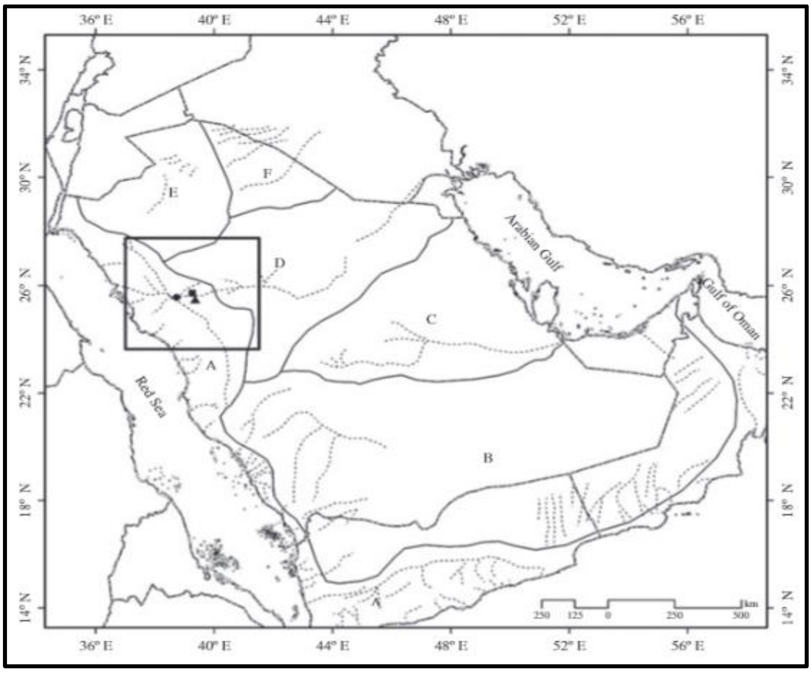


Figure 2.13. Distribution of *Acanthobrama hadiyahensis in* Saudi Arabia (Hamidan & Aloufi, 2014). Picture of *A*. *hadiyahensis* taken by Hamidan & Aloufi (2014).

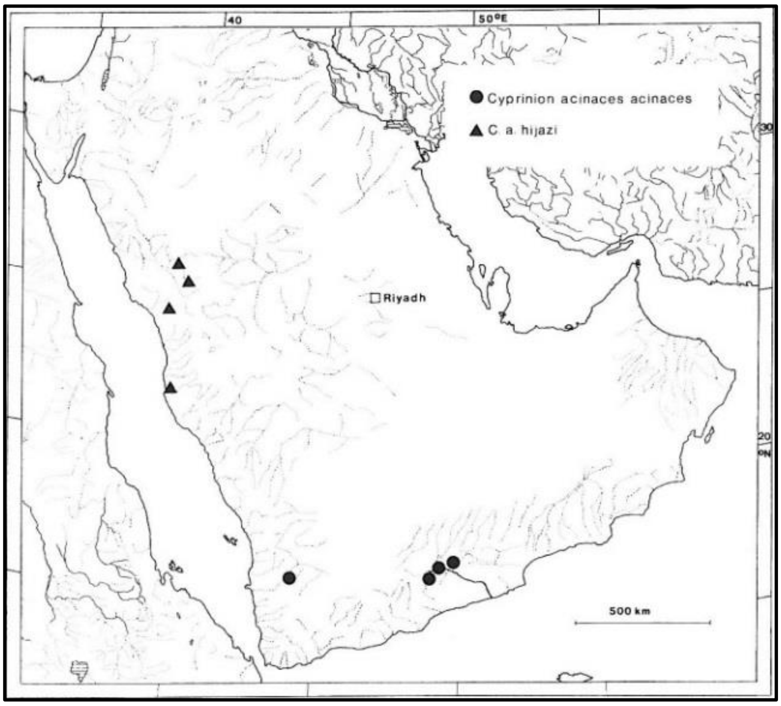
Diagnosis. The species was described by Coad et al. (1983) and Coad (2010): total gill rakers 17-19; mouth angle 40° or less with the horizontal**;** lateral line scales 54-58, branched dorsal fin rays 7**;** branched anal fin rays 14-17**;** pharyngeal tooth count 5-5 or 6-5**;** and total vertebrae 38-39; a dark mid-lateral band becomes diffuse anteriorly; maximum standard length 76.3 mm.

Distribution. Endemic to the upper course of Wadi Hadiyah in western Saudi Arabia (Figure 2.13). Found in Qusaiba'a Dam, Al-Thamad region of Khaybar city (EPAA, 2002).

Niche. Wadis streams, spring and dams.

Current situation. EPAA (2002) considered this species as the most threatened freshwater fish. Populations are severely fragmented and decreasing (EPAA, 2002). Krupp failed to find the species in 1990 as mentioned in (EPAA, 2002). Hamidan & Aloufi (2014) rediscovery of this species in the ancient Qusaiba'a Dam in the Al-Thamad area of Khaybar city (25° 29'·122N; 39°21'792 E). It is in the IUCN Red List as critically endangered (CR).

2.4.4 *Cyprinion acinaces hijazi* Banister and Clarke, 1977



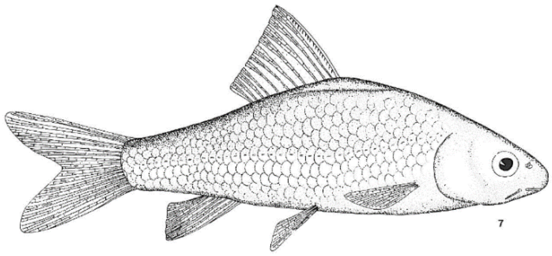


Figure 2.14. Distribution of *Cyprinion acinaces* (Krupp, 1983).

Diagnosis. The species was described by Krupp (1983): one dorsal fin; less than three pairs of barbels; no teeth in jaws; no mental disc; lower lip covered with sharp-edged horny sheath; 7 branched anal fin rays; last unbranched dorsal ray large and strongly serrated; 16-18 scales around caudal peduncle; less than 8 scales between lateral line and dorsal fin origin; 10-13 gill rakers on lower limb of first gill arch.

Distribution. *Cyprinion acinaces* has two different subspecies (Figure 2.14). *Cyprinion acinaces acinaces* dwells in Yemen. *Cyprinion acinaces hijazi* inhabits central and north-western Saudi Arabia (Krupp, 1983; EPAA, 2002).

Niche. Freshwater wadis, wide range.

Current situation. Fragmented habitat. It is in the IUCN Red List as least concern (LC)

2.4.5 *Cyprinion mhalensis* Al-Kahem & Behnke, 1983

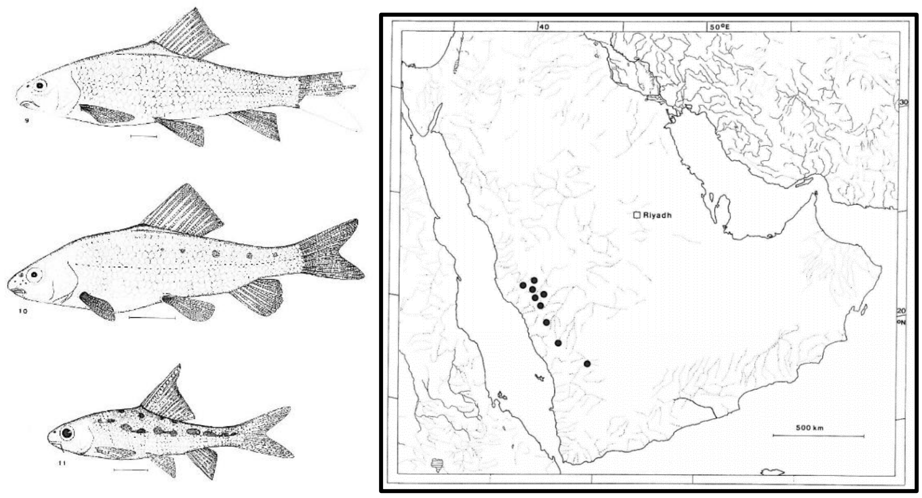


Figure 2.15. Distribution of *Cyprinion mhalensis* in Saudi Arabia (Krupp, 1983). Picture displays the appearance of adult, sub adult and juvenile specimens by Krupp (1983).

Diagnosis. The species has been described by Krupp (1983): one dorsal fin; less than three pairs of barbels; no teeth in jaws; no mental disc; lower lip covered with sharp-edged horny sheath, 7 branched anal fin rays; last unbranched dorsal ray large and strongly serrated, 20 scales around the least circumference of the caudal peduncle; more than 7 scales between the lateral line and the origin of the dorsal fin, the lateral line scales number 39-44.

Distribution. It is endemic to Saudi Arabia (Krupp, 1983; Al-Kahem et al., 1990). The species name after Wadi Al-Mahalah in Abha region, which was first observation for this species. It occurs in south-western Saudi Arabian inland drainages (Figure 2.15).

Niche. Within wadis especially upper reaches.

Current situation. Its habitat is fragmented and there was a reduction in range by 21% to 50% over 5 years and the associated populations are declining (EPAA, 2002). It is in the IUCN Red List as least concern (LC).

2.4.6 *Garra buettikeri* Krupp, 1983

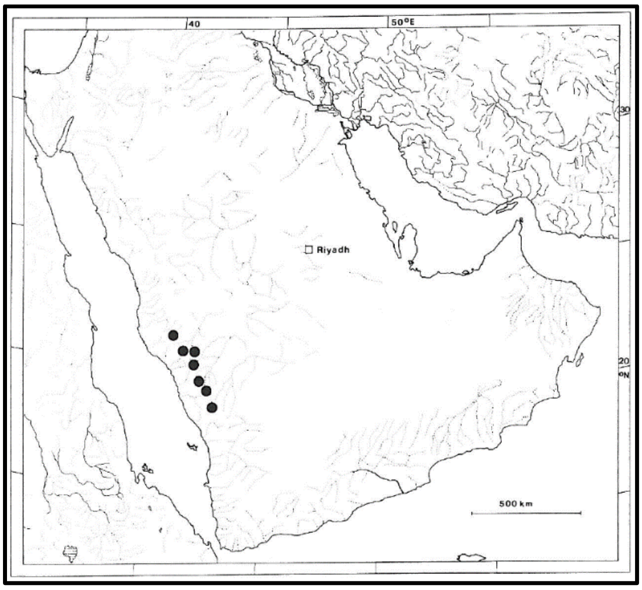


Figure 2.16. Distribution of *Garra buettikeri* in Saudi Arabia (Krupp, 1983). Picture of *G. buettikeri* taken during sampling trips.

Diagnosis. The species was first described by Krupp (1983): it has one dorsal fin; less than three pairs of barbels; no teeth in jaws; mental disc present on ventral surface of the head; 14-20 scales around least circumference of caudal peduncle; 7 branched dorsal fin rays; 20 scales around least circumference of caudal peduncle, the lateral line scales number 36-39.

Distribution. This species is endemic to Saudi Arabia, dwelling in Wadi Al-Dawasir drainage system along to Wadi Turbah (Figure 2.16).

Niche. Wadis upper reaches and reservoirs.

Current situation. Habitat fragmented and declined by 21% to 50% over 5 years (EPAA, 2002). It is in the IUCN Red List as Vulnerable (VU).

2.4.7 *Garra sahilia gharbia* Krupp, 1983

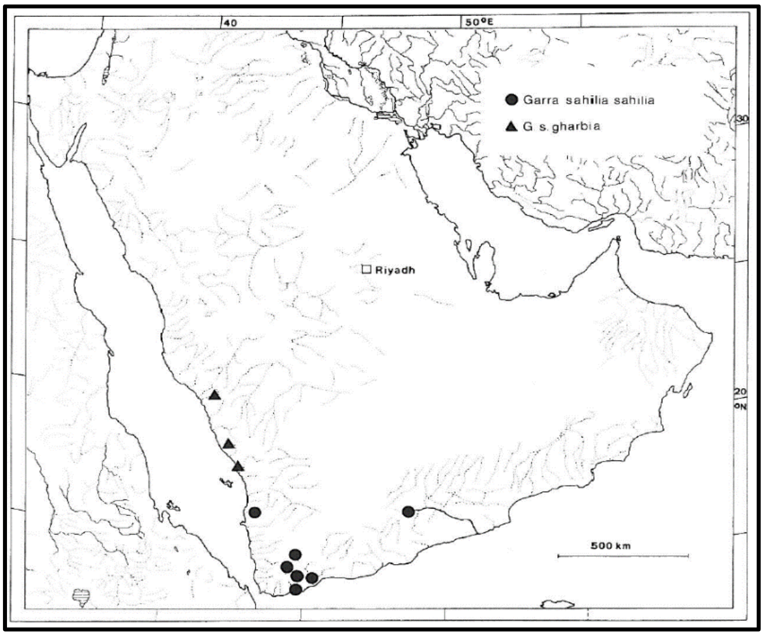


Figure 2.17. Distribution of *Garra sahilia* in the Arabian Peninsula (Krupp, 1983). Picture by Hamidan & Shobrak (2019).

Diagnosis. The species/sub-species has been described by Krupp (1983): it has one dorsal fin, less than three pairs of barbels, no teeth in jaws, mental disc present on ventral surface of the head, 14-20 scales around least circumference of caudal peduncle, 8 branched dorsal fin rays, less than 11 gill rakers on lower limb of first gill arch, the lateral line scales number 32-36.

Distribution. *Garra sahilia* is broadly distributed in the Gulf of Aden and the Red Sea drainages of Yemen, and the Red Sea drainages of Saudi Arabia (Krupp, 1983; EPAA, 2002). There are two subspecies: Garra *sahilia gharbia* occurs within south-eastern Saudi Arabia drainages while *Garra sahilia sahilia* mostly occurs in Yemen (Figure 2.17).

Niche. Within wadis, dams and inland wetlands.

Current situation. Population severely fragmented (EPAA, 2002). It is in the IUCN Red List as least concern (LC).

2.4.8 *Garra tibanica tibanica* Trewavas, 1941

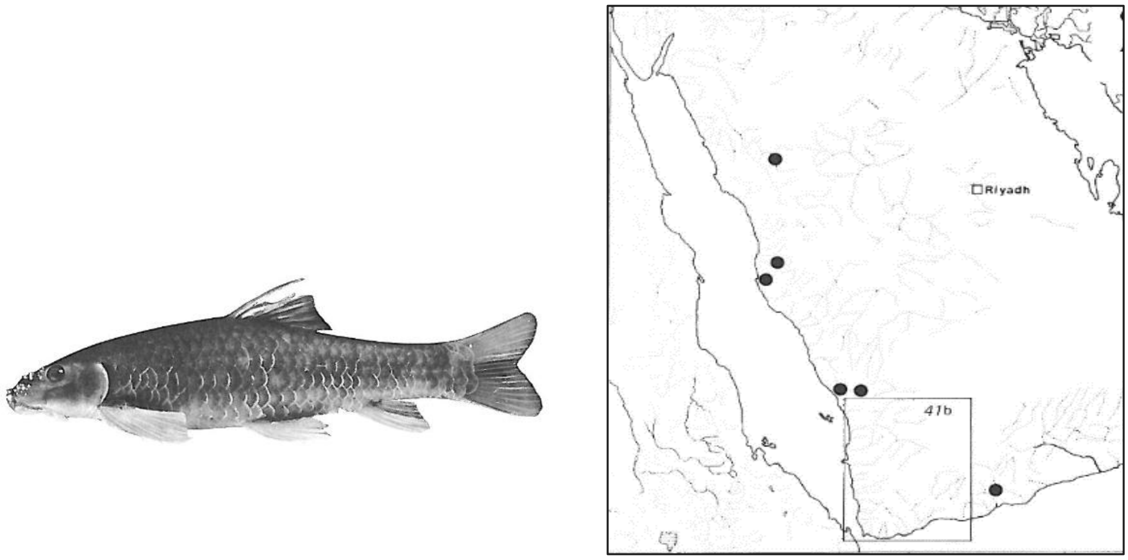


Figure 2.18. Distribution of *Garra tibanica* in the Arabian Peninsula (Krupp, 1983).

Diagnosis. The species was described by Krupp (1983): one dorsal fin; less than three pairs of barbels; no teeth in jaws; mental disc present on ventral surface of the head; 14-20 scales around least circumference of caudal peduncle; 7 branched dorsal fin rays; 14-16 scales around least circumference of caudal peduncle; 16 scales around least circumference of caudal peduncle; the lateral line scales number 32-36.

Distribution. *Garra tibanica* is the most wildly distributed cyprinid fish in Arabia (Figure 2.18). Occurring from the Gulf of Aden in the south to the Dead Sea rift valley in the north (Krupp, 1983; EPAA, 2002). *Garra tibanica tibanica* occurs in Yemen and Saudi Arabia and *Garra tibanica ghorensis* occurs in Jordan (Figure 2.17). However, a recent study suggested a new name for *Garra tibanica ghorensis* which is *Garra ghorensis* as they are genetically different from *Garra tibanica* (Hamidan, 2016).

Niche. Within wadis, dams and inland wetlands in general.

Current situation. Populations exhibit extremely fluctuations with the expectation of decreasing (EPAA, 2002).

2.4.9 *Aphanius dispar dispar* Rüppell, 1828

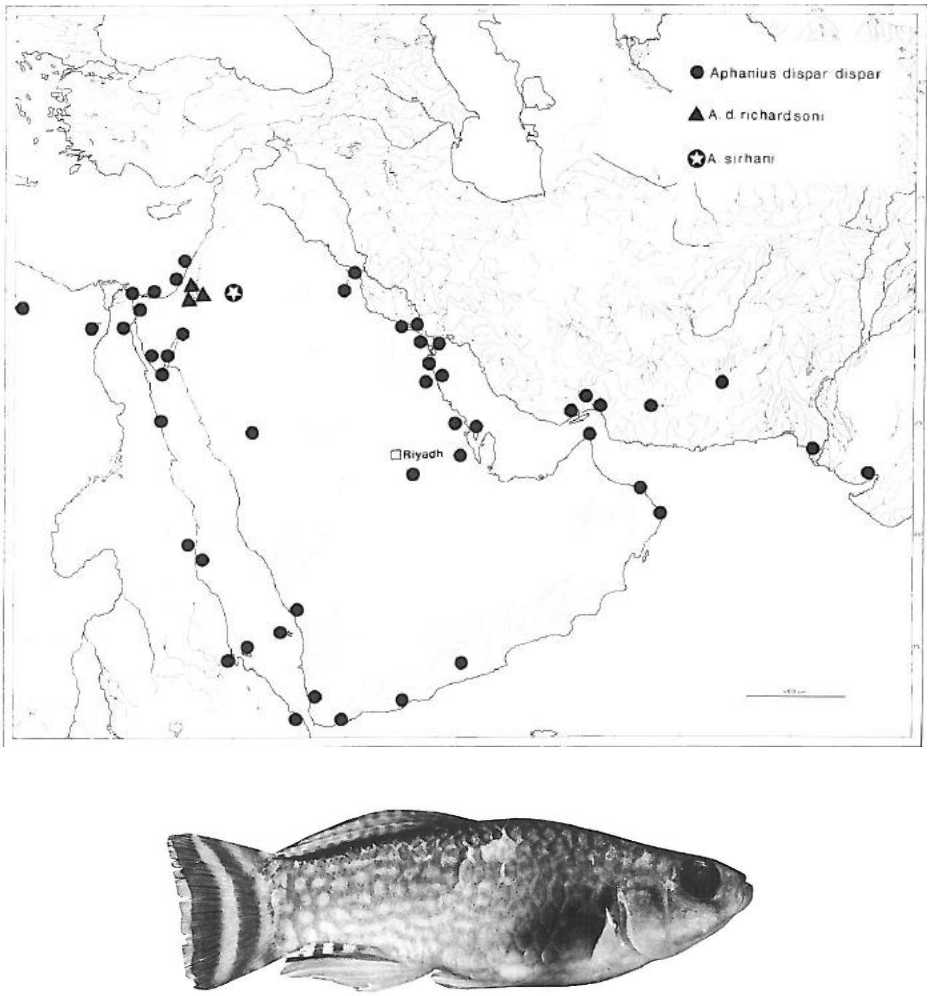


Figure 2.19. Distribution complex of *Aphanius dispar* (Krupp, 1983).

This species is the only genus of secondary freshwater fishes described from Arabia (Krupp, 1983).

Diagnosis. The species was described by Jouladeh et al. (2015) and by Krupp (1983): dorsal-fin rays in males 8-11, in females 9-11; 9-11 anal-fin rays; 14-17 pectoral-fin rays; 6-8 pelvic-fin rays; dorsal fin in large male reaching caudal fin base.

Distribution. This species is a euryhaline organism. It is widely distributed in the Arabian region (Figure 2.19). Krupp (1983) clarified complexities and how this fish became widely distributed.

Niche. Marine, brackish and freshwater such as irrigation canal, springs and man-made lakes. It can live in a variety of environments and tolerate poor water quality, a wide temperature range and varied substrate quality (Haas, 1982).

Current situation. Al-Kahem et al. (2008) suggested that *Aphanius dispar* populations are decreasing because of different stressors, for instance, competition from invasive species and habitat loss.

2.5 Marine and inland water fish production

The largest source of the fish for consumption in Saudi Arabia comes from the marine fisheries sector (Figure 2.20). Total production in 2016 was 67,995 tonnes (FAO, 2018; MEWA, 2018). There are no specific data for freshwater fisheries, but it is important that freshwater fisheries be incorporated into fisheries legislation, which will be discussed in Chapter 9, in relation to formulating a fisheries management plan.

Total production from the aquaculture sector (Figure 2.21) includes production from shrimp farms, freshwater inland farms and marine farms (source: FAO, 2018; MEWA, 2018;), with shrimp farms making the greatest contribution (Figure 2.22). There was a sharp decline in production from shrimp farms in 2011- 2013 but it recovered in 2014. Freshwater fish farming came second for production until 2016, when the marine aquaculture sector overtook freshwater fish production due to the expansion of floating cages and an increase in government support.

The contribution of different species (shrimp; Nile tilapia; catfish; sturgeon; sea bream; sparidentex; red tilapia; grouper; mullet; sigan) to total aquaculture production in 2010 (Table 2.3), showed shrimp was the most important with 20652 t and 78.3% of production. Tilapia in freshwater farms was in second place with 3382 t and 12.8% of total production. In third place was sea bream, with a production of 1300 tons and 4.9% of total production. Others species production is between 0.1-2.1%. In recent years, sea bass in floating cages in the Red Sea has increased dramatically. Fish farming was not limited to the traditional species which people usually use in nutrition but there are ornamental fish farm and sturgeon farm for meat and caviar (33.5 t in 2010).

To conclude, fish consumption in Saudi Arabia is increasing and raising the demand for production. Sea bass farming in the marine environment and tilapia in freshwaters has expanded and tilapia has been found in some dams and wadis as a result of their escape from fish farms. It is important that expansion of aquaculture takes due consideration of indigenous freshwater fishes.

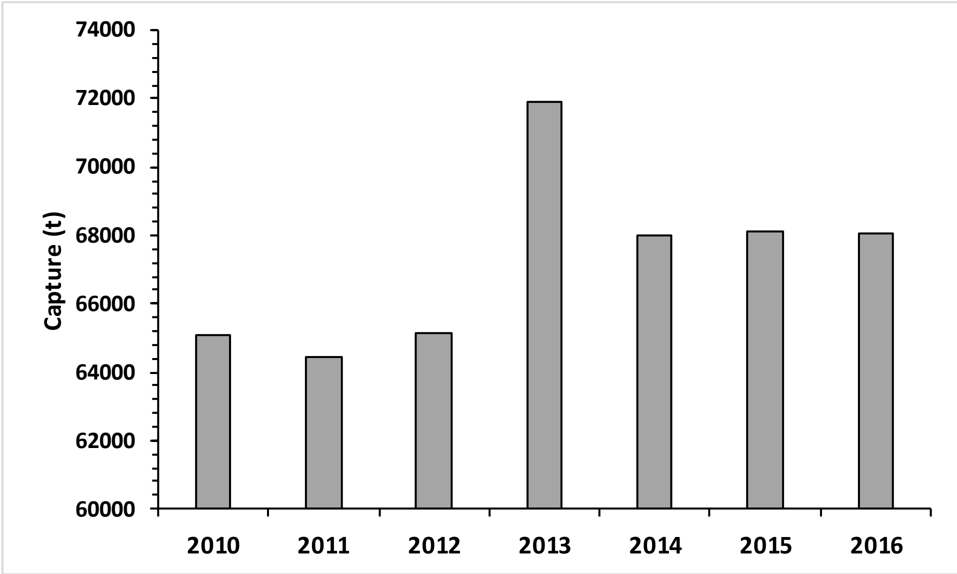


Figure 2.20. Total marine fisheries catch between 2010 and 2016 (FAO, 2018; MEWA, 2018;)

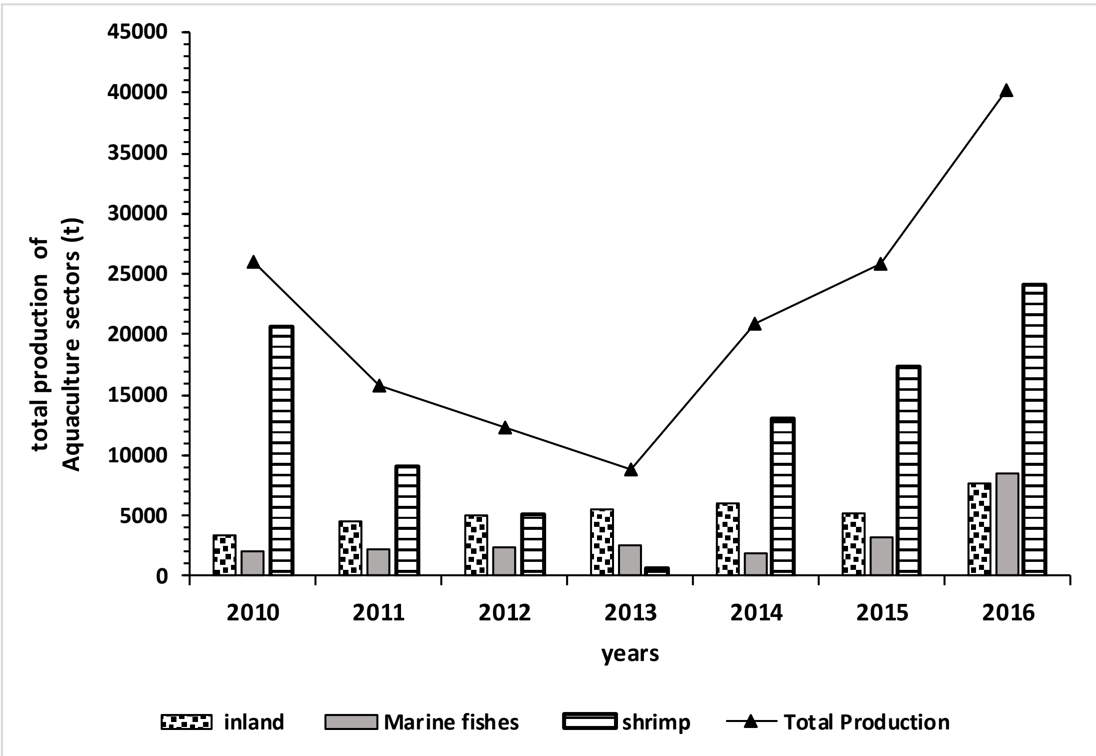


Figure 2.21. Total production (t) of shrimp, freshwater and marine fish farms between 2010 and 2016.

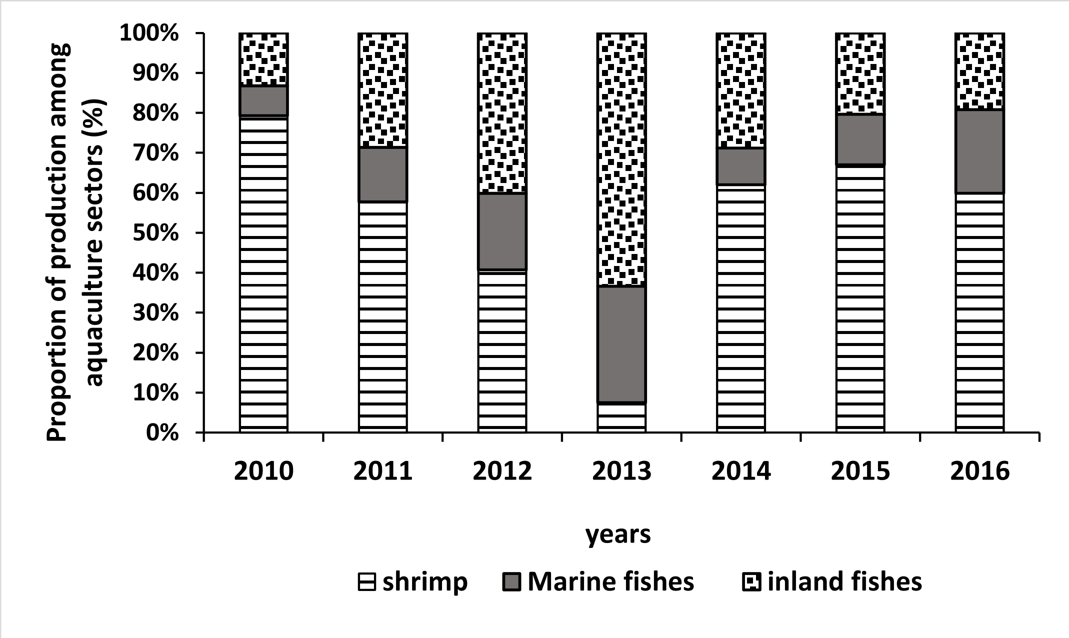


Figure 2.22. The proportion of shrimp, marine fishes and inland fishes produced through aquaculture in Saudi Arabia between 2010 and 2016

Table 2.3. Aquaculture production in Saudi Arabia for different species in 2010

species	Production (t)
Shrimp	20652
Nile tilapia	3382
Cat fish	47
Sturgeon	30
Sea bream	1300
Sparidente	540
Red Tilapia	300
Grouper	50
Mullet	38
Sigan	30
total	**26369**

Chapter 3 Overview of study sites (features, environmental parameters, conditions)

Fish and the aquatic life depend on functioning ecosystems to maintain ecological integrity, and long-term sustainability. Understanding the structure and functioning of study sites is therefore imperative to underpin how fishes survive and tolerate the harsh conditions in wadis and other freshwater systems in Saudi Arabia. Fish and other aquatic biota are adapted to withstand the most difficult conditions in these waterbodies and have evolved responses to cope with environmental changes. Al-Obaid et al. (2017) stated that species that are less phenologically adapted to change or are unable to alter behaviours are less resilient to environmental changes or recolonization and are likely be extirpated. It is therefore necessary to build up a basic understanding of the study sites and potential threats to aquatic fauna, such as location characteristics, water quality parameters or potential risks from human activities that may influence fish survival to underpin the ecological information collected in this study.

Many researchers have discussed the factors that impact on aquatic organisms. For example, sediment transportation and deposition can alter ecosystem features, affect vegetative development and smother spawning habitat and habitat for benthic organisms (Czuba et al., 2011). Spawning habitats typically are characterised by particular sediment sizes and fine sediments may impact fish eggs and other benthos (EPA, 2012). Hydrological properties that affect fish directly or indirectly have also been examined and include: temperature, conductivity, turbidity, pH, dissolved oxygen, besides climate change, drought, water flow, rainfall patterns, morphology of wadi systems, production and other parameters such as effects associated with drawdown (Welcomme, 1985; Cole, 1994; Behar et al., 1996; Wetzel, 2001; Subyani, 2004; Stevens et al., 2006; Webster & Lim, 2006; Wilde, 2006; Alharhi, 2011; Al-Ahmadi & Almazroui et al., 2012; Al-Ahmadi, 2013; RBAS, 2013; DeNicola et al., 2015; Torrans et al., 2015; Behar, 1996; Fondries, 2018; Hellawell, 2012).

Currently there is little scientific information linking the ecology of Saudi Arabian freshwater fishes to these parameters to support the objectives of this study and the potential impact of alteration of habitats on ecological characteristics lacking. In addition, a preliminary picture was built about assessing the exposure of Saudi freshwater fish in study sites to the potential risks expressed in Table 3.1. These risks were observed during the sampling trips. These observations moreover are a preliminary overview of the overall assessment as each of them needs independent research. Still, there is a lack of studies related to these threats in Saudi freshwater fish habitats. So of that, a combination of several parameters with expected threats was built for all study sites. Such information is imperative if the fish species are to be conserved and managed for the future, and to meet obligations to international protocols such as the Aichi Targets or Convention for Biological Diversity.

This chapter describes the basic features of the study sites and their general characteristics, then explores the potential threats to fish at these locations. Physicochemical characteristics, rainfall data and water levels are also examined so they can be related to the ecological characteristics of Saudi Arabian freshwater fishes.

3.1 Study locations

Sampling sites were chosen to be representative of two types of water body systems: wadis and man-made water bodies. They include two wadis (Wadi Turbah and Wadi Bouwa), and five dams and a lake as man-made systems (Figure 3.1). The wadis and dams are located in the south-west of the Kingdom and the lake, Al-Asfer Lake, is located in Eastern Province. Wadi Turbah and Al-Ahsa Oasis are amongst the most important Saudi wetland sites but are under great pressure from multiple uses, especially water withdrawal for drinking and agriculture purposes (Scott, 1995). The dams and wadis were chosen because they are inhabited by three endemic species within their native distribution range. These selected sites are in the western part of the Rub' al-Khali drainage (see Chapter 5) and represent the distribution range of many primary freshwater fishes. Many of the threats to freshwater fishes are also generally found in these sites. Al-Asfer Lake within Al-Ahsa County, Eastern Province, typifies where secondary and non-native freshwater fish are distributed. Strengthening knowledge about these endemic species in those important sites and drawing an actions for management plan that could apply in future for other sites are the main reasons that the study sites were selected.

Note, Saudi Arabia does not have any permanent rivers and the term wadi (= Arabic word for valley) means dried-up river beds, although wadis can hold water after heavy rainfall and this sometimes stays for long periods.

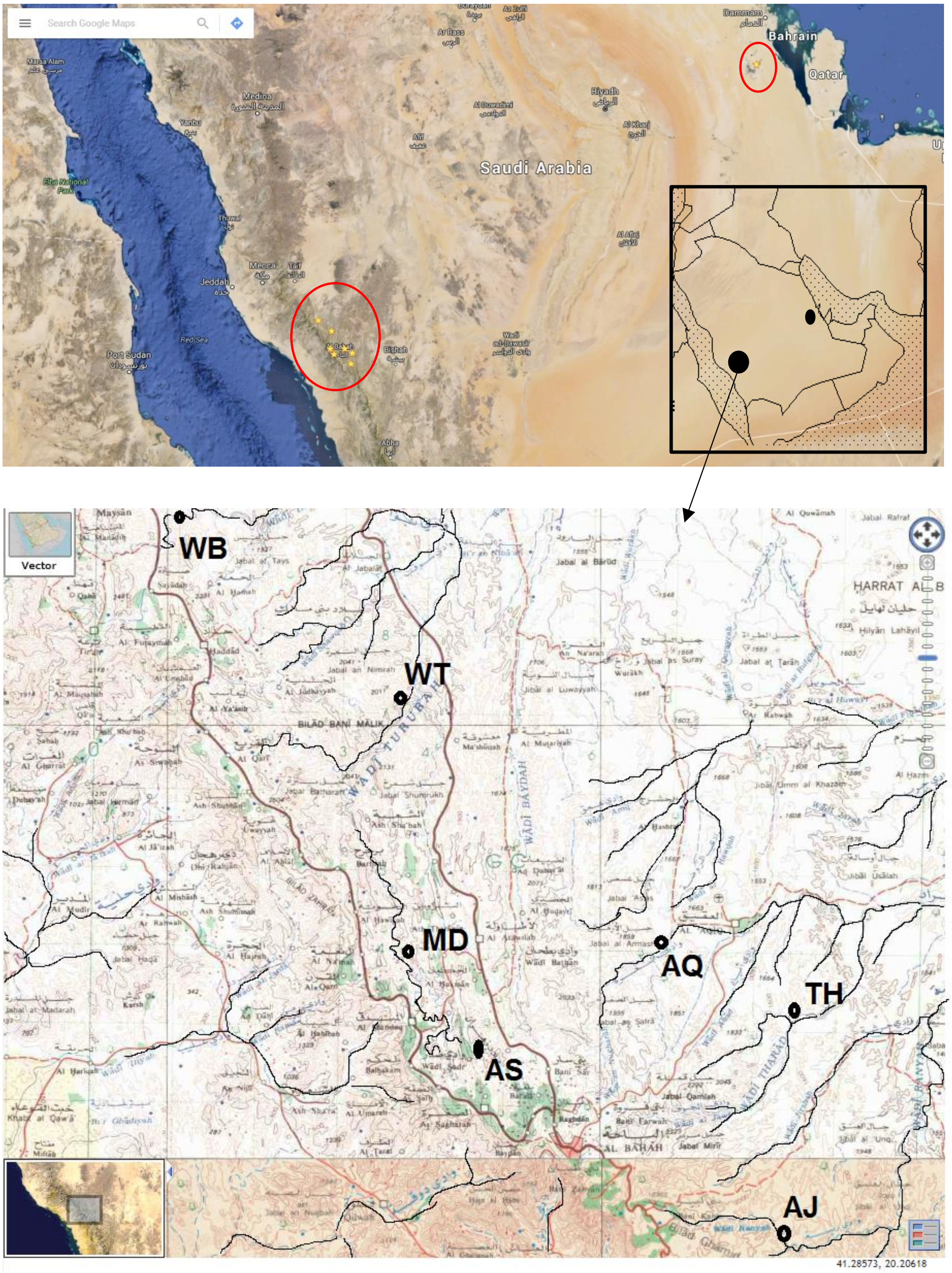


Figure 3.1. Top map shows the Kingdom of Saudi Arabia and location of fish sampling in red circles. The bottom map shows two major wadi basins (WB and WT) and dams (MD, AS, AQ, TH, AJ) where the sampling sites are found (Source gis.mewa.gov.sa). Full names of Wadi basins and dams are presented in the description of study locations.

3.1.1 Al-Sadr Dam (AS)

Al-Sadr (Figure 3.2) was constructed for irrigation in 1982 (mowe.gov.sa). Additionally, there is a public park situated beside the dam, which enhances the recreational value of the waterbody. The reservoir is surrounded mostly by steep mountains. The dam bed is generally silty but it has also boulders and cobbles, especially on the banks. The reservoir has a surface area of 0.144 km^2. The length of the dam wall is 100 m with a depth of 18 m, and water capacity is 500,000 m^3. This reservoir is severely affected by several threats: tourism and hiking, fishing and water pollution (Table 3.1)**.** Marwa village and several farm lands are located at the tail of the reservoir, and thus pollution is conceivable.

Figure 3.2. Location of Al-Sadr dam [20°07'35.6"N 41°21'29.4"E].

Table 3.1. Exposure of Saudi freshwater fish at different study sites (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WT= Wadi Turbah; WB = Wadi Bouah; ASFR = Al-Asfer Lake) to different pressures (- Not observed + Low prevalenace ++ prevalent +++ High prevalenace).

Threats& features	**AQ**	**AJ**		**AS**	**MD**	**TH**		**WT**	**WB**	**ASFR**
R = reservoir W = wadi	**R**	**R**	**W**	**R**	**R**	**R**	**W**	**W**	**W**	**Lake**
Habitat degradation and modifications	+	+	+++	++	++	-	+++	+	+	++
Environmental contaminants	++	++	-	++	++	++	++	+	+	+++
Fishing practised	+	+++	+	+++	+	++	+	-	-	++
Eutrophication	+++	+	-	-	++	+	-	-	-	+++
Water abstraction	+++	+++	-	+	+++	+++	-	++	++	
Water level fluctuations	++	++	+	+	+++	++	+	-	-	+++
Presence of marshes and shallow sites	+	++	++	+	+	+	++	++	++	+++

Threats& features	AQ	AJ		AS	MD	TH		WT	WB	ASFR
R = reservoir W = wadi	**R**	**R**	**W**	**R**	**R**	**R**	**W**	**W**	**W**	**Lake**
Water flow blocked	+	++	-	++	+++	-	-	+	++	+
Drought	+++	++	++	++	+++	+	++	++	+++	+++
Disease vector control(pesticides)	+	-	++	-	++	-	++	+++	+++	-
Tourism and hiking	++	+++	++	+++	+++	+++	+++	+++	++	+++
Cattle watering	+	-	+	+	+	+	++	+++	+++	-
Habitat loss after dam construction	+++	+	-	++	++	+++	-	-	-	+++
Introduced species	-	+	-	-	+	+	-	-	-	+++
Piscivorous birds	+	+	+	+	+	++	+	++	++	+++

3.1.2 Al-Aqiq Dam (AQ)

Al-Aqiq dam was built in 1987 to feed groundwater wells that supply domestic water (mowe.gov.sa) (Figure 3.3). The area of the reservoir is around 2.199 km^2. The maximum depth is 28 m and the length of the dam wall is 160 m with a capacity of 22,500,000 m^3. A pumping station below the dam wall abstracts water to a treatment plant then to houses or tanker distribution points (call locally Al-Ashyab), from where tankers distribute water to consumers. The area of the reservoir is fenced and closed to the public, but those wanting to fish are allowed to enter near the dam wall. They fish using hook and line. This reservoir is heavily threatened by eutrophication, water abstraction and habitat loss (Table 3.1). The area below the dam is arid and pools downstream are not able to function for as habitat for fish because the dam blocks flow. The dam is the biggest and most important for supplying Al-Baha city with drinking water. Fish die in the dam impoundment from time to time as result of excessive water abstraction.

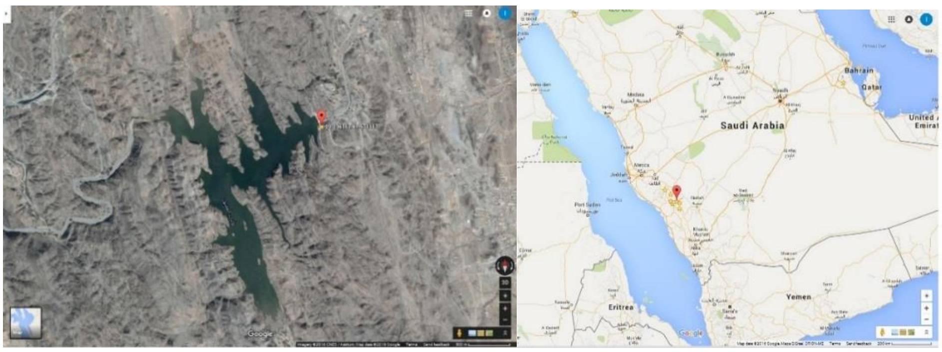


Figure 3.3. Location of reservoir of Al-Aqiq dam, 20°14'10.0"N 41°34'16.4"E.

3.1.3 Tharrad Dam (TH)

This dam is used for water supply (mowe.gov.sa) by pumping water to a treatment station then to houses or tanker distribution points (Figure 3.4). The area of the dam is around 0.675 km^2. The length of the dam wall is 120 m, its maximum depth is 20 m with a water capacity of 14,136,000 m^3. The dam bed is silty and some parts are mixed with boulders and cobbles. Water in the dam is smelly, probably because the dam's water is mixed with urban discharge from nearby cities. The dam is sited between two steep mountains and access is poor because of rough roads. There is a channel after the dam to take water along Wadi Tharrad. This reservoir is heavily affected by water abstraction. A treatment station is under construction at this dam. The area of Wadi Thrrad upstream of the reservoir is under pressures from tourism, habitat degradation and habitat modifications (Table 3.1). Fishing is occasionally practised by hook and line off the dam.

Figure 3.4. Location of reservoir of Thrrad Dam [20°09'28.3"N 41°43'15.9"E].

3.1.4 Al-Janabeen Dam (AJ)

Al-Janabeen Dam (Figure 3.5) was constructed mainly for drinking water. The area of the dam is around 0.926 km^2. The length of the dam wall is 180 m and max depth 22 m with a water capacity of 16,000,000 m^3. There is a small treatment station constructed near the dam. This reservoir is heavily affected by tourism, fishing and water abstraction (Table 3.1). There is a public park being built on the right side of the reservoir. Fishing is practiced intensively in this dam; the number of fishermen observed was more than other sites visited. A treatment station is under construction near to this dam. The part of the wadi upstream of the reservoir tail seems to be in good condition, but the habitat downstream of the dam wall is becoming degraded by urban development and road construction and fish are losing access to pool habitats during the flood periods.

Figure 3.5. Location of reservoir of Al-Janabeen Dam [19°54'03.5"N 41°42'39.9"E].

3.1.5 Medhaas Dam (MD)

Medhaas dam (Figure 3.6) was built in 1987 to feed groundwater wells and support agricultural activities (MOWE,2018). The area of the dam is around 0.105 km^2. The length of the dam wall is 90 m and max depth 10 with a water capacity of 1,500,000 m^3. This reservoir is heavily affected by water abstraction for agricultural purposes, high water level fluctuations and tourism (Table 3.1). Agricultural activities near the dam are extensive, mostly fruits cultivation, such as pomegranate. The area beside the dam is pleasant and attractive for ramblers. This enhances the tourist value of the site, but littering is one of the problems caused by tourism. A few fishermen were observed during sampling.

Figure 3.6. Location of Medhaas dam [20°13'17.6"N 41°16'27.7"E].

3.1.6 Wadi Turbah (WT)

Wadi Turbah is one of the biggest wadi systems in Saudi Arabia, draining the Asir mountains. It rises near Al-Mandaq, just north Al-Baha, and follows a north-easterly course as a prominent landscape feature for over 200 km to beyond Turbah town (Scott, 1995). Water runs along the wadi and disappears in some places, but ponds and streams are found where the surface water layer is exposed (Figure 3.7 &Figure 3.8). There are many artesian wells along the wadi for drinking purposes and different sizes of dams have been built. It is a highly important wetland due its rich biodiversity. This wetland faces threats (Table 3.1) from water abstraction, pastoralism, hiking, fishing and hunting. Cultivation takes place around some settlement zones.

A new dam is being constructed some 90 km upstream of Al-Baha town. These actions make it vulnerable to degradation. A number of tropical diseases, such as bilharzia, are prevalent in the surface standing waters, which health authorities are making efforts to combat.

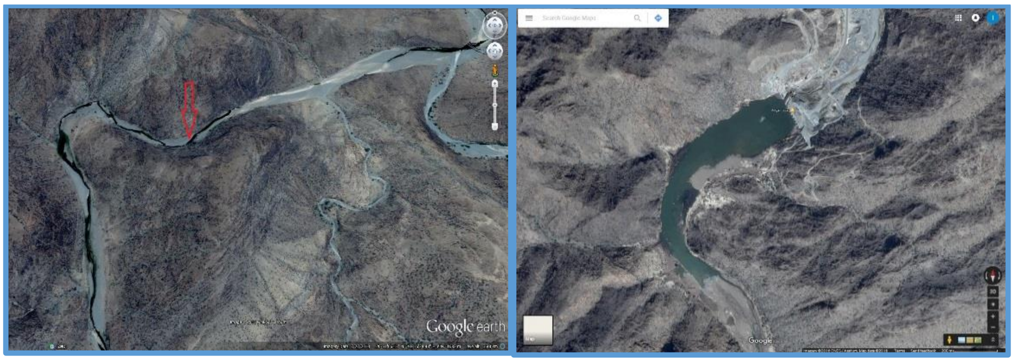


Figure 3.7. Wadi Turbah, 20°31'20.4"N 41°16'19.5"E, and the new dam that is being built near to sampling site.

Figure 3.8. Stream pool in Wadi Turbah from which fish were sampled.

3.1.7 Wadi Bouwa (WB)

Wadi Bouwa is a tributary of Wadi Turbah that runs from the Al-Hijaz Mountains, passes through Abu Raka village until it flows into Wadi Turbah. The origin of its name derives from the word “epidemic”: people in the past gave it this name because of unknown disease affecting people at that time as they pass through it. The disease caused abdominal swelling then later death (likely to be bilharzia). Some areas of the wadi are remote and therefore naturally protected from human impacts. The wadi has many large permanent pools in the more upstream reaches. This wadi is affected by water abstraction, cattle watering, disease vector control (pesticides), and mining and sand abstraction (Table 3.1) (Figure 3.10).

Figure 3.9. Sampling site within the low reach of Wadi Bouwa [20°44'23.3"N 41°00'50.5"E]. Circle is a temporary stay for pastoralists near wadi water pools.

Figure 3.10. Mining and sand abstraction in Wadi Bouwa near sampling site.

3.1.8 Alasfr Lake (ASFR)

Al-Asfer Lake (Figure 3.11 &Figure 3.13) is located in the eastern part of Al-Hasa County about 20 km southeast of Alaayoune Town in Eastern Province. Al-Hasa is an important oasis that covers an area about 16,000 ha of land, about 8600 ha of which is used for agricultural activities (Figure 3.13). This oasis was added to the World Heritage List at a meeting held by the World Heritage Sites Selection Committee at the United Nations Educational, Scientific and Cultural Organization (UNESCO), in Bahrain capital on 29 June 2018. Palm trees are the main crop at the oasis. Over the last few decades, the oasis has also produced vegetables and fruits. Springs, wells and groundwater are the main sources of water used for agriculture. Some water is recycled after full treatment. The area of Alasfr Lake is about 36.714 km^2. Alasfr Lake is filled mainly from agricultural drainage water or water from a wastewater treatment plant. About 35,000,000 m^3 of agricultural wastewater flows towards the lake from the main channel (Figure 3.12. In winter, it plays a key role to store rainwater. The lake varies in size and depth according to season, its area usually declines and retreats during the summer due to evaporation leading to increased salinity and levels of organic matter. Total rainfall is low, about 70 mm/yr (see Section 3.4, Rainfall, page 58), and it exhibits a very high rate of evaporation up to 3300 mm/yr. The size of the lake in winter is usually double that in summer and depth can exceed more than 2 m in places. Fishes (native or introduced) and native freshwater turtles *Mauremys caspica* (Gmelin) are present in the lake as well as channels. These channels are generally in poor condition because of waste, highly vegetated banks, excavations, and the water is greenish and smelly (Figure 3.12.). These channels need rehabilitation works to reinstate their ecological integrity. Many migratory birds stopover in the lake; these include large and small birds, such as *Ixobrychus minutus* (Linnaeus, 1766), *Ardea purpurea* Linnaeus, 1766 and *Recurvirostra avosetta* Linnaeus, 1758. Salinity is high in the lake, but the water quality meters used during field visits were not able to read the levels because they were calibrated to read freshwater ranges, but was thought to be around 5000-10,000 µS/cm (see Environmental and physicochemical characteristics of wadis in Section 3.3). The lake is surrounded by sand dunes, which makes accessibility difficult. Sabkha (periodically flooded salt flats) form in different places around the lake, especially when water recedes. Sabkha makes access to some area of the lake more difficult and impassable; people will highly lose their vehicles if they drive through Sabkha. Fishing is not allowed in the lake, but tonnes of fish caught illegally are reported many times in official newspapers. A few dead fish were seen in the lake that might be because of raised temperature and oxygen depletion. Fish are stocked in the lake by the laboratory of Irrigation and Drainage Authority. Therefore, to summarize, this lake is heavily affected by, pollution, eutrophication, high water level fluctuations and introduced species (Table 3.1). The question remains as to what is the feasibility and what is the potential cost of rehabilitating and managing this lake to provide various services, then incomes derived from activities will be able to cover rehabilitation and maintenance costs. For example, fishes from this lake are not suitable for human consumption because they are contaminated with heavy metals and they have a role in biological control, but if the quality of lake water is improved, it may be possible to develop recreational fishing.

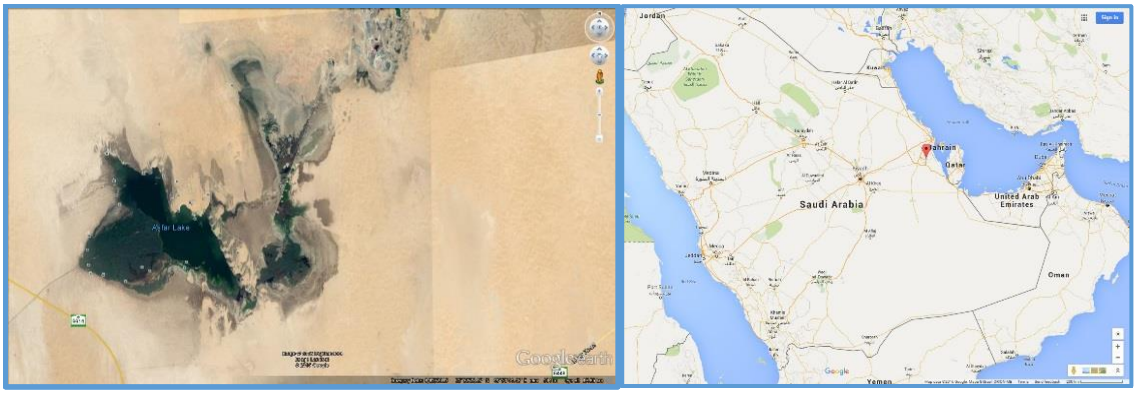


Figure 3.11. Location of Al-Asfer Lake, 25°31'13.19"N 49°46'2.81"E.

Figure 3.12. Channels that take water to AL-Asfer Lake. Some channels are affected by dense vegetation.

Figure 3.13. Top Al-Hasa Oasis has around 3 million palm trees. Bottom AL-Asfer Lake receives wastewater from the oases. Photos by (sauditourism.sa).

3.2 Major drainage systems and wadis

The GIS database of the Ministry of Environment, Water & Agriculture (gis.mewa.gov.sa) and Al Shareef (2002) were used to map the major drainage basins occupied by freshwater fish in the South and South-West Regions of Saudi Arabia (Figure 3.14). There are two main natural systems: the eastern and western drainage basins. The systems are separated by the Sarawat Mountains series, which extend along most of the western sector of Saudi Arabia with a range of elevations between 1600 and 3000 m above sea level (Figure 3.15). These drainage systems have the greatest availability of surface water and they are the main areas inhabited by freshwater fishes in Saudi Arabia. Construction of dams in these basins is leading to fragmentation of fish habitat which the need for a management plan that takes both the needs for water and protection of fish into account.

(A) Eastern drainage system: Wadis (= valleys) in this system flow generally towards the east or north-east of the Kingdom (Krupp called them the Empty Quarter drainage). They have few drainage channels across a wide area, and because of drought conditions these channels serve the connection between permanent water bodies. The eastern system has six distinguished main basins:

1- **Wadi Najran Basin**, the most important wadi in this basin is Wadi Najran, which extends about 180 km, and some of its tributaries Thi Khoahil, Huson and Thoaban.

2- **Wadi Habawnah Basin,** runs eastward and is more extensive than Wadi Najran, with a basin area of 12,500 km^2 (Figure 3.14).

3- **Wadi Tathleeth Basin** covers an area of 31,000 km^2 of the Asir Plateau, starting from the southern Asir Mountains of Sarat Qahtan and running northeast towards Wadi al-Dawasir. The main channel runs about 400 km (Figure 3.14).

4- **Wadi Bishah Basin**, the largest and most important basin in the eastern system with an area of 45,000 km^2, runs about 450 km. Some of its main tributaries are Wadi Abha, Wadi al-Mahalla and Athena which have a plentiful supply of water because of the high rainfall in the region. Other wadis are Tindah, Turg, Horan and Tabalaa (Figure 3.14).

5- **Wadi Ranyah Basin** covers an area of 11,000 km^2 and runs about 225 km. Its water is derived from its tributaries, Shawas, Al-Muqallah, Basrah, Qersha, Al-Aqiq and Thrrad (Figure 3.14)

6- **Wadi Turbah Basin** covers an area of 17,000 km^2 and extends for about 400 km. It starts in the foothills of Sarrat Zahran. Its water derives from the following wadis: Al Sadr, Bani Malik, Shawqab, Bouwa, Dhraa, Al Hageer, Kerra and Baiadah.

(B) Western drainage systems (Red Sea Drainages): these systems drain towards the west, heading directly from sources in the Sarawat Mountains to the sea, although some reaches run parallel with the coastline (Figure 3.14 and Figure 3.15). The wadis are divided into three groups based on their location and discharge.

Group1 (G1): The first group includes basins located between the Yemen border in the south to the end of the Wadi Heli basin in the north (Figure 3.14). There are 24 wadis within an estimated area of 29,250 km^2, and these wadis discharge towards the Red Sea over a shoreline length of 340 km, which is equivalent to one wadi every 14 km of coastline. Wadis in this group are characterized by considerable water discharge. They are short compared with the wadis in the east drainages. The most significant wadis of this group are Khleb, Jazan, Damad, Sabyaa, Baish, Otwood and Hali, which are considered the most water rich wadis in the kingdom. Wadi Baish is the largest and most important in this group, with a basin area of 4700 km^2.

Group2 (G2): The second group of wadis originates from Wadi Heli to the Wadi Al-Ahsabah basin in the north. Floods in these wadis are moderate occurring during the same period as the first group but they are less dense. They are thus less destructive to people and infrastructure, may not occur in some years. The most prominent wadis of this group, with good water accumulation, are Uoubah, Ganoonah, Al-Ahsabah, Ajaah and Loomah. The water of these wadis reaches the Red Sea along 100 km of shoreline and thus there is approximately one wadi for every 20 km, with a combined area of 19,000 km^2.

Group3 (G3): The wadis of this group start after Wadi Al-Ahsabah until the basin of Wadi Sa'a over a coastline length of about 180 km. The wadis of these group cover an area of about 9000 km^2. They rarely flood and flooding occurs it only lasts for a short period, and they do not reach the Red Sea coast.

Medina Wadis (M): The most important wadis in Medina, where freshwater fish are present are Khyber, Khadra and Wadi Hadiyah. Hadiyah is most important and is inhabited by the endemic species *Acanthobrama hadiyahensis,* which was named after this wadi.

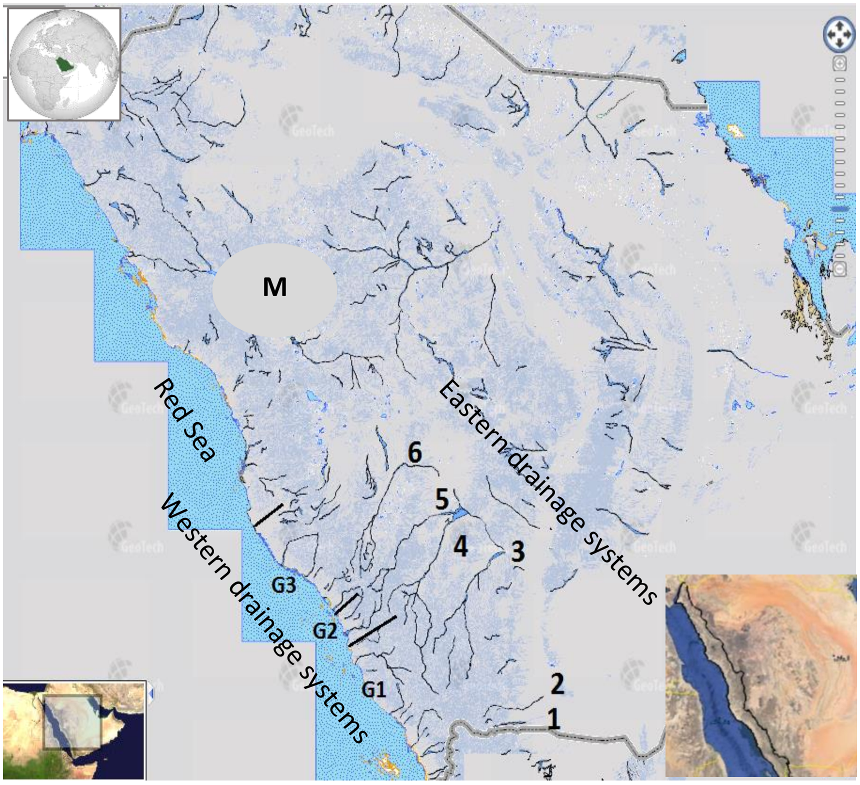


Figure 3.14. Location of the main eastern and western river basins in south-east Saudi Arabia that drain into the Red Sea where freshwater fish are concentrated. (1) Wadi Najran; (2) Wadi Habawnah Basin; (3) Wadi Tathleeth Basin; (4) Wadi Bishah Basin; (5) Wadi Ranyah Basin; (6) Wadi Turbah Basin are the highland eastern basin. G1, G2, G3 are major wadis located in lowlands to the southwest. (M) the Madinah Region has some important wadis.

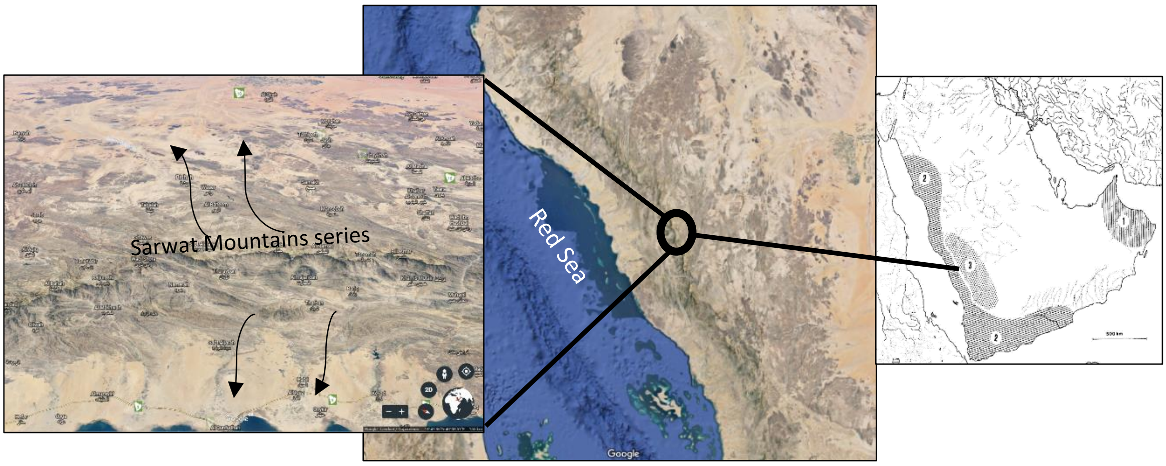


Figure 3.15.The right-hand map is from Krupp (1983) showing the main drainages containing freshwater fish in the Arabian Peninsula in general (1 = Oman mountains; 2 = Red sea and Gulf of Aden drainage; 3 = Empty Quarter drainage). The satellite images taken from Google Maps show the location of the high-altitude Sarwat mountain range separating the two main drainage systems.

3.3 Environmental and physicochemical characteristics of wadis

This section describe trends in some physiochemical factors that were measured during the sampling period or analysed from official reports (about 20-year periods for temperature and rainfall from reports by the General Authority of Meteorology & Environmental Protection; 5 years of dam water level data from the Ministry Of Environment Water & Agriculture open database website (http://app.mewa.gov.sa/DailyRainsNews/Rain_Dams.aspx). This information will help provide a description of baseline conditions for fish and their suitability for various fishing activities and production.

3.3.1 Temperature

Mean (plus maximum and minimum) air temperatures (in Celsius) (Figure 3.16) for stations close to the study sites (Al-Asfer Lake = Al-Hasa station; dams = Al-Baha city station; wadis = Taif city station) between 1994 and 2016 were collated from data provided by the General Authority of Meteorology & Environmental Protection (www.pme.gov.sa). Surface water temperatures (in Celsius) were estimated by recording water and air temperatures during sampling periods, then correlating against air temperatures to determine water temperature characteristics (Figure 3.16). Considerable variation in air temperature was found between day and night as is typical for a natural desert climate (Figure 3.16). Two main periods for both air and water temperature are evident (Figure 3.16): one between May and October which is characterized by extremes in temperature and second between November and March, which characterized by moderate or sometimes cold temperatures. More extreme temperatures were prevalent at Al-Hasa station than at wadis and dams (Al-Baha city station and Taif city station). Air temperatures around wadis and dams ranged between 20 and 36.3 °C during the May to October period, but were lower (9.3-30.8 °C) between November and April, while air temperatures around Al-Asfer Lake ranged from 25.3-45.9°C between May and October and 9-35.9°C for the period between November and April. Even during winter, air temperatures can rise to high levels (30 °C), especially during the daytime.

Water surface temperatures in the wadis and dams ranged from 16.4 to 29.8 °C between May and October but were lower (7.6-25.3°C) between November and April. Water temperatures in Al-Asfer Lake were slightly higher (20.7-30.9°C) between May and October and for the period between November and April (7.3-29.4°C).

Temperatures in the various water bodies examined can reach extreme levels that could have adverse impact on fish autecology, such as foraging, growth and reproduction. There is no information about temperature preference ranges for Saudi freshwater fishes, so the effect of temperature fluctuations and extremes on fishes is unknown, but fish are likely to cease activities during periods of high temperatures in the summer, especially July. Furthermore, fish may escape the heat by resting in deeper water, or, if there is no deep water as in wadis (average depth = 2 m), in streams pools, which usually have large rocks and aquatic plants that could help fish escape the extreme heat. Nevertheless, fish were absent from pools in some wadis because they were not deep enough, and exposed to extreme temperatures that fish cannot survive. For example, dead fish, like tilapia, were observed in shallow areas around Al-Asfer or in areas with dense vegetation where fish were trapped due to receding water levels. This lake lies in the desert where temperature levels probably exceed the thermal thresholds for the fish. Tilapias, for example, can tolerate temperatures between 37°C and 17°C, thus these mortalities are probably temperature-induced stress problems (Webster & Lim, 2006). The impacts of these extreme temperatures fluctuations in Saudi freshwater fish environments may also be exacerbated by other indirect problems, such as eutrophication.

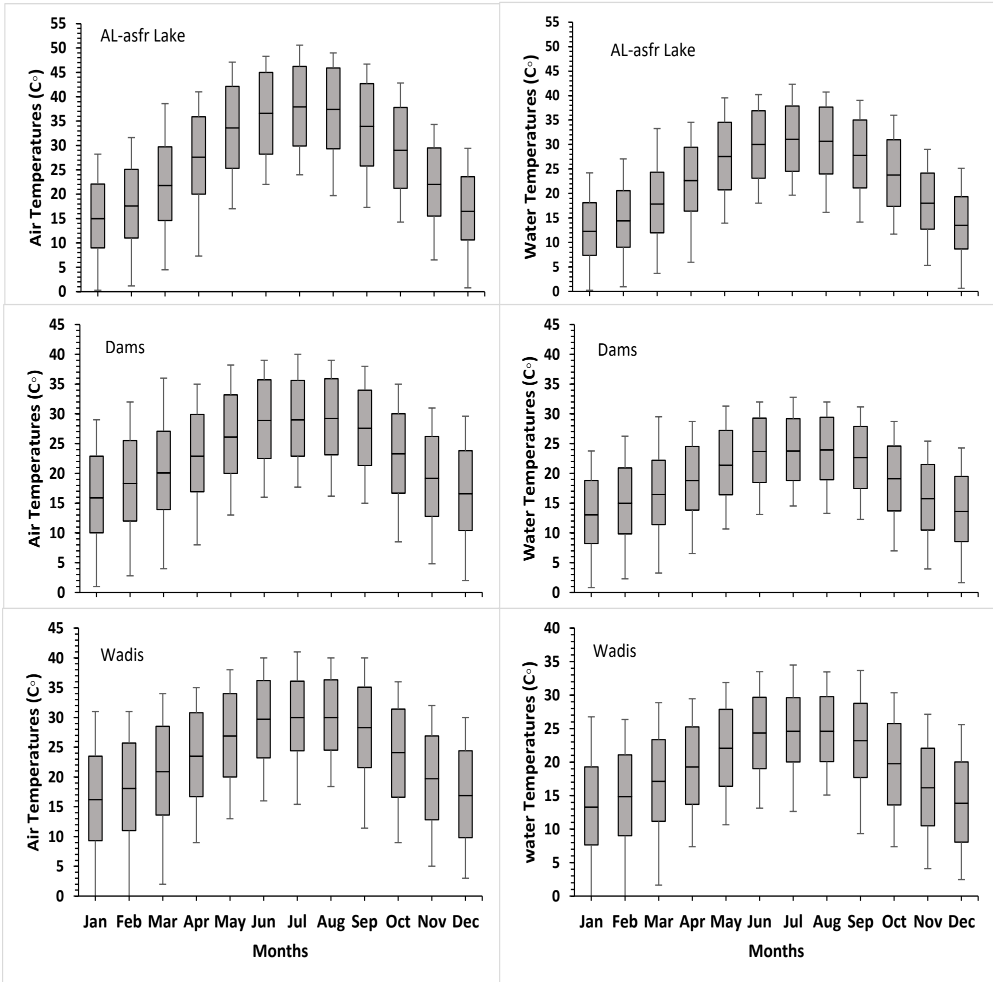


Figure 3.16. Mean, maximum and minimum air temperatures (°C) for stations close to the study sites (Al-Asfer Lake = alhsa station; Dams = Al-Baha City station; wadis = Taif City station) between 1994 and 2016. Whiskers illustrate extreme temperatures. Air temperature data provided by General Authority of Meteorology & Environmental Protection (www.pme.gov.sa) while water temperature was estimated by correlating air and water temperatures during sampling.

3.3.2 Conductivity (µS/cm)

Water conductivity is a measure of the concentration of anions and cations in the water and an indicator of the salinity of the water body. Conductivities in Saudi fresh waters are high variable and characterised by surrounding geology, water runoff, land use, pollution, and evaporation from the surface water. Different fish species and life stages have different tolerances to conductivity and many freshwater fishes cannot survive in high conductivity waters because of their inability to cope with the osmotic stresses brought about by high ionic levels. Understanding the variability in conductivities of the water bodies under study is therefore important.

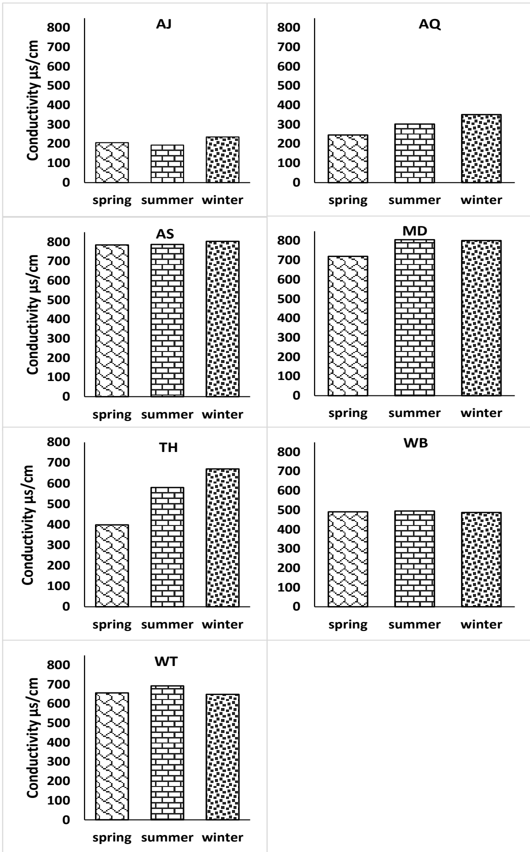


Figure 3.17. Variations in conductivity between study sites and seasons during sampling period.

Conductivity was measured at each study site during each visit using a Hanna Instruments HI-98129. Conductivity varied between 200 µS/cm and 800 µS/cm among the different study sites, and less so between seasons (Figure 3.17). The highest values were recorded in Al-Sadr and Medhaas (800 µS/cm). Little variation in conductivity was observed between seasons except in Thrrad Dam, where large differences in conductivity were found between seasons (398-670 µS/cm) due to flooding or potential contamination from nearby towns (suspicion based on water smell). Further, there was road construction work in the mountains near Wadi Tharad, and wash off of construction materials during the rains into the wadi may have caused the conductivity to rise.

Unfortunately, there are no studies to determine salinity preferences for Saudi freshwater fishes and its relation to various ecological or biological activities. Pollutants or any urban and industrial discharge, evaporation and geology in the catchment (wadis differ in their geological nature), are the fundamental factors that can change conductivity. In Al-Asfer Lake, about 7,600 t of sediments and 25,000 t of salts accumulate each year according to the Saudi Irrigation Organisation (hida.gov.sa). Hanna Instruments HI-98129 that was used for water quality assessment in the project was not able to read conductivity in Al-Asfer Lake due to the equipment's maximum detection level of 3999 µS/cm, which that means Al-Asfer Lake conductivity is possibly as high as 5000-10000 µS/cm as result of the industrial wastewater discharged into the lake.

3.3.3 Turbidity - water transparency (cm)

Turbidity is a proxy of particles suspended in the water that influence water visibility. It is a key indicator of suspended sediments and soil erosion as well as algal concentrations. It is influenced by rainfall, which mobilises sediments that are transport in rivulets to the wadis. Turbidity can raise water temperature, depress dissolved oxygen, prevent light from reaching aquatic plants (which decreases their capacity to photosynthesize), and impacts fish gills and eggs (Behar, 1996).

Turbidity was measured at each study site during each visit using a Secchi disk. The Secchi measurement, as an indicator of water turbidity, was recorded by lowering the disk until it could not be seen and then slowly lifting until the disc reappeared (Cole, 1994). A Secchi disk measurement was taken in the shady area (dam wall or near big rock for wadis) around 12:00 noon. The average of two Secchi depth measurements was reported (Figure 3.18). Water clarity -as a synonym of water transparency (high Secchi disk values means water are more transparent less turbid) - was usually high in shallow streams in wadis with depths less than approximately two metres. Wadi Turbah (2 m average depth), as an example, was with 100% transparent to bottom in winter and summer when the samples were taken, but there was a reduction in clarity during spring, which may because of the heavy rain and flooding that occurred before the survey. However, not all stream pools have high clarity, because they are influenced by disturbance of muddy substrates that makes the water turbidity. In dams, light penetration is low and mostly less than 1 m depth. Water clarity in dams varies but much depends on the depth; in some shallow dams clarity is low. For example, the deepest depth of transparency in Al-Sadr Dam was about 2 m during winter. In some dam with extensive growth of aquatic plants, such as Al-Janabeen, this can help sediment stability and lead to a rise in water clarity.

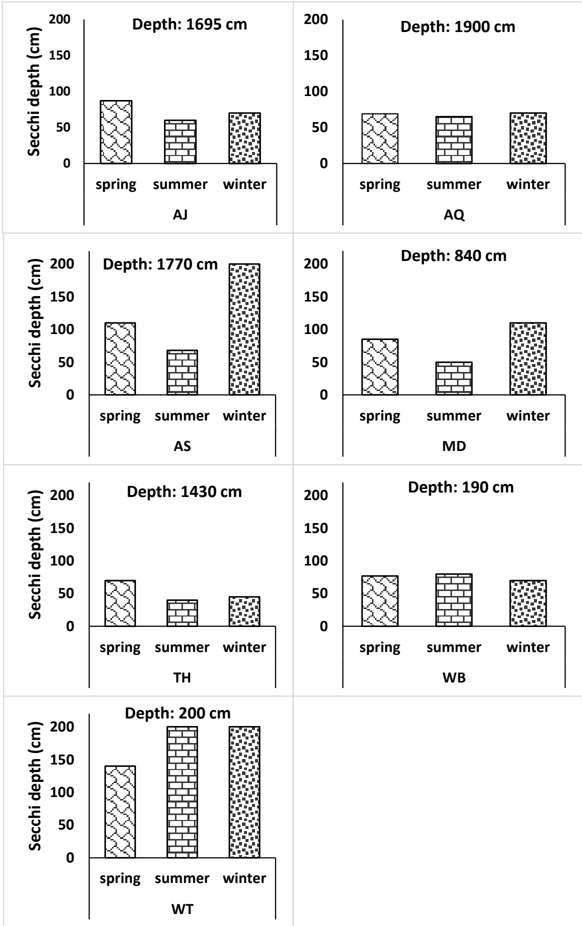


Figure 3.18. Secchi depth (cm) as measure of turbidity in the study sites compared with their recorded depths.

3.3.4 pH

pH, a measure of acidity and alkalinity, is an important characteristic that dictates the presence and absence of fish and other aquatic biota in water bodies. Most freshwater aquatic organisms favour a pH between 6.5 and 8.0 (Behar, 1996).

pH was measured at each study site during each visit using a Hanna Instruments HI-98129. pH values were within the range that fish can tolerate (Figure 3.19). However, there was an increment in pH values in Al-Janabeen reservoir (average: 9.2), which may because of the limestone rocks that water flows over to enter the reservoir, which raises alkalinity. This is exacerbated by drilling operations of the limestone rocks that occurred to establish a public park next to the reservoir. The highest pH was 9.6 during the spring rainy season, which supports this conclusion. Moreover, this dam was characterised by the presence of dense water plants and algal blooms that were not present at other dams at the time of sampling, which could also lead also to reduced pH due to respiration and decomposition. Thus, pH ranges are acceptable for the fish species identified at the project sites, but there may be some other aquatic organisms that may be more sensitive to pH changes, which may affect the food of the fishes.

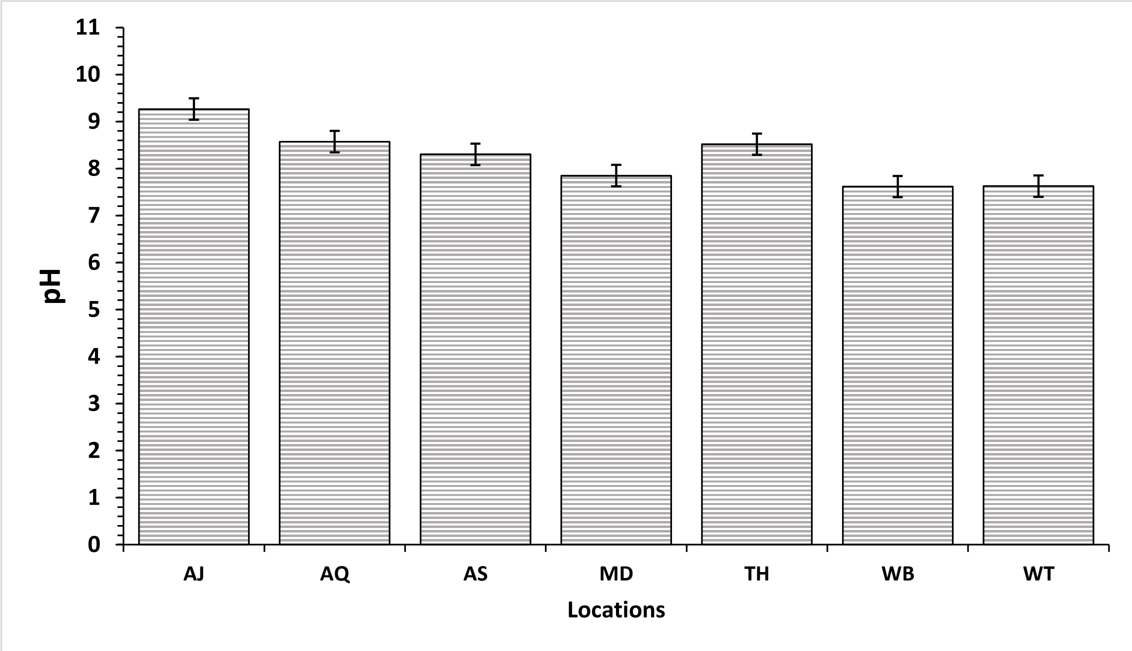


Figure 3.19. Average (and 95% CL) pH readings taken from study sites through all study seasons

3.3.5 Dissolved oxygen (mg/L)

Dissolved oxygen is important for survival of aquatic organisms, especially fish. There are many factors affect dissolved oxygen levels in water, such temperature, seasons, altitude, depth, runoff and the time of day (Cole, 1994; Wetzel, 2001; Stevens et al., 2006; Hellawell, 2012; Torrans et al., 2015; Fondries, 2018;). Understanding the variability in dissolved oxygen of the water bodies under study is therefore important.

There is a lack of studies that discussed the levels of dissolved oxygen in water and its relationship to Saudi freshwater fishes and the impact of low concentrations of it on the fish performance, or other aquatic species in the Saudi Arabian freshwater environment. Fish species or other aquatic organisms have different requirement of dissolved oxygen concentrations. Behar (1996) suggested a general overall of levels of dissolved oxygen that could applicable for many habitats: Below 2 mg/L is insufficient to support life, a few fish and aquatic insect species can survive 2-4 mg/L while most organisms can survive in levels of 4-7 mg/L but 7-11 mg/L is appropriate for most stream fish. Alharhi (2011) found monthly changes in dissolved oxygen concentrations in Wadi Bua, with the highest levels found in January and then gradually reducing to lowest levels in August and then rising again in September: concentrations were within the range 6.7-10.3 mg/L which were able to sustain primary freshwater fishes.

Dissolved oxygen was measured just below the surface at each study site during each visit using an Extech D0600-K Dissolved Oxygen Meter. Dissolved oxygen concentrations were between 4.2 mg/L and 12.3 mg/L at all study sites during the three sampling periods (Figure 3.20). Lower dissolved oxygen were found in wadis (5.8-6.4 mg/L) than reservoirs (4.2-11.2 mg/L), probably because the streams in wadis were shallow and pools small, and they are likely to be more exposed to higher temperatures, which leads to reduced dissolved oxygen levels. In addition, decomposition processes in the streams may result in lower dissolved oxygen concentrations. The dissolved oxygen concentrations in these small streams may not be sufficient to meet all aquatic organisms' oxygen demands. In the dams, oxygen concentrations were higher in spring (8.6-11.2 mg/L) and winter (7.6-10.7 mg/L), with the lowest concentrations in the summer (4.2-8.8 mg/L), partly because of the high summer temperatures. Algae bloom were also observed in some dams, such as Al-Aqiq Dam, which probably resulted in depleted oxygen concentrations over night when photosynthesis is not replenishing oxygen used for respiration. Other factors that influence dissolved oxygen concentrations in the sites studied include flooding, the absence of wind that causes mixing, altitude and contaminated water discharged into some dams (Thrrad dam had a decaying odour during the first trip that likely indicted water contamination). Moreover, some reservoirs have channels or still ponds made of concrete below the dams to control water flow during flooding. These structures may contain fish, but also experience high temperatures that may affect the fish and the dissolved oxygen concentrations. In the eastern region, where Al-Asfer Lake is located, some dead fish were noted possibly due high evaporation rates along with dense decaying vegetation, leading water to receding water levels and low oxygen levels in some areas of the lake. The dead fish included tilapia, which are able to tolerate the tough conditions experienced.

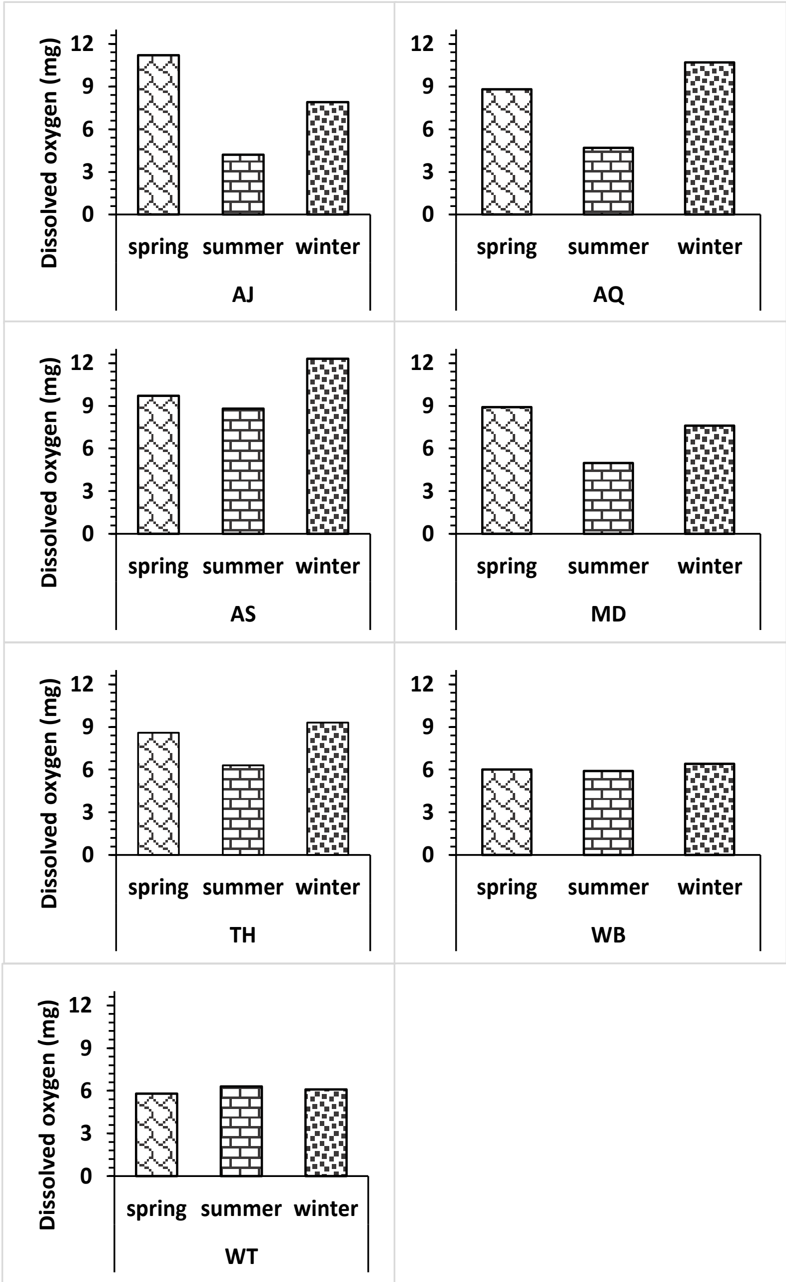


Figure 3.20. Dissolved oxygen concentrations recorded in surface waters during the three sampled seasons at different study sites.

3.4 Rainfall

Annual rainfall across Saudi Arabia is largely deficient because of the influence of a subtropical high-pressure system, but there is considerable variation in temperature and humidity across the Kingdom. For example, the region of Asir along the Western coast is influenced by the Indian Ocean monsoons, which usual occur between October and March, when an average of 300 mm of rain occurs; this represents around 60% of the annual rainfall in the Kingdom. Elsewhere in the Kingdom, rainfall is negligible and unreliable. The entire year's rainfall may consist of one or two local, heavy cloudbursts or thunderstorms. See Subyani (2004), Almazroui et al. (2012), Al-

Ahmadi & Al-Ahmadi (2013), RBAS (2013) and DeNicola et al. (2015) for discussions about annual rainfall and implications about water scarcity.

The monthly mean rainfall data and extremes (mm) for stations close to the study sites (Al-Asfer Lake = Alhsa station; Dams = Al-Baha city station; wadis = Taif city station) between 1994 and 2016 were provided by the General Authority of Meteorology & Environmental Protection (www.pme.gov.sa) (Figure 3.21). Total annual rainfall for Taif station was 161.9 mm, Alhsa station 83.5 mm and Al-Baha city station 122.7 mm. The main rainy season at Taif and Baha stations were during the spring between March and May. At Alhsa station, the rainy season was also in the spring but shorter between March and April. Rain also falls in other months around Taif station but February, June, July and December were the driest months. At Al-Baha station, February, June, July, November and December had the lowest rainfall, while rain was scarce between May and October at Alhsa station, with zero rainfall during June, July and September. However, the main sources of water that feed Al-Asfer Lake in Alhsa city are groundwater and rainfall. The water is used mainly for agriculture activities and urban desalination plants. While rainwater is the main source of water for primary fishes in wadis and reservoirs, periods of extreme rainfall (compared with low rainfall rate) occur mostly during the spring, autumn and winter. The spring season is the time when most fish species become active in terms of growth and reproduction in response to the abundant rains, food and conducive weather patterns.

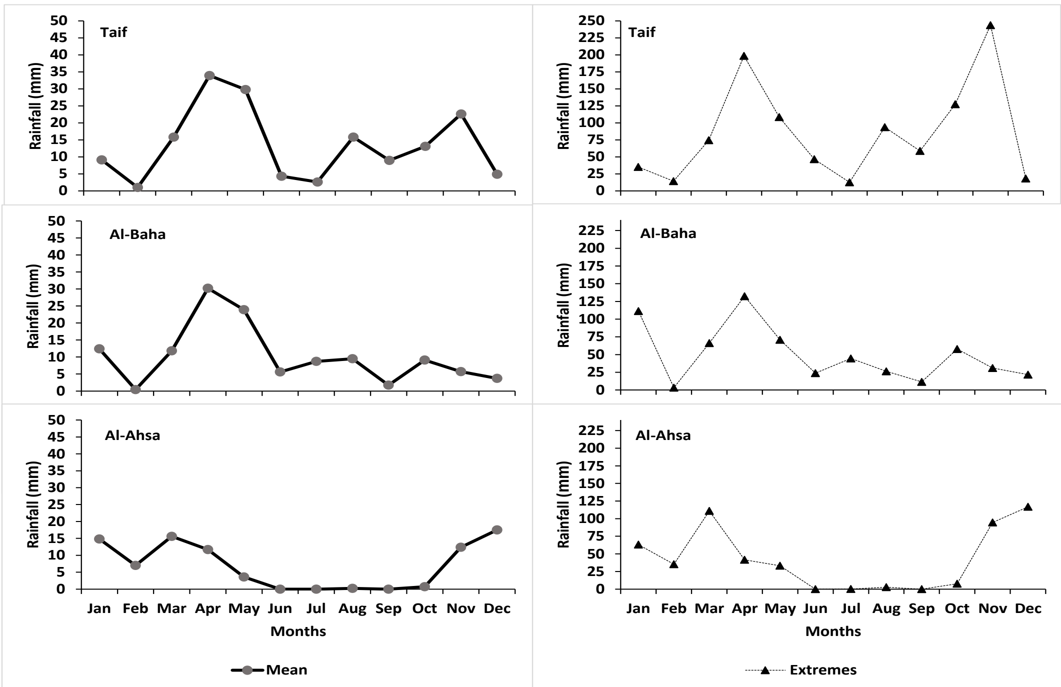


Figure 3.21. Monthly mean (left) and extreme (right) rainfall (in mm) for stations close to the study sites (Al-Asfer Lake = Alhsa station; Dams = Al-Baha city station; wadis = Taif city station) between 1994 and 2016. The data were provided by the General Authority of Meteorology & Environmental Protection (www.pme.gov.sa)

3.5 Water level in dams

Information about water level variation in the study dams was available from the Ministry of Environment, Water & Agriculture open database (app.mewa.gov.sa/DailyRainsNews/Rain_Dams.aspx) between 2010 and late 2015 (Figure 3.22). These dams are usually fed by permanent rain-fed runoff from wadis and their tributaries, and springs or exposed layers of groundwater. Generally, water levels were stable over the study period with some drawdown during the summer periods, except in Medhaas Dam. Water levels typically decrease during the summer, such as in Al-Aqiq and Tharad dams, because high rates of water withdrawals during this period but the levels mostly recover following the rainy periods in spring (Figure 3.22).

The water level in Medhaas dam fluctuated massively over the five-year period. The water level reached critical points of <2 m depth, which would make large areas of Medhaas reservoir vulnerable to drying out, and puts pressure on the resident fish stocks. The purpose of Medhaas dam is to support nearby wells that support downstream farms, and the large fluctuations in water level are caused by the sequential release of water from the dam. Using water for agriculture is one of the human activities that needs to be balanced to conserve fish during these critical water levels.

Moreover, one of the most prominent drops in water level in all reservoirs was in early 2010, when a sharp drop in water levels in Tharad, Al-Sadr and especially Al-Aqiq dams were observed (Figure 3.22). Al-Aqiq dam supplies Al Baha town with drinking water, and tonnes of fish died in dam basin (see Chapter 2, Section 2.3.9, page 22) as a result of high rates of withdrawal coupled with the absence or delay in rains; here increased demand for water lead to higher levels of abstraction for drinking water, leading to depletion. It is imperative that appropriate plans are put into place to encourage people to consume water appropriately during periods of water scarcity and avoid habitat degradation and protect the endemic aquatic fauna. In summary, dams are subject to extreme fluctuations in water level, especially when rains are delayed, as a result of pressures to withdraw water for agriculture and drinking purposes.

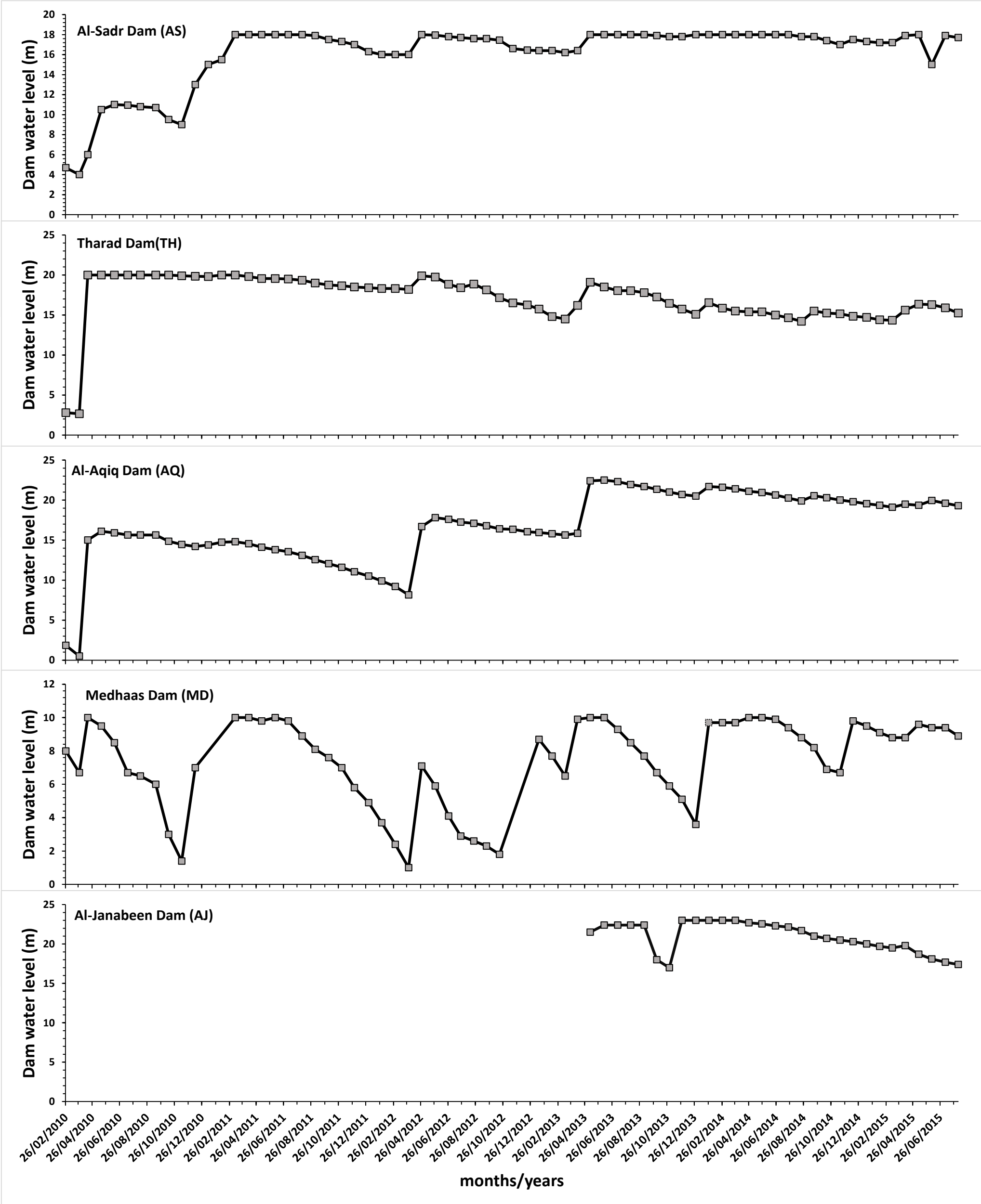


Figure 3.22. The information about water levels differences in studied dams.

3.6 Conclusions

Little scientific information has been derived to link the ecology of Saudi Arabian freshwater fishes to environmental parameters. Thus, some of the important measures (temperature, conductivity, turbidity, pH, dissolved oxygen, annual rainfall, and water level variation) have been examined to enhance this understanding of Saudi fishes and their interaction with their environment, including assessing the exposure of Saudi freshwater fish in the study sites to potential risks. Habitat loss, high water abstraction, environmental contamination, expansion of fishing practises, introduced species, tourism, control of disease vectors (pesticides), drought and climate change are the main problems found at study sites. These diverse uses and their impacts will be considered and incorporated into an integrated management plan (Chapter 9).

There is a two-phase pattern for both air and water temperature at the study sites. The period between May and October is characterized by sharp elevations in temperature, while the period between November and March is characterized by moderate or sometimes cold temperatures. The minimum and maximum air temperatures for wadis and dams (9.3-36.3 °C) differed from Al-Asfer Lake (9-45.9 °C), as did surface water temperatures for wadis and dams (7.6-29.8 °C) and Al-Asfer Lake (7.3-30.9 °C). The extreme temperatures could have adverse impacts on fish autecology and survival.

Conductivity varied between study sites (between 200 and 800 µS/cm). The highest values were recorded in Al-Sadr and Medhaas. Little variation in conductivity was observed between seasons.

Water turbidity was usually less in shallow streams in wadis. Transparency in dams was genrally low and mostly <1 m depth. Al-Sadr Dam recorded the highest transparency, about 2 m during winter.

pH values were within the range that fish can tolerate, but there may be some other aquatic organisms that may be more sensitive to pH changes, which may affect the food of the fishes. However, there was an increment in pH values in Al-Janabeen reservoir (average: 9.2).

Dissolved oxygen concentrations were between 4.2 mg/L and 12.3 mg/L among all study sites in three sampling periods (Figure 3.18). Dissolved oxygen levels were lower in wadis than reservoirs. The dissolved oxygen concentrations in these small streams may not be sufficient to meet all aquatic organisms' oxygen demands. In the dams, oxygen concentrations were higher in spring and winter, with the lowest concentrations in the summer, partly because of the high summer temperatures.

Annual rainfall across Saudi Arabia is largely deficient because of the influence of a subtropical high-pressure system, but there is considerable variation in temperature and humidity across the Kingdom. Total annual rainfall for Taif station was 161.9 mm, Alhsa station 83.5 mm and Al-Baha city station 122.7 mm. The main rainy season at Taif and Al-Baha stations were during the spring between March and May. At Alhsa station, the rainy season was also in the spring but shorter between March and April.

Water levels in the study dams were generally stable between 2010 and late 2015 with some drawdown during the summer periods, except in Medhaas Dam that fluctuated massively over the five-year period. Water levels typically decrease during the summer because high rates of water withdrawals during this period, but the levels mostly recover following the rainy periods in spring. These environmental data will be used to underpin interpretation of the distribution and ecology Saudi freshwater fishes in subsequent chapters.

Chapter 4 General Methodology

The following section provides a description of the basic sampling methods and strategy used for the current study of freshwater fish and fisheries in Saudi Arabia.

4.1 Fieldwork and fish sampling

Between July and September in 2015 (summer), 16 sites in different regions of Saudi Arabia were visited and the fish populations sampled to get an understanding of the diversity of species and freshwater habitats in the country. Five dams, two wadis and one lake were chosen as representative sites for this project. These sites were revisited during winter between 25 December 2015 and 25 January 2016 and again during spring between 28 April 2016 and 19 May 2016. The following fishing methods were used during each fishing trip.

4.2 Sampling strategy

On the first visit, several sampling locations were chosen in each water body and were sampled consistently on each sampling occasion (Figure 4.1). Different types of gears most suitable for the conditions encountered were used to catch fish of all sizes where possible (see Section 4.3, Fishing gears). Surveys at each location usually took one to two days. A small inflatable boat was used to sample areas that were not easily accessible from the shore, such as in dams.

During each visit, notes were taken of the physical characterization of the water body, observations of human interventions recorded and water quality data collected using standard methods (see Appendix D for details of the form used and Chapters 5, 6, 7 and 8 for details of methodologies used). The following habitat and environmental data were collected: water depth, dam water level, dam length, turbidity, water and air temperature, dissolved oxygen, conductivity, pH, stream characterization and resource users. Fish caught were quickly preserved in 4% formaldehyde and then transported to the laboratory in the United Kingdom for further investigation. The abdominal region of all fish caught was pricked (needle) prior to preservation to ensure the gastrointestinal contents were also preserved. A group of fish (about 30 fish per species, *Carasobarbus apoensis* = 10.9-45.0 cm; *Cyprinion mahalensis* = 9.8-19.0 cm; *Garra buettikeri* = 11.5-15.5 cm; *Oreochromis niloticus* = 10.4-20.0 cm) were also measured (length in mm and weight g) and tagged to track shrinkage in size and weight due to preservation in formalin. Fish based on their location and site preserved in labelled jar and transported to one of the Saudi wildlife labs for preparation of shipping to the United Kingdom. Shipment plastic box were labelled based on location, site, species, total catch weight, number of fishes, data, time were recorded for each sampling trips.

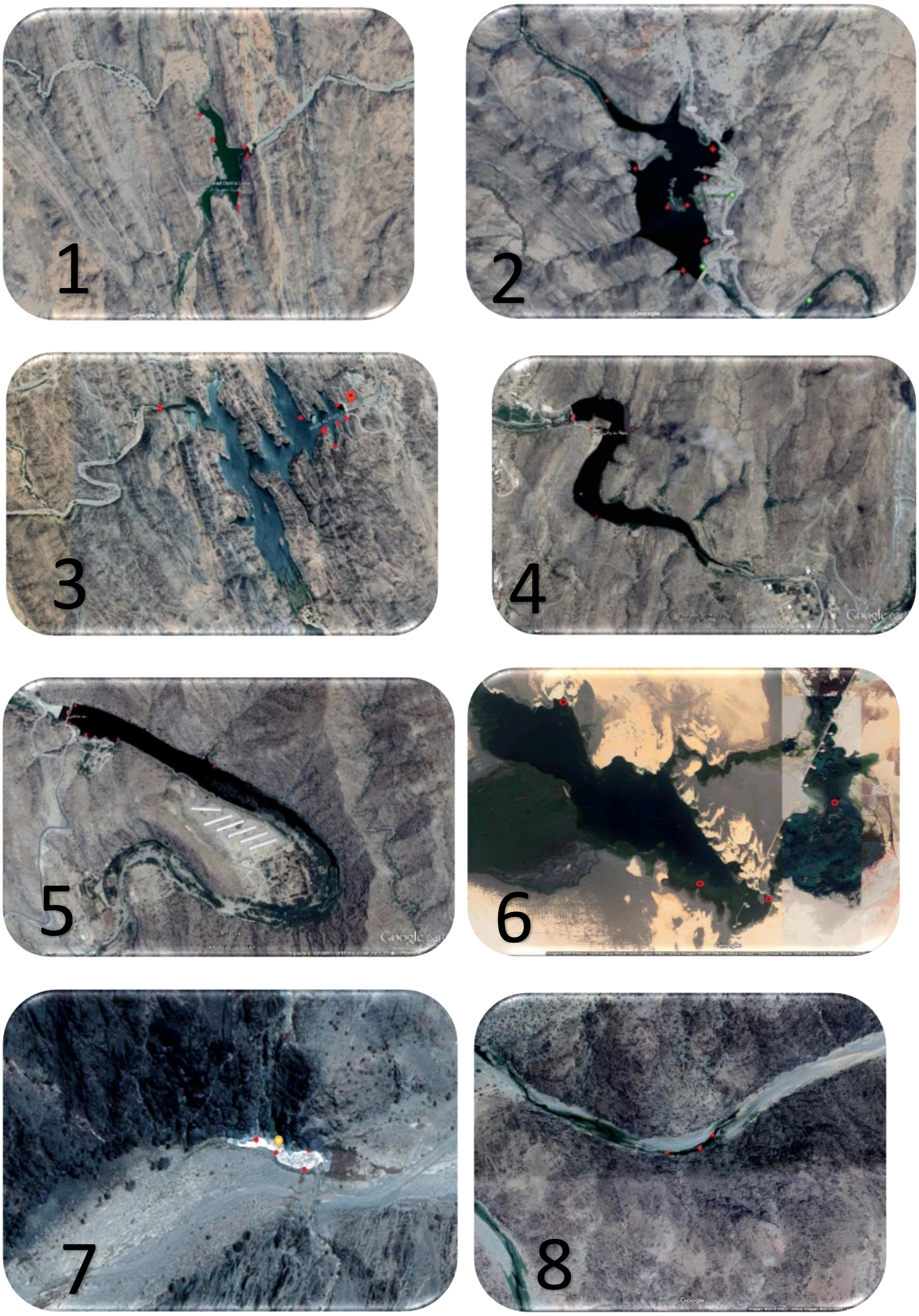


Figure 4.1. Red dots show where fishing gears took place (1 = Thrrad Dam;2 = Al-Janabeen Dam; 3 = Al-Aqiq Dam; 4 = Al-Sadr Dam; 5 = Medhaas Dam; 6 = Al-Asfer Lake; 7 = Wadi Bouah; 8 = Wadi Turbah).

4.3 Fishing gears

More than one fishing method were used at each location to catch fish of different sizes.

Fyke nets: Fyke nets were set in pairs with a 5 m leader net joining them (Figure 4.2). The net was green in colour and the mesh size of Fyke nets was 1.5 cm. This net mostly used to catch small and medium-sized fish, although some large fish were also trapped.

Figure 4.2. Fyke nets in a green colour similar to this.

Fish traps: Conical fish traps about 1.5 m long with two entrances at the terminal ends were used (Figure 4.3). These traps were set in marginal areas and amongst vegetation, and were mostly used to catch small and medium-sized species; the benthic species *Garra* sp. was the species most commonly caught species in the traps.

Figure 4.3. Conical fish traps.

Gillnetting: Two sorts of gillnet were used for sampling: single mesh panel gillnets with a 6.35 (cm) mesh size and dual layer trammel nets with mesh sizes of 6.35 and 17.78 (cm). All nets were 30m long and 1.5m deep (hanging ratio E = 0.5). The nets were set overnight in two or three in each site, in the shallow littoral zone or around rocks or tree stumps. In the reservoirs, finding a suitable place to set the nets was challenging because few places less than 5 m deep near the shore were suitable.

Cast netting: Cast netting from the bank was used in some sites, especially wadis, but the gear was ineffective in many sites due to tree branches and turbid water.

Angling: Angling was used on occasions and was found to especially effective during the early morning and to catch various sizes of fishes.

Chapter 5 Fish species distribution

5.1 Introduction

Understanding the distribution and basic ecology of aquatic biota, and the factors driving those ecological characteristics are essential to underpin the formulation of management plans for the conservation of biodiversity and associated ecosystems. It is essential to understand the underlying reasons for the presence of fish species in certain places and their absence elsewhere, and whether it is driven by biogeographical reasons or changes in exploitation pressures or degradation and change in the ecosystem quality and functioning. It is particularly important to understand any causes for the disappearance of species from a particular location so that remedial and restorations measures can be formulated to conserve the indigenous biodiversity of species regions.

Most of the provisional studies to determine the distribution of freshwater fishes in Saudi Arabia were conducted in the 1980s and 1990s (Krupp, 1983; Al-Kahem et al., 1988; Al-Kahem et al., 1990; Al-Ghamdi & Abu-Zinadah, 1998), but updated periodically since that time mostly through the inclusion of new records for existing species (Al-Kahem, 2004; Al-Kahem et al., 2007; Borkenhagen & Krupp, 2013; Hakami et al., 2013; Younis et al., 2015), and includes a mapping of the present distribution of certain, mostly endemic, species (Hamidan & Shobrak, 2019). It is critical that information on the distribution of species is kept up to date and include all species, both native and non-native, as well as the problems facing the conservation of these fish species. The purpose of this chapter is refreshing the current distribution of Saudi Arabian freshwater fishes based on existing literature and information collected during this study. Information on the main factors influencing the distribution of these species, both positive and negative were also collected to understand the potential pressures acting on various populations and ecosystems, including changes to or destruction of habitats. Furthermore, the distribution of non-native fish species is mapped; this is considered critical because little is known about the spread and invasiveness of these species. The information will be used to identify the most important water basins and wadis that will be the focus of future conservation management plans. Moreover, an attempt has been made to understand the distribution of dams in each Saudi Region, since dams are one of the main problems that threaten fish and have not been adequately studied in terms of their impact on fish.

5.2 Methods

The distribution of freshwater fish species in Saudi Arabia was determined by collating the geographical coordinates of locations where Saudi freshwater fishes were recorded from literature sources (Banister & Clarke , 1977; Krupp, 1983; Al-Kahem et al., 1988; Al-Kahem et al., 1990; Al-Ghamdi & Abu-Zinadah, 1998; Al-Kahem, 2004; Al-Kahem et al., 2007; Borkenhagen & Krupp, 2013; Hakami et al., 2013; Younis et al., 2015; Hamidan & Shobrak, 2019) and places sampled in this project (see Appendix B for locations of water bodies). The open GIS (Geographic Information System) database of the Ministry of Environment, Water and Agriculture (mewa.gov.sa) was examined for dam locations and available information about major drainage and wadis systems. The geographical coordinators were then plotted on maps using Maptive.com. Maptive.com is an online tool which can be used map the distribution of each species, and contains a grouping tool, filter tool and heat map tool to present the data in visual format.

Multivariate analysis based on species presence/absence in different water bodies in different regions was used to determine the biogeographical distribution of fish species in Saudi Arabia. The similarity of fish species assemblages in each water body was compared using Jaccard index based on presence of different species. The data were submitted to a similarity matrix and cluster analysis was carried out to group similar sites. Data were also ordinated using non-metric multidimensional scaling (MDS) to investigate similarities in the species composition in different localities. The matrices were then submitted to permutational multivariate analysis of variance (PERMANOVA) (9999 random permutations) to assess the average similarity of species composition between sites based on the Jaccard resemblance matrix (Anderson, 2001; Clark & Gorley, 2006; Anderson et al., 2008). All analyses were carried out in PRIMER 6 (Plymouth Routines in Multivariate Ecological Research).

5.3 Results and discussion

5.3.1 Distribution of Saudi freshwater fishes

The distribution of freshwater fishes in Saudi Arabia was mapped based on previous studies and new sites visited during this study. Previous studies that were used as source of information include: Krupp (1983); Al-Kahem et al. (1988); Al-Kahem et al. (1990); Al-Ghamdi & Abu-Zinadah (1998); Al-Kahem (2004); Al-Kahem et al. (2007); Borkenhagen & Krupp (2013); Hakami et al. (2013); Younis et al. (2015) and Hamidan & Shobrak (2019) (Figure 5.1). Sixteen new sites were visited in this study (see Appendix E to compare this study's location records with previous studies' records). In this study, five dams, two wadis and a lake were sampled. Additionally, this study generated maps containing the distribution records of species according to the time the studies were conducted compared with this study. This study also produced several alien fish species distribution maps for the first time (Figures Figure 5.5-Figure 5.11 &Figure 5.13) and three species belonging to the *Oreochromis* and *Carassius* genera were found in the presence of indigenous freshwater fish.

Indigenous and secondary freshwater fish species as well as alien species were plotted in a heat map using maptive.com, with markers representing the density of each fish species group (indigenous, non-native and secondary) based on the number of records of sites in each area occupied by freshwater fishes. The drainages of the Empty Quarter are located in the highlands and discharge towards the east and north-east of the Kingdom (Figure 3.14 and Figure 3.15). Endemic fish species present in the drainages of the Empty Quarter eastern drainages were *Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri*. The native species extant in the western, lowland drainages discharging towards the Red Sea were: *Garra tibanica tibanica, Garra sahilia gharbia, Cyprinion acinaces hijazi, Carasobarbus arabicus, Aphanius dispar,* although Borkenhagen & Krupp (2013) mentioned that *Carasobarbus apoensis* exists in both eastern and western drainages.

Non-native fish species, which have been introduced for fish farming and biological control, occur mostly within the central and eastern regions of the kingdom, although some species have been introduced into dams in the south-western region where endemic species typically exist, and may be a possible risk to their existence. Figure 5.1 also shows the distribution of secondary freshwater fish species, which refer to fish that have entered inland water habitats from Red Sea or Arabian Gulf and are able to tolerate a wide range of saline conditions. They are found in inland and coastal waters in Saudi Arabia and adjacent countries, and include *Aphanius dispar* and *Mugil cephalus.*

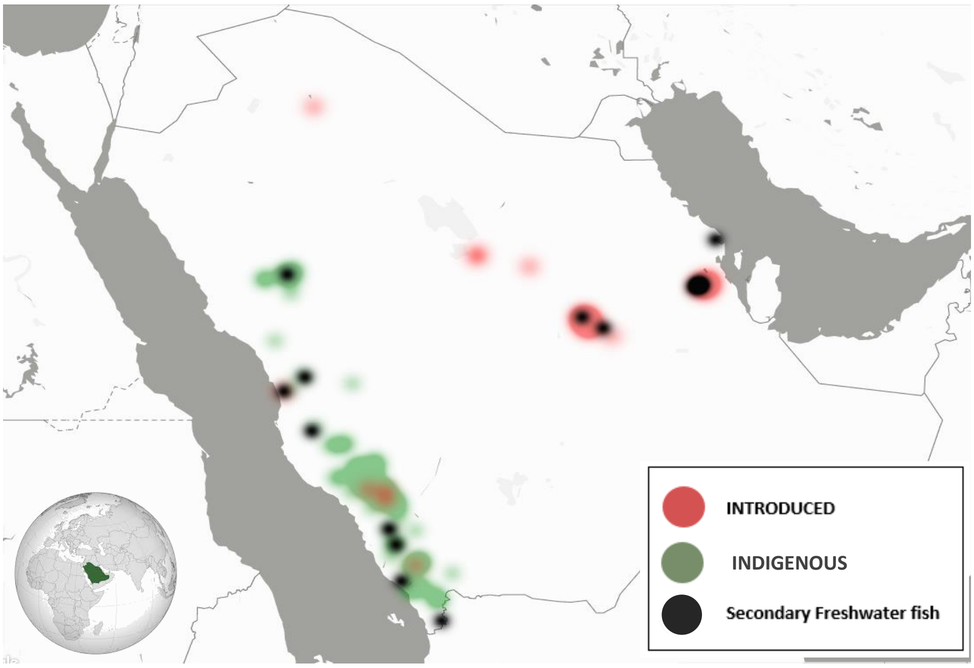


Figure 5.1.Heat map represents marker density based on a data base involve freshwater fish sites from this study and the previous studies. (INDIGENOUS) only found in Saudi habitat; (Secondary Freshwater fish) that entered from sea or crossed from one to another; (INTRODUCED) non-native fish species.

5.3.2 Distribution of indigenous freshwater fish species in Saudi Arabia

The distribution of indigenous freshwater fish has already been described in Chapter 2 (Section 2.4, page 24) based on previous studies. This section compares the previous known distribution of indigenous freshwater fish species between 1977 and 2018 with that collated during field trips in this study. Distributional maps of alien species are also compiled because these species did not receive attention in the past and it was an important to create maps to understand their expansion and the potential dangers they may pose to the indigenous fish species. All distribution coordinates used in this study are listed in Appendix (B) based on region, water body type, location name, latitude and longitude.

Carasobarbus apoensis (Banister & Clarke, 1977)

This species is endemic to Saudi Arabia and mostly occurs in endorheic eastern drainage systems located in the south-west of the Kingdom (Krupp called them Empty Quarter drainage), whose water flows generally towards the east or north-east (Figure 5.2). Moreover, *Carasobarbus apoensis* has been found in lowland Red Sea drainages, such as Wadi Hajrah and Wādī 'Ilyab (Borkenhagen & Krupp, 2013). It also occurs in some of the Al-Madinah Region wadis such as Wādī Hadīyah (Borkenhagen & Krupp, 2013).

The differences between the limited historical distribution data since its discovery in 1977 and the current study suggests a significant lack of geographic information about this species.

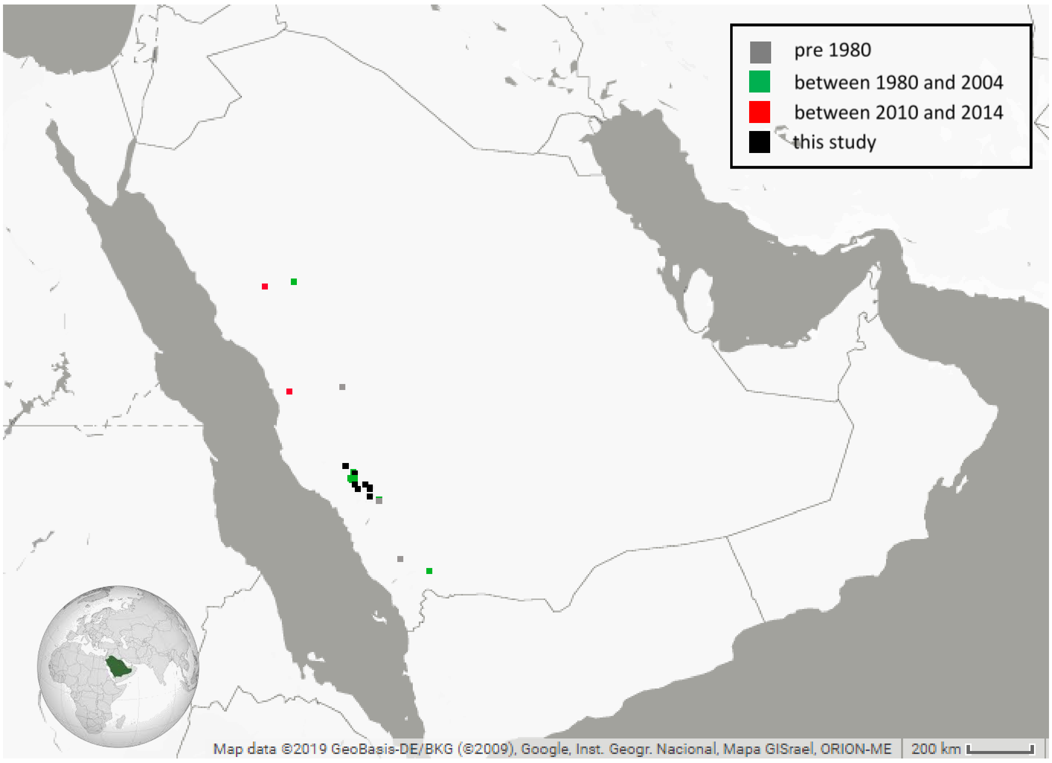


Figure 5.2. Distribution of *Carasobarbus apoensis* in Saudi Arabia.

Cyprinion mhalensis Al-Kahem & Behnke, 1983

This species is endemic to Saudi Arabia and only occurs in the endorheic eastern drainage systems in the south-west of the Kingdom (Krupp called them Empty Quarter drainage), which flows generally towards the east or north-east (Figure 5.3). The distribution area extends from the highlands of the Asir Region northwards to the highlands in Al-Baha Region and towards Makah region and is found in some wadis in Taif County.

The differences between the limited historical distribution data since its discovery in 1983 and the current study suggests a significant lack of geographic information about this species.

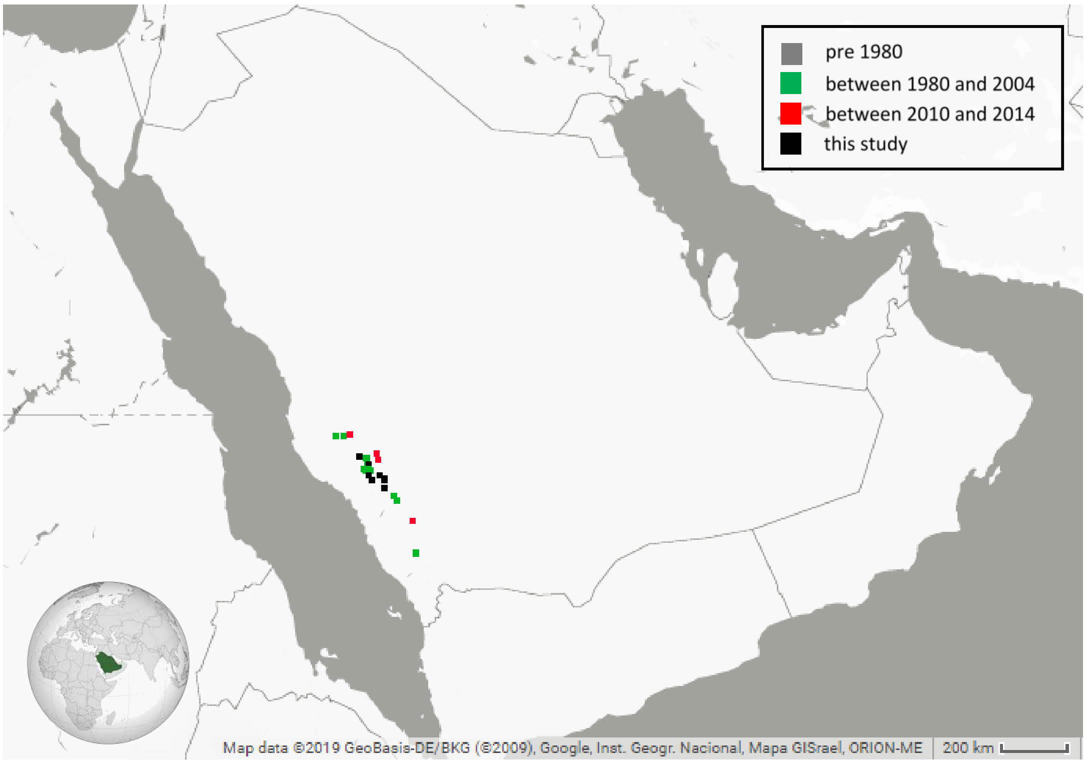


Figure 5.3. Distribution of *Cyprinion mhalensis* in Saudi Arabia.

Garra buettikeri Krupp, 1983

This species is endemic to Saudi Arabia and only occurs in the endorheic eastern drainage systems in the south-west of the Kingdom (Krupp called them Empty Quarter drainage), which flows generally towards the east or north-east (Figure 5.4). The distribution area extends from the highlands of the Asir Region northwards to the highlands in Al-Baha Region and towards Makah region and is found in some Jeddah county wadis. It has a similar distributional range to *Cyprinion mhalensis*. The EPAA (2002) suggested the species occupies and area of under 500 km^2. A recent study reported the occurrence of *Garra buettikeri* in Wadi Al-Bagarah in the Red Sea drainage (Hamidan & Shobrak, 2019). This is probably due to a taxonomic error because *Garra buettikeri* is close to both *Garra tibanica, Garra sahilia gharbia,* which usually occur in Red Sea drainages.

The differences between the limited historical distribution data since its discovery in 1983 and the current study suggests a significant lack of geographic information about this species.

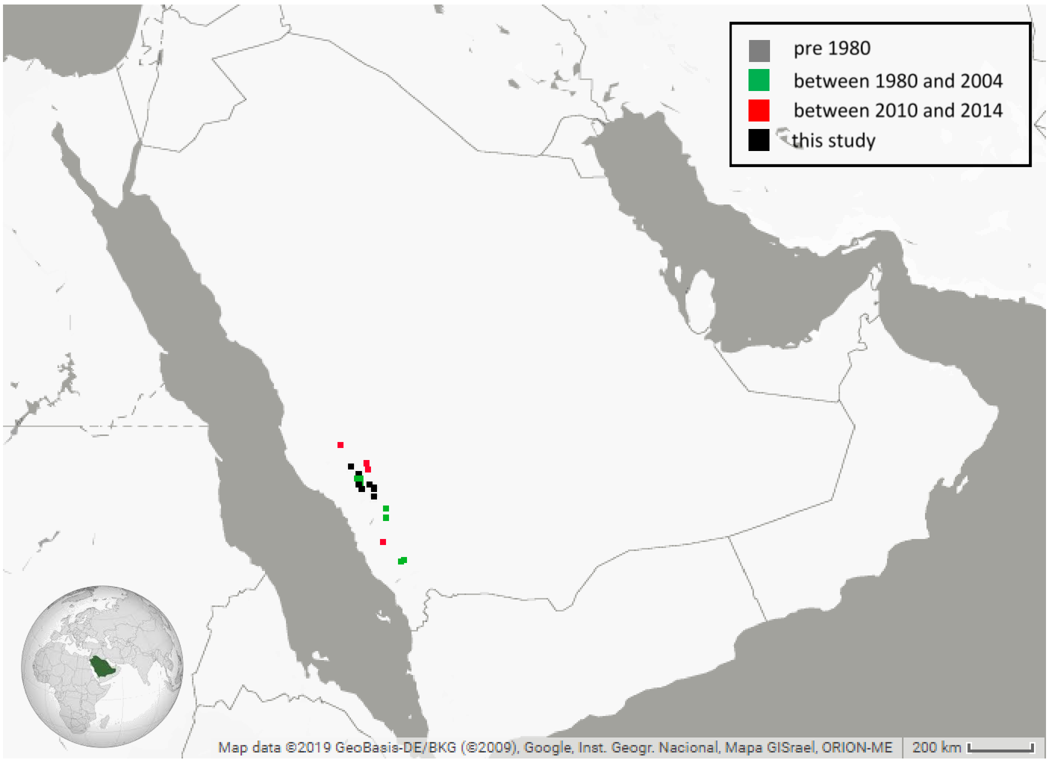


Figure 5.4. Distribution of *Garra buettikeri* in Saudi Arabia.

5.3.3 Distribution of non-native freshwater fish species in Saudi Arabia

Non-native fish species have been introduced into Saudi Arabia for biological control, ornamental fishes (controlling algal blooms, aquatic plants, snails, mosquitos) and unintentionally (Welcomme, 1988; Coad, 1996; Cowx, 1999; Deniz, 2012). Introduced freshwater fishes species occur mostly within two regions: Riyadh Region and Eastern Province. However, this study found some non-native fish species within the range of indigenous fish species (Figure 5.1).

In Riyadh Region, fishes were mostly introduced species for biological control purposes or aquaculture, although some artificial lakes have been stocked for recreational fishing. Non-native species (*Poecilia latipinna, Poecilia reticulata, Xiphiphorus maculatus, Clarias gariepinus, Oreochromis* spp.) are common in Wadi Haneefah and its tributary in Riyadh City, plus other waterways and springs near Al-Kharj City. These include temporary waters, such as rawdat (= meadow), marshlands and fayadh (flooded areas), which are created during the rainy season or flooding period, and are invaded by fish escaping from nearby fish farms. They are also found in pools created by discharge of waste water into dry wadis, which creates aquatic habitat that can be occupied by these non-native species that tolerate poor water quality conditions.

In the Eastern Province, several cities, such as Al-Ahsa, Qatif and Hofuf, are famous for the existence of springs, oases and irrigation channels for agriculture, especially palm trees, and those channels usually pour into artificial lakes. Water used for irrigation has become semi-saline and salinity rates are increasing according to drainage agency reports. Many species that can tolerate a wide range of salinity have been introduced for biological control of mosquitoes or weeds, but the introduced are under direct pressure from intensive fishing. In addition, marine and estuarine species, such as *Mugil cephalus* and *Aphanius dispar,* which are native to Saudi Arabia, have ingresses into the channels to exploit the changing environment. Nevertheless, *Aphanius dispar* populations are generally declining as a result of interaction with non-native species and other reasons (Al-Kahem et al*.,* 2008).

Non-native, invasive species were reported for the first time in the west and south-west provinces. The arrival of these non-native invasive fish species to this part of the Kingdom highlights the potential threat to local endemic fish species, and the need for more surveys of all dams and wadis in the region to better understand the overall status.

Oreochromis species

Tilapia species have been extensively used for inland aquaculture and biological control purposes in many Saudi regions. *Oreochromis niloticus* is the most common species used in aquaculture and is present in many water bodies, including urban wastewater wadis. *Oreochromis niloticus* is found in wadis or man-made lakes in Central Region, such as Wadi Haneefah (24°28'55.3"N 46°47'47.2"E), Nemar Dam (24°34'31.0"N 46°41'07.6"E), Al-Hair (24°26'17.4"N 46°48'56.0"E), Al-Majmaah (25°54'02.5"N 45°19'35.9"E) and Al-Kharj (24°32'03.1"N 46°45'32.9"E), as well as in Al-Hasa canal (25°21'45.4"N 49°40'59.8"E) and agricultural waste drainage lakes, such as Al-Asfer Lake (25°31'10.7"N 49°49'09.4"E) and Al-Wyoon Lake (25°41'25.8"N 49°41'04.8"E) in Eastern Province (Figure 5.5). The species was also recorded in Thrrad Dam (20°09'27.8"N 41°43'19.3"E), an important site for endemic freshwater fish species, but was not found in Wadi Thrrad.

Several factors have contributed to the spread of this species, and is likely it will reach most areas where endemic species are found: the expansion of fish farming and escape of fish from these farms, flooding, the introduction by some government administrative bodies for biological control purposes, the introduction by some wildlife enthusiasts. For example, many individual *Oreochromis niloticus* were seen dead in the streets of Jeddah following severe flooding in 2015.

Other tilapia species found in Saudi Arabia include *Oreochromis aurius* in Wadi Al-Hair wetland in Central Region (24°23'01.7"N 46°49'47.2"E) (Al-Kahem, 2004) and *O. spilurus,* which is widely cultured in floating cages in the Red Sea, has been stocked in some artificial lakes in the far north of the Kingdom in Northern Borders Region (29°48'37.5"N 39°54'33.0"E) (Figure 5.6).

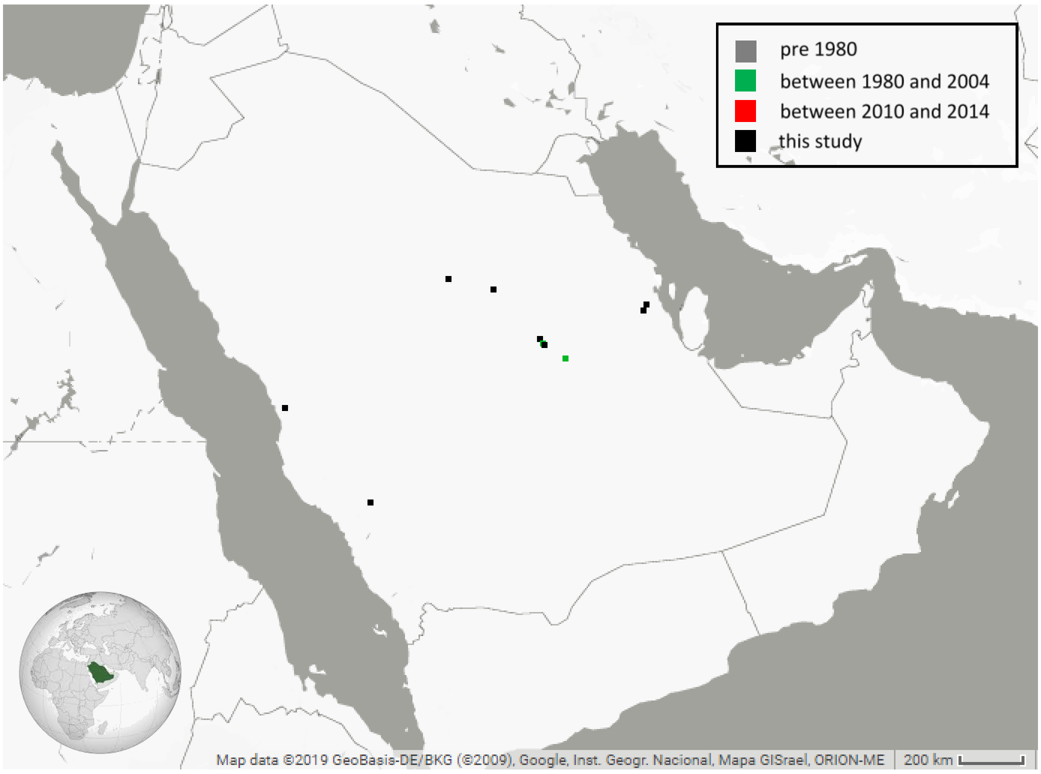


Figure 5.5. Distribution of *Oreochromis niloticus* in Saudi Arabia.

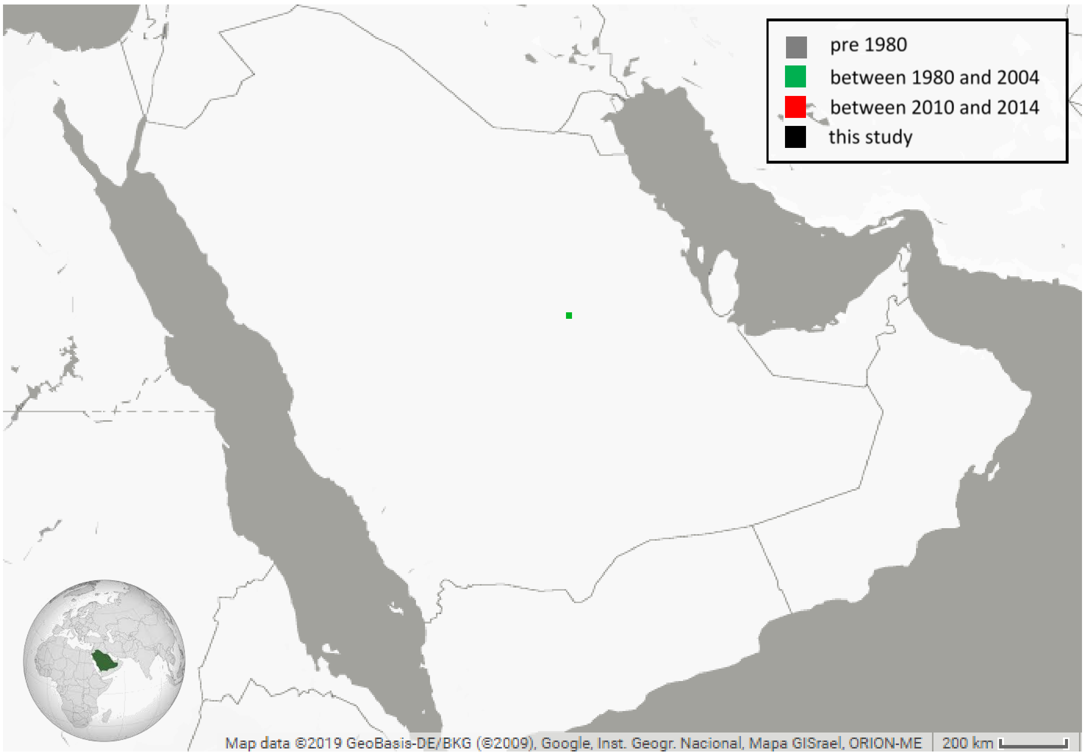


Figure 5.6. Distribution of *Oreochromis aurius* in Saudi Arabia

Gambusia affinis (Baird & Girard, 1853)

Gambusia affinis was found in main sites including Al-Asfer Lake (25°32'19.2"N 49°48'42.9"E) and channels in Al-Hasa (25°24'18.6"N 49°44'07.2"E) (Figure 5.7). This species was released into Dumat Al-Jandal Lake (29°48'27.3"N 39°54'41.7"E) in 2018 together with tilapia and seabream species. There is no documentation about first introduction of *G. affinis* to Saudi Arabia, but mosquitofish has been introduced into Saudi Arabia by some government agencies under the premise it preys on mosquito larvae and thus control mosquitoes as a vector of malaria and minimizes the use of pesticides. However, studies have shown that when other food sources are available, *G. affinis* does not necessarily prefer mosquito larvae (Goodsell & Kats, 1999) and is not a good control agent. Additionally, this species is sold in ornamental fish shops, which may contribute to its distribution in Saudi water bodies.

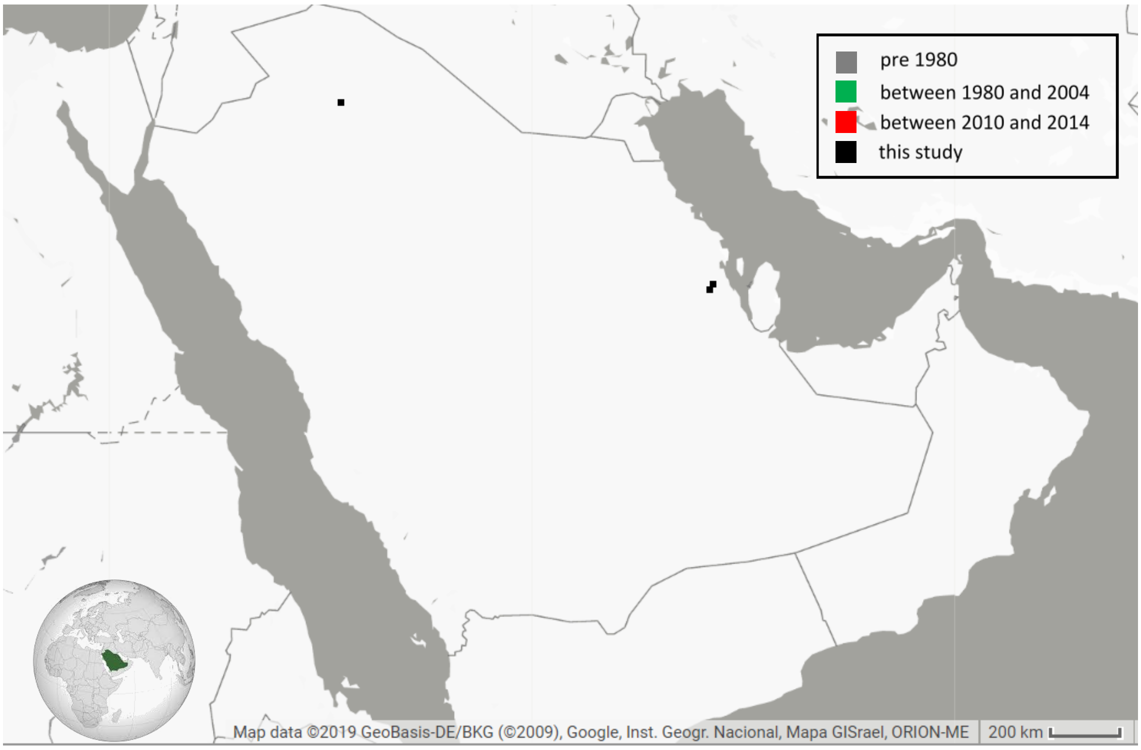


Figure 5.7. Distribution of *Gambusia affinis* in Saudi Arabia.

Poecilia latipinna (Lesueur, 1821)

This species originates from south-eastern North America and Mexico, but has been transported to many parts of the world as part of the ornamental fish trade and for biological control, including the Kingdom of Saudi Arabia. This species found in the Eastern Province in Al-Hofuf, Al-Qatif and Al-Ahsa oases within agricultural irrigation channels or man-made lakes (25°23'35.6"N 49°42'48.9"E), Al-Asfer Lake (25°32'19.2"N 49°48'42.9"E) (Figure 5.8). This species also occurs in the central region within Riyadh urban discharge wadis and artificial wetlands, such as Nemar Dam (24°34'29.3"N 46°41'08.5"E) (Figure 5.8). This species was introduced for biological control purposes and is also sold in ornamental fish shops.

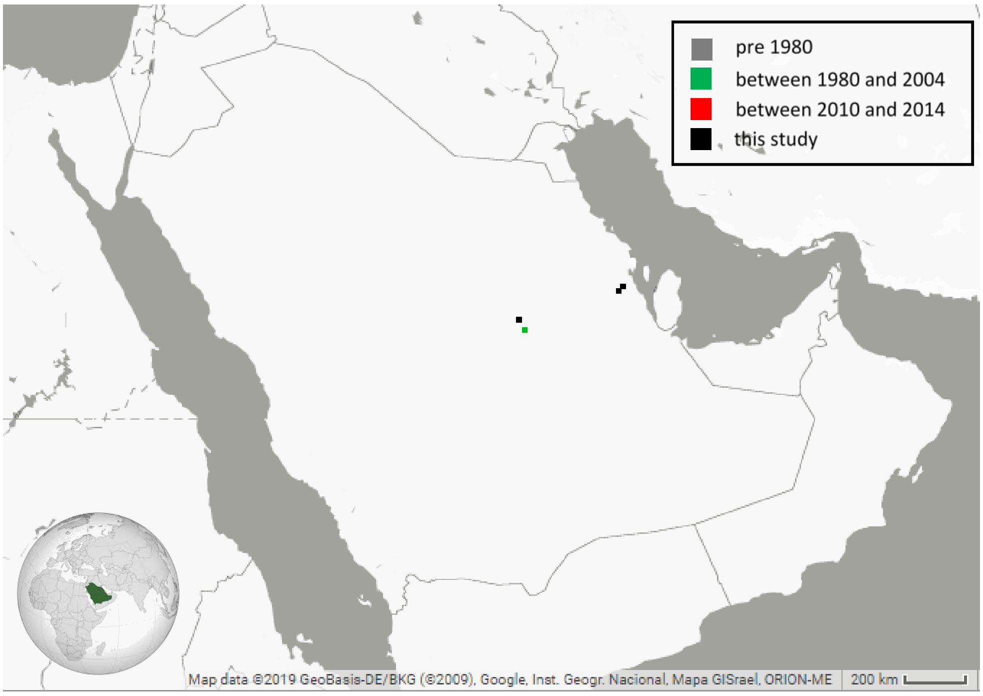


Figure 5.8. Distribution of *Poecilia latipinna* in Saudi Arabia.

Poecilia reticulata Peters, 1859 and *Xiphiphorus maculatus* (Günther, 1866)

These two species were found in Wadi Haneefah (24°34'08.0"N 46°40'22.2"E) and in springs and irrigation channels in Eastern Province (Figure 5.9 & Figure 5.10) (Al-Kahem, 2004). There is little information about these species, which have been introduced for biological control purposes and they are also popular aquarium fishes.

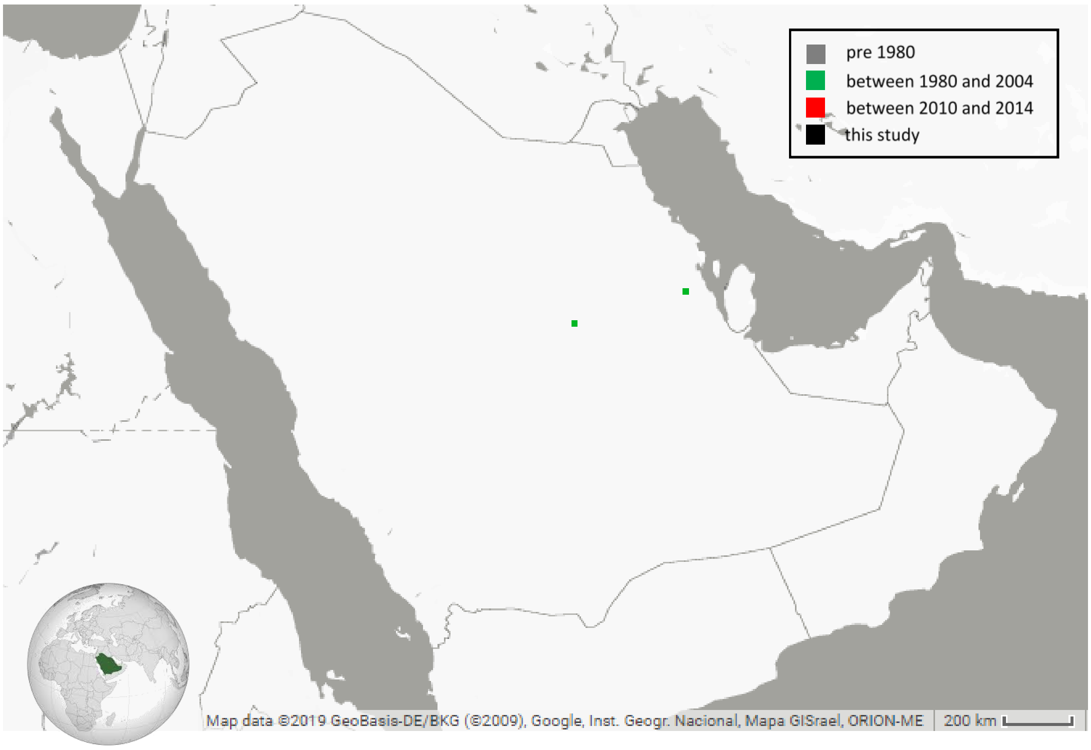


Figure 5.9. Distribution of *Poecilia reticulata* in Saudi Arabia.

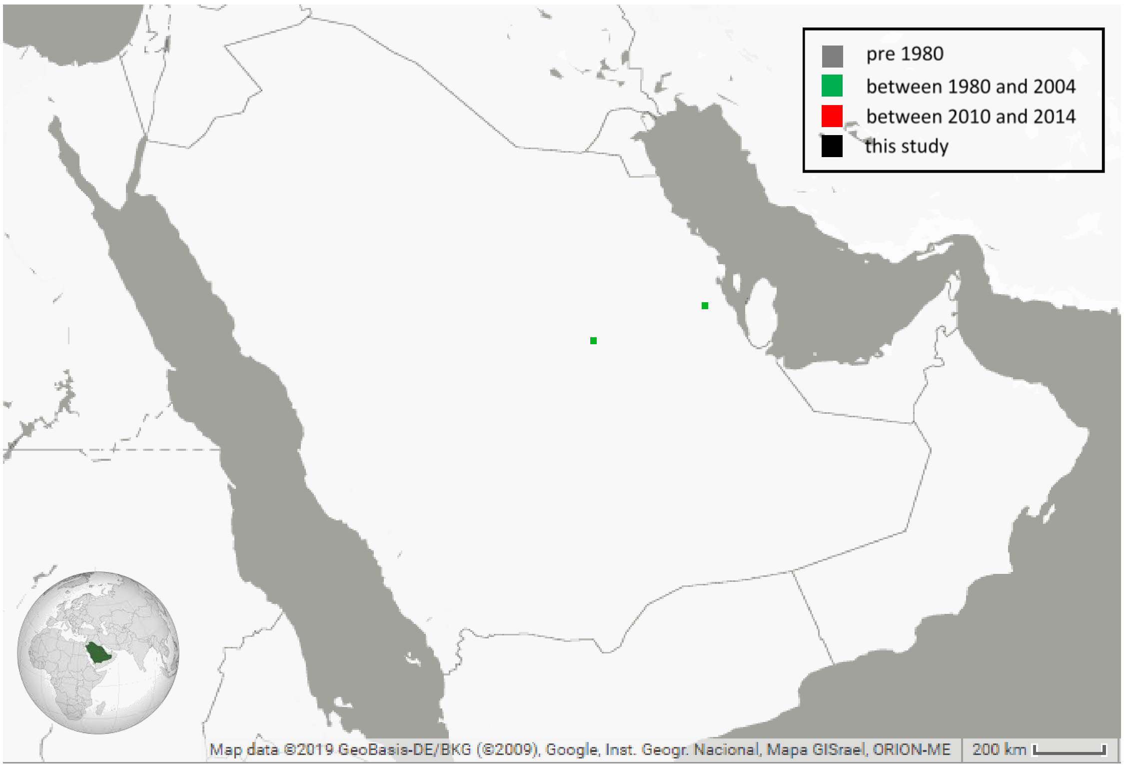


Figure 5.10. Distribution of *Xiphiphorus maculatus* in Saudi Arabia.

Clarias gariepinus (Burchell, 1822)

Clarias gariepinus has been introduced worldwide for aquaculture, including to Saudi Arabia. This species has colonised many places in the middle region of the Kingdom, having escaped from fish farms to inhabit artificial wetlands. It found in urban drainage wadis in Riyadh, such as Wadi Haneefah (24°23'07.3"N 46°50'42.9"E), Nemar Dam and Al-Hair (24°34'18.8"N 46°40'55.7"E) and in Wadi Rumah in Al Qassim Region (26°11'07.6"N 44°00'31.1"E) (Figure 5.11) . Mass mortalities have sometimes been observed in the deserts when the species has been transported with floods to drought-prone areas (Figure 5.12).

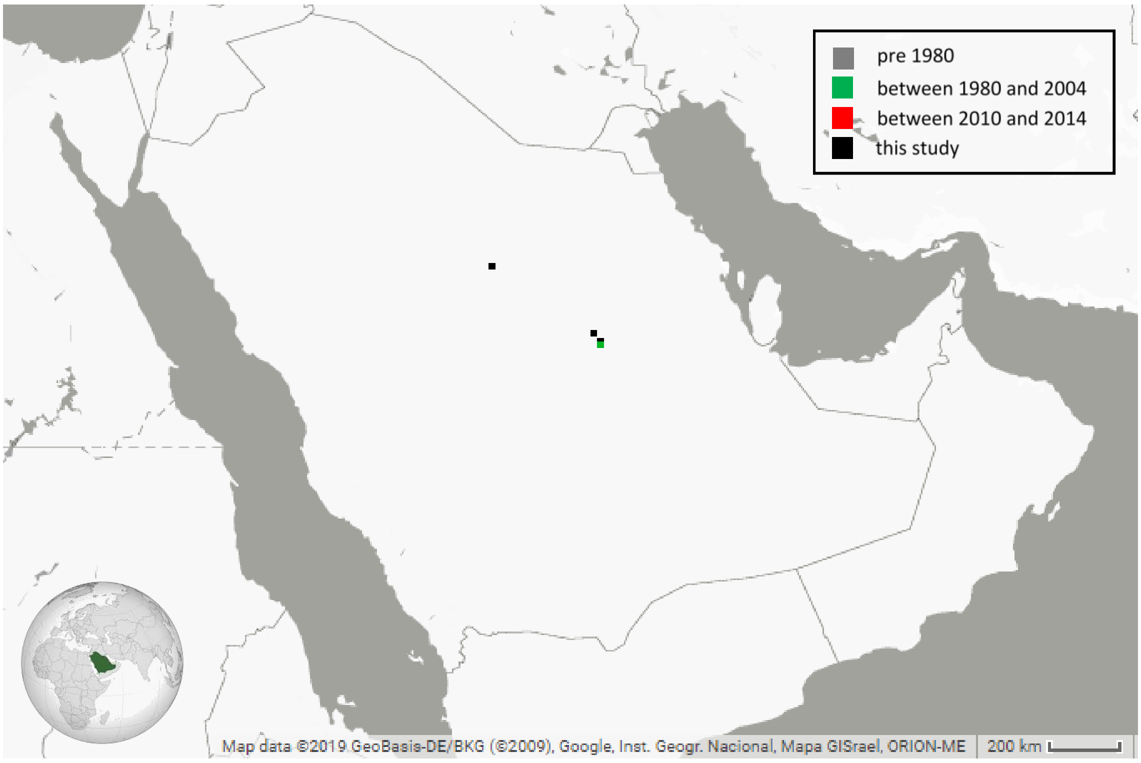


Figure 5.11. Distribution of *Clarias gariepinus* in Saudi Arabia.

Figure 5.12. Many YouTube videos went viral due to people question how these species reach arid areas (www.youtube.com/watch?v=EZJRpR3eKYQ) and (www.youtube.com/watch?v=IgaVdwyAjTg)

Ctenopharyngodon idella (Valenciennes, 1844)

Grass carp has been introduced in many countries to control aquatic vegetation. In Saudi Arabia, this species has been introduced into irrigation channels in Al-Hasa Oasis by the Saudi Irrigation Organization (SIO) in the belief it is safest and most economical way to control aquatic vegetation compared with chemical or mechanical methods. This fish was imported to Saudi Arabia from Egypt in 2008 to irrigation channels in the Eastern Province (25°28'10.7"N 49°37'31.5"E) (Figure 5.13). The SIO experiment showed the success of this species in the reduction of aquatic weeds, but the ecological conditions in the channels were not suitable for the reproduction of grass carp. Consequently, channels had to be regularly stocked from hatcheries to compensate for losses due to death or fishing, which may rise the cost. People have started to catch these fish with hooks and nets, which is compromising the success of the weed control operations (Figure 5.14).

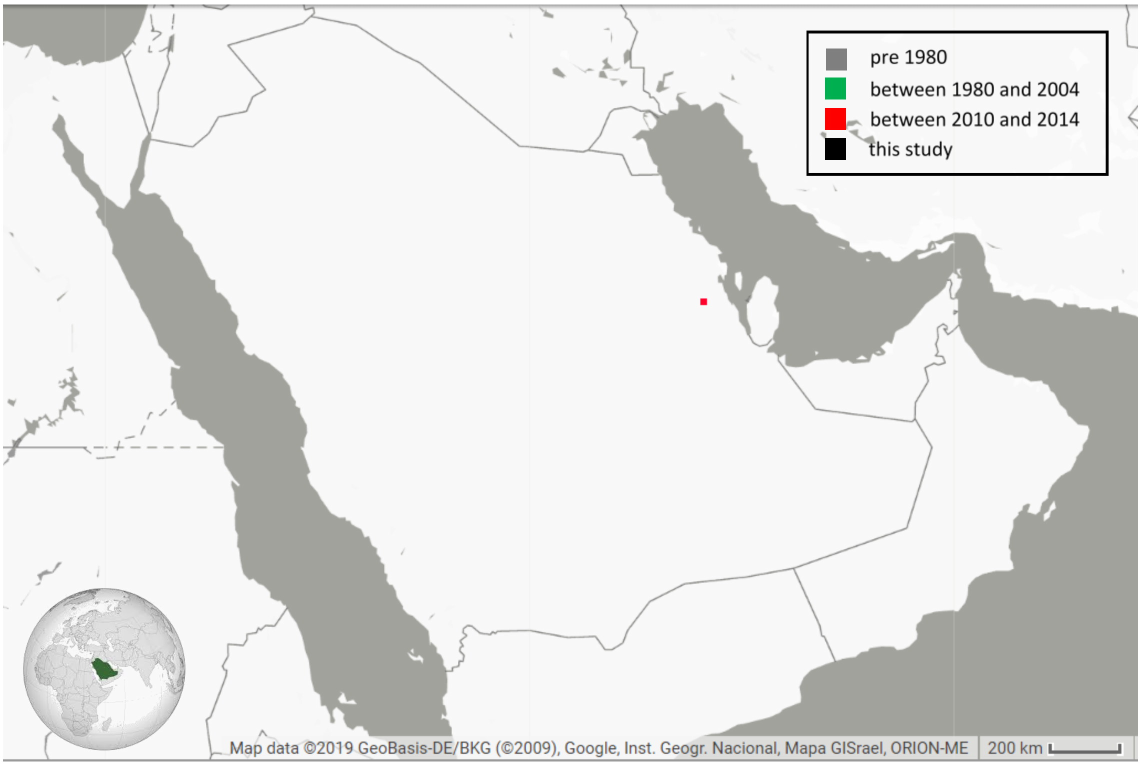


Figure 5.13. Distribution of *Ctenopharyngodon idella* in Saudi Arabia.

Figure 5.14. Fisherman illegally catching *Ctenopharyngodon idella* from irrigation channels: picture by Saudi Irrigation Organization (SIO).

Carassius carassius (Linnaeus, 1758) and *Carassius auratus* (Linnaeus, 1758)

Both *Carassius carassius* and *C. auratus* have been introduced into Saudi (Figure 5.15 & Figure 5.16), but only *C. carassius* was found in this study, in AL-Janabeen Dam (19°54'12.6"N 41°42'41.8"E). *C. auratus* appears to be more widely established than *C. carassius*, but ornamental fish traders have hybridized the two species, so it is difficult to distinguish them. A very large population of *Carassius* spp. exists in Abha Dam. The possible reasons for the introduction of *Carassius* spp. as ornamental fishes, which intentionally or non-intentionally have established in the distribution range of Saudi endemic freshwater fishes. At this stage recording the presence of both *C. carassius* and *C. auratus* is important as they could affect endemic species, and further investigations are needed.

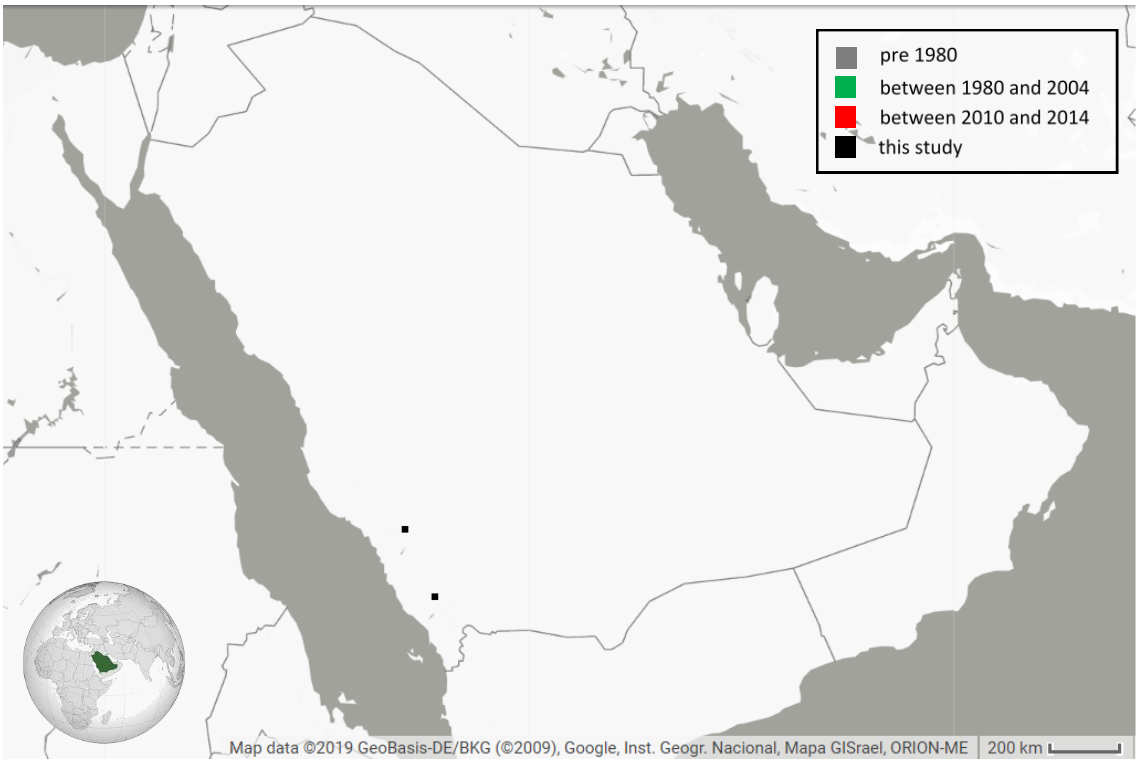


Figure 5.15. Distribution of *Carassius carassius* in Saudi Arabia.

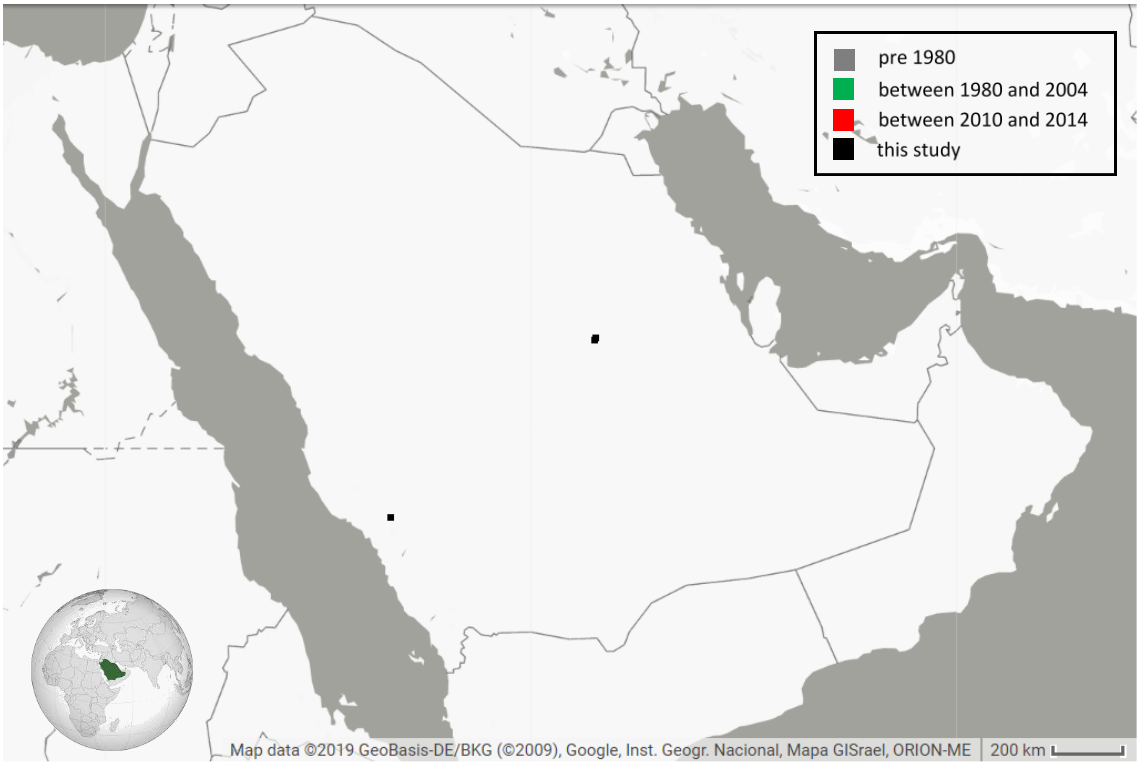


Figure 5.16. Distribution of *C. auratus* in Saudi Arabia.

5.3.4 Biogeographical distribution of fish assemblages in Saudi Arabia

The biogeographical distribution of freshwater fish species assemblages in Saudi was examined based on historical records of species presence/absence and data collected during this study. The analysis was based on eight indigenous freshwater fish species, 10 introduced species and two species that move from the sea to inhabit freshwater habitats in Saudi Arabia. Cluster analysis based in Jaccard similarity matrices was used to determine groupings of sites with similar species assemblages and Multidimensional scaling (MDS) to display groupings of similar sites in a 2-D space. The contribution of the main species driving the groupings was determined using the Excel Pivot Table tool.

The biogeographical distribution of freshwater fish species assemblages in Saudi was categorised into six regions (Figure 5.17 & Figure 5.18): eastern drainage systems located within high lands in the south and south-west of the Kingdom; western drainage systems in the coastal plains in the south and south-west region (Figure 3.14); Eastern Province; Central Region; North Central Region; and Northern Borders Province. There are a three partially separated regions in MDS (Figure 5.17) and eight statistically significant clusters of wadis at similarity levels between 0.4% ($\pi = 4.71$, $p = 0.001$) and 16.69% ($\pi = 16.23\%$, $p = 0.001$) (Figure 5.18), irrespective of water body type. These three partially separated groups in MDS were: the western drainage systems (WDS); eastern drainage systems (EDS) and the remainder of regions that supported freshwater fishes, which are dominated by introduced species. The species contributing to these groupings of sites were as follows.

Eastern drainage systems (EDS): three-endemic species *Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri* dominated this system contributing almost 48.7% of average similarity between wadis and dams in this system. *Carassius* sp. and *Oreochromis* sp. were also caught during trips associated with this study.

Western drainage systems (WDS): *Garra tibanica tibanica*, *Garra sahilia gharbia*, *Cyprinion acinaces hijazi*, *Carasobarbus arabicus*, *Acanthobrama hadiyahensis* and *Aphanius dispar* occur usually in western drainage systems (WDS). *Garra sahilia gharbia, Aphanius dispar, Garra tibanica tibanica* and *Arabibarbus arabicus* contributed to 17.6% of this system species average similarity. There are also sub groups of wadis in these systems, with the presence of several endemic species contributing to the dissimilarity, such as *Carasobarbus arabicus* and *Acanthobrama hadiyahensis*. *Acanthobrama hadiyahensis* is endemic to certain wadis in the far north of the western drainage systems like Wadi Hadiyah, Al-Bint Dam and Qusaiba'a Dam, and *Carasobarbus arabicus* occurs in the south of the western drainage systems and even into Yemen water bodies. *Aphanius dispar,* as a land-locked marine species, is widely distributed in the western drainage systems, Central Region and Eastern Province. *Oreochromis* spp. are also becoming more prominent in some wadis in the western drainage system.

(EP) Eastern Province; (MR) Central Region; (MRN) north Central; (NORTH) Northern Borders Province Region: Non-native species (*Oreochromis* sp., *Gambusia affinis*, *Poecilia latipinna*, *Poecilia reticulata*, *Xiphiphorus maculatus*, *Clarias gariepinus*, *Ctenopharyngodon idella*, *Carassius carassius* and *C. auratus*) dominate in the artificial water bodies, such as ponds, lakes and irrigation channels, in the Central and Northern regions and Eastern Province and account for between 10% and 50% of the average similarity in fish assemblages between sites. These species have been introduced for biological control purposes or have escaped from fish farms. Dry wadis into which urban waste water is discharged and artificial lakes constructed to receive waste water are often inhabited by these fish species that have the ability to withstand the stressful environmental conditions.

The first of the eight statistically significant clusters in Figure 5.18 comprised of Baish Dam, Wadi Baish, Wadi Damad, Wadi Juva, Taif, Wadi Sulaym, Ain Al-Hammah – Khaibar, Khaibar, Wadi Hesu'a and Wadi North Jizan. This cluster shared four indigenous fish species, including *Arabibarbus arabicus*, *Cyprinion acinaces hijazi*, *Cyprinion mhalensis* and *Garra tibanica*. The second cluster comprised of Alein Al-Harrah, Al-Ahsabah Dam, N of Jizan, Wadi Al-Gassah, Wadi Gaanah, Wadi Haroub, Wadi ileeb, Wadi Minsah, Wadi Al-Bagarah and Wadi Kudais. This cluster shared two indigenous fish species (*Garra buettikeri*[2], *Garra sahilia gharbia*) and one land-locked fish species (*Aphanius dispar*). The third cluster comprised of al-Asfer Lake, Duma Jandal Lake, al-Hair-Riyadh, al-Majmaah, Nemar Dam and Wadi Rumah. This cluster shared six introduced fish species, namely *Oreochromis niloticus*, *Oreochromis aurius*, *Gambusia affinis*, *Poecilia latipinna*, *Claris gariepinus* and *Carassius auratus*. The fourth cluster comprised of al-Hasa oasis and Wadi Hanefah. This cluster shared six introduced fish species (*Oreochromis niloticus*, *Gambusia affinis*, *Poecilia latipinna*, *Xiphiphorus maculatus*, *Xlaris gariepinus*, *Ctenopharyngodon idella*) and two land-locked fish species (*Aphanius dispar, Mugil cephalus*). The fifth cluster comprised of al-Kharj, Wadi Rabig, Wadi Fatima, Wadi Khadrah, Wadi Khulab, Wadi Reem, al-Hufuf, al-Qatif, Ein Al-Buhairah and Khodod spring. This cluster shared one indigenous fish species (*Garra tibanica*), one land-locked fish species (*Aphanius dispar*) and one introduced fish species (*Oreochromis niloticus*). The sixth cluster comprised of Abha Dam, Wadi Noval, Khamis Mshait, Wadi Haqqaq, Wadi Afrak, Wadi Tarj, Wadi Shumrukh, Wadi Al-Arj, Wadi noaman, Wadi Al-Mahallah, Wadi shuqub, Thrrad Dam, Al-Janbeen Dam, Wadi Turabah, Al-Aqiq Dam, AL-Sdar Dam, Wadi Buwah, Wadi Thrrad, Medhas Dam, Wadi Adama, Wadi Al-Aqiq and Wadi Al-Janbeen. This cluster shared three dominant endemic fish species (*Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri*). The seventh cluster comprised of Wadi Hadiyah, Al-Bint Dam and Qusaiba'a Dam. This cluster shared three indigenous (*Carasobarbus apoensis, Acanthobrama hadiyahensis, Cyprinion acinaces hijazi*). The eighth cluster comprised of near Medhaas and Salam Lake. This cluster shared one introduced fish species (*Carassius auratus*).

To summarize, there is a differentiation in the regions inhabited by freshwater fish into highland wadis, coastal lowland wadis and other regions in the central and eastern parts of the kingdom. The differences between these regions are driven by dominance of endemic species – eastern and western drainages, and the remaining areas that are characterized by a dominance of invasive fish.

[2] Hamidan & Shobrak (2019) found this species in Wadi Al-Bagarah, which is located in lowland drainage system, so was probably a mis-identification as this species usually dwells in highland drainage system.

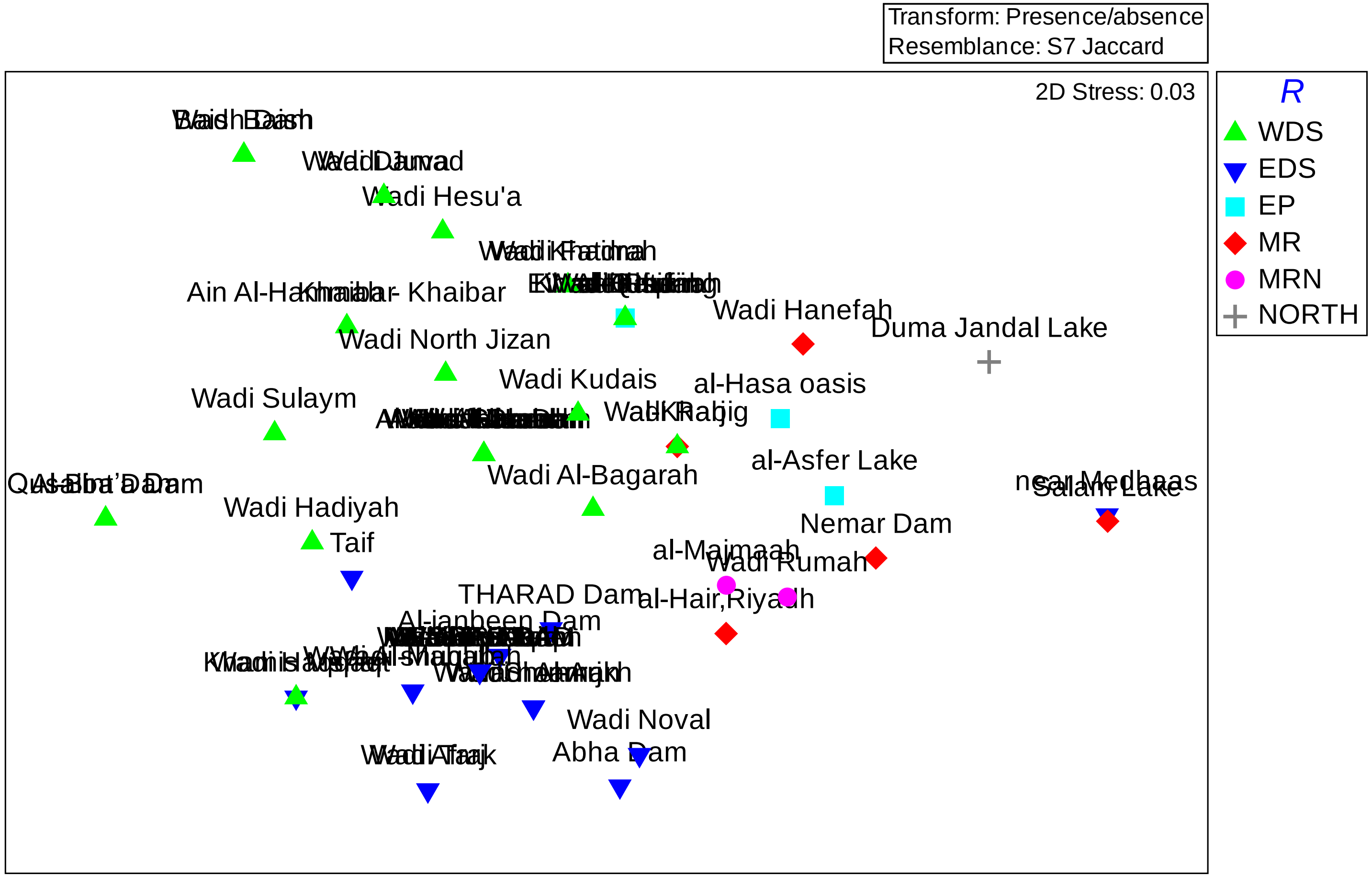


Figure 5.17.Non-metric multidimensional scaling (MDS) ordination plot to compare species presence/absence similarity between all location records within different drainage systems regions (WDS = Western drainage systems; EDS = Eastern drainage systems; EP = Eastern Province; MR = Central Region; MRN = North Central; NORTH = Northern Borders Province Region).

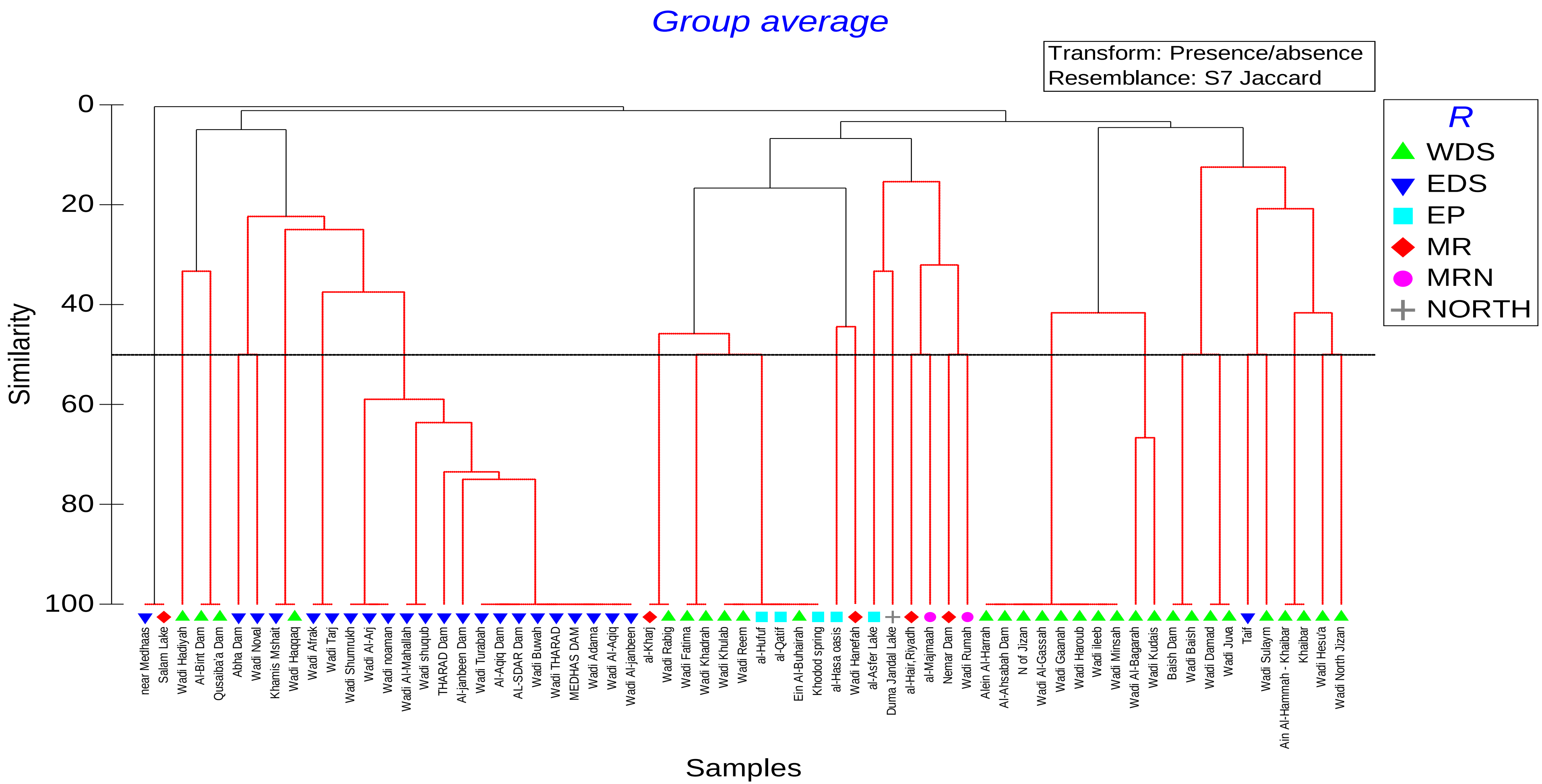


Figure 5.18. Hierarchical cluster analysis to compare species presence/absence similarity which fish members are shared and which are separate in all location records.

5.3.5 Recolonisation of wadis after drought periods

Some local people living near wadis wonder how fish can return to watercourses after the drought season. Some say fish eggs evaporate with the water and are later brought back in the rain, while others believe aquatic birds play a role in transporting fish eggs that stick to the birds' legs. In reality, as observed during field visits, it is likely fish survive in refuge pools and habitats in the upper reaches of wadis until it rains again and then colonises the wadi in a downstream direction with the flood. In the upper reaches of Wadi Turbah (WT) close to its headwaters in the Buthrah Mountain, there were small pools with no flowing water connections during the drought period that held adult fishes. These ponds likely operate as refugia until the rainy season and then fishes travel with the flood to recolonise the lower reaches. The importance of such refugia was highlighted by McNeil et al. (2013) as essential habitats that protect organisms from the impact of drought. The different species in Saudi Arabia, however, are likely to have different morphological advantages and behavioural responses at the time of flooding (Bolland, 2008) This supposition that small ponds and streams within the wadis in the upper reaches or floodplains where fish are found act as refugia, needs further investigations to understand how fish behave to avoid the extreme hydrological and hydraulic conditions during flood events, which can displace adult, juvenile and egg stages and large scale movements of sediments and debris. There are also some fish species that migrate back to the upper wadis when there is plenty of water and the ecological characteristics of this migration strategy needs further investigation, particularly the recruitment dynamics.

Below are some issues that need further study but must also be embedded into any management and conservation initiatives.

- The role of fish refuges during drought need more attention and protection in conservation management plans because they are key habitats that are fundamental to the sustainability of fish populations in these drought prone systems.
- As flood events are characterized by the length and width of wadis and the associated catchment size, it is important to understand the impact of these differences in flood intensity on the fish movements, redistribution and recolonization. For example, *Cyprinion mhalensis* was observed to be dispersing throughout Wadi Medhaas during a field visit, whereas the sympatric species *Carasobarbus apoensis* and *Garra buettikeri*, were not seen to be dispersing. It is therefore important to understand the different migration strategies of endemic species so management of water resources is optimised for the protection of all species.

- *Garra buettikeri* uses pectoral fins as a sucker to fix to the rocks during flood events. This species has seen trying to return to the reservoir by climbing the dam wall after being displaced by the floods and fish have also been seen migrating upstream against the high flows using their mental disk and pectoral fins as suckers fin to return to the upper reaches of wadis. This behaviour needs further investigation.
- Dams have exacerbated the problem of species dispersal during flooding, including physical damage caused when fish pass through by dam water gates. For example, many fish were observed near the gates of Al Sadr Dam after releasing water a flood event. Dams also regulate flows and may cause desertification and more intense drought conditions in areas of the wadi that were traditionally refuge areas but these habitats are now disappearing due to insufficient water. The impact of this change in flow regime of fisheries is needed and needs to be optimized for the protection of the species.

5.3.6 Dams as a barrier of fish distribution.

The main drainage basin groups that are characterized by the existence of abundant water are attractive for the development of water infrastructure to impound and supply water for domestic supply and agriculture. These basins unsurprisingly overlap with the drainage basins that are inhabited by fish. Najran, Asir, Al-Baha, Makkah and Madinah are regions where Saudi native species happen and about 70% of the dams (about 357 of 500) in Saudi Arabia are located within the areas of occupied by freshwater fish (Figure 5.19). There are high number of dams with a high storage capacity especially in Asir region (171 dams), Makkah (57 dams) and Al Baha (48 dams) which overlap with areas occupied by endemic freshwater fishes. The big numbers of dams concentrated in the distribution range of endemic species could be major issue for the sustainability of these species' populations because the dams act as barriers to the fish migration, disrupting connectivity and causing fragmentation of populations (see Chapter 2, Section 2.3.3, page 15, for discussion of potential impact of dams on fish). Whilst the impounded areas may act as refugia they also could have flooded out valuable spawning habitat for riverine species. This linkage between location of dams and distribution of fishes will again be used as baseline information for the establishment of a conservation management plan, which is a step to ensure measure are taken to minimise or mitigate any impact on fish fauna.

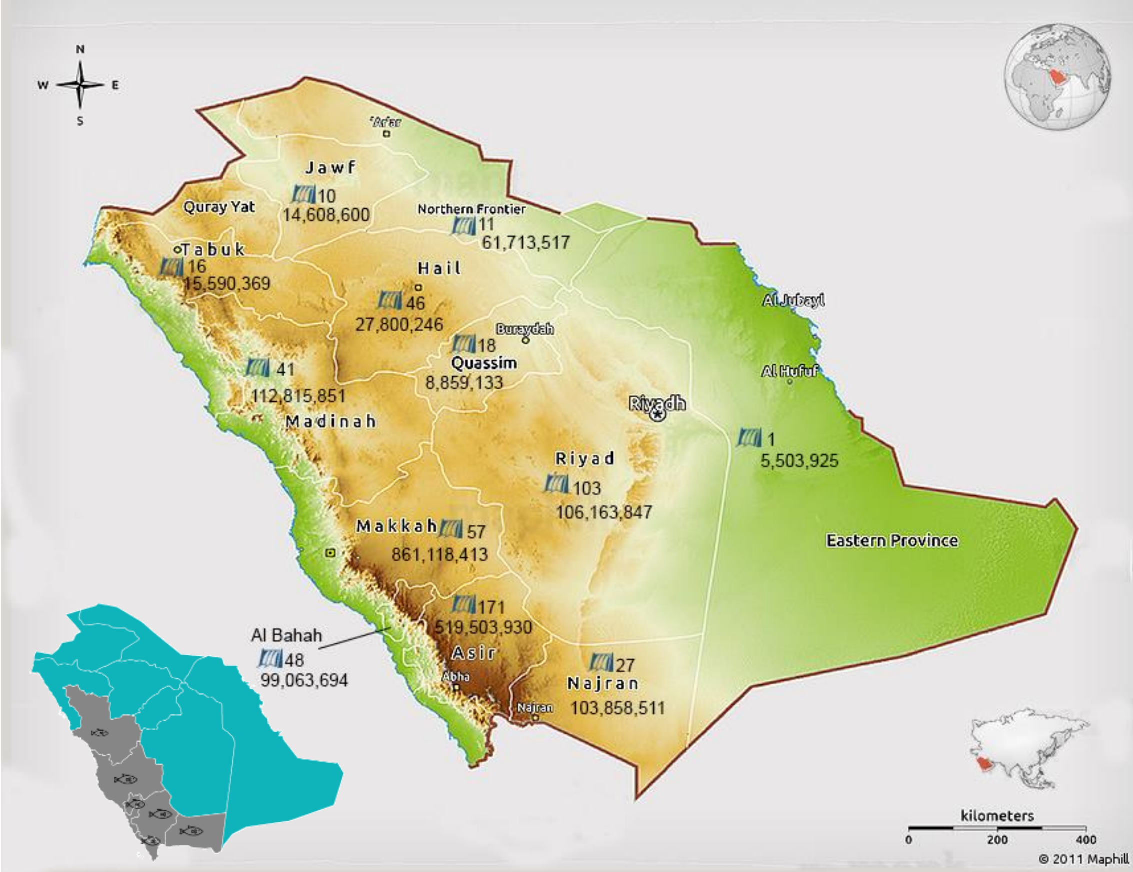


Figure 5.19. Distribution of dams in each administrative Region. Najran, Asir, Al Baha, Makkah and Madinah are regions where the native Saudi species occur, 70% of the dams are located within the areas of the Kingdom's freshwater fish. Total storage capacity is in m^3.

5.4 Conclusion

Freshwater fish in Saudi Arabia are mainly located within drainages in the south-west of the Kingdom, both in lowlands (western drainage systems) and highlands (eastern drainage systems) of the Sarawat Mountain Range. Three endemic species (*Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri*) dominated the eastern drainage systems. *Garra tibanica tibanica*, *Garra sahilia gharbia*, *Cyprinion acinaces hijazi*, *Carasobarbus arabicus*, *Acanthobrama hadiyahensis* and *Aphanius dispar* occur in the western drainage systems. Importantly, this study recorded the presence of non-native fish species in the dams located in Al Baha Region, Abha and Rabigh, which means both western and eastern drainage systems are being invaded by non-native species such as *Oreochromis* spp. and *Carassius* spp. Eastern Province, Central Region, north Central and Northern Borders Province are dominated by non-native fish species introduced mainly for biological control or escaped from fish farms. The differentiation between regions where freshwater fish are found are driven by dominance of endemic and non-native species. The environmental differences between wadis appear to be more pronounced in water bodies in western drainage systems. In addition, this study showed the most important drainages and wadis that need to be targeted and managed for the purpose of protecting freshwater fish, and largely in in the eastern and western drainage systems. The distribution of dams by region somewhat influence the dispersal of fish within their natural habitats, as does the regulation of flows and abstraction of water for drinking or agriculture. The information in this chapter will be used in the formulation of the fisheries management plan (Chapter 8), which will build and target the hot spots where the fish are located and also where dams are present.

Chapter 6 Fish ageing and growth

6.1 Introduction

Determining the growth characteristics of fish is fundamental to help understand elements of fish population structure and dynamics (Bagenal, 1978). Knowledge of growth is necessary for undertaking stock assessment and management of stocks, such as age and size at which fish are reproductively active, recruitment processes and production of the water body. Many studies provided frameworks for determining fish growth and the key factors that control growth (e.g. Welcomme, 1985, 2008; Weatherley et al., 1987; Wootton, 1990; Halls, 1997; Di Santo & Bennett, 2011; Tarkan et al., 2011). Although, determination of age and growth from fish scales is fraught with problems, especially in tropical systems where there is no seasonal variation, this method considered viable in the desert climate in Saudi Arabia because the seasonal flooding is likely to result in an accelerated growth that can be discriminated on the scales.

This study aims to determine the basic age structure and growth rates of Saudi freshwater fishes in a range of water bodies to understand factors driving growth rates. The study will test the suitability of scales for determining growth rates and fit the data to von Bertalanffy growth models to derive underlying growth characteristics. The study is believed to be the first to attempt to understand growth of Saudi freshwater fishes, and the first to explore differences between habitats/wadis. The potential causes for different growth rates between sites will therefore also be examined although it is acknowledged the possible explanations for fish growth performance from one location to another may be difficult to ascertain. However, these comparisons may illustrate some of the factors that regulate the growth of these fishes and possible cations that may be needed to improve the status of the fishes.

6.2 Methods

Fish specimens were collected from different locations during the field trips to Al-Aqiq Dam; Al-Janabeen Dam; Al-Sadr Dam; Medhaas Dam; Thrrad Dam; Wadi Bouah; Wadi Turbah; Al-Asfer Lake sites (see general methodology Chapter 4). Fish samples were preserved in 4% formaldehyde and brought from Saudi Arabia to the laboratory in the United Kingdom for further investigations.

A total of 2462 specimens from seven species (*Cyprinion mhalensis* = 600; *Carasobarbus apoensis* = 1012*; Garra buettikeri* = 656*; Carassius carassius* = 5*; Oreochromis niloticus* = 138*; Poecilia latipinna* = 41; *Gambusia affinis* = 9) were used for the age and growth studies. Each fish examined was given a unique code relating to its scientific name, and location and season of capture. Some fish were measured (total length, nearest mm; weight, nearest g) in the field before preservation and tagged to test for shrinkage caused by preservation in formalin. Fish preserved in formalin shrank by an average of 2% to 4% (Section 4.2, page 63), which was considered within the arithmetic error.

6.2.1 Length frequency analysis

Where sufficient data were available, length frequency distribution plots were created for individual fish lengths for each species in each water body and each season. Modes in the distribution, equivalent to specific age groups were identified where possible and related to length for age determined from the back-calculation of growth. All analyses were carried out using the Histogram function in Excel.

6.2.2 Age and growth analysis

All fish collected were identified, measured (total length nearest mm), weighed (nearest 0.01 g), sexed, and several scales were removed from all fish examined, dried in small paper envelopes and examined under a microfiche reader to determine age and growth. The total scale radius and distance from the focus to each annulus was measured using a microfiche reader (x 32 magnification). More than one scale was inspected to ensure the correct interpretation of the annuli and account for any false checks. The distance to each annulus was converted to length at age using Dahl-Lea's formula (Francis, 1990), viz:

$$Li = (Si/Sc) \times Lc \qquad \text{(equation 1)}$$

Where Li is the length (mm) at year i, Si is scale radius at length Li, Lc the total length of the fish and Sc the total scale radius. The mean length for age for all fish of a species from the specific water body were calculated and growth rates compared between locations.

Furthermore, the von Bertalanffy growth model was used to determine the maximum length of an infinitely old fish of the given stock ($L\infty$) and K, which is a "curvature parameter" that expresses how fast the fish grows.

$$Lt = L_\infty(1\text{-exp-}k(t\text{-}t_0)) \qquad \text{(equation 2)}$$

Where L_{inf} or L_∞ is the largest length fish can achieve according the von Bertalanffy model. $L\infty$ can be assessed from graphical plots (Gulland and Holt, 1959), in which the growth rate was plotted against length, then from a linear equation in which L_∞ infinity was calculated from the plot of Lt against Lt+1 as: L_∞ = intercept/1- slope; K is calculated as K = -(LN (slope)), and t_0 is the theoretical time when length is zero, calculated as: $t_0 = t + [(1/k)*(\log_e((L_\infty-L_t)/ L_\infty)))]$

6.2.3 Weight-length relationships

Weight-length relationships were developed for all species where sufficient data were available according to:

$$weight = a \times length^{b} \qquad \text{(equation 3)}$$

Where b is between 2 and 4 (normally around 3) and is converted into a straight line through logarithmic conversion as:

$$\log W = \log a + b \log L \qquad \text{(equation 4)}$$

The values for the factors a and b are determined from the linear regression of weight on length.

6.2.4 Condition factor

Condition factor is used as a measure for individual fish's 'well-being' that varies with seasons or ecological conditions (Bagenal, 1978). It depends on the supposition that the heavier a fish is for a given length, the better is the condition. Fulton's condition factor (K`) uses the value of the coefficient b from the weigh-length relationship to enable comparisons between locations and seasons according to:

$$K' = 100 \times W / L^{b} \qquad \text{(equation 5)}$$

where b is the value attained from the weight-length regression.

The condition factor K` was compared between seasons and sites using two way ANOVA where data were collected for both factors (season and site), and one way ANOVA to test the effect of season where the species was collected from one location.

6.3 Results

6.3.1 Age and growth analyses

Carasobarbus apoensis

Length frequency distributions, based on 1028 fish distributed across locations and seasons (Figure 6.1), indicated modal distributions in the populations from TH, AJ and AQ. Most fish were within the length range from 120 mm to 200 mm, which appear to relate to 3-5-year-old individuals. Specifically, a prominent mode was found around 120 mm (3+ fish) and a few fish <100 mm were caught. This is probably because of selectivity of the fishing methods used not catching juvenile or small-sized fishes.

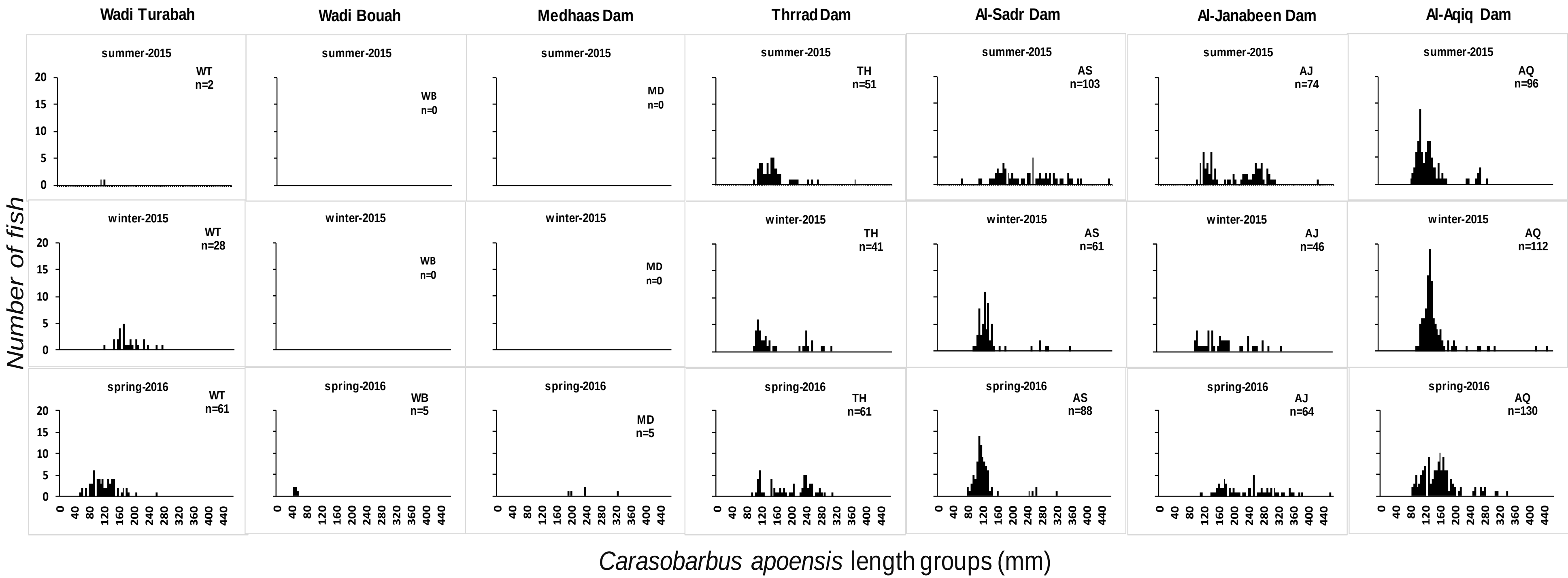
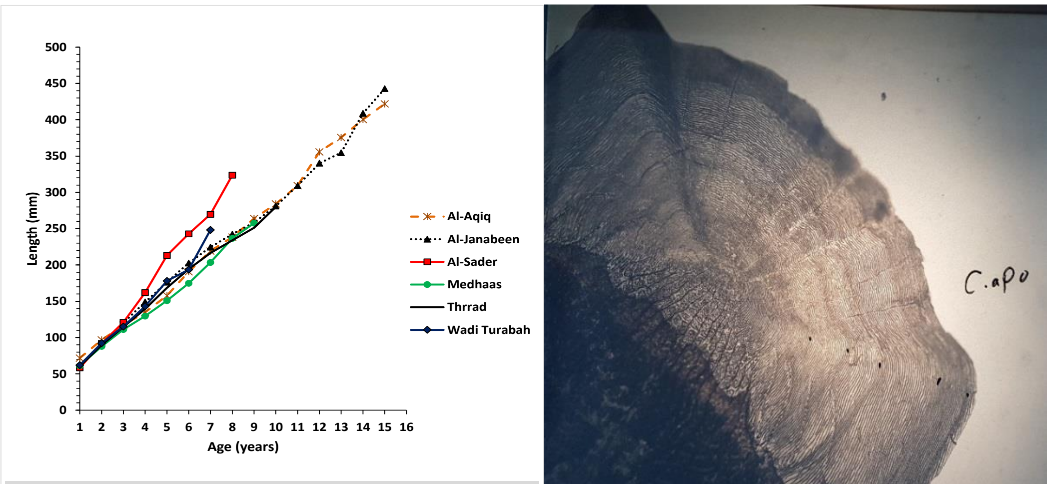


Figure 6.1. Length–frequency histograms for *Carasobarbus apoensis* from different locations (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD= Medhaas Dam; TH= Thrrad Dam; WB = Wadi Bouah; WT = Wadi Turbah) and seasons.

The maximum age recorded for this species was 15 years old (Figure 6.2). The growth trajectories in all the study sites were similar, with the exception of Al-Sadr Dam, which fish had a faster growth rate compared with other locations after 4 years of age. Growth rates in all populations tended to be fairly constant over time, with an annual growth increment of 25-30 mm, except in the first year of life when the fish achieved about 60 mm in length. The results of the von Bertalanffy growth model (Figure 6.2), indicated that the highest value of L_∞ recorded in Al-Sadr (1726 mm), Al-Janabeen (1386 mm) and Al-Aqiq (847 mm), which seems unrealistic given the largest fish recorded was 460 mm, but this is probably a reflection of the continuous growth throughout life. Fish in Al-Janabeen and Al-Aqiq were, however, found to live longer and grow larger, hence possibly contributing to the larger L_∞. K values were greater in Medhaas and Thrrad reservoirs suggesting they grow faster towards L_∞.



Sites	Al-Aqiq	Al-Janabeen	Al-Sader	Medhaas	Thrrad	Wadi Turabah
L∞	847.8153	1386.468	1726.055	417.7172	402.0875	542.682
K	0.045416	0.025523	0.025933	0.10425	0.116197	0.085994

Figure 6.2.Composite age-at-length growth curves for *Carasobarbus apoensis* from the various study sites. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from *Carasobarbus apoensis*.

Cyprinion mhalensis

Length frequency distributions, based on 636 fish distributed across locations and seasons (Figure 6.3), indicated modal distributions in the populations from Al-Sadr Dam (AS) and Al-Janabeen Dam (AJ) in spring. Most fish were within the length range 75 mm to 150 mm, which appears to relate to 0-4-year-old individuals. Specifically, a prominent mode was found around 125 mm (2+ fish) and 187 fish <100 mm were caught. New recruitment occurs mostly in spring and may extend until summer (varied among locations because of sample size).

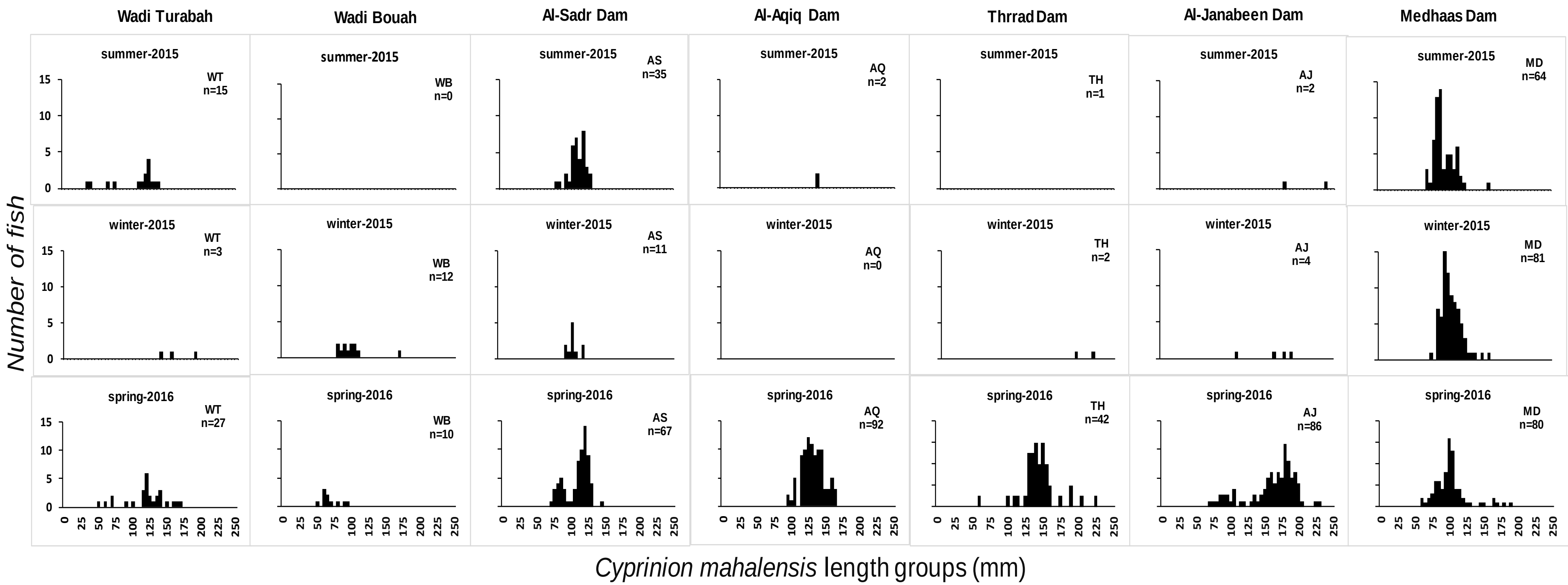
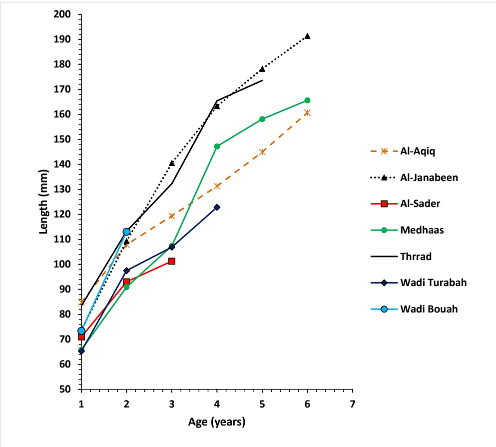


Figure 6.3. Length–frequency histograms for *Cyprinion mhalensis* from different locations (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WB = Wadi Bouah; WT = Wadi Turbah) and seasons.

The maximum age recorded for this species was 7 years old (Figure 6.4). The growth trajectories in all the study sites varied. Al-Janabeen dam and Thrrad Dam had a faster growth rate compared with other locations. Growth rates in all populations tended to contrast over time, with an annual growth increment of 8-40 mm, except in the first year of life when the fish achieved about 65-85 mm in length. The results of the von Bertalanffy growth model (Figure 6.4), indicated that the greatest value of L_∞ were estimated for the Al-Janabeen (207 mm) and Thrrad (179 mm) populations. Fish in Al-Janabeen and Thrrad were, however, found to live longer and grow larger, hence possibly contributing to the larger L_∞. K values were higher in Al-Sader reservoir suggesting they grow faster towards L_∞.



Sites	Al-Aqiq	Al-Janabeen	Al-Sader	Medhaas	Thrrad	Wadi Turabah	Wadi Bouah
L∞	149.7451	207.5235	104.4338	178.8953	179.4566	127.9728	159.6649
K	0.729396	0.400328	1.133825	0.39839	0.563172	0.707449	0.615446

Figure 6.4. Composite age-at-length growth curves for *Cyprinion mhalensis* from the various study sites. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from *Cyprinion mhalensis*.

Garra buettikeri

Length frequency distributions, based on 668 fish distributed across locations and seasons (Figure 6.5), indicated modal distributions in the population from Medhaas. Most fish were within the length range 120 mm to 160 mm, which appears to relate to 3-6-year-old individuals. Specifically, a prominent mode was found around 140 mm (4+ fish) and a few fish <100 mm were caught. This is probably because of selectivity of the fishing methods used not catching juvenile or small-sized fishes.

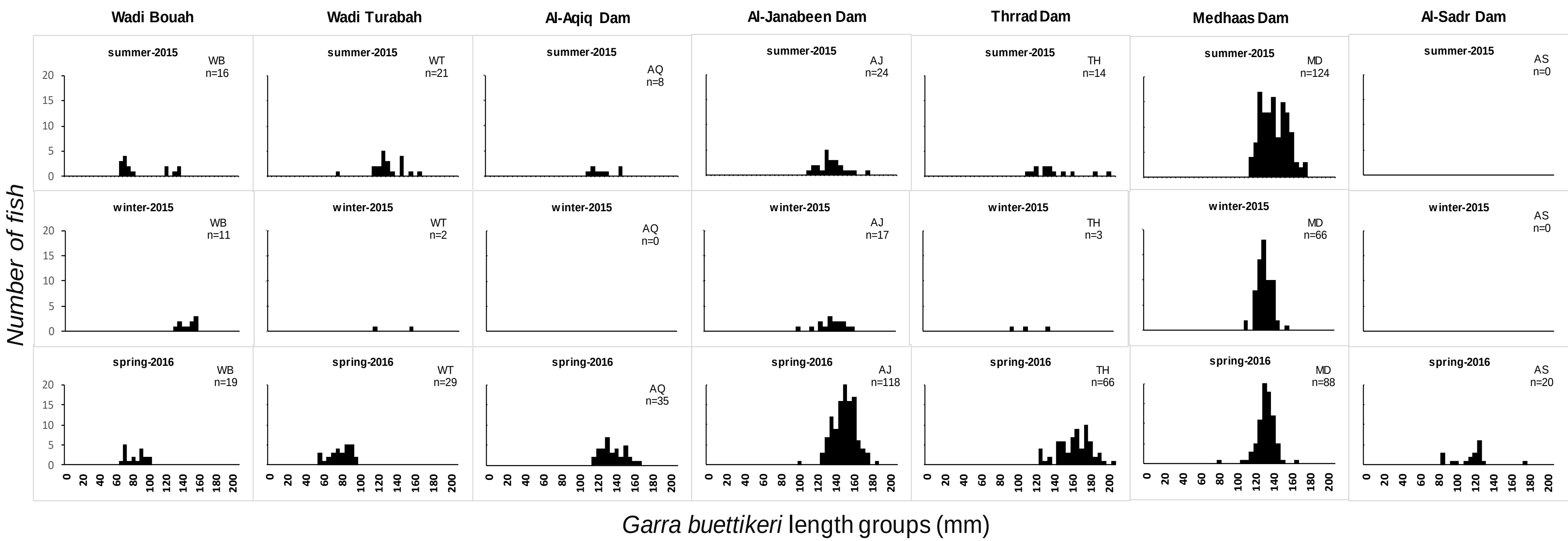
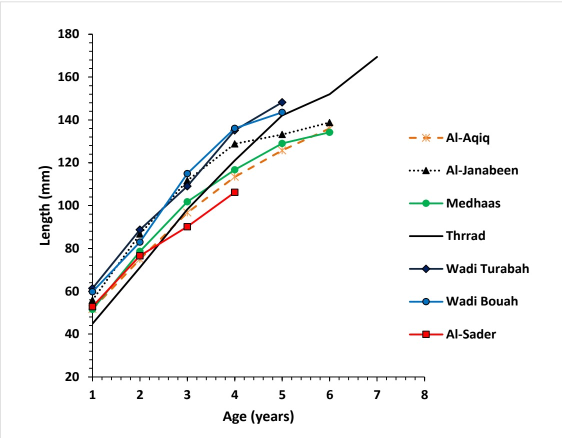


Figure 6.5. Length–frequency histograms for *Garra buettikeri* from different locations (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WB = Wadi Bouah; WT = Wadi Turbah) and seasons.

The maximum age recorded for this species was 8 years old (Figure 6.6). The growth trajectories in all the study sites were varied. This species has a faster growth rate in wadis compared with reservoirs. Growth rates in all populations tended to vary over time, with an annual growth increment of 14-32 mm, except in the first year of life when the fish achieved about 55 mm in length. The results of the von Bertalanffy growth model (Figure 6.6) indicated that the highest estimated value of L_∞ was in Thrrad (223 mm), Wadi Turbah (167 mm) and Wadi Bouah (162 mm). Fish from Thrrad were, however, found to live longer and grow larger, hence possibly contributing to the larger L_∞. K values were greater in Al-Sader reservoir suggesting they grow faster towards L_∞.



Sites	Al-Aqiq	Al-Janabeen	Al-Sader	Medhaas	Thrrad	Wadi Turabah	Wadi Bouah
L∞	149.296	148.3859	109.6692	146.1964	223.4142	167.1454	162.6908
K	0.376732	0.463783	0.637902	0.409473	0.200038	0.408871	0.418398

Figure 6.6. Composite age-at-length growth curves for *Garra buettikeri* from the various study sites. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from *Garra buettikeri*.

Oreochromis niloticus

Length frequency distributions, based on 139 fish distributed across locations and seasons (Figure 6.7), indicated modal distributions in the populations from Al-Asfer Lake. Most fish were within the length range from 120 mm to 180 mm, which appear to relate to 2-5-year-old individuals. Specifically, a prominent mode was found around 160 mm (4+ fish) and a few fish <100 mm were caught. This is probably because of selectivity of the fishing methods used not catching juvenile or small-sized fishes.

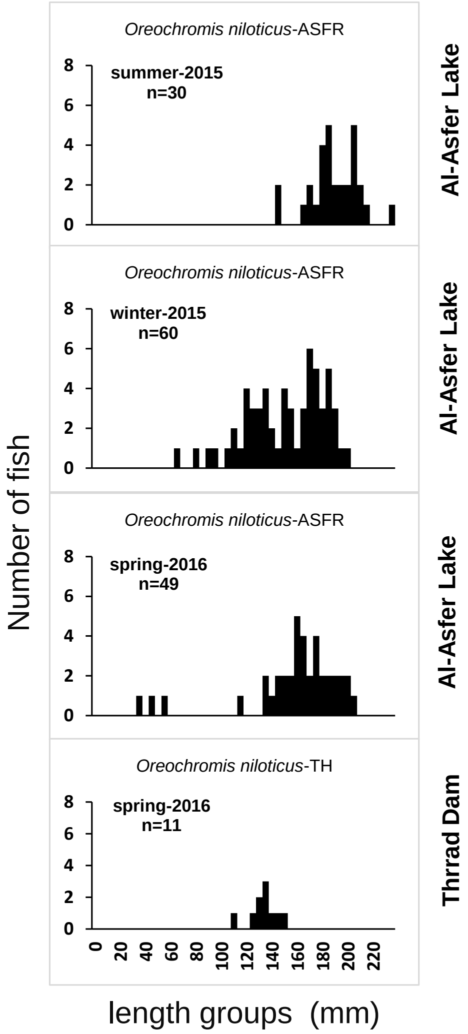


Figure 6.7.Length–frequency histograms for *Oreochromis niloticus* from two different locations (TH = Thrrad Dam; ASFR = Al-Asfer Lake) and seasons.

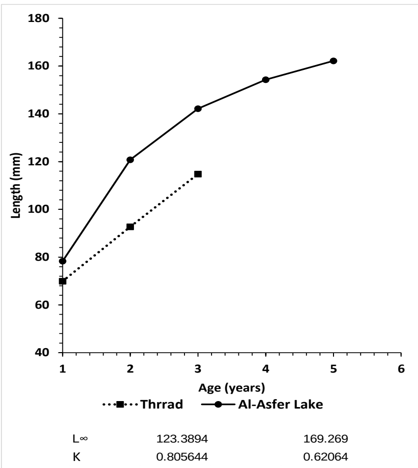


Figure 6.8. Composite age-at-length growth curves for *Oreochromis niloticus* from the various study sites. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from *Oreochromis niloticus*.

The maximum age recorded for this species was 5 years old (Figure 6.8). The growth trajectories in the two study sites were different. *Oreochromis niloticus* had a faster growth rate in Al-Asfer Lake than Thrrad Dam. Growth rates in both populations tended to be reasonably constant over time, with an annual growth increment of 20-40 mm, except in the first year of life when the fish achieved about 75 mm in length. The results of the von Bertalanffy growth model (Figure 6.8), indicated that the highest L_∞ value was for the Al-Asfer population (169 mm). Fish from Al-Asfer were, however, found to live longer and grow larger, hence possibly contributing to the larger L_∞. K values were similar for both sites.

Poecilia latipinna

It was not possible to construct length frequency distributions for *Poecilia latipinna* as only 46 fish were caught in the winter (n = 14) and spring (n = 32) sampling. All but one small fish, 25 mm long caught in the spring, were in the length range between 45 and 85 mm, probably representing 2-year old fish. This species is also ovoviviparous and has a long spawning season which may account for the lack of discrimination of length modes.

Poecilia latipinna reached and age of 2+ years in Al-Asfer Lake with an L_∞ of 81 mm (Figure 6.9). This is comparable with the maximum age of 3 years and a maximum length of 97 mm in Wadi Haneefah described by Al-Kahem et al. (2007).

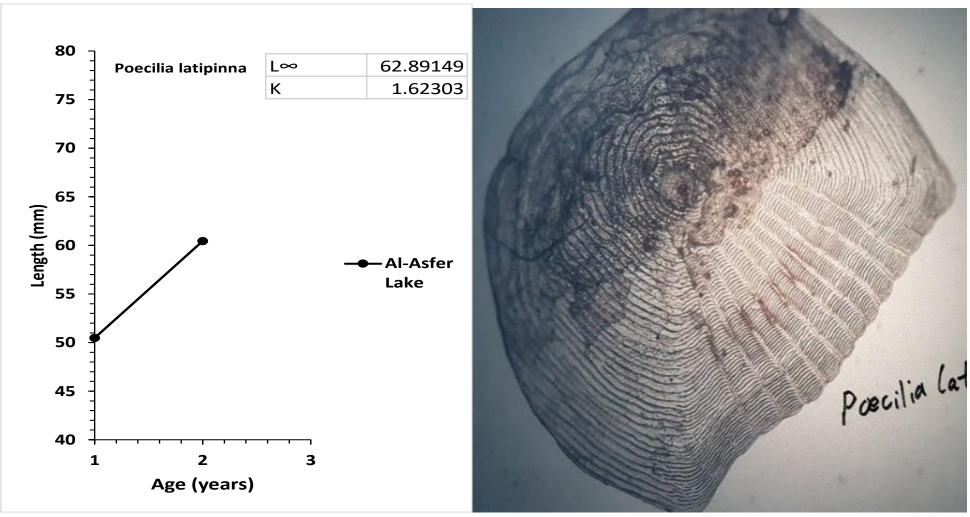


Figure 6.9. Composite age-at-length growth curves for *Poecilia latipinna* from the various study sites. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from sailfin mollies.

Gambusia affinis

Only 12 *Gambusia affinis* were caught in this study, all in Al-Asfer Lake in the spring. All fish were between 30 and 48 mm with the exception of one 15 mm fish.

Gambusia affinis is a small-sized fish species that is not long living. *Gambusia affinis* reach 1.5 years or age and a maximum length of 65 mm (Johnson, 2008). This species reached 2+ years and a maximum size of 48 mm as a maximum size in Al-Asfer Lake (0+ group). L_∞ value was low 38 mm and K indicate a fast growth to reach L_∞, but the results are suspect because of the short-lived nature of the species (Figure 6.10).

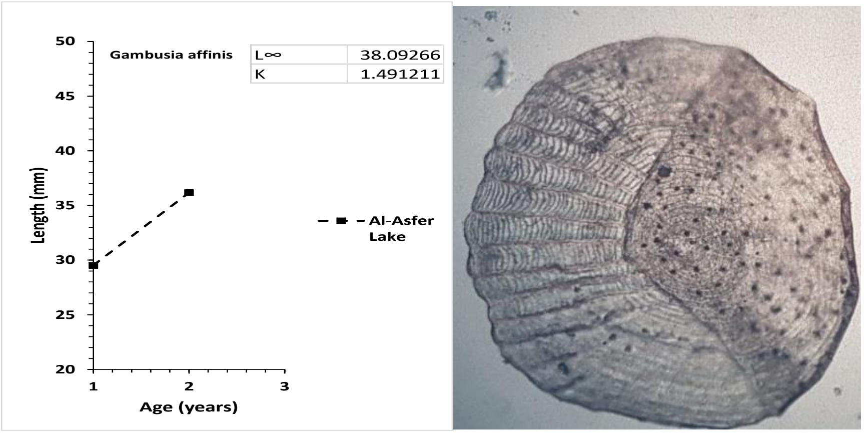


Figure 6.10. Composite age-at-length growth curves for *Gambusia affinis* from Al-Asfer Lake. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from *Gambusia affinis*.

Carassius carassius

Five *Carassius carassius* were caught in Al-Janabeen in the winter survey. All fish were between 180 and 195 mm in length. From individuals caught, the maximum age was 6+ years with a largest length of 195 mm (Figure 6.11). This fish reached 65 mm in its first year of life and had growth increments of about 30 mm per year, although growth slowed in later life until they reached maximum age of 6+ years. Furthermore, L_∞ value was 201 mm and K was 0.34 which fits with other studies, e.g. Petschora River where L_∞= 228 mm and K = 0.358 and in culture ponds where L_∞ = 298 mm and K = 0.093 (FishBase, 2018). It was not possible to draw a clear picture of fish growth of this species in Saudi because of the small sample size and further work needs to be done to gain a full picture of the success of the introduction of this species.

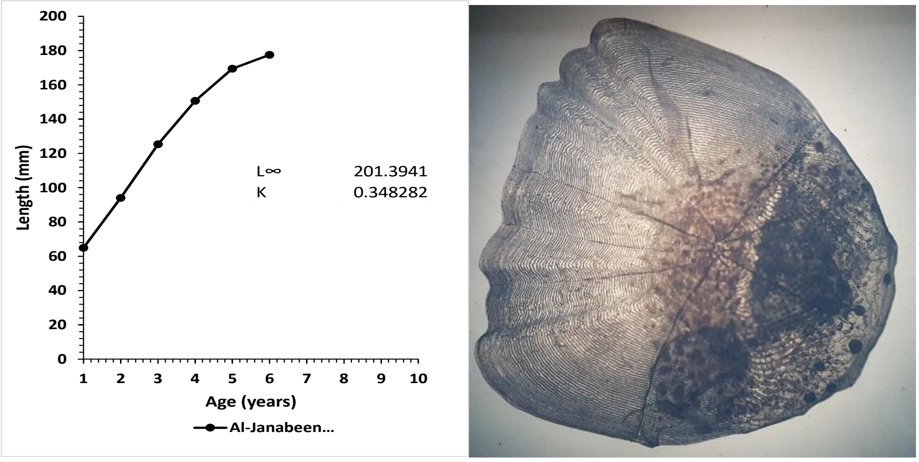


Figure 6.11. Composite age-at-length growth curves for *Carassius carassius* from Al-Janabeen Dam. L_∞ and K values from the von Bertalanffy growth model also given. Photo of typical cycloid scale from *Carassius carassius*.

6.3.2 Weight-length relationships

Weight-length relationships were generated for six species (Table 6.1). All show isometric growth with growth coefficients (b) of around 3 or slightly bigger which suggests these latter species in these water bodies are slightly heavier for their length.

Table 6.1. Weight-length relationships results of regression analyses

Species	N	L (mm)	W(g)	Log a	b	r^2
Carasobarbus apoensis	1028	41-460	0.78-1427	-5.2252	3.1213	**0.9938**
Cyprinion mhalensis	630	34-237	0.45-157	-5.3458	3.1725	**0.9725**
Garra buettikeri	667	52-201	1.35-99.9	-4.9963	3.007	**0.977**
Oreochromis niloticus	139	32-233	0.7-229	-4.716	3.0062	**0.983**
Poecilia latipinna	44	25-81	0.24-12.1	-5.3968	3.3674	**0.9536**
Gambusia affinis	10	30-48	0.45-1.71	-4.8891	3.0496	**0.9745**

6.3.3 Condition factor

Fulton’s condition factors were calculated using the exponent (b) from the weight-length relationships for each site and seasons (Figure 6.12). K` values were generally close to 1. There were insignificant differences in condition factor between seasons for all three species collected in different locations and seasons (two-way ANOVA, $p>0.05$), but highly significant differences between sites (two-way ANOVA, $p < 0.0001$ for all three species). Given the marginal variability between seasons, it is likely ecological factors such as water body productivity contribute to the differences between locations. *Carasobarbus apoensis* from Al-Janabeen and Al-Sadr reservoirs had slightly higher K’ values possibly because most fish were large and mature from these locations. *Cyprinion mhalensis* showed little variation between sites, although fish from Al-Janabeen were in better condition, different K' values among several locations may be linked to fish living in preferred habitat type, like flowing water, which this likely affects environmental quality and provides suitable breeding grounds. Condition of *Garra buettikeri* in Wadi Bouah was also much higher than other sites, perhaps reflecting the habitat in this wadi was more suitable for this species than other reservoirs. Tilapia as an alien species in Thrrad Dam (TH) was in a better situation than their colleagues in ALasfr Lake (ASFR) which possibly the quality of water in the lake is very poor. However, the ovarian of some individuals of *Oreochromis niloticus* reached a weight of 30% of the total weight of the fish which may give a high value of condition factor in Al-Asfer Lake. In Thrrad Dam, *Oreochromis niloticus* samples was too small.

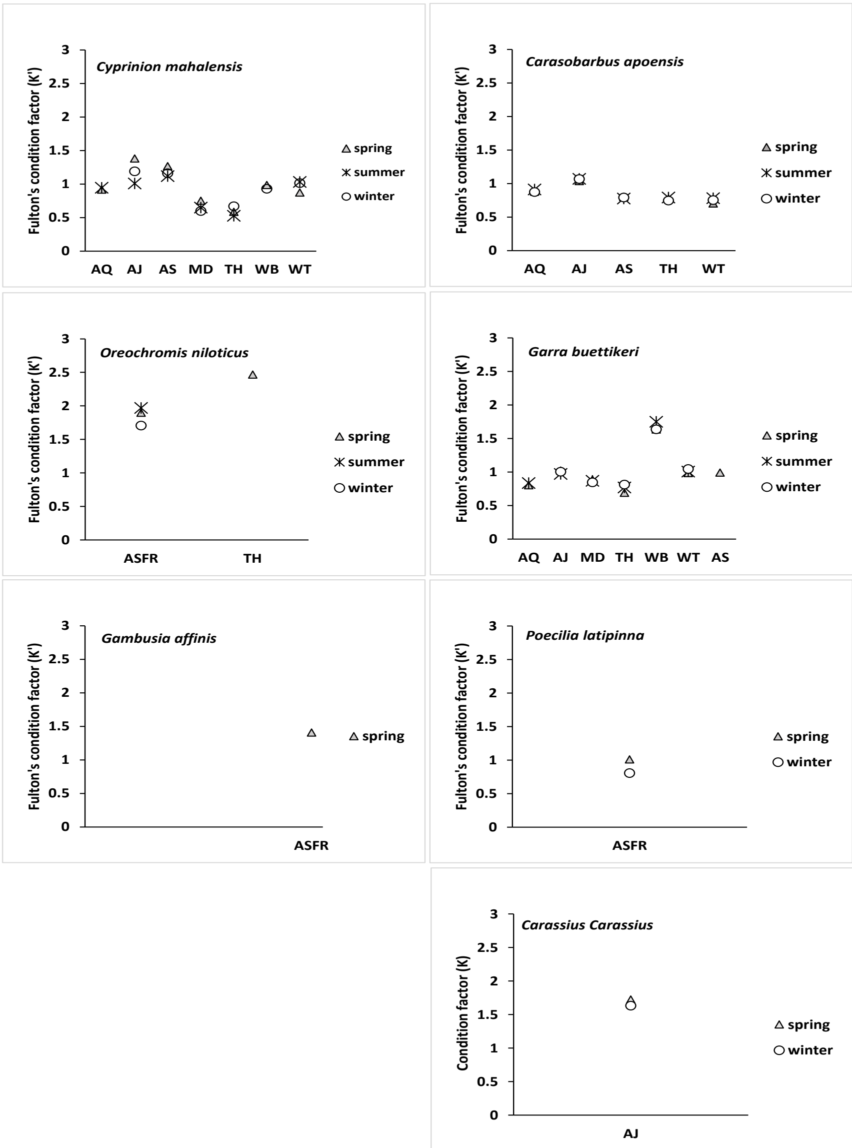


Figure 6.12. Fulton's condition factors (K`) for different species at locations (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WB = Wadi Bouah; WT = Wadi Turbah; ASFR = Al-Asfer Lake) and seasons.

6.4 Discussion

This is the first study that attempts to determine age and growth characteristics of freshwater fish species in Saudi Arabia. It mostly concentrates on three indigenous species (*Carasobarbus apoensis, Cyprinion mhalensis* and *Garra buettikeri*) in their natural distribution range, with supplementary information on non-native species in lakes and wadis in Saudi. Unfortunately, there were limited sample sizes to gain a full understanding of growth of non-native species and two species, *Poecilia latipinna* and *Gambusia affinis,* are short-lived (maximum age of 2 years) so information on growth from this study are restricted.

Two classical approaches were adopted to determine age and growth characteristics: length frequency analysis and back-calculation of growth for interpretation of hard structures, in this case scales.

Length Frequency Analysis (LFA) is typically used in tropical waters where no seasonal growth patterns are found for interpretation on hard structures. It is a useful method to discriminate age groups and potential recruitment pulses if growth is fast enough to tease out cohorts in the modal distribution patterns generated. There was only sufficient data to undertake LFA on the indigenous species (*Carasobarbus apoensis, Cyprinion mhalensis* and *Garra buettikeri*) and the non-native species, *Oreochromis niloticus*, but in the latter case discrimination of age modes is problematic because the species adopts a batch spawning reproductive strategy across a protracted reproductive period (see Chapter 8).

For the indigenous species, there was evidence of cohorts of fish (discrete modal distributions) that were presumably annual recruitment pulses in the length frequency histograms, but there is little evidence of juvenile recruitment, mainly because the sampling methods used were ineffective at catching small-sized fishes. It is also possible that juvenile fishes were only present after the flooding period when sampling conditions were difficult. In the future, it is recommended that micromesh seine nets are used to get a better understanding of juvenile recruitment processes.

The results of this study demonstrate that it is possible to determine growth rates from interpretation of growth checks, presumed annuli, on the scales of fish. Distinct checks were found on scales of the three indigenous species as well as the non-native species. These checks are probably laid down in the transition between the end of the high temperatures summer period and the onset of the rains when fish both breed and the increasing water levels bring lower water temperatures and improved food availability. Further, more intense (monthly) sampling is required to confirm the timing of the deposition of the annual marks on the scales.

The growth rates should also be validated against other methods, especially more extensive sampling to construct length frequency histograms that include fish less than 100 mm and use of other hard structures such as otoliths.

Considerable differences in back-calculated growth rates were found between water bodies for each of the main species studied, with the exception of *Carasobarbus apoensis* (Table 6.2). Growth of all populations of *Carasobarbus apoensis* were similar, with the exception of the fast-growing population in Al-Sadr Dam. By contrast, growth rates of *Cyprinion mhalensis* and *Garra buettikeri* varied considerably between sites with some fast, some average and some slower growing populations (categorization of growth rate is based on visual interpretation of comparative growth trajectories in back-calculated length-for-age plots. There appears to be no relationship between the rate of growth and the maximum length L_∞, thus making interpretation of the underlying reasons for the growth variability difficult.

Table 6.2. Categorization of growth rates of indigenous fish species in different water bodies, together with L_∞ (mm) determined from the von Bertalanffy growth model (values given in brackets).

	Al-Aqiq Dam	Al-Janabeen Dam	Al-Sadr Dam	Medhaas Dam	Thrrad Dam	Wadi Bouah	Wadi Turbah
Carasobarbus apoensis	Average (847)	Average (1386)	Fast (1726)	Average (417)	Average (402)	-	Average (542)
Cyprinion mhalensis	Average (148)	Fast (207)	Slow (104)	Average (174)	Fast (179)	Fast (127)	Slow (150)
Garra buettikeri	Average (149)	Fast (148)	Slow (109)	Average (146)	Fast (223)	Fast (167)	Average (162)

It is possible the faster growth rate of the *Carasobarbus apoensis* population in Al-Sadr was linked the stable water levels in this reservoir and high-water visibility (low turbidity) compared with other reservoirs. This is probably conducive to higher primary production in the system. Production in Al-Sadr reservoir is also enhanced by leakage of wastes from houses, including pharmaceuticals, surrounding the water body, into the reservoir which may affect fish development (Doerr-MacEwen & Haight, 2006), although this needs confirmation. Furthermore, fishing is widely practised in Al-Sadr reservoir, and this may be a response to fishing pressure reducing the population density, reducing intraspecific competition for food resources, and elevating growth rates. *Carasobarbus apoensis* in Al-Janabeen and Al-Aqiq were, however, found to live longer and grow larger, hence possibly contributing to the larger $L\infty$. It is possible these fish benefit from the intense floods in these systems that provide stable conditions each year for optimal growth.

There is a variation in the growth rate of *Cyprinion mhalensis* between locations, with the higher growth rates recorded in Al-Janabeen and Thrrad reservoirs (Table 6.2). These two dams have connections between the tailwaters of the reservoirs and the streams running from the upstream wadis, providing shallow running water habitat with vegetation on the banks and good water quality conditions. Individual *Cyprinion mhalensis* found in these streams were larger than those found in the sites of the reservoir probably because the streams provided the habitat with food and appropriate water quality parameters that the species required, enabling the fish to grow bigger. Moreover, *Cyprinion mhalensis* from Wadi Bouah also showed faster growth rates and again fish were caught in streams flowing through the wadi, but here no older fish were caught. By contrast, *Cyprinion mhalensis* in Wadi Turbah were slow growing despite being found in similar habitat to those found in Al-Janabeen and Thrrad tailwaters. The stream in Wadi Turbah is, however, more prone to drought conditions and may dry up for longer periods causing decline in water quality and exposure to high water temperature, which make the environmental conditions less suitable for growth and survival. Growth of *Cyprinion mhalensis* in Al-Aqiq reservoir was slow and may be linked to dramatic reductions in water levels due to increased water withdrawal for drinking purposes because of delays in the rainy period (see Chapter 3, Section 60, page 60), and most fish died during this period, perhaps affecting growth of the remain fish community. Considerable fluctuations in water levels were also observed in Medhaas reservoir, largely due to onset of floods and abstraction for agricultural activities, which may affect the growth rate of *Cyprinion mhalensis* in this system. It appears therefore that *Cyprinion mhalensis* prefers flowing water conditions in the streams associated with the reservoirs and this influences growth rates.

Difference in growth rates between sites were also observed in *Garra buettikeri* populations (Table 6.2). Faster growth rates were recorded in wadis than reservoirs. The lowest growth rates were recorded in Al-Sadr, Medhaas and Al-Aqiq reservoirs. The fastest growth rate was in Al-Janabeen, where the sampling site, as indicated above, is a flowing water environment and possibly preferred by this species. *Garra buettikeri* from Thrrad reservoir were found to live longer and grow larger than elsewhere, but it is unclear for the reason for this status.

It was not possible to make robust conclusions about the growth characteristics of non-native fish species (*Oreochromis niloticus*, *Poecilia latipinna*, *Gambusia affinis*, *Carassius carassius*) caught during the sampling programme. All fish caught appeared to be in good condition and able to tolerate the extreme conditions experienced in the reservoirs and lakes where they were captured. *Oreochromis niloticus* is mainly herbivorous and consumes algae, which possibly explains the average growth rates observed compared with populations elsewhere (Fishbase.org). *Poecilia latipinna* and *Gambusia affinis* are small-sized, short-lived species. Both species are highly adaptable to stressful conditions, although dead fish were observed during field visits, especially in highly confined vegetated areas. *Gambusia affinis* is unable to tolerate temperatures below 4°C (Johnson, 2008) but can endure water temperatures up to 38°C and flourish in warm conditions (Wydoski & Whitney, 2003), conditions typically found in Saudi freshwater systems. Lockwood et al. (2007) attribute to the success of *Gambusia affinis* to its resilience to broad environmental conditions, short life cycle, high fecundity, fast growth, early sexual development and broad diet, thus its apparently good growth makes it a potentially problematic invasive species.

Carassius carassius caught during winter and spring sampling trips in Al-Janabeen reservoir were all 4+, 5+ and 6+ aged fish. *Carassius carassius* is able to live more than 10 years of age (Tarkan et al., 2011) and the growth rate was slower than populations elsewhere (Tarkan et al., 2011). It is likely temperature is not a limiting factor on growth of this species because the species is able to cope with and survive high temperatures (Kottelat & Freyhof, 2007). Typically, *Carassius carassius* is not predominant in water bodies with a diversity ichthyofauna, but abounds in systems with few species (Billard, 1997; Kottelat & Freyhof, 2007). The observation that this species was restricted to shallow, marginal, densely vegetated areas in Al-Janabeen reservoir and only mature *Carasobarbus apoensis*, sharing the same habitat, were caught may partially explain the slow growth of *Carassius carassius* in Al-Janabeen reservoir. By contrast, *Carassius carassius* thrive in Abha reservoir (not included in this study) where it is the primary species. It would be valuable to determine the growth rate of *Carassius carassius* in Abha reservoir to test this hypothesis.

It is difficult to predict the reasons behind the variability in growth rates in the different water bodies, but if is probably due to a complex array of factors that influence fish growth. In this study, preferred habitat was considered major factor contributing the variable growth rates observed, but other factors, not least productivity of the water body and potential for competition for food resources, may also contribute. The association with flowing water habitats appears conducive to higher growth in *Cyprinion mhalensis* and *Garra buettikeri* populations. Availability of flowing water possibly provides a buffer against the adverse conditions during long drought periods and provide a continuous source of food. Drought, high temperatures, evaporation and limited food in drawn down reservoirs and poor water quality conditions in lakes may lead to the variation in the growth rate of these fish among locations. It was not possible to link the growth rates directly to food resources because no studies were carried out the food base or the nutritional value of the different food items. However, the fact that most species have high volumes of algae, detritus, and plant material in their stomachs (Chapter 7) suggests they are generally eating low calorific foods. Other factors that may contribute to the variability in growth, and found by other studies (Weatherley et al., 1987; Wootton, 1990; Halls, 1997; Welcomme, 2008; Di Santo & Bennett, 2011), include:

- Fish species have their own biological or physiological characteristics that could limit growth, such as genetic integrity or size of maturity;
- Food quality and availability as discussed above, foraging rates and the nutritional value of absorbed foods;
- Fish have different tolerances to abiotic factors, especially temperature, pH and oxygen level, which could influence growth rates;
- Rain and water discharge, as discussed above, are likely to influence fish growth, especially when the fish are under stress during extreme drought periods that not only reduce growth but also can lead to death;
- Fish have their preferred habitat like still or running water, substrate type or water depth, and changes in these favourite habitats could alter growth rates;
- Fish respond differently to pressures likes drought, flooding and overfishing that influence growth rates;
- Fish are heavily influence by other biotic factors such as predation, diseases and competition with other species in the same habitat which may control fish growth performance.

It is not clear which, if any, of these factors are responsible for the variation in growth rates found, but as the database of information accumulates the causal factors may be teased out. Welcomme (1985) suggested both biotic and abiotic factors at different times of the year probably affect growth rates in extreme environments, but abiotic factors, such as temperature; conductivity; water transparency; pH; dissolved oxygen; rain; water level (as discussed in Chapter 3), all likely the main contributors. Temperature in particular affects metabolic activity that influences growth directly (Di Santo & Bennett, 2011), but also impacts on several other parameters such as oxygen solubility, changing the physical and chemical characteristics of the water (Viadero, 2005). There is still a need to learn more about the tolerances of Saudi freshwater fishes and determine their optimal temperature ranges and the impact of extreme temperatures in the wadi streams and ponds to increase the fish metabolic rates or cause stress. Temperatures over 35°C, as can be found in Saudi freshwater systems, can cause physiological and cellular breakdown causing death in fishes, and is probably the cause of the dead fish observed during several field visits, such as in Al-Asfer Lake. Fish in this lake may be particularly prone to high temperatures because the lake is in the desert and eutrophic because it is impacted by nutrients and fertilisers from agricultural wastes and may cause depleted oxygen levels in the early mornings. Nonetheless, fish have adapted to these high temperatures, and when the temperatures become extreme, they avoid the surface area and swim deeper to escape the heat. Fish also seem to forage more actively during the early morning before temperatures rise, although no information is known about foraging at night.

6.5 Conclusions

This study has shown it is possible to determine age and growth of freshwater fish from inland waters in Saudi Arabia using hard structures, supported by LFA. Considerable variation was found in growth rates of the same species between water bodies, and this has been tentatively linked to preferred habitat conditions, especially the presence of flowing water and capacity to adapt to or avoid extreme environmental conditions. Further studies are required to validate the tools and ensure checks on scales are annual marks and not laid down when experiencing extreme conditions, i.e. false checks. In addition, the growth studies need to be expanded to other water bodies and determine variability between populations in a wider range of water body types in different regions. This work needs to be coupled with more in-depth studies on the topographical features, hydrology, environmental conditions and productivity in water bodies to validate the associations with growth proposed above.

These results on growth rates provide insights into the key environmental conditions that affect dynamics of fish populations in Saudi freshwater environments. In particular, it highlights the need to preserve the ecosystem integrity and links between standing waters and streams, as well as maintain stable water levels in reservoirs where possible. Such information is valuable for formulating actions for conserving the native freshwater fishes of Saudi, designing rehabilitation measures for habitat improvement, and optimising water resource management.

Chapter 7 Feeding ecology of Saudi freshwater fishes

7.1 Introduction

The growth and survival of fish populations is heavily dependent on how well individual fish are nourished over time. Thus, as a primer, it is essential to understand the food and feeding habits of the different species of fish in their natural habitat over their lifespan. It is also essential to investigate the dietary changes in fish species to obtain the relevant information to understand the relationships between different fish species in a specific location and their prey. Such studies are also essential in helping to understand fish food availability including non-living aspects (Kumar et al., 2017), and understand aquatic food webs. Understanding such ecological interactions is vital in developing appropriate measures, should they be required, to address problems associated with fish productivity in natural environments (Louca, Lindsay & Lucas, 2009).

Numerous studies have discussed fish feeding perspectives in freshwater fishes (Greenhalgh &; Hartley, 1948; Bagenal 1978; Hyslop 1980; Costello, 1990; Harper, 1992; Amundsen et al., 1996; Cortés 1997; Ovenden, 2007), but few studies have been carried out on freshwater fishes in Saudi Arabia.

Some studies have been carried out on the diet of *Arabibarbus arabicus* in Beesh Dam (Hakami et al., 2013) and *Cyprinion mhalensis* in Wadi Bua (Al-Kahem et al., 1988; Ahmad et al., 2013) and *Cyprinion acinaces* in Ain (Spring) Salaeem, Khayber (Al-Kahem et al., 1990). A few studies have also discussed the feeding ecology of introduced species in artificial lakes and dry wadis used for urban drainage wastewater, e.g. the feeding ecology of sailfin molly (*Poecilia latipinna*) in Wadi Haneefah stream (Al-Kahem et al., 2007). In addition there are numerous studies of the feeding ecology of the non-native fish species found in Saudi (*Poecilia latipinna*, *Carassius carassius*, *Gambusia affinis*, *Carasobarbus canis*, *Garra rufa*, *Garra ghorensis*, *Oreochromis niloticus*) in their natural distribution range or where they have been introduced elsewhere (Man & Hodgkiss, 1981; Getachew, 1987, 1993; Krupp et al., 1989; Etnier & Starnes, 1993; Yamamoto & Tagawa, 2000; Njiru et al., 2004; Webster & Lim, 2006; Yalcin-Ozdilek & Ekmekci, 2006; Kottelat & Freyhof, 2007; Johnson, 2008; Hassan-Williams et al., 2009; Hamidan, 2016; Ray & Robins, 2016; FishBase, 2018).

The goal of this part of the research was to provide information on the feeding ecology of some Saudi freshwater fish and to construct a feeding comparison between wadis, as natural habitats, and dams, as artificial environments. Additionally, shifts in diet between seasons and as fish get older and larger were investigated. This information was used to explore whether there is potential overlap in diet between native and introduced species, and thus identify possible impact of non-native fish species on the native fish fauna in Saudi.

The many research questions that are being asked through this research are: What are the main dietary habits of freshwater fishes in Saudi Arabia? Do fish species alter their diet between locations and seasons or as they get older? Is there any dietary overlap between species, especially native and non-native species? What are the feeding strategies for each species and do they shift strategies when in the presence of different species, especially non-native species?

7.2 Methods

A total of 1393 fish specimens belonging to seven species (*Cyprinion mhalensis* = 314; *Carasobarbus apoensis* = 605*; Garra buettikeri* = 323*; Carassius carassius* = 5*; Oreochromis niloticus* = 103*; Poecilia latipinna* = 34; *Gambusia affinis* = 9) were collected for diet analysis from different study sites, including five dams, two wadis and a lake during three sampling trips. Fish were preserved by injecting 4% formaldehyde using a syringe and later shipped from Saudi Arabia to the laboratory in the United Kingdom for further investigations.

In the laboratory, each of the fish specimens was given a code, identifying species, location and season caught. The length, weight, age and sex of each fish specimen were recorded. The fish were cut open, the stomach extracted and the stomach relative fullness index was classified as one of the following five categories: 0, 0.25, 0.5, 0.75 and 1.0, where 0 meant empty stomach and 1.0 meant a full stomach. Each stomach was cut open, the contents spread in a petri dish and examined under a dissecting microscope. The following prey items were identified according to their prevalence in most fish species: Myxophyceae; Chlorophyceae; Desmidiaceae; Bacillariaceae; protozoans; Mastigophora; rotifers; detritus/digested food; unidentifiable insect parts; unidentifiable algae; nauplius*; Daphnia; Ceriodaphnia; Eurycercus; Acroperus; Diaphanosoma; Diaptomus; Limnocalanus; Cypridopsis; Canthocamptus; Cyclops; Simocephalus; Chydorus; Camptocercus; Polyphemus; Eubranchipus*; plant material; dough; worms; fish scales; fish; aquatic Hemiptera larvae; water beetle larvae; dipteran larvae; freshwater molluscs; unidentifiable food items; fish eggs.

Identification of most of these prey items was done using guides from scientific literature (Ward & Whipple, 1918; Needham & Needham, 1938; Macan, 1959; Fitter & Manuel, 1986) as there is no guides for Saudi freshwater flora and fauna. The contribution of each food item in the stomach was subjectively allocated points in proportion to its visually estimated contribution to stomach fullness (personal judgment) following Hynes (1950). The proportional representation of the diet % *Pi* was given as *Pi/Pt* where *Pi* is the points given to food category and *Pt* the total points based on stomach fullness.

All the collected data were recorded in an Excel sheet which included information for all the variables to be analyzed.

Analysis of these data included the following:

Bray-Curtis similarity matrices (Bray & Curtis, 1957) were calculated in the PRIMER package (Clarke & Gorley, 2006; Anderson et al., 2008) using 4^{th} root transformed relative abundance data of each dietary item consumed by each fish species and ordinated using non-metric multidimensional scaling (MDS) to investigate similarities in dietary composition. The matrices were then submitted to permutational multivariate analysis of variance (PERMANOVA) and ANOSIM (9999 random permutations) to assess the statistical significance of any differences in the diet of the species (Anderson, 2001; Anderson et al., 2008). ANOSIM provides the significance levels (P-value) and the strength of the factors (location, seasons, age, age group, species, or a combination between two or more factors) on the samples (R-value). R-value is assumed to differ between 0 and 1, but sometimes negative values can be obtained, meaning samples are highly dispersed. R-values close to 1 indicate high separation between factors, e.g. between fish age 1+ and 7+, i.e. no overlap in diets. R-values close to 0 indicate no separation between factors, i.e. strong overlap in diets and potential competition. In addition, similarity percentages (SIMPER) analysis of the prey items was used to determine the percentage similarity and dissimilarity between factors, between levels of factors and for specific levels of other factors. The null hypothesis would be "there were no differences between various species or age groups of individual species" in the same water body or between the same species in different water bodies.

Shifts in the diets of the different species of fish were examined in relation to age, location and season as well comparing diets between species at the same location using cluster analysis and multidimensional scaling (MDS) in the PRIMER package (Clarke & Gorley, 2006; Anderson et al., 2008).

Prey-specific abundance was calculated based on modification of the Amundsen et al. (1996) graphical by Costello (Costello, 1990). The Costello (1990) method combines prey-specific abundance and frequency of occurrence, and allows prey importance, feeding strategy and the inter- and intra-individual components of niche width to be explored (Figure 7.1). Prey-specific abundance is expressed as:

$$P_i = (\Sigma S_i / \Sigma S_{t_i}) \times 100$$

where *Pi* is the prey-specific abundance of prey *i,* S_i the stomach content (volume) contributed by prey *i,* and S_{ti} the total stomach content in only those predators with prey *i* in their stomach. Prey points located in the lower right corner of Figure 7.1 represent those that have been eaten by most fish but in only small numbers (high within-phenotype component, WPC).

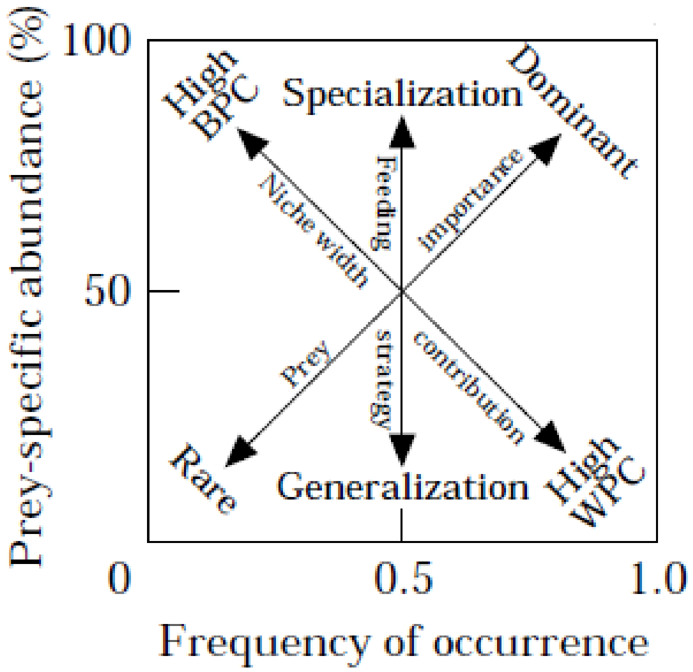


Figure 7.1. Hypothetical Costello (1990) graph to understand feeding strategy, niche width contribution and prey importance of different species. Between-phenotype component to niche width (BPC), niche width (rare or dominant) and within-phenotype components (WPC) are expressed.

The Costello graphs were created in Microsoft Excel for each fish species based on differences between sampling locations. Percent abundance, increasing along the diagonal from the lower left to the upper right corner, provides a measure of prey importance, with dominant prey at the upper, and rare or unimportant prey at the lower end. The feeding strategy of the fish in terms of specialisation or generalisation is represented by the vertical axis. Fish specialised on prey positioned in the upper part of the graph, whereas prey positioned in the lower part were eaten less frequently. Prey points located at the upper left of the diagram indicate specialisation by individual fish (high between-phenotype component, BPC), and those in the upper right represent specialisation of the fish population.

The diet data were analysed based on fish age, sampling location and season, with varying number of numbers of fish of each species by these factors (Appendix F).

7.3 Results

Variation in the diet of the major fish species found in Saudi water bodies sampled are presented in the following sub-sections.

7.3.1 *Carasobarbus apoensis* (CA)

There is considerable variation in diet between age groups in *Carasobarbus apoensis* (Figure 7.2). There was a shift in diet from green algae, aquatic hemipteran, dipteran larvae and some crustaceans in the early age groups to plant material, Chlorophyceae and small fishes in older age groups, although Chlorophyceae and plant material were found across all age groups. The diversity of food items seems to decline with age (Figure 7.2). Bread dough was found in many stomachs and arises because fishermen use bread or dough to attract fish. Moreover, *Carasobarbus apoensis* rarely feeds on freshwater molluscs or Diptera larvae, indicating the species will not be suitable to control the Schistosomiasis parasite associated with molluscs as a vector or mosquito driven diseases.

These results were confirmed by the PERMANOVA test, which found significant differences in diet between juvenile (0+) and 1-5 age group (G1) ($p \leq 0.05$). Again, differences were found between 1-5 age group and 6-10 age group (G2), but no significant differences were found between 6-10 age group and the 10-15 age group (G3). Chlorophyceae, detritus/digested food, plant material, Myxophyceae, aquatic hemipteran, unidentifiable algae and unidentifiable insect parts were the main food items consumed by *Carasobarbus apoensis* represented in all age groups (SIMPER test).

The diet of *Carasobarbus apoensis* was found to vary between locations and among seasons (Figure 7.3) and was confirmed by the PERMANOVA test ($p \leq 0.05$) and MDS analysis (Figure 7.4) (results presented in Appendix C). The diets of *C. apoensis* from Wadi Bouwa, Al-Sadr Dam and Medhaas were considerably different from other sites. Variation in diet was also found between seasons at some but not all sites (Figure 7.4), for example, diet *C. apoensis* in Al-Janabeen Dam during the summer (T1) was different from winter (T2) and spring (T3).

The major prey items that contributed most to the differences in diet between locations (note order of items in the lists indicate level of contribution) were as follows:

- **Wadi Bouwa**: *Cyclops* (45.4%); Diptera larvae (23.7%); water beetle larvae (21.38%).
- **Wadi Turbah**: plant material (32%); Chlorophyceae (30.9%); Bacillariaceae (22.2%); aquatic Hemiptera (11.2%).

- **Al-Aqiq Dam**: plant material (40.3%); Chlorophyceae (20.3%); Myxophyceae (18.8%); aquatic Hemiptera (6.1%); *Daphnia* (4.1%); fish (1.8%).
- **Medhaas Dam**: plant material (97.1%).
- **Thrrad Dam**: Chlorophyceae (31.4%); plant material (29.2%); Myxophyceae (20.2%); aquatic Hemiptera (4.5%); *Simocephalus* (3.3%); *Cyclops* (2.8%).
- **Al-Janabeen Dam**: Chlorophyceae (22.1%); Myxophyceae (19.8%); aquatic Hemiptera (12.6%); detritus/digested (10.4%); unidentifiable insect parts (9.8%); plant material (8.5%); unidentifiable algae (6.7%); *Daphnia* (4.5%).
- **Al-Sadr Dam**: detritus/digested (53.2%); Chlorophyceae (23.2%); unidentifiable algae (8.0%); Myxophyceae (6.0%).

The food items that contributed most to the variation in diet in each season were as follows:

- **T1 summer**: detritus/digested (36.4%); Chlorophyceae (23.7%); Myxophyceae (10.8%); unidentifiable algae (8.2%); unidentifiable insect parts (6.8%); plant material (4.8%).
- **T2 winter**: Chlorophyceae (42.2%); Myxophyceae (14.2%); plant material (13.5%); detritus/digested (12.5%); aquatic Hemiptera (3.7%); Bacillariaceae (3.1%); Mastigophora (1.8%).
- **T3 spring**: plant material (29.3%); Chlorophyceae (24.4%); Myxophyceae (16.8%); aquatic Hemiptera (6.4%); Bacillariaceae (5.3%); detritus/digested (4.7%); unidentifiable algae (3.8%).

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Carasobarbus apoensis* from different sampling locations (Figure 7.5) indicated that most points were located in the lower-left side, which means some dietary items are eaten infrequently in most locations. However, in some sites (AQ, AS, AJ, WB and WT) some prey points moved towards the lower right side which indicates a generalist feeding strategy. By contrast, plant material was the dominant food item in the MD site. To conclude, the major prey taxa for *Carasobarbus apoensis* are Chlorophyceae, detritus/digested items, plant material, Myxophyceae, aquatic Hemiptera, unidentifiable algae and insect parts.

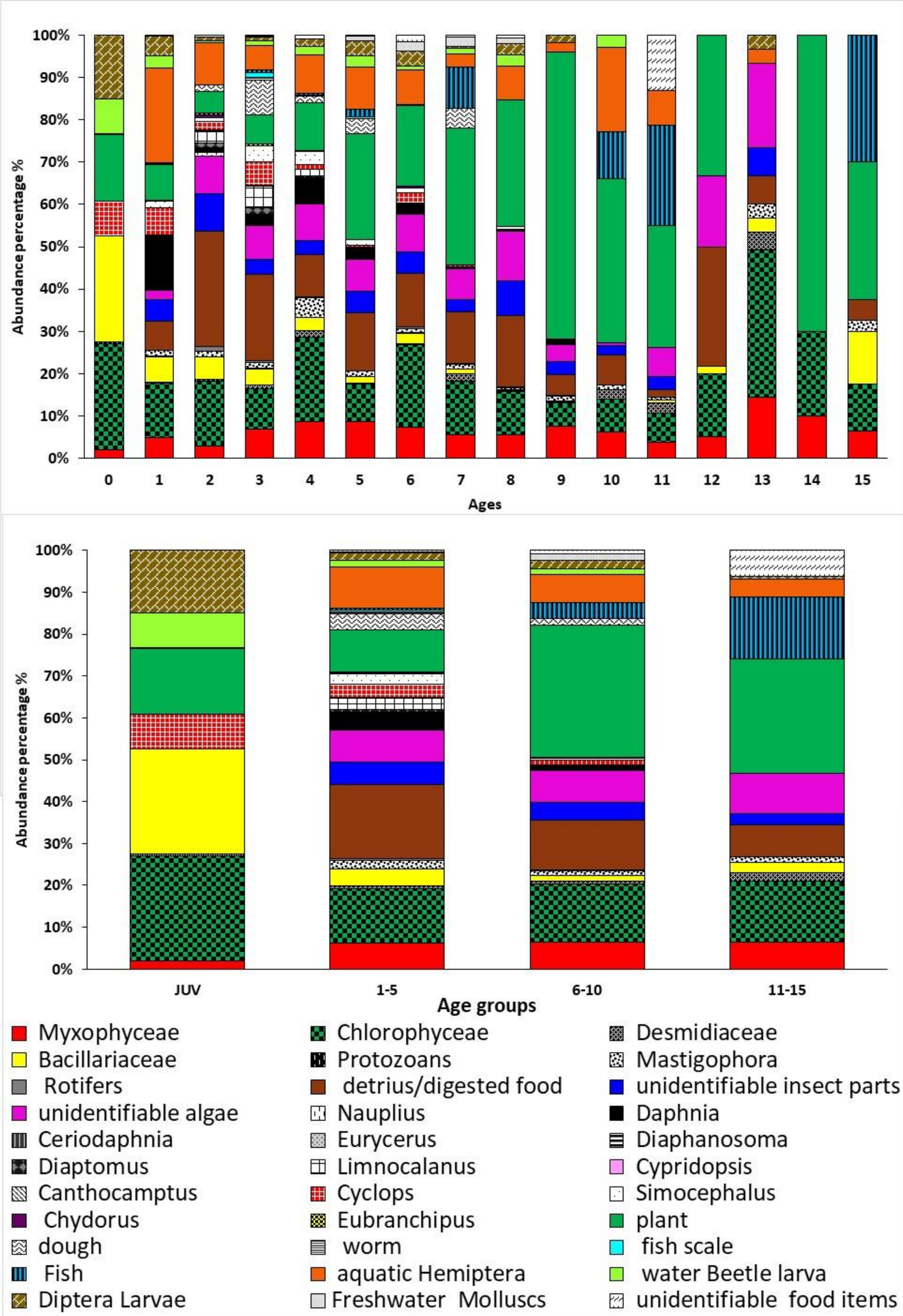


Figure 7.2. Variation in diet composition between each age (upper) and age groups (lower) of *Carasobarbus apoensis* based on mean values for all individuals from all sites in all seasons.

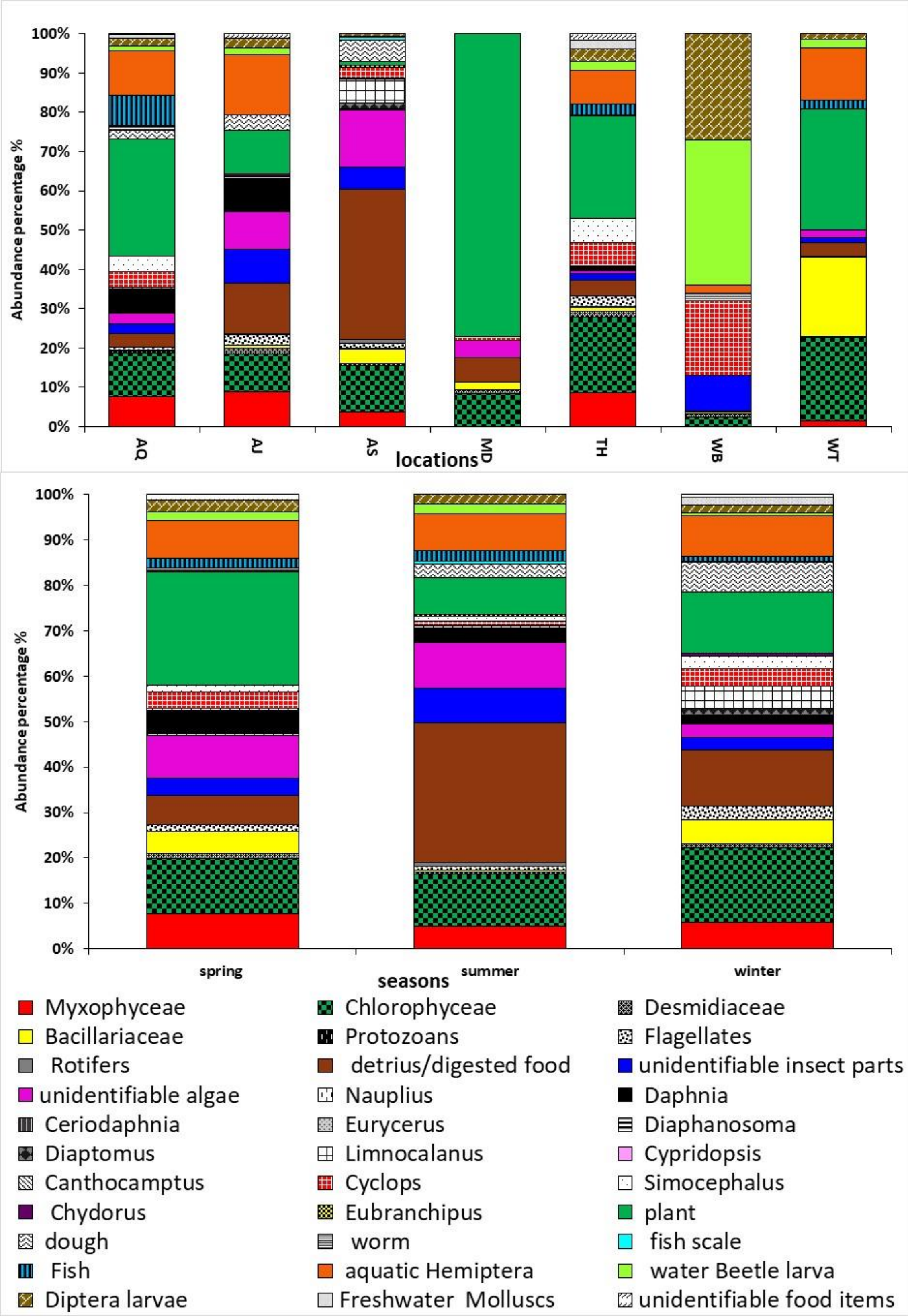
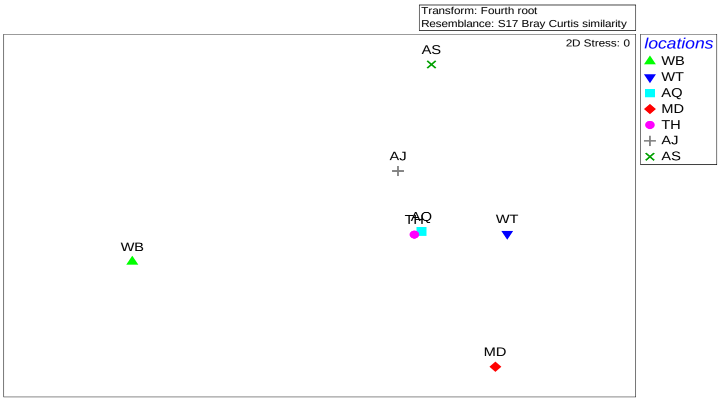


Figure 7.3. Diet composition of *Carasobarbus apoensis* between locations and seasons (WB = Wadi Bouwa; WT = Wadi Turbah; AS = Al-Sadr Dam; AQ = Al-Aqiq Dam; TH = Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam) based on mean values for all individuals of all ages.



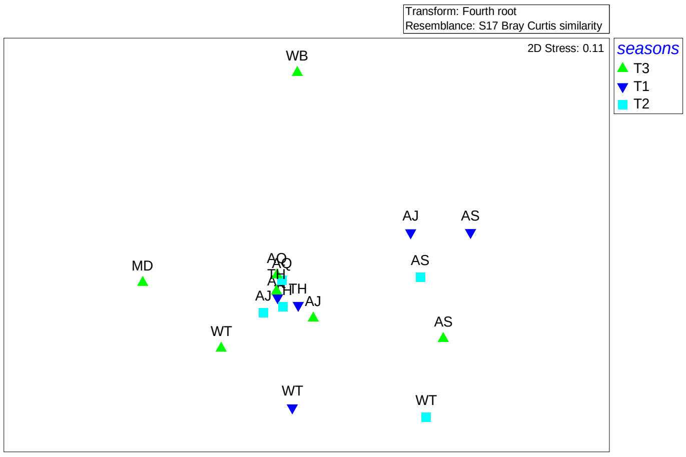


Figure 7.4. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition between location (upper) and seasons (lower) for *Carasobarbus apoensis* (WB = Wadi Bouwa; WT = Wadi Turbah; AS = Al-Sadr Dam; AQ = Al-Aqiq Dam; TH = Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam. T1 = summer; T2 = winter; T3 = spring) based on all fish individuals of different ages combined.

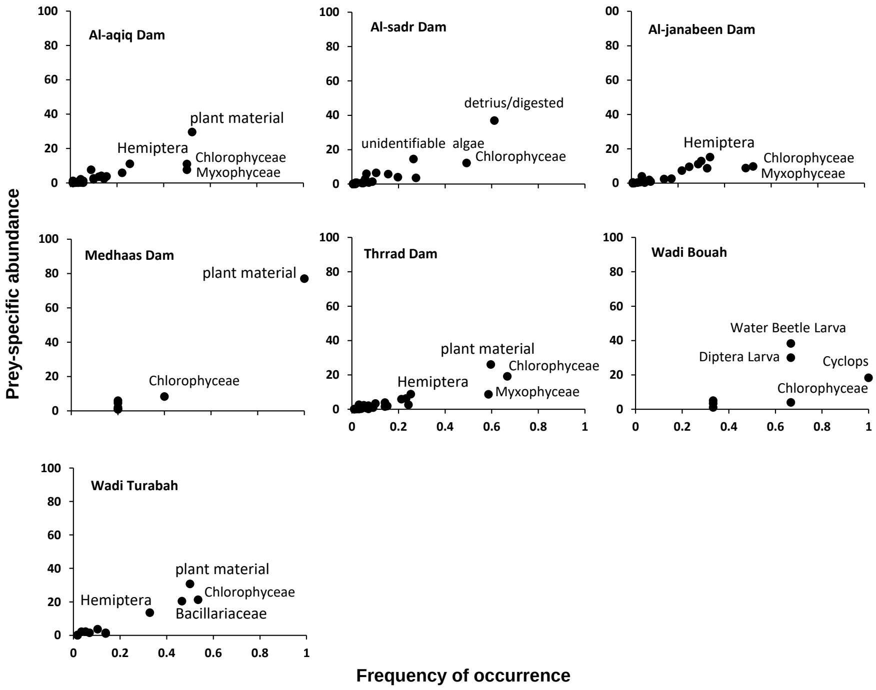


Figure 7.5. The prey-specific abundance graphs for *Carasobarbus apoensis* in different locations based on fish of all age groups and different seasons combined.

7.3.2 *Cyprinion mhalensis* (CM)

There was little variation in diet between age groups in *Cyprinion mhalensis* (Figure 7.6). Chlorophyceae, detritus, diatoms and Myxophyceae were most frequent food items consumed by all age groups. Moreover, *Cyprinion mhalensis* rarely feeds on rotifers, insect, crustaceans and protozoans.

These results were confirmed by the PERMANOVA and ANOSIM tests, which found no significant differences in diet between juvenile (0+) and 1-3 age group (G1) ($p \geqslant 0.05$). Again, no differences were found between juvenile (0+) and the 4-6 age group (G2), but small differences were found between the 1-3 age group (G1) and the 4-6 age group (G2) ($p = 0.045$). The MDS plot (Figure 7.7) support this conclusion for most *C. mhalensis* ages except fish aged 4+ which seemed to have shift their diet, this was probably a sampling artefact. Chlorophyceae, detritus, diatoms, Myxophyceae and plant material were the main food items consumed by *Cyprinion mhalensis* in all age groups (SIMPER test).

The diet of *Cyprinion mhalensis* varied between locations (except between AQ and AJ) and among seasons at some sites (Figure 7.8) and was confirmed by the PERMANOVA test ($p \leqslant 0.05$) and MDS analysis (Figure 7.9; bottom). For example, the diet of *Cyprinion mhalensis* in MD and AS during the spring (T3) was different from winter (T2) and summer (T1).

The prey items that contributed most to the differences in diet between locations (note order of items in the lists indicate level of contribution) were as follows:

- **Wadi Bouwa**: detritus (37.5%); Mastigophora (20.7%); Chlorophyceae (18.2%).
- **Wadi Turbah**: Chlorophyceae (45.9%); Bacillariaceae (24.9%); Myxophyceae (10.7%); detritus (8.5%); plant material (7.0%).
- **Al-Aqiq Dam**: detritus (41.9%); Chlorophyceae (28.7%); Myxophyceae (19.6%).
- **Medhaas Dam**: Chlorophyceae (28.8%); plant material (21.6%); detritus (14.4%); Myxophyceae (12.3%); unidentifiable algae (7.3%); Bacillariaceae (6.4%).
- **Thrrad Dam**: Bacillariaceae (31.8%); detritus (27.0%); Desmidiaceae (15.8%); Chlorophyceae (11.6%); Mastigophora (6.9%).
- **Al-Janabeen Dam**: Chlorophyceae (30.0%); detritus (25.0%); Myxophyceae (22.1%); Bacillariaceae (12.4%); plant material (8.6%).
- **Al-Sadr Dam**: detritus (52.4%); Chlorophyceae (31.1%); Bacillariaceae (10.8%).

The main food items for each season were:

- **T1 summer**: Chlorophyceae (50.1%); Myxophyceae (20.1%); detritus (17.0%); plant material (4.9%).
- **T2 winter**: Chlorophyceae (31.3%); detritus (26.2%); Myxophyceae (17.0%); plant material (8.7%); Mastigophora (6.3%); Desmidiaceae (3.2%).
- **T3 spring**: detritus (35.7%); Bacillariaceae (26.2%); Chlorophyceae (22.9%); Myxophyceae (6.5%).

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Cyprinion mhalensis* from different locations (Figure 7.10) indicated that most points were located in the lower-left side, which means some dietary items are eaten infrequently in most locations. However, in some sites (AQ, MD, AJ, TH, WB and WT) some prey points moved towards the lower right side which indicates a generalist feeding strategy. By contrast, detritus was the dominant food item at the AS site. To conclude, the major prey items for *Cyprinion mhalensis* are detritus, Chlorophyceae, diatoms, Myxophyceae.

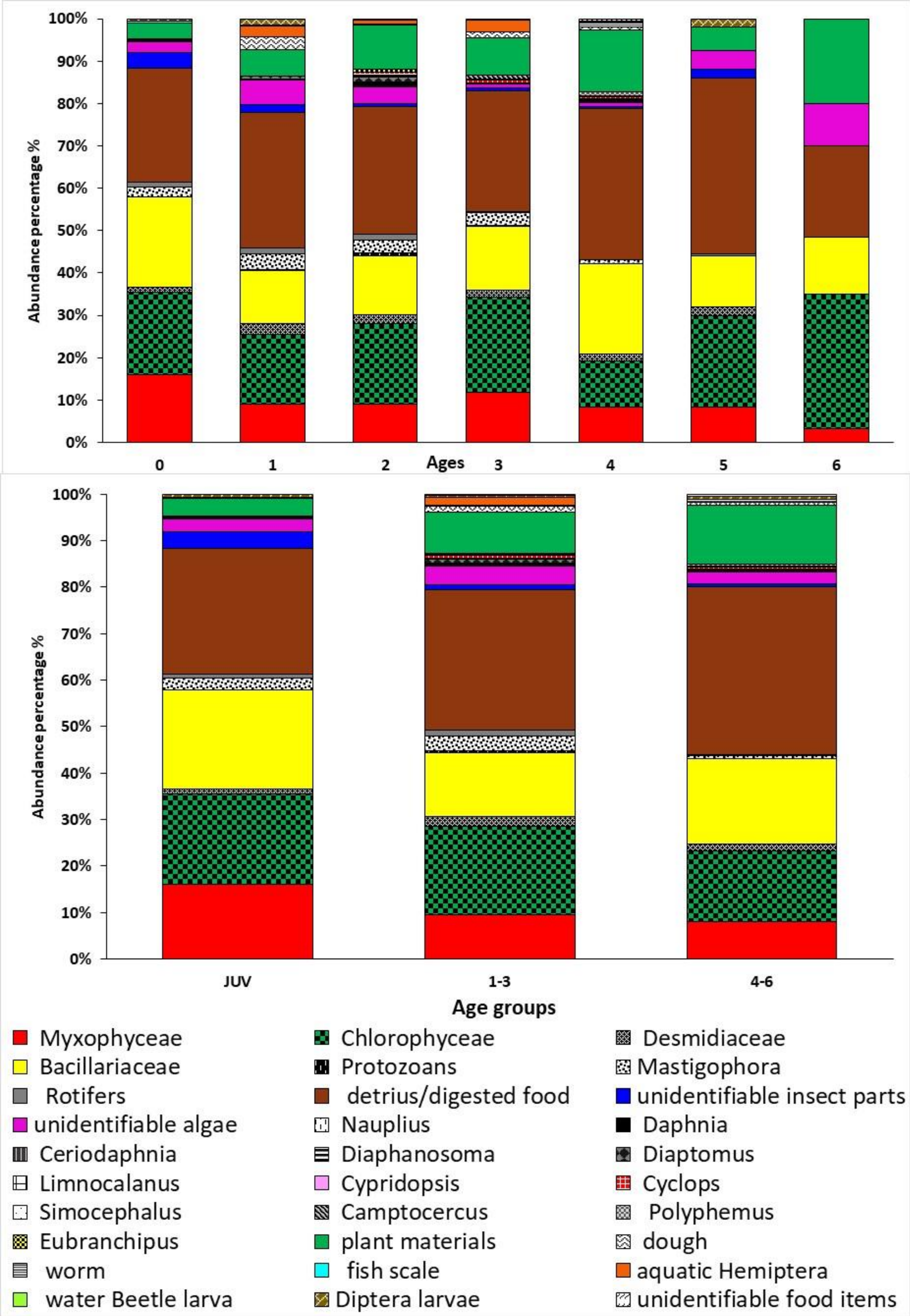


Figure 7.6. Variation in diet composition between each age (top) and age groups (bottom) of *Cyprinion mhalensis* based on values for all individuals from all sites in all seasons.

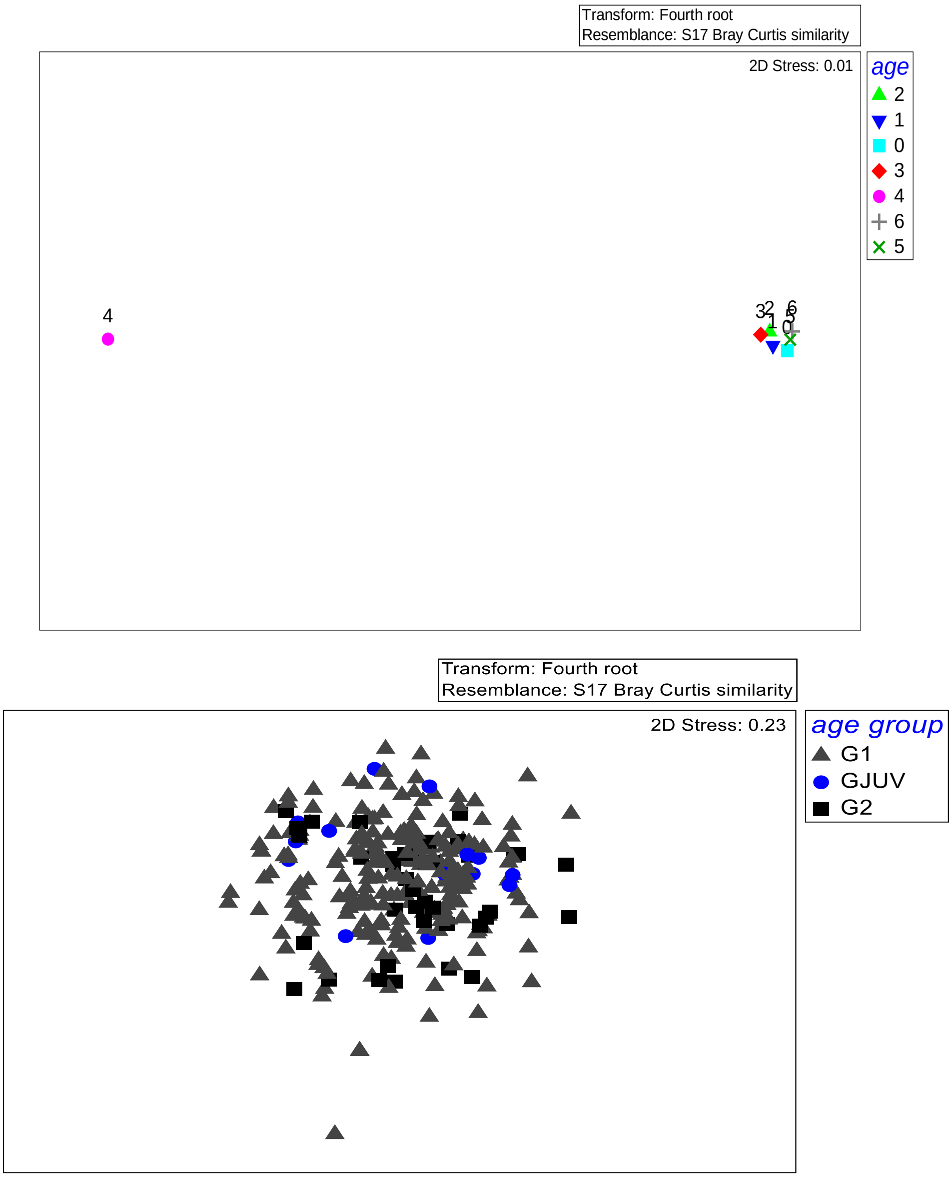


Figure 7.7. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition among age groups for *Cyprinion mhalensis* (GJUV = fish with 0+ age; G1 = age 1 to 3; G2=age 4 to 6) based on values for all individuals from all sites in all seasons.

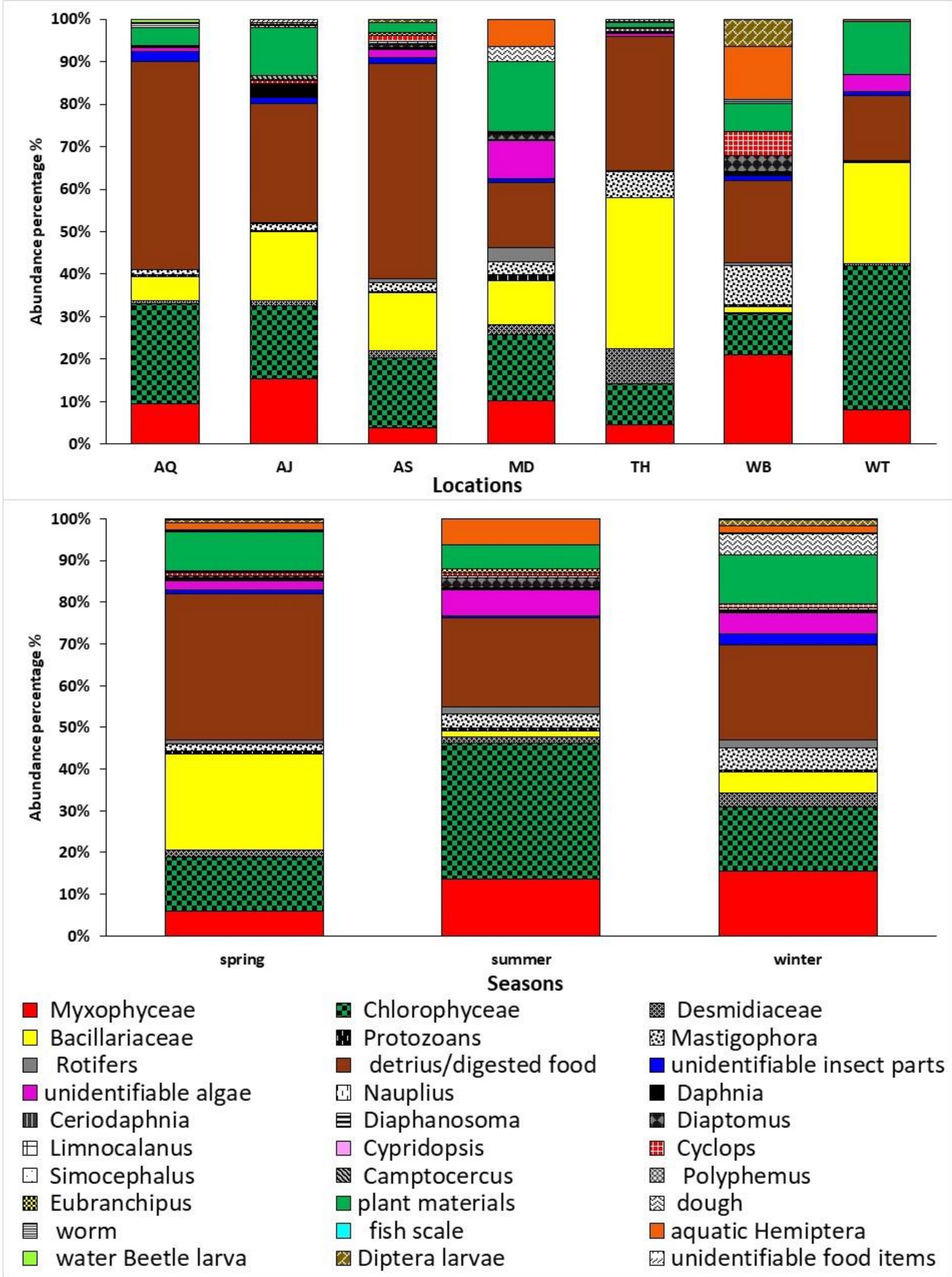


Figure 7.8. Variation in diet composition of *Cyprinion mhalensis* species between locations and seasons based on values for all individuals of all ages (WB = Wadi Bouwa; WT= Wadi Turbah; AS = Al-Sadr Dam; AQ = Al-Aqiq Dam; TH = Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam).

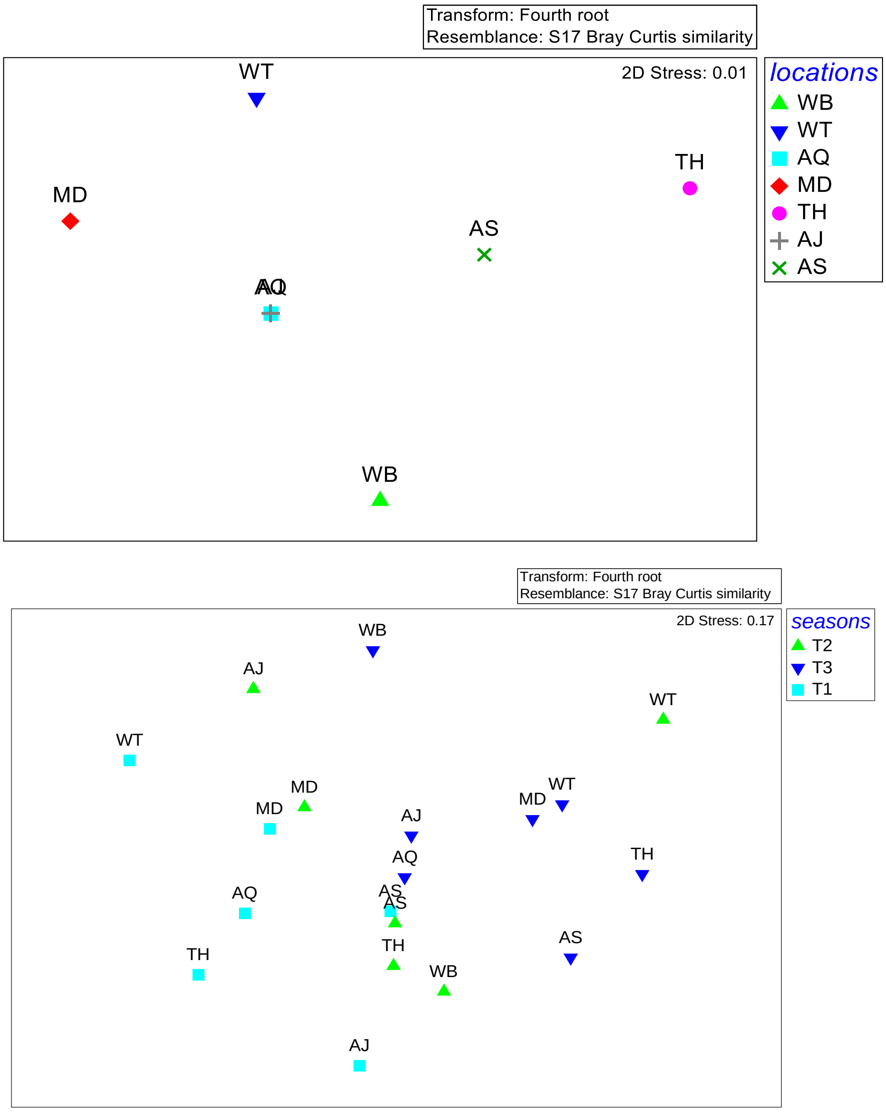


Figure 7.9. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition among locations (upper) and seasons (lower) for *Cyprinion mhalensis* (WB=Wadi Bouwa; WT= Wadi Turbah; AS = Al-Sadr Dam; AQ = Al-Aqiq Dam; TH =Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam. T1 = summer; T2 = winter; T3 = spring) based on all fish individuals of different ages combined.

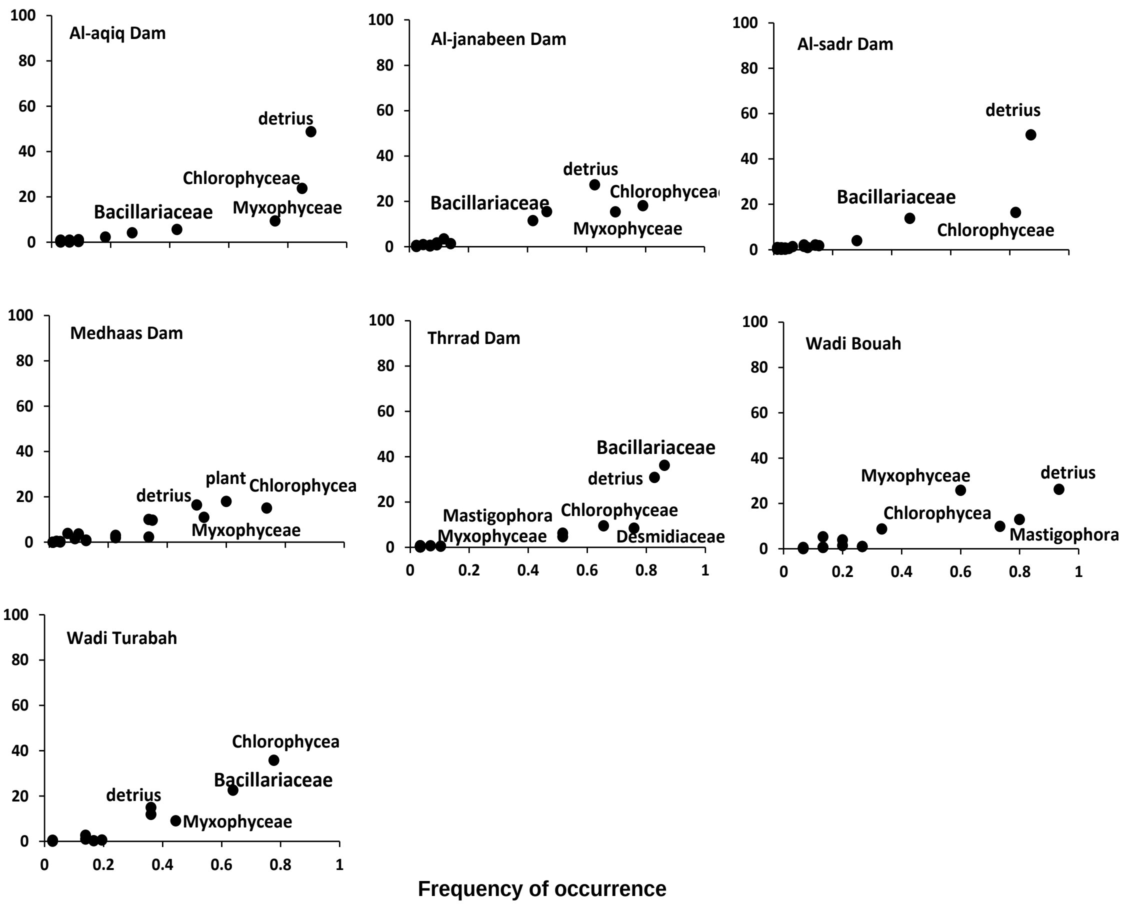


Figure 7.10. Prey-specific abundance graphs for *Cyprinion mhalensis* in different locations based on fish of all age groups and different seasons combined.

7.3.3 *Garra buettikeri* (GB)

There was considerable variation in diet between age groups in *Garra buettikeri* (Figure 7.11). There was as shift in diet from aufwuchs (unspecified food) and diatoms in the early age groups to Mastigophora in older age groups. Algae (Chlorophyceae; Myxophyceae) predominated in the diet of *Garra buettikeri* in all age groups. This species sometimes consumes zooplankton like *Cyclops* and rotifers, but in small quantities.

These results were confirmed by the PERMANOVA and ANOSIM tests, which found significant differences in diet between juvenile (0+) and the 5-7 age group (G2) ($p \leqslant 0.05$). Again, differences were found between the 1-4 age group (G1) and the 5-7 age group (G2), but no significant differences were found between juvenile (0+) and the 1-4 age group ($p = 0.275$). MDS analysis confirmed the dietary differences among *G. buettikeri* age groups (Figure 7.12). Chlorophyceae, Myxophyceae, Mastigophora, detritus (aufwuchs) and plant material were the main food items consumed by *Garra buettikeri* represented in all age groups (SIMPER test).

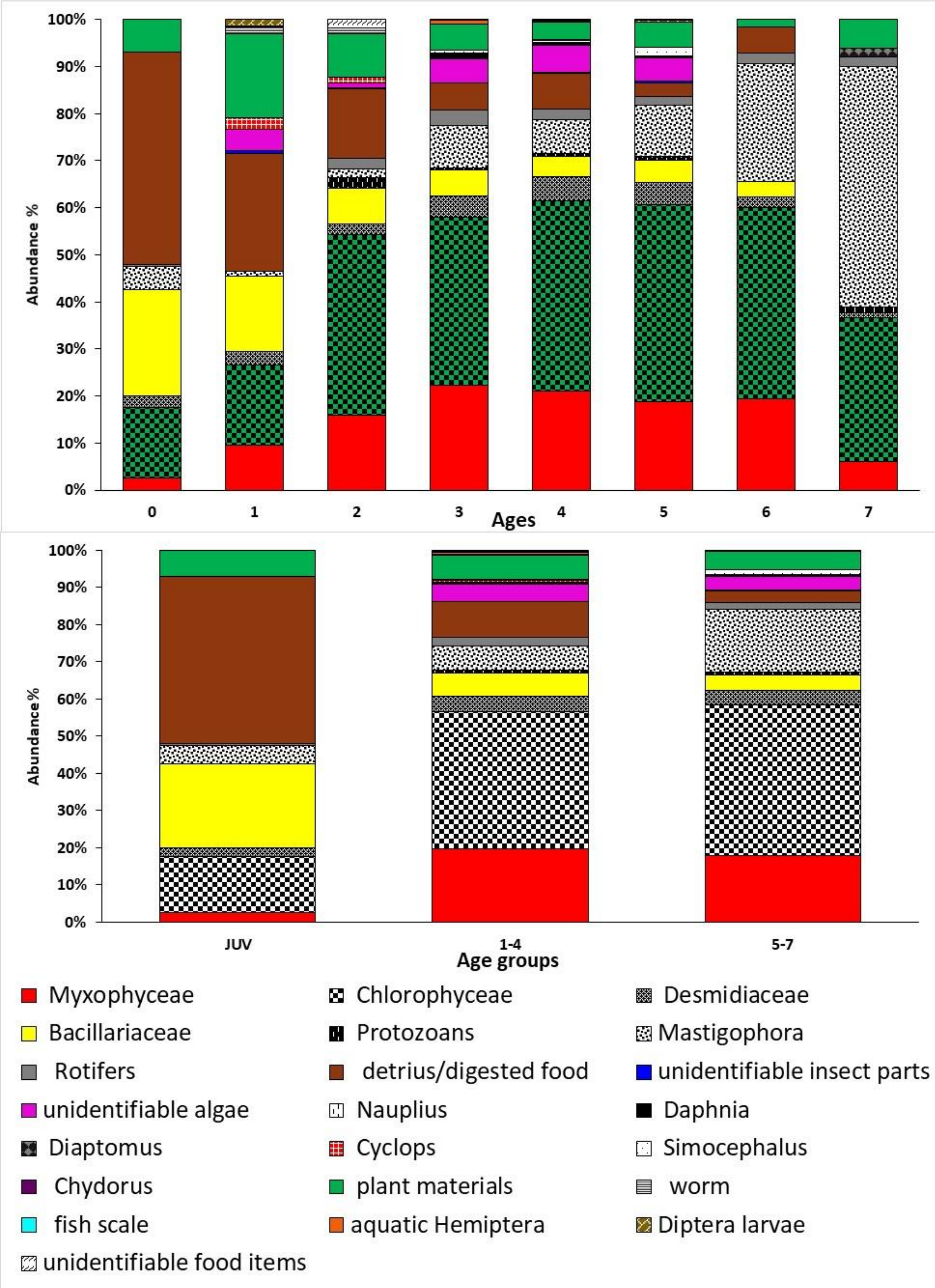


Figure 7.11. Variation in diet composition between each age (top) and age groups (bottom) of *Garra buettikeri* based on mean values for all individuals from all sites in all seasons.

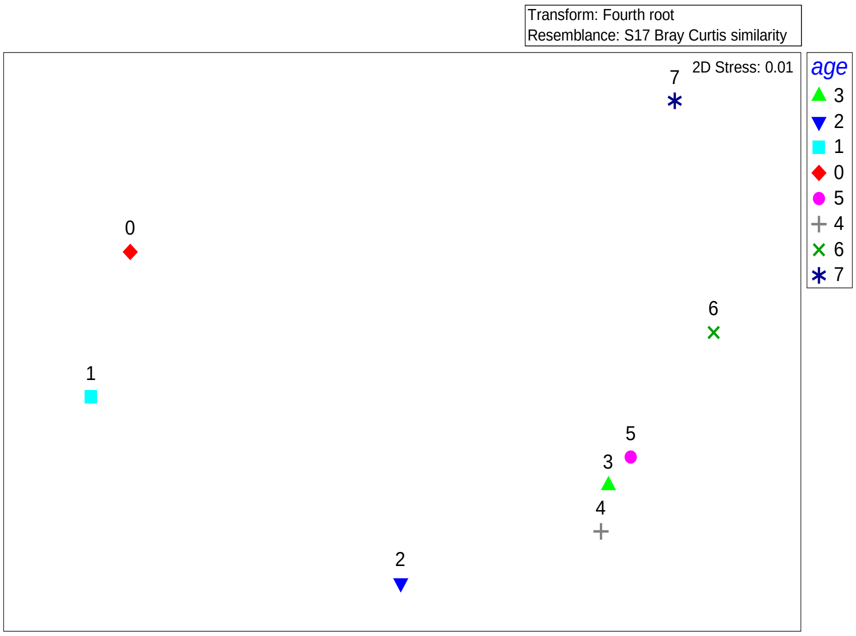


Figure 7.12. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations in diet composition among *Garra buettikeri* ages based on values for all individuals from all sites in all seasons.

The diet of *Garra buettikeri* was found to vary between locations (except between WB and WT) and among seasons (Figure 7.13) and was confirmed by the PERMANOVA test ($p \leqslant 0.05$) and MDS analysis (Figure 7.14) found diet differences among locations (except between WB and WT) and seasons. *Garra buettikeri* that inhabit wadis had a different diet than other members of this species in reservoirs. Variation in diet was also found between seasons at some but not all sites (Figure 7.14) (bottom), for example, diet *Garra buettikeri* in WT was different in all seasons and in WB during the winter (T2) the diet was different from summer (T1) and spring (T3).

The prey items that contributed most to the differences in diet between locations (note order of items in the lists indicate level of contribution) were as follows:

- **Wadi Bouwa**: Chlorophyceae (32.8%), plant material (20.3%); Myxophyceae (16.3%); aufwuchs (13.7%); Bacillariaceae (9.1%).
- **Wadi Turbah**: Chlorophyceae (36.7%); Bacillariaceae (22.6%); plant material (16.8%); aufwuchs (12.7%) Myxophyceae (9.1%).
- **Al-Aqiq Dam**: Chlorophyceae (64.2%); Myxophyceae (31.5%).
- **Medhaas Dam**: Chlorophyceae (41.8%); Myxophyceae (27.9%); Mastigophora (6.8%); unidentifiable algae (5.6%); plant material (4.4%); Bacillariaceae (4.2%).
- **Thrrad Dam**: Chlorophyceae (46.1%); Myxophyceae (25.9%); Mastigophora (21.7%).
- **Al-Janabeen Dam**: Chlorophyceae (49.8%); Myxophyceae (38.8%); aufwuchs (4.0%).
- **Al-Sadr Dam**: Chlorophyceae (32.1%); Myxophyceae (19.7%); Bacillariaceae (17.4%); Mastigophora (7.8%); aufwuchs (7.8%); rotifers (7.8%).

The main food items for each season were:

- **T1 summer**: Chlorophyceae (52.7%); Myxophyceae (31.2%); Mastigophora (4.4%); aufwuchs (3.9%).
- **T2 winter**: Chlorophyceae (36.2%); Myxophyceae (28.8%); Desmidiaceae (8.8%); Mastigophora (8.8%); plant material (5.8%); rotifers (3.5%).
- **T3 spring**: Chlorophyceae (48.6%); Myxophyceae (26.5%); Bacillariaceae (8.7%); Mastigophora (5.8%); aufwuchs (4.4%).

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Garra buettikeri* from different sampling locations (Figure 7.15) indicated that most points were located in the lower-left side, which means some dietary items are eaten infrequently in most locations. However, in some sites (MD, TH and WB) some prey points moved towards the lower right side which indicates a generalist feeding strategy. By contrast, Chlorophyceae was the dominant food item in the AQ and AJ sites. To conclude, the dietary items for *Garra buettikeri* are Chlorophyceae, Myxophyceae and Mastigophora.

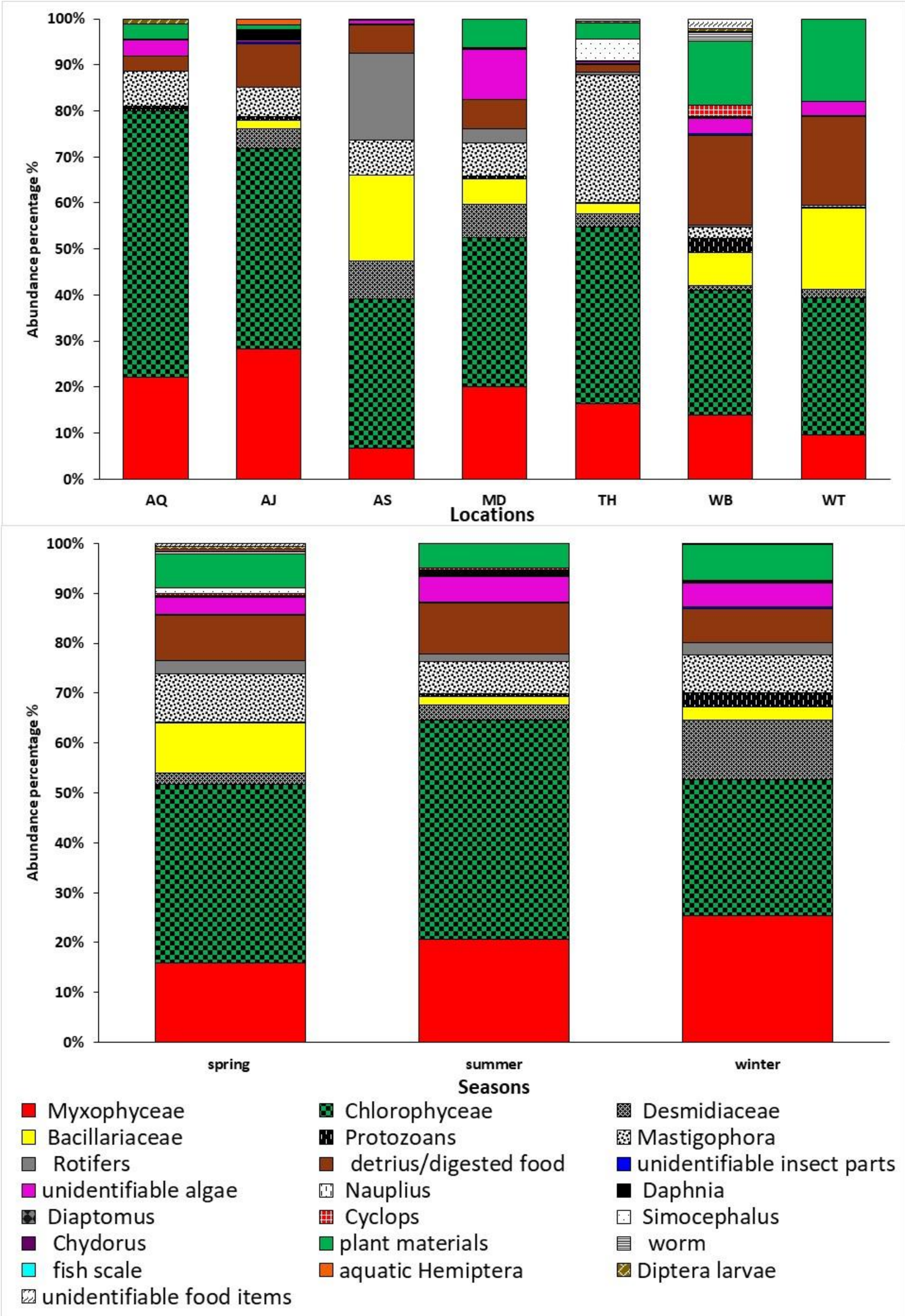


Figure 7.13. Variation in diet composition between locations (upper) and seasons (lower) based on mean values for all individuals of all ages in *Garra buettikeri* (WB = Wadi Bouwa; WT= Wadi Turbah; AQ = Al-Aqiq Dam; TH = Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam).

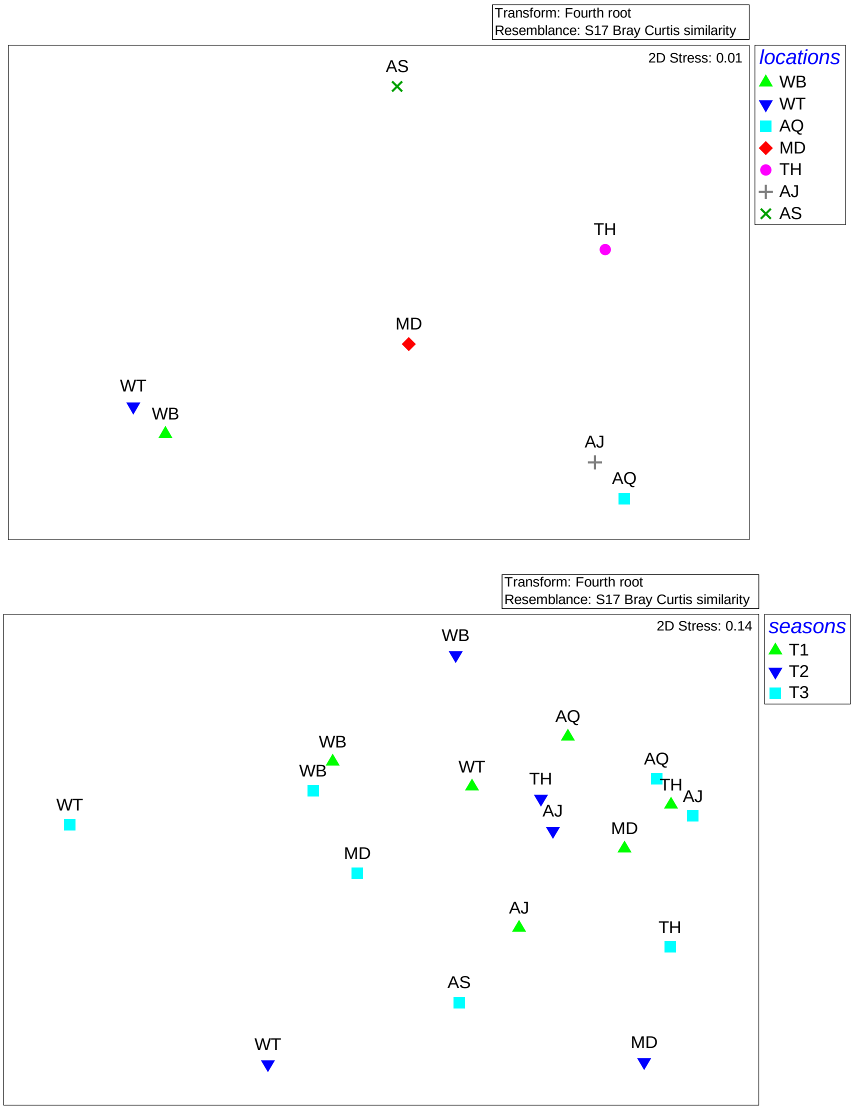


Figure 7.14. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition among location (upper) and seasons (lower) for *Garra buettikeri* (WB=Wadi Bouwa; WT=Wadi Turbah; AS= Al-Sadr Dam; AQ = Al-Aqiq Dam; TH = Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam.T1 = summer; T2 = winter; T3 = spring) based on all fish individuals of different ages combined.

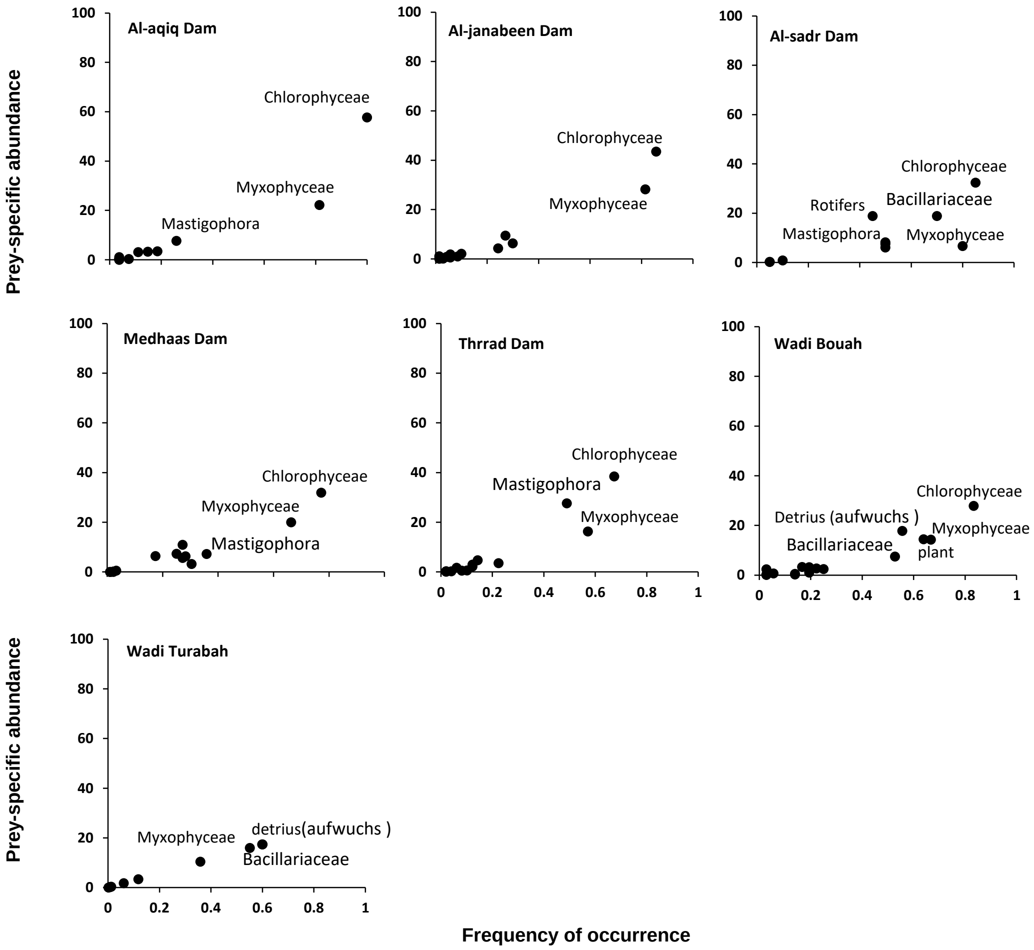


Figure 7.15. Prey-specific abundance graphs for *Garra buettikeri* in different locations based on fish of all age groups and different seasons combined.

7.3.4 *Oreochromis niloticus* (ON)

There is considerable variation in diet between age groups in *Oreochromis niloticus* (Figure 7.16). The diet of 0+ fish was significantly different than other age groups. There was as shift in diet from Chlorophyceae, *Cypridopsis* and plant material followed by blue-green algae, diatoms, Mastigophora and insect in the early age groups to Myxophyceae, plant material, Mastigophora and Chlorophyceae in older fish. *Oreochromis niloticus* rarely feeds on rotifers, Diptera larvae and crustaceans.

These results were confirmed by the PERMANOVA test, which found significant differences in diet between juvenile (0+) and the 1-3 age group (G1) ($p \leqslant 0.05$). Again, differences were found between juvenile (0+) and the 4-5 age group (G2), but no significant differences were found between the 1-3 age group and the 4-5 age group. MDS analysis (Figure 7.17) found diet differences among *Oreochromis niloticus* ages and age groups in the two sampling locations (Al-

Asfer Lake, Thrrad Dam). Myxophyceae, plant material and Mastigophora were the main food items consumed by *Oreochromis niloticus* represented in all age groups (SIMPER test).

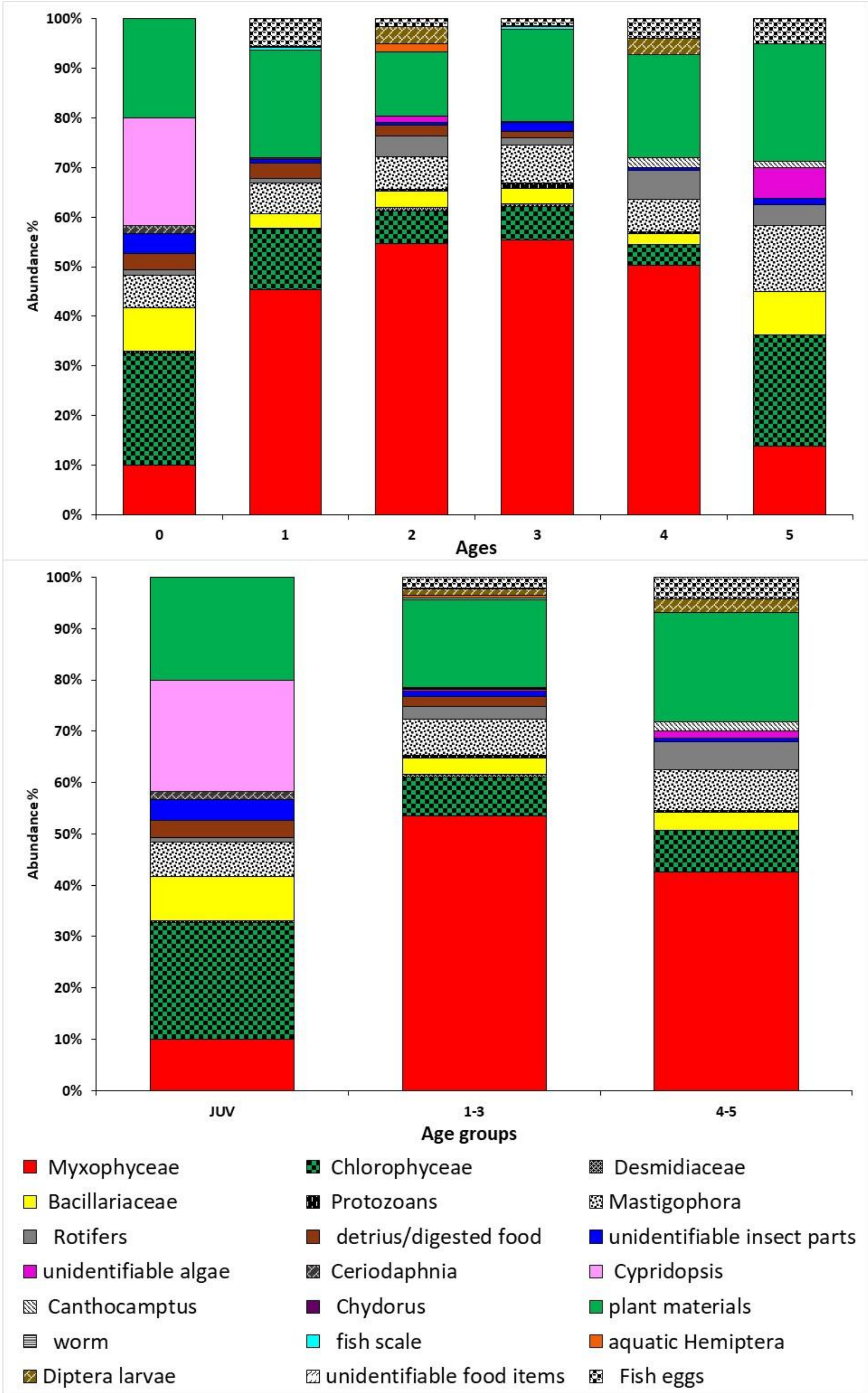


Figure 7.16. Variation in diet composition between each age (upper) and age groups (lower) of *Oreochromis niloticus* based on mean values for all individuals from all sites in all seasons.

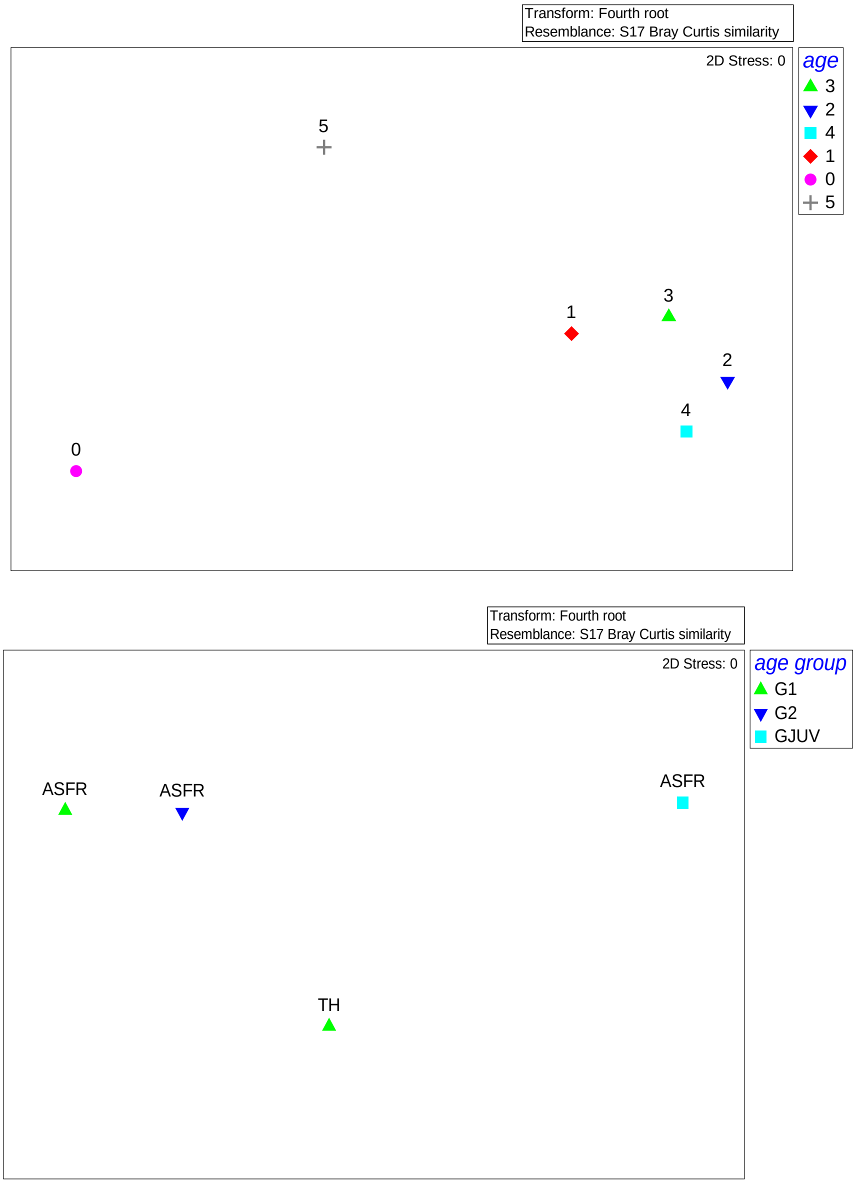


Figure 7.17. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition among each different aged (upper) and age groups (lower) of *Oreochromis niloticus* (G1= age 1 to 3; GJUV = fish with 0+ age; G2 = age 4 to 5; ASFR = Al-Asfer Lake; TH = Thrrad Dam) based on values for all individuals from all sites in all seasons.

The diet of *Oreochromis niloticus* varied between Al-Asfer Lake and Thrrad Dam sites and between seasons in Al-Asfer Lake ($p \leqslant 0.05$) (Figure 7.18), and was confirmed by the PERMANOVA test ($p \leqslant 0.05$) and MDS analysis (Figure 7.19). This species was only caught in Thrrad Dam in the spring (Trip 3) after a flash flood.

The prey items that contributed most to the differences in diet between locations (note order of items in the lists indicate level of contribution) were as follows:

- **Al-Asfer Lake**: Myxophyceae (56.2%); plant material (16.9%); Mastigophora (13.1%); Chlorophyceae (5.0%).

- **Thrrad Dam**: Myxophyceae (31.1%); Chlorophyceae (27.5%); Mastigophora (19.3%); plant material (17.0%).

The main food items for each season were:

- **T1 summer**: Myxophyceae (79.9%); Mastigophora (11.2%).
- **T2 winter**: Myxophyceae (62.3%); plant material (14.9%); Mastigophora (7.2%); Chlorophyceae (6.0%).
- **T3 spring**: plant material (29.1%); Myxophyceae (26.2%); Mastigophora (17.9%); Chlorophyceae (14.6%); Bacillariaceae (7.3%)

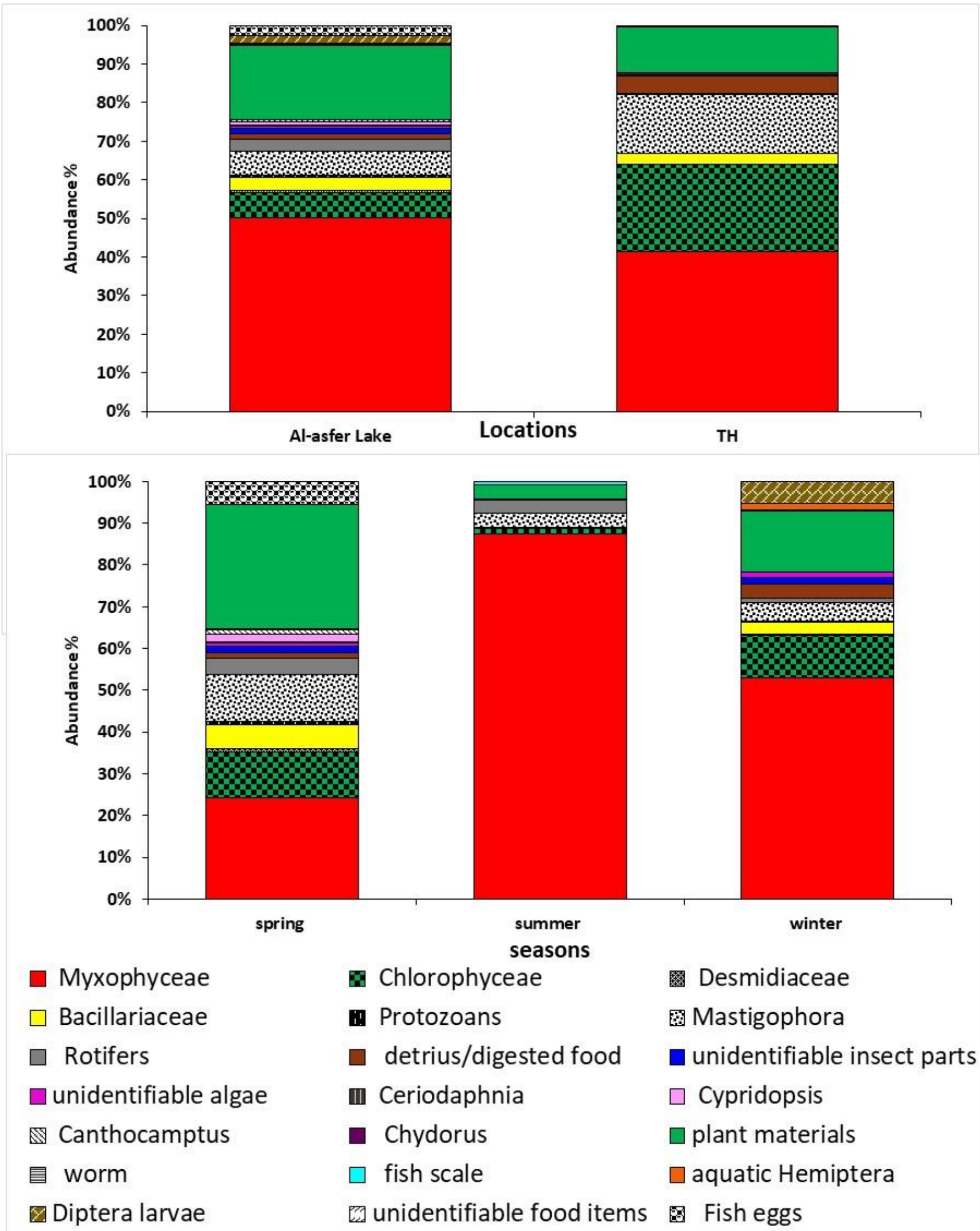


Figure 7.18. Variation in diet composition of *Oreochromis niloticus* between locations (upper) and seasons (lower) based on mean values for all individuals of all ages (TH = Thrrad Dam; ASFR = Al-Asfer Lake).

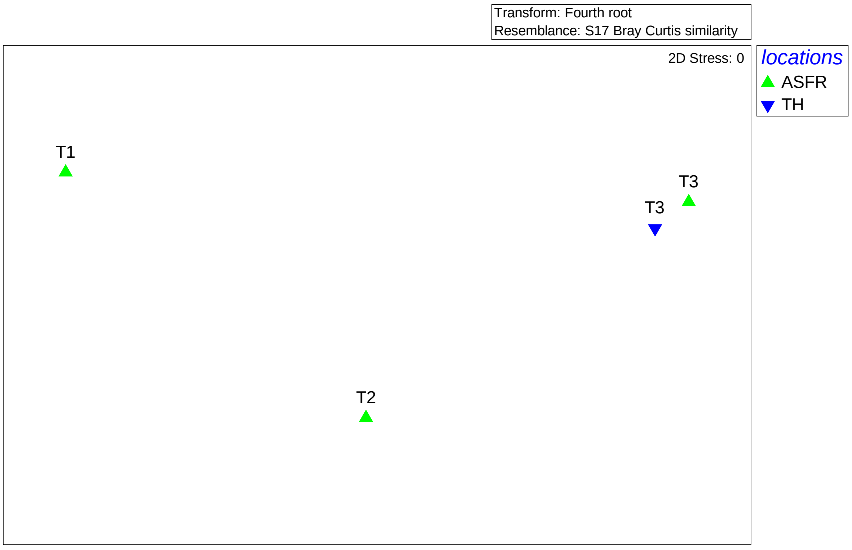


Figure 7.19 Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition between locations and season for *Oreochromis niloticus* (TH = Thrrad Dam; ASFR = Al-Asfer Lake.T1 = summer; T2 = winter; T3 = spring) based on all fish individuals of different ages combined.

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Oreochromis niloticus* from different sampling locations (Figure 7.20) indicated that most points were located in the lower-left side in Al-Asfer Lake, which means some dietary items are eaten infrequently in most locations. However, in Thrrad Dam most prey points moved towards the lower right side suggesting a generalist feeding strategy. Myxophyceae was the dominant food item in both sites, followed by plant material, Mastigophora and Chlorophyceae.

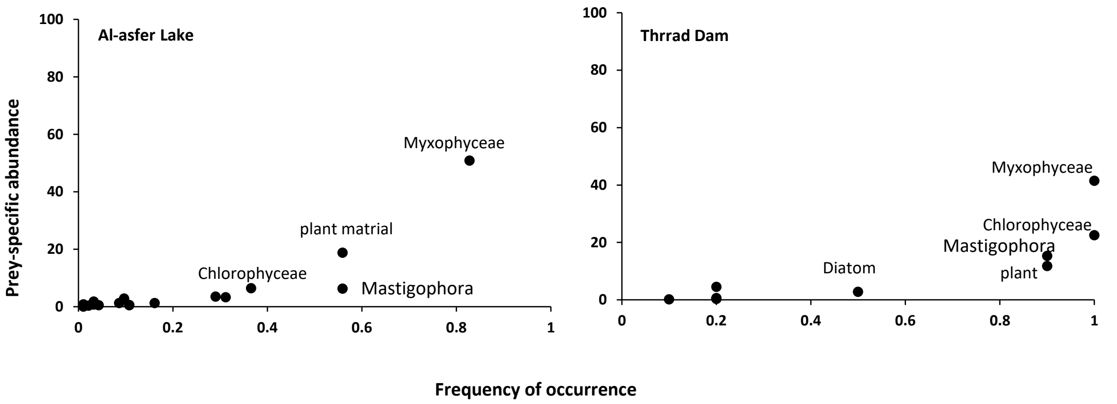


Figure 7.20. Prey-specific abundance graphs for *Oreochromis niloticus* in two locations based on fish of all age groups and different seasons combined.

7.3.5 Carassius carassius (CC)

Carassius carassius were only caught in Al-Janabeen Dam during winter and spring and only 4+, 5+ and 6+ year old fish were collected (Figure 7.21). No difference was found in the diet of *Carassius carassius* between ages or sampling seasons, but only five specimens were caught.

The main food items consumed by *Carassius carassius* were Chlorophyceae, Myxophyceae, plant material, insect, *Daphnia* and *Chydorus*.

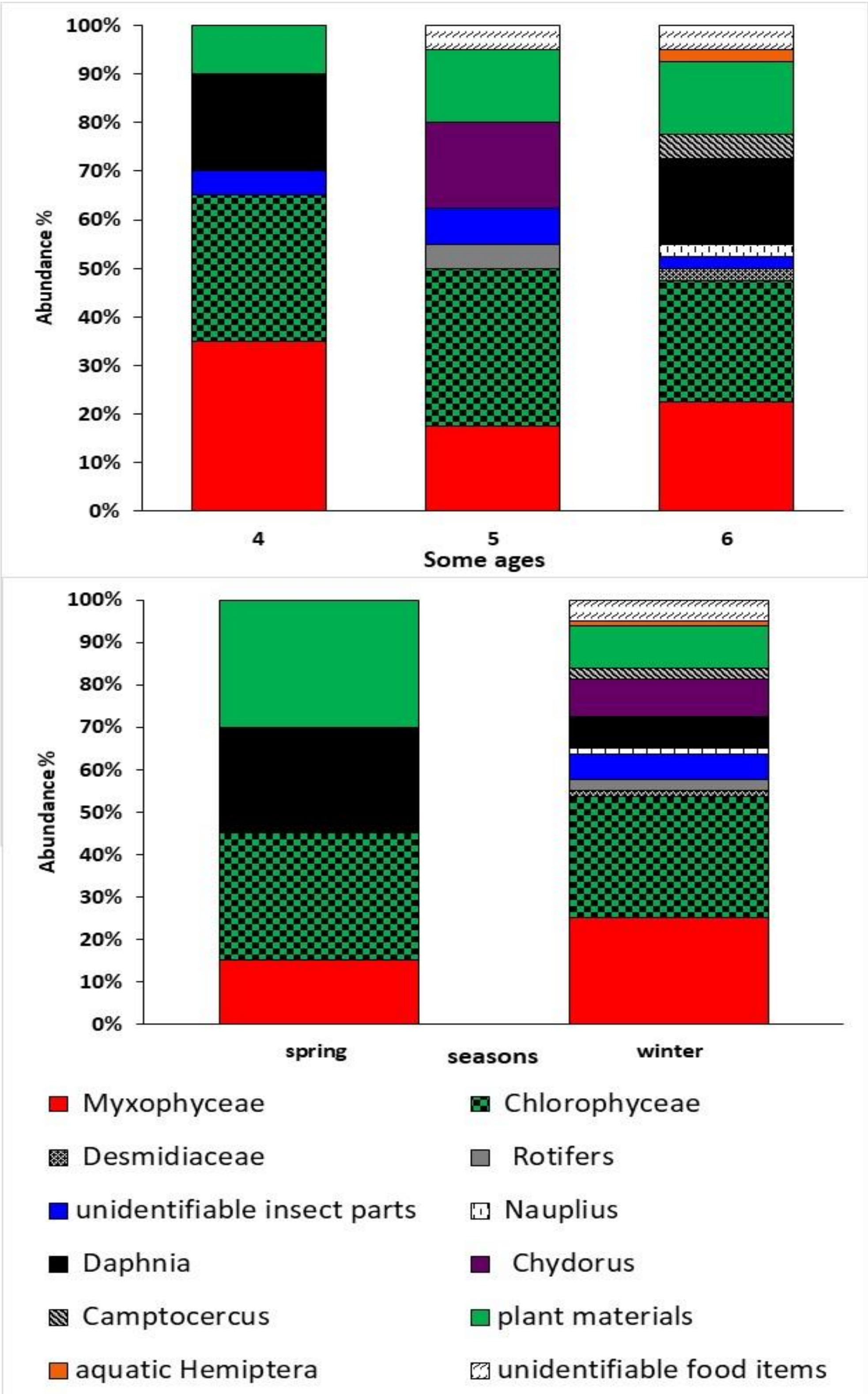


Figure 7.21. Variation in diet composition of *Carassius carassius* by age group and season.

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Carassius carassius* from Al-Janabeen Dam (Figure 7.22) indicated that most points were located in the lower right side which indicates a generalist feeding strategy. The major food items for *Carassius carassius* were Chlorophyceae, Myxophyceae, plant material, insect parts and Daphnia.

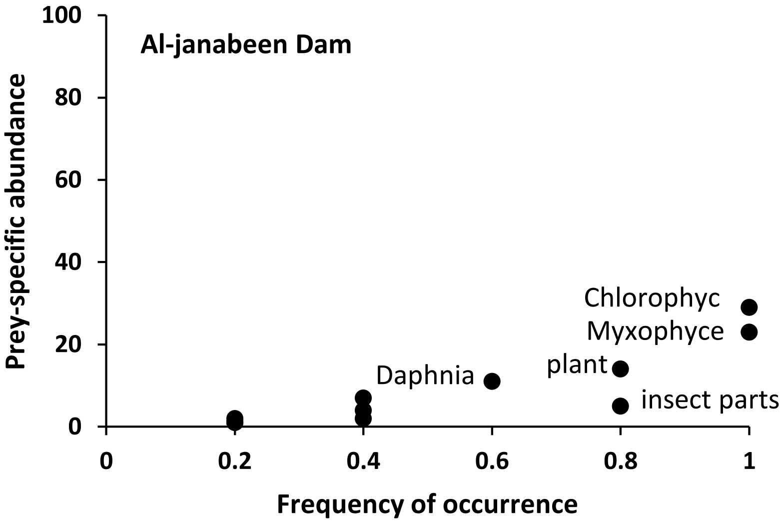


Figure 7.22. Prey-specific abundance graph for *Carassius carassius* in Al-Janabeen Dam based on fish of all age groups and different seasons combined.

7.3.6 *Poecilia latipinna* (Pl)

There was little variation in diet between 1+ and 2+ year old *Poecilia latipinna,* and no differences in diet between juvenile (0+) and 1+ fish (Figure 7.23). There was considerable variation in diet between the two sampling seasons (winter, spring), confirmed by the PERMANOVA test ($p \leqslant 0.05$). Bacillariaceae, Chlorophyceae, Myxophyceae, plant material, Mastigophora were the main food items consumed by *Poecilia latipinna* by all age groups (SIMPER test). *Poecilia latipinna* infrequently feeds on Rotifers, Desmidiaceae, insects and Protozoans.

The main food items for each season were:

- **T2 winter**: Myxophyceae (28.7%); Chlorophyceae (26.8%); plant material (21.3%); Bacillariaceae (7.8%); Desmidiaceae (5.6%).
- **T3 spring**: Bacillariaceae (30.2%); Chlorophyceae (22.4%); Myxophyceae (19.6%); plant material (14.1%); Mastigophora (10.2%).

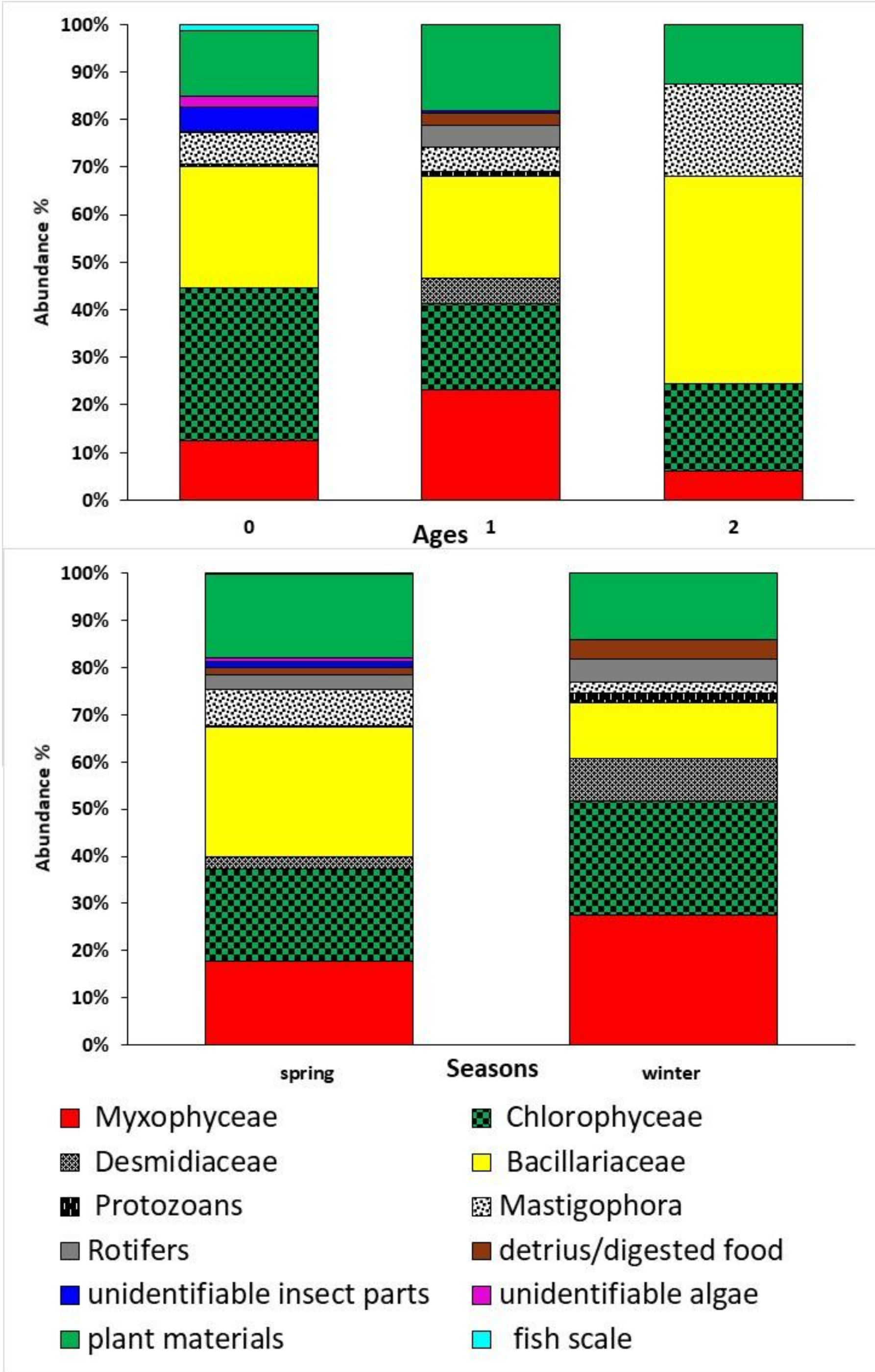


Figure 7.23. Variation in diet composition of *Poecilia latipinna* by age (upper) and season (lower).

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Poecilia latipinna,* which indicated that most points were located in the lower right side (Figure 7.24), which indicates a generalist feeding strategy. The major food items for *Poecilia latipinna* were Bacillariophyceae, Chlorophyceae, Myxophyceae and plant material.

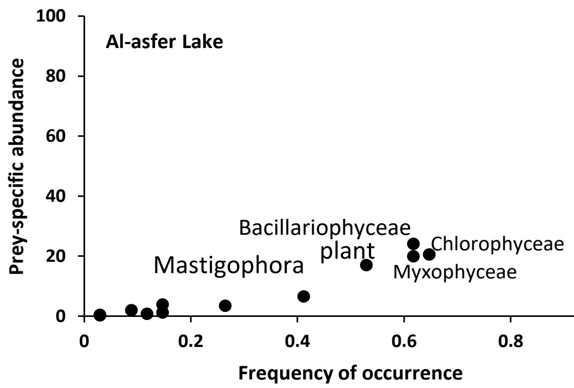


Figure 7.24. Prey-specific abundance graph for *Poecilia latipinna* in Al-Asfer Lake.

7.3.7 *Gambusia affinis* (GA)

Gambusia affinis only caught during spring season in Al-Asfer Lake in this study, fish of 1+ and 2+ age only found. There is no considerable variation in diet between those two ages (Figure 7.25). Fish of 1+ age feed on plant, insect, Diptera larvae and aquatic Hemiptera. While fish with age 2+ feed largely on plant and aquatic Hemiptera. These results were confirmed by the PERMANOVA and ANOSIM tests, which found no significant differences in diet between fish with 1+ age and fish with 2+ age ($p \geq 0.05$) ($p = 0.42$). However, the results of PERMANOVA show a small number of all possible permutations (<100), which means the results invalidate due to the samples was too small. Statistically, plant materials (39.8%), unidentifiable insect parts (33.3%), aquatic Hemiptera larvae (12.0%) and Diptera larvae (10.7%) were the main food items consumed by *Gambusia affinis* represented in all age groups (SIMPER test).

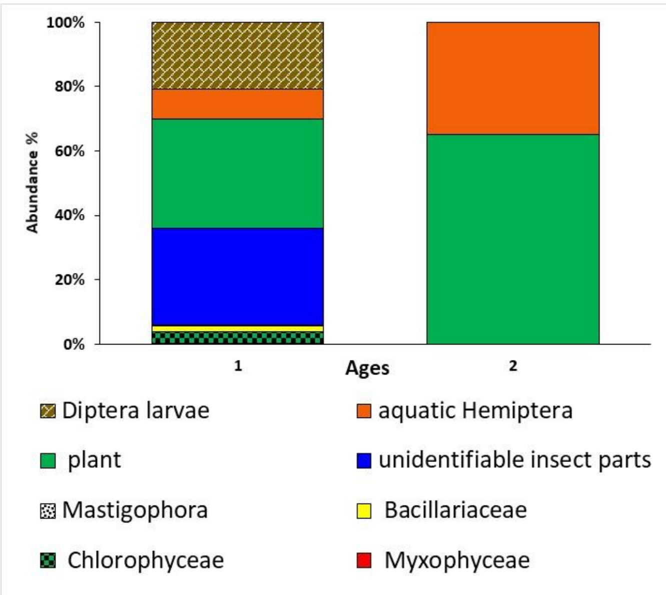


Figure 7.25. Variation in diet composition of *Gambusia affinis* in each age group.

Costello (1990) plots of prey-specific abundance plotted against the frequency of occurrence of prey for *Gambusia affinis* from Al-Asfer Lake (Figure 7.26) indicated that most points were located in the lower-left, which means some dietary items are eaten infrequently but, there was evidence of consuming plant material and insects points towards the lower right side, which indicates a generalist feeding strategy. The major prey's taxa for *Gambusia affinis* are plant material and Insects and they prey infrequently on Diptera larvae and aquatic Hemiptera larvae.

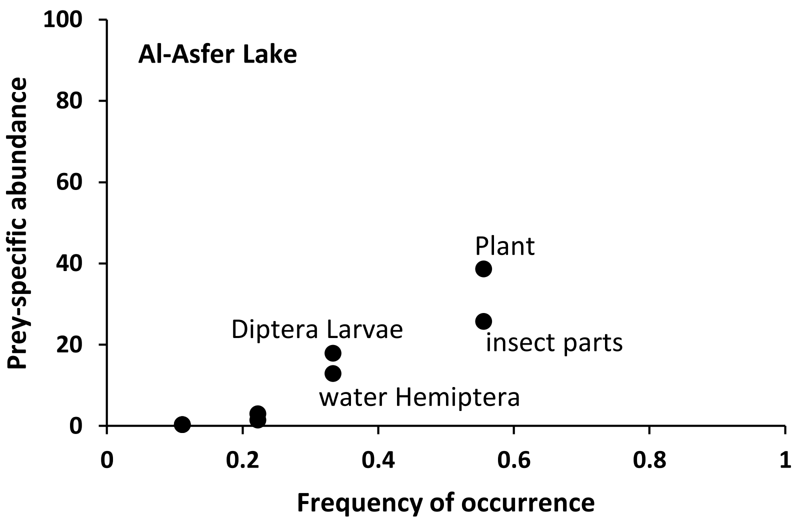


Figure 7.26. Prey-specific abundance graph for *Gambusia affinis* in Al-Asfer Lake.

7.3.8 Feeding interactions and dietary overlap between fish species.

There were significant differences in diet between the different fish species sampled across all sampling sites (PERMANOVA test; $p < 0.05$). Most fish species had a lot of detritus and plant material in their stomachs, but there were varying contributions of other materials, which suggests they may have distinct feeding strategies. This discrimination is shown in the Multidimensional scaling (MDS) plots which separated the species in terms of diet (Figure 7.27 upper panel) and across locations (Figure 7.27; lower panel), although some indication of overlap in diet was found at certain locations.

These differences were confirmed by ANOSIM (see Appendix C) and given the main items of diet are ubiquitous materials with some elements of specialism of diets, there is unlikely to be any food competition or food partitioning. However, further studies of abundance of various prey items in the habitat can be more illuminating as to whether or not competition for food occurs. It is noted that there was a possibility of food overlap between endemic species, as well as with non-native species in Al-Asfer Lake (Figure 7.27). For example, there appears to be some dietary overlap between *Cyprinion mhalensis* and *Carasobarbus apoensis* in Al-Sadr Dam and Wadi Turbah (Figure 7.27). Similarly, *Garra buettikeri* and *Cyprinion mhalensis* had similar diets in Wadi Turbah and Wadi Bouah, but their diets were different in most reservoirs, Thrrad Dam, Al-Aqiq Dam, Al-Janabeen Dam and Al-Sadr Dam. The diet of tilapia *Oreochromis niloticus,* a non-native species, appeared to overlap with *Carasobarbus apoensis* and *Garra buettikeri* in Thrrad Dam. The diet of *Carassius carassius* and *Carasobarbus apoensis* also overlapped somewhat in Al-Janabeen Dam. Most species that inhabit Al-Asfer Lake are non-native and considerable overlap in diet was found between *Oreochromis niloticus* and *Poecilia latipinna*.

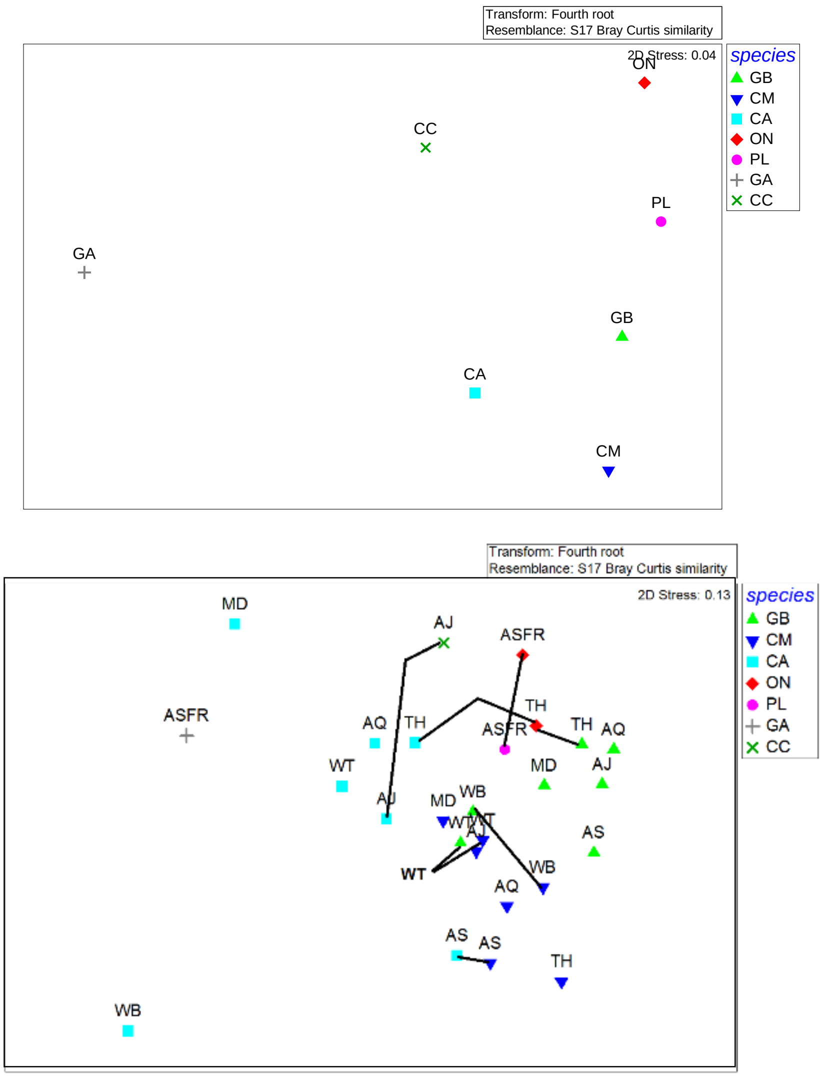


Figure 7.27. Non-metric multidimensional scaling (MDS) ordination plots illustrating variations In diet composition showing differences in diet between each species (upper) and species across locations (lower) (WB = Wadi Bouwa; WT = Wadi Turbah; AS = Al-Sadr Dam; AQ = Al-Aqiq Dam; TH = Thrrad Dam; AJ = Al-Janabeen Dam; MD = Medhaas Dam; ASFR = Al-Asfer Lake.GB = *Garra buettikeri*; CM = *Cyprinion mhalensis*; CA = *Carasobarbus apoensis; ON = Oreochromis niloticus; PL = Poecilia latipinna; GA = Gambusia affinis*). Lines drawn between any two point reflect how closely related the diet of different species sharing the same location are based on ANOSIM R values.

7.3.9 Saudi freshwater fish feeding guilds classification

Based on the above information, an attempt was made to classify Saudi freshwater fish into trophic guilds (Table 7.1). In general, all species are omnivorous/detritivorous. *Carasobarbus apoensis* consumes a wide variety of food types during its life, including plant material, insects, plankton, crustaceans and fish and is classed as omnivorous. *Cyprinion mhalensis* mainly ingests detritus and phytoplankton, especially Chlorophyceae and Bacillariophyceae, and phytobenthic Bacillariophyceae, and is classed as omnivorous/detritivorous. *Garra buettikeri* has a high proportion *of* phytoplankton, aufwuchs and some zooplankton and is classified as planktivore/benthivore. *Oreochromis niloticus* consumes phytoplankton (especially blue green algae), plant material and some zooplankton and insects and is classed as herbivore/omnivore. *Poecilia latipinna* feeds on Bacillariaceae, Chlorophyceae, Myxophyceae, plant material, Mastigophora and infrequently on rotifers, Desmidiaceae, insect and Protozoa, and is classed as planktivore/omnivore. *Gambusia affinis* consumes a variety of food items, but mainly plant material, insects, Diptera larvae and aquatic Hemiptera, and is categorised as omnivore. *Carassius carassius* consumes Chlorophyceae, Myxophyceae, plant material, insects, *Daphnia* and *Chydorus*, and is classed as planktivore/omnivore.

Table 7.1. Feeding guilds of some Saudi freshwater fishes.

SPECIES	Guild	Feeder descriptions	Mouth shape and position
CARASOBARBUS APOENSIS	Omnivores	Feeds on a wide range of flora and fauna	Terminal
CYPRINION MAHALENSIS	Detritivore-Omnivore	Contains a high proportion of detritus and planktons	Terminal-horny sheath on the lower lip
GARRA BUETTIKERI	Planktivore Benthivore	Contains a high proportion of phytoplankton, aufwuchs and some zooplankton	Sub-terminal; Mental disc present on ventral surface of the head
OREOCHROMIS NILOTICUS	Herbivores Omnivore	Contains a high proportion of phytoplankton (especially blue green algae), plant material and some zooplankton and insects.	Terminal
POECILIA LATIPINNA	Planktivore Omnivore	Contains a high proportion of phytoplankton, plant material and some zooplankton	Upturned mouth; Superior
GAMBUSIA AFFINIS	Omnivore	Feeds on a wide range of flora and fauna	Superior
CARASSIUS CARASSIUS	Planktivore Omnivore	Diet contains phytoplankton, zooplankton, plant material and insect.	Terminal

7.4 Discussion

The current study explored the feeding ecology of three indigenous and four non-native species in an array of water body types. With the exception of *Garra buettikeri*, all species are omnivorous, with varying degrees of specialism towards planktivorous, herbivorous or detritivorous diet, depending on age; *Garra* is essential a planktivorous/benthivorous species (Table 7.1). There is evidence that species alter their feeding habitats with age/size and locations, the latter probably reflecting the habitat quality and food resources available in the different water bodies.

7.4.1 Ontogenetic shifts in diet

Carasobarbus apoensis consume a wide variety of food items during its life but shifts from a predominance of Chlorophyceae supplemented by Coleoptera and Diptera larvae and some crustaceans in the early life to being essentially herbivorous as the fish get older. This shift in diet is consistent with the feeding ecology of a closely related species, *Arabibarbus arabicus,* in Beesh Reservoir in south-western Saudi Arabia (Hakami et al., 2013) but contrasts with the diet of another closely related species, *Carasobarbus canis,* dwelling in streams and lakes of the Jordan which consume mostly invertebrates and small fish (Krupp et al., 1989). This ontogenetic shift in diet could be related to differences in physiological and biological requirements of the fish as they grow and due to existence of environmental fluctuations and food supply.

Again, differences were found, although less so, between age groups of *Cyprinion mhalensis* which consume mostly detritus and phytoplankton, especially Chlorophyceae and Bacillariophyceae, and some zooplankton while young but mostly phytoplankton when older. Ahmad et al. (2013) similarly found *Cyprinion mhalensis* to feed mainly on phytoplankton, specifically diatoms, but found no shift in diet with age. Al-Kahem et al. (1988), by contrast, found smaller *Cyprinion mhalensis* to generally feed on zooplankton while adults mostly consumed phytoplankton. The difference in ontogenetic shifts in diet of *Cyprinion mhalensis* between this study and that of Ahmad et al. (2013) could be related to differences in spatial and temporal availability of prey items in the habitats of fish.

The diet of *Garra buettikeri* is predominantly phytoplankton (Chlorophyceae; Myxophyceae) and detritus throughout life, although small quantities of zooplankton, like *Cyclops* and rotifers, are eaten especially by smaller fish. Krupp et al. (1989) and Hamidan (2016) described the diet of the closely related species *Garra ghorensis* and *Garra rufa* as almost entirely based on algae, with some unspecified aufwuchs. These species, like *Garra buettikeri,* have a mental disc present on the ventral surface of the head, which they employ for grazing algae from stones and vegetation. They also dwell mostly on the substrate. Marginal shifts in the diet of *Garra buettikeri* were found with age, with the younger age groups having small quantities of zooplankton in the diet. Yalcin-Ozdilek & Ekmekci (2006) found a similar shift in *Garra rufa* with age which predominantly feed on benthic phytoplankton, but consume rotifers and protozoa in the younger age groups.

The diet of non-native species *Poecilia latipinna*, *Carassius carassius*, *Gambusia affinis* and *Oreochromis niloticus* are commonly known elsewhere globally (Fishbase.org) and will be largely compared with other studies as sample sizes and distribution are limited in this study.

Oreochromis niloticus shift their diet from Chlorophyceae, *Cypridopsis* and plant material to Myxophyceae, plant material, Mastigophora and Chlorophyceae in older fish. This species is considered to be herbivorous (Webster & Lim, 2006), but Njiru et al. (2004) also found insects and fish in stomachs suggesting it is able to adapt its feeding habitats to exploit other food sources, a trait that probably contributes to its success as an invasive species. Getachew (1993, 1987) also found *Oreochromis niloticus* can shift its feeding habits depending on factors that affect primary production and the diet directly or indirectly.

The diet of *Carassius carassius* was largely Chlorophyceae, Myxophyceae, plant material, insect, *Daphnia* and *Chydorus*, but shift in diet with age could not be conclusively determined because only older fish (five specimens caught in Al-Janabeen reservoir) were examined. Penttinen & Holopainen (1992) examined the seasonal feeding activity and ontogenetic dietary shifts for this species and found that the diets of four size classes in the summer comprised of differing extents of planktonic and benthic arthropods, including Odonata in the largest individuals. Chironomid larvae were consumed even by the smallest fish examined, albeit planktonic Cladocera were favoured by this size class. Benthic Cladocera were missing from the diets of fish greater than 10 cm. The authors concluded that habitat segregation between size groups changed in relation to the shift in benthic food items.

The diet of *Poecilia latipinna* largely contains Bacillariaceae, Chlorophyceae, Myxophyceae, plant material and Mastigophora, and is considered a planktivore. Some other studies also found that algae was the main dietary component, but the species also consumes rotifers, small crustaceans, such as copepods and ostracods, and aquatic insects (Yamamoto & Tagawa , 2000; Williams et al., 2009; Ray & Robins, 2016) . There was little variation in diet between 1+ and 2+ year old *Poecilia latipinna*, and no differences in diet between juvenile (0+) and 1+ fish. Al-Kahem et al. (2007), studying the feeding ecology of *Poecilia latipinna* in Wadi Haneefah, considered the species to be herbivorous, feeding on green and blue-green algae, with no food of animal origin and found no notable difference in the diets of fish of different sizes, which is concurs with the findings of this study. It therefore appears the species is able to adapt its diet to available resources, again contributing to its success as an invasive species.

Gambusia affinis was only caught during the spring in Al-Asfer Lake and its diet was omnivorous, feeding on plant material, insects, Diptera larvae and aquatic Hemiptera. Some other studies similarly described *Gambusia affinis* as omnivorous, consuming zooplankton, small insects and detritus, but also as an aggressive predator feeding on eggs, young fish and small adults of other fish species (Man & Hodgkiss, 1981; Etnier & Starnes, 1993; Johnson, 2008). The findings of the current study in relation to the diet of the *Gambusia affinis* concur with Garcia-Berthou (1999) who reported an ontogenetic shift in the diet of this species from predominantly microcrustaceans (Cladocera) to nematodes, which are larger prey items, in addition to seasonal and sampling site variations. This makes sense from the energetic point of view as organisms naturally need to take larger prey items to satisfy the higher energy demand as they grow (Gerking, 2014). Importantly, this fish does not favour mosquito larvae when other food sources are available (Johnson, 2008), questioning its utility in controlling mosquito larvae in biological control programmes.

7.4.2 Dietary variations between locations

Considerable variation was found in the diet of the indigenous species between waterbodies. These species potentially adapt their feeding strategies in relation to the habitat type, environmental conditions, such as water flow, depth, vertical visibility and primary production, temperature variations and chemical properties, and food availability. However, these differences must be perceived from the context that sample sizes and size classes of fish varied between sample location (see Appendix F), which may limit the scope of interpretation.

The diet of *Carasobarbus apoensis* was distinct in Wadi Bouwa (WB), Al-Sadr Dam (AS) and Medhaas reservoir (MD) compared with other sites. These differences were probably related to differences in habitat type where the fish been caught. Wadi Bouwa WB is a series of ponds exposed to drought conditions and linked by streams in the rainy season. Samples of *Carasobarbus apoensis* were collected in the nearest pool closest to the access point where fish were found, and most *Carasobarbus apoensis* caught were less than 7 cm long (juveniles). The dietary composition was mostly insect larvae and zooplankton, which is different from the plant-based foods elsewhere. The diet of *Carasobarbus apoensis* in Al-Sadr dam was mostly phytoplankton with little contribution of aquatic macrophytes, typically found elsewhere. Furthermore, the reservoir is impacted by agricultural wastes from nearby farms that cause eutrophication and loss of macrophytes (Greenhalgh & Ovenden, 2007). Detritus and bread dough (from angling) were also important components in the diet of *Carasobarbus apoensis* from this site. The diet of *Carasobarbus apoensis* from Medhaas Dam was distinctive, probably because habitat had been altered after an enormous rain and flash flood in spring, washing out all macrophytes.

Considerable variation in diet of *Cyprinion mhalensis* was found between sites, probably linked to whether the fish were caught its preferred habitat of flowing water or not. *Cyprinion mhalensis* is an omnivorous species that favours detritus, Chlorophyceae and diatoms (Ahmad et al., 2013), but no similarity was found between sites, except between Al-Aqiq and Al-Janabeen dams, which had a high proportion of Chlorophyceae and detritus.

Again, considerable differences were found in the diets of *Garra buettikeri* inhabiting wadis those dwelling in reservoirs. Chlorophyceae was the main dietary item at all sampled locations, but blue-green algae were also important in Al-Aqiq, Al-Janabeen and Medhaas dams, Mastigophora in Thrrad Dam, rotifers in Al-Sadr Dam and aufwuchs in Wadi Bouwa and Wadi Turbah. It is likely that food availability in relation to the habitat structure contributed these differences. *Garra buettikeri* is a benthic feeder grazing on Chlorophyceae, which is probably more abundant in shallow wadis than deeper reservoirs.

The diet of *Oreochromis niloticus* occupying Thrrad Dam was similar to caught those in Al-Asfer Lake, despite fish from Thrrad Dam only being caught in the spring after severe floods. This was a little surprising, as Al-Asfer Lake is highly eutrophic being loaded with agricultural wastes and fertilisers and there is an abundance of blue-green algae, which this species is able to digest.

Habitat type and seasonal variations in water quality and quantity seem to explain the variability in diet of the different species between sites. Specifically, the shallow depths of wadis compared to reservoirs and lakes, and the flushing effects of floods in wadis possible alter the availability of food for the fish present, end for example the growth of aquatic macrophytes and benthic algae, which several native species (*Cyprinion mhalensis* and *Garra buettikeri*) prefer to forage on. Agricultural wastes and drainage of waste water could seep into lakes also creates eutrophic condition that likely impacts on the dietary composition, especially of invasive species like *Oreochromis niloticus.*

7.4.3 Dietary variations between seasons

Some seasonal variation in diets was found in different species, but in general the diets are more similar between seasons in the same water bodies than between water bodies. The small differences found were probably linked to shifting environmental conditions, especially in wadis following floods and as a result of heavy drawdown in reservoirs. For example, *Carasobarbus apoensis* caught in Medhaas Dam at spring after a flash flood consumed mostly plant material (97%), whereas a wider variety of foods was consumed in the other seasons. Similarly, the diet of *Garra buettikeri* in Medhass Dam in spring was different from the summer and winter diets.

7.4.4 Dietary overlap between species

Comparison of the diets of different species provides an indication a potential feeding niche overlaps between species, and particularly to determine if non-native species may potentially impact on native fish species (Gozlan et al., 2010). In the majority of cases there was significant differences in diet between the different fish species sampled across all sampling sites. Most fish species had a lot of detritus and plant material in their stomachs, but there were varying contributions of other food items, which suggests they may have distinct feeding strategies. This discrimination is shown in the MDS plots, which separated the species in terms of diet and across locations, although some indication of overlap in diet was found at certain locations, e.g. between *Cyprinion mhalensis* and *Garra buettikeri* in Wadi Turbah and Wadi Bouah, but not in reservoirs. The probable reason for this overlap was that *Cyprinion mhalensis* and *Garra buettikeri* are both benthivorous and occupy the same resource space, especially in wadis that are characterised by their shallowness and limited space. Similarly, there was some overlap between *Cyprinion mhalensis* and *Carasobarbus apoensis* in Al-Sader Dam and Wadi Turbah; these species are omnivores feeding on a wide range of food items but in this case they both consumed mainly detritus, Chlorophyceae and macrophytes.

Little overlap in diets was found between Saudi native species (*Carasobarbus apoensis, Cyprinion mhalensis* and *Garra buettikeri*) and non-native species (*Oreochromis niloticus*, *Poecilia latipinna*, *Gambusia affinis* and *Carassius carassius*), and where it was observed it was largely food items in abundant supply such as detritus and benthic algae. It is also unlikely that direct competition will be observed in the present study because non-native species occupy different water bodies (artificial lakes) to native species (wadis and reservoirs). However, care must be taken to avoid the introduction of non-natives into the natural water bodies, either through escape from fish farms (*Oreochromis niloticus*) or introduce to control disease vectors (*Poecilia latipinna* and *Gambusia affinis*).

7.4.5 Conclusions

The dietary studies provided valuable information about the feeding habits of native and non-native fish species in Saudi Arabia and how foods consumed varied between species, habitat types, size/age of fish species and with season. All species were found to be omnivorous, with varying degrees of specialism towards planktivorous, herbivorous or detritivorous diet, with the exception of *Garra buettikeri*, which is a planktivorous/benthivorous species.

Differences in diets were found between locations and seasons for the three native species, and these were concluded to be related to variability of environmental conditions and approximation to the preferred habitat type of the species. The ability of the species to shift their diets probably reflects the adaptability and resilience of each species and their capacity to tolerate adverse conditions in Saudi freshwater bodies because of the extreme climate conditions experienced. Ontogenetic shifts in diet were found among the three native species examined, but the small individual sizes of two of the non-native species *Poecilia latipinna* and *Gambusia affinis* and small sample sizes of other non-natives precluded such an analysis.

Little overlap was found between the food items consumed by Saudi native and non-native species, and where it was observed it was largely food items in abundant supply such as detritus and benthic algae. Caution must be heeded with respect to these results because non-native species were uncommon in habitats where natives were found, and the potential for competition and impact of non-natives on the native fish fauna remains of concern. Further studies on the impact of non-natives fish species are necessary to underpin guidelines on species introductions into Saudi Arabia.

Chapter 8. Reproductive ecology

8.1 Introduction

Understanding the reproductive ecology of fishes is fundamental to establishing fisheries management actions to protect fish stocks both for exploitation and conservation. Information related to Saudi freshwater fish reproductive biology such as temporal patterns or reproduction strategies is deficient. Al-Akel et al. (2010) investigated the reproductive biology of *Poecilia latipinna* in Wadi Haneefah streams, Riyadh, Saudi Arabia. They found *P. latipinna* was reproductively active all year round but with peaks from February to May and August to November. Although Saudi freshwater species are resilient to drought and high temperatures, human pressures on these species (see Chapter 3) are increasingly making them vulnerable to extirpation, but how these pressures are affecting the reproductive biology of the species is unknown. Therefore, it is critical to understand the reproductive ecology, such as fecundity, breeding seasons and the size at maturity, to devise management strategies to manage the optimal exploitation of the species and to protect the fishes against miscellaneous threats.

The aim of this chapter was to examine aspects of the reproductive biology of some Saudi freshwater fishes (*Carasobarbus apoensis, Cyprinion mhalensis*, *Garra buettikeri, Oreochromis niloticus, Poecilia latipinna* and *Gambusia affinis*). The research will examine size at maturity, gonadosomatic index as an indicator of spawning season, fecundity, and its relationships with weight and length, and reproductive strategies. These results will contribute to formulating a conservation management plan, especially to regulate fishing activities that operate with little knowledge of their impacts. Understanding the reproductive ecology will contribute to developing regulations and legislation that allow these fish to recruit sustainably and avoid overexploitation.

8.2 Methods

The fish specimens were collected from the different study sites on three occasions (See Chapter 4 for details). Fish samples were preserved in 4% formaldehyde and brought from Saudi Arabia to the laboratory in the United Kingdom for further investigations. A total of 1393 specimens from all studied fishes were used for the reproductive studies. There were not adequate numbers of fish of some species to carry out complete analyses, such as individuals carrying ripe eggs to determine fecundity or mature individuals of different sizes to determine size at maturity. The following methods were used to examine individual fish.

Maturity stages: The maturity stages were determined according to the methodology described in Bagenal (1978) and Kesteven (1960). All examined fish reproductive organs were categorised based on maturity stages (immature stages, ripe stages and spent stages). Immature stages mean there are no noticeable eggs. Ripe means that the gonads hold clear eggs or sperms. The ovaries of spent fish are flaccid and bloodshot. A microscope was sometimes used to confirm the assessment. Maturity stages were combined in the main Excel file to correlate those stages with fish age or sizes. Knowledge of the maturity cycle is important to track the reproduction seasons of the species.

Size at maturity: The proportion of each maturity stage in each length category (1-cm) were plotted to determine the size at maturity. The size of maturity was deemed when 50% of the individuals are mature. The maturity status of each species was plotted on separate curves, but because of small sample sizes, data from fish of each species from all sites were combined. The results of the maturity stages were calculated using a Pivot Table in Excel, the proportion of mature fish (fish with stage 4 and above are mature) in combination with fish size and locations were then transferred into SigmaPlot software to analyse data and generate sigmoid curves (Figure 8.1): (y = y0+a/(1+exp(-(x-x0)/b))^c).

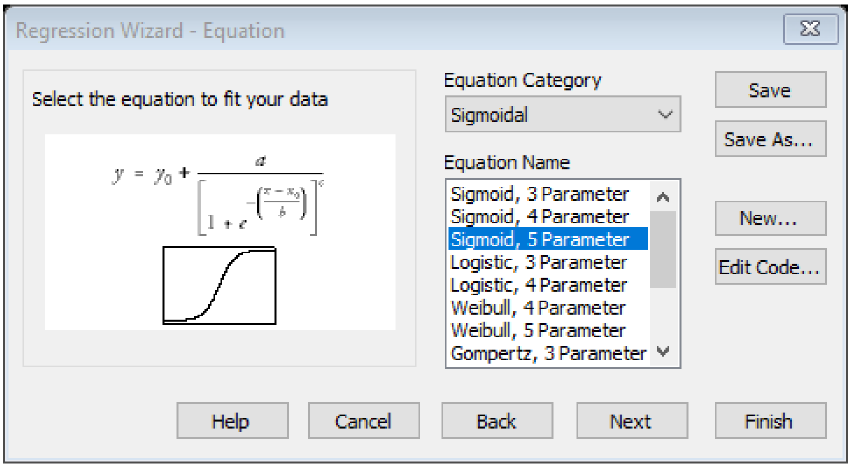


Figure 8.1. SigmaPlot (v14) interfaces which size at maturity Sigmoid curves were analysed and produced.

Gonadosomatic Index (GSI): The principle behind this coefficient is that the weight of gonads increases during maturity development until a sharp drop in gonad weight occurs following spawning time. The gonadosomatic index was calculated for male and female fish from the three surveys. GSI was calculated following Hickling (1970) & Bagenal (1978):

$$GSI\ \% = \frac{\text{Weight of Gonads in grams}}{\text{Weight without guts}} \times 100$$

The values of this coefficient were calculated for different sizes of fish, so that differences in sizes and thus maturity could be calculated, especially since some fish are immature and were only collected in three seasons.

Fecundity: Fish brought from the field were examined for maturity. The gonads of mature females were removed, weighed (mg) and the eggs counted by the gravimetric sub-sampling method. Three sub-samples were taken from different parts of the ovary, weighed (mg) then eggs were counted in each sub-sample. The total number of eggs (F) was calculated as a proportion of the weight of the subsample to the total ovary weight (Bagenal, 1978) as:

$$\text{Estimated eggs (F)} = \frac{number\ of\ eggs\ in\ sampled\ ovary\ part \times ovary\ total\ weight}{The\ weight\ of\ sampled\ ovary\ part}$$

The average of the number of eggs in the three sub-samples was the final estimated fecundity (absolute fecundity).

The relationships between fecundity and length or weight were calculated as:

$$\text{Length} \quad F = a\,L^b \qquad \text{weight} \quad F = a\,W^b$$

Where: F is absolute fecundity (number of eggs); L - total length (mm); W - total weight (g); a, b - constants calculated from linear regression. The exponential equation was converted to a logarithmic equation to obtain a linear relationship as suggested by Bagenal (1978).

Length: log Fecundity = log a + b (log length)

Weight: log Fecundity = log a + b (log weight)

8.3 Results

8.3.1 Size at maturity

Size at maturity was determined for males and females of *Carasobarbus apoensis* (Figure 8.2), *Cyprinion mhalensis* (Figure 8.3), *Garra buettikeri* (Figure 8.4) and *Oreochromis niloticus* (Figure 8.5). Although there was variation in size at maturity of different species between sites they more or less followed the same pattern. Size at 50% maturity for each species and sex are shown in (Table 8.1). *Carasobarbus apoensis* and *Garra buettikeri* males matured at smaller size than females but the reverse was true for *Oreochromis niloticus.* No comparable data are available for Saudi endemic species but the length at maturity for female *Oreochromis niloticus* was between 8.0 and 18.7 cm and for males 9.2-18.0 cm in other warm water systems (fishbase.org 2018).

Table 8.1. Size and age at 50% maturity of male and female fishes from Saudi water bodies (note the description of the process of ageing fish in Chapter 6).

Species	Size at 50% maturity (cm)	
	Male	Female
Carasobarbus apoensis	12 (average age 2+)	22 (average age 5+)
Cyprinion mhalensis	12 (average age 2+)	12 (average age 2+)
Garra buettikeri	10 (average age 2+)	13 (average age 3+)
Oreochromis niloticus	18 (average age 3+)	15– 16 (average age 2+)

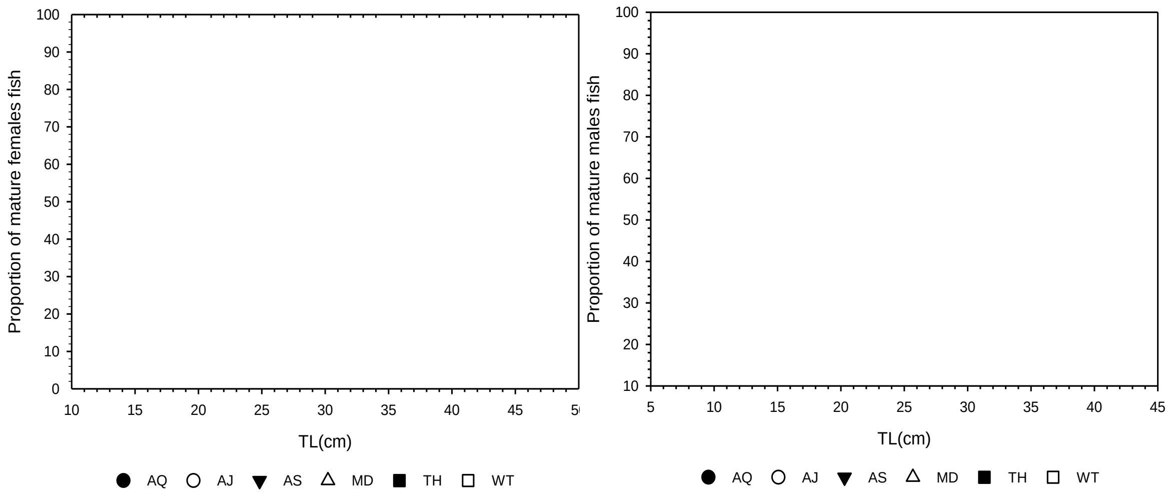


Figure 8.2. Percentage of mature female (left) and male (right) *Carasobarbus apoensis* at different lengths (TL) and between sites (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WT = Wadi Turbah).

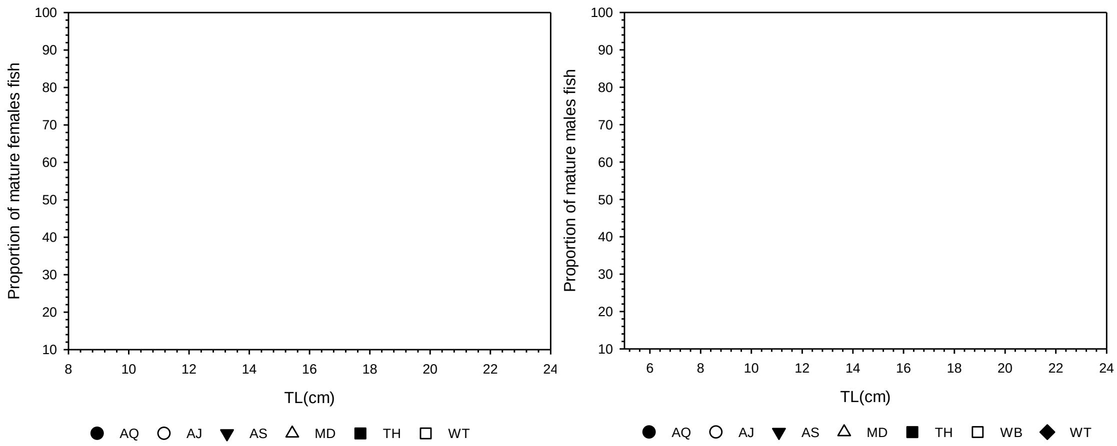


Figure 8.3. Percentage of mature male(right) and female(left) *Cyprinion mhalensis* at different lengths (TL) and between sites. (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD= Medhaas Dam; TH = Thrrad Dam; WB = Wadi Bouwa; WT= Wadi Turbah).

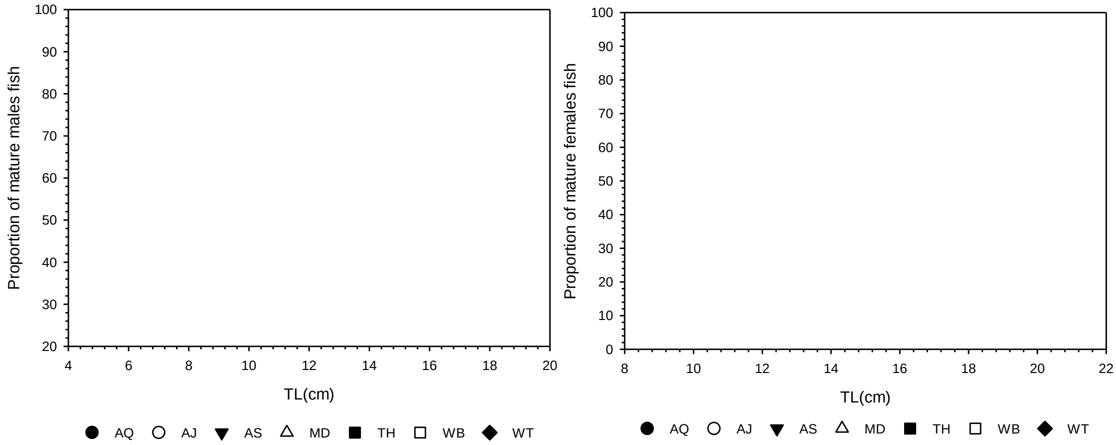


Figure 8.4. Percentage of mature male and female *Garra buettikeri* at different lengths (TL) and between sites (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WB = Wadi Bouwa; WT = Wadi Turbah).

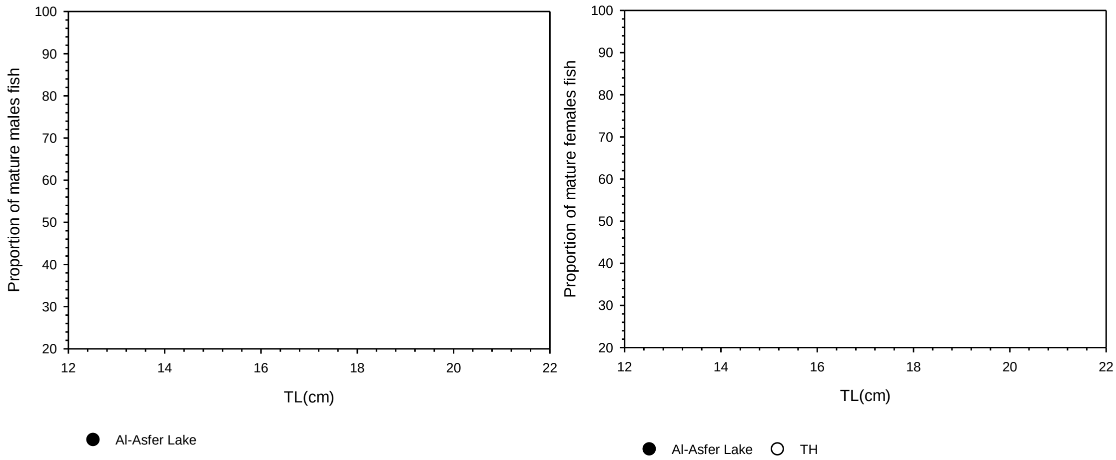


Figure 8.5. Percentage of mature male (left) and female (right) *Oreochromis niloticus* at different lengths (TL) and between sites (Al-Asfer Lake; TH = Thrrad Dam).

8.3.2 Gonadosomatic Index (GSI)

GSI in *Carasobarbus apoensis* was high in the spring season for both males and females, and may extend to early summer (Figure 8.6 &Figure 8.7), highlighting the likely timing of spawning of this species, i.e. between March and May. Some small sized males also had high GSI value which suggests this species matures early at small sizes, as identified above. Smaller-sized females, especially fish with lengths 4-14 cm, had low GSIs, which reflects that they had not yet matured, and suggests females mature a year later than males.

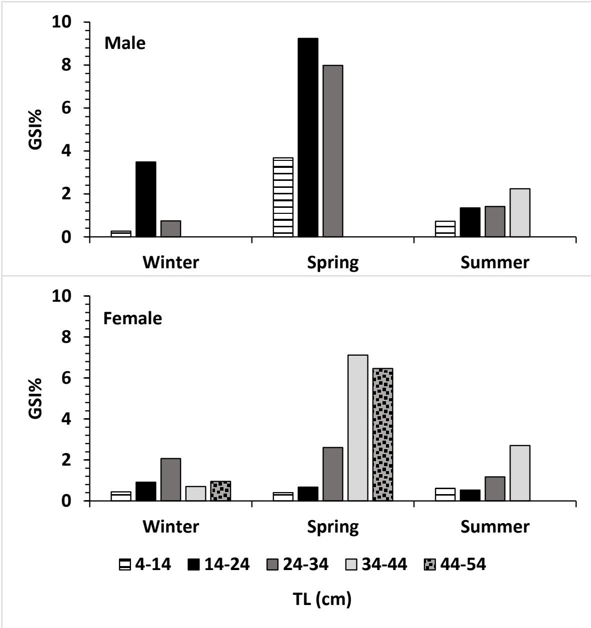


Figure 8.6. Gonadosomatic Index (GSI) in males and females among different size groups of *Carasobarbus apoensis* during three seasons, Female N = 312, Male N = 303.

Figure 8.7. Mature male *Carasobarbus apoensis.*

GSI for both male and female *Cyprinion mhalensis* were high in the spring season, but showed evidence of maturation in the winter period. Spawning is thus in the spring period (Figure 8.8). Interestingly, all sizes of fish (5 cm to 15 cm) showed evidence of maturation in the spring period and this probably reflects the early size at maturity (about 12 cm) for both males and females of this species.

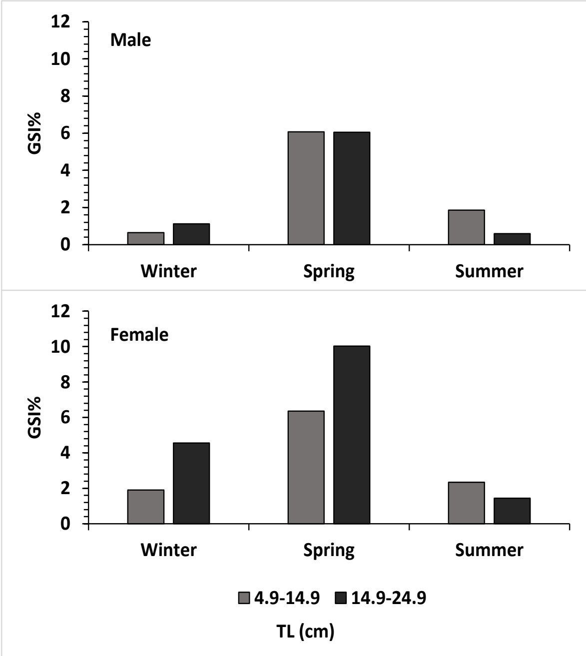


Figure 8.8. Gonadosomatic Index (GSI) in males and females among different size groups of *Cyprinion mhalensis* during three seasons, Female N = 207, Male N = 135.

Figure 8.9. Mature female of *Cyprinion mhalensis*

Garra buettikeri appear to exhibit batch spawning (Figure 8.10 & Figure 8.11). Mature fish were found in all seasons and some ovaries containing more than one mature stage of eggs in different seasons, i.e. developing batches of eggs, supporting this conclusion of a protracted reproductive period extending from winter, through spring into the summer. Further investigation is needed to confirm this because the period of study was short and it is necessary to confirm these findings.

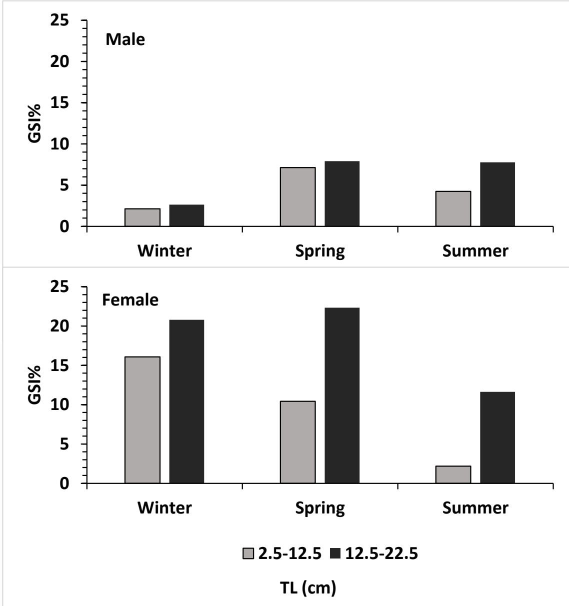


Figure 8.10. Gonadosomatic Index (GSI) in males and females among different size groups of *Garra buettikeri* during three seasons, Female N = 190, Male N = 132.

Figure 8.11. Mature female *Garra buettikeri*

Oreochromis niloticus is a higher reproductive species (Figure 8.13). They can spawn many times throughout the year (*fishbase.org, 2018)*. Thus, due to the limited sampling trips assessment of the GSI (Figure 8.12) may not represent all spawning periods for this species. The GSI for big sized females was highest in the summer period, which suggests the main spawning period may be between summer and autumn, probably July to August. However, many females caught in the spring were found to be incubating eggs in their mouth, supporting the continuous breeding viewpoint. GSIs for males were low because of the modest representation of males in the total catch. Furthermore, many males were mature in all seasons, and it seems that males are able to reproduce during all periods of the year.

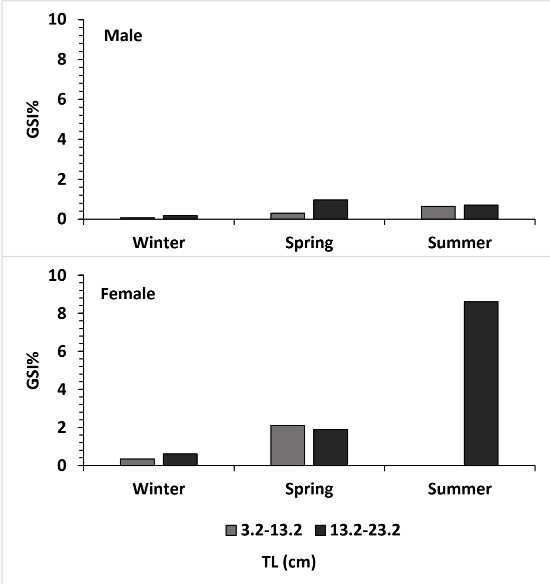


Figure 8.12. Gonadosomatic Index (GSI) in males and females among different size groups of *Oreochromis niloticus* during three seasons, Female N = 60, Male N = 43.

Figure 8.13. Mature highly fecund female *Oreochromis niloticus*

Al-Akel et al. (2010) investigated the reproduction of *Poecilia latipinna* in Wadi Haneefah rivulet, running through Riyadh, the capital city of Saudi Arabia. *Poecilia latipinna* is a viviparous species that develops young internally. They found this species to be reproductively active most of the year. The peak reproduction periods were from February to May and August to November, suggesting two distinctive periods of reproduction each year.

In the current study, *Poecilia latipinna* was found in the harsh environment of Al-Asfer during winter and spring only. It appears that the main reproductive period was spring as this was the period when developing embryos (gestation stage) were observed in the female fish. Because of the small size of these fish, males exhibited very low GSI values and do not show GSI as clearly as females, but spring appears to be the spawning season for males also (Figure 8.14).

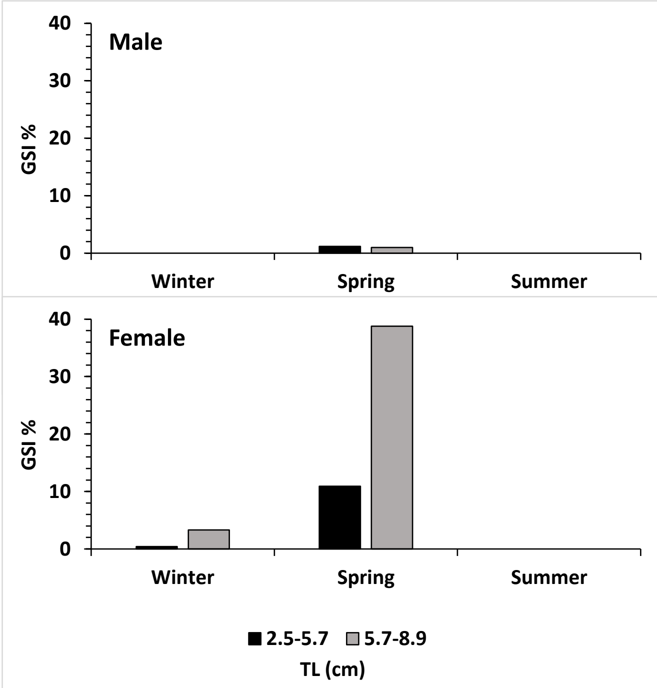


Figure 8.14. Gonadosomatic Index (GSI) in males and females among different size groups of *Poecilia latipinna* during three seasons, Female N = 27, Male N = 9.

8.3.3 Fecundity

Data on fecundity in this study are limited to *Carasobarbus apoensis*, *Cyprinion mhalensis*, *Garra buettikeri* and *Oreochromis niloticus* (Figure 8.15). The estimated number of eggs (observed fecundity) varied between individuals and appears to be related to size of the specimens. *Carasobarbus apoensis* reached up to 45 cm in total length, their size at maturity is about 22 cm and they produce between 4000 and 15000 eggs, with a mean of 9000 eggs. The large specimen of this species produced around 27000 eggs. *Cyprinion mhalensis* reached 23.7 cm long, their age at maturity is about 12 cm, and they produce between 2000 and 4000 eggs, with a mean of 3000 eggs; the biggest individual produced 8000 eggs. *Garra buettikeri* reached 20 cm in total length and female size of maturity was around 13 cm. This species seems reproductively active throughout the year and is a batch spawner. They produce between 4000 to 8000 eggs, with a mean of 6000 eggs. Differences in high and low values of egg numbers are due to the difference in the number of mature eggs for each ova without estimating the number of maturing batches, so fecundity in a reproductive year is much higher. *Oreochromis niloticus* is an active spawner throughout the year. This species was found to produce up to 1000 eggs per individual, but some females were highly fecund, producing up to 8000 eggs (Figure 8.13). This species is a mouthbrooder, and up to 240 eggs were counted being carried in the mouth of individual *Oreochromis niloticus*.

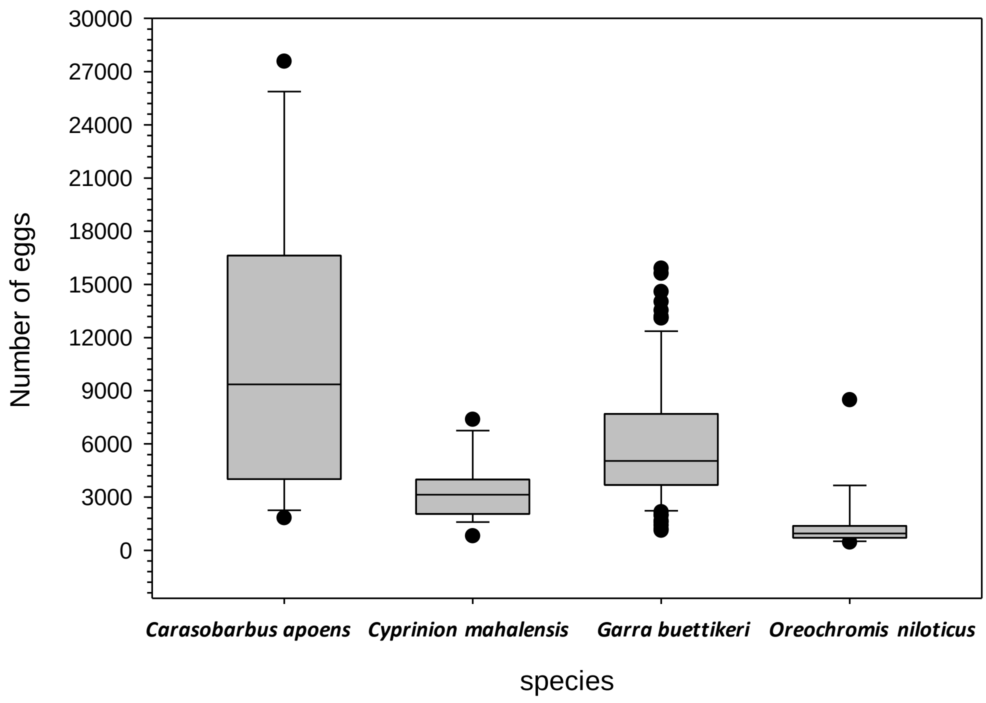


Figure 8.15. Box and whisker plots of the absolute fecundity for some of the studied fish species.

The relationships between absolute fecundity and total weight and total length in *Cyprinion mhalensis, Garra buettikeri* and *Carasobarbus apoensis* were not linear and were log transformed (Table 8.2 and Figure 8.16). As expected, fecundity increased exponentially with length and age in all species examined. Larger individuals of all species produced considerably more eggs than smaller individuals thus their contribution to recruitment is likely higher than smaller individuals. However, since the information about the abundance of the fish was not collected it is difficult comment on how these fecundity values influenced recruitment of the fish. Additionally, in this study, egg size was not measured. However, it is hypothesized that large individuals may produce larger eggs, which likely produce better quality offspring (Wootton & Smith, 2014).

Table 8.2.The relationship between absolute fecundity and total length (TL) and total weight (W) for three freshwater fishes endemic to Saudi Arabia.

Species	**N**	**TL (mm)**	**W(g)**	**Log a**	**b**	**r^2**
Cyprinion mhalensis (W)	19	120-204	17.8-87.6	1.6947	1.1403	**0.703**
Cyprinion mhalensis (TL)				- 3.2595	3.1032	**0.6409**
Garra buettikeri (W)	89	104-201	11.8-99.9	2.1491	1.0542	**0.5508**
Garra buettikeri (TL)				- 3.6114	3.4002	**0.529**
*Carasobarbus apoensis (*W)	15	198-460	88.7-1427	1.6908	0.8715	**0.8409**
Carasobarbus apoensis (TL)				-3.1013	2.8298	**0.8208**

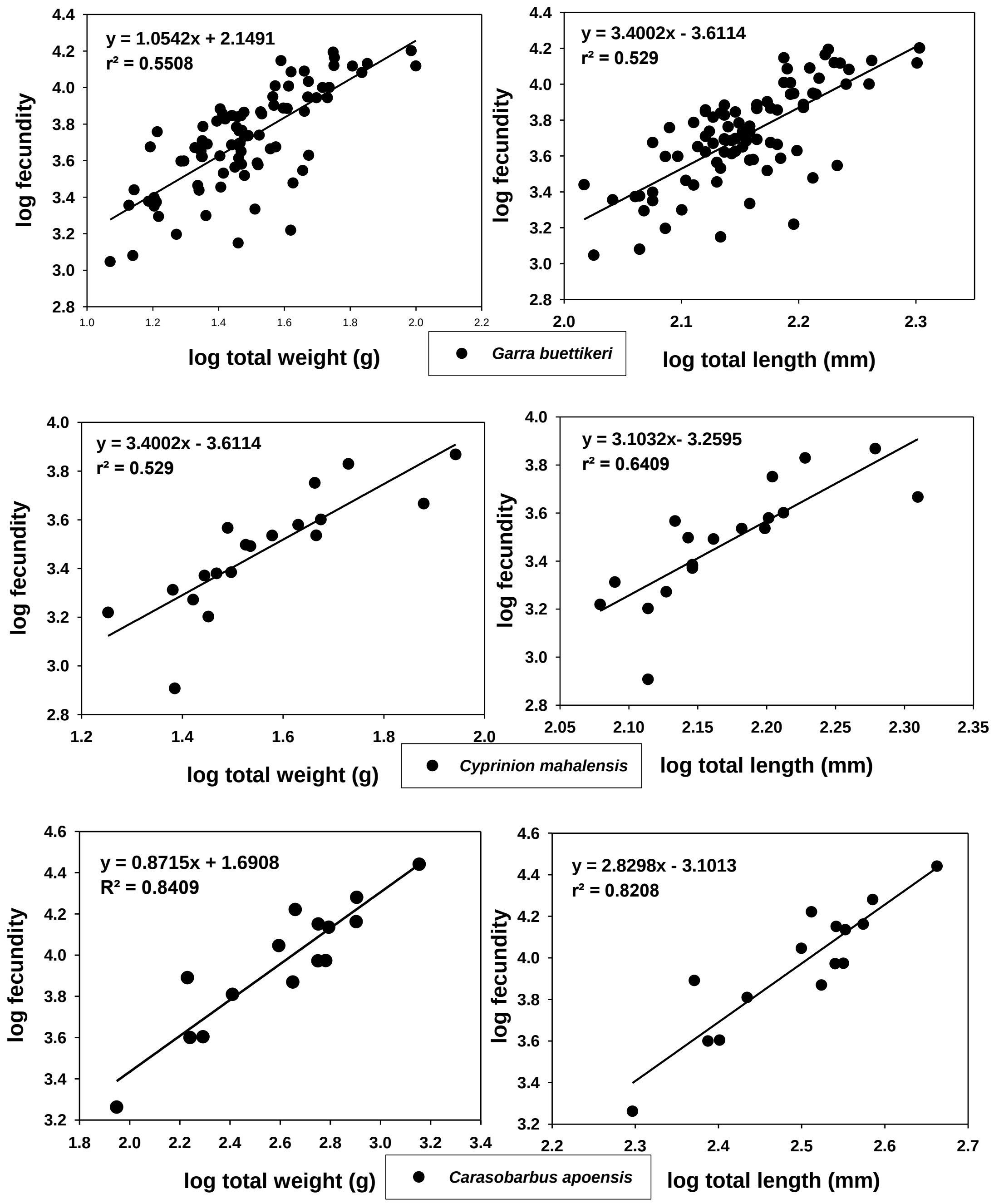


Figure 8.16. The relationships between log absolute fecundity and log total length (TL) and log total weight (W) for three freshwater fishes endemic to Saudi Arabia (*Garra buettikeri*, *Cyprinion mhalensis*, *Carasobarbus apoensis*).

Relative fecundity (the number of ripening oocytes and mature ova per gram of body weight just prior to spawning) differed between study sites for *Garra buettikeri* and *Cyprinion mhalensis* (Figure 8.17). Relative fecundity in *Cyprinion mhalensis* was higher in Thrrad Dam than other locations, and lowest in Al-Sadr Dam. By contrast, although relative fecundity in *Garra buettikeri* varied between sites, it was lower in in Al-Sadr Dam than at other locations. Much of the variation is likely to have arisen because of differences in egg sizes and reproductive strategies.

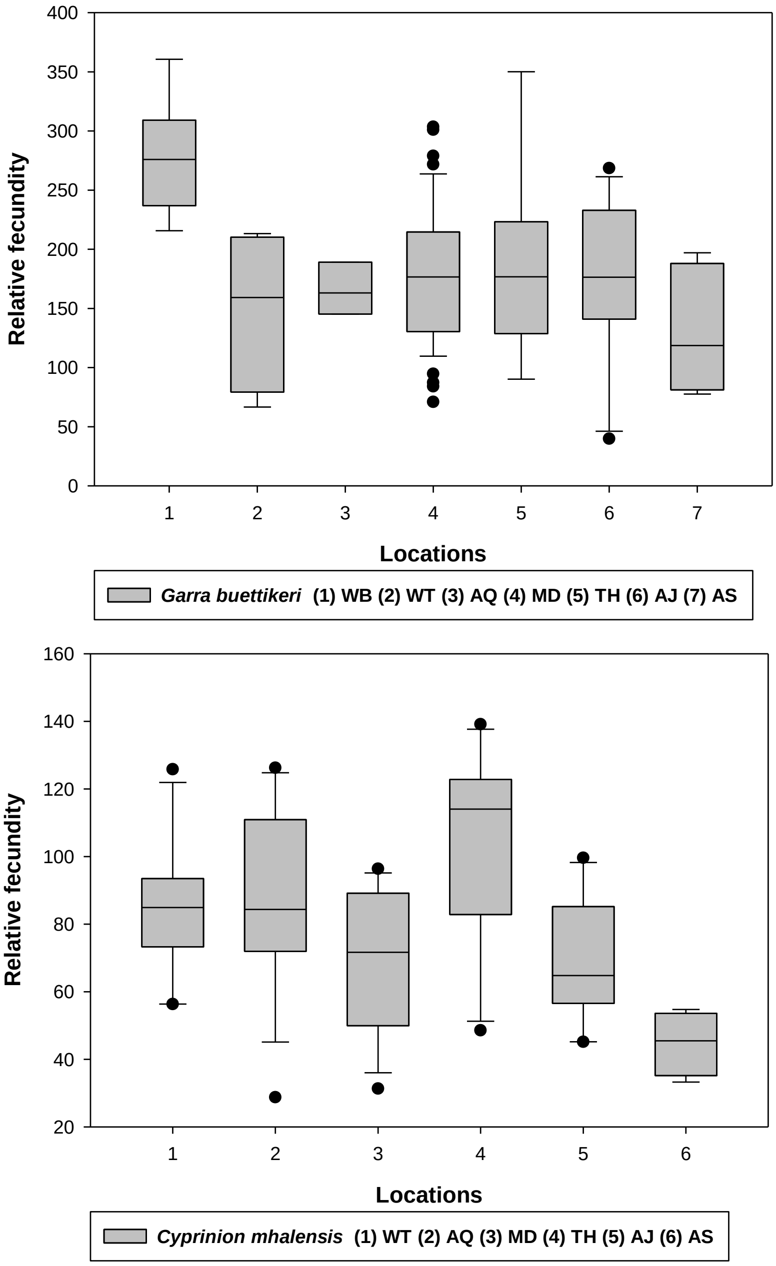


Figure 8.17. Differences in absolute fecundity between locations (AQ = Al-Aqiq Dam; AJ = Al-Janabeen Dam; AS = Al-Sadr Dam; MD = Medhaas Dam; TH = Thrrad Dam; WT = Wadi Turbah) for *Garra buettikeri* and *Cyprinion mhalensis.*

8.3.4 Vivipary in Poecilia latipinna and Gambusia affinis

Poecilia latipinna and *Gambusia affinis* are viviparous species that gestate developing embryos internally then give birth to live young. *Poecilia latipinna* were only caught in winter and spring in this study. Fish with viviparous stages were only found in spring while fish caught in winter still had developing eggs, although a few had already delivered their young. Males caught in spring were between 42 and 73 mm long and all were mature. The maximum number of embryos *Poecilia latipinna* can gestate was approximately 180, although the number of embryos increases with length. Some mature individuals had broods of different embryo stages developing at the same time, which suggests some form of batch reproduction (Figure 8.18). This species was observed to carry gestating embryos from a length of 46 mm, which is similar to Al-Akel et al. (2010), although they found size at maturity of 67 mm for females and 69 for males. Wischnath (1993) indicated that the gestation period for *Poecilia latipinna* is 28 days and they produce 10 to 100 young per individual. Al-Akel et al. (2010) stated that absolute fecundity of this species is between 35 to 161 eggs.

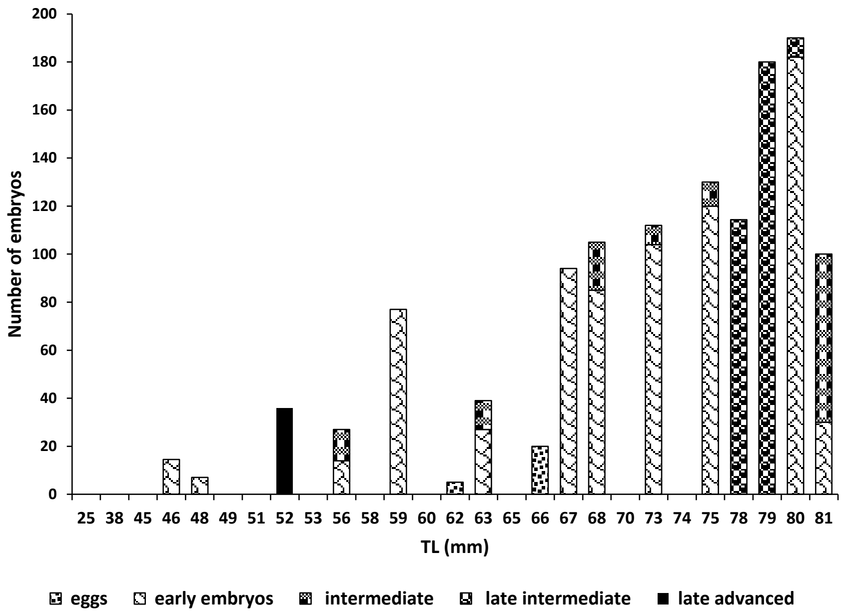


Figure 8.18. Number of each development stage of embryos at each body size of female *Poecilia latipinna*.

Figure 8.19. Left: *Poecilia latipinna* embryos at an advanced stage of development. Right: gravid mature female, *Poecilia latipinna* at the top, and mature male at the bottom

Gambusia affinis is an internal livebearer (Seale, 1917). This species was only caught in the spring during sampling. All females were mature and were reproductively active and were gestating up to 60 embryos (Figure 8.20). Large females are capable of carrying more young than are smaller females. In this study, *Gambusia affinis* started gestation at a length of 30 mm. Johnson (2008) mentioned that females could yield somewhere from one to seven broods per reproductive season, with each brood comprising around 200 embryos and reproductive seasons generally covers a period of about seven months, but in warmer climates they could breed all year.

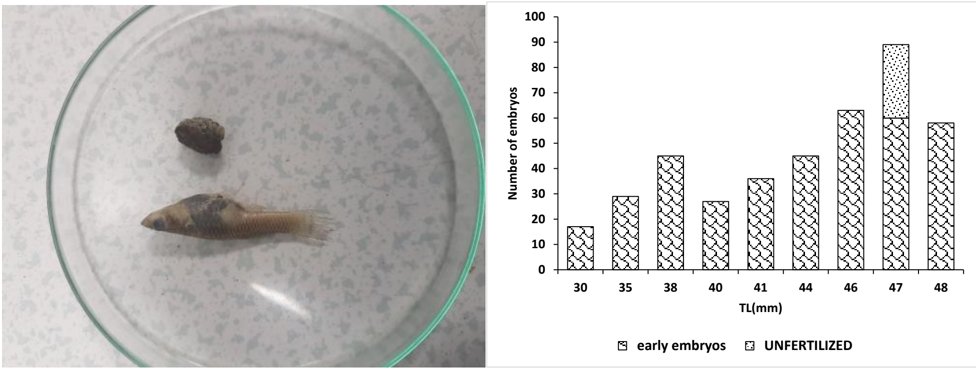


Figure 8.20. Left: mature female *Gambusia affinis*. Right: number of embryos at each body size of female *Gambusia affinis*

8.4 Discussion and Conclusions

Some aspects of reproductive biology of Saudi freshwater fishes were studied according to availability of mature fish specimens during the three seasons of sampling. These observations are the first known investigations on the reproductive aspects of endemic species so there are no previous data for comparison. The main aim of this preliminary study is to understand the reproductive strategies of endemic species and how these fishes recruit during their lifetime. The information will be used, where possible, to provide indications of the potential threats to ecological sustainability of these vulnerable species to human interventions and support the formulation of a management plan to protect these species.

Size at maturity was estimated for three endemic species and an alien species, viz.: *Carasobarbus apoensis* (max. length = 46 cm; max. age = 15 y; female L_{50} = 22 cm; male L_{50} = 12 cm), *Cyprinion mhalensis* (max. length = 24 cm; max. age = 6 y; L_{50} for males & females = 12 cm), *Garra buettikeri* (max. length = 20 cm; max. age = 7 y; female L_{50} = 13 cm; male L_{50} = 10 cm) and *Oreochromis niloticus* (female L_{50} = 15-16 cm; male L_{50} = 18 cm). Males matured earlier than females in *Carasobarbus apoensis* and *Garra buettikeri* but the opposite was found for *Oreochromis niloticus,* with females maturing earlier; males and females matured at the same size in *Cyprinion mhalensis.* Previous studies in other countries (fishbase.org) indicate *Oreochromis niloticus* females mature between 8.0-18.7 cm and males between 9.2-18.0 cm, which is consistent with this study, wherein this study fish reached maturity at a greater size in Al-Asfer Lake. Size at maturity can vary between water bodies and is driven by several factors such as the availability of food, temperature, flow regime and the surrounding conditions that stimulate the fish to start breeding seasons. Fish may change their age at maturity in response to pressures, such as fishing (Wootton & Smith, 2014). Fish, thus, have varying responses to surrounding conditions in terms of growth and need to reproduce to complete their life cycles. Minimal variability was found in the size at maturity of the species between water bodies suggesting they experience similar conditions. Some fish are reproductively active at an early size but some, like *Carasobarbus apoensis*, reach maturity at advanced sizes. Fish with higher sizes at maturity would be at greater risk of unmanaged fishing operations before having the opportunity to contribute to recruitment. One objective of fisheries management is to ensure that fish, and females in particular, are not taken before they reach maturity (Cochrane, 2002; Wootton & Smith, 2014), to avoid stock recruitment failure. Thus, the size at maturity information will be useful to establish rules about minimum size of retention of individuals for regulating fishing in the various water bodies (see Chapter 9).

Based on the current observations on gonadosomatic index and spawning time (Section 8.3.2, page 152), it appears that *Carasobarbus apoensis* and *Cyprinion mhalensis* mainly spawn in the spring, but with a protracted spawning period into the summer. *Garra buettikeri* seems to be a batch spawner, with mature eggs in the gonads during all seasons sampled, potentially indicating spawning extends from winter, through spring and into the summer. Further studies are needed to clarify the reproductive strategy for this species and whether it varies between water bodies. It is suggested monthly surveys are carried out to determine the main reproductive period for this species. *Oreochromis niloticus* is a highly reproductive species that can spawn many times throughout the year (fishbase.org, 2018). Thus, due to the limited sampling events, the three sampling trips may not provide a good representation of spawning periods for this species. The GSI was high in the summer period for larger females, suggesting the main spawning was around this time, probably between July and August, possibly extending into autumn. However, many female fish caught in the spring were observed to be incubating eggs in their mouth, thus spawning may be a year-round activity as was found by Welcomme (1985).

Welcomme (1985) suggested that spawning in freshwater fish is highly seasonal and essentially related to two elements, temperature and flow; but nearer the tropics the impact of temperature apparently decreases and the flood regime becomes progressively more important as a driver of reproduction. Scott (1979) moreover explained that times of reproduction depended on photoperiod, as well as changes in temperature and food availability. It is unlikely temperature is a major driver of reproductive activity in Saudi fish, as temperatures are high most of the year, but with some extremes. Furthermore, Welcomme (1985) stated that spawning may happen at low water, rising water or peak flood, but rarely amid falling flood levels. The main rainy season in Saudi Arabia is spring (Chapter 3, Section 3.4, page 58), although some rain falls in some winter months. Thus, water flow appears to be the most important factor influencing the breeding season for these fish, and spawning achievement may be discouraged by the long dry seasons experienced in many water bodies, except for the species with batch spawning. In general, therefore, it appears that spawning is linked to flooding period when the rivers are flowing and even flood into surrounding lands. This flooding is conducive to reproduction as it provides rich food resources and nursery areas for the larvae and juvenile fishes (Lowe-McConnell, 1979; Munro et al., 1990; Wootton & Smith, 2014). However, the problems may arise in the future with increased pressures on water resources, especially water withdrawal for agricultural supply that may disrupt the flooding cycles, and disturb their breeding timing and habits. Construction of dams with little attention to establishing environmental flows downstream may make this problem worse as demand for water increases.

The data on fecundity are somewhat limited in this study. Absolute fecundity was determined for *Carasobarbus apoensis*, *Cyprinion mhalensis*, *Garra buettikeri* and *Oreochromis niloticus. Carasobarbus apoensis* reached up to 45 cm in total length and produced between 4000 eggs and 15,000 eggs. A positive relationship was found between fecundity and fish size (length and weight), with the largest individual of this species producing around 27,000 eggs. *Cyprinion mhalensis* reached a maximum size of 23.7 cm TL. They produce between 2000 and 4000 eggs, with the largest specimens produce up to 8000 eggs. Again, a positive relationship was found between fish size (length and weight) and fecundity. *Garra buettikeri* reached to 20 cm in total length. This species is a batch spawner and is reproductively active throughout the year. They develop between 4000 to 8000 eggs with a mean of 6000 eggs. Differences in the range of eggs present are due to differences in the number of mature eggs for each ova without accounting for the number of batches. Considerable deviation was found in the relationships between absolute fecundity and total weight and total length, which possibly reflects this batch spawning and inability to count the number of mature eggs accurately. *Oreochromis niloticus* is an active spawning throughout the year, with an average of 1000 eggs per fish and a maximum number of eggs of about 8000 eggs. This species is a mouthbrooder and up to 240 eggs were counted in the mouths of some individuals. There is also some variation in the fecundity of *Cyprinion mhalensis* and *Garra buettikeri* between locations. This may be driven by several factors, most importantly water runoff, water quality, availability of food, the presence of the species in its preferred environment and the reproductive strategy, i.e. total versus batch spawning. The higher fecundity of *Oreochromis niloticus* in Al-Asfer Lake than other studies may be due to the nutrient enrichment of the lake causes by agricultural and organic run-off and the ability of this species to digest blue-green algae. These preliminary estimates of fecundity provide an impression of the potential recruitment of these species each year, but further studies are needed to fully understand the recruitment dynamics of the endemic species to support affirmative actions to enable sustainability of the stocks.

Sexual dimorphism was found in several species of fish in the present study. Mature male *Cyprinion mhalensis* have horny tubercles on the top and the side of their snout and sometimes cover whole body and fins. The function of these tubercles is not known but may be associated with courtship and competition between males to access females. There are also clear differences in shapes between males and females in the viviparous species *Poecilia latipinna* and *Gambusia affinis,* and male and female *Oreochromis niloticus* can be differentiated through genital papilla. No sexual dimorphism was recognisable in *Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri*.

This study also investigated some reproductive aspects of two viviparous species, *Poecilia latipinna* and *Gambusia affinis* in Al-Asfer Lake, although samples sizes were limited. Those two species are livebearers and small brood spawners (Welcomme, 1985). It appears the main breeding period for *Poecilia latipinna* with fish holding viviparous life stages was spring. Al-Akel et al., (2010) studying the reproductive biology of *Poecilia latipinna* in Wadi Haneefah rivulet, in the Riyadh found this species was reproductively dynamic throughout the year but with peak reproduction periods from February to May and August to November. *Gambusia affinis* were only caught during the spring survey. All females were mature and reproductively active with gestating embryos. Studies from elsewhere suggest this species is reproductively active throughout the year but peak maturation occurs during the early periods of the two wet seasons every year (Johnson, 2008; Al-Akel et al., 2010; Wootton & Smith, 2014). Critically these studies identified that this short-lived species matures in the first year of life. Fluctuations in water levels in the lake, and minor rains which occur mostly in two periods of the year may be the cue for these fish species to start breeding. Dense vegetation and extremes in water temperature during the summer, coupled with receding water levels at some sites, may create harsh micro-environments beyond the species' tolerance, resulting in mortality, and this needs to be considered in any management actions.

In this study, the endemic species *Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri* seem to have two distinguishable temporal reproductive patterns. *Carasobarbus apoensis* and *Cyprinion mhalensis* spawned exclusively in spring during the rainy seasons. *Garra buettikeri* is batch spawner, and was reproductively active throughout the year. Mature *Cyprinion mhalensis* were mostly found in wadis or the tailwaters of reservoirs where the water is shallow but flowing. *Carasobarbus apoensis* (large adults) were mostly found reproducing in stagnant water amongst dense stands of aquatic plants in the reservoir margin or deeper parts of the wadi channels. Those two species appear to be total spawners, but individuals may spawn over a protracted period, but more evidence is needed. By contrast, *Garra buettikeri* prefer the benthic area of wadis streams with fast water. In Al-Asfer Lake, *Oreochromis niloticus* is reproductively active throughout the year, and *Poecilia latipinna* and *Gambusia affinis* are viviparous species with two main periods of spawning in spring and autumn. Spawning appears to be driven by rainfall and increased productivity associated with high water events. This information will help build a conservation management plan for these species to address conflicts with human activities.

Chapter 9. Fisheries conservation management plan

9.1 Introduction

Since the provisional distribution of Saudi Arabia freshwater fishes was established in 1980, no action has been taken to develop any management initiatives to protect this important element of the Saudi biodiversity or the habitats they rely on, despite calls for action to reduce the increasing pressures on these valuable ecological assets. This study has highlighted some of the key issues that are affecting freshwater fish and fisheries in Saudi Arabia and established baseline information on which to develop a conservation plan targeting this important element of the country's biodiversity. Freshwater fish and fisheries in Saudi are subjected to many pressures including exploitation of stocks, introduction of invasive species, tourism, pollution and conflicts over exploitation of water resources for drinking and agriculture and industrial usage. These activities have direct or indirect impacts on fish, which need be regulated and harmonised to meet national and international obligations to protect the Saudi freshwater resources and fisheries.

Fisheries management has undergone tremendous change since the turn of the Millennium and many types of research are being carried out with a variety of management objectives (Welcomme, 2008), such as extractive objectives, sustainability objectives, social objectives, governance objectives or a combination of these objectives. Management processes are allied with assessment of status and trends of resources, such as fish stock assessments, environmental indicators and economic or social characteristics associated with the fisheries sector. Management of fisheries and fish stocks in Saudi wadis and dams can benefit from the concepts of management conducted in different parts of the world, despite the rather distinct environmental conditions found in the country.

The aim of this chapter was to formulate a Saudi freshwater fish management plan targeting mainly conservation issues. The plan will not just target the fish assemblages and fisheries but environment issues and water resource management. It will be based on information collected during the course of this study and additional material from policy, guidelines, reports and research documentation (Cowx, 1998, 2008; EPAA, 2002; Paris et al., 2003; SWA, 2008; Welcomme, 2008; Cowx & Kalonga, 2013; RBAS, 2013; GWP CEE, 2015; Al-Obaid et al., 2017). The structure of the plan follows similar strategies adopted elsewhere (Cowx & Kalonga, 2013).

9.1.1 Establishing a conservation plan for fisheries and aquatic biodiversity in Saudi Arabia freshwater ecosystems (SFMP).

Globally, wetlands and other natural water bodies provide valuable services to society and the environment, but the systems are generally under considerable pressures from exploitation of the water and associate renewal natural resources. This is particularly true in wadis and other water bodies in Saudi Arabia where water is scarce and in high demand for drinking and agricultural purposes. The services provided by these systems are multiple, including livestock rearing, tourism, water uses for agriculture and drinking purposes, in addition to various hunting or fishing activities. The water bodies are, however, being degraded by a range of activities, not least effluent discharges and agriculture affecting water quality, unregulated fishing activities and damming, in addition to water abstraction. To avoid further degradation of these critical habitats and the services they deliver requires affirmative action and a holistic management plan, which should be based on scientific criteria that maintain the sustainable use of the resources to restore the natural ecosystem function for future generations. For a management plan for Saudi wetland systems to be effective requires all components of the ecosystem, including fish, amphibians, reptiles, birds, insects and various aquatic plants, to be considered in addition to the overriding use of the water and surrounding land, and engage with all users and stakeholders to account for their needs at present and in the future. Any developmental activities, such as water projects, agriculture and tourism, must account for all potential conflicts between sectors but also impacts on the natural resources and biodiversity, besides the development of economic and social aspects. This is particularly important to sites that are sources of water and hotspots for biodiversity, as conflicts are likely to occur between water users and the fundamental obligation to protect native biodiversity under international agreements, such as the Convention for Biological Diversity. There is a need to harmonise resource use to benefit all and provide mechanisms to ensure further degradation is avoided, such as the use of protected areas. For example, the use of water for drinking purposes is a contentious issue because it tends to override conservation aims, thus there is a need to establish a management plan based on information, research, modelling, rationalizing the use of water use, especially in irrigation systems, for the optimal use of the ecosystem and avoidance of excessive exploitation of the water resources.

9.1.2 Principles for management of fisheries in wadis and reservoirs

Freshwater fisheries in Saudi are under increasing pressure from both within and outside the sector. Currently, freshwater fish and fisheries lack protection and are largely overlooked by management, despite their importance to rural livelihoods, and for food and recreational benefits. Management of the fisheries in Saudi wetlands therefore needs a holistic view that not only targets fishing but the fish stocks and environment, such that they are not treated in isolation from the causes and effects of various environmental issues (Cowx, 1998). The goals of any fisheries management plan should also target conservation issues and find opportunities to gradually introduce fisheries legislation, especially for recreational fishing that remove the catch for consumption as this is the growing area for exploitation. There is also a need for legislation to manage the introduction and movement of non-native freshwater fishes. Finally, any plans should engage and target conflicts with and from other users that directly and indirectly affect Saudi freshwater fishes. Cowx (2008) discussed a multiplicity of management approaches that can potentially be applied in Saudi wadis and reservoirs. Those approaches fall under three domains, managing the fish stocks, managing the fishery and management of the environment.

Managing the fish stocks

There are several ways of managing individual fish stocks directly, including enhancement (stocking), creation of new fisheries (introductions) and eradication of unwanted stocks.

- Stock enhancement: stocking is perhaps the most used tool for enhancing fish stocks, but brings with it many problems, such as loss of genetic integrity, increase disease risks and ecological imbalance of the aquatic system (Cowx, 2008). Stocking can be used as a mechanism is Saudi systems, where the natural environment has been degraded and recruitment of native species has been compromised, or locations where the populations have been impacted by severe droughts or floods. It is unlikely to be effective for enhancing stocks directly because the costs will almost certainly outweigh the benefits in terms of increased productivity. Captive breeding and stocking would potentially be useful for endangered species and those of high conservation value, such as *Acanthobrama hadiyahensis*, which is rarely found in the natural habitats.
- Introduction of new species: this option remains viable for man-made system far from natural waters, to promote recreational fisheries or small-scale fisheries if there is a possible market for the product, but this purpose is subject to debate because of the negative impacts of the species being transferred to wadis and other water bodies in the distribution range of native species in the south and east of the country. Tilapia and carps are probably the better species to consider for this purpose, but strict regulations will be required to avoid unwanted movements of fish.
- Eradication of pest species: this applies to alien species that compete with native species for resources in the natural water bodies where the latter occur, or where the species is causing ecological disruption to, for example, the food web, or environmental degradation.

Management of the fishery

Freshwater fisheries in Saudi Arabia are increasingly being exploited for recreational and small-scale fishing purposes, thus there is a need to consider regulations to protect stocks and avoid over-exploitation. Many management tools can be used to regulate fisheries to be consistent with sustainable use criteria (Cowx, 2008; Welcomme, 2008). Establishing such regulations will require a basic understanding of the status of the stocks to determine harvest potential and the basic ecological characteristics of the individual populations, such as size of maturity and spawning seasons. This study has provided the latter but there is a still a need for further studies linked to stock assessment studies. This knowledge base will allow the formulation of regulations to protect the stocks, including minimum landing sizes, close seasons and closed areas to protect recruitment and gear restrictions to control destructive fishing methods. Currently, freshwater fisheries seem to be practiced in a limited range of habitats, but as fishing pressure increases this may expand so appropriate regulations need to be formulated and implemented. Cost-effective methods are needed to monitor stock dynamics and enforce legislation. The most likely mechanism is by engaging the local communities in ongoing management processes, thus ensuring that fishing is conducted in accordance with those principles.

Management of the environment

Freshwater fisheries are notoriously resilient to environmental change, but are heavily impacted by ecosystem change and degradation (Cowx, 2008). A number of mechanisms are open to manage the environment for the benefit of fish and fisheries including: do nothing, pro-active habitat improvement measures, pollution control and prevention, bio-manipulation, and water resource management. These approaches can address many of the issues associated with freshwater fish in Saudi as mentioned in Chapter 2. This study has highlighted some of the environmental problems that have affected freshwater fish and which require corrective action. Numerous restoration measures are available and need to be considered as part of the plan to address environmental problems.

9.2 Issues affecting freshwater fisheries and biodiversity

Many issues were observed during field trips besides that will affect the fish stocks, fisheries and their aquatic environment (see Chapter 4). These range from the impacts of dams on fish migration, water quality issues, over abstraction of water and exploitation of the fish stocks (Table 9.1). These problems need affirmative actions, sometimes urgent, to improve or regulate the stocks and fisheries (Table 9.2). Such actions need to be embedded into an integrated framework for the conservation of the aquatic environments in Saudi and their associated fisheries that engages with all user groups and optimises exploitation of Saudi wetlands. The actions will differ between wadis (valleys) as a natural water bodies and dams that were created for water conservation purposes and artificial lakes created as a result of the disposal of agricultural or urban waste water or agricultural irrigation channels. The conservation plan will be formulated to address these issues and attempt to improve the environmental quality to ensure sustainable fish populations in the face of water resource utilisation.

Table 9.1. Issues affecting fisheries in Saudi fresh waters and potential actions to resolve problems.

Issue	Action	Expected outputs
Introduced species		
Non-native, invasive species have been introduced for biological control purposes, especially in many in artificial lakes and irrigation channels.	- Expand more risk assessment studies on invasiveness impacts - Pro-active measures approach for future entry	- Achieve the actual goal of the entry, avoiding any potential risks from the input operations.
Non-native fish species (*Oreochromis niloticus; Carassius* sp.) have dispersed to natural water bodies, and there is some evidence that they may be impacting on native species either through competition for food resources or habitat.	- Conduct more extensive assessment studies on impact of invasive species on native species and ecosystems. - Consider the possibility of eradication of non-native species.	- Reduce the impact of non-native invasive species and reduce the likelihood of further spread. - Provision of a value commodity to supplement diets of rural people and support tourist activities, especially fishing.
Unregulated fishing activities		
There are no fisheries regulations managing the exploitation of stocks, thus both mature and immature fish can be harvested, potentially impacting recruitment.	- Establish minimum size of capture based on size of maturity of different species, e.g. >27 cm for *Carasobarbus apoensis* >15 cm for *Cyprinion mhalensis* >16 cm for *Garra buettikeri*	- Avoid harvesting fish before they reach maturity to avoid stock recruitment failure.
No regulations to protect breeding fish during their reproductive period.	- Establish close season to protect mature native fish species from overexploitation during their breeding period. Spring between March and May would be the optimal period as it appears to be the peak spawning season. - Ban fishing during the flood period to avoid capture of fish recolonising wadis and migrating to spawning habitats. - Close breeding areas to fishing during the peak breeding period	- Fish allowed to migrate and spawn unimpeded to benefit recruitment.

Issue	Action	Expected outputs
	to protect adult fish and juvenile life stages on nursery habitats. - Gather catch data to assess impact of fishing on stock status and recruitment	
The use destructive fishing gears to overexploit stocks, especially juvenile fishes.	- Ban destructive fishing, such as small mesh sized gill nets and multilayer nets with different sizes of mesh. - Allow angling for recreational and subsistence fishing.	Regulate exploitation of fish stocks and species targeted
Fishing in artificial water bodies where fish are not suitable for human consumption.	- Adopt fish catch and release strategies and impose a ban on removal if fish for consumption.	- The establishment of sport fisheries, which may contribute to local economies and provision of financial resources to improve water and habitat quality of these lakes.
Dam related problems		
Dams and impoundments disrupt fish migration and alter spawning and nursery habitats. Water quality in impoundments poor, especially where used of effluent discharge and agricultural run-off.	- Dam gates and barriers need modification to improve fish passage - Monitor water level fluctuations and impact on spawning habitat and nursery areas. - Improve water quality in impoundment and enhance habitat for fish production. - Assess alteration in habitat on fish and aquatic biodiversity after construction of dams.	- Improved fish recruitment. - Improve habitat quality and productivity. - Provide an optimal environment for fish growth, reproduction and foraging.
Drought and lack of rain		
Drought is an unavoidable and natural characteristic of the Saudi region, but there is a need to build resilience to manage extreme events.	- Pro-active measures to protect water resources that benefit fisheries and aquatic biota. - Emergency plans and drought management actions	- Minimize the effects of drought on fish
Extensive pumping of water for domestic supply and agriculture		
Demand for water is leading to excessive water abstraction from wadis and degrading the habitat for aquatic biota.	- Establish water use measures & standards for individuals or the industrial sector (drinking or agriculture) to conserve wetland environments and avoid degradation and disappearance.	- Work towards a satisfactory compromise for this contentious issue.

Issue	Action	Expected outputs
Water quality issues		
Wadis used for disposal of urban wastewater discharge and run-off of agricultural wastes (fertiliser and pesticides). Eutrophication noted in some impoundments.	- Enforce laws related to pollution control and impose fines on those polluting. - Pollution control and prevention measures implemented, and amelioration treatment of waste water effluents.	- Recovery of favourable environments for fish with improved water quality and less contaminated fish.
Urbanization and rural development		
Development of rural communities and associated amenities degrading aquatic habitats.	- Pro-active measures to protect water resources that benefit fisheries and aquatic biota. - Evaluation and remediation of affected sites.	- Minimize the impact of these developments on fish and their environment and recover degraded habitats.
Pastoralists and tourists		
The effects use of water by pastoralists	- Evaluation, research and take appropriate action not to influence conflicting interests	- Limit impact of development activities on fish and aquatic habitats. - Maintain fisheries potential of water bodies.
Tourism activities degrading aquatic habitats.	- Standards for green tourism, and the enforcement of regulations to protect habitats and aquatic resources.	
Disease vector control (pesticides)		
Freshwater fish vulnerable as a result of actions against tropical diseases	- Training health workers who deal with tropical diseases to rescue fish and affected organisms. - Equipped health workers with tools to facilitate fish rescues and relocation of fish.	- Minimize the effects of controlling tropical disease on the status of fish populations and distribution.

9.3 Freshwater fisheries management plan for Saudi Arabia

This plan will target Saudi wetland ecosystems in general and freshwater fishes in particular, taking into account some of the issues highlighted by the results of this study and mechanisms to address the degrading state of the fisheries and their habitats.

9.3.1 Vision

Managing the diverse uses (fisheries; water abstraction; industrial; agricultural, urban; tourist, biodiversity) of wetlands (wadis, reservoirs, lakes and other water bodies) to ensure that fish and other biodiversity components are not affected by development and exploitation activities. Involving stakeholders in the management of wetlands to guarantee the sustainability and harmonious exploitation without exposing the wetland systems to excessive utilisation and ecosystem degradation that affect their productivity, biodiversity and socio-economic roles.

9.3.2 Freshwater fish management targets

When establishing any fisheries conservation plan there is a need for not only defining actions to address the problems faced but to also set targets/goals that must be achieved within a defined timeframe. Table 9.2 shows three levels of management which directly or indirectly relate to management of Saudi freshwater fishes. To develop a clear plan requires moving outside the fisheries domain itself and managing the ecosystem and external activities that effect the functioning of the ecosystem in a sustainable manner. There is also the need for emergency actions to respond critical problems that arise in a timely manner. This ecosystem approach is required because societal development interacts with all aspects of the ecosystem, exploiting both its living and non-living elements. If these activities are consistent with the ecosystem dynamics, the systems are likely to functional sustainably, but if these activities threaten the ecosystem dynamics, then it will likely lead to imbalances that will affect fisheries and biodiversity and that must be addressed or moderated.

Table 9.2. Division of activities and various management objectives associated with freshwater fish and fisheries

Ecosystem Management	**Management of human activities**	**Emergency Actions**
•Wadis and fish refugia •Dams and reservoir habitats •Man-made lakes and irrgations channels	•Fisheries •Agriculture •Water abstraction •Water pollution •Tourism •Urban development •Disease control •Introduction of non-native species	•Drought and climate change •Rescue operations during floods or throughout outbreaks of disease •Stock enhancement •Eradication of non-native fish where they are deemed problematic

9.3.3 Regulatory principles

The Saudi Freshwater Fisheries Management Plan (SFFMP) is built around existing legislation and operating rules that provide the underlying regulatory mechanisms, although it is recognised this legislation is weak and may need revising to protect the fisheries and biodiversity in the face of societal development.

The SFFMP will be devised in accordance with the following regulatory requirements:

- The Law of Fisheries, Investment and Protection of Living Aquatic Resources in the Territorial Waters of the Kingdom of Saudi Arabia Act No 14 of 1408 H, and its implementing regulations Act No 21911 of 1409 H.
- The Law Of Regulating Trade in Endangered Species and Their Products Act No 54 of 1421H.
- General Law of The Environment, and its implementing regulations Act No 193 of 1426H.

Additionally, other laws and regulations related to water and its uses or quality are relevant. The existence of these laws provides a powerful basis for actions related to water resource activities that impact on ecosystem functioning. In addition, new legislation may be needed to provide greater protection for freshwater fish and wetland biodiversity, conservation and management, such as the adoption of appropriate standards in dams for inland fishes and water uses. Such legislation would be aligned to Saudi obligations to international treaties such as the Convention on Biological Diversity.

The National Law Of Regulating Trade in Endangered Species and Their Products Act No 54 of 1421 H, has several appendices of threatened species that are regulated in trade, typically linked to CITES regulations. Species included in these appendices are protected and not allowed to be caught or traded or to be displayed without permission. Saudi indigenous freshwater fish were added to these appendices in the past for protection as a precautionary measure until such time as supporting information becomes available to change this status. This study will work on incorporating these regulated species into fisheries management programmes, to benefit from their potential role in economic and social development. Taking Saudi species to be controlled under fisheries implement regulations would be more effective presumably than leaving freshwater fishes controlled under The National Law Of Regulating Trade in Endangered Species.

The plan should include co-operation between government agencies and stakeholders, emphasising the importance of working together to ensure all development activities do not impact on other users (Welcomme, 2008). The Ministry of Environment, Water and Agriculture in the Kingdom of Saudi Arabia will be entity that will oversee the Freshwater Fisheries Management Plan, because many of the administrative bodies that would contribute to implementing the plan work under this Ministry.

9.3.4 Strategic objectives for delivery of the Saudi Freshwater Fish Management Plan SFFMP (2021-2026).

Strategic actions generally target the weaknesses or issues that need to be addressed and contribute to reducing their impacts, in this case the problems associated with freshwater fish and fisheries. Until such time as long-term goals are established for Saudi freshwater fisheries in the Ministries, the SFFMP proposed as part of this study will target short to medium term strategic objectives. The overall timeframe for this plan is five years (2021-2026), and the potential outcomes will include the protection and management of freshwater fisheries within the main framework of the Ministry of Environment, Water and Agriculture of the Kingdom of Saudi Arabia, as an important resource in Saudi wetlands. The strategic objectives of the SFFMP, which arise from the outputs of this study and consultation with stakeholders are presented below and the framework for implementation is given in Table 9.3.

Improve data collection systems for Saudi freshwater fish and fisheries, conservation and management, and upscale research efforts

There is limited information about the freshwater fish and fisheries in Saudi, and awareness about these fish. There is also little work related to the impacts of water use and development activities in wetlands or fish to support management of exploitation of these fisheries, either for food or recreation purposes. It is fundamental to enhance research in freshwater fisheries and build a solid information base that supports any vision or plan to manage freshwater fisheries, regulate activities and conserve wetland biodiversity.

Establish and regulate sustainable freshwater fisheries and define appropriate levels of exploitation

Fisheries in wadis and reservoirs are rapidly expanding and it is becoming increasingly important to establish fisheries regulations to manage fishing pressure. There is also a need to find appropriate mechanisms to evaluate the status of fisheries through an appropriate low-cost fish catch data collection system or similar mechanism. If there is no efficient and cost-effective means of collecting data to represent the importance of freshwater fisheries the SFFMP may be rejected because the small-scale nature of the sector would likely not attract government spending within its environmental provisions. Establishing a licensing mechanism may enhance the importance of the sector and provide a potential income that may cover operational costs, although regulating such a licencing system may be prohibitive. This can build on the extensive experience that marine fisheries have in the management of fisheries resources. The establishment of freshwater fisheries as a branch of this administrative department may contribute to facilitating the implementation of the SFFMPs. A Freshwater Fisheries branch could work on developing the objectives and legislation for freshwater fisheries (wadis, wetlands and artificial waters), besides establishing the criteria to ensure they do not deteriorate by determining the potential fisheries harvest, codification of fishing gears, register of available fishing sites and seasonal and gear restrictions, register of recreational fishing opportunities, including species, seasons, size limits and methods of angling and raising public awareness of species. This activity can build on the present study which provides basic fisheries information for the management of the following indigenous species *Carasobarbus apoensis*, *Cyprinion mhalensis* and *Garra buettikeri*.

Critical to meeting this objective will be the establishment of freshwater fisheries "clubs" or fisheries community management units to contribute to the monitoring, protection of fisheries and their environments. This will require training in fishery-related skills, such as collecting data on fishing harvest and effort to underpin fisheries management activities.

Develop an appropriate institutional framework for the management of freshwater fisheries and wetlands

Coordination and promotion of efforts towards freshwater fisheries are essential if the SFFMP is to be successfully implemented. All government departments, agencies and stakeholders need to be engaged in the implementation of the plan and thus should have knowledge of the importance of these species and other aquatic biota to ensure they are considered in development plans. The coordination of activities should promote cooperation, resolve conflicts and problems and reduce deficiencies in knowledge to meet this strategic aim.

Develop strategic monitoring and assessment framework for freshwater fish and associated habitats

Fish refugia, if monitored, classified and protected, will contribute to protecting Saudi fishes from potential threats and the risk of extreme climate changes as they work as a natural stock and source of recruitment. This strategy will aim to build a bio-geographical database around these sensitive sites for monitoring and conservation and map the diversity of human activities surrounding them that may lead to degradation.

Control and regulate invasive species introduction and movements through development of risk assessments as part of species introduction procedures

Non-native invasive species are rapidly spreading across Saudi Arabia and critically into natural freshwater environments. These introductions do not appear to have undergone any environmental impact assessments to determine the impact of these invasive species on indigenous species. This study suggests there may be some dietary overlap between native and non-native species which could lead to loss of biodiversity. It is important to act to regulate movements of non-native invasive species and establish a governance system to control the use of non-native invasive species in aquaculture, for biological control or for capture fisheries. There is also a need to establish regulations and standards for the importation and selling of ornamental fishes through pet shops. For example, adding a mandate condition as an obligatory requirement for those buying any pet to not release them into the wild, and enforcing financial penalties for releasing non-native invasive species without permission, should be considered.

Improving the design, construction and operation of dams to meet the requirements of fish and their habitats

This action attempts to minimize the potential impacts of dams on fish and their environments, such as barriers to migration and flooding of critical habitat. Structural design standards and mitigation measures need to be established that support fish population dynamics and recruitment processes. For example, dams preventing the movement of fish in both upstream and downstream directions, causing disconnection and fragmentation of fish habitats, should be fitted with fish passage facilities. Moreover, water abstraction from some dams can have severe effects on the fish populations, especially through loss of water in downstream areas and water level fluctuations in the impoundment that disrupt the functioning of the habitat but also recruitment processes. There is a clear need to establish guidance and regulation to control water abstraction and avoid detrimental effects to the aquatic ecosystem and biodiversity.

Development of drought management plans to protect fish and their habitats during periods of prolonged and atypical drought conditions

Drought is a natural feature of the Saudi desert environment. Wetlands face severe desiccation during some periods of the year, but the effects are moderated by heavy rainfall during specific times of the year. Most organisms living in wadis and other natural water courses are adapted to these harsh environmental conditions as long as the refugia areas in the drought stricken areas are preserved. Unfortunately, human activities have disrupted the natural ecosystem functioning and climate change is leading to more intense periods of drought and flooding. As a consequence, the fish populations are becoming more stressed and affirmative action is needed to address this problem and avoid extirpation of populations of species in Saudi. Managing the exploitation of available water resources in harmony with the environment is an essential element of the SFFMP, but additional responsive actions to rescue stranded and dying fishes in atypical adverse conditions should be built into the management measures in the plan and resources should be made available carry out such actions.

Raising awareness and highlighting the role of the individuals, communities and cross-sectoral involvement in the management processes

Raising awareness of the presence and importance of native fish species in natural water bodies is essential if individuals, communities and other sectors are to act responsibly and not cause damage to the fish communities in water bodies. Knowing that there are aquatic organisms living in the natural water bodies and that they also have needs of the water resources is the first step to resolving water-related problems. Awareness raising campaigns targeting the public and agencies that operate in the water sector is an important strategic objective alongside research, information gathering and data interpretation. All users and beneficiaries should be fully aware of the complexities of wetland ecosystems and their interventions should be within a framework that protects both the wetlands and the biota, and provide them with the proper conditions to perpetuate and recruit naturally.

Rehabilitation of artificial lakes, and improve water quality to enable investment in recreational fishing

A number of artificial lakes have been formed across Saudi by urban or agricultural drainage, and some have become tourist destinations. These lakes are, however, not suitable for some activities such as swimming or fishing. Fishes present in these lakes are generally introduced for biological control purposes and they are not fit for human consumption. There is an urgent need to improve the environmental conditions in these lakes and improve their amenity value as well as minimise the human health risks. There is a challenge to improve the water quality in these lakes to enable a variety of other activities. Investment in this action could bring economic benefits to the local communities through tourism and improved amenity value for local people. It will also improve the quality of the fisheries and fishing experience.

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
Strategic goal 1 ***Improve data collection systems for Saudi freshwater fish and fisheries, conservation and management, and upscale research efforts***				
Specific objective: Formulate and implement data collection and dissemination systems for freshwater fisheries and their habitats, including impact of human activities, as primary input to support conservation of Saudi wetlands and their fisheries.				
Establish an effective and easy-to-implement approaches to catch assessment and collect data on exploitation and stock population size of freshwater fisheries. (**initiative 1).**	High	Years 2-3	Access to information on catch size and fish stocks for managing action on sustainable use.	Comparisons between population assessments and fisheries exploitation to underpin decision frameworks to manage fish stocks sustainably. Long-term evaluation of status and trends in freshwater fish stock.
Direct some financial support for research provided by King Abdulaziz City for Science and Technology (KACST) or other university research centres towards research on ecology of Saudi freshwater fishes including on impact of habitat degradation, behavioural responses to floods or drought, and genetic studies.	High	Year 5	Building a basic information data base on Saudi freshwater fish and their environments	Upgrade of research into freshwater fisheries in Saudi to fill gaps in knowledge and enable better decision making for the conversation of biodiversity in wetlands.
Prioritise research on wetlands that need to be taken up within the scope of research university projects.	High	Year 1	Establish research priorities for freshwater fish conservation and wetland management.	Ensure that such researches have become within the objectives of some universities research centres.

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Goal / Action	Priority	Timeframe	Outputs	Indicators
Establishing a research database of completed projects that contribute to supporting decision making **(initiative 2).**	Medium-high	Continuous	Centralisation of research and assessment data related to Saudi freshwater fishes for use by all stakeholders.	Books, scientific papers and digital open access database of fisheries information.
Strategic Goal 2: ***Establish and regulate sustainable freshwater fisheries and define appropriate levels of exploitation***				
Specific objective: Integration and establishment of freshwater fisheries management as a branch under General Directorate of Fisheries management structures				
Establishment of freshwater fisheries management unit under General Directorate of Fisheries management structure.	High	Years 2-3	Managing freshwater fisheries under the appropriate directorate.	The existence of a functional entity and cadres working for freshwater fisheries.
Issuing legislation and regulations relating to Saudi freshwater fisheries, including the banning of damaging fishing gears and establishing an operational team to perform fisheries management duties.	High	Years 2-4	Formulation of regulations for freshwater fisheries management.	Adoption of regulations and legislation by legislative bodies and enforcement of regulations.
Inform all fishers of regulations related to freshwater fisheries and fishing methods and to find a way to ensure that such information is clearly and practically accessible to all.	High	Continuous	Access to regular updates of regulations and information on sustainable fishing practices by fishers and their full awareness of related procedures.	- By introducing such measures regulate excessive fishing pressure and use of illegal fishing gears. - Keep fishers up to date of legislative changes and aware of problems facing

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
				the fisheries through Intelligent Fisheries Program App (see initiative 1). - Conduct random inspections of fishing sites to check compliance and status of the fisheries.
Formulation of regulation for establishment of freshwater fisheries clubs	Medium-high	Years 2-5	Strengthening the economic and social role of freshwater fisheries in Saudi Arabia.	Considering the number of applicants for investment in fishing clubs and issuing guidance to clubs of their roles and responsibilities.
Activating the role of the local community coordinators (such as Fishermen Sheikhs) in fisheries management operations and increase awareness of fisheries regulations.	Medium-high	Continuous	To highlight the role of the local fisheries community in management and to listen to expected problems.	At the locations of the fisheries, a representative of the fishermen from their community should communicate their voice and problems to the Fisheries Department.
Strategic goal 3: ***Develop an appropriate institutional framework for the management of freshwater fisheries and wetlands***				
Specific objective: Establish a coordinating council comprising all government agencies and stakeholders, to coordinate efforts on wetlands and users.				
Promote cooperation and harmony among all stakeholders and raise attention of the importance of living and non-living components of wetland ecosystems as pillars of a joint action plan.	High	Continuous	To promote mutual cooperation and awareness of the biodiversity components at their operations, to highlight their role in conservation.	Through periodic meetings of the Coordinating Council, and discussion of biodiversity and freshwater fish in their area of work and ways to avoid specific problems

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
Review plans, reports and propose solutions to common problems.	Annual	Annual	Monitoring and reviewing all processes occurring in the wetlands and their relationship to fish and biodiversity.	All parties operating in wetlands should provide the Council with a report each year.
Forming collaborative partnerships and draw cooperation agreements for all or between some of the concerned agencies, stakeholders and local communities near or within wetlands.	High	Continuous	Promote mutual understanding and unify efforts to develop the wetlands environment and promote sustainable use.	Access to clear written criteria for regulating water resource use to ensure the safety of aquatic organisms and to monitor those standards through a neutral body.
Acquaint all partners with key issues and proposed measures to understand and resolve potential conflicts between stakeholders to optimise use of wetland resources.	High	Annual		
Recommendation for Saudi Arabia to join the Ramsar Convention and register important sites/hotspots with the Convention Secretariat.	Medium	Years 1-2	Access to the Ramsar wetlands expertise, programmes and funding that is available to members of the Convention.	At least one site would be registered during the five-year period of the plan, with more to follow as the procedures are understood.
Involve the department responsible for the control of tropical diseases that result in the death of fish in finding a solution to reduce the impact of these operations on fish.	High	Years 1-4	Rescue fishes impacted by tropical disease control operations	At least 60% of sites where disease control actions occur support a worker trained I the rescue of fish.

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
Minimize the effects of diverse human activities such as tourism, agriculture and grazing on the wetland environments and define criteria for sustainable use.	High	Years 4-5	Establish frameworks, standards and scientific evidence to make control activities less damaging to wetland environments.	Annual reports from the departments responsible for organizing these various activities.
Support training programmes for human cadres	High	Annual	Develop the skills of workers in different sectors related to the wetland environment and freshwater fish	Establish annual training programmes through the Natural Resources Training Center to improve skills base in fisheries conservation and in accordance with needs of the Coordinating Council.
Strategic Goal 4: ***Develop strategic monitoring and assessment framework for freshwater fish and associated habitats***				
Specific objective: Institute and maintain a database and Geographical Information System involving spatial information of importance to freshwater fisheries management.				
Conduct a survey using GIS software to identify and classify water bodies supporting freshwater fisheries and identify the pressures on these systems and the associated risks to fish and fisheries.	Medium-high	Year 5	Identify and protect important fish habitats and formulate actions to address issues.	At least 100 key sites will be identified throughout the distribution range of Saudi freshwater fishes.
Identify priority locations to be protected from diverse human activities or promote interventions for restoration of degraded wetlands.	Medium-high	Year 1	Build on ancient traditional protection systems (such as Hema) and create freshwater	At least 10 protected sites representative of indigenous freshwater fish species in coastal plain wadis and wadis in mountainous highland areas.

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
			fish protection or conservation areas.	
Involve local people who benefit from fisheries and wetland ecosystem services (e.g. tourism sector) in awareness campaigns to protection the systems and control extractive or damaging uses.	Medium-high	Continuous	Highlight the role of local people in protecting sites from unsustainable exploitation.	Through regular field visits to these sites and visits to the local communities, recruit individuals as wildlife guards to enforce regulations in important locations.
Develop a mechanism for transferring and stocking fish between sites likely to be affected by drought or by human activities like disease control operations **(initiative 4, 6).**	High	Continuous	Conserve stressed fish populations from sharp declines in abundance and compensate the losses at sites that need support.	Establish two holding sites in the distribution range of Saudi freshwater fish as holding sites stocking conservation and restoration purposes.
Strategic Goal 5: ***Control and regulate invasive species introduction and movements through development of risk assessments as part of species introduction procedures***				
Specific objective: Establishment of a supervisory and coordinating body to control the introduction of invasive species into the freshwater environments, and assess potential risks, raise awareness and provide regulations for the introduction of any non-native species outside its natural range.				
Mapping of the current distribution of invasive species, conduct risk assessments of their current status and impact and devise possible eradication proposals.	High	Years 2-3	Improve knowledge the distribution of non-native fish species and mitigate potential impacts of non-native invasive species on native flora and fauna.	Issue maps of the distribution of non-native invasive species in most regions of the Kingdom of Saudi Arabia, especially through the range of indigenous freshwater fishes, and link with maps of

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
				valley drainage systems and their estuaries to assess the colonization risk.
Establish clear procedures for any individual or entity wanting to introduce non-native species for beneficial purposes such as aquaculture of disease control.	High	Year 1	Control the introduction of non-native species for different purposes.	Approve procedures and improve understanding of regulations before obtaining import licenses for non-native species, including ornamental fishes.
Create standards to ensure that fish, especially non-native species, do not escape from fish farms.	High	Years 2-3	Minimize the probability of fish escaping into the wild.	Periodic visits to fish farms to ensure adherence to these standards and their implementation. Also add these conditions under licenses granted for aquaculture projects.
Setting the necessary criteria for the possession or importation of any non-native species by individuals or organizations, and build cooperation with entities that issue import licenses.	High	Continuous	Educate owners of pets the problems arising from release of non-native species into the wild and finding a mechanism to receive unwanted animals to mitigate this issue.	Inspection visits to pet shops by Municipal staff to ensure compliance with procedures.
Spread awareness of the impact of invasive species and involve communities in the removal of harmful non-native species.	High	Years 1-5	Raise awareness and communicate the risk from introduction of non-native species to the public and create a responsible attitude among	The number of advertisements and advertising and dissemination tools that cover most segments of society, e.g. Facebook, Twitter.

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
			the public to address the source of the problem.	
Strategic Goal 6: ***Improving the design, construction and operation of dams to meet the requirements of fish and their habitats***				
Specific objective: Upgrading standards for design and operation of dams and artificial environment to improve connectivity and enhance the utility of new habitats for fish.				
Creating a framework aimed at balancing water requirements for irrigation or drinking purposes and for the conservation of wetland diversity; some water should remain in reservoirs for fish during period of high consumption and low rainfall.	High	Continuous	Establishment of early warning systems based on dam water levels reports issued by water companies in all regions.	Periodic reports of dam water levels and notification of potential adverse drought conditions.
Minimize the effect of some dams on the movement of fish and reduce the habitat fragmentation, in addition to corrective action to address barrier effects at existing dams.	High	Year 5	Minimize or mitigate problems cause by dams on migration success, habitat alterations or habitat fragmentation.	Periodic assessments that indicate ecological wellbeing of aquatic life and fish stocks.
Create design standards for new dams to ensure fish migration in both up and downstream directions is not compromised, especially during the flood season.	High	Year 2	Future dams constructed to defined specifications that protect fish habitat and access needs	Reaching agreements with dam operators and developers about the current problems with dams and making future designs suitable for fish.
Inspection for potential risks from water abstraction on fish and make adjustments to	High	Year 1	Determine the probable mortality due to the proximity of	In the case of death rates occurrence, it should be in the lowest estimates taking

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
abstraction procedures to minimize any potential impact.			fish to pumps at key stages of their life cycle.	appropriate measures and re-amendment those pumps.
Improve water quality in some reservoirs and enforce legislation or laws that control urban discharge, littering and disposal of agricultural waste high in nutrients.	High	Continuous	Control any contaminants that contribute to changing water quality to improve environment for fish and amenity.	Dams located on natural water bodies should be protected from any problematic illegal discharges and periodic inspections made to sites vulnerable to polluting discharges.
Enhancement of statistical data and databases for control of natural water resources and establish early warning plans for the rescue fishes that may be impacted by severe drought conditions.	High	Continuous	Emergency legislation to ensure impacts of depleted water stocks are reported and rescue operations instigated.	Records of early warning signals to appropriate agencies and action taken to address problem before it occurs.
Improvement and rehabilitation measures to protect fish spawning sites that may be desiccated by water abstraction or low water levels	High	Year 3	Make appropriate adjustments to the dam environment to be more suitable for fish.	Thorough checks to ensure dams (new and old) meet requirements for fish.
Strategic Goal 7: ***Development of drought management plans to protect fish and their habitats during periods of prolonged and atypical drought***				
Specific objective: Reduce the effects of drought and desertification on aquatic ecosystems				
Create outlines, indicators and guidelines to improve the resilience of wetlands to drought at the national level as a part of the National Program to Combat Desertification.	Medium-high	Year 5	Prediction of drought and proactive action to reduce impacts of drought on wetland habitats at the national level.	Establishment of comprehensive guidelines for drought management, contingency and mitigation measures,

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
Create an early warning plan and proactive measures based on both short-term and long-term responses, including monitoring frameworks for the timely warning of onset of drought conditions.	High	Year 5		such as presented by Rossi et al. (2007) and GWP CEE (2015).
Develop a national drought policy and implementation strategy plan for wetlands.	High	Year 5		
Strategic Goal 8: ***Raising awareness and highlighting the role of the individuals, communities and cross-sectoral involvement in the management processes***				
Specific objective: Promote environmental awareness via media tools of the importance of conservation of freshwater fish species and wetland biodiversity				
Build greater awareness through cooperation and engagement with various media types.	High	Continuous	Promote freshwater fish species is part of the natural heritage of the Saudi environment. Enhance the role of the media and civil society in spreading awareness and preserving wetland habitats and their organisms.	Number of published media materials and feedback from the observers.
Promote public events and festivals to raise awareness and engage with the non-profit sector in raising responsible use of wetlands**.**	High	Year 3		Public fairs and awareness weeks contribute to building a positive image and highlighting the role of environmental issues in a positive way. Involving the local community in saving fish during the time of drought or floods contributes to a valuable message.

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
Involvement of the educational sector to highlight the wetlands environment and its biodiversity, and to acquaint students with the politics of dealing with these environments and their living organisms.	High	Continuous	Inform the role of the next generation in protecting these valuable assets.	Highlighting of fish species and the wetland environment as part of the public education curriculum.
The establishment of wetlands museum including a living Saudi freshwater fish aquarium that highlights the role of wetlands and their biodiversity component**. (initiative 3)**	low	Year 5		Establish at least one living museum during the period of the plan for public or school visits that raises awareness of the importance of wetland habitats and their fishes.
Establishment of a voluntary association for the rescue of freshwater fish. **(initiative 4)**	Medium	Year 3		Voluntary association established.
Strategic Goal 9: Rehabilitation of artificial lakes, and improve water quality to enable investment in recreational fishing				
Specific objective: Develop and enhance the role of artificial lake for the purpose of recreational fishing,				
Comparing the costs and profits of artificial lakes restoration for improving these lakes water quality for various activity and recreational fishing. If there is no potential feasibility, an Adopt fish catch and release strategies can apply and impose a ban on removal fish for consumption.	Medium	Year 3	The establishment of sport fisheries, which may contribute to local economies and provision of financial resources to improve water and habitat quality of these lakes.	Restoration costs can be covered from the income from various activities. Water quality reaches appropriate standards. A recreational fishing club Established

Table 9.3. Strategic objectives, implementation actions, priorities and timeframe for delivery of SFFMP (2021-2026). Links to research initiatives highlighted under implementation plan (see Section 9.4) highlighted

Goal / Action	Priority	Timeframe	Outputs	Indicators
Promote these lakes for Investment by recreational sector.	High	Continuous	Enhancing educational, social, economic and recreational aspects of lakes.	
Strengthen educational aspects of these lakes such as bird watching, aquatic life monitoring.	low	Year 5		

9.4 Implementation

Within the framework of the wetland conservation management plan, there is the need to define priority actions targeting short to medium term actions to ensure sustainability of Saudi wetlands and associated fisheries. These proposed actions are summarised in Table 9.4. Implementation of the programme of actions will largely depend on availability of funding, but it is recommended that high priority actions are incorporated into the MEWA activities to ensure no net deterioration of the fisheries or ecosystem services from the fisheries / wetlands in the foreseeable future.

Table 9.4. Initiatives to support the implementation of the main strategies in the management plan

initiative 1: Mobile application (fisheries) to obtain fish catch information from fishermen	Using a smartphone application to collect and disseminate information about species catch at different water bodies to aid manage of freshwater fisheries. It includes licensing, harvested species and all fisheries operations, which will incorporate intelligent analysis processes and then the issuance of appropriate regulations at strategic times.
initiative 2: Enhanced research and information database	The establishment of an online central repository for all scientific information collected on freshwater fish, their habitats and associated problems. A comprehensive database of information about living and non-living components of wetland ecosystems to support conservation planning and future actions to protect these valuable ecosystems.
initiative 3: **Living Museum**	Establish a Living Wetlands Museum for Saudi freshwater fish for educational purposes.
Initiative:4 Establishment of refuge areas or operational rescue actions	Creating refuge areas within dams at times of water depletion which are suitable fish spawning or act as nursery grounds and not affected by water level fluctuations, is essential. Establishment of a charitable organisation, based on local communities, to help protect fish and wetlands and respond to stranded dying fish during extreme drought or flood periods would provide much needed support to conservation agencies. Provide suitable transport vehicles for use in rescue operations, for stocking operations or to transport fish from sites affected by pollution or spraying of pesticides for disease control.
initiative 5: **Green tourism**	Educate workers in the tourism sector about the importance of wetlands, so that their programmes support actions to protect and not damage the environment due to tourism activities, and to ensure that the conditions for any leisure industry project provide the necessary data and information to educate the tourists about environmental values.

Key elements to ensure successful implementation of the plan are:

- Integration of conservation management plans into an appropriate institution framework (see Section 9.4.1).
- Appropriate financial resources from ministries and other internal and external sources.
- Provision of the central, open access, repository for all information collected, and mechanisms for disseminating key information in a timely manner.
- Availability and motivation of personnel, including support from MEWA, regional councils, and communities exploiting the water bodies. This could be disaggregated to conservation areas as defined in Section 9.4.2.
- Necessary logistical resources and equipment available to implement the actions defined.
- Establishment of local management committee, involving all stakeholders and user groups to discuss and address local issues and formulate ongoing management actions.

This will provide a better understanding of the scale and diversity of the fisheries exploitation and non-fisheries related pressures on individual water bodies and recognition of issues arising and adaption strategies to address the issues in a timely manner.

A critical element of implementing the management plan is dissemination of the information collected and timely feedback to stakeholders and a wider national, regional and international audience. This is critical as many wetland systems throughout the world suffer from similar issues, thus the outcomes of the conservation plan will be of interest to the international audience and organisations like the IUCN, CBD and FAO. These wider dissemination activities will also improve capacity and incentivize staff to deliver quality outputs. In addition, a series of dissemination workshops should be organized at strategic intervals to inform stakeholders and enable feedback on the outcomes (benefits) derived from the actions.

9.4.1 Institutional framework and organisation

The aim of this plan is to have concerted efforts by all concerned parties to address the problems related to freshwater fish and implement the SFFMP. Figure 9.1 shows the recommended institutional structure to implement the plan including the establishment of a new department dealing with freshwater fisheries management as a part of General Directorate of Fisheries. There is also a need for a coordinating council that includes all parties to encourage continuous dialogue between agencies and reduce potential conflicts. This will create a working group of government agencies and stakeholders working in harmony to strengthen their role in protecting freshwater fish according to the terms of the SFFMP. The Ministry of Environment, Water & Agriculture (MEWA) is the entity that will implement the proposed plan in association with the following government agencies each providing input according to its specialization.

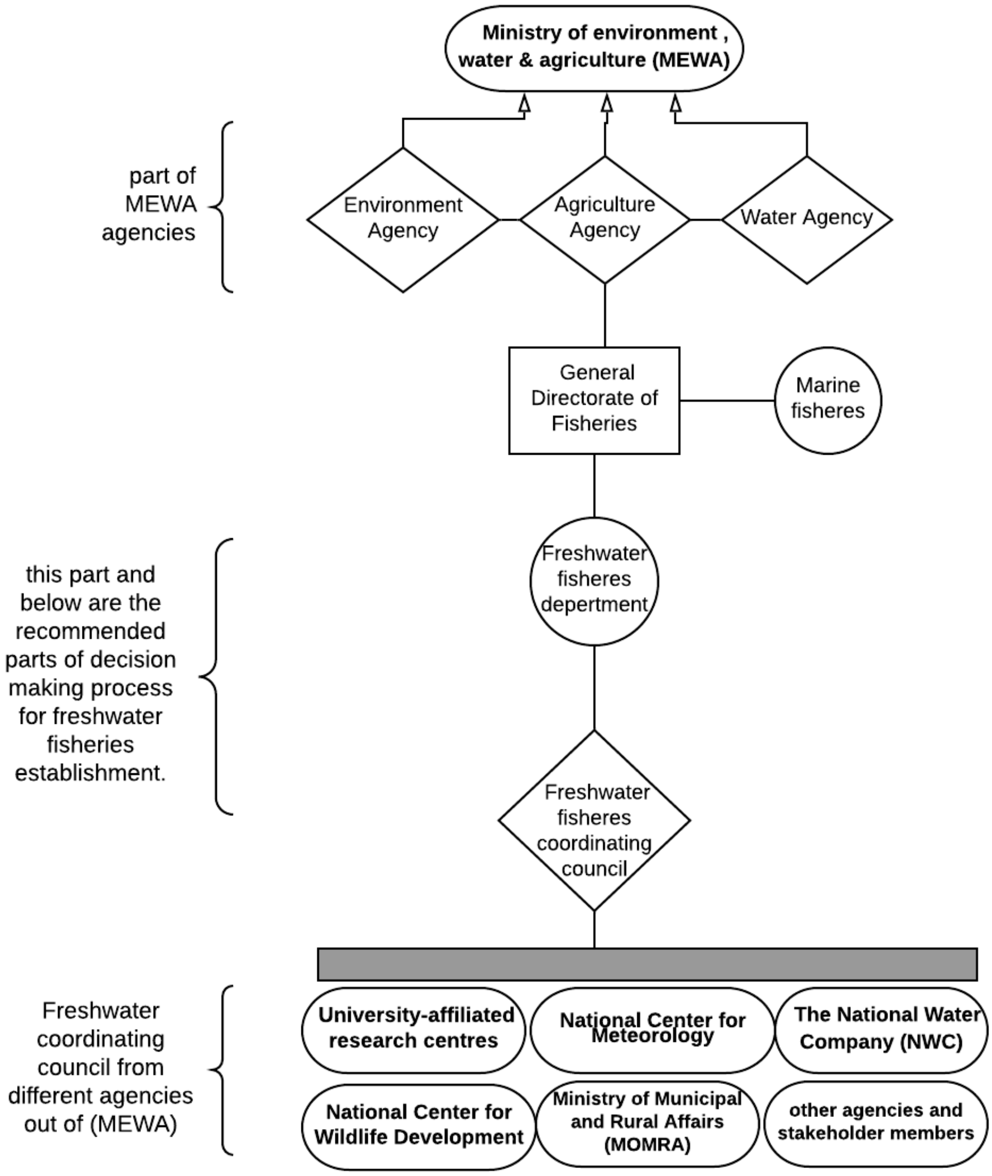

Figure 9.1. Recommended decision-making structure for the establishment of a new department concerning freshwater fisheries management as a part of the General Directorate of Fisheries.

- Ministry of Environment, Water & Agriculture (MEWA)

  - Environment Agency (National Environmental Strategy)

  - Water Agency (National Water Strategy)

  - Agriculture Agency (General Directorate of Fisheries (DoF))

- Saudi Irrigation Organization (SIO)
- National Center for Wildlife Development

  - Natural Resources Training Centre.

- The National Water Company (NWC)

- National Center for Meteorology
- Ministry of Municipal and Rural Affairs (MOMRA)
- King Abdulaziz City for Science and Technology (KACST)
- Saudi Commission for Tourism and National Heritage (SCTH)
- University-affiliated research centres

Cooperation between these different agencies would raise the level of environmental commitment by all sectors to development, thus reducing pollution and other negative impacts on the freshwater environment. It would also enhance the effectiveness of the freshwater fisheries sector (institutional framework, governance, operational model, environmental regulations and sector sustainability), protect wildlife and conserve biodiversity.

9.4.2 Saudi Freshwater Fishery Management Regions

The main distribution range of native freshwater fishes in Saudi Arabia is the south and west of the country (Figure 9.2). There are six administrative counties in this region and it is recommended that district offices of the Ministry of Environment, Water & Agriculture (MEWA) are established in these counties. The General Directorate of Fisheries will oversee the establishment of freshwater fisheries management operations and prioritize this region in the SFFMP. Priority actions in the other areas (shown in Figure 9.2 without fish symbols) should focus around monitoring of non-native species distribution and promotion of recreational fisheries in artificial lakes, coupled with managing other water quality related problems.

Figure 9.2. Saudi freshwater fish distribution range (grey) that will be targeted by the SFFMP. Areas in turquoise will target promoting recreational fisheries in artificial lakes.

9.5 Conclusions

There has been an urgent action needed from a long time ago to address the problems related to Saudi freshwater fishes and to create an integrated conservation plan, includes many strategies to ensure the safety of fish and the enhancement of its socio-economic roles. Hence, this plan was built to address many problems (introduced species, unregulated fishing activities, dam related problems, drought and lack of rain, extensive pumping of water for domestic supply and agriculture, water quality issues, urbanization and rural development, pastoralists and tourists and pesticides), then draw practical frameworks within government agencies to tackle or reduce the impacts on fish. Ecosystem management, management of human activities and emergency actions were the three main divisions targeted by the plan. The main strategies of this plan included:

- Information and research enhancement.
- Sustainable establishment and regulation of freshwater fisheries.
- Enhanced cooperation, harmony and coordination among those responsible for the implementation of this plan.
- Monitoring of vital freshwater fish sites to ensure protection from potential threats.
- Regulation and control of invasive species and conducting appropriate risk assessments prior to release.
- Addressing problems related to dams on fish.
- Developing drought management plans to conserve fish during these periods.
- Raising awareness and enhancing the role of the individual.
- The community and relevant stakeholders.
- Improving water quality in artificial lakes to have their greater role in recreational fisheries and diverse economic activities.

Also, many of initiatives proposed to support the implementation of the main strategies in the management plan, such as:

- The use of smart devices to support fisheries management processes.
- The issuance of appropriate licenses and to obtain fish catch information from fishermen fishing activity.

The plan included as well the recommended institutional structure and regions to implement the plan containing the establishment of a new department dealing with freshwater fisheries management as a part of General Directorate of Fisheries. In addition, the recommendation of establishing a coordinating council that includes all parties to encourage continuous dialogue between agencies and reduce potential conflicts.

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Appendix A Saudi freshwater fishes identification keys.

By Krupp (1983), diagrams by Ibrahim

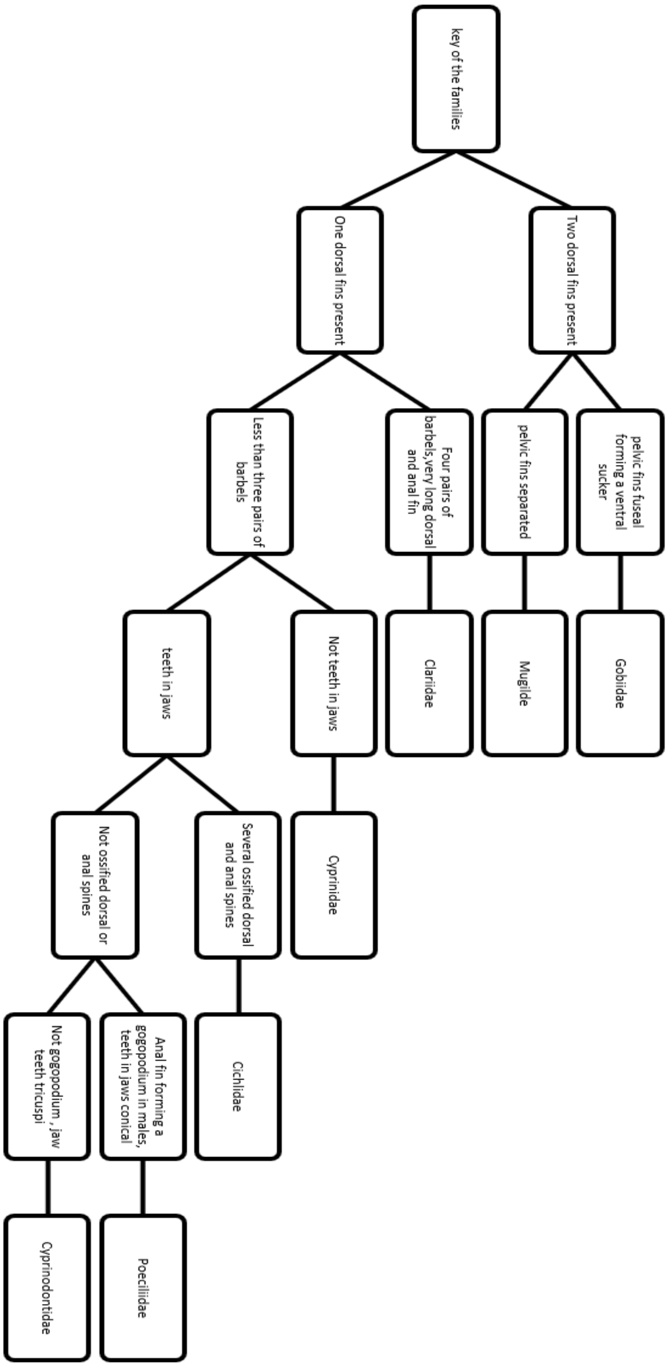


Diagram (1): shows Krupp's keys to Saudi freshwater fishes Only Cyprinidae and Cyprinodontidae described.

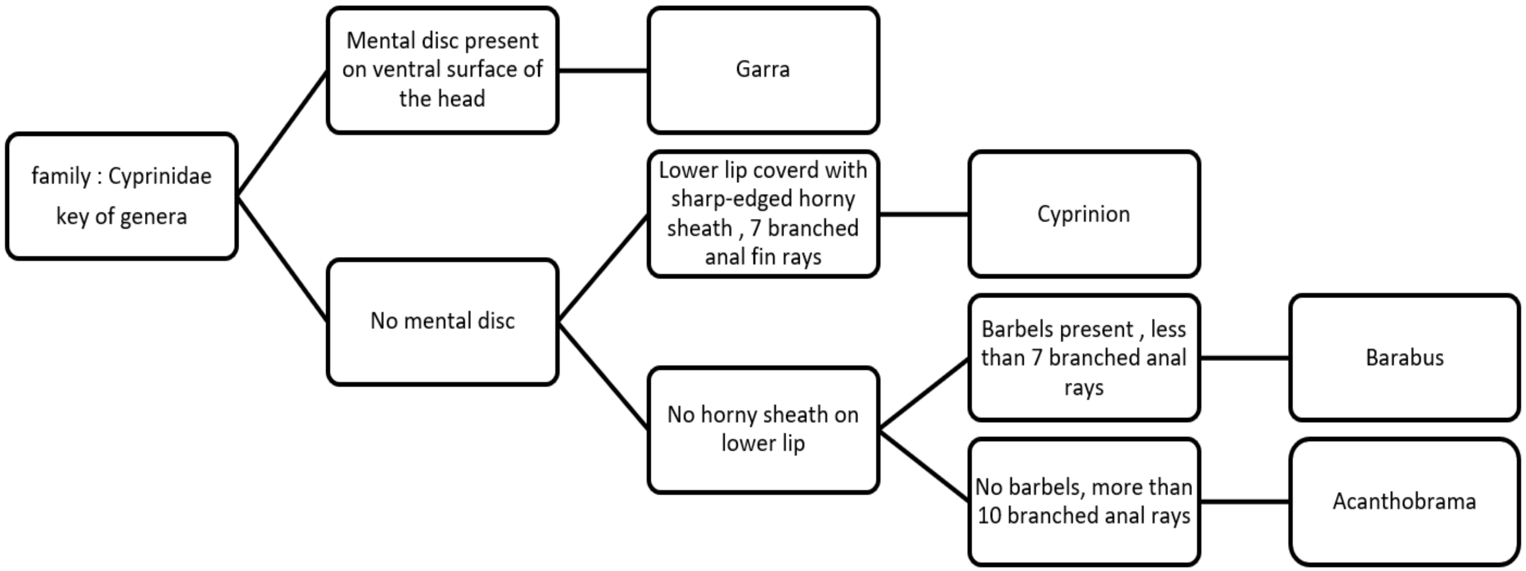


Diagram (2): Shows Krupp’s keys to Saudi freshwater fishes, Cyprinidae family, key of genera.

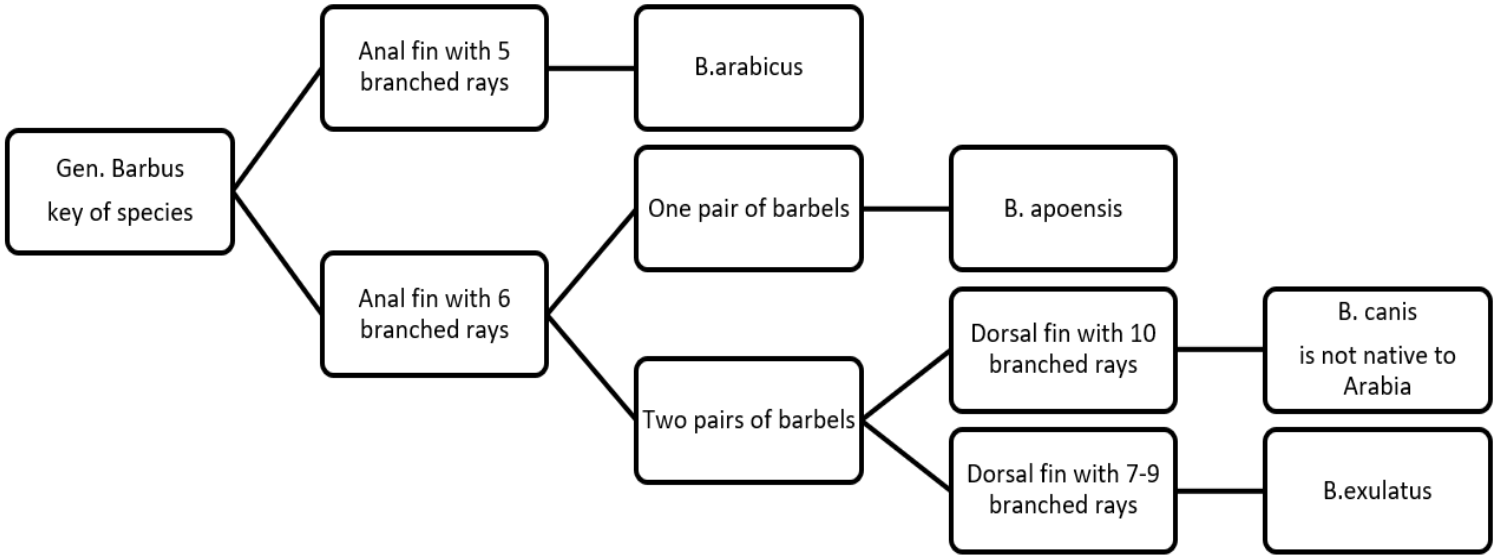


Diagram (3): Shows Krupp's keys to Saudi freshwater fishes, Barbus Genus, key of species.

Diagram (4): Shows Krupp’s keys to Saudi freshwater fishes, Cyprinion Genus, key of species and subspecies.

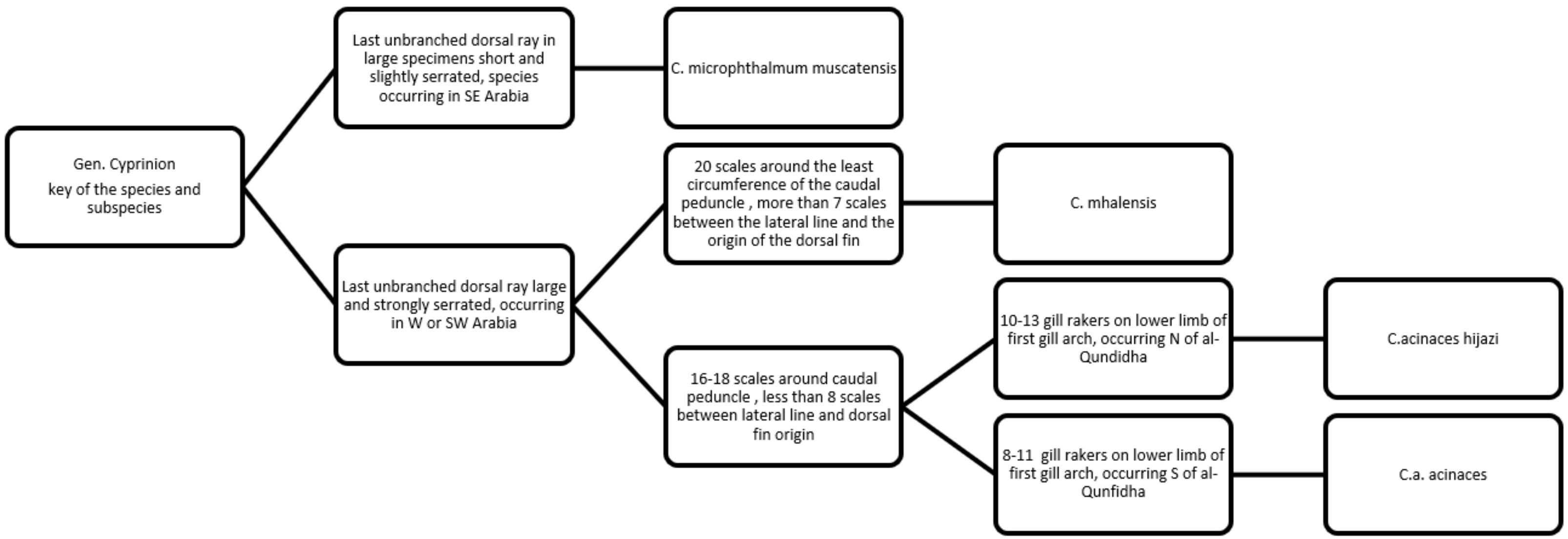
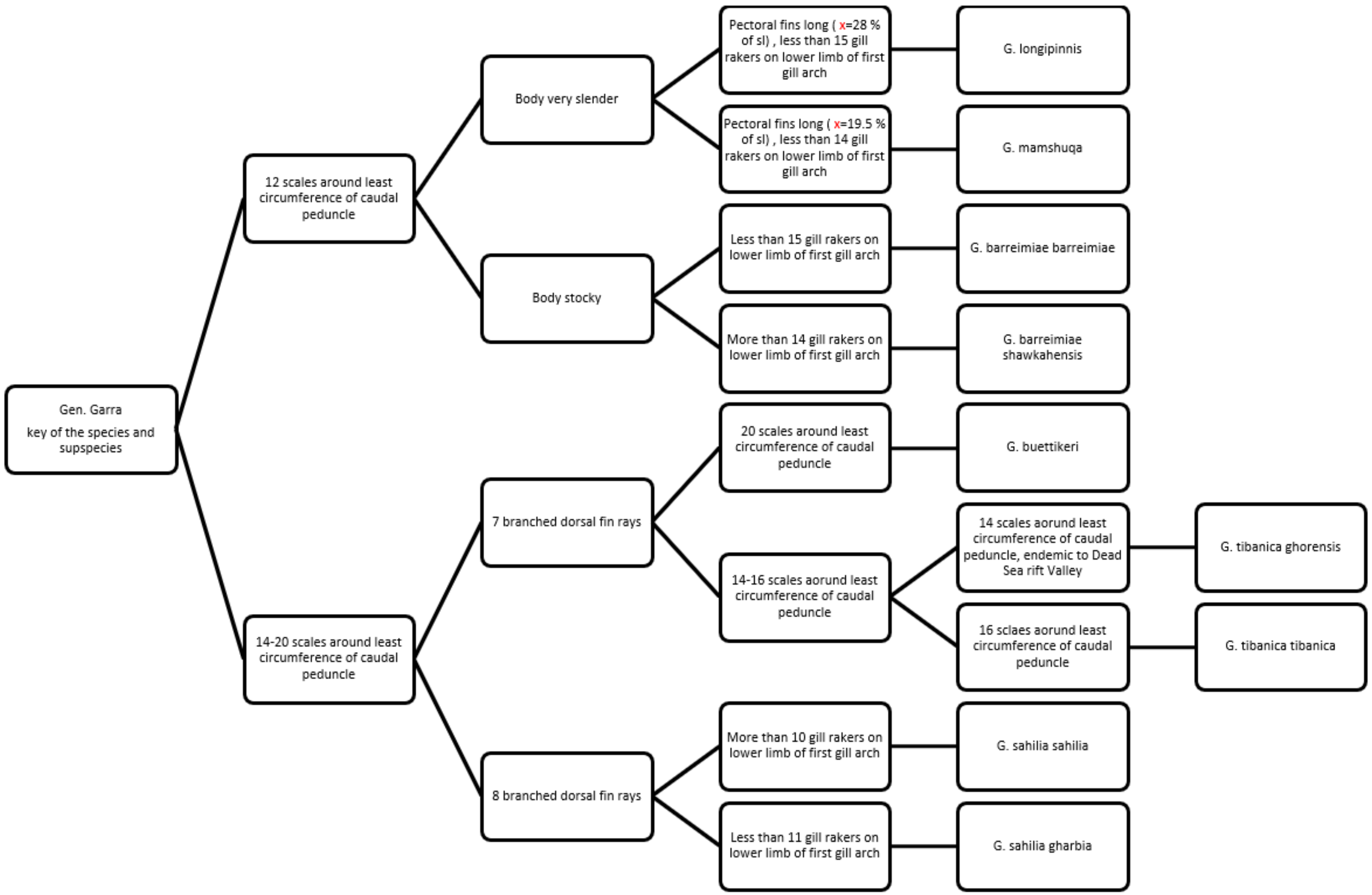


Diagram (5): Shows Krupp's keys to Saudi freshwater fishes, Garra Genus, key of species and subspecies.



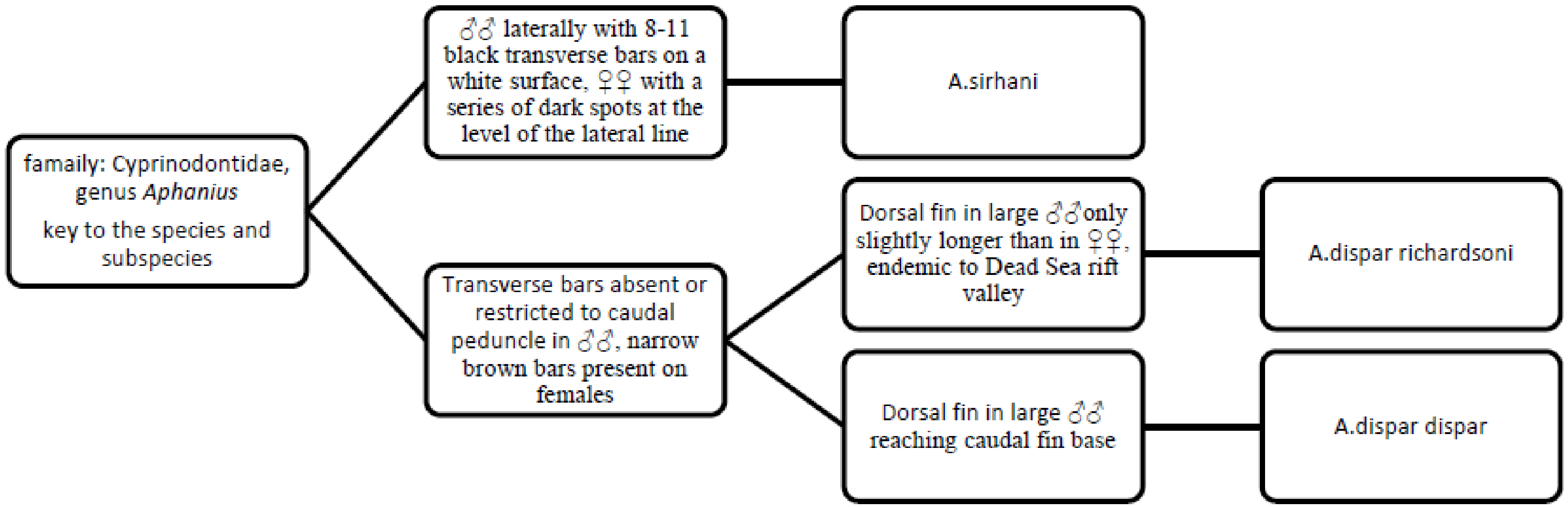


Diagram (6) : Shows Krupp's keys to Saudi freshwater fishes , Cyprinodontidae famaily, genus *Aphanius*, Key of species and subspecies

Appendix B The locations of water bodies

Region	WBT	location name	Latitude	Longitude
EDS	Wadi	Khamis Mshait	18.283333	42.566667
		Wadi Turbah	22.933333	40.9
		Wadi Adama	19.883333	41.95
		Wadi Al-Mahallah	17.966667	43.4
		Wadi Hadiyah	25.7	39.516667
		Wadi Turbah	20.483333	41.15
		Wadi Turbah	20.5	41.283333
		Wadi Turbah	20.483333	41.2
		Wadi shuqub	20.65	41.216667
		Khamis Mshait	18.291286	42.576817
		Wadi Adama	19.888135	41.956617
		Wadi Turbah	20.454089	41.194244
		Wadi Turbah	20.508852	41.268017
		Wadi Al-janbeen	19.928982	41.69185
		Wadi THARAD	20.137023	41.717087
		Wadi Al-Aqiq	20.236721	41.55131
		Wadi Buwah	20.740136	41.015227
		Wadi Turbah	20.540643	41.285626
		Wadi Shuqub	20.645758	41.223477
		Khamis Mshait	18.291531	42.572097
		Wadi Adama	19.891014	41.957681
		Taif	21.333333	40.5
		Wadi Turabah	20.483333	41.15
		Wadi Turabah	20.483333	41.2
		Wadi Turabah	20.5	41.283333
		Wadi Afrak	19.8	41.983333
		Wadi Adama	19.683333	42.066667
		Wadi Shuqub	20.65	41.216667
		Wadi Buwah	20.783333	41.2
		Wadi Shumrukh	20.433333	41.3
		Wadi noaman	18.233333	42.583333
		Taif	21.333333	40.35
		Wadi Tarj	19.116667	42.483333
		Wadi Shumrukh	20.75	41.533333
		Wadi Al-Arj	21.383333	40.75
		Wadi Turabah	20.9	41.466667
		Wadi Turabah	20.456037	41.189652
		Wadi Turabah	20.540643	41.285626
		Wadi Al-janbeen	19.928982	41.69185
		Wadi THARAD	20.137023	41.717087
		Wadi Al-Aqiq	20.236721	41.55131
		Wadi Shuqub	20.615632	41.204644
		Wadi Buwah	20.759352	41.182264
		Wadi Buwah	20.739855	41.014036

		Wadi Shumrukh	20.438607	41.298809
		Wadi Al-Mahallah	18.303726	42.586125
		Taif	21.338856	40.571308
		Wadi Turabah	20.483333	41.2
		Wadi Turabah	20.5	41.283333
		Wadi Adama	19.433333	42.05
		Wadi Adama	19.683333	42.066667
		Wadi Shumrukh	20.45	41.316667
		Wadi Noaman	18.233333	42.583333
		Wadi Shumrukh	20.75	41.533333
		Wadi Al-Arj	21.383333	40.75
		Wadi Turabah	20.9	41.466667
		Wadi Turabah	20.503007	41.276293
		Wadi Turabah	20.52213	41.271506
		Wadi THARAD	20.137023	41.717087
		Wadi Buwah	20.737927	41.027103
		Wadi Noval	20.383333	41.316667
		Wadi Shumrukh	20.468573	41.304092
		Wadi Al-Aqiq	20.236721	41.55131
		Wadi Al-janbeen	19.928982	41.69185
	reservoir	Al-janbeen Dam	19.902398	41.710634
		THARAD Dam	20.158583	41.721276
		Al-Aqiq Dam	20.237057	41.571396
		AL-SDAR,Wadi and Dam	20.125952	41.358881
		MEDHAS DAM	20.222733	41.274157
		MEDHAS DAM	20.222733	41.274157
		Al-janbeen Dam	19.902398	41.710634
		THARAD Dam	20.158583	41.721276
		Al-Aqiq Dam	20.237057	41.571396
		AL-SDAR,Wadi and Dam	20.125952	41.358881
		Abha Dam	18.216667	42.483333
		MEDHAS DAM	20.222249	41.275566
		Al-Janbeen Dam	19.911046	41.711293
		THARAD Dam	20.164583	41.716489
		Al-Aqiq Dam	20.241246	41.563219
		AL-SDAR,Wadi and Dam	20.125952	41.358881
		THARAD Dam	20.157583	41.722222
		Al-janbeen Dam	19.903505	41.711611
		Abha Dam	18.21071	42.487509
		near Medhaas	20.213884	41.275912
WDS	Wadi	Wadi Haqqaq	22.816667	39.366667
		Wadi Hadiyah	25.566667	38.683333
		Wadi Juva	17.637997	42.390331
		Wadi Damad	17.333333	43.033333
		Wadi Baish	17.586043	42.618308
		Khaibar	25.7	39.2

WDS	Wadi	Wadi Hadiyah	24	39
		Wadi Sulaym	25.6	39.266667
		Wadi Al-Bagarah	18.77	41.98
		Wadi Hadiyah	25.55	38.733333
		Wadi Hadiyah	25.547724	38.813584
		Wadi Minsah	20.516667	40.666667
		Wadi North Jizan	17.533333	42.416667
		Bani Sharfa (Al-Ahsabah Dam)	19.7	41.4
		Wadi Gaanah	18.433333	41.883333
		Wadi Kudais	19.15	41.82
		Wadi Al-Gassah	18.72	41.99
		Wadi Al-Bagarah	18.77	41.98
		Wadi Haroub	17.46	42.88
		Wadi Minsah	20.51853	40.669433
		N of Jizan	17.572977	42.424881
		Wadi ileeb	20.108197	40.867726
		Wadi North Jizan	17.533333	42.416667
		Khaibar	25.7	39.2
		Wadi Hesu'a	18.083333	42.35
		Wadi Damad	17.283333	43.1
		Wadi Damad	17.333333	43.033333
		Wadi Khadrah	23.1	39.7
		Wadi Fatima	21.791382	40.007432
		Wadi Damad	17.204278	43.002611
		Wadi Juva	17.637997	42.390331
		Wadi Hesu'a	18.084899	42.350282
		Khaibar	25.677731	39.21192
		Wadi Khulab	16.76	43.12
		Wadi Al-Bagarah	18.77	41.98
		Wadi Kudais	19.15	41.82
		Wadi Khadrah	23.1	39.7
		Wadi Fatima	21.698361	39.887139
		Wadi Reem	17.782709	42.140124
		Wadi Rabig	22.745938	39.182643
		Wadi Rabig	22.743694	39.192528
	reservoir	Baish Dam	17.667402	42.659532
		Al-Bint Dam	25.484514	39.362822
		Qusaiba’a Dam	25.203333	39.363194
	spring	Ain Al-Hammah - Khaibar	25.783333	39.433333
		Alein Al-Harrah	20.46	40.46
		Ain Al-Hammah - Khaibar	25.783333	39.433333
		Ein Al-Buhairah	25.72	39.26
EP	Irrigation channels	al-Qatif	26.55	50
		al-Hufuf	25.4	49.466667
		al-Hasa oasis	25.43275	49.614028
		al-Hasa oasis	25.362621	49.683272

		al-Hasa oasis	25.405178	49.735335
		al-Hasa oasis	25.393228	49.713575
		al-Hasa oasis	25.376561	49.698757
		al-Hasa oasis	25.376075	49.70458
		al-Hasa oasis	25.469644	49.625417
		al-Hasa oasis	25.466139	49.594917
	LAKE	al-Asfer Lake	25.519056	49.805211
		al-Asfer Lake	25.538676	49.811926
		al-Asfer Lake	25.511485	49.826422
	spring	Khodod spring	25.422	49.587167
MR	LAKE	Salam Lake	24.619333	46.708528
	reservoir	Nemar Dam	24.570203	46.673129
		Nemar Dam	24.574809	46.68568
		Nemar Dam	24.571889	46.682139
		Nemar Dam	24.570361	46.674417
	Wadi	al-Kharj	24.35	47.183333
		Wadi Hanefah	24.633525	46.657588
		al-Kharj	24.132085	47.400812
		al-Kharj	24.534189	46.759139
		al-Hair,Riyadh	24.418972	46.814314
		al-Hair,Riyadh	24.383806	46.829763
		Wadi Hanefah	24.383298	46.825124
		Wadi Hanefah	24.568876	46.672821
		Wadi Hanefah	24.55194	46.738566
		Wadi Hanefah	24.384607	46.827722
		Wadi Hanefah	24.385347	46.845238
MRN	LAKE	al-Majmaah	25.900701	45.326626
	Wadi	Wadi Rumah	26.185451	44.00864
		Wadi Rumah	26.185451	44.00864
NORTH	LAKE	Duma Jandal Lake	29.814229	39.910684

Appendix C (Data Analysis output)

The diet differences among Carasobarbus apoensis age groups PERMANOVA Permutational MANOVA

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
age group	ag	Fixed	4

PAIR-WISE TESTS

Term 'ag'

Groups	t	P(perm)	Unique perms
G1, GJUV	1.6065	0.016	999
G1, G2	3.2925	0.001	999
G1, G3	1.4848	0.048	998
GJUV, G2	1.687	0.017	998
GJUV, G3	1.4595	0.055	985
G2, G3	0.98213	0.45	999

Denominators

Groups	Denominator	Den.df
G1, GJUV	1*Res	381
G1, G2	1*Res	505
G1, G3	1*Res	392
GJUV, G2	1*Res	134
GJUV, G3	1*Res	21
G2, G3	1*Res	145

Average Similarity between/within groups

	G1	GJUV	G2	G3
G1	24.844			
GJUV	23.406	40.269		
G2	24.107	24.533	28.161	
G3	24.868	27.232	28.684	29.16

Differences in diet between *Carasobarbus apoensis* locations PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
locations	lo	Fixed	7

PAIR-WISE TESTS

Term 'lo'

Groups	t	P(perm)	Unique perms
WB, WT	2.3716	0.001	962
WB, AQ	1.9753	0.002	975
WB, MD	3.1747	0.022	56
WB, TH	2.1613	0.001	996
WB, AJ	1.9946	0.001	996
WB, AS	2.3989	0.001	998
WT, AQ	3.1469	0.001	999
WT, MD	1.889	0.024	998
WT, TH	3.5475	0.001	998
WT, AJ	4.167	0.001	998
WT, AS	6.2723	0.001	999
AQ, MD	1.6797	0.023	998
AQ, TH	1.6885	0.016	999
AQ, AJ	3.0855	0.001	998
AQ, AS	6.7202	0.001	998
MD, TH	2.0796	0.002	997
MD, AJ	2.3262	0.001	997
MD, AS	2.9621	0.001	999
TH, AJ	3.6837	0.001	998
TH, AS	7.1627	0.001	998
AJ, AS	5.6055	0.001	999

Average Similarity between/within groups

	WB	WT	AQ	MD	TH	AJ	AS
WB	47.072						
WT	14.349	39.645					
AQ	13.091	26.465	27.536				
MD	9.0929	35.898	30.958	54.804			
TH	17.083	29.419	29.993	30.442	34.616		
AJ	13.25	23.25	23.863	19.421	26.406	27.411	
AS	11.851	18.815	16.158	15.582	19.604	23.466	35.391

Differences in diet between *Carasobarbus apoensis season*
PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
seasons	se	Fixed	3

PAIR-WISE TESTS

Term 'se'

Groups	t	P(perm)	Unique perms
T3, T1	4.4121	0.001	998
T3, T2	2.5957	0.001	999
T1, T2	3.4277	0.001	999

Average Similarity between/within groups

	T3	T1	T2
T3	27.591		
T1	23.215	27.671	
T2	24.685	23.595	24.914

The diet differences among *Cyprinion mahalensis* age groups
PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem3
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
age group	ag	Fixed	3

PAIR-WISE TESTS

Term 'ag'

Unique

Groups	t	P(perm)	perms
G1, GJUV	0.77318	0.705	999
G1, G2	1.5671	0.045	998
GJUV, G2	1.0789	0.343	999

Average Similarity between/within groups

	G1	GJUV	G2
G1	43.491		
GJUV	42.51	41.227	
G2	43.168	42.203	44.111

The diet differences among *Cyprinion mahalensis* locations
PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem3
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
locations	lo	Fixed	7

PAIR-WISE TESTS

Term 'lo'

Groups	t	P(perm)	Unique perms
WB, WT	2.8792	0.001	999
WB, AQ	2.5705	0.001	999
WB, MD	2.4381	0.001	999
WB, TH	3.5698	0.001	996
WB, AJ	2.2372	0.003	998
WB, AS	3.0342	0.001	998
WT, AQ	2.6453	0.003	999
WT, MD	2.4957	0.001	998
WT, TH	3.4056	0.001	999
WT, AJ	1.7487	0.022	999
WT, AS	3.734	0.001	998
AQ, MD	3.1819	0.001	999
AQ, TH	4.535	0.001	999
AQ, AJ	1.5226	0.072	998
AQ, AS	2.3472	0.002	999
MD, TH	4.2476	0.001	998
MD, AJ	2.3924	0.001	998
MD, AS	4.9058	0.001	999
TH, AJ	3.6787	0.001	999
TH, AS	3.9375	0.001	999
AJ, AS	3.4779	0.001	999

Average Similarity between/within groups

	WB	WT	AQ	MD	TH	AJ	AS
WB	50.334						
WT	33.819	42.201					
AQ	49.077	44.9	61.84				
MD	36.618	35.845	41.785	38.063			
TH	43.071	42.037	49.839	35.997	63.063		
AJ	41.946	42.191	52.598	38.901	44.879	46.749	
AS	44.75	41.242	56.034	37.372	50.73	46.595	56.428

The diet differences among *Cyprinion mahalensis* seasons PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: Resem3
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
seasons	se	Fixed	3

PAIR-WISE TESTS

Term 'se'

Groups	t	P(perm)	Unique perms
T2, T3	4.1512	0.001	999
T2, T1	2.0961	0.002	998
T3, T1	5.436	0.001	999

Denominators

Groups	Denominator	Den.df
T2, T3	1*Res	230
T2, T1	1*Res	126
T3, T1	1*Res	238

Average Similarity between/within groups

	T2	T3	T1
T2	38.939		
T3	39.024	50.741	
T1	39.994	39.395	44.577

The diet differences among Garra buettikeri age group

PERMANOVA
Permutational MANOVA

```
Resemblance worksheet
Name: Resem4
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors
Name       Abbrev. Type   Levels
age group  ag      Fixed       3

PAIR-WISE TESTS

Term 'ag'

                             Unique
Groups         t  P(perm)   perms
G1, GJUV  1.1224    0.275     942
G1, G2    2.2638    0.001     999
GJUV, G2  1.6364    0.044     936


Average Similarity between/within groups
         G1    GJUV     G2
G1   46.177
GJUV 37.853  17.423
G2   47.736  33.657  51.135
----
```

The diet differences among Garra buettikeri locations

PERMANOVA
Permutational MANOVA

```
Resemblance worksheet
Name: Resem4
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors
Name       Abbrev. Type   Levels
locations  lo      Fixed       7

PAIR-WISE TESTS
```

Term 'lo'

Groups	t	P(perm)	Unique perms
WB, WT	1.3271	0.141	999
WB, AQ	4.0384	0.001	999
WB, MD	3.0658	0.001	999
WB, TH	3.9275	0.001	999
WB, AJ	4.5988	0.001	999
WB, AS	3.07	0.001	999
WT, AQ	4.1213	0.001	997
WT, MD	3.1564	0.001	999
WT, TH	4.1493	0.001	999
WT, AJ	4.7693	0.001	999
WT, AS	2.7889	0.001	999
AQ, MD	2.7495	0.001	999
AQ, TH	2.752	0.001	998
AQ, AJ	1.9	0.007	999
AQ, AS	4.0191	0.001	999
MD, TH	2.6282	0.001	998
MD, AJ	3.2782	0.001	999
MD, AS	2.1664	0.006	998
TH, AJ	3.1556	0.001	999
TH, AS	3.1076	0.001	998
AJ, AS	3.609	0.001	998

Average Similarity between/within groups

	WB	WT	AQ	MD	TH	AJ	AS
WB	46.926						
WT	46.028	47.144					
AQ	42.438	41.573	63.278				
MD	42.314	41.018	50.059	47.974			
TH	40.703	38.132	55.074	47.948	55.436		
AJ	43.145	41.019	60.011	49.732	53.896	60.111	
AS	43.383	44.279	46.279	48.685	47.37	49.7	60.039

The diet differences among Garra buettikeri seasons

PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem4
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
seasons	se	Fixed	3

PAIR-WISE TESTS

Term 'se'

Groups	t	P(perm)	Unique perms
T1, T2	2.0203	0.004	998
T1, T3	2.4035	0.001	999
T2, T3	2.4757	0.001	999

Average Similarity between/within groups

	T1	T2	T3
T1	52.875		
T2	48.569	48.457	
T3	48.732	44.805	47.31

The diet differences among *Oreochromis niloticus* age groups PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: Resem5
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
age group	ag	Fixed	3

PAIR-WISE TESTS

Term 'ag'

Groups	t	P(perm)	Unique perms
G1, G2	0.78581	0.649	998
G1, GJUV	1.7413	0.021	984
G2, GJUV	1.5586	0.044	750

Average Similarity between/within groups

	G1	G2	GJUV
G1	50.744		
G2	50.242	48.743	
GJUV	45.182	45.57	57.257

The diet differences among *Oreochromis niloticus locations and seasons*

Term 'lo'

Groups	t	P(perm)	Unique perms
ASFR, TH	1.7588	0.016	997

Denominators

Groups	Denominator	Den.df
ASFR, TH	1*Res	91

Average Similarity between/within groups

	ASFR	TH
ASFR	48.892	
TH	54.127	73.294

Factors

Name	Abbrev.	Type	Levels
seasons	se	Fixed	3

PAIR-WISE TESTS

Term 'se'

Groups	t	P(perm)	Unique perms
T1, T2	2.6945	0.001	999
T1, T3	5.6335	0.001	999
T2, T3	2.897	0.001	998

Average Similarity between/within groups

	T1	T2	T3
T1	69.205		
T2	53.044	49.555	
T3	42.154	47.303	54.965

Factors

Name	Abbrev.	Type	Levels
locations	lo	Fixed	2
seasons	se	Fixed	3

PAIR-WISE TESTS

Term 'loxse' for pairs of levels of factor 'locations'

Within level 'T3' of factor 'seasons'

Groups	t	P(perm)	Unique perms
ASFR, TH	1.8701	0.013	999

Denominators

Groups	Denominator	Den.df
ASFR, TH	1*Res	39

Average Similarity between/within groups

	ASFR	TH
ASFR	52.191	
TH	56.466	73.294

The diet differences among *Poecilia latipinna* age groups

PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: Resem6
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
age	ag	Fixed	3

PAIR-WISE TESTS

Term 'ag'

Groups	t	P(perm)	Unique perms
1, 2	1.5342	0.043	171
1, 0	1.368	0.099	928
2, 0	1.2207	0.313	15

Average Similarity between/within groups

	1	2	0
1	66.622		
2	58.105	53.74	
0	67.303	65.856	75.448

Differences in diet between the different fish species

PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: Resem1
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
species	sp	Fixed	7

PAIR-WISE TESTS

Term 'sp'

Groups	t	P(perm)	Unique perms
GB, CM	7.565	0.001	999
GB, CA	7.8323	0.001	998
GB, ON	7.0224	0.001	999
GB, PL	3.0823	0.001	999
GB, GA	4.3023	0.001	999
GB, CC	2.0555	0.009	999
CM, CA	6.2464	0.001	999
CM, ON	8.9803	0.001	999
CM, PL	3.4853	0.001	997
CM, GA	3.6839	0.001	999
CM, CC	2.4837	0.001	999
CA, ON	6.7412	0.001	998
CA, PL	3.3115	0.001	999
CA, GA	2.0758	0.001	999
CA, CC	1.5102	0.036	996
ON, PL	3.5229	0.001	998
ON, GA	3.9119	0.001	998
ON, CC	2.3004	0.001	999
PL, GA	4.4466	0.001	997
PL, CC	3.1154	0.001	996
GA, CC	2.2828	0.004	581

Average Similarity between/within groups

	GB	CM	CA	ON	PL	GA	CC
GB	48.086						
CM	39.764	43.33					
CA	29.22	29.548	24.829				
ON	39.592	30.816	24.565	50.164			
PL	49.239	43.798	30.943	49.543	65.795		
GA	15.372	17.46	21.245	21.543	26.719	41.024	
CC	42.117	32.878	30.591	41.299	47.687	29.699	60.991

Differences in diet between fish species at specific location

PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem1
Data type: Similarity
Selection: All
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 999

Factors

Name	Abbrev.	Type	Levels
locations	lo	Fixed	8
species	sp	Fixed	7

PAIR-WISE TESTS

Term 'loxsp' for pairs of levels of factor 'species'

Within level 'WB' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	2.5302	0.003	998
GB, CA	2.8194	0.001	948
CM, CA	3.0651	0.001	578

Average Similarity between/within groups

	GB	CM	CA
GB	46.926		
CM	41.246	50.334	
CA	17.457	13.664	47.072

Within level 'ASFR' of factor 'locations'

Groups	t	P(perm)	Unique perms
ON, PL	3.6208	0.001	999
ON, GA	3.802	0.001	999
PL, GA	4.4466	0.001	998

Average Similarity between/within groups

	ON	PL	GA
ON	48.892		
PL	47.842	65.795	
GA	21.119	26.719	41.024

Within level 'WT' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	0.66216	0.715	999
GB, CA	2.3182	0.004	998
CM, CA	2.6198	0.002	998

Average Similarity between/within groups

	GB	CM	CA
GB	47.144		
CM	45.159	42.201	
CA	37.906	34.847	39.645

Within level 'AQ' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	5.2454	0.001	999
GB, CA	4.0974	0.001	999
CM, CA	4.4025	0.001	999

Average Similarity between/within groups

	GB	CM	CA
GB	63.278		
CM	45.711	61.84	
CA	27.856	26.75	27.536

Within level 'MD' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	3.4596	0.001	999
GB, CA	3.4897	0.001	998
CM, CA	2.1685	0.001	998

Denominators

Groups Denominator Den.df

GB, CM	1*Res	155
GB, CA	1*Res	81
CM, CA	1*Res	82

Average Similarity between/within groups

	GB	CM	CA
GB	47.974		
CM	38.383	38.063	
CA	22.725	32.246	54.804

Within level 'TH' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	6.308	0.001	999
GB, CA	3.689	0.001	999
GB, ON	1.6465	0.026	999
CM, CA	5.7072	0.001	999
CM, ON	5.0488	0.001	999
CA, ON	1.9664	0.003	999

Average Similarity between/within groups

	GB	CM	CA	ON
GB	55.436			
CM	34.851	63.063		
CA	35.629	23.238	34.616	
ON	59.022	40.696	42.569	73.294

Within level 'AJ' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	4.5112	0.001	999
GB, CA	5.5436	0.001	999
GB, CC	2.6734	0.002	999
CM, CA	3.5047	0.001	999
CM, CC	2.1414	0.004	998
CA, CC	1.4602	0.058	998

Average Similarity between/within groups

	GB	CM	CA	CC
GB	60.111			
CM	43.648	46.749		
CA	30.059	29.066	27.411	
CC	45.786	39.484	33.308	60.991

Within level 'AS' of factor 'locations'

Groups	t	P(perm)	Unique perms
GB, CM	4.3443	0.001	999
GB, CA	3.5045	0.001	999
CM, CA	2.8461	0.001	999

Average Similarity between/within groups

	GB	CM	CA
GB	60.039		
CM	44.737	56.428	
CA	32.319	42.217	35.391

ANOSIM
Analysis of Similarities

Two-Way Crossed Analysis

Resemblance worksheet
Name: Resem1
Data type: Similarity
Selection: All

Factor Values
Factor: locations
WB
ASFR
WT
AQ
MD
TH
AJ
AS
Factor: species
GB
CM
CA
ON
PL

TESTS FOR DIFFERENCES BETWEEN species GROUPS
(across all locations groups)
Global Test
Sample statistic (Global R): 0.062
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
GB, CM	0.249	0.1	Very large	999	0
GB, CA	0.109	0.1	Very large	999	0
GB, ON	-0.071	78.2	Very large	999	781
GB, CC	0.526	0.1	9657648	999	0
CM, CA	0.037	2.5	Very large	999	24
CM, ON	0.644	0.1	472733756	999	0
CM, CC	0.211	3.7	1370754	999	36
CA, ON	-0.215	99.6	Very large	999	995
CA, CC	-0.162	96.6	552689424	999	965
ON, PL	0.073	7.2	Very large	999	71
ON, GA	0.687	0.1	Very large	999	0
PL, GA	0.853	0.1	2035800	999	0

Appendix D Physical characterization/water quality field data sheet

STREAM/Dam/.. : NAME	LOCATION	
STATION #_________ RIVERMILE_________	STREAM CLASS	
LAT ______________ LONG ______________	RIVER BASIN	
INVESTIGATORS		
FORM COMPLETED BY	DATE ________ TIME _________ AM PM	REASON FOR SURVEY

WEATHER CONDITIONS	**Now** / **Past 24 hours** ☐ storm (heavy rain) ☐ ☐ rain (steady rain) ☐ ☐ showers (intermittent) ☐ ☐____% cloud cover ☐____% ☐ clear/sunny ☐ **Has there been a heavy rain in the last 7 days?** ☐ Yes ☐ No **Air Temperature**_____ ^{0}C **Other**___________________________
STREAM CHARACTERIZATION	**Vegetation** ________________________________ **Stream Origin**____________ **Stream Type** ☐ Coldwater ☐ Warm water **Catchment Area**__________km^2 **Stream bed** Bedrock ☐ Boulder ☐ Cobble ☐ Gravel ☐ Sand ☐ Silt ☐ Clay ☐ mix as ____
SITE LOCATION/MAP	**Draw a map of the site and indicate the areas sampled (or attach a photograph)**
Resource users	☐ cattle watering ☐ recreation and tourism ☐ Urban development ☐ water supply ☐ irrigation ☐ wildlife ☐ Birds + other piscivores ☐ commercial licensed fisheries ☐ aquaculture ☐ subsistence fisheries ☐ recreational fisheries ☐ other ________________________________ __________________________________
WATER QUALITY	**Temperature**________ ^{0}C **Conductivity (µS)**________ **Dissolved Oxygen** ________ **pH** ________ **Turbidity** ________ **Water Odors** ☐ Normal/None ☐ Sewage ☐ Petroleum ☐ Chemical ☐ Fishy ☐ Other_________________ **Water Surface Oils** ☐ Slick ☐ Sheen ☐ Globs ☐ Flecks ☐ None ☐ Other___________________________ **Turbidity (if not measured)** ☐ Clear ☐ Slightly turbid ☐ Turbid
	Gear/net used ____ ____. **How were the samples collected?** ☐ wading ☐ from bank ☐ from boat
Comments	

	Data : time:	

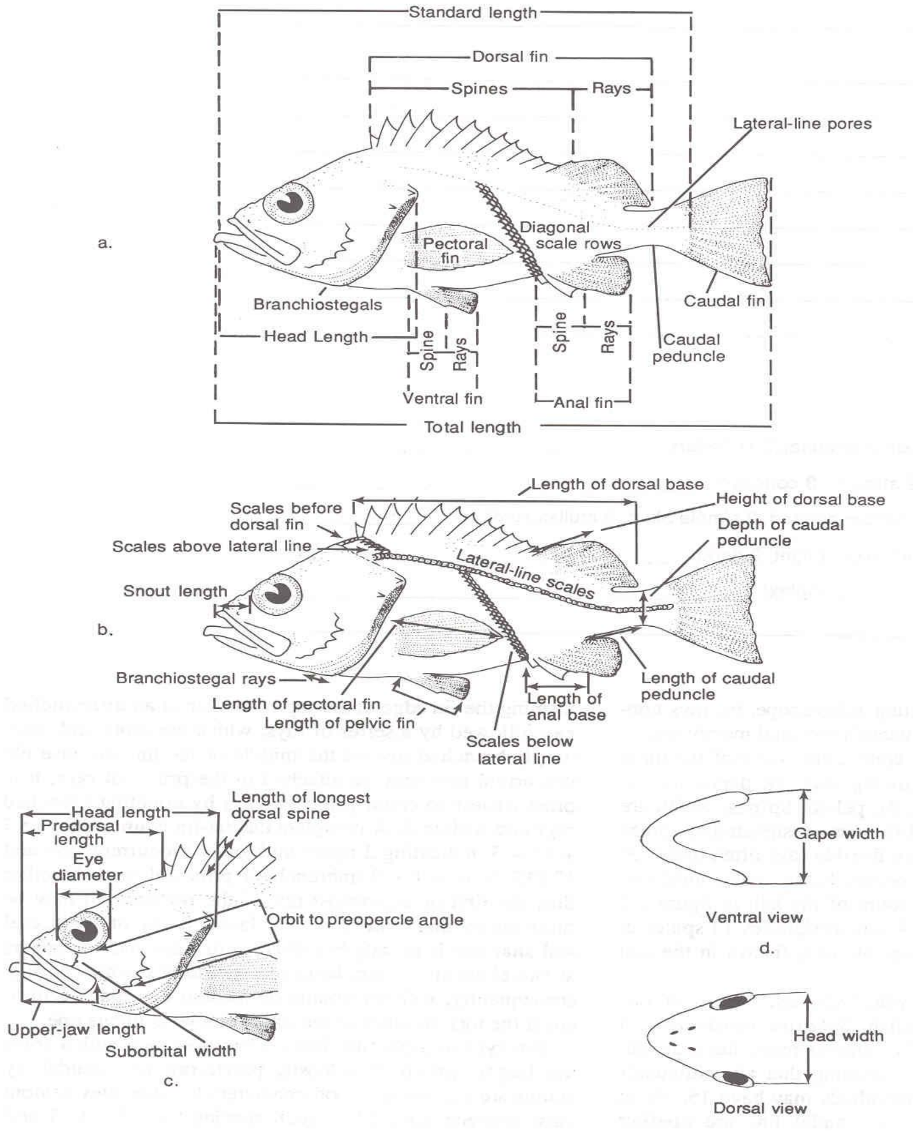
SAMPLING DATA

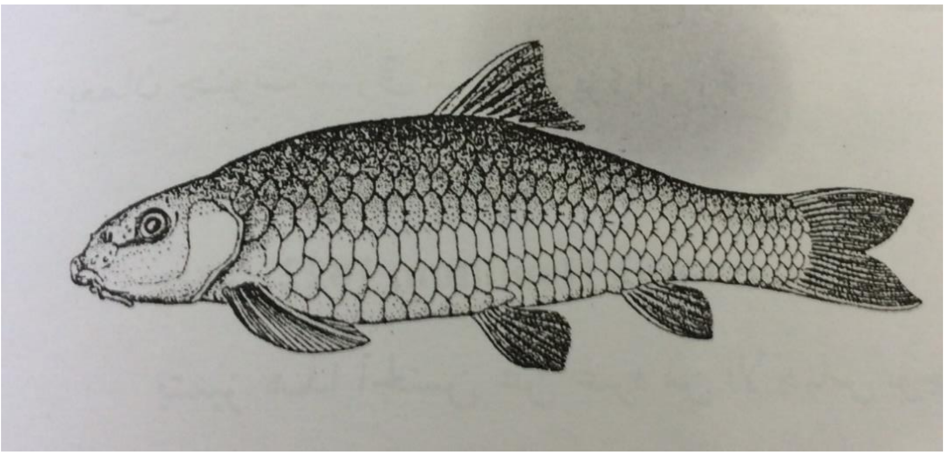
STRM OR Dam CHARACTERIZTION

Area (km²) : Depth max (m) : Depth mean (m) : Catchment area (km²) :
Width (m) : Length (m) :
Average CPUE (KG/NET) :

Site	Depth (m)	Gear Type	Operation Act /	Mesh Size	No. nets	Species / Taxa (each species has key no)	No. of fish	Tot. W t. (g)	Total / Fork Length of individual specimens (cm)	Link NO to biometric sheet
Comments										

List of Measurements if the species unknown														
Standard Length														
Body depth														
Caudal peduncle depth														
Predorsal length														
Length of dorsal base														
Length of anal base														
Height of dorsal fin														
Height of anal fin														
Length of pectoral fin														
Length of pelvic fin														
Length of longest dorsal spine														
Head length														
Head width														
Snout length														
Suborbital width														
Eye diameter														
Upper-jaw length														
Counts														
Dorsal fin elements														
Anal fin elements														
Pectoral fin elements														
Scales along the lateral line														
Branchiostegal rays														
Total gill rakers on first arch														
Qualitative														
Position of mouth: Inferior, terminal , superior														
Snout Profile: Convex, concave, straight														
Upper-jaw teeth shape: Simple pointed, simple blunt, multicuspid														
Shade of body background color: Light, dark														
Pattern of body color: Plain, complex														


Standard length
Dorsal fin
Spines
Rays
Lateral-line pores
a.
Pectoral fin
Diagonal scale rows
Branchiostegals
Caudal fin
Head Length
Spine
Rays
Spine
Rays
Caudal peduncle
Ventral fin
Anal fin
Total length
Length of dorsal base
Scales before dorsal fin
Height of dorsal base
Scales above lateral line
Depth of caudal peduncle
Lateral-line scales
Snout length
b.
Branchiostegal rays
Length of caudal peduncle
Length of pectoral fin
Length of anal base
Length of pelvic fin
Scales below lateral line
Length of longest dorsal spine
Head length
Predorsal length
Eye diameter
Gape width
Ventral view
Orbit to preopercle angle
d.
Head width
Upper-jaw length
Suborbital width
Dorsal view
c.



Appendix E The comparison between fish species locations records in this study with the previous studies records.

The comparison between fish species records in this study with the previous studies records. It should be noted that not all previously sampled site locations were sampled in the current study since size of the country was too big to visit all previously sampled locations during the limited time period of the current study. Future work will focus on sampling more of the previously sampled sites to determine changes of species composition in all these sites.

Sampling site visited during current and previous studies	***Acanthobrama hadiyahensis***	***Aphanius dispar***	***Arabibarbus arabicus***	***Carasobarbus apoensis***	***Carassius Carassius***	***Carassius auratus***	***claris gariepinus***	***Ctenopharyngodon idella***	***Cyprinion acinaces hijazi***	***Cyprinion mhalensis***	***Gambusia affinis***	***Garra buettikeri***	***Garra sahilia gharbia***	***Garra tibanica tibanica***	***Mugil cephalus***	***Oreochromis aurius***	***Oreochromis niloticus***	***Poecilia latipinna***	***Poecilia reticulata***	***xiphiphorus maculatus***	***Number of fish species***
Al-Bint Dam																					
Pre-studies	✓																				1
Abha Dam																					
Current study					✓																1
Pre-studies												✓									1
Ain Al-Hammah - Khaibar																					
Pre-studies									✓					✓							2
Al-Aqiq Dam																					
Current study				✓						✓		✓									3
al-Asfer Lake																					
Current study											✓						✓	✓			3
Alein Al-Harrah																					
Pre-studies													✓								1
al-Hair,Riyadh																					
Current study																	✓				1
Pre-studies																✓					1
al-Hasa oasis																					
Current study											✓						✓	✓			3
Pre-studies		✓						✓							✓				✓	✓	5
al-Hufuf																					
Pre-studies		✓																			1
Al-janbeen Dam																					
Current study				✓	✓					✓		✓									4
al-Kharj																					
Pre-studies		✓															✓				2
al-Majmaah																					
Current study																	✓				1
al-Qatif																					
Pre-studies		✓																			1
AL-SDAR,Wadi and Dam																					
Current study				✓						✓		✓									3
Baish Dam																					

The comparison between fish species records in this study with the previous studies records. It should be noted that not all previously sampled site locations were sampled in the current study since size of the country was too big to visit all previously sampled locations during the limited time period of the current study. Future work will focus on sampling more of the previously sampled sites to determine changes of species composition in all these sites.

Sampling site visited during current and previous studies	***Acanthobrama hadiyahensis***	***Aphanius dispar***	***Arabibarbus arabicus***	***Carasobarbus apoensis***	***Carassius Carassius***	***Carassius auratus***	***claris gariepinus***	***Ctenopharyngodon idella***	***Cyprinion acinaces hijazi***	***Cyprinion mhalensis***	***Gambusia affinis***	***Garra buettikeri***	***Garra sahilia gharbia***	***Garra tibanica tibanica***	***Mugil cephalus***	***Oreochromis aurius***	***Oreochromis niloticus***	***Poecilia latipinna***	***Poecilia reticulata***	***xiphiphorus maculatus***	**Number of fish species**
Pre-studies			✓																		1
Bani Sharfa (Al-Ahsabah Dam)																					
Pre-studies													✓								1
Duma Jandal Lake																					
Current study											✓										1
Ein Al-Buhairah																					
Pre-studies		✓																			1
Khaibar																					
Pre-studies									✓					✓							2
Khamis Mshait																					
Pre-studies				✓																	1
Khodod spring																					
Pre-studies		✓																			1
MEDHAS DAM																					
Current study				✓						✓		✓									3
N of Jizan																					
Pre-studies													✓								1
near Medhaas																					
Current study						✓															1
Nemar Dam																					
Current study						✓	✓										✓	✓			4
Qusaiba'a Dam																					
Pre-studies	✓																				1
Salam Lake																					
Current study						✓															1
Taif																					
Pre-studies									✓	✓											2
THARAD Dam																					
Current study				✓						✓		✓					✓				4
Wadi Adama																					
Pre-studies				✓						✓		✓									3
Wadi Afrak																					
Pre-studies										✓											1
Wadi Al-Aqiq																					
Current study				✓						✓		✓									3

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Sampling site visited during current and previous studies	***Acanthobrama hadiyahensis***	***Aphanius dispar***	***Arabibarbus arabicus***	***Carasobarbus apoensis***	***Carassius Carassius***	***Carassius auratus***	***claris gariepinus***	***Ctenopharyngodon idella***	***Cyprinion acinaces hijazi***	***Cyprinion mhalensis***	***Gambusia affinis***	***Garra buettikeri***	***Garra sahilia gharbia***	***Garra tibanica tibanica***	***Mugil cephalus***	***Oreochromis aurius***	***Oreochromis niloticus***	***Poecilia latipinna***	***Poecilia reticulata***	***xiphiphorus maculatus***	**Number of fish species**
Wadi Al-Arj																					
Pre-studies										✓		✓									2
Wadi Al-Bagarah																					
Pre-studies		✓										✓	✓								3
Wadi Al-Gassah																					
Pre-studies													✓								1
Wadi Al-janbeen																					
Current study				✓						✓		✓									3
Wadi Al-Mahallah																					
Pre-studies				✓						✓											2
Wadi Baish																					
Pre-studies			✓																		1
Wadi Buwah																					
Current study				✓						✓		✓									3
Pre-studies										✓											1
Wadi Damad																					
Pre-studies			✓											✓							2
Wadi Fatima																					
Pre-studies		✓												✓							2
Wadi Gaanah																					
Pre-studies													✓								1
Wadi Hadiyah																					
Pre-studies	✓			✓					✓												3
Wadi Hanefah																					
Pre-studies		✓					✓											✓	✓	✓	5
Wadi Haqqaq																					
Pre-studies				✓																	1
Wadi Haroub																					
Pre-studies													✓								1
Wadi Hesu'a																					
Pre-studies														✓							1
Wadi ileeb																					
Pre-studies													✓								1
Wadi Juva																					
Pre-studies			✓											✓							2
Wadi Khadrah																					

The comparison between fish species records in this study with the previous studies records. It should be noted that not all previously sampled site locations were sampled in the current study since size of the country was too big to visit all previously sampled locations during the limited time period of the current study. Future work will focus on sampling more of the previously sampled sites to determine changes of species composition in all these sites.

Sampling site visited during current and previous studies	***Acanthobrama hadiyahensis***	***Aphanius dispar***	***Arabibarbus arabicus***	***Carasobarbus apoensis***	***Carassius Carassius***	***Carassius auratus***	***claris gariepinus***	***Ctenopharyngodon idella***	***Cyprinion acinaces hijazi***	***Cyprinion mhalensis***	***Gambusia affinis***	***Garra buettikeri***	***Garra sahilia gharbia***	***Garra tibanica tibanica***	***Mugil cephalus***	***Oreochromis aurius***	***Oreochromis niloticus***	***Poecilia latipinna***	***Poecilia reticulata***	***xiphiphorus maculatus***	**Number of fish species**
Pre-studies		✓												✓							2
Wadi Khulab																					
Pre-studies		✓																			1
Wadi Kudais																					
Pre-studies		✓											✓								2
Wadi Minsah																					
Pre-studies													✓								1
Wadi noaman																					
Pre-studies										✓		✓									2
Wadi North Jizan																					
Pre-studies													✓	✓							2
Wadi Noval																					
Pre-studies												✓									1
Wadi Rabig																					
Current study		✓															✓				2
Wadi Reem																					
Pre-studies		✓																			1
Wadi Rumah																					
Current study							✓										✓				2
Wadi Shumrukh																					
Pre-studies										✓		✓									2
Wadi shuqub																					
Pre-studies				✓						✓											2
Wadi Sulaym																					
Pre-studies									✓												1
Wadi Tarj																					
Pre-studies										✓											1
Wadi THARAD																					
Current study				✓						✓		✓									3
Wadi Turabah																					
Current study				✓						✓		✓									3
Pre-studies				✓						✓		✓									3
Total number of records	**3**	**14**	**4**	**17**	**2**	**3**	**3**	**1**	**5**	**19**	**3**	**17**	**11**	**8**	**1**	**1**	**9**	**4**	**2**	**2**	**132**

Appendix F Sampling size based on locations , age and seasons for chapter 7. Feeding ecology

Row Labels	Al-aqiq Dam	Al-asfer Lake	Al-janabeen Dam	Al-sadr Dam	Medhaas Dam	Thrrad Dam	Wadi Bouah	Wadi Turabah	Grand Total
Carasobarbus apoensis	90		157	193	5	99	3	58	605
Carassius Carassius			5						5
Cyprinion mahalensis	33		43	78	80	29	15	36	314
Gambusia affinis		9							9
Garra buettikeri	27		70	20	92	49	36	29	323
Oreochromis niloticus		93				10			103
Poecilia latipinna		34							34
Grand Total	150	136	275	291	177	187	54	123	1393

Row Labels	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Grand Total
Carasobarbus apoensis	6	41	103	152	75	65	54	45	22	15	10	8	3	3	1	2	605
Carassius Carassius					1	2	2										5
Cyprinion mahalensis	15	77	132	48	29	10	3										314
Gambusia affinis		7	2														9
Garra buettikeri	2	16	46	85	104	51	13	6									323
Oreochromis niloticus	4	12	26	38	17	6											103
Poecilia latipinna	8	22	4														34
Grand Total	35	175	313	323	226	134	72	51	22	15	10	8	3	3	1	2	1393

Row Labels	spring	summer	winter	Grand Total
Carasobarbus apoensis	201	221	183	605
Carassius Carassius	1		4	5
Cyprinion mahalensis	176	77	61	314
Gambusia affinis	9			9
Garra buettikeri	161	101	61	323
Oreochromis niloticus	43	30	30	103
Poecilia latipinna	25		9	34
Grand Total	616	429	348	1393