Investigating mangrove ecosystems for supporting biodiversity and identifying conservation opportunities in the southern Arabian Gulf

Amna Almansoori

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Abstract

Mangroves in the Arabian region are often connected to nearby habitats, greatly benefiting local marine life and people. However, while mangrove research has expanded globally, those in the Arabian region remain understudied. This thesis aims to investigate the role of mangrove habitats in supporting marine species and the perceptions of people to identify the best ways to use available information to target conservation efforts in the Arabian region. Two systematic literature reviews were undertaken to identify publication trends in the mangrove literature on the importance of mangrove habitat for supporting marine species (Chapter Two), and on the literature temporal trends and geographical coverage in the Arabian region (Chapter Three). Fish habitat use within mangrove microhabitats (Chapter Four) and the perception of people on the conservation of mangroves in Arabia were investigated (Chapter Five). The results show that at least 65% of the research focused on fish populations in mangroves and adjacent habitats, typically concentrated in the tropical Atlantic and Oceania regions. Arabian literature on mangroves has steadily increased, yet it exhibits a lack of diversity in research topics, with an underrepresentation of areas known for their substantial mangrove presence, such as the southern Gulf subregion. The underwater visual census showed young fish in greater abundance and diversity in mangroves exhibiting greater structural complexity compared to less complex habitats like mudflats. Fish patterns were influenced by seasonal temperature changes, which underscores the sensitivity of fish communities to environmental conditions. Through semi-structured interviews, regional perspectives on mangroves among different groups varied. Key challenges in the region include research and restoration method gaps, lack of policies to address threats from human activities, and insufficient communication between different stakeholder groups, such as local communities and environmental managers. This thesis suggests we should prioritize scientific research of mangroves and adjacent coastal ecosystems, seek to incorporate traditional knowledge into conservation planning and improve regional and international collaboration. Filling these gaps will adopt a holistic approach that bridges ecological and social considerations to strengthen mangrove protection and raise the international profile of Arabian mangroves.

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CHAPTER 1: Introduction

1. INTRODUCTION

1.1 Background to mangrove ecosystems

Mangroves are trees or shrubs occupying coastal, rivers and estuarine areas within tropical and subtropical regions (Duke, 1992; Ellison *et al.*, 1999; Saenger, 2002). The word mangrove originated from either '*manggi-manggi*', a word in Malaysian, or from '*mangue*', a word from Portuguese and Spanish (MacNae, 1969), or a combination of Malaysian and Arabic words '*al-gurm*' and '*mang-gurm*' (Saenger, 2002). The first historical description of mangroves was in the Arabian Gulf region in the fourth century BC by Theophrastus and Aristotle, where they described the mangroves of Tylos (now known as the country Bahrain) (Saenger, 2002). Mangroves form the main vegetation in saline wetlands and exclusively disperse along intertidal areas by sea currents (Tomlinson, 2016). Mangroves grow on soils that consist of mud, clay, and silt (Kathiresan and Bingham, 2001), but some are able to grow on loose sand, peat, and rock substrates (Saenger, 2002).

Tomlinson (2016) defines a mangrove community as a taxonomically distinct group of plants that exhibit unique morphological and physiological adaptations to survive in a marine environment. This means that the classification of mangroves is based on their structural attributes (e.g. tree height) and the environmental conditions they inhabit (e.g. geomorphology). Initially, six types of mangrove forms were identified: fringe, overwash, scrub, hammock, riverine, and basin (Lugo and Snedaker, 1974). However, they were later grouped into three categories: fringe (tide-dominated mangroves), riverine (river-dominated mangroves), and basin (interior mangroves) (Woodroffe, 1992). Each region's mangroves are unique, reflecting their specific geomorphology and ecological features, which influence their structural and functional processes (Twilley and Day, 1999). According to Worthington and Spalding (2018), the global classification of mangroves recognizes four broad classes of mangrove types; deltas, estuaries, lagoons, and fringing.

1.1.1 Distribution and species of mangroves

Mangroves are generally distributed between 30°N and 30°S latitude (Alongi, 2002; Giri *et al.*, 2011; Bunting *et al.*, 2022). However, the largest concentration of mangroves is between 5°N and 5°S, in the following regions: Asia (42%), North and Central America (15%), and South America (11%) (Giri *et al.*, 2011). Mangrove distribution is highly associated with sea-surface temperatures (Tomlinson, 2016). Apart from temperatures, other environmental components influence mangrove distribution (Duke, 1992). These include wave action, tidal inundation, sea currents, and shallow shores (Saenger, 2002; Alongi, 2009; Tomlinson, 2016). The limiting factors of mangrove growth are attributed to the composition of soil salinity and waterlogging, as well as the limitation of nutrient supply (Koch and Snedaker, 1997; Lovelock *et al.*, 2004). The diversity of world mangroves is estimated to be 70 species in 28 genera that belong to 20 families (Hogarth, 2015). The mangrove plant *Avicennia marina*, belonging to the Acanthaceae family, is one of the most widespread species found in almost every tropical, subtropical, and temperate region of the world (Saenger *et al.*, 1983; Duke, 1992; Kathiresan and Bingham, 2001; Alongi, 2002; Spalding *et al.*, 2010).

1.2 Mangroves of the Arabian Gulf

The coastline of the Arabian Gulf comprises the northern latitudinal limits of the Indo-Pacific East African mangrove distribution; thus, mangrove diversity in the region is low (Sheppard *et al.*, 1992; Saenger *et al.*, 2004; Saenger, 2002). It was suggested by Plaziat (1995) that the mangrove species *Rhizophora* was once abundant in the region due to favourable wetter climate conditions and the presence of potamiid mollusc fauna (*Terebralia palustris*) some 3,800 years BP. However, due to the changes in sea levels over thousands of years, *Rhizophora* species declined and became extinct in many parts of the region (Plaziat, 1995), with few stands remaining along the Iranian coast.

Presently, the only widespread species in the entire Arabian Gulf is the salt-tolerant *Avicennia marina* (Saenger, 2002; Saenger *et al.*, 2004; Almahasheer, 2018). The species *Avicennia marina* was first described in the Arabian region along the Red Sea by Pher Forsskal and was named after the famous medical scientist Ibn Sina (Saenger, 2002). The regional assessment of mangroves in the Arabian Gulf indicates that the ecosystem is at risk (Almansoori *et al.*, 2024). However, while existing research on mangrove ecosystems worldwide is well established (e.g. Lovelock *et al.*, 2004; Beitl *et al.*, 2014; Himes-Cornell *et al.*, 2018; Su *et al.*, 2021), mangroves of the Arabian region remain one of the least represented regions in global mangrove literature, and particularly the southern Arabian Gulf subregion (Saenger *et al.*, 2004; Zahran and Elamier, 2016; Almahasheer, 2017; EAD, 2019; Vaughan *et al.*, 2019; Adame *et al.*, 2020). Recently, the regional assessment of mangroves in the Arabian Gulf indicates that the ecosystem is at risk (Almansoori *et al.*, 2024: see Appendix B.4).

1.2.1 Southern Arabian Gulf

The southern Arabian Gulf covers a coastline of approximately 750 km^2 along the United Arab Emirates (UAE), which includes seven Emirates: Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Ajman, Umm Al Quwain, and Fujairah (MOEC, 2023). The Emirates are located north and northeast of the Arabian Gulf, except for Abu Dhabi Emirate, which is situated along the southern Arabian Gulf (Almahasheer, 2018; MOEC, 2023) (Figure 1.1). The climate of the southern Arabian Gulf is hyper-arid and typically extreme in environmental conditions (Hellyer and Aspinall, 2005; Alsalam, 2007). The semi-enclosed Gulf is relatively shallow, with an average depth of 35 m (Sheppard *et al.*, 1992; Saenger *et al.*, 2004). It has an annual precipitation of less than 90 mm and fluctuating sea-water temperatures that range from 16°C in winter to 35°C during the summer (Sheppard *et al.*, 1992; EAD, 2003; Alsalam, 2007; AGEDI, 2008; EAD, 2011; Vaughan *et al.*, 2019). In addition, high evaporation rates cause extreme salinity offshore of nearly 40 ppt and exceed roughly 50 ppt inshore (Saenger *et al.*, 2004). As a result, mangroves occur in monospecific stands of *Avicennia marina* along coastal lagoons, typically alongside other important ecosystems, including saltmarsh communities, mudflats, and seagrass meadows (Loughland *et al.*, 2004; Alsalam, 2007; AGEDI, 2008; Brown *et al.*, 2008; EAD, 2011).

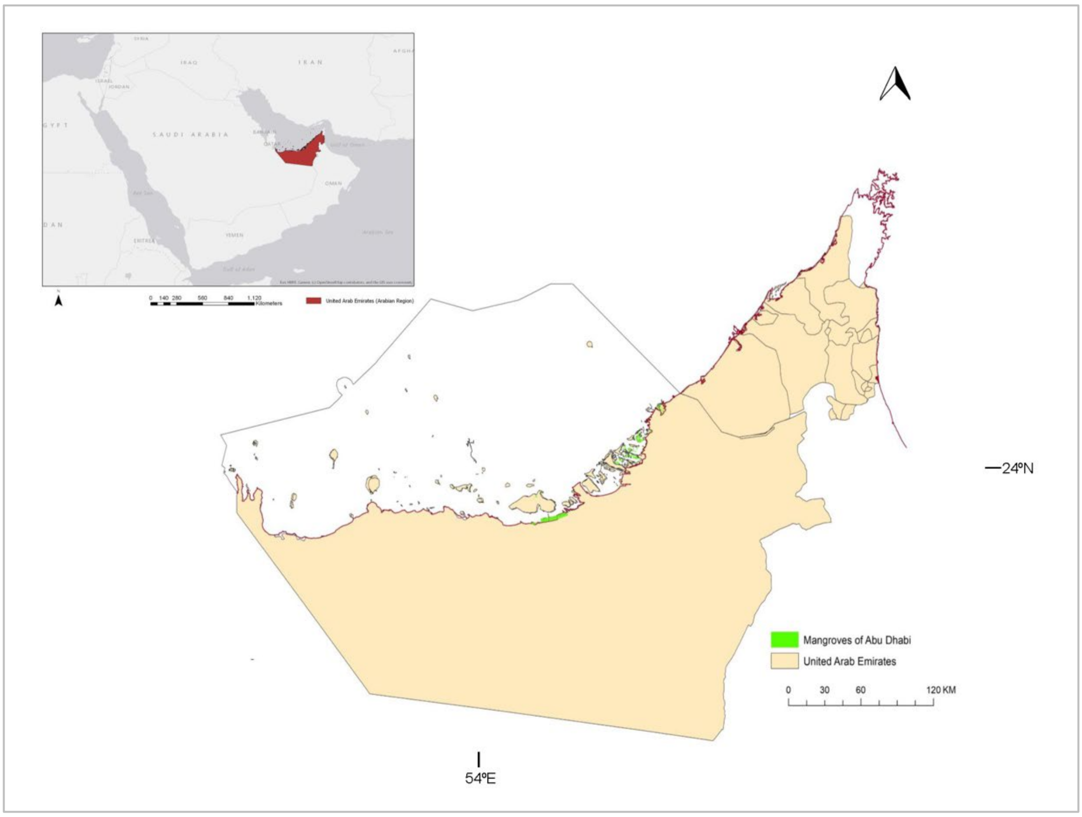


Figure 1. 1. The distribution of mangroves along the southern Arabian Gulf in the United Arab Emirates.

1.2.2 Spatial distribution of mangroves in the southern Arabian Gulf

Mangroves of the southern Arabian Gulf represent half of the entire Arabian Gulf region's mangrove forest extent (Almahasheer, 2018; Almansoori *et al.*, 2024). Almahasheer (2018) recorded approximately 165 km^2 of mangrove along the interior of the Arabian Gulf region, with more than 50% found along the southern coastline of Abu Dhabi in the UAE. Recently, it was reported that the regional coverage of mangroves in the Arabian Gulf is approximately 209.5 km^2, with more than 47% situated in the southern Arabian Gulf (Almansoori *et al.*, 2024). According to the Environment Agency (EAD), Abu Dhabi mangrove extent estimate is 57 km^2 (EAD, 2018). This estimate was similar to the extent reported by the Global Mangrove Watch of 54 km^2 along the UAE coastline (Bunting *et al.*, 2022). The spatial distribution of Arabian Gulf mangroves represents 0.1% of the global mangrove extent (Bunting *et al.*, 2022).

UAE's mangrove extent has increased over the past two decades (Almahasheer, 2018; Almansoori *et al.*, 2021). Historically, it was estimated that mangroves covered at least 35 km^2 in 1980, and in 2005, it was reported to be approximately 41 km^2 (FAO, 2005; Alhabshi *et al.*, 2007). The increase was mainly due to the large reforestation efforts led by the UAE government (Saenger *et al.*, 2004; Almahasheer, 2018). Despite these gains, mangroves remain vulnerable in the region due to intense coastal infrastructure (Sheppard *et al.*, 2010; Almansoori *et al.*, 2021; Almansoori *et al.*, 2024). According to Almansoori *et al.* (2021), the National Red List of Ecosystems assessment of mangroves in the UAE assigned an 'Endangered' status due to their restricted area of occupancy and recent anthropogenic threats. Recent research for the IUCN Red List of Ecosystems assigned a 'Vulnerable' status for mangroves of the Arabian Gulf, also owing to their restricted area of occupancy and regional threats from human activities (Almansoori *et al.*, 2024: see Appendix B.4).

1.3 Ecosystem services of mangroves

Mangroves are one of the most productive ecosystems of the tropical and subtropical shorelines (Ellison *et al.*, 1999; Alongi, 2009). Where they occur, they are one of the dominant features of the shoreline, adjacent to equally important ecosystems, such as saltmarshes (Hogarth, 2015), seagrass beds (Sudo *et al.*, 2021), and coral reefs (Singh *et al.*, 2023). Research on mangroves revealed much about their ecological role, functions, and services. The ecosystem services and benefits provided by mangroves and saltmarshes yield values of 25 US$ trillion annually (Costanza *et al.*, 2014). Mangrove habitat extent is also linked to high productivity in nearby coastal fisheries (e.g. Aburto-Oropeza *et al.*, 2008; zu Ermgassen *et al.*, 2020), which could reach an estimated economic value of up to 16,500 US$ per hectare of mangroves (UNEP, 2006).

Mangroves are adapted to the saline environment and provide a variety of services and benefits to coastal communities, adjacent marine ecosystems, and numerous terrestrial and marine species (Nagelkerken, 2009; Curnick *et al.*, 2019; Gayo, 2022; Leal and Spalding, 2022). At least 40% of the global human population lives near coastal areas (UNEP, 2020), and thus coastal communities and coastal villages may be vulnerable to climate change stressors (e.g. Goldberg *et al.*, 2020; Hagger *et al.*, 2022). Research shows that coastal communities could be protected from waves, intense storms, and flooding by the structural complexity and root system of mangrove trees (Patel *et al.*, 2014; Chen *et al.*, 2023; Reciproco *et al.*, 2023).

Mangroves store four to five times more carbon content belowground than other terrestrial ecosystems (Donato *et al.*, 2011). Research shows that the slow process of organic matter decomposition over time in the waterlogged soils of mangroves renders them major blue carbon sinks (Alongi, 2009; Donato *et al.*, 2011; Zou *et al.*, 2023). For example, Indo-Pacific region mangroves contain, on average 1,023 mg carbon per hectare (Donato *et al.*, 2011). Hence, mangroves are one of the most essential blue carbon ecosystems that are vital for maintaining a resilient profile in the face of climate change mitigation (Donato *et al.*, 2011; Lovelock *et al.*, 2015; Goldberg *et al.*, 2020; Diana *et al.*, 2023).

Moreover, mangroves are efficient at trapping sediment (Alongi, 2009). This process enhances the water quality and clarity, recycles material, and provides nutrients to its environment and neighbouring marine ecosystems (Twilley and Day, 1999; Lovelock *et al.*, 2004; Nagelkerken, 2009). In addition to trapping sediments, mangroves also offer numerous resources to terrestrial and marine species (Aburto-Oropeza *et al.*, 2008; Nagelkerken, 2009; Igulu *et al.*, 2014). They support species by offering habitat services, such as shelter, food, and protection (see e.g. Igulu *et al.*, 2014; Carrasquilla-Henao *et al.*, 2022; Ponton-Cevallos *et al.*, 2022). For example, an abundance of various species such as birds, reptiles, amphibians, mammals, fish, and shrimp species are typically found in mangroves due to their considerable habitat resources (Nagelkerken, 2009; Luther and Greenberg, 2009; Ponton-Cevallos *et al.*, 2022).

Intrinsically, cross-ecosystem interactions are common among mangroves and nearby coastal habitats, such as the exchange of nutrients and the movement of species (Nagelkerken, 2009). The latter is well-investigated across the world, especially by the movement of marine fish (see e.g. Nagelkerken, 2009; Kimirei *et al.*, 2013; Carrasquilla-Henao *et al.*, 2019; Sievers *et al.*, 2019). However, while extensive research is evident globally, some regions, such as Arabia, remain poorly studied in coastal connectivity studies (Adame *et al.*, 2020; Almahasheer 2018; Almansoori *et al.*, 2024). In fact, prior research revealed that studies investigating the multi-habitat use by fish were mainly conducted across the tropical Atlantic region, the Caribbean, and Australia (see e.g. Nagelkerken, 2009; Sambrook *et al.*, 2019).

1.3.1 Benefit of mangroves for fish

Numerous studies worldwide demonstrate the importance of mangroves as an essential habitat for fish species (Bell *et al.*, 1984; Robertson and Duke 1987; Chong *et al.*, 1990; Nagelkerken *et al.*, 2000; Dorenbosch *et al.*, 2007). Mangroves provide a refuge for fish mainly due to the availability of food resources, shelter, structural complexity, and reduced predation risk due to the size of refuge spaces and distance from offshore habitats (Nagelkerken *et al.*, 2000). Research by Hutchison *et al.* (2014) showed that mangrove habitats provide important primary production, e.g. detritus or leaves, that form an important part of the marine food web for fisheries. As such, mangroves are widely accepted as essential nursery habitats for fish (e.g. Blaber, 2000, Kathiresan and Bingham 2001), and their contribution to nearshore fisheries has been well documented (Manson *et al.*, 2005; Beitl, 2014).

Mangrove areas are important for economically valuable marine species (see e.g. Nagelkerken *et al.*, 2000; Manson *et al.*, 2005; Reis-Filho *et al.*, 2016; Carrasquilla-Henao, 2017), but have also been shown to provide livelihoods for small-scale fisheries. According to zu Ermgassen *et al.* (2020), mangrove areas sustain at least 70 individual fish, crustaceans, and molluscs per square metre annually and support approximately 4.1 million small-scale fishers worldwide. Although, it is evident that our knowledge of the linkage between mangrove habitats and fish has increased over the past decade (see e.g. Kimirei *et al.*, 2013; Igulu *et al.*, 2014; Reis-Filho *et al.*, 2016; Carrasquilla-Henao, 2017), it has been largely carried out across the tropical Atlantic region, the Caribbean, and Australia, with relatively few studies elsewhere, e.g. parts of Asia (e.g. Manson *et al.*, 2005; Sambrook *et al.*, 2019). For instance, in the Arabian region, much of the research on mangrove habitats and fish has been carried out in the Red Sea and the northern coast of the Arabian Gulf mangroves (see e.g. El-regal and Ibrahim 2014, Dunne *et al.*, 2023). Little has been documented from the southern coastline of the Arabian Gulf, which hosts the largest extent of mangroves in the region (Almahasheer, 2018; Almansoori *et al.*, 2024). Where there are fisheries-related studies in the southern Arabian Gulf, they are mostly found within offshore coral reef ecosystems or commercial landings (see e.g. Francis *et al.*, 2022; Vaughan *et al.*, 2021).

1.3.2 Benefits of mangroves to local communities

There is a growing body of literature that recognizes the importance of mangrove ecosystems for local communities (e.g. Carrasquilla-Henao and Juanes, 2017; Costanza *et al.*, 2017; Huxham *et al.*, 2017; Himes-Cornell *et al.*, 2018). Mangrove ecosystems support the livelihoods of millions in coastal populations around the world through their habitat provision, nursery role for fish and invertebrate species, water quality enhancement, recreation, and climate mitigation (Howard *et al.*, 2017; Carrasquilla-Henao and Juanes, 2017; Himes-Cornell *et al.*, 2018). Elwin *et al.* (2024) demonstrated the importance of understanding local knowledge about mangrove ecosystem health from personal experiences. For instance, the study revealed that the historical tsunami event of 2004 was perceived by local participants to mark the lowest health conditions of mangrove ecosystems through significantly disrupting fisheries production and altering the habitat, which in turn affected livelihoods (Elwin *et al.*, 2024).

Research has also revealed that differences between cultures may affect the way local communities perceive and experience ecosystems, e.g. ecosystem health and livelihoods (Robards *et al.*, 2011; Satterfield *et al.*, 2013). This is thought to be because individuals perceive benefits differently, according to the cultural and socio-economic context of the individual (Diaz *et al.*, 2018), or that community experiences vary due to the differences in ecosystem benefits that are both spatially and temporally dynamic (Roces-Diaz *et al.*, 2014). Despite the importance of traditional local knowledge, current literature revealed limited information on the involvement of local communities in conservation strategies across Arabia (Hellyer and Aspinall, 2005; Alsalam, 2007; Ghasemi *et al.*, 2010).

Traditional local knowledge and the involvement of local communities in mangrove management are important elements in mangroves conservation (Datta *et al.*, 2012; Cebrian-Piqueras *et al.*, 2020). Indeed, Ghasemi *et al.* (2010) reported that the conservation of mangroves showed success in Iran, mainly due to the support of local communities, and reflected socio-economic benefits, such as medicinal resources. Globally, successful mangrove conservation has been shown to involve local community participation in restoration projects (e.g. Reyes-Garcia *et al.*, 2019), and failing to do so can lead to the failure of conservation strategies (e.g. Klain *et al.*, 2012; Satterfield *et al.*, 2013).

1.4 Threats to mangroves

Historically, humans have posed significant threats to mangrove ecosystems most directly by clearing and conversion of large areas into aquaculture, agriculture, and urban development in many regions (e.g. Saenger *et al.*, 1983; Alongi, 2002). As mangroves become fragmented and eventually lost, their ecological services and benefits also decline (Duke *et al.*, 2007). By the late 1990s, it was estimated that mangrove forests had declined in extent by 35% (Valiela *et al.*, 2009). According to Duke *et al.* (2007), mangrove loss reached at least 86% in some areas, mostly in developing countries where approximately 90% of mangroves are located. The reduction in the extent of global mangroves has been mainly attributed to the impacts of human activities near the coastline, such as infrastructure, pollution, and land conversion for shrimp farms and rice production, as well as climatic factors (Sheppard *et al.*, 2010; Goldberg *et al.*, 2020; Hagger *et al.*, 2022).

However, awareness of the importance of mangroves has improved in the past two decades, which has resulted in a decrease in their loss and even some gains in some countries (Hagger *et al.*, 2022). By 1996, mangrove extent was estimated at 152,604 km^2 globally (Bunting *et al.*, 2022). FAO reported a similar estimate from the same year at roughly 169,248 km^2 (Wilkie and Fortuna, 2005). The reduction of net mangrove loss was observed between 1996 and 2007 at 2.74 %, and between 2007 and 2016, rates reduced to 1.58 %, and by 2020, the total mangrove extent covered approximately 147,359 km^2 (Bunting *et al.*, 2022). Therefore, mangrove habitat reduction and even gains in some countries were associated with understanding the overall benefits of mangrove ecosystem services, restoring previously degraded areas, and initiating the protection of forests (see e.g. Bunting *et al.*, 2022; Hagger *et al.*, 2022; Leal and Spalding, 2022).

1.5 Thesis aims

The overall aim of my thesis is to investigate the role of mangrove habitats in supporting marine species, explore how people perceive mangroves, and how we can use the available information to guide conservation efforts in the Arabian region.

The individual aims of the thesis chapters are as follows:

- Chapter 2: To establish the importance of mangrove habitat for supporting biodiversity and describe the current literature knowledge and whether the connectivity facilitated by the movement of marine species has been examined. This will be achieved through a systematic literature review to identify the publication trends, such as research topics, description of habitats, taxonomic groups studied, historical changes and geographical coverage of the literature to obtain an overall understanding of the literature on the ecological role of mangrove habitats and the associated marine life, and the regions where this type of research has been investigated.
- Chapter 3: To highlight mangrove research in the understudied Arabian Gulf region, by exploring temporal trends, geographical coverage, and research gaps. A systematic literature review in English and Arabic languages using a combination of scientific bibliographic databases, grey literature, and resource hubs of locally-based databases will be used to extract data. This will include the number of publications, authorship and affiliates, research topics and primary taxa, and research efforts according to mangrove typologies. The information will contribute to the understanding of the temporal trends and geographical coverage of scientific literature on Arabian mangroves to help direct research for the following Chapters.
- Chapter 4: To gather primary data to address research gaps in previous chapters concerning the connectivity facilitated by the movement of marine species. The goal is to establish the habitat use by fish in mangroves of the southern Arabian Gulf. Here, the relationship between mangrove ecosystems and fish populations will be examined to determine the similarities and differences in fish assemblages associated with various mangrove microhabitats and to assess whether environmental variables influence fish assemblages. An underwater visual census will be conducted to gather data on fish populations in various mangrove microhabitats within the southern Arabian Gulf lagoonal systems. This will provide an overall understanding of fish use in mangroves and support the conservation of these habitats and their associated species.

- Chapter 5: To address the research gap found in Chapter Three regarding the lack of information on the social aspects of mangrove ecosystems for people in the region by collecting a broad range of regional perspectives on the conservation of mangroves in Arabia. This will be accomplished through semi-structured interviews with different groups, including local community members, academia, environmental experts, non-environmental experts, and representatives from non-governmental organizations, guided by research questions such as how people perceive the importance and applications of mangrove ecosystems, how people assess the health of mangroves, what are people's perspectives on potential threats to mangroves, and how do people recognize any challenges that may impede conservation efforts. The results will support the exploration of people from diverse backgrounds' perceptions of mangrove ecosystems, capturing traditional knowledge and public awareness and finding ways to engage the community in mangrove conservation efforts.

CHAPTER 2: The importance of mangrove habitat for supporting species: A synthesis of the current literature

2.1 INTRODUCTION

Mangroves are located in a distinct intertidal zone that serves as a critical link between terrestrial and marine ecosystems (Hogarth, 2015; Friess *et al.*, 2019). These ecosystems offer numerous ecological services that include coastal protection from extreme floods and storms, sedimentation trapping, nutrient cycling, significant rates of carbon sequestration, and various resources for numerous species (FAO, 1994; Mumby, 2006; Friess *et al.*, 2019). The latter comprises essential habitat services to species, such as the supply of abundant food resources, shelter, and protection due to their complex structure (Mumby, 2006; Nagelkerken, 2009). In this way, mangroves offer immense livelihood opportunities to local communities, such as fisheries, material supply, medical production, and tourism, which directly adds economic value (e.g. income) to local communities (Sarhan and Tawfik, 2014; DasGupta *et al.*, 2017; Schwenke and Helfer, 2021). Despite their importance, deforestation and land conversion of mangroves are still increasing, posing a major threat to their ecological services (Goldberg *et al.*, 2020). Consequently, these socio-economic systems remain at risk of habitat disruption, and with habitat modification, all ecosystem services provided by mangroves will be affected, thus impacting both the livelihoods of local communities and coastal connectivity (Nagelkerken, 2009; Berkstrom *et al.*, 2020).

Coastal connectivity is fundamental for healthy ecosystems (Nagelkerken, 2009; Vargas-Fonseca *et al.*, 2016; Olds *et al.*, 2018). It has been demonstrated that species movement across the seascape matters and sustains the long-term health of the ecosystem (Olds *et al.*, 2018). In addition, the arrangement of multiple coastal habitats is a key factor in the distribution, growth, and survival of species (Irlandi and Crawford, 1997; Micheli and Peterson, 1999). In fact, according to Green *et al.* (2012) and Staveley *et al.* (2017), the seascape configuration (e.g. the spatial scale of mangroves, seagrass beds, and other coastal habitats) has been shown to influence the structure of marine species. For instance, fringing mangroves are occupied by juvenile reef sharks and fish, while basin mangroves are utilized by smaller-bodied organisms, e.g. invertebrates (Faunce and Layman, 2009; Chin *et al.*, 2013; Sambrook, 2019). Nagelkerken (2009) also documented distinct patterns of faunal utilization across mangrove ecosystems and nearby habitats, such as seagrass beds. This pattern is particularly evident within fish populations, especially during their juvenile stages, as they seek refuge and food in vegetative areas before eventually transitioning to offshore habitats (Sheaves, 2005; Mumby, 2006; Faunce and Layman, 2009; Nagelkerken, 2009).

Variations in mangrove structure across different geographic areas shape the extent and quality of the ecosystem services they offer (Gillanders *et al.*, 2003; Sheaves, 2005; Ewel *et al.*, 1998; Faunce and Layman, 2009; Honda *et al.*, 2013). This, in turn, leads to a complex and often challenging relationship between mangroves and associated fauna, which can impact research and conservation efforts (FAO, 1994; Sambrook, 2019). Stronger linkages between our understanding of coastal ecology and implementing management actions (e.g. marine spatial planning) appear to improve conservation outcomes (Olds *et al.*, 2016).

The extent of coastal connectivity could indicate our effectiveness in achieving successful conservation outcomes (Olds *et al.*, 2016). Yet, a large knowledge gap in mangrove research remains limited worldwide (e.g. Gerona-Daga and Salmo, 2022; Ho and Mukul, 2021). For instance, the growing body of literature contains research from across the tropical Atlantic region, the Caribbean, and Australia (e.g. Mumby *et al.*, 2004; Mumby, 2006; Honda *et al.*, 2013; Serafy *et al.*, 2015; Smale *et al.*, 2018; Reis-Filho *et al.*, 2016; Carrasquilla-Henao and Juanes, 2017; Carrasquilla-Henao *et al.*, 2019; Sambrook, 2019), while limited research is found in other geographical areas, e.g. parts of Asia, Africa, and Arabia (Serafy *et al.*, 2015; Almahasheer, 2018; Sambrook, 2019; Hai *et al.*, 2020). And where mangrove ecosystems are examined, they remain investigated as systems isolated from the wider seascape (Sheaves, 2005; Berkstrom *et al.*, 2012; Almaslamani *et al.*, 2013; Sambrook, 2019).

There is a pressing need, therefore, to capture fully where research into coastal connectivity among mangrove ecosystems has been conducted around the world, what type of topics are leading research, and how we can capture publication trends to fully offer opportunities for future research. From this perspective, this chapter aims to describe the current knowledge about the importance of mangrove habitats for supporting biodiversity and whether the connectivity facilitated by the movement of marine species has been examined. Through a systematic literature review, the objectives are to identify the publication trends, such as research topics, description of habitats, taxonomic groups studied, historical changes and geographical coverage of the literature.

2.2 METHODS

2.2.1 Literature search

This chapter followed the guidelines for systematic literature reviews (Pullin and Stewart 2006; Rutter *et al.*, 2013; Saran *et al.*, 2018; Page *et al.*, 2020), and was performed using three scientific bibliographic databases: Web of Science, Scopus, and Science Direct, and a search engine, Google Scholar. The search engine Google Scholar was limited to the first '50' hits (.doc, .txt, .xls, and .pdf documents) due to the many irrelevant results found after several reviews of the next pages. The search was conducted on 24 June 2020 and used the following combination of search terms: [mangroves* OR mangrove ecosystems* OR mangrove habitats* AND biodiversity AND (proximity OR vicinity) OR (connectivity OR movement) AND ("shallow water habitats*" OR "coastal habitats*") AND NOT (lakes* OR freshwater)]. These terms were chosen according to the objectives of the study (Appendix A.1). The search outcomes were imported and managed using the reference management software EndNote X9 (EndNote, 2019).

The initial list identified 1,210 records, of which 30 were removed after filtering for duplicates and 1,019 were removed after reviewing by title. Subsequently, 161 were screened by title and abstract, of which 77 were removed due to irrelevance to the topic leaving 84 relevant articles identified after a full-text screening. A supplementary search was conducted using the references from the identified relevant articles (Badzmierowski *et al.*, 2021), which recognized an additional 40 records. At this stage, several articles were excluded, e.g. non-relevant populations or unable to source the full text. The final list included 102 records, as shown in Figure 2.1, following the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram (Page *et al.*, 2020).

2.2.2 Selection criteria

The criteria used to assess the eligibility of a publication to be included in this review were: (a) the relevant subject(s) had to include either mangrove ecosystems or several mangrove areas, or an additional marine habitat, excluding riverine or freshwater ecosystems, such as lakes and rivers, (b) the relevant population had to include either terrestrial or marine species population, or both, that moves across habitats, (c) the relevant comparator had to include an indication of connectivity or proximity to mangrove ecosystems, e.g. spatially, to adjacent marine habitats: studies with no significance to the connectivity, presence or proximity of one mangrove patch to another were excluded, (d) the relevant study outcomes had to describe whether species, diversity, and structure changes were examined or measured within mangroves in comparison to other areas or adjacent marine habitats: study outcomes that included conservation and monitoring were also included, and finally (e) the relevant study types were primary or secondary research published in the English language. These criteria were evaluated by screening titles and abstracts of all documents and a full-text screening if the information in the title and abstract was not sufficient.

2.2.3 Data extraction

A meta-data extraction on the final list of relevant articles was then performed to obtain full descriptive information following Pullin and Stewart (2006) and Saran *et al.* (2018), e.g. publication date, publication type, and specific sub-topics related to the research questions, e.g. type and number of habitat(s) included in the study (Table 2.1). To ensure transparency, consistency, and organization, the meta-data was sorted using Microsoft Excel Workbook (details in Appendix A.2).

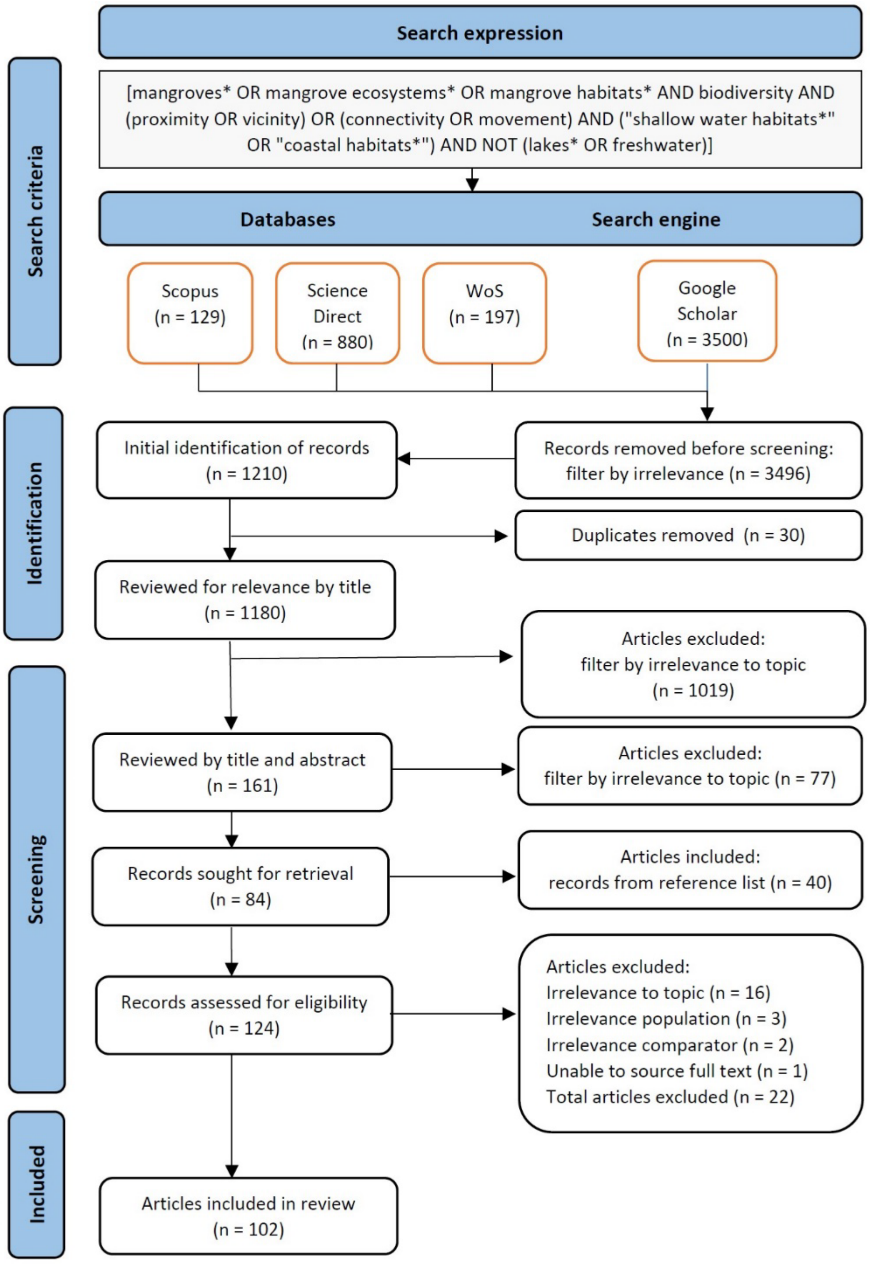


Figure 2. 1. Flow chart representing the records included and excluded at each stage of the systematic review process following PRISMA (Page *et al.*, 2020).

Topic	Description
Publication	Information about the publication, e.g. full reference (Author(s), title, year, publisher, etc.), year of publication (date of publication), and language.
Publication Type	The type of publication, e.g. journal article, conference paper, book (or book chapter), dissertation paper, technical report, and government document.
Length of study	The duration of the study in blocks of time, e.g. less than six months, one year, two years, one to three years, five to nine years, more than ten years, or unknown.
Study location	The location of study, e.g. name of country, name of region, multiple regions, or unknown.
Data source	The source of research or type of source, e.g. primary research, secondary research.
Data type	The type of data collected, e.g. quantitative, qualitative.
Study design	The type of study design, e.g. experimental, observational.
Specific sub-topics	
Number of habitat(s)	The number of habitat(s) included in the research, such as single habitat, two habitats, or multi-habitats.
Type of habitat(s)	The type of habitat(s) included, such as mangroves; mangroves and other; mangroves and seagrass beds; mangroves, seagrass beds and other; mangroves and coral reefs; mangroves, coral reefs and other; mangroves, seagrass, and coral reefs; mangroves, seagrass, coral reefs, and other.
Proximity of habitats assessed	(If) the proximity between habitats was assessed quantitatively, such as distance or spatial scale, in the study (yes), and if not assessed (no).
Group of species population	The type of species population assessed in the research, e.g. marine species (fish, sharks), terrestrial species.
Type of research topic	The type of research topic, such as biodiversity (e.g. assemblage and composition, biomass and richness), ecosystem services, spatial mapping, monitoring, connectivity (e.g. biological), and conservation. The research topic may include more than one; if available, specific research topics should be identified.
Type of approach	The type of methodology used, such as visual census (e.g. underwater), camera (e.g. video-recording, photography), passive gears (e.g. seine net, trawling, traps, other), acoustic telemetry, mapping, modeling, meta-analysis, other methods (e.g. interview, literature review). The type of methodology may include more than one.

Table 2. 1 Description of information for extraction.

2.3 RESULTS

2.3.1 Number of publications and trends

Initially, the three bibliographic databases (Web of Science, Scopus, Science Direct), and Google Scholar search engine revealed substantial publications. Of the four, the grey literature by Google Scholar search engine identified 3500 publications irrelevant to the topic of interest; thus, upon screening the literature of the first ‘50’ hits, eleven publications were relevant and included in the review. As shown in Figure 2.1, a total of 102 publications were relevant to this review. Of these, ninety-three (91.2%) were peer-reviewed articles presenting primary information. The nine (8.8%) remaining data sources were from books or book chapters and reports, presenting either primary or secondary information.

The duration of studies varied across the published literature, with numerous articles not specifying a particular study duration (34%, n = 35). The findings show that twelve studies were conducted over less than six months (e.g. Kruitwagen *et al.*, 2010, and Le *et al.*, 2018), twenty-five articles in one year (e.g. Hemingson *et al.*, 2020, and Marley *et al.*, 2020), nine articles in two years (e.g. Kimirei *et al.*, 2015, and Jelbart *et al.*, 2007), seven articles between one to three years (e.g. Bell *et al.*, 1984; Chin *et al.*, 2012; and Chin *et al.*, 2013), only three extending between five and nine years (e.g. Aburto-Oropeza *et al.*, 2008), and eleven spanning more than a decade (e.g. Zharikov and Milton, 2009; Vasconcelos *et al.*, 2014; and Sambrook *et al.*, 2019).

In terms of the types of study identified in this review, there was a clear focus on field-based data sampling through primary data collection in the field (e.g. sampling fish in mangroves using gears) (60%, n = 61), compared to data collected through observation and measurement of variables without intervention (e.g. visual census) (38%, n = 39), and experimental by testing hypothesis under a controlled environment (e.g. to determine cause and effect relationship) (2%, n = 2). Concerning the data type found in the publications, quantitative information from the literature accounted for 76% (n = 78), and qualitative data for 24% (n = 24). The former data types involved quantitative investigations using numerical values suitable for statistical analysis (e.g. multivariate variance analysis to determine species composition across multiple habitats; see e.g. Huijbers *et al.*, 2008; Kimirei *et al.*, 2011; Honda *et al.*, 2013; and Hylkema *et al.*, 2015).

The qualitative data type in the publications consisted of descriptive analysis, mainly relating to literature reviews. For instance, reviews were found on the relationship of habitat connectivity with regard to fisheries (Blader, 2009), and the biological connectivity of mangrove-bird communities (Buelow and Sheaves, 2015). In addition, several publications used meta-analysis to extract specific information relating to mangrove-fisheries linkages (e.g. Sheridan and Cynthia, 2003; Faunce and Joseph, 2006; Igulu *et al.*, 2014; and Carrasquilla-Henao, 2017). Other than literature reviews, qualitative data were also gathered using semi-structured interviews (e.g. Das, 2017; and Carrasquilla-Henao *et al.*, 2019).

2.3.2 Research topics and approach

Of all the publications, the research topics found in the literature were ecology, connectivity, conservation/ management, monitoring, and others (Table 2.2). The latter (others) mainly dealt with aspects of ecosystem services provided by mangroves (e.g. Benzeev *et al.*, 2017; Carrasquilla-Henao *et al.*, 2019). Most publications focused on ecological research (48%, n = 49), such as species community structure (84%, n = 41) and species foraging (14%, n = 7). Other publications examined connectivity topics (36%, n = 37), specifically the movement of species across multiple habitats, such as the works by Robertson and Norman (1987), Dorenbosch *et al*. (2007), Davis *et al*. (2014), Aguilar *et al*. (2014), Almaslamani *et al*. (2013), De-Abreu and Macia *et al*. (2017). In contrast, the least investigated research topics dealt with conservation and management (9%, n = 9) and monitoring (3%, n = 3). The conservation management research publications involved marine spatial planning (e.g. Devitt *et al.*, 2015), and monitoring research topics focused on long-term information, such as dispersal and connectivity between species and coastal habitats (Chin *et al.*, 2013).

A range of approaches were used to collect information, with some publications using more than one approach. Of these, the majority used literature reviews (31%, n = 34), of which meta-analyses comprised 12% (n = 4). This was followed by approaches using visual census (25%, n = 27), and passive gears (22%, n = 24), specifically seine net (n = 9), other types of nets (n = 6), traps (n = 4), trawling (n = 2), push net (n = 1), fyke net (n = 1), and other passive gear (n = 1). Additional approaches found in the publications included mapping techniques and modeling (7%, n = 8) (e.g. Devitt *et al.*, 2015; Brown *et al.*, 2016). The results also found publications regarding the use of acoustic telemetry (5%, n = 5), semi-structured interviews (2%, n = 2), camera usage for video-recording (5%, n = 5), stable isotope (2%, n = 2), catch and release techniques (1%, n = 1), and tagging species to determine their movement across the seascape (1%, n = 1).

Examples of publications that used more than one approach include research by Nagelkerken *et al*. (2001) that used underwater visual census and seine nets to collect fish data across habitat types. Similarly, work by Kimirei *et al*. (2015) used underwater visual census and seine nets to investigate fish communities, and Ho *et al*. (2018) also used visual census but with camera usage for video-recording to explore the influence of habitat complexity on fish density and species richness.

Research topic	Description	No. of publications	Example(s)
Ecology	Research focused on general ecological aspects (including biodiversity and species population structure within a given area)	n = 49, 48%	(Adkins *et al.,* 2016; Harborne *et al.*, 2016)
Connectivity	Studies primarily focused on biological connectivity, interlinkage, or the movement of species among habitats	n = 37, 36%	(Meynecke *et al.*, 2008; Marley *et al.*, 2020)
Conservation/ Management	Publications focused on the management and/or conservation of species and habitats	n = 9, 9%	(Devitt *et al.*, 2015)
Monitoring	Research focused on monitoring changes in population and/or habitat over time	n = 3, 3%	(Haig *et al.*, 2018)
Other (e.g. ecosystem services)	Studies on the ecosystem services provided by mangroves with an explicit focus on habitat provision	n = 4, 4%	(Benzeev *et al.* 2017; Carrasquilla-Henao *et al.*, 2019)

Table 2. 2 Topics of research and description as presented in the literature. Note that several of the studies focused on more than one topic.

2.3.3 Representation of habitats and species

The literature represented a range of habitats; namely, single mangrove habitats and variations within these (e.g. the edge and centre), two different habitats (e.g. mangroves and seagrass beds), or multiple habitats (e.g. mangroves, seagrass beds, and coral reefs) (Figure 2.2). The most represented habitats investigated in the literature were mangroves and other shallow-water habitats (e.g. mudflats, rocky shores) (63%, n = 43). The less-represented habitat types were mangroves, seagrass beds, and other shallow-water habitats (6%, n = 4). Other shallow-water habitats that included various coastal areas, such as rocky shores, mudflats, and seagrass beds, were the primary investigated areas adjacent to mangroves. For example, Hajisamae *et al*. (2003) investigated a range of littoral and shallow sublittoral zones near mangroves to determine species of fish. Huijbers *et al*. (2008) explored a variety of habitat types consisting of juvenile habitats (e.g. mangroves, seagrass beds, adjacent areas such as boulders) as well as non-typical juvenile habitats (e.g. shelf patch reefs), and Ramos *et al*. (2015) identified species populations across inshore and offshore coastal habitats, such as fringing reefs, mangroves, and seagrass beds.

While most research focused on exploring the habitat role of mangroves and other shallow-water habitats, few examined the role of different zones (or depth ranges) within a mangrove forest, such as work by Reis-Filho *et al*. (2016) that showed fisheries migration patterns in different tidal cycles in various mangrove zones, revealing how distinct habitats and environmental variables influence fish assemblages, and work by Kimirei (2011) that investigated various depth ranges within multiple coastal habitats to study species movement. Moreover, eighty publications (78%) of all studies assessed the proximity of mangrove habitats to the other studied habitats using a quantifiable figure (e.g. a numerical value) (e.g. Verweij and Nagelkerken, 2007; Aguilar *et al.*, 2014; Adkins *et al.*, 2015; Almaslamani *et al.*, 2015; Benzeev *et al.*, 2017).

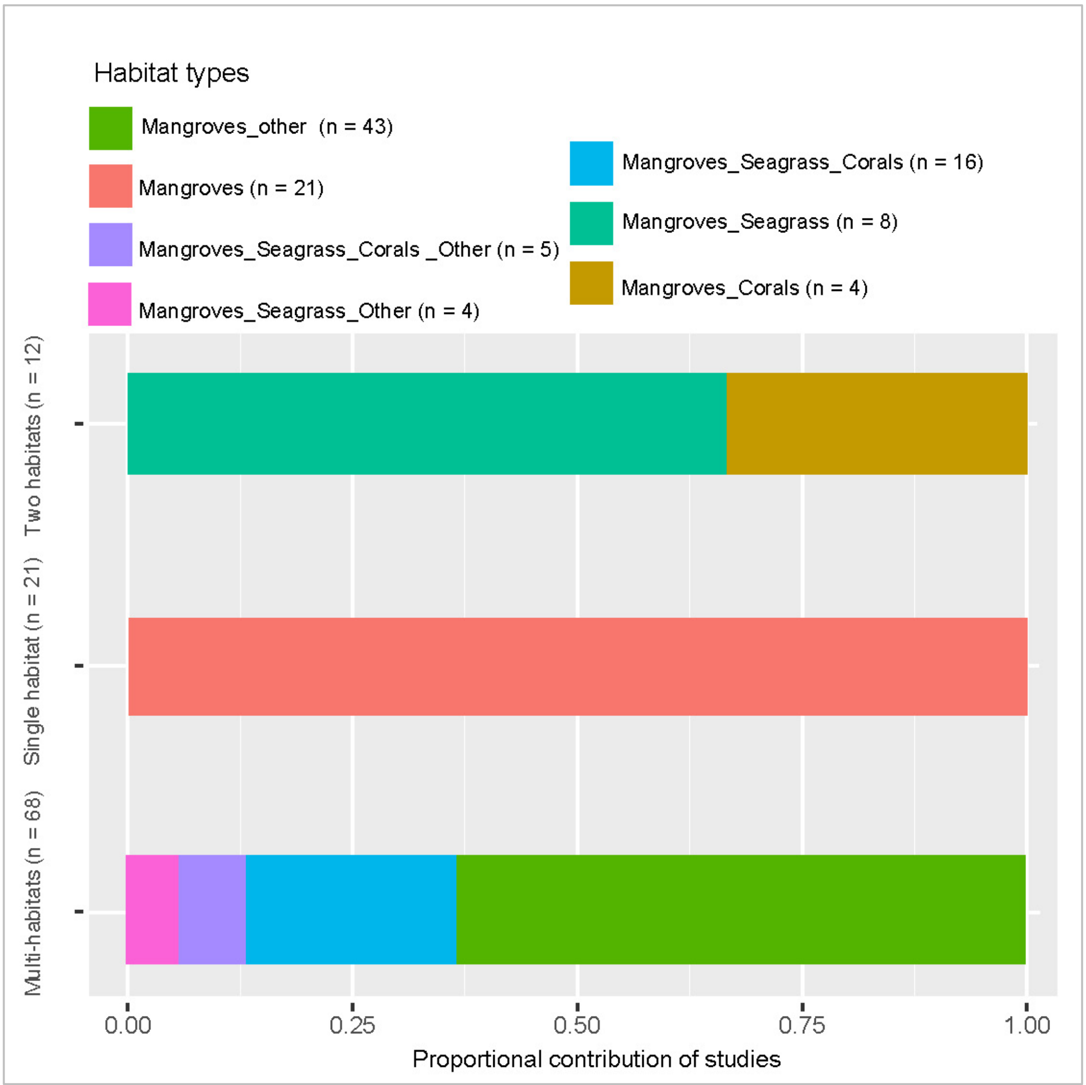
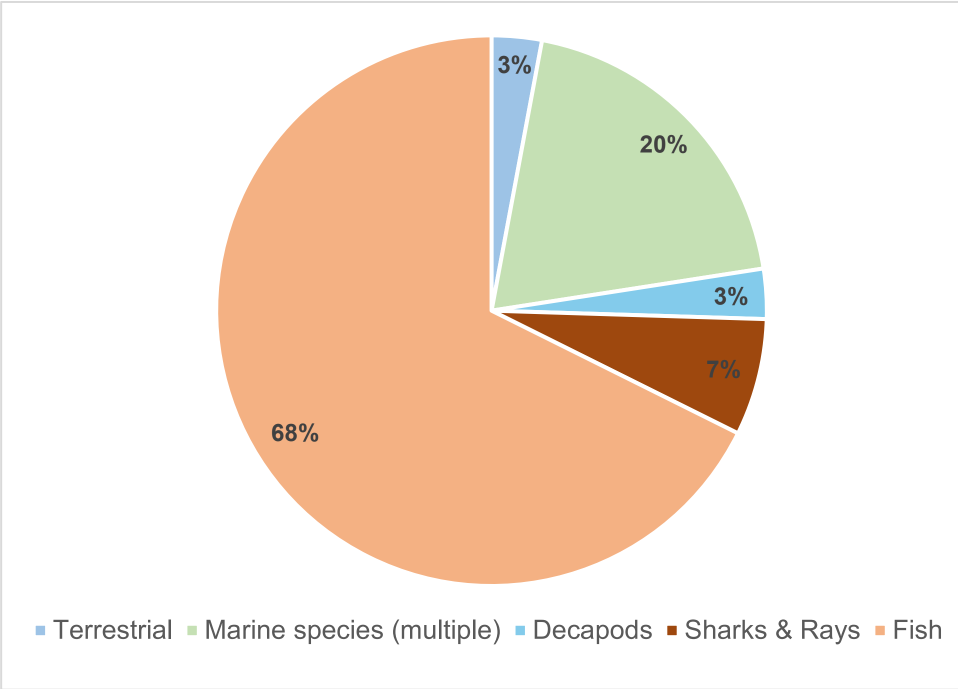


Figure 2. 2 The range of habitat types investigated in the literature (n =102 publications).

Ninety-seven percent of the 102 publications were concerned with marine species, with the remaining 3% were terrestrial species (e.g. Zharikov and Milton, 2009; Buelow and Sheaves, 2015; Sandilyan and Kathiresan, 2015); note that several studies investigated multiple populations in one study (Figure 2.3a). Most publications studied fish species (67%, n = 78) across multiple habitat types near mangrove ecosystems. The following studied species were multiple groups of marine species (9%, n= 10), including fish, decapods, sharks, shrimp, and other benthic fauna. These publications focused on investigations such as ecosystem services provided by mangroves and other habitats for multiple species, compiling evidence of connectivity between juvenile and adult habitats for multiple species and understanding patterns of habitat variability in exploited marine species (e.g. Moberg and Ronnback, 2003; Gillanders *et al.*, 2003; Vasconcelos *et al.*, 2014). The remainder of the publications examined shark species (6%, n = 7), decapods (4%, n= 5), and shrimps (3%, n= 4). The shark publications explored the importance of inshore habitats and mangrove channels for juvenile shark species (e.g. Wetherbee, 2007; Murchie, 2010; Chin, 2012; Chin, 2013; Haig, 2018).



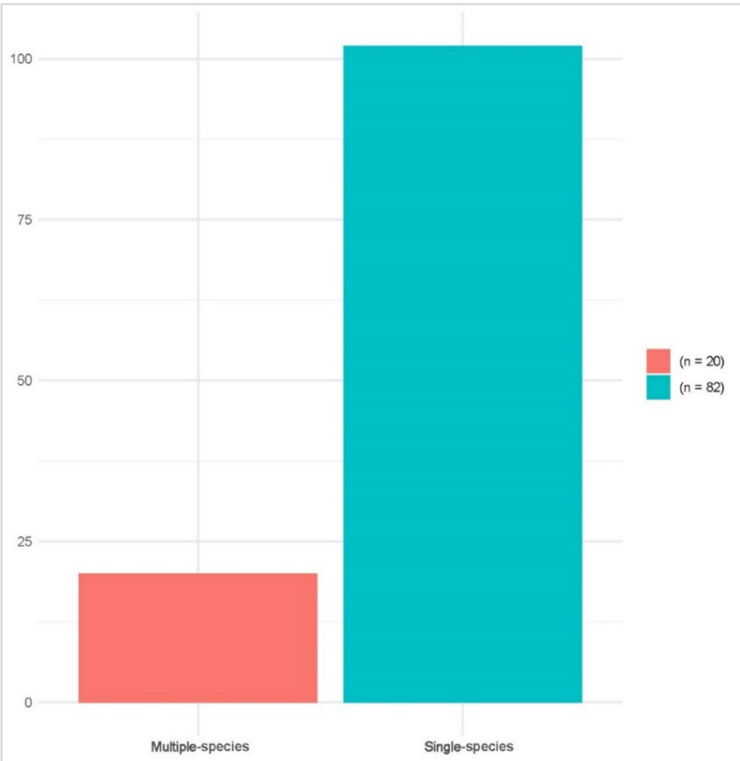


Figure 2. 3 (a) Above: The type of species presented in the literature (n = 102 publications), (b) Below: The cumulative number of publications for multiple-species and single-species presented in the literature (n = 102 publications).

2.3.4 Historical trends and geographical coverage of mangrove research

Since the first publication identified in this review (Bell, 1984), a steady accumulation of articles can be seen up to 2020 (Figure 2.4). The studies that describe the role of mangroves and other habitat types in supporting species grew slowly during the 1980s (n = 5). By the early 1990s, investigations on fish community structure in mangroves and adjacent habitats were the dominant research topics (Thayer *et al.*, 1987; Hutchings and Saenger, 1987; Blaber *et al.*, 1989; Robertson and Blaber, 1992). Afterward, a growing number of publications focused on investigating fish populations among coastal habitats. These publications were mainly from mangroves of the Caribbean Sea and its surrounding coasts (Figure 2.5).

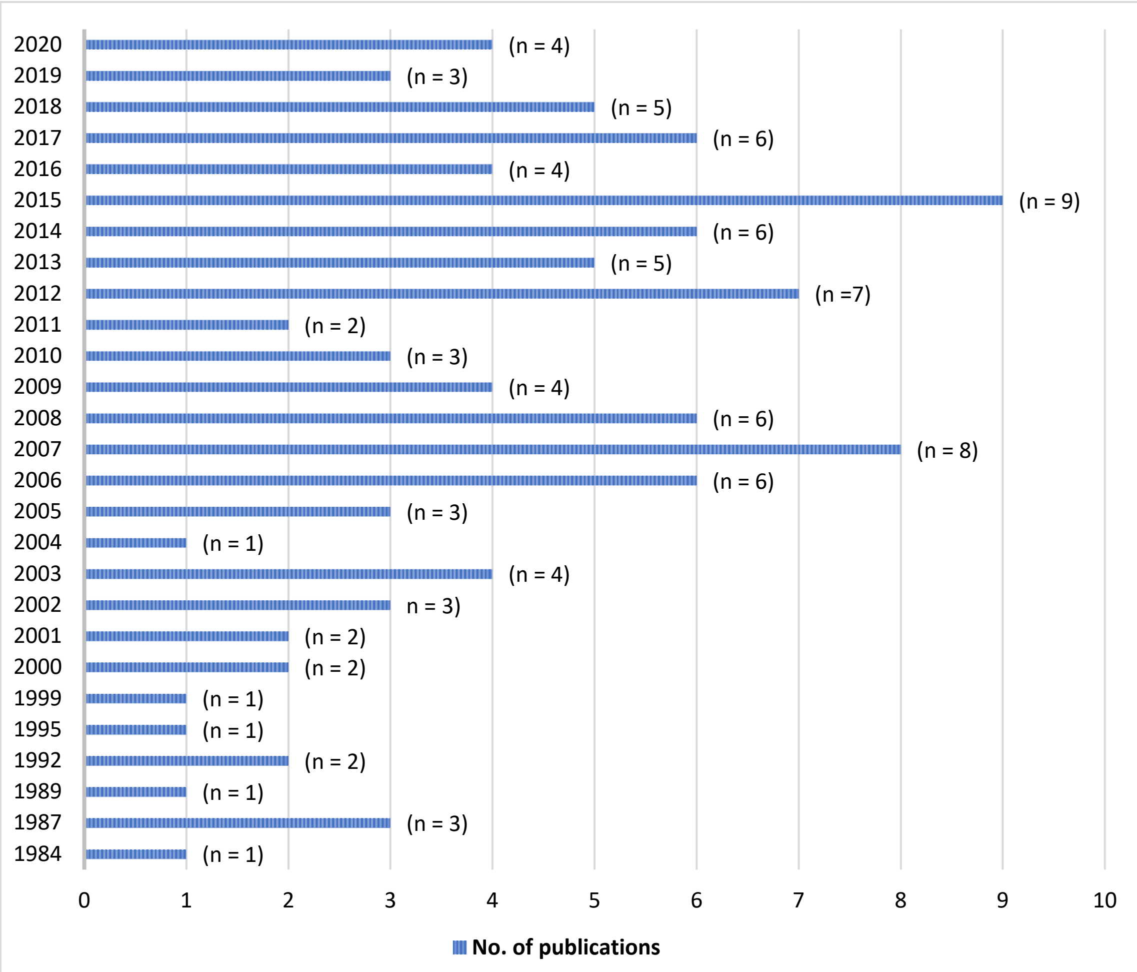


Figure 2. 4 The number of studies published from the year 1984 to 2020 (n = 102 publications).

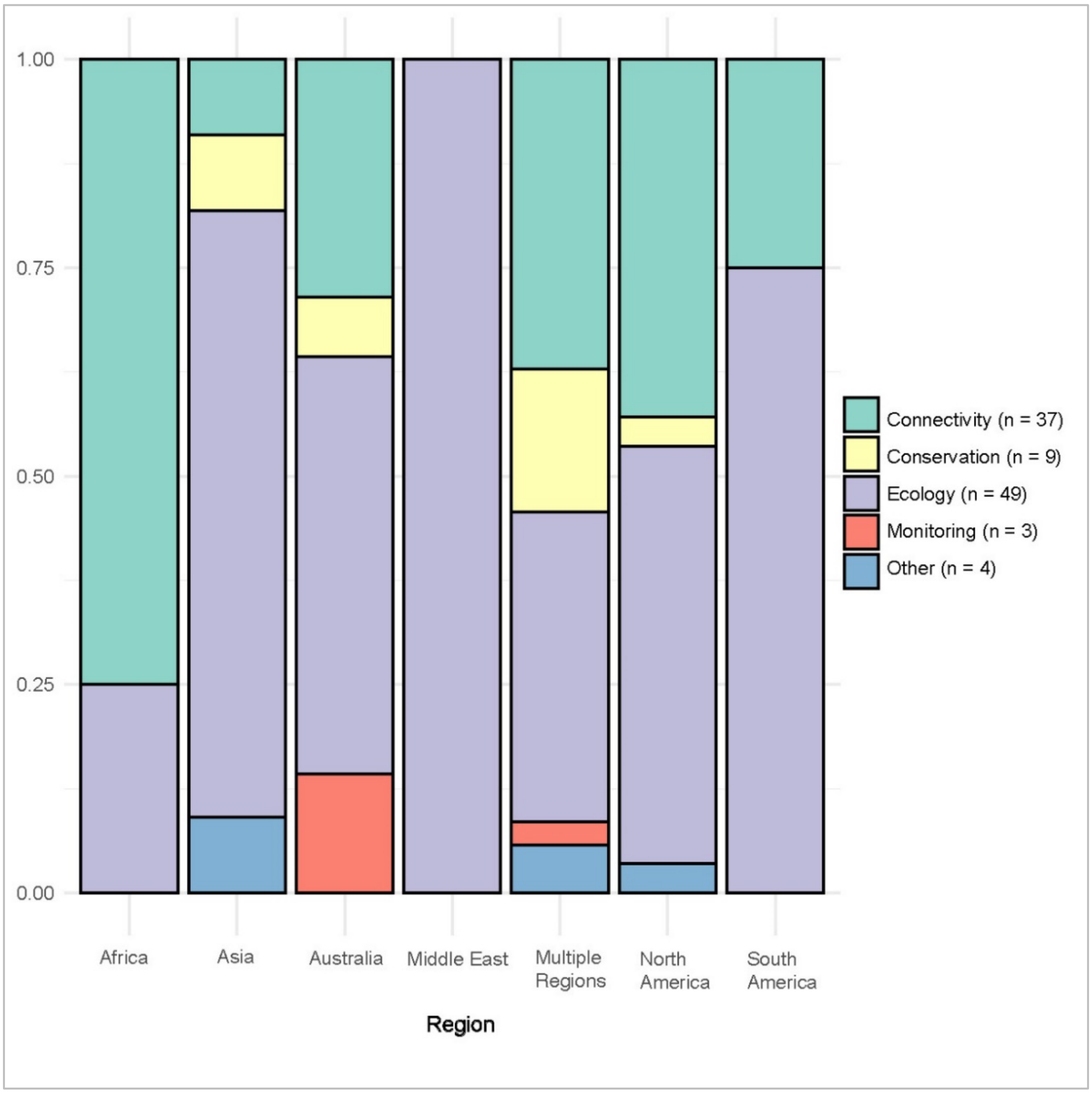


Figure 2. 5 The proportion of publications in each research topic in each region (n = 102 publications). Africa (Connectivity n=6, Ecology n=2), Asia (Connectivity n=1, Ecology n=8, Conservation n=1, Other n=1), Australia (Connectivity n=4, Ecology n=7, Conservation n=1, Monitoring n=2), Multiple Regions (Connectivity n=13, Ecology n=13, Conservation n=6, Monitoring n=1, Other n=2), North America (Connectivity n=12, Ecology n=14, Conservation n=1, Other n=1), South America (Connectivity n=1, Ecology n=3).

The distribution of publication topics varied worldwide (Figure 2.6). The Americas and Australia were the top regions with the highest publications, and Asia, Arabia, and Africa with the least publications. Multiple-country publications investigated several regions (25%, n = 26) (e.g. Saenger, 2002; Hogarth, 2015; Carrasquilla-Henao, 2019; Sambrook, 2019; Sievers, 2019), while single-country studies mainly originated from the Caribbean (16%, n = 16) and Australia (15%, n = 15). These locations focused on investigating fish populations among multiple coastal habitats (e.g. Dorenbosch *et al.*, 2007).

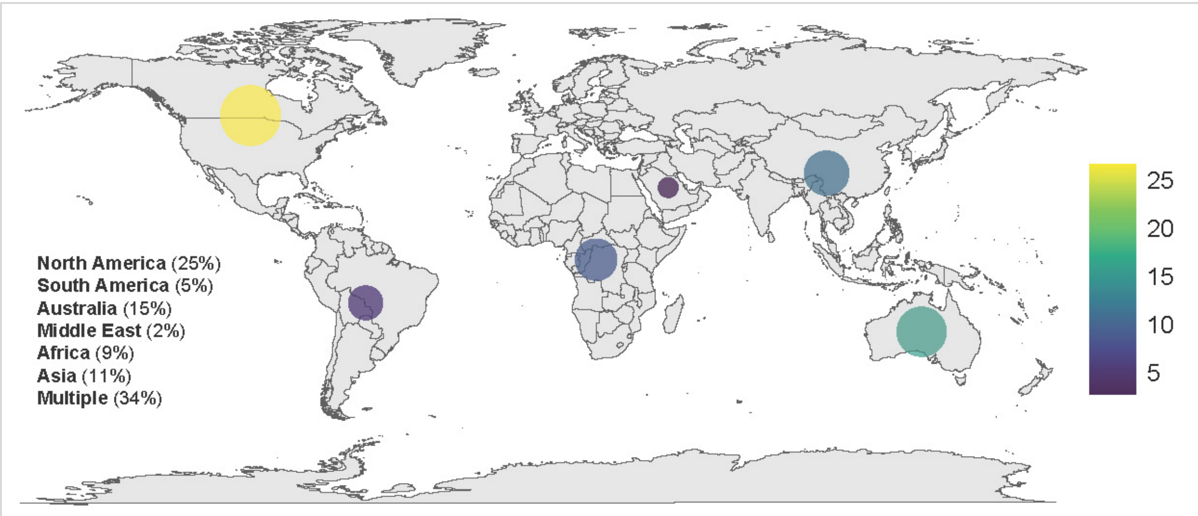


Figure 2. 6 The proportion of publications in each region (n =102 publications).

2.4 Discussion

2.4.1 Key findings and insights

This study captured the available literature on where and what has been represented in global mangrove research between 1982 and 2020. According to the most widely used scientific databases, peer-reviewed articles about ecological connectivity in mangroves started to appear in the 1980s, and only in the mid-2000s did the number of articles reach, on average, five per year. Google Scholar provided a large initial number of potential publications (n = 3500), but contributed less than 10% of those records to the study, suggesting that few grey literature publications report relevant outcomes. The combination of different databases and a search engine in this synthesis has produced meaningful insights, but if repeated, the search terms could be broadened beyond the movement of species to capture publications concerned with broader ecological interlinkages in mangroves systems and adjacent areas (e.g. the transfer of energy and nutrients, or export of organic matter). This consideration highlights the critical need for future literature reviews to incorporate a diverse and broad set of search terms to better represent the whole ecological role of mangroves in supporting species (see e.g. Nagelkerken *et al.*, 2008; Brander *et al.*, 2012; Mukherjee *et al.*, 2014).

The results imply that research on the movement of marine species across mangrove ecosystems and nearby habitats has had a steady accumulation over time (on average 2.5 papers per year). Geographically, research was concentrated along coastal areas of North America and parts of Australia. Relatively little attention has been given to mangrove areas in arid and hyper-arid regions (e.g. the Arabian Peninsula). The variation in mangrove research volumes across regions may be explained by not only the extent of mangroves in each area, but also the historical presence and accessibility of ocean research centres, facilities, and initiatives. Research, especially in the past two decades, has been examining the role of connectivity among habitats by the movement of marine fish species widely on patterns in the distribution of fish within mangrove ecosystems and the immediate shallow-water habitat. As such, research has helped to provide a reasonable knowledge base on the importance of mangrove habitats for supporting marine fish.

This work complements previous research, indicating that studying the movement of fish has been an important element in mangrove research (e.g. Pittman *et al.*, 2003; Nagelkerken, 2009; Sheaves *et al.*, 2015; Sambrook *et al.*, 2019). It has also been demonstrated that the spatial distribution of various coastal habitats influences the distribution, growth, and survival of marine species (Irlandi and Crawford, 1997; Micheli and Peterson, 1999), and that biological interconnectedness is vital for sustaining the long-term health of the ecosystem (Vargas-Fonseca *et al.*, 2016; Olds *et al.*, 2018).

2.4.2 Research gaps and future directions

The results of this study have helped us understand where in the world research has been covered on species and their movements in mangroves around the world, suggesting that there is a notable geographic bias. Previous research suggests that countries such as Indonesia, Malaysia, and the Philippines, have well-established mangrove restoration studies that were principally funded by international programmes (Salmo, 2021; Hai *et al.*, 2020; Nawari *et al.*, 2021). Yet, regions like Arabia may have funding resources, but marine research in general is still in its infancy, as suggested by Sheppard *et al.* 2010. This indicates that research in this particular field, until now, has been carried out in tropical and sub-tropical regions where, historically, accessibility of expertise and research facilities is centred.

While the emergent body of literature helps us understand how important multi-habitats are for ecological interactions (e.g. movement of species across the seascape), much of this knowledge originates from areas where 'favourable' wetter conditions present high species diversity in both plants and fauna (see e.g. Mumby *et al.*, 2004; Mumby, 2006; Honda, 2013; Serafy *et al.*, 2015; Smale *et al.*, 2018; Reis-Filho *et al.*, 2016; Carrasquilla-Henao and Juanes, 2017; Carrasquilla-Henao *et al.*, 2019; Sambrook, 2019). This finding complements the results of other studies that suggest variations in the distribution of scientific literature on mangrove ecosystems worldwide (see e.g. Sannigrahi *et al.*, 2020; Castellanos-Galindo *et al.*, 2021; Schwenke and Helfer, 2021; Bimrah *et al.*, 2022). Although mangrove research worldwide is accumulating, and recently, there have been more publications from countries rarely represented before (e.g. India, China, and Brazil), it still appears that the North American region leads in the production of articles per year (see e.g. Ho and Mukul, 2021).

Other geographical areas, such as Africa and regions of arid and hyper-arid mangroves, e.g. the Middle East, remain underrepresented in global mangrove literature (Gerona-Daga and Salmo, 2022; Ho and Mukul, 2021). As such, mangrove research investigating ecological connectivity through species movement should broaden its geographical scope to encompass regions that have consistently had limited literature research. Prioritizing mangrove research will have to first tackle the geographical bias in the literature identified in this synthesis. Secondly, mangrove research should prioritize ecological interlinkages of processes other than just the movement of fish and also consider other species in a holistic approach that also integrates social aspects (e.g. coastal communities).

Looking ahead, there has been a recent surge in seascape conservation efforts (see e.g. UNEP-WCMC, 2020), and the provision of sound baseline knowledge will help improve the scientific foundations for more effective restoration of diverse habitats in understudied regions. Future research would benefit from investigating the complex connections between coastal communities, ecosystem services, and fisheries production through transdisciplinary or cross-disciplinary approaches, such as examining how low mangrove ecosystem productivity can affect the assemblage of fish and coastal communities over time. Research could also focus on ecological interconnectedness of multiple-coastal habitats by incorporating local community knowledge to support decision-makers in seascape conservation (e.g. the recognition of restoring multi-coastal habitats such as the 'Seascape Programs' by Conservation International by Mcafee *et al.*, 2022). This might be especially important in regions with a high chance of coastal development plans, such as the United Arab Emirates in the southern Arabian Gulf subregion.

2.5 Conclusion

Mangroves are productive coastal ecosystems that offer many ecological services for biodiversity and local communities. Mangrove habitats are increasingly recognized as important for supporting a wide range of species. This bibliographic analysis has identified useful trends in the published literature regarding ecological interlinkage by the movement of species in mangrove ecosystems and beyond. The combination of different databases highlights the importance of using a variety of sources to document knowledge across a range of geographical areas and, thus, has indicated key knowledge gaps that can be seen as opportunities for future research.

While mangrove research has been conducted worldwide to document the importance of mangrove habitat services to species, many regions with substantial mangrove cover (Bunting *et al.*, 2022), such as those in Arabia, Brunei, Cambodia, Laos, and Myanmar, still have a relatively low contribution to the mangrove knowledge base. With coastal habitats progressively being affected by various natural and anthropogenic stressors, setting geographical and research priorities will help to understand how mangroves will survive in the future. As mangrove research grows, owing to its recognition as a critical habitat for fish, so will the need for further investigation of the movement of all species beyond mangroves and into adjacent complex habitats such as seagrass beds.

Future research is required to extend the literature analysis to quantify the linkage between multi-habitat patches or seascape configurations, the structure of fish communities, and how that might impact coastal communities and restoration efforts. In addition, it is acknowledged that a large range of literature has yet to be captured on mangroves, as the field of ecological connectivity is also concerned with a range of important mechanisms in addition to species movement, such as the export of organic matter. As research progresses, there will be a need to understand the patterns of connectivity fully. Using transdisciplinary approaches can be used to identify thresholds where interlinkages between habitats and species are weakened to effectively manage the wider seascape configuration. In addition, mangrove research should be expanded geographically, particularly by exploring understudied regions of the world, such as the Arabian region.

CHAPTER 3: Mangrove research in the Arabian Gulf: Temporal trends, geographical coverage, and research gaps

3.1 INTRODUCTION

Mangrove ecosystems in the Arabian region are situated in one of the most extreme marine environments in the world (Sheppard *et al.*, 1992) and so are of particular scientific interest due to their unique characteristics. The Arabian Gulf is situated in one of the world's hyper-arid and arid regions, characterized by limited precipitation (between 250mm in the north and less than 90 mm in the south), extreme sea-water temperatures, and high salinity levels, where many areas experience temperatures exceeding 34°C and salinity levels reaching 50 ppt, e.g. southern Arabian Gulf (Orif and El-Maradny 2018; Rostami *et al.*, 2022; Almansoori *et al.*, 2024). Mangroves in this geographical region extend over 209.5 km^2, representing roughly 0.1% of the global mangrove area (Bunting *et al.*, 2022). Along the Arabian Gulf, mangroves are mainly dominated by the grey mangrove (*Avicenna marina*) (Saenger *et al.*, 2004; Almahasheer, 2018). According to Worthington and Spalding (2018) the mangrove ecosystem types found in the Middle East region include fringing, lagoonal, and deltaic mangrove formations. Despite the importance of mangroves for coastal communities and biodiversity in the Arabian region, they are being subjected to increasing anthropogenic pressures (Sheppard *et al.*, 1992; Sheppard *et al.*, 2010; Almansoori *et al.*, 2024).

Rapid economic growth in the region has impacted marine ecosystems from coastal development and human population expansion after the 1970s discovery of oil and gas (Sheppard *et al.*, 2010; Sale *et al.*, 2011; Burt, 2013; Almahasheer, 2018). The degradation of mangrove habitats has consequently led to a growth in regional research on mangroves, especially relating to plantation efforts (Almahasheer, 2018; Almansoori *et al.*, 2021; Almansoori *et al.*, 2024). Yet, despite their importance, the Arabian Gulf remains the least represented in the global mangrove literature (see e.g. Chapter 2 of this thesis; Sheppard *et al.*, 1992; Almansoori *et al.*, 2021; Burt, 2024). Scientific studies on mangrove ecosystems along the southern coasts of the Arabian Gulf have often lagged behind those conducted on other local marine ecosystems, such as coral reefs (see e.g. Riegl and Purkis, 2012; Burt, 2013). Mangrove studies in the southern Gulf have been conducted primarily by locally-based government environmental agencies, namely the Environment Agency of Abu Dhabi (EAD) and the Ministry of Climate Change and Environment (MOCCAE), making it challenging to access and disseminate mangrove information widely (Almansoori *et al.*, 2021). Over the last 20 years, mangrove research has been conducted extensively in regions with excellent access to research funding, facilities, and scientific expertise (e.g. Australia; Alongi, 2009; and USA; Lee *et al.*, 2017; Sievers *et al.*, 2019). While global awareness of the importance of mangroves has led to a notable body of scientific literature worldwide, publication patterns have varied between countries (Lee *et al.*, 2017). Partelow *et al.* (2020) observe that although research findings have been published in languages other than English, they may not be widely accessible to the broader scientific community or English-speaking audience, especially in some countries where English is not the native language. Despite consistent research output in some regions previously understudied (e.g. Colombia; Castellanos-Galindo *et al.*, 2020; and Asia; Bimrah *et al.*, 2022), progress in mangrove research has been relatively slow in countries located in western Africa and Arabia, where mangroves are also crucial but have received far less attention and fewer resources (Lee *et al.*, 2017; Friis and Burt, 2020).

The rise in published research in different fields highlights the value of systematic literature reviews to help researchers understand the current state of knowledge and focus on their area of interest (Gurevitch *et al.*, 2018). As such, systematic reviews can help identify knowledge gaps and guide both research and conservation efforts (Gurevitch *et al.*, 2018), which has proven helpful in multiple marine and coastal ecosystems, such as mangroves (Sierra-Correa and Cantera Kintz, 2015; Himes-Cornell *et al.*, 2018; Castellanos-Galindo *et al.*, 2020), coral reefs (Comte and Pendleton, 2018), and seagrass beds (Unsworth *et al.*, 2018). Therefore, an important body of literature on Arabian mangrove ecosystems has yet to be captured by a systematic review of well-known multidisciplinary databases (e.g. Scopus and grey literature). This gap presents a valuable opportunity to shed light on the extent and scope of Arabian mangrove research.

This chapter aims to synthesize the literature base to summarize what is known and identify thematic knowledge and geographic gaps to propose future research on regional mangroves for better conservation and management in Arabia. Specifically, this study is intended to identify: (1) the temporal trends and geographical coverage of scientific literature on mangroves in the Arabian Gulf, (2) the geographical scope of literature production of authorship and affiliations, and (3) the spatial trends in research efforts according to mangrove typologies (Worthington and Spalding, 2018).

3.2 METHODS

3.2.1 Literature search

A systematic literature search was conducted using a combination of scientific bibliographic databases (Web of Science and Scopus), the search engine Google Scholar, and resource hubs of locally based environmental agencies (EAD and MOCCAE). This literature search aimed to take a regional focus to capturing the extant body of research on mangroves, in contrast to the previous chapter, which concentrated on a global review of mangrove connectivity and biodiversity. In this chapter, the term "region" refers to the Arabian Gulf and "subregion" refers to a part of the Arabian region. The initial search was conducted on 12 May 2021 and consisted of two steps. The first step involved searching the bibliographic databases Web of Science and Scopus using the search terms: [mangrove* AND "Arabian Gulf" OR "Persian Gulf"]. The second step supplemented this by searching the resource hubs tab on the main web pages of the leading environmental agencies in the United Arab Emirates (EAD and MOCCAE) in English and Arabic languages using the search term "mangrove". This additional search aimed to capture any records specific to the southern Arabian Gulf region that may have been missed in the global peer-reviewed databases; however, this search found unpublished material not relevant to this review (details in Appendix B.2: see also Figure 3.1).

A follow-up search was conducted on 7 June 2024 using Web of Science, Scopus, and the search engine Google Scholar, using the same search terms in the initial step, to update the literature database with relevant records after the initial search. The grey literature search was performed using the software Publish or Perish (PoP) version 8 (Harzing, 2007) in the search engine Google Scholar. The search performed in PoP included all available years to June 2024 using the 'keyword' field following the same search terms as in 2021 [mangrove* AND "Arabian Gulf" OR "Persian Gulf"] and retrieved the first '100' hits. The literature was managed using the reference management software EndNote X9 (Endnote, 2019). The results were then merged using simple steps following Caputo and Kargina (2022), which included converting the datasets to bibliography files (e.g. BibTex) and manually merging the datasets using Excel. In total, 140 publications were retrieved following the PRISMA process (Figure 3.1).

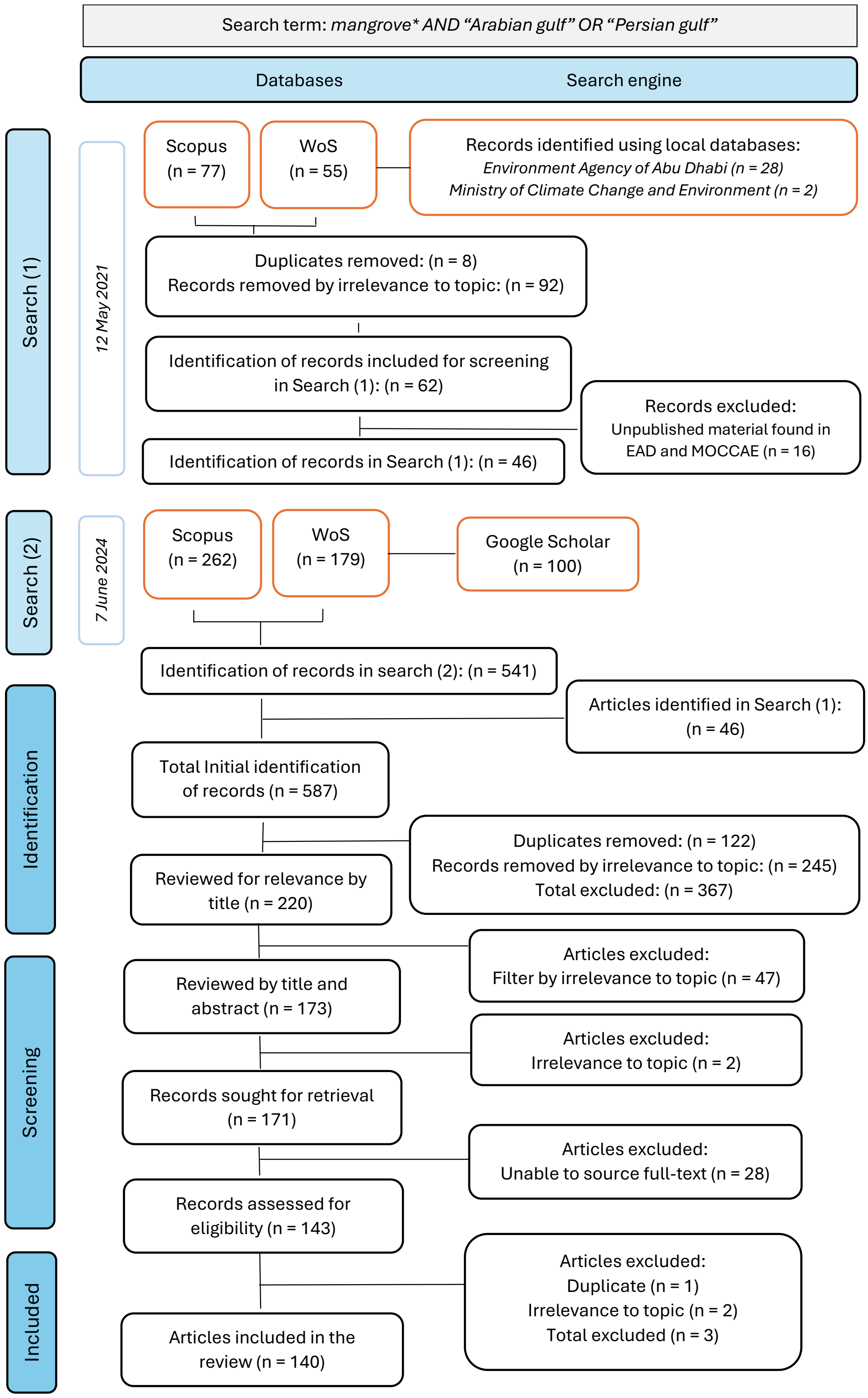


Figure 3. 1. Flow chart representing each stage of the systematic review process following PRISMA (Page *et al.*, 2020).

3.2.2 Selection criteria

A publication was included in the review if it met the following criteria; (1) the article reported research on mangrove ecosystems, and (2) the article described research undertaken in the Arabian region that is bounded by the Arabian Gulf, Red Sea, Gulf of Aden, Gulf of Oman, and Arabian Sea. Figure 3.1 presents the procedure for the exclusion and inclusion of records, following the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) process (Page *et al.*, 2020). The first step of the screening process included the title and abstract (n = 173), at this stage if the information was not sufficient to determine eligibility of the articles, a full-text review was performed.

3.2.3 Data extraction

To populate the literature corpus the following information was extracted: (a) publication year, (b) type of document (e.g. journal article, conference proceedings, book, book chapter, or technical report), (c) study type (e.g. primary or secondary data), (d) study location (e.g. name of country), (e) subregion (e.g. Arabian Gulf, Red Sea, etc.), (f) study outcome, or research topics (e.g. ecology of mangroves), (g) affiliation of lead author, and (h) country of affiliation of lead author. A publication that included multiple locations in the region, e.g. Arabian Gulf and Red Sea, or Oman and Kuwait, was considered in the category 'multiple locations'. Similarly, if more than one research topic had been studied, the category 'multiple topics' was applied. The study outcome, or research topic, was assigned to a specific category (Table 3.1). Additionally, when sufficient information was available in a study, the mangrove type was determined, following Worthington and Spalding (2018) of the four different mangrove typologies: (1) deltas, (2) estuaries, (3) fringes, and (4) lagoons. Prior to full data extraction, the process was first tested using at least 20 records to ensure cross-checking, agreement, and compliance with the set criteria.

Topic	Criterion
Biodiversity	Research related to the diversity of fauna species that are associated with mangrove ecosystems, such as terrestrial, marine, invertebrates, and studies focused on food webs and species composition.
Phenology	Research on the plant life cycle and biological aspects related to growth, development, flowering, litter production, and plant biomass.
Connectivity	Research focused on biological connectivity, such as biological, chemical, or interlinkage among mangrove habitats or adjacent areas.
Ecosystem description	Research concerned with describing the coastal area, with an emphasis on mangrove ecosystems but without an explicit focus on mechanisms or interactions within mangroves.
Evolutionary biology	Research focused on evolutionary processes and mangrove species diversity or genetics.

Table 3.1 (Continued) Study outcome or research topic and criteria.

Physiology	Research focused on the physiological characteristics of mangrove ecosystems.
Sediment	Research focused on the composition and characteristics of sediments or soil within mangrove ecosystems.
Carbon	Research focused on the study of organic carbon content, carbon sequestration, and blue carbon in mangrove ecosystems.
Spatial distribution	Research using spatial techniques to determine the distribution, health, or vegetation cover of mangrove areas.
Conservation management	Research focused on the management, conservation, restoration, and mitigation of mangrove ecosystems.
Other	Publications related to (a) government documents, such as federal law and policy, (b) reports, such as technical and baseline surveys, (c) literature reviews or interviews

Table 3. 1. Study outcome or research topic and criteria.

3.3 RESULTS

3.3.1 Temporal trends and geographical coverage of mangrove research

The first scientific study identified in this review was published in 1982 (Khan, 1982) as part of a coastal description review in the Bulletin of the Emirates Natural History Group on mangroves of the southern Arabian Gulf in the United Arab Emirates (UAE). After this study, nine further studies were published in the 1990s, with the number of publications increasing slowly through the 2000s, particularly in Iran in the northern Arabian Gulf (Figure 3.2a). Most publications emerging from the Arabian Gulf were from Iran along the northern part of the Gulf region (n = 67, 48%), followed by Saudi Arabia and the UAE, each contributing 25 studies (18%). The UAE has a longer history of investigating mangrove ecosystems (1982 to 2022) (e.g. Khan, 1982; Embabi, 1993; Shriadah, 1999; and Nelson *et al.*, 2022) than Saudi Arabia (1994 to 2023). The Gulf countries Qatar and Kuwait produced nine and six publications, between 1991 to 2021 and 1996 to 2020, respectively. Oman, Egypt, and Bahrain produced the least number of publications (1% each) over the same period. The publications represent studies that span the three major subregions: the Arabian Gulf (n = 122, 87%), the Red Sea (n = 7, 5%), and the Gulf of Oman (n = 1, 1%), which includes eight Gulf countries (Figure 3.2b). The remainder of the publications were found across multiple regions (n = 10, 7%).

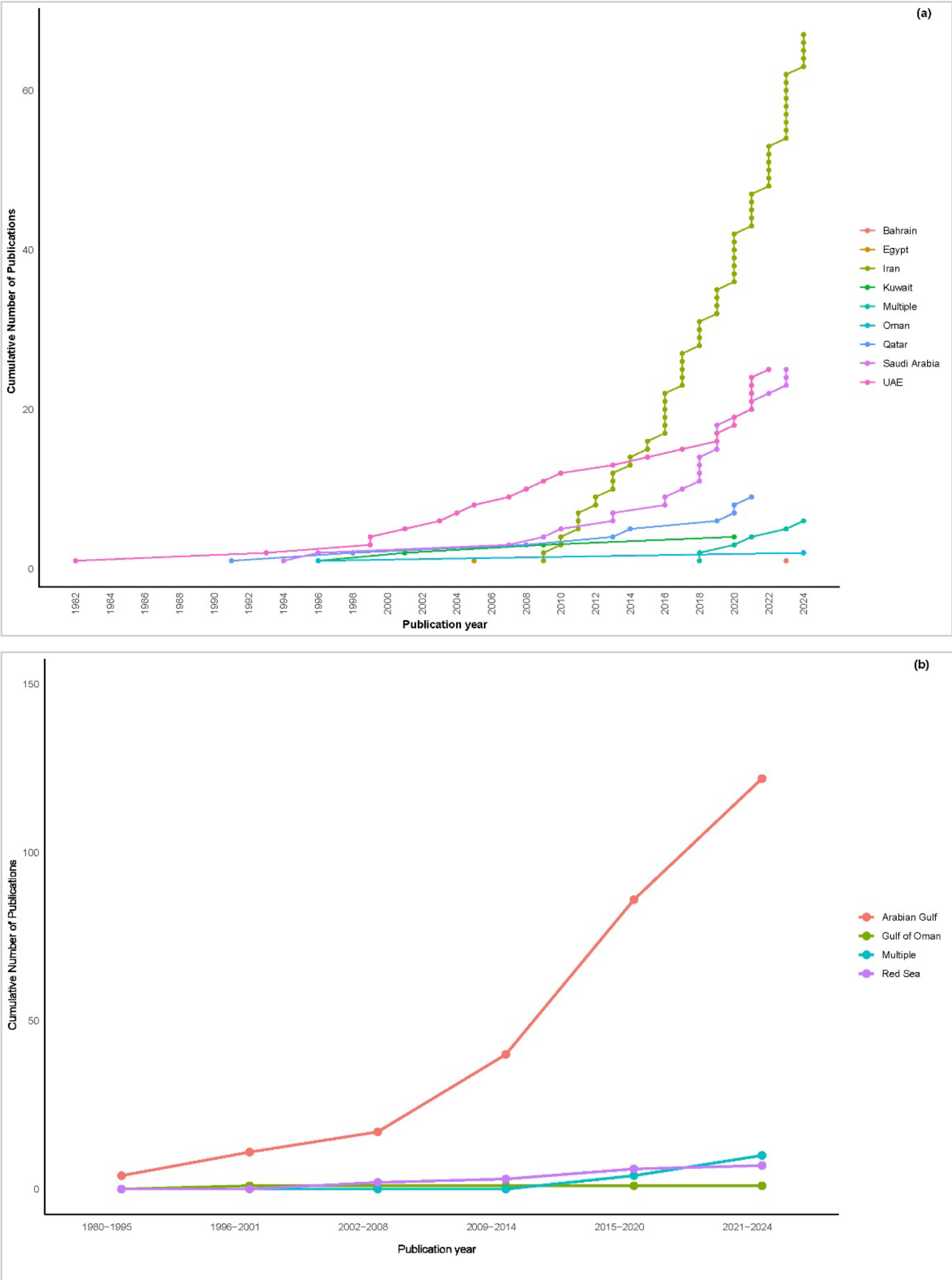


Figure 3. 2. (a) Historical trend in mangrove studies in the Arabian region by study location (n = 9) from the year 1982 to 2024 (n = 140). The total number of publications for each study location is indicated for: Bahrain (n = 1), Egypt (n = 1), Iran (n = 67), Kuwait (n = 4), Multiple locations (n = 6), Oman (n = 2), Qatar (n = 9), Saudi Arabia (n = 25), and the United Arab Emirates (n = 25); (b) publication trends by subregions (n = 140).

Of the ten publications that included multiple subregions, six included two Gulf countries: four studies in Saudi Arabia along both the Red Sea and Arabian Gulf, and two studies in Iran and Oman along the Arabian Gulf and Gulf of Oman (Figure 3.3). The variety of research topics increased progressively between 1982 and 2024, with a notable rise in the last decade (Figure 3.4). In the Red Sea subregion, Saudi Arabia showed an even distribution across research topics, with spatial distribution-related topics being the most prominent topic (see Red Sea subregion in Figure 3.4). The most distinguished year for biodiversity-related studies occurred in 2023, with seven publications originating mainly from Iran (northern Arabian Gulf subregion).

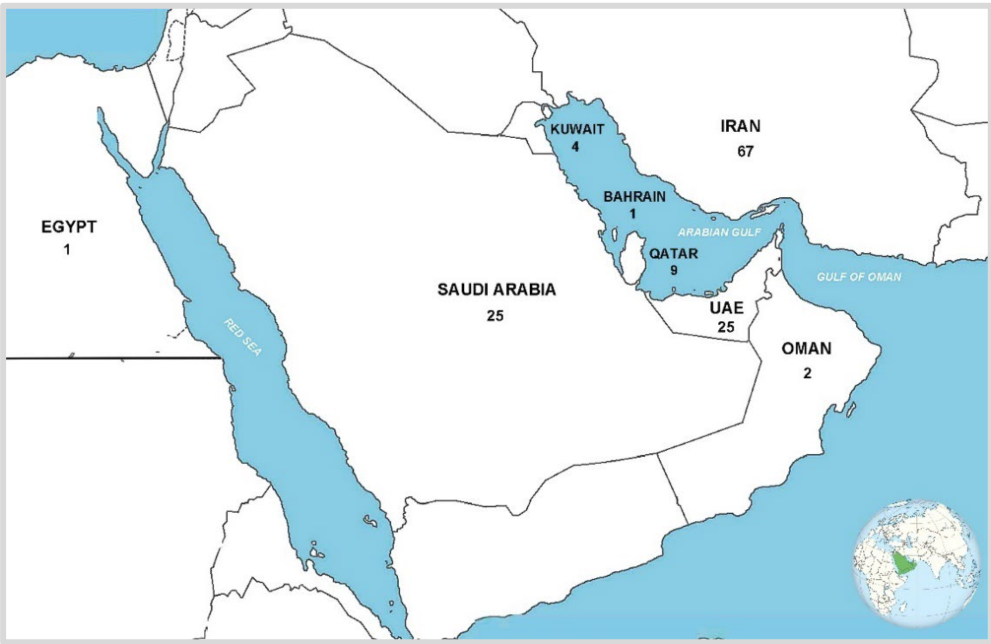


Figure 3. 3. The distribution of study sites in mangrove scientific publications by Gulf countries in the Arabian region (n = 140). The map displays the total number of publications (n = 134) for the study locations: Iran (n = 67), Saudi Arabia (n = 25), United Arab Emirates (n = 25), Qatar (n = 9), Bahrain (n = 1), Egypt (n = 1), Kuwait (n = 4), and Oman (n = 2). The remainder of publications were conducted in multiple countries (n = 6).

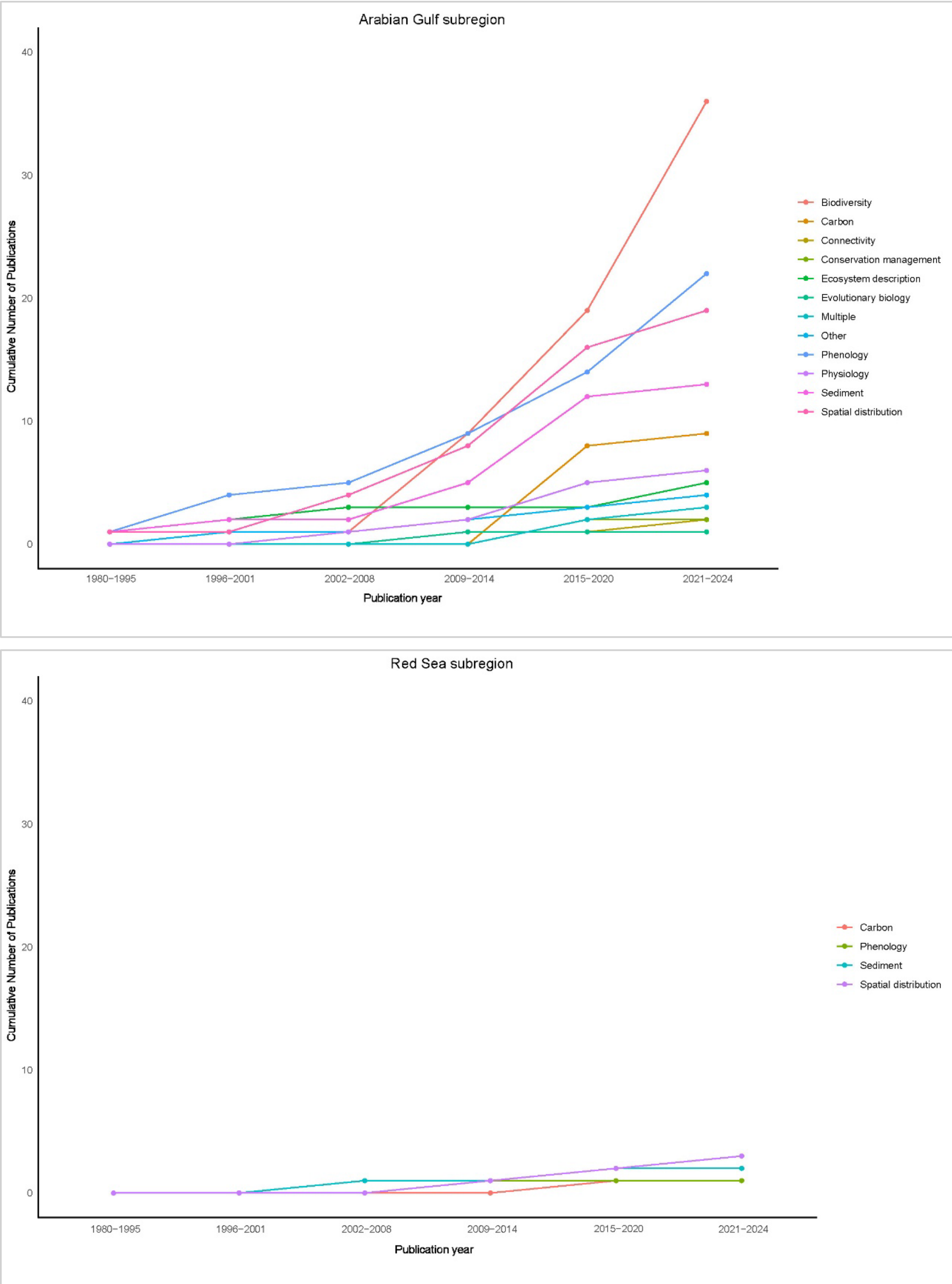


Figure 3. 4. Temporal trends in the proportion of publications for each research topic related to mangrove studies in the Arabian region between the 1980s and 2024 for each of the subregions: Arabian Gulf and Red Sea.

3.3.2 Representation of studies according to authorship and institutes

Of the 140 publications, 134 (96%) were journal articles, and the remaining were reports (n = 3), book chapters (n = 1), datasets (n = 1), and preprints (n = 1), with most publications collecting primary data (n = 128, 91%). The search results in the resource hubs of locally based environmental agencies uncovered a report on the main web page of the Environment Agency of Abu Dhabi, published by AGEDI (2008) and authored by regional experts.

The results from this review show that in expanding the corpus beyond peer-reviewed journal articles, the first authors were regionally-based researchers who contributed the majority of mangrove research publications (73%). The top three Gulf countries by contribution rank were first authors from Iran (n = 62, 44%), Saudi Arabia (n = 24, 17%), and UAE (n = 17, 12%). The remainder of the publications were led by foreign-based authors that contributed to a total of twenty-three studies, accounting for nearly 16% of all studies. By country, these included the United States (n = 6, 4%) and Australia (n = 4, 2%); together, they contributed ten studies (7%) out of the 140 total publications (Figure 3.5).

In total, nineteen countries and seventy institutions contributed to Arabian mangrove research, with a strong contribution from Iranian (n = 48) and Saudi Arabian (n = 8) institutions. The institute with the largest number of publications from Iran was Tarbiat Modares University (n=11). This is followed by the Islamic Azad University (Iran), King Saud University (Saudi Arabia), and the University of Hormozgan (Iran), each with eight publications. Qatar University follows closely with seven publications, and Shaherkord University (Iran) ranks sixth with five publications.

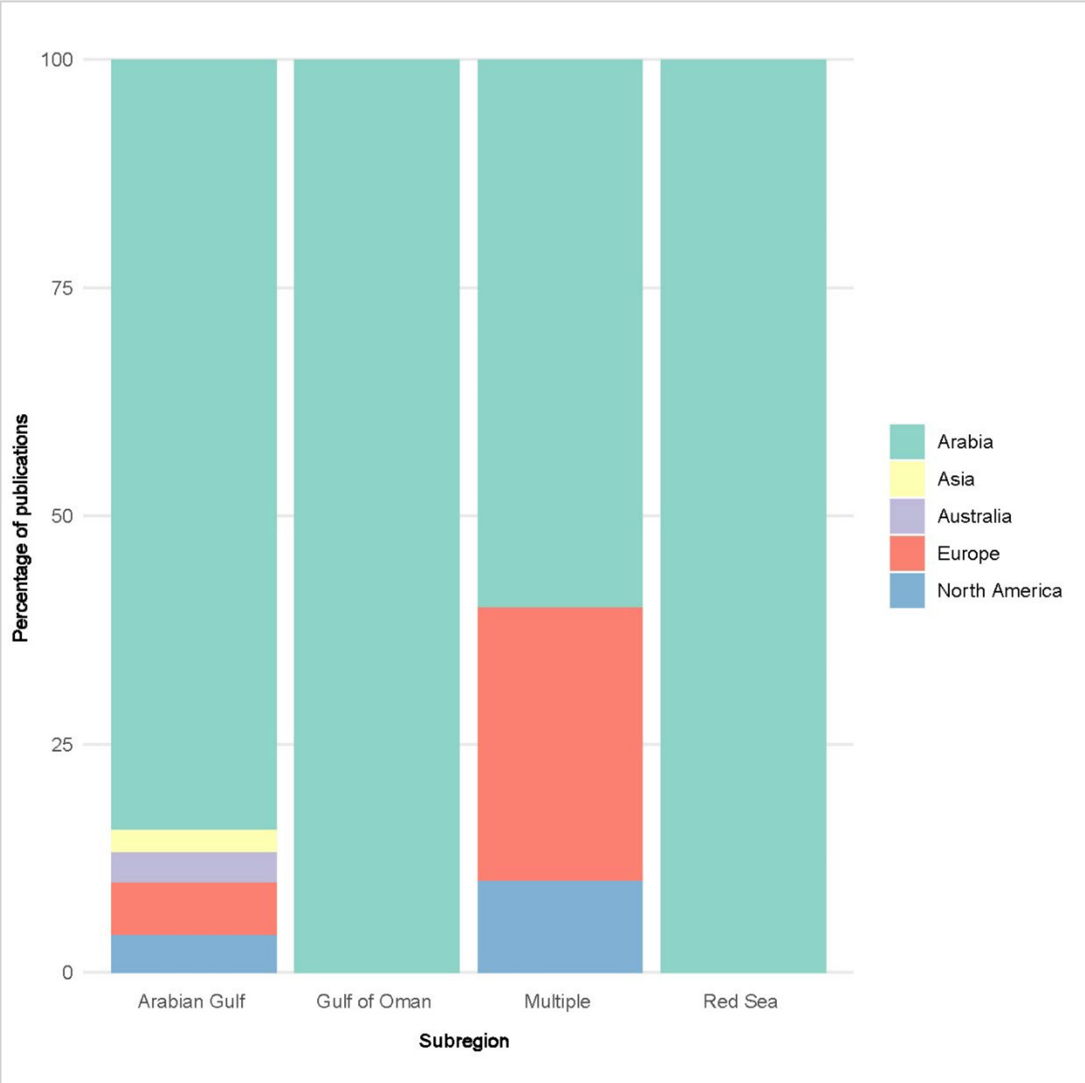


Figure 3. 5. Percentage of first authorships from each subregion based on the lead author of the total publications (n = 140).

3.3.3 Main research topics

Twelve research topics were identified in the publications, including 'multiple,' which consists of more than one topic (Figure 3.6). Across the Arabian region, the top three topics were biodiversity (n = 40, 29%), phenology (n = 24, 17%), and spatial distribution (n = 23, 16%), with most of the research originating from the Arabian Gulf subregion. The top three topics found in the publications across the Arabian Gulf subregion were related to biodiversity (n = 36), phenology (n = 22), and spatial distribution (n = 19). The other research topics were related to carbon research (n = 10, 7%), physiology studies (n = 5, 4%), conservation management and connectivity studies, with both contributing two studies (1% each).

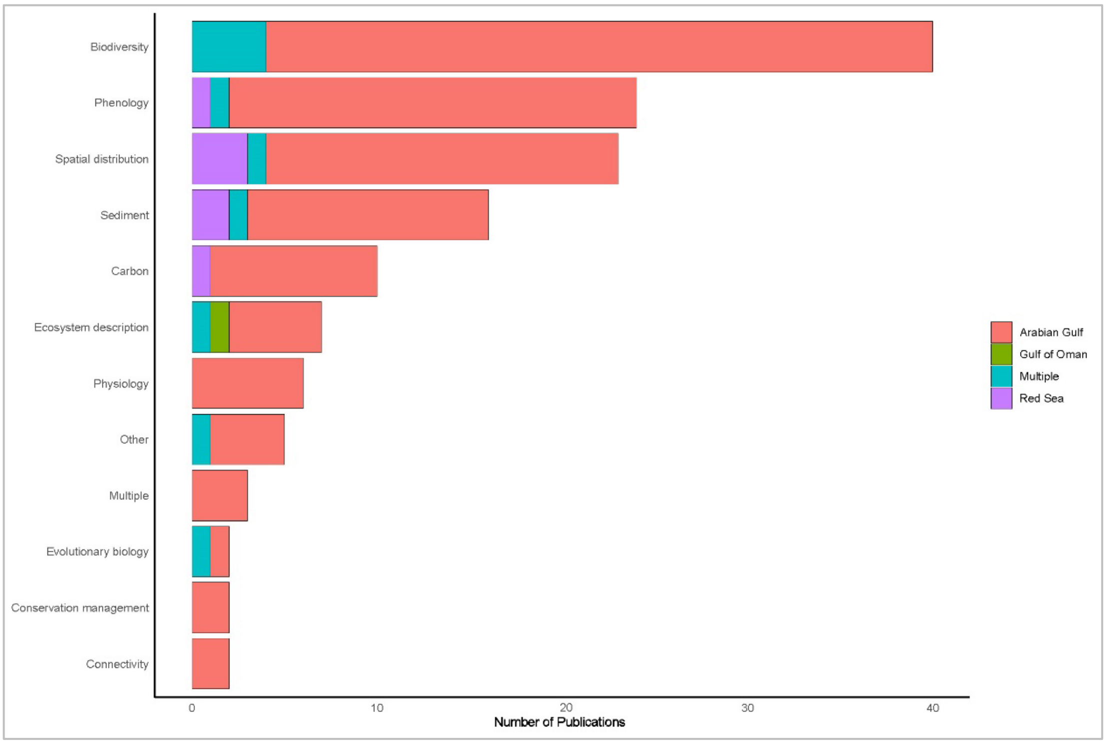


Figure 3. 6. Research topics covered by mangrove studies in the Arabian region between 1982 and 2024 (n = 140). The distribution of studies conducted in the Arabian region is presented by the three main subregions: the Arabian Gulf (red), Gulf of Oman (green), and Red Sea (purple). The subregion category 'multiple' indicates more than one subregion. The research topic category 'multiple' presents publications that focus on more than one research topic.

On conservation management, recent publications appeared in Saudi Arabia (Amin *et al.*, 2018) and the United Arab Emirates (Paleologos *et al.*, 2019), both of which have indicated an urgent need for conservation strategies or restoration efforts. The connectivity studies took place in Iran in the northern Arabian Gulf on crab composition across mangrove areas (Hemmati *et al.*, 2021) and in Qatar on the role of outwelling within and outside mangrove areas, e.g. in seagrass beds (Walton *et al.*, 2014). Studies focused on biodiversity topics (n = 40, 29%) focused on species composition in mangroves (Figure 3.7). Of these species, macrofauna was the most investigated (e.g. Al-Khayat *et al.*, 2019; Salimi *et al.*, 2021; Akbari *et al.*, 2022; Noghabi *et al.*, 2022), while molluscs, shrimps, and sponges were the least studied.

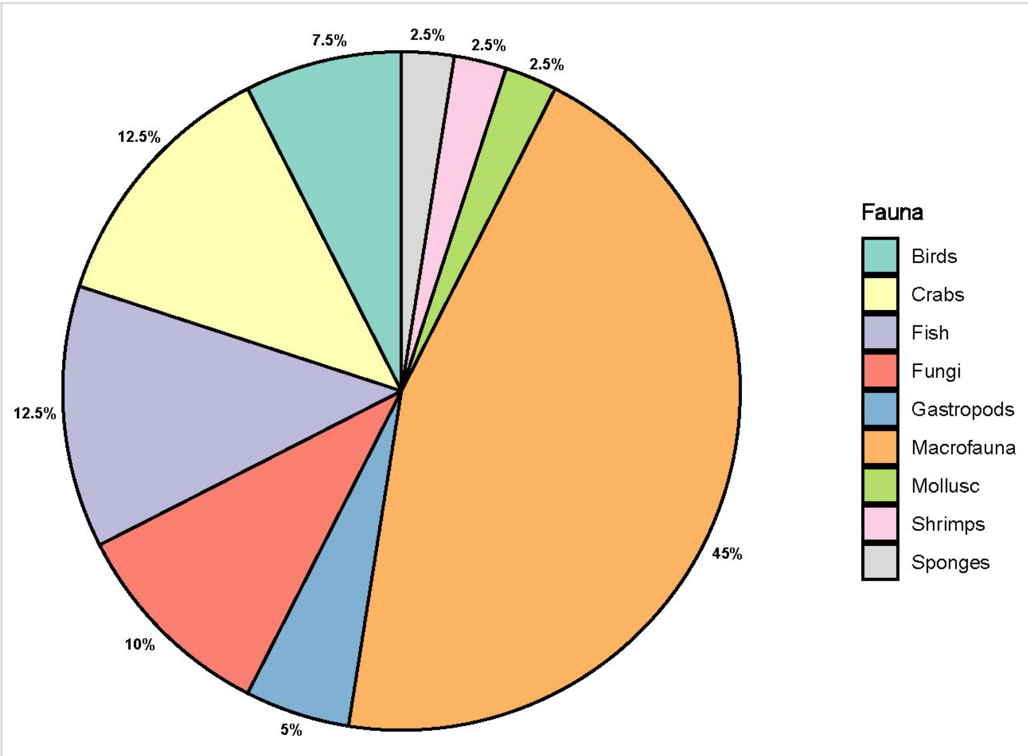


Figure 3. 7. The percentage contribution of the total primary fauna in publications of the 'Biodiversity' research topic in the Arabian region (n = 40).

3.3.4 Representation of studies according to mangrove type

The mangrove typologies present in the Middle East region are fringing (224 km^2), Lagoonal (82 km^2), and deltaic (12 km^2) (Worthington and Spalding, 2018) (Figure 3.8). This study found that fringing mangroves were the most studied type (n = 98, 70%), lagoonal mangroves (n = 37, 26%), and both lagoonal (n = 5, 4%). The most frequently examined mangrove type by study location was found in fringing mangroves in Iran (n = 67, 48%), fringing mangroves in Saudi Arabia and lagoonal mangroves in UAE (n = 25, 18%) (Table 3.2). In terms of primary fauna research in publications by mangrove type, fringing mangrove systems were most investigated (83%), compared to lagoonal systems (18%).

Study location	**Mangrove type**	**Subregion**	**Number of publications**
Bahrain	Fringing	Arabian Gulf	(n = 1, 1%)
Egypt:	Fringing	Red Sea	(n = 1, 1%)
Iran	Fringing	Arabian Gulf	(n = 67, 48%)
Kuwait	Lagoonal	Arabian Gulf	(n = 4, 3%)
Oman	Fringing	Gulf of Oman	(n = 2, 1%)
Saudi Arabia	Fringing	Arabian Gulf/ Red Sea	(n = 25, 18%)
UAE	Lagoonal	Arabian Gulf	(n = 25, 18%)
Qatar	Lagoonal	Arabian Gulf	(n = 9, 6%)
Multiple locations	Fringing/ lagoonal	All subregions	(n = 6, 4%)

Table 3. 2. Representation of publications by mangrove type across the Arabian region (n = 140). All subregions include the Arabian Gulf, Gulf of Oman, Red Sea, and Multiple subregions.

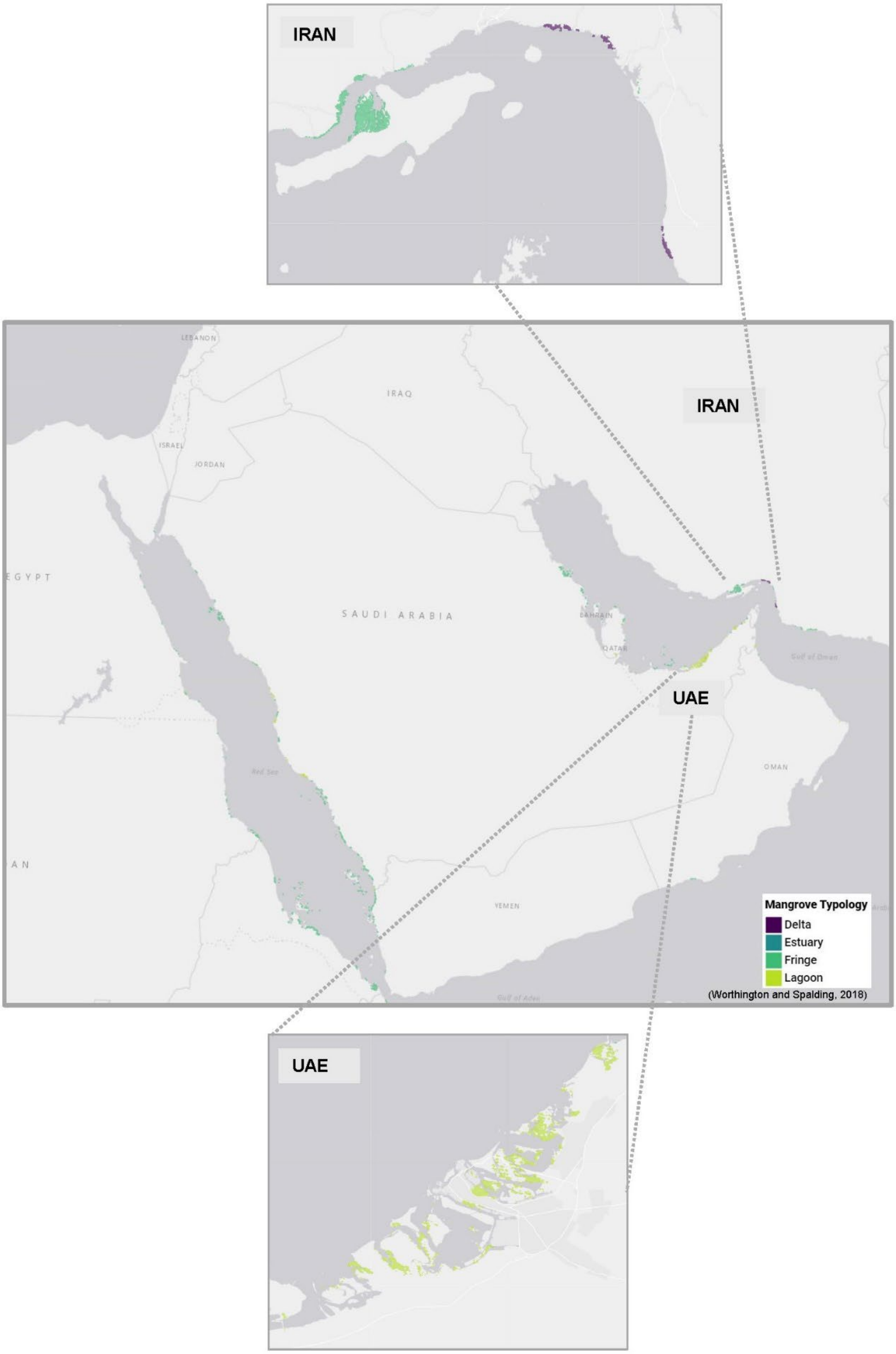


Figure 3. 8. Map of the Arabian Gulf with mangrove areas classified according to Worthington and Spalding (2018) typology. Iran (above) is represented by fringe and delta mangroves, and UAE (below) by lagoon mangrove ecosystems.

3.3.5 Representation of mangrove characteristics and zonation in the southern Arabian Gulf

The publications that dealt with mangrove phenology-related studies along the southern Arabian Gulf subregion (see e.g. Saenger *et al.*, 2004; Almardeai *et al.*, 2017; Samara *et al.*, 2020), found that *Avicennia marina* species exhibit some of the lowest productivity levels and growth rates (Table 3.3). Generally, mangroves in Arabia have exhibited a relatively low average above-ground biomass compared to those in other regions of the same species (*Avicennia marina*), such as subtropical or sub-humid climates (Table 3.4). Moreover, it was noted in the publications (n = 25) that *Avicennia marina* mangroves along the southern Arabian Gulf are often fragmented and stunted stands along tide-dominated intertidal areas, mostly lagoons, that frequently compete with other marine habitats, such as saltmarshes (see e.g. Saenger *et al.*, 2004; AGEDI, 2008; Samara *et al.*, 2020) (Figure 3.9).

Country/ Region	Mangrove area 2020 (km^2)	Species	Mangrove type	Average tree height (m)	Growth rate (cm)	Climate	Source
United Arab Emirates (southern Arabian Gulf)	74.45	*A. marina*	Lagoon	3	0.1	Hyper-arid	(Saenger *et al.*, 2004; Almardeai *et al.*, 2017; Samara *et al.* 2020)
Iran (northern Arabian Gulf	111.77	*R. mucranata*/ *A. marina*)	Fringe/ Lagoon	3.54	0.7	Semi-arid	(Zahed *et al.*, 2010; Al-mayah and Al-Asadi, 2023)
Saudi Arabia (Red Sea/ Arabian Gulf)	77.10	*R. mucranata*/ *A. marina*)	Fringe/ Lagoon	3	0.1	Arid	(Sheppard *et al.*, 1992)

Table 3. 3. Mangrove forest structure characteristics across different Arabian regions. Mangrove area indicates the total country/ territory according to Bunting et al., 2022; Species indicates mangroves *Avicennia marina* and *Rhizophora macrunata*; Mangrove type indicates the forest typology according to Worthington and Spalding, 2018; Climate is based on Koeppen's Classification (Chen and Chen, 2013).

Country/ Region	**Mangrove area 2020 (km^2)**	**Mangrove type**	**Average above-ground biomass (t/ha^{-1} or $MgC\ ha^{-1}$)**	**Climate**	**Source**
United Arab Emirates (southern Arabian Gulf)	74.45	Lagoon	78 to 110 t/ha^{-1}	Hyper-arid	(Saenger *et al.*, 2004)
Western Australia	10,170.81	Fringe/ Estuary	147.6 ± $MgC\ ha^{-1}$	Sub-humid	(Alongi, 2009)
Zambezi River Delta, Mozambique	3027.35	Delta/ Estuary	111 ± t/ha^{-1}	Sub-tropical	(Trettin *et al.*, 2016)
East Sumatra, Indonesia	29,533.98	Delta/ Estuary/ Fringe	279 ± $MgC\ ha^{-1}$	Tropical	(Kusmana *et al.*, 1992)
Dominican Republic	4700 ±	Delta	233 ± $MgC\ ha^{-1}$	Tropical	(Sherman *et al.*, 2003)

Table 3. 4. Forest characteristics of *A. marina* among different climatic regions.

The findings in these publications indicate that the coastal arrangement of habitats is unique, in which, at the landward edge, numerous coastal features such as hyper-saline flats (known in Arabic as ‘Sabkhas’), cyanobacterial mats, and salt marshes often fragment mangrove communities (see schematic representation Figure 3.10). However, this is not uncommon for mangrove communities in hyper-arid climates and extreme environmental conditions (see e.g. Hellyer and Aspinall, 2005; and Almansoori *et al.*, 2021), who noted uneven ecosystem description in the locality of Abu Dhabi Emirate in the UAE.

Figure 3. 9. Representation of mangroves and surrounding coastal habitats along the southern Gulf of Arabia, Abu Dhabi Emirate, United Arab Emirates. Top left: mangrove species (*Avicennia marina*) along the eastern coast near Jubail and Ramhan Islands. Top middle and top right: saltmarsh species (*Arthrocnemum macrostachyum*) coexisting with mangroves found near Ras Ghurab and Ramhan Islands. Bottom left: Aerial view of Jubail Island presenting naturally fragmented mangroves, saltmarsh, and cyanobacterial mats. Bottom right: hyper-saline coastal flats near mangroves in Bu Tinah Island (known as ‘Sabkhas’ in Arabic).

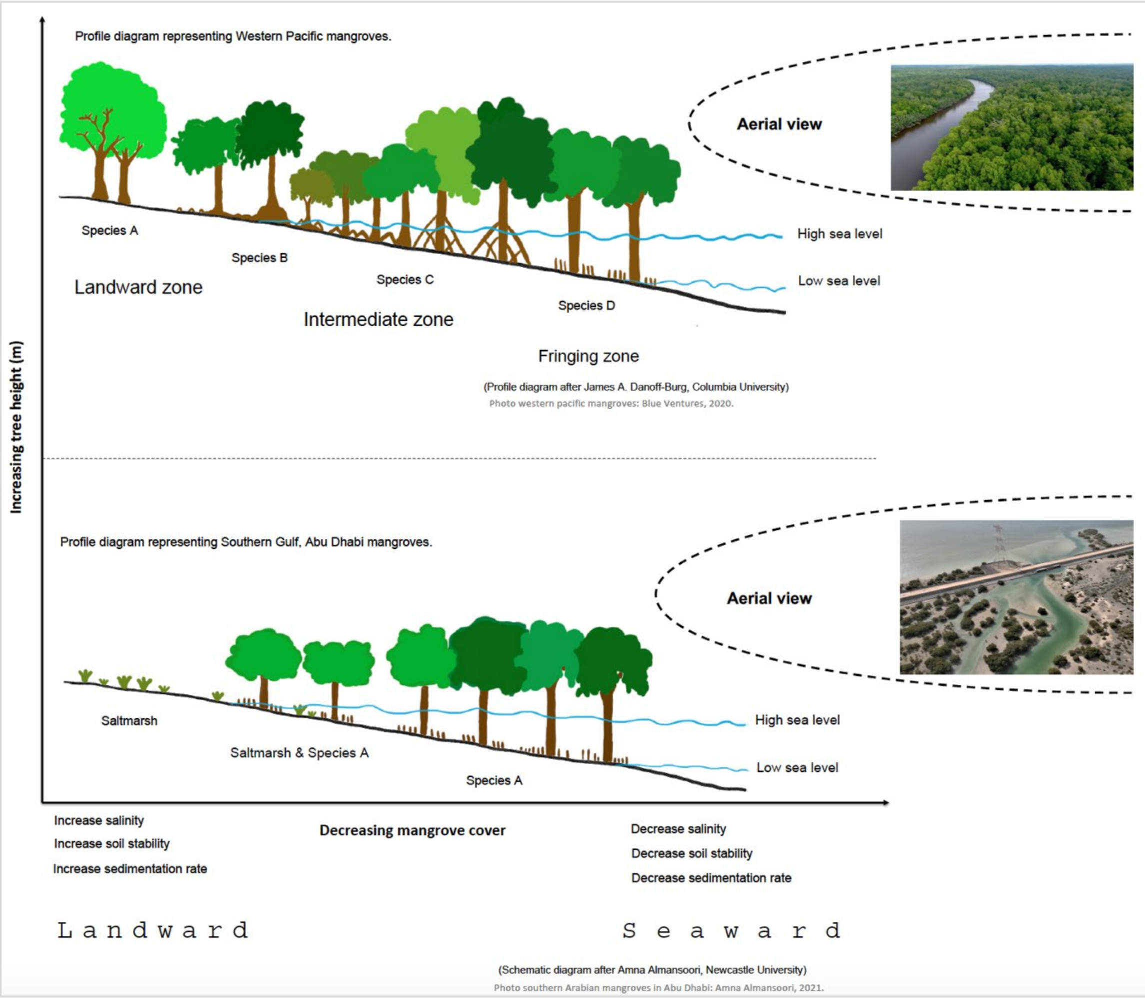


Figure 3. 10. A schematic representation of a classic mangrove zonation pattern of a tide-dominated shore (above) in comparison to the profile of the southern Arabian Gulf mangroves (below). Western Pacific mangroves (above) show a clear classic zonation where different species grow at each zone depending on their responses to geomorphology, physiology, species dominance, and plant succession. Southern Arabian Gulf mangroves (below) show saltmarsh communities co-existing with mangroves, causing coastal fragmentation, as described in the publications of this review. The diagram features; Y-axis: Increasing tree height in meters; western Pacific trees reach nearly 20m, and southern Arabian Gulf trees about 8m; X-axis: decreasing mangrove cover toward the seaward edge; Salinity, soil stability, and sedimentation rate increase toward the landward edge and decreases toward the seaward edge in both regions.

3.4 DISCUSSION

3.4.1 Key findings

This study provides insights into the temporal, spatial, and thematic aspects of mangrove research conducted in the Arabian Gulf. The key findings suggest that research on mangroves in the Arabian Gulf has progressed slowly, likely due to a lack of marine and ecological scientists specializing in mangroves, and that studies are not evenly distributed across the subregions. The body of literature on Arabian mangrove ecosystems has emerged since the 1980s, with over 80% published in the past two decades and a proportional increase in publications since the 1990s (e.g. Embabi, 1993; Howari *et al.*, 2009; Mafi-Gholami *et al.*, 2017; Gholami and Baharlouii, 2019; Ghayoumi *et al.*, 2022). The results show that mangrove research in Arabia varied across the subregions. Notably, the southern and western subregions of the Arabian Gulf remain underrepresented in the existing mangrove literature. Mangrove research in the Arabian Gulf has been primarily driven by regionally-based scholars from Iran. The findings indicate that research efforts have focused mainly on fringing mangrove types and suggest that mangrove research is not closely tied to the spatial distribution of mangrove extents.

3.4.2 Mangrove research efforts based on published literature

Historically, mangrove research in the Arabian region has received little attention (Friis and Burt, 2020; Almansoori *et al*., 2024). However, in recent years, some Gulf countries, such as Iran and those bordering the Red Sea, have prioritized mangrove research. This is evident in the past two decades, where the majority of publications on the Arabian Gulf have focused on the Iranian coasts, such as Qeshm Island (e.g. Mohammadizadeh *et al.* 2009; Ebrahimi-Sirizi and Riyahi-Bakhtiyari, 2013). To a lesser extent, there has been research along the western Arabian coast, including in Khuzestan Province (e.g. Baboli and Sahar, 2017; Orif and El-Maradny, 2018), and the southern Arabian Gulf coast in the United Arab Emirates (e.g. Saenger *et al.*, 2004; Alsalam, 2007). The findings of this review point to a pronounced focus of mangrove research, which is predominantly centred on mangroves in the northern Arabian Gulf, in Iran. These results are consistent with patterns observed in previous literature (see e.g. Vaughan and Burt, 2016; Friis and Burt, 2020; Almansoori *et al.*, 2024).

The representation of authorship on mangrove research in Arabia varied marginally based on the country of affiliation of the lead author and the study location. For example, this study revealed that the majority of publications in the United Arab Emirates were authored by researchers based outside of Arabia. This suggests the possibility of limited marine research centres or affiliations in the region (Sheppard *et al.*, 2010; Burt, 2013; Almansoori *et al.*, 2021), or that international collaborations occur due to the inclusion of sub-regional datasets in regional or global-scale analyses (see e.g. Giri *et al.*, 2011; Alongi, 2015). Another observation is that the majority of mangrove research in the northern subregion of the Arabian Gulf has been contributed by regionally-based researchers, while foreign-based researchers have been responsible for a significant portion of the research in the southern subregion, consistent with previous literature (e.g. Sheppard *et al.*, 2010; Van Lavieren *et al.*, 2011; Burt, 2013; Vaughan and Burt, 2016; Friis and Burt, 2020).

3.4.3 Existing research gaps on mangroves of Arabia

Overall, twelve research topics studied in the Arabian Gulf can be classified into two primary thematic areas: spatial distribution and ecological-related studies. Spatial distribution-related publications dominate the literature in Arabia, presumably due to the rapid urbanisation and human expansion into coastal areas (Erdelen, 2007; Almansoori *et al.*, 2024). Historically, more than 40% of the coastlines in most areas of the Arabian Gulf had been altered, leading to considerable declines in biodiversity and productivity (Al-Ghadban and Price, 2014), and presently, coastal development continues to be degrading mangrove habitats (Almahasheer, 2018; Almansoori *et al.*, 2024). While there appears to be a recent interest in the conservation of mangroves in the region (see e.g. EAD, 2020; Arachchige *et al.*, 2024), there is limited information on the effects of large-scale coastal development projects on mangroves. Thus, it is expected that spatial distribution and related mapping techniques will continue to dominate mangrove science, as this research underpins management efforts that are gaining interest both regionally (e.g. Brown *et al.*, 2008; Paleologos *et al.* 2019) and internationally (e.g. Romanach *et al.*, 2018; Ellison *et al.*, 2020).

According to this review, research on even mangrove's locations within the Arabian region is limited, leaving other aspects of these ecosystems largely unexplored. A few studies have focused on long-term shifts in the extent, health, and associated biodiversity of mangrove ecosystems over decades. Examining the long-term changes of mangrove distribution could provide valuable insights for long-term ecological targets (Tran *et al.*, 2024). Limited data is available on how mangroves in the Arabian region respond to climate-driven stressors. There is also a paucity of data regarding the contribution of mangroves to fisheries productivity and community livelihoods, as well as local communities' perspectives of mangroves and conservation needs.

Acquiring such knowledge would support future conservation efforts (see e.g. Romanach *et al.*, 2018; Jamaluddin *et al.*, 2022; Tran *et al.*, 2024). Across the subregions, this review found few peer-reviewed studies from the southern Gulf subregion, despite the subregion encompassing 47% of the total mangrove extent in the entire Arabian province (Almansoori *et al.*, 2024). Lack of subregional mangrove knowledge makes it challenging to clearly understand the ecology of mangrove ecosystems, including plant productivity, growth patterns, and species interactions, or to use scientific-based evidence for conservation efforts.

3.4.4 Opportunities to scale-up mangrove research and conservation efforts

Mangroves of the Arabian Gulf province have been recently classified as a 'vulnerable ecosystem' (Almansoori *et al.*, 2024), and preparing for the future, whether it is for climate change scenarios or meeting national conservation targets, continuous research, monitoring of mangrove ecosystems, and regional collaboration will be essential. While remote sensing and mapping have been applied in many mangrove areas worldwide (see e.g. Cipta *et al.*, 2021; Jamaluddin *et al.*, 2022), further investigations and biodiversity assessments are required. This includes examining the productivity of mangroves, identifying local patterns in species distribution and abundance, and understanding the underlying mechanisms driving habitat patterns in the local context of Arabia. Research from the Arabian region suggests that mangroves offer a unique setting of both lagoonal and fringing types; but that mangroves also considerably compete with other nearby ecosystems (e.g. saltmarshes, hyper-saline flats, and mudflats) (see e.g. Hellyer and Aspinall, 2005; Alsalam 2007; Almansoori *et al.*, 2021), which could be due to the restricted area of occupancy of the Arabian coastline (Almansoori *et al.*, 2021; Almansoori *et al.*, 2024). Therefore, the contribution of coastal profile and biodiversity knowledge could support managers and decision-makers to effectively plan and monitor mangroves conservation programs in Arabia (e.g. Malik *et al.*, 2019; Pimple *et al.*, 2022).

In this review, the mangrove classification framework by Worthington and Spalding (2018) has provided a useful basis for examining the mangrove ecosystem types that have been the primary focus of research efforts in the Arabian region. However, it could be further developed to accommodate local-scale mangrove typologies to show the differences in some coastal areas. For example, mangroves of the southern Arabian Gulf in Jubail and Ramhan Islands along the eastern coast of Abu Dhabi Emirate could consist of both lagoonal and fringing mangroves, but were identified as only lagoonal systems. As such, local-scale mangrove types could significantly improve restoration programmes especially when dealing with the site selection of mangrove plantations, that otherwise fail due to poor local information (e.g. Etemadi *et al.*, 2020; Erftemeijer *et al.*, 2020; Afefe, 2021).

Local information is often overlooked in restoration programmes in Arabia, leading to potential failures is ‘large-scale planting targets’ (see e.g. MOCCAE, 2023). Although restoration programs could fail for many reasons (Ellison *et al.*, 2020), establishing an early understanding of the coastal area suitable for mangroves is a fundamental element in restoration programmes (Beeston *et al.*, 2023). Following best practices in the restoration of mangroves that have led to highly successful outcomes elsewhere (see e.g. Coleman *et al.*, 2008; Ren *et al.*, 2008; Romanach *et al.*, 2018; Ellison *et al.*, 2020; Hai *et al.*, 2020), is an approach that regional management could undertake. Another approach to scale up conservation efforts would be to set up marine protected areas to conserve existing mangrove habitats, and develop local capacity through workshops, training programs, universities, enabling self-sufficiency in research development (Van Lavieren *et al.*, 2011). Mangrove experts from the international scientific community and regional researchers across Arabia should communicate to engage in such capacity-building programmes. This would help improve scientific research that would allow for a better understanding of these ecosystems and increase their representation in the global literature. In the absence of mangrove expertise or sufficient data, applying baseline marine surveys, regular monitoring, and well-designed mangrove restoration programs using scientific-based guidelines (e.g. Beeston *et al.*, 2023), may be an appropriate starting point.

3.5 CONCLUSION

This review analyses the geographical and temporal trends in mangrove research across the Arabian Gulf region. Although the Arabian region remains one of the least studied mangrove areas of the world (Almahasheer, 2018; Almansoori *et al.*, 2021), the findings of this study showed that there is a sound basis of knowledge distributed throughout the Arabian region and that knowledge is increasing. However, there are geographical differences in research efforts between Gulf nations that have led to knowledge gaps in some areas. Research efforts appear to be unevenly spread across the region despite the recognition of the importance of mangroves. Accordingly, the research gaps in the Arabian region should be viewed as valuable opportunities for future investigations, as proposed by previous studies (see e.g. Almahasheer, 2017; Friis and Burt, 2020; Jawad, 2021; Almansoori *et al.*, 2021). Moving forward, several areas, such as the western and southern Arabian coast, would benefit from future research on mangrove ecosystems such as biodiversity assessments, environmental impact studies, and the influences driving coastal patterns and habitat distribution. Addressing existing research gaps and developing appropriate plans to fill them is imperative, as this would contribute to safeguarding mangrove ecosystems in the Arabian region.

CHAPTER 4: Evaluate the habitat use by fish in mangroves of the southern Arabian Gulf

4.1 INTRODUCTION

Mangrove habitats provide a wide range of ecosystem services, such as provisioning services (e.g. food and raw material) (Lopez-Angarita *et al.*, 2016; Carrasquilla-Henao and Juanes, 2017), regulatory and supporting services (e.g. primary productivity) (Brander *et al.*, 2012). Despite the importance of mangrove ecosystems, they are still being lost worldwide (Friess *et al.*, 2020), mainly due to impacts of land conversion, pollution, and unsustainable use, such as aquaculture and overfishing (e.g. Duke *et al.*, 2007; Halpern *et al.*, 2008). Studies of mangrove fish habitat use have been well documented worldwide (see e.g. Faunce and Joseph, 2006; Mumby *et al.*, 2006; Nagelkerken and Van der Velde, 2004; Sambrook *et al.*, 2019). Traditionally, researchers have paid considerable attention to the study of mangrove fish habitat use across multiple coastal and marine ecosystems (or inter-habitats), such as seagrass beds (Unsworth *et al.*, 2018), and coral reefs (Mumby *et al.*, 2004; Dorenbosch *et al.*, 2005). As such, the seascape configuration of inter-habitats (Green *et al.*, 2012), and the environmental factors, such as tidal regimes and temperatures (Igulu *et al.*, 2014; Bradley *et al.*, 2020), have been shown to influence the structure of fish communities. However, understanding of such fish habitat uses between microhabitats of mangroves (e.g. intra-habitats or niches within mangrove habitats) and the environmental variables that drive this, remains scarce.

In a broad sense, mangrove habitats encompass a wide array of biological, chemical, and physical elements that significantly influence the composition of fish communities (Robertson and Blaber, 1992; Igulu *et al.*, 2014). In a practical sense, fish-habitat associations are highly complex and context-dependent, driven by various factors including local environmental variables (e.g. rainfall and tidal range) (Bradley *et al.*, 2020), regional differences (e.g. mangrove species and coastal geomorphology) (Reis-Filho *et al.*, 2016; Sambrook *et al.*, 2019). Studies of fish habitat use within intra-habitats of mangroves have mainly focused on the influence of environmental variations, such as rainfall, temperatures, or tidal regimes (Brenner and Krumme, 2007; Giarrizzo *et al.*, 2010; Krumme *et al.*, 2014), on fish community structure across tropical or subtropical regions, primarily in deltaic or estuarine mangrove ecosystems (Igulu *et al.*, 2014; Reis-Filho *et al.*, 2016; Sambrook *et al.*, 2019). However, evidence for mangrove use by fish in arid or hyper-arid mangrove systems and among lagoonal mangrove systems, particularly in the Arabian region, is notably scarce, highlighting the significance and relevance of further research in this area.

Studies of mangrove use by fish in Arabia have mainly investigated fish assemblages focusing on inter-habitats (e.g. between mangroves and corals) for marine fishes in the Red Sea (e.g. Dunne *et al.*, 2023), the role of mangroves as a nursery ground for juvenile reef fishes in the southern Egyptian Red Sea (e.g. El-regal and Ibrahim, 2014), and fish diversity of mangrove ecosystems in Oman (e.g. Al-Jufaili *et al.*, 2021). Little attention has been given to mangroves in the Arabian Gulf, particularly within the intra-habitats of the southern coast. The southern Arabian/Persian Gulf (hereafter, the ‘‘southern Gulf’’) is among the most hostile marine environments in the world (Alsalam, 2007; Vaughan *et al.*, 2021). The Gulf experiences extreme environmental conditions, including limited precipitation (< 90 mm annually), high salinity levels (> 50), and temperature fluctuations (e.g. 16°C to greater than 35°C) (Sheppard *et al.*, 1992; Price *et al.*, 1993; Vaughan *et al.*, 2019). The annual sea surface temperatures exceed 36 °C in the Gulf, making it the hottest sea on Earth during the summer months (Sheppard *et al.*, 1992). Moreover, the Arabian Gulf experiences temperature variation within itself, with the southern region along the United Arab Emirates (UAE) coast exhibiting the most extreme conditions (annual ranges of 24°C) (Sheppard *et al.*, 1992). This exposes the region's fish populations to temperatures higher than those experienced by any other fish globally (Vaughan *et al.*, 2021). Long-term studies on reefs in the southern Gulf have shown evidence of fish community variation due to dramatic seasonal temperature changes (see e.g. McCain *et al.*, 1984; Burt *et al.*, 2013; Feary *et al.*, 2011).

As a result of the extreme marine environment, mangroves in the Gulf are distinguished by niche intra-habitats or microhabitats of different mangrove communities along the intertidal zone (Sheppard *et al.*, 1992; Saenger *et al.*, 2004). On this coastline, geomorphological conditions differ from those present on offshore islands. For example, on the western side of the southern Gulf, mangrove habitats are typically found on offshore islands in dense, fringing systems, limited to one other habitat type, such as offshore coral reefs or seagrass beds (Almansoori *et al.*, 2021). In these areas, temperatures, tides, and salinity fluctuate significantly due to the influence of the open sea and high currents (Vaughan *et al.*, 2019). In contrast, on the eastern coast of the southern Gulf coastline, mangroves grow in sheltered, lagoonal systems adjacent to a diverse habitat mosaic of saltmarshes, mudflats, and rocky shores (Saenger *et al.*, 2004; Almansoori *et al.*, 2021). Here, the mangrove communities are fragmented by natural creek systems, and the environmental conditions, including temperature, tides, and salinity, are relatively stable (Sheppard *et al.*, 1992; Almansoori *et al.*, 2021).

In such cases, mangroves in the lagoonal systems of the eastern coast of the southern do not share environmental conditions with mangroves in other regions, such as Caribbean lagoon systems (Reis-Filho *et al.*, 2016), or with high tidal regimes, such as Indo-West Pacific mangroves, where fish have limited foraging and shelter time in mangroves (Igulu *et al.*, 2014). In addition, mangroves of the southern Arabian Gulf are low in diversity (< two mangrove species) and often in monospecific stands (Sheppard *et al.* 1992; Loughland *et al.* 2004; Alsalam, 2007), showing a degree of atypical mangrove zonation patterns (see e.g. Twomey, 2022). Unlike mangrove areas in deltaic-like systems, and tropical regions, the lagoonal mangroves in the southern Gulf experience unusual patterns of tidal rhythms and coastal configuration (Sheppard *et al.*, 1992; Almansoori *et al.*, 2021). The tidal rhythms in lagoons and creek-like channels of the intertidal areas of the Gulf are extremely low in velocity, with cycles that range between 0.2 and 2.5 m (Siddiq *et al.,* 2019; Emmanuel *et al.,* 2023). As such, microtidal characteristics provide continuous food access to fish, primarily due to the fact that they are constantly inundated (Nagelkerken and Van der Velde, 2004).

Recent studies in microtidal environments have demonstrated the importance of adjacent habitats, such as mudflats, for fish species (Marley *et al.*, 2020) as well as the significance of mangrove habitats in supporting local communities, especially artisanal fisheries (Sandoval Londono *et al.*, 2020). In Arabia, mangrove research is generally limited (but see e.g. Saenger *et al.*, 2004; Almahasheer, 2018; Almansoori *et al.*, 2021), and there is even less focus on the perspectives of mangrove fish ecology. Despite some investigation into fish habitat use across multiple coastal and marine ecosystems in Arabia (e.g. El-regal and Ibrahim, 2014; Dunne *et al.*, 2023), our continued examination of fish use across diverse habitats and large distances has not yielded sufficient information to prioritize the microtidal environments of mangroves and their influence on fish community structure in Arabia.

The purpose of this study was to determine fish community structure in different mangrove microhabitats within lagoonal systems in the southern Arabian Gulf. Specifically, the study objectives were to determine (a) how similar or dissimilar fish assemblages are associated with different mangrove microhabitats, and (b) whether the environmental variable temperature influences fish assemblages. The hypothesis is that abundance and diversity would be greater in mangrove habitats that consist of high structural complexity and features, e.g. rocky shores, than those associated with mudflats or saltmarshes, and that temperature will have an impact on the structure of fish communities among habitats.

4.2 METHODS

4.2.1 Study area

Fish assemblages were investigated in mangroves of the southern Arabian Gulf at Jubail and Ramhan situated on the coast of Abu Dhabi in the United Arab Emirates (Figure 4.1). The hyper-arid climate of the southern Arabian Gulf region is characterized by sea-surface temperatures (ranging from 16°C and 35°C), high salinity (> 50), and limited freshwater input (rainfall < 90 mm annually) (Sheppard *et al.,* 1992; Prince *et al.,* 1993; Kottek *et al.,* 2006; Vaughan *et al.,* 2019). The seasons are summer (June to August), fall (September to November), winter (December to February), and spring (March to May), and the highest precipitation rates typically occur between winter months (Vaughan *et al.,* 2019; Almansoori *et al.,* 2021; Dasari *et al.,* 2022).

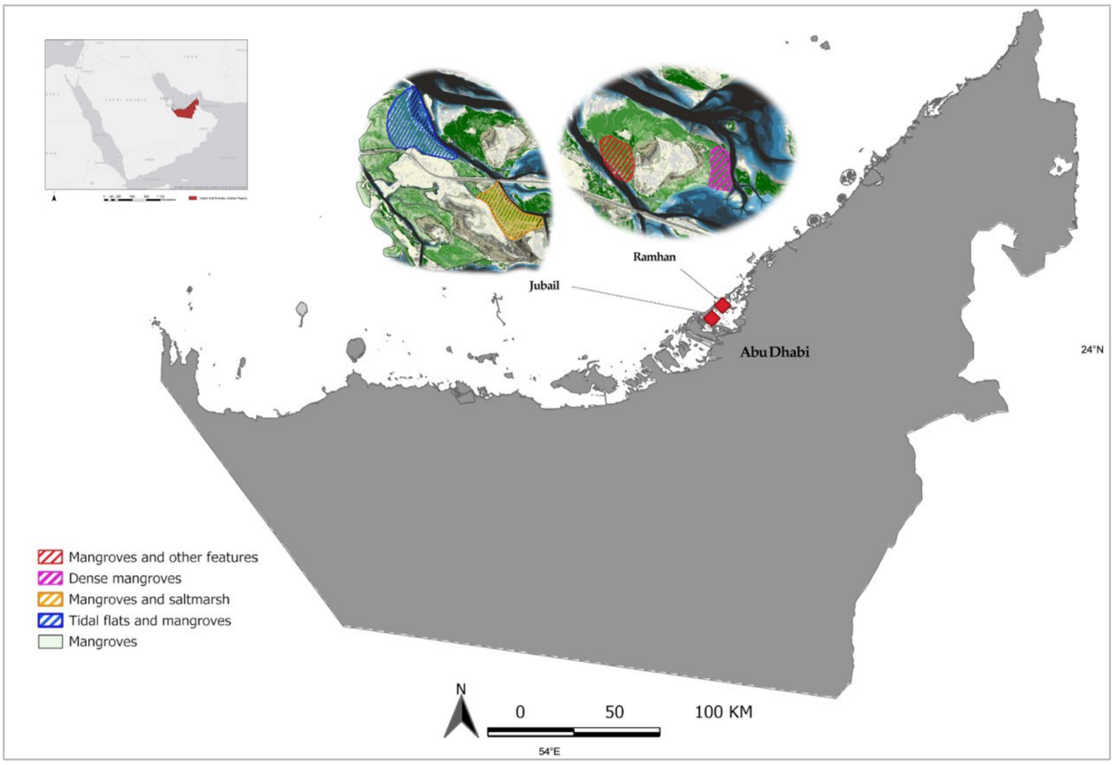


Figure 4. 1. The study area in the east coast of the southern Arabian Gulf. Red squares indicate sampling stations (Jubail and Ramhan), and coloured lines represent the habitat classification.

The study area is dominated by one mangrove species; *Avicennia marina* (Saenger *et al.,* 2004; Almahasheer, 2018). These monospecific mangroves grow in narrow fringes often restricted to shallow waters (< 1 m deep) and generally appear stunted or dwarf-like (Saenger *et al.,* 2004). Mangroves receive tides usually twice daily that range between 0.2 and 2.5 m (Siddiq *et al.,* 2019; Almansoori *et al.,* 2021; Emmanuel *et al.,* 2023), with many creek-like channels along the intertidal areas remaining partially flooded due to the physical configuration of the seabed (Almansoori *et al.,* 2021). The physical characteristics of mangrove creeks and their configuration vary in size and habitat composition (Hellyer and Aspinall, 2005; Zahran and Elamier, 2016), typically providing unusual patterns of different mangrove microhabitats. It is common to find wide creeks greater than 50 m that consist of sparse mangroves (tree spacing > 2.5 m) intersecting with saltmarshes and extensive tidal flats (or mud flats), while on the other side dense mangroves (tree spacing average 0.5 m) nearby subtidal seagrass beds and rocky shores (Sheppard *et al.,* 1992; Hellyer and Aspinall, 2005; EAD, 2020; Almansoori *et al.,* 2021).

The region contains five critical coastal habitats: mangroves, tidal flats, saltmarshes, rocky shores, and seagrass beds (Sheppard *et al.,* 1992; Hellyer and Aspinall, 2005; EAD, 2020). Tidal flats and saltmarshes are often found together along the intertidal area and have high secondary productivity, while the latter ecosystem also acts as natural filters trapping sediments and nutrients (Sheppard *et al.,* 1992; Barbier *et al.,* 2011). Rocky shores consist of solid rocks with various rock pools, boulder platforms, and cliffs and are biologically rich with macroalgae, mollusks, bivalves, and birds (Hellyer and Aspinall, 2005; EAD, 2020). Seagrass beds are the immediate subtidal habitat near mangroves found extensively along the entire coastline and deeper waters of the region (Sheppard *et al.,* 1992; EAD, 2020).

4.2.2 Classification of habitats

A pre-site survey to determine the habitat types and characteristics of the study area was conducted in January 2022 (Table 4.1). The survey followed the guidelines of the Abu Dhabi Classification of Intertidal Habitats and Mangrove Forest Assessment (EAD, 2020; Almansoori *et al.*, 2021). For other references on mangrove ecosystems, the guidelines of the IUCN Habitats Classification of the region (IUCN, 2012) and the IUCN Global Ecosystem Typology were used (Keith *et al.*, 2020). The classification of the mangrove typologies was based on Worthington and Spalding (2018), and the mangrove habitat characteristics (e.g. maturity, canopy cover, and density) were based on English *et al*. (1997). Accordingly, the habitat of the study area consisted of lagoonal mangrove types (Worthington and Spalding, 2018), characterized as follows: sheltered tidal flats with sparse mangroves (Site A); mangroves with dense saltmarsh in the upper margin (Site B); mature mangrove stands (Site C); and mangroves with other habitats, namely; seagrass beds and rocky shores (Site D) (details in Appendix C.1).

Site A included sheltered tidal flats exposed at low tide that typically form when mud is deposited by tide and currents, with a lack of vegetation and less than 10% mangrove vegetation area (11 to 30 % canopy cover) along the seaward edge. Site B included saltmarsh vegetation (Sp. *Arthrocnemum macrostachyum* and *Halocnemum strobilaceum*) on the upper margin of the tidal flat (> 50 %) partially covered at high tide and sparse patches of short mangrove stands (0 to 10 % canopy cover). Site C included mature mangrove stands (height > 1.3 m and 51 - 75 % canopy cover). Site D comprised of mature and dense mangrove stands (76 to 100 % canopy cover) with patches of seagrass beds (Sp. *Halodule uninervis*, *Halophila stipulacea* and *Halophila ovalis*) along the shallow sub-tidal substrate of unconsolidated sediments at mid-depths (4 to 10 m), and sub-tidal feature of exposed rocks and hard-bottom habitat in shallow areas at mid-depths (0 to 2 m). Due to the local geomorphology variation, the site selection criteria included accessible natural creeks with a length greater than 100 meters and a width range of 2 to 5 meters. Modified or dredged channels by human activities were excluded.

				Habitat characteristics				
Site	**Name**	**Coordinates**	**Habitat type**	**Mangrove area (sqm)**	**Width of creek (m)**	**Mangrove maturity**	**Mangrove canopy cover (%)**	**Mangrove typology**
A	Jubail (A)	Lat: 24.555003° / Long: 54.488596°	Sheltered tidal flats with sparse mangroves (TFSM)	1.33	25 to 30	Height > 1.3 m	11 to 30	lagoon
B	Jubail (B)	Lat: 24.513355° / Long: 54.516956°	Mangroves with dense saltmarsh in the upper margin (MGSM)	1.36	38 to 48	Tree height > 1.3 m and saplings > 1 m girth < 4 cm	0 to 10	Very sparse
C	Ramhan (A)	Lat: 24.539015° / Long: 54.546968°	Mature mangrove stands (DM)	1.69	10 to 15	Height > 1.3 m	51 to 75	Dense
D	Ramhan (B)	Lat: 24.534942° / Long: 54.509870°	Mangroves with other marine habitats, e.g. seagrass beds and rocky shores (MGOT)	1.05	10 to 18	Height > 1.3 m	76 to 100	Very dense

Table 4. 1. Classification of habitat types and characteristics. Mangrove area (sqm) and width of creek (m) are derived from Environmental Agency Coastal and Marine Portal Viewer Map (EAD, 2021). Mangrove maturity and mangrove canopy cover (%) are based on English et al. (1997). Mangrove typologies are based on Worthington and Spalding (2018).

4.2.3 Fish sample procedures

A belt-transect technique was used to guide underwater visual census (UVC) to record fish in their natural environment (Bohnsack and Bannerot, 1986). The UVC method was selected for its wide application in coastal habitats such as coral reefs, mangroves, and seagrass beds. UVC enables direct observation of fish without causing any harm or disturbance to their natural environment, where it records the diversity, abundance, and size estimation of fish species, and allows for comparisons with other studies, resurveying over time, and repetition across multiple habitats (Nagelkerken *et al.,* 2000). However, using UVC also has several challenges, such as the high census speed that can cause underestimation, observer training to identify fish, and transect width (English *et al.,* 1997). To overcome these, the speed was confined to two gentle swimming strokes, limited from 5 to 10 minutes per transect. Before sampling, the observer was trained by an expert fisheries scientist using pre-defined fish identification and a ruler to practice size estimation underwater using objects. Furthermore, the transect width was pre-defined to 5 meters (2.5 meters x 2.5 meters).

The sampling protocol followed Bohnsack and Bannerot (1986). Each site was sampled once during the daytime over seven months from January to September 2022, encompassing three main seasons (winter, spring, and summer). To maintain uniformity, sampling commenced during the first peak of the high tide and in water depths ranging from 0.8 to 2 meters (details in Appendix C.2, Table C.2.1). A total of twenty-four transects were taken during each sampling month (six transects per site) across four days per month (n = 168). Each transect was collected by a single observer using snorkeling gear parallel to submerged roots of mangroves, covering a sampling area of 750 m^2 at each site. It is acknowledged that fish may avoid the observer by sheltering in mangrove roots. Therefore, the transect width was pre-defined to 5 meters (2.5 meters x 2.5 meters); (a) to ensure fish count is restricted to 2.5 meters distance from the observer to the edge of the channel, and (b) to avoid variability in water depths, which restricted the sampling of fish at depths greater than 0.8 within transects and at each habitat. Prior to fish surveys, the environmental variables were recorded at each site during each sampling day, using the instrument HI-98194 multiparameter waterproof meter for salinity, sea-water temperature, and pH, a Hondex Digital Depth Sounder for measuring water depth, and a Secchi disc to ensure clarity of the water (Figure 4.2).

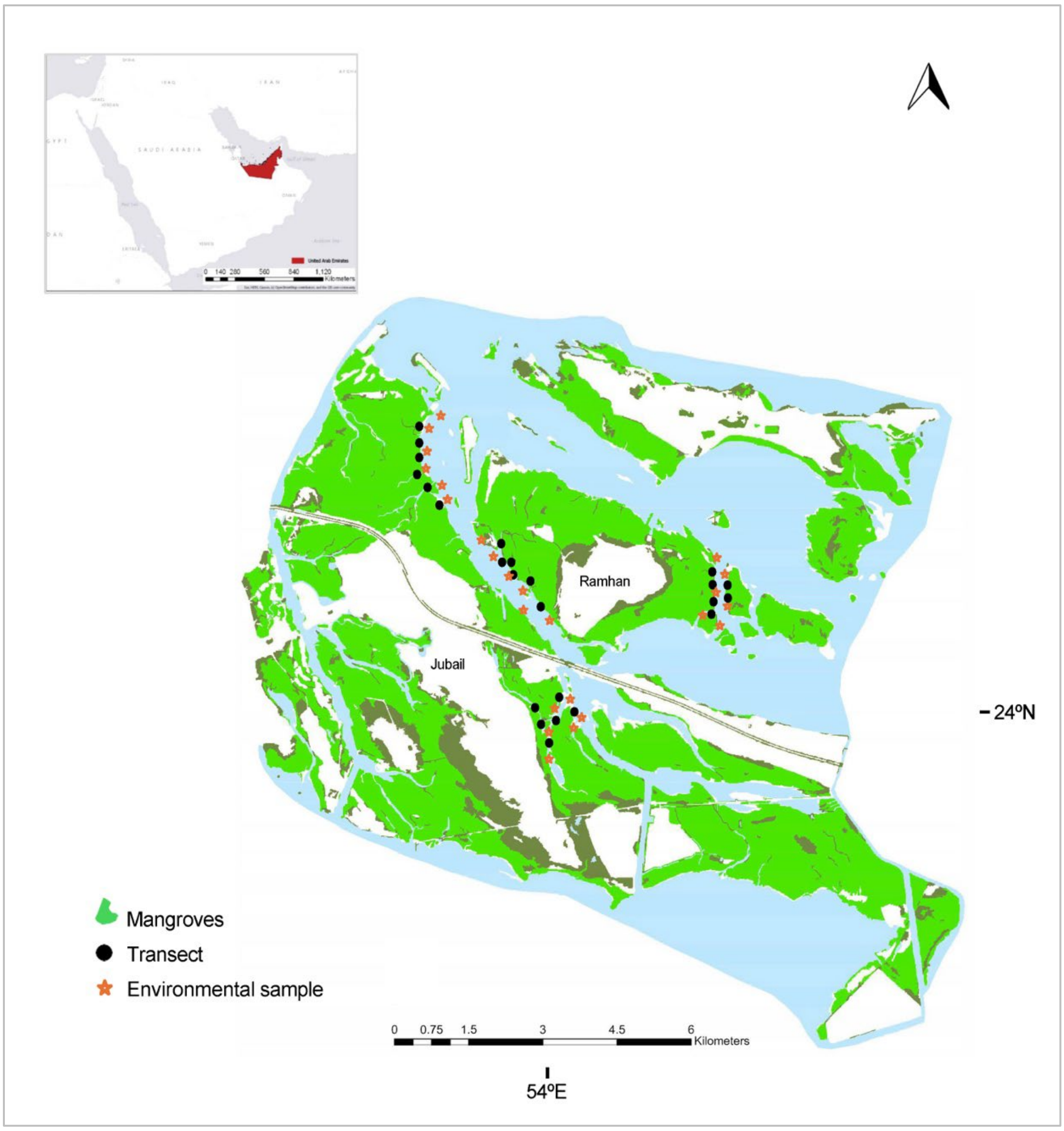


Figure 4. 2. Map of study area and sampling location in mangroves of the southern Arabian Gulf.

Fish observed along the transect were counted, and total body length was estimated according to pre-defined categories: abundance (Log-1) and size (Log-2) to ensure standardization (details in Appendix C.2, Table C.2.2). Fish during post-larval stages were not counted (< 3cm) to avoid potential errors in species identification due to small body size (English *et al.* 1997). The maturation size of each fish and its exploitation status (e.g. commercial importance) was assessed based on reports and databases from FishBase, IUCN Red List Status, and Local Fisheries Stock Assessments (Grandcourt *et al.,* 2008; Grandcourt *et al.,* 2010; Francis *et al.,* 2016; Francis *et al.,* 2019; Froese and Pauly, 2023). A pre-determined fish species ID list supplied by fisheries experts at the Environment Agency of Abu Dhabi was used as a guide during the survey (Grandcourt, 2008; Francis *et al.,* 2022) (details in Appendix C.2, Table C.2.3).

4.2.4 Data analysis

Pearson's correlation coefficient using the function *cor* in R software was calculated to determine whether there was a relationship between variables (Freedman *et al.,* 2007). The values of the correlation coefficient may range from +1 to the value -1, where numbers closer to 1 show a strong relationship, the negative values show a strong negative relationship, and those closer to 0 suggest no relationship. To describe the difference in environmental variables, such as sea-surface temperature, salinity, water depth, and pH, and fish community structure, e.g. fish abundance and length (response variables), between different habitat types (explanatory variable), an analysis of variance (ANOVA) using the function *aov* in R software was performed (RStudio 2022). The Kruskal-Wallis test (non-parametric) was used if the assumptions of ANOVA were not met (Kruskal and Wallis, 1952). A Dunn-Bonferroni post-hoc test was used for the pairwise multiple-comparison procedure among groups (Dunn, 1964).

The relative abundance (RA = Number of individuals for species A / Total number of individuals) X 100% was computed to determine the dominant species. To estimate the diversity of species between habitat types, a Shannon index was calculated, where S is the number of species, N is the total number of individuals within the community, n_i is the number of individuals of the i-th species, and p_i represents the proportion of the number of individuals of the i-th species relative to the total number of individuals in the sample (Clarke and Warwick, 2001). To evaluate the number of different species and the evenness of distribution among species, a Simpson's diversity index was calculated, where n_i is the number of individuals in species i, N is the total number of species in the sample, p_i is the proportional abundance for each species, and R is the total number of species within the sample. According to Simpson (1949), values ranging from 0 represent infinite diversity, and 1 represents no diversity. Moreover, an analysis of similarities (ANOSIM) was performed to compare differences in the fish community structure using the dissimilarity measure Bray-Curtis in the function *anosim* in R package *vegan* 2.6-4 (RStudio, 2022). Finally, to visualize the fish assemblage composition between habitat types and environmental variables, a principal component analysis (PCA) using the function *prcomp* was performed for data visualization (RStudio, 2022).

4.3 RESULTS

4.3.1 Environmental variables

Positive correlations were observed between the environmental variable sea-water temperature and the number of fish (count), and between the length of fish and the number of fish (count) ($r = 0.38$ and $r = 0.22$; respectively) (Figure 4.3). Environmental variables indicate moderate temperatures among the habitat types, but higher in mangroves with saltmarsh and mangroves with other features such as rocky shores. Higher fish abundances and larger fish sizes were associated with very dense mangrove habitat types, indicating that these environments may support better conditions for fish. Salinity was found to be higher across dense and very sparse habitat types compared to slightly lower levels of salinity at sparse and very dense habitats. Very dense habitat types showed the lowest levels of water depth (1.05 ± 0.09) compared to the rest of the habitat types, while the pH levels showed slight differences among the habitat types (Table 4.2). The ANOVA results for the environmental variables and fish community between habitat types showed significant differences ($p = < 0.05$). ANOVA results showed both temperature and salinity ($p = < 0.05$) to be significant environmental variables among the different habitat types. The Kruskal-Wallis test showed a statistically significant difference in fish abundance between seasons ($p = 0.006$). Following, the Dunn-Bonferroni post-test revealed that the pairwise group comparison of winter and summer seasons was statistically significant ($p = < 0.05$) (Figure 4.4).

	Temperature (°C)	**Salinity**	**Depth (m)**	**pH**
Habitat types		**(mean ± sd)**		
Tidal flat with sparse mangroves	20.82 ± 0.76	43.52 ± 0.77	1.23 ± 0.59	8.76 ± 0.05
Mangroves with saltmarsh	28.61 ± 4.14	45.73 ± 0.79	1.50 ± 0.51	8.64 ± 0.18
Dense mangroves	25.42 ± 3.44	44.31 ± 1.23	1.65 ± 0.48	8.74 ± 0.06
Mangroves with other	31.09 ± 2.95	42.67 ± 1.07	1.05 ± 0.09	8.72 ± 0.12

Table 4. 2. The differences in environmental variables between the habitat types.

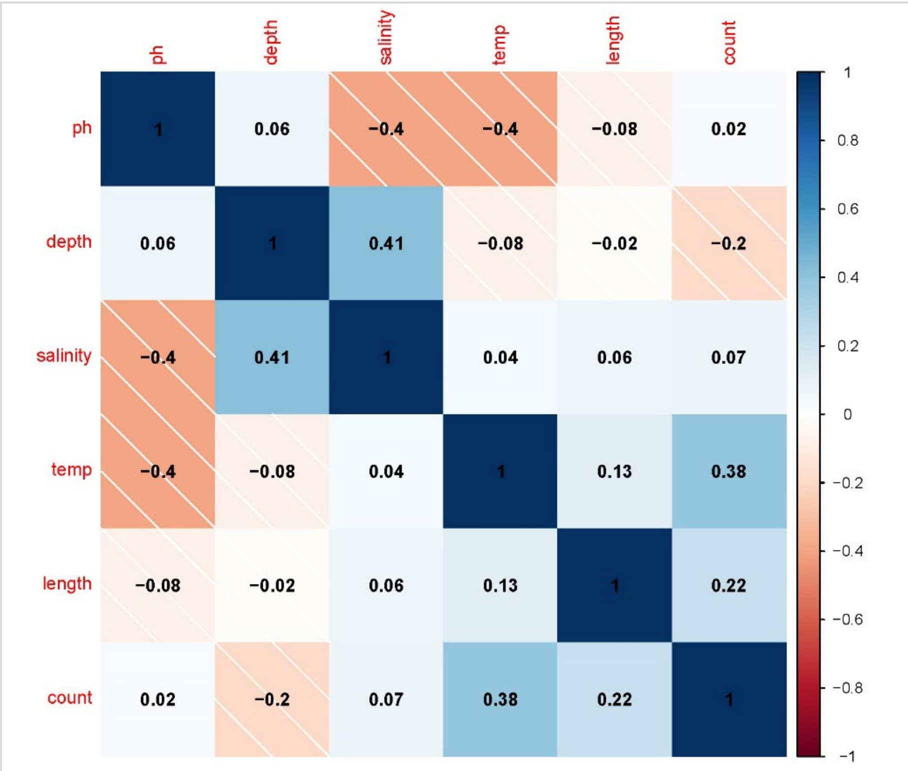


Figure 4. 3. Pearson's correlation coefficient plot between variables is presented using the function *CORRPLOT* in R software. Variables presented are pooled together across all the study sites, as follows: pH: pH levels, depth: water depth, salinity: sea-surface salinity, temp: sea-water temperature, length: total fish length, e.g. size (cm), and count: total number of fish. The values of the correlation coefficient range from +1 to the value -1.

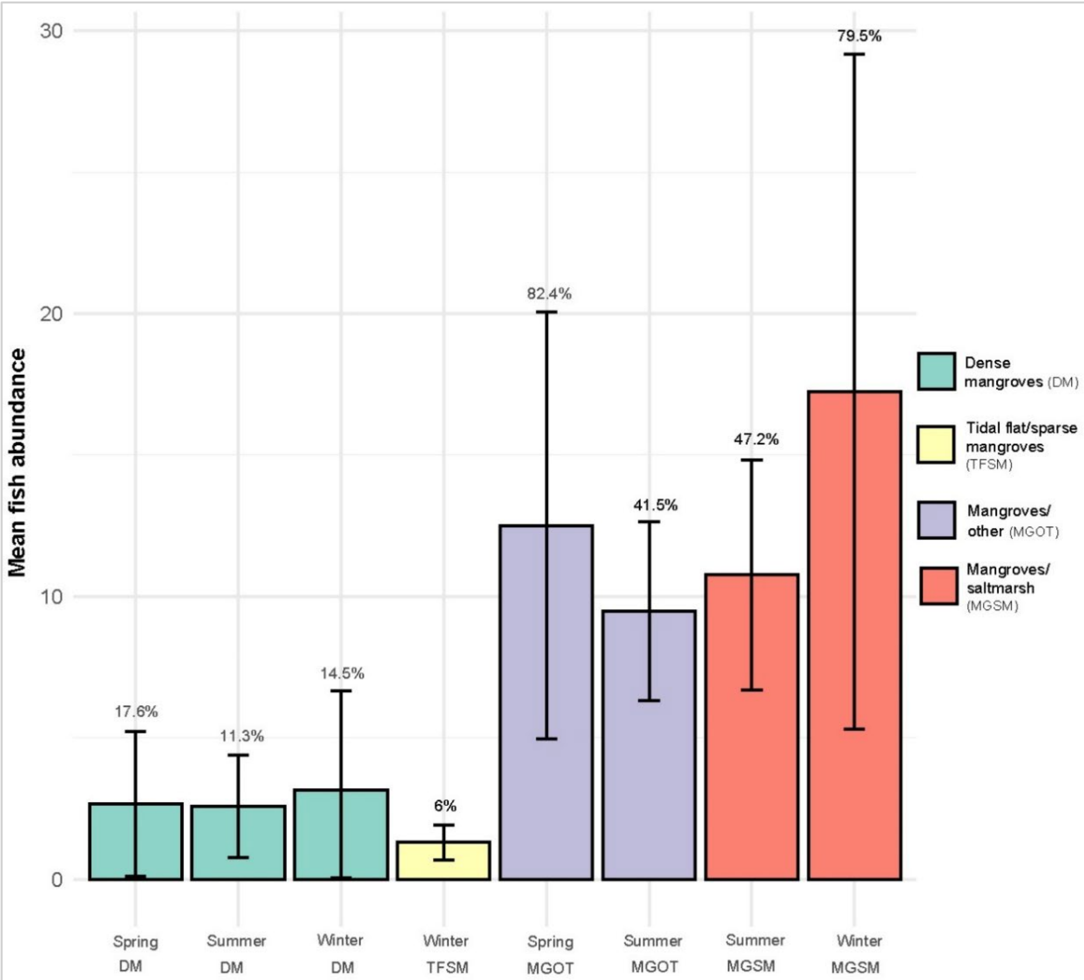


Figure 4. 4. The mean abundance of fish species among habitat types and season.

4.3.2 Fish assemblage among habitat types

A total of 1137 fish were recorded during this study, belonging to eleven families, and fourteen species. Among these, *Gerres longirostris* was the most abundant, accounting for 44.59% of the total species (Table 4.3a). However, the presence of fish species varied among habitat types. The Whittaker plot showed high fish species evenness in mangroves with saltmarsh and mangroves with other marine habitats, while the tidal flats with sparse mangroves found the least abundance of species and the lowest evenness across habitat types (Figure 4.5). The most species-rich habitat was found in dense mangroves adjacent to other structured habitats (*H'* = 1.63, *D'* = 0.75) when compared to all other habitat types. The majority of fish species were juveniles that performed ontogenetic migration, and according to regional fisheries stock assessments at least nine of the fourteen species have been reported as commercially important species in the region (Table 4.4) (Grandcourt *et al.,* 2008; Grandcourt, 2008; Grandcourt *et al.,* 2010; Francis *et al.,* 2016; EAD, 2019; Francis *et al.,* 2019; Francis *et al.,* 2022) (details in Appendix C.3).

(a)	Fish abundance in different habitats					
	TFSM	MGSM	DM	MGOT		
Shannon Index (H') =	0.22	1.39	1.04	1.63		
Simpsons Diversity Index (D') =	0.11	0.69	0.51	0.75		
Species					**Relative Abundance**	**Average length (cm)**
Gerres longirostris	65	106	180	156	44.59%	6.70
Lutjanus ehrenbergii	4	167	17	24	18.65%	6.00
Strongylura leiura	0	0	2	0	0.18%	6.50
Lutjanus argentimaculatus	0	3	38	135	15.48%	6.42
Epinephelus coioides	0	0	2	12	1.23%	9.93
Lutjanus fulviflamma	0	0	26	0	2.29%	9.00
Lethrinus lentjan	0	11	1	0	1.06%	12.00
Maculabatis arabica	0	1	0	0	0.09%	*NA*
Monodactylus argenteus	0	37	0	43	7.04%	6.00
Acanthopagrus latus	0	37	0	21	5.1%	8.00
Gobiidae*	0	4	0	0	0.35%	*NA*
Lethrinus nebulosus	0	0	0	42	3.69%	6.00
Pomacanthus maculosus	0	0	0	1	0.09%	10.00
Acanthopagrus berda	0	0	0	2	0.18%	10.00
	69	**366**	**266**	**436**		

(b) Species	**No. of individuals**	**Min. Length**	**Max. Length**	**Mean ± Std.**
Gerres oyena	507	3	14	7.93 ± 2.8
Lutjanus ehrenbergii	212	3	12	8.48 ± 2.03
Lutjanus argentimaculatus	176	3	12	7.77 ± 2.92
Monodactylus argenteus	80	6	6	6 ± 0
Acanthopagrus arabicus	58	6	12	8.69 ± 3.01
Lethrinus nebulosus	42	6	6	6 ± 0
Lutjanus fulviflamma	26	9	9	9 ± 0
Epinephelus coioides	14	4	14	9.93 ± 3.67
Lethrinus lentjan	12	12	12	12 ± 0
Gobiidae*	4	6	6	6 ± 0
Strongylura leiura	2	5	8	6.5 ± 2.12
Acanthopagrus berda	2	9	11	10 ± 1.41
Maculabatis arabica	1	11	11	11 ± *NA*
Pomacanthus maculosus	1	10	10	10 ± *NA*
	1,137			

** = family name, species level not identified. NA= results 0 of 0 due to species observed once.*

Table 4. 3. **(a)** List of fish species and their distribution among different habitats in mangrove ecosystems. TFSM: Tidal flat with sparse mangroves. MGSM: Mangroves with saltmarsh. DM: Dense mangroves. MGOT: Mangroves with other (e.g. seagrass, rocky shores). NA: not applicable, **(b)** Total fish size (cm) description.

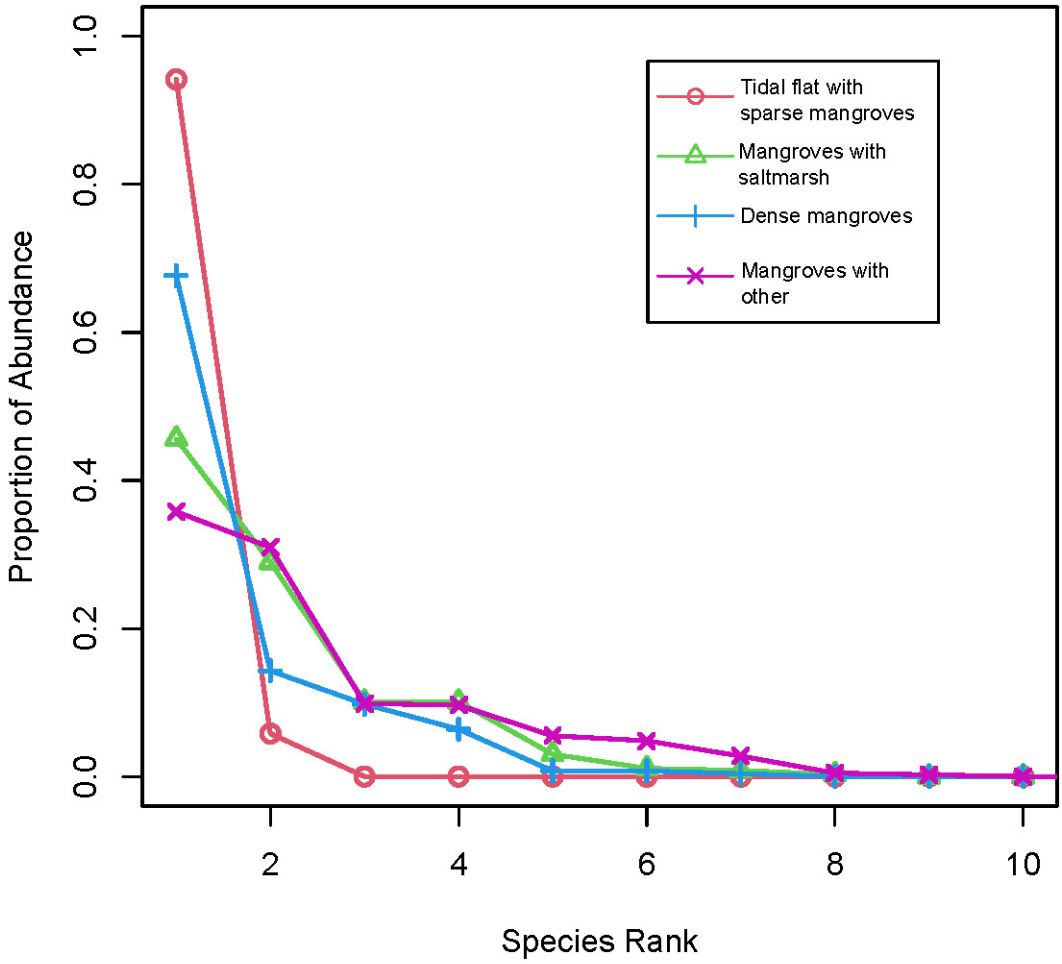


Figure 4. 5. Rank-abundance distribution for the total sample of fish species across habitat types. The Whittaker plot x-axis represents the rank of each species from highest to lowest abundance and the y-axis displays the species abundance.

Species name	Commercial importance	IUCN Red List Status	Maturation size (cm)	Ontogenetic migration	Availability of biology data
G. longirostris	Yes	Least Concern (LC)	20	+	Yes
L. ehrenbergii	Yes	Least Concern (LC)	20	+	Yes
S. leiura	No	Not Evaluated	*NA*	+	No
L. argentimaculatus	Yes	Least Concern (LC)	57	+	No
E. coioides	Yes	Vulnerable (VU)	40	+	Yes
L. fulviflamma	Yes	Least Concern (LC)	19	+/-	No
L. lentjan	Yes	Least Concern (LC)	24	+/-	No
M. arabica	No	Critically Endangered (CR)	*NA*	*NA*	*NA*
M.s argenteus	No	Least Concern (LC)	13	+/-	No
A. latus	Yes	Least Concern (LC)	24	+/-	No
Gobiidae*	*NA*	No data available	*NA*	*NA*	No
L. nebulosus	Yes	Least Concern (LC)	38	+	Yes
P. maculosus	No	Least Concern (LC)	21	+/-	No
A. berda	Yes	Least Concern (LC)	21	+/-	No

Table 4. 4. Description of fish species found in mangroves. The commercial importance and availability of regional biology data are based on regional fisheries stock assessments (Grandcourt et al., 2008; Grandcourt, 2008; Grandcourt et al., 2010; Francis et al., 2016; EAD, 2019; Francis et al., 2019; Francis et al., 2022). The IUCN Red List Status is derived from IUCN database (2022). The maturation size and ontogenetic migration are based on FishBase (Froese and Pauly, 2023). Maturation size refers to the sexual maturity of the fish species. Ontogenetic migration refers to the migration of juvenile species to offshore (or deeper) habitats when reaching adulthood (e.g. coral reefs); +/- (partial ontogenetic migration). NA = not applicable, and No data = no data available.

The distribution of fish species sizes (cm) varied for each combination of habitat type and season (Figure 4.6). The largest fish in terms of size (14 cm) were found in dense mangrove habitats (species *G. longirostris*) in spring, and in very dense mangrove habitats (species *G. longirostris* and *E. coioides*) in both spring and summer seasons. ANOVA revealed a statistically significant difference between fish size among habitat types ($p = < 0.001$) and a significant effect of season on the size of fish ($p = < 0.05$). The Dunn-Bonferroni post-hoc test revealed that habitat types; TFSM (tidal flats with sparse mangroves) and MGSM (mangroves with saltmarsh); TFSM (tidal flats with sparse mangroves) and MGOT (mangroves with other); MGSM (mangroves with saltmarsh) and DM (dense mangroves) were each statistically significant pairwise ($p = < 0.05$).

The largest fishes were found in the habitat type MGOT during spring. Moreover, ANOVA showed a significant difference in fish abundance between habitat types ($p = < 0.001$). The Dunn-Bonferroni post-test showed that habitat types; TFSM (tidal flats with sparse mangroves) and MGSM (mangroves with saltmarsh); TFSM (tidal flats with sparse mangroves) and MGOT (mangroves with other), MGSM (mangroves with saltmarsh) and DM (dense mangroves); and DM (dense mangroves) and MGOT (mangroves with other) were each statistically significant pairwise ($p = < 0.05$). The PCA findings suggest that warmer and saltier waters are associated with higher fish counts and fish sizes, in contrast to cooler, less saline waters with lower pH levels (Figure 4.7). Fish inhabiting tidal flat areas with sparse mangroves tend to be linked to lower salinity and pH, whereas those found in dense mangrove environments align with higher salinity and temperatures. The results of the ANOSIM test ($r = 0.04$) and NMDs visualization revealed that the fish assemblage was affected by habitat types (Figure 4.8).

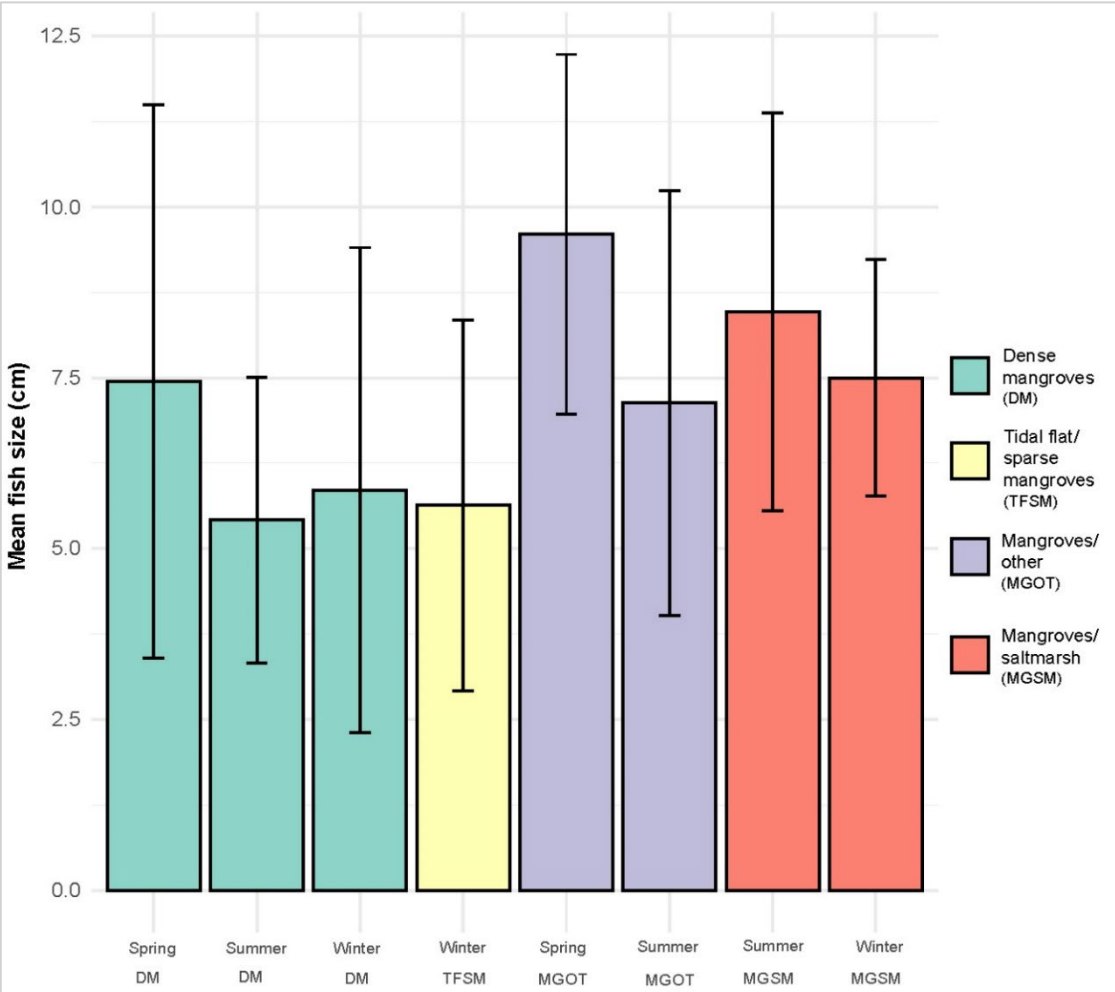


Figure 4. 6. The mean size of species for each combination of habitat type and season (n = 1,137).

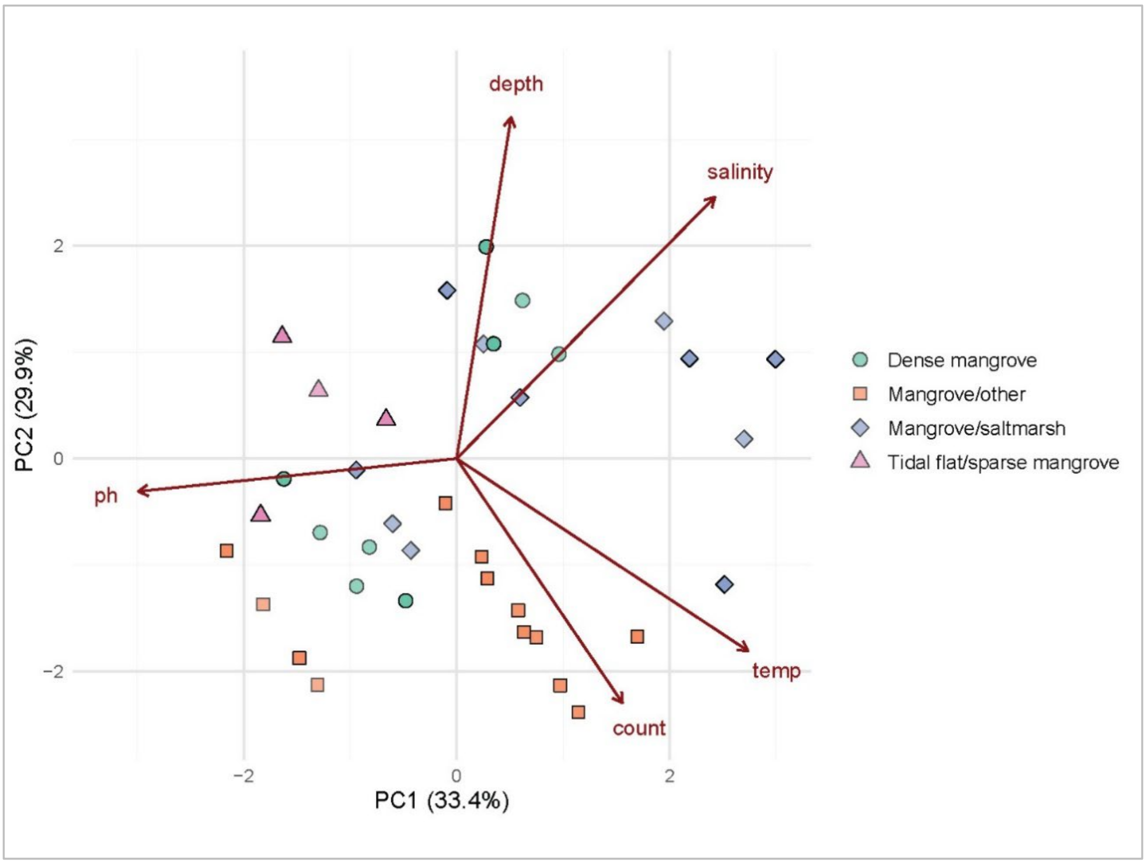


Figure 4. 7. Principle component analysis (PCA) of fish assemblage across habitat types and environmental variables. 'Depth' refers to water depth (m), 'salinity' refers to salinity levels, 'pH' refers to pH levels, 'temp' refers to sea-surface temperature, 'size' refers to fish size (cm), and 'count' refers to fish abundance. Dense = dense mangroves, tidal flat/sparse = tidal flat with sparse mangroves, mangrove/other = mangroves with other habitat, and sparse/ saltmarsh = mangroves with saltmarsh.

4.4 DISCUSSION

4.4.1 Key findings

This study provides clear evidence for fish community structure shifts in abundance and species richness associated with different mangrove microhabitats and seasons in the southern Arabian Gulf. The results suggest that fish assemblages are dissimilar across different mangrove microhabitats in the southern Gulf. The change in fish abundance is influenced, to a notable degree, by the structural characteristics, e.g. rocky shores and saltmarshes in mangrove habitats (MGOT and MGSM). The higher abundance of fish in these areas was likely associated with the intra-habitat features of hard rocky structures and shallow-water seagrass beds on and near mangrove areas. The tidal creeks were much narrower, and water levels remained relatively stable, which supported the highest mean abundance of fish species. These attributes were likely associated with the necessity of many fish species using flooded mangrove areas with higher structural forms as refuge habitats. These expectations were based on structurally complex mangrove habitats providing better foraging grounds and protection from predators (Cocheret de la Moriniere *et al.*, 2004; Nagelkerken *et al.*, 2017).

Variations in fish community structure and habitats were primarily driven by species *G. longirostris*, *L. ehrenbergii*, and *L. argentimaculatus*, which appear to cause the differences among dense mangrove habitats (MGOT) and mangroves with saltmarshes (MGSM). These associations also reveal some variations among MGOT and MGSM microhabitats in species composition, where *G. longirostris* species were commonly found across all the microhabitats, while the species *L. ehrenbergii* were predominantly associated with mangroves that contained saltmarshes (MGSM). Although the underlying reason for these associations may be minor and is beyond this study, but in a broad sense, multiple factors could have an influence on fish assemblages in different mangrove habitats, including the spatial configuration of the coastline, temporal and tidal regime, and local geomorphology (Bradley *et al.*, 2020; Bradley *et al.*, 2024; Reis-Filho *et al.*, 2016).

By contrast, microhabitats of mangroves with less structural features, e.g. tidal flats and sparse stands (TFSM), revealed fewer fish occurrences across the sampling period. These observations were anticipated due to the extensive tidal flat area that lacks vegetation or structure, such as seagrass or saltmarsh, or possibly due to human disturbances, such as dredging, near the habitat during the sampling period. A number of factors may account for the difference in fish communities among microhabitats, including direct impact on the habitat, which could indirectly alter fish populations (Larentis *et al.*, 2022), resource availability, such as food or shelter (Cocheret de la Moriniere *et al.*, 2004; Mumby *et al.*, 2004; Benzeev *et al.*, 2017; Nagelkerken *et al.*, 2017) or simplicity water depth or tidal cycle preferences (Brenner and Krumme, 2007; Rypel *et al.*, 2007; Reis-Filho *et al.*, 2016).

4.4.2 Environmental drivers of fish communities

Most studies on fish and their associated habitats have revealed that environmental variables, such as salinity (e.g. Barletta *et al.,* 2005; Amezcua *et al.,* 2019), tidal regime (e.g. Reis-Filho *et al.,* 2016; Soria-Barreto *et al.,* 2021), and precipitation (e.g. Bradley *et al.,* 2020) influence fish communities. In a practical sense, salinity and precipitation may not play a major role in changes to the fish assemblage within mangrove habitats, particularly in the southern Arabian Gulf, where environmental conditions are more extreme than on coasts in the same region. For instance, the present mangrove area receives less than 90 mm of annual precipitation (Vaughan *et al.*, 2019), whereas rainfall along the northern Arabian Gulf is typically 60% higher (Dasari *et al.*, 2022; Rostami *et al.*, 2022). Several studies on fish and mangrove habitat associations showed that temperature and salinity influence the structure of fish (such as in Iran, e.g. Shahraki *et al.*, 2016; and Oman, Al-Jufaili *et al.*, 2021). Temporally, the results of this study indicate that fish communities differed among the months sampled, possibly related to the change of season across months.

Among the microhabitats, we imply that there is spatial homogeneity across all the study sites, indicating that the temperature change between winter and summer is the primary influence on the structure of fish communities within these habitats. The fish communities were higher in abundance and diversity during the warmer months of the sampling period (average temperature 26°C) than in winter, indicating that fish may be using mangrove canopies and structures for shade during the extreme summer months in this geographical area. Such fish patterns may be the case, as fish communities are influenced by both the structural complexity of the habitat and the degree of shade (Cocheret de la Moriniere *et al.*, 2004). Overall, these observations may allow fish to have a longer duration of foraging within the intertidal complex microhabitats while simultaneously reducing the risk of predation (Nagelkerken *et al.*, 2001; Hampel *et al.*, 2003; Reis-Filho *et al.*, 2016).

4.4.3 Mangroves as fundamental habitats for fish

The results of this study suggest that mangrove habitats may serve as important nursery areas for juvenile fish, despite some minor differences in the size distribution across different microhabitats within the mangrove ecosystem. Smaller-size fish were typically found among all habitat types, while marginally larger fish were only present during summer months and in mangroves that contained rocky shores and seagrass beds (MGOT). Changes in fish size distribution among habitats may be dependent, to some extent, on the type of microhabitat or fish growth over time. Like this study, a similar pattern was observed in other subregions of Arabia (e.g. Al-Jufaili *et al.*, 2021; Dunne *et al.*, 2023). This also seems to be a general pattern in many other regions (e.g. Chong *et al.*, 1990; Nagelkerken *et al.*, 2000; Mumby *et al.*, 2004; Benzeev *et al.*, 2017).

While these patterns of juvenile presence in mangroves have been well-documented (e.g. Faunce and Joseph, 2006; Mumby *et al.*, 2006; Nagelkerken and Van der Velde, 2004; Sambrook *et al.*, 2019), direct comparisons between studies and among various habitats (e.g. both intra-habitat and inter-habitat) may lead to misinterpretation of fish nursery roles in mangrove habitats. Therefore, the role of microhabitats in providing key nursery functions to fish remains complex (Nagelkerken *et al.*, 2004; Nagelkerken *et al.*, 2009; Benzeev *et al.*, 2017), and evidence must be sufficient to prove that a particular habitat contributed significantly per unit area to adult fish populations in other habitats, such as coral reefs (Whitfield, 2017). Even though this study showed high proportions of juvenile fish in mangrove microhabitats and that small fish are common in mangrove creeks, it may not be relevant to assume that mangroves are nursery grounds without further investigations.

4.4.4 Limitations and recommendations for future research

Furthermore, the present study has limitations that could be addressed through future investigations, mainly by enhancing the methodology and sampling efforts, as well as increasing the duration of sampling to cover more mangrove sites and seasons. Specifically, this study focused on daytime sampling and did not consider the potential influence of microtidal changes on fish movement; therefore, it would be recommended that future investigations account for both seasonal fluctuations and tidal regimes. Additionally, although measures were taken to reduce the challenges of underwater visual census sampling, fish obscured by mangrove roots or sedimentation uplift caused by the observer may have been miscounted or missed. As such, future studies should address these challenges and, where possible, consider additional factors, such as distance to the edge of mangroves, when seeking to understand fish communities in structurally complex habitats. Hence, the results of this study must be interpreted with caution, as these ecosystems are complex, and direct comparisons may lead to misinterpretation.

While the behavioural patterns and habitat preferences of fish within the diverse microhabitats of mangrove ecosystems remain largely unexplored globally (see e.g. Nagelkerken *et al.*, 2001; Hampel *et al.*, 2003; Reis-Filho *et al.*, 2016; Sambrook *et al.*, 2019), this knowledge gap is particularly noticeable in mangrove regions of the Arabian Peninsula. The fundamental interrelationships between habitat and fauna may be an important issue for future research as climate change progresses. Given that mangrove ecosystems in Arabia already operate at the limits of their environmental tolerance, further investigations on the fish community structure, alongside examinations of their associated behaviours, and relevant abiotic factors such as tidal regimes, salinity, and temperature, could enhance our capacity to understand and effectively manage these intertidal habitats under a ‘natural laboratory’ that could then inform future projections of mangrove ecosystems in other regions.

4.5 CONCLUSION

The present study provides the first comprehensive description of the fish community structure in different mangrove microhabitats within lagoonal systems in the hyper-arid southern Arabian Gulf. Fish species are dissimilar among habitats and may access different microhabitats for various reasons, such as complexity, shade, and food. Therefore, it is essential to determine the habitat characteristics and associated environmental variables that promote variations in ecosystem services. The fish structural differences in this study may be associated with seasonal temperature changes or fish behaviour responses, such as feeding or seeking shelter from predators in mangrove areas. While fish behaviour and habitat preferences within different microhabitats of mangroves remain largely unstudied worldwide, this is especially true in the mangroves of the Arabian region. Further investigations of the fish community structure associated behaviour and abiotic factors, such as tidal regimes and temperature, may improve our ability to understand and manage intertidal habitats. Mangrove forests and their fundamental relationship with adjacent intertidal habitats and associated environmental conditions are crucial factors in preserving the structure and diversity of fish communities. These interconnected microhabitats support a wide range of fish species and play a critical role in maintaining the overall health and productivity of coastal ecosystems.

CHAPTER 5: Regional perspectives on the conservation of mangroves in Arabia

5.1 INTRODUCTION

Healthy and effectively functioning ecosystems are now widely acknowledged as the foundation for the sustainable advancement of human societies (IPBES, 2019). Initiatives such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services Values Assessment (IPBES, 2022), Nature's Contributions to People (Brauman *et al.*, 2019), and the United Nations Sustainable Development Goals (SDGs) (United Nations, 2015) targets such as SDG 14 (Life Below Water) and SDG 15 (life on land) emphasizes healthy ecosystems to local communities, aiming to incorporate social sciences more inclusively (Diaz *et al.*, 2018). The new Kunming-Montreal Global Biodiversity Framework reflects the importance of collective action in conservation efforts, with its core consideration of a 'whole-of-government and whole-of-society' approach (Joly, 2022). This approach recognizes the importance of local knowledge, local communities' involvement, and their perspectives of the ecosystem as essential elements in future conservation efforts (Datta *et al.*, 2012; Scholte *et al.*, 2015; Cebrian-Piqueras *et al.*, 2020). It underscores the significant role that local communities play in conserving mangroves and the importance of their active participation in these efforts.

The increased public understanding of the importance of mangroves and the awareness of the socio-ecological contributions of these ecosystems have made them a top priority for international conservation initiatives (Friess *et al.*, 2020; Elwin *et al.*, 2024). These initiatives, such as the International Blue Carbon Initiative to Mitigate Climate Change or 'The Blue Carbon Initiative' (https://www.thebluecarboninitiative.org/), and the Global Mangrove Alliance and the Mangrove Breakthrough 'pledge to action' (https://www.mangrovealliance.org/). The growth in conservation efforts has contributed to the reduction of mangroves in recent years (e.g. Hamilton and Casey, 2016; Friess *et al.*, 2020; Goldberg *et al.*, 2020), offering hope for the future of mangroves, but also highlighting the pressing need for continued efforts.

Sustaining the benefits of mangrove conservation will possibly require continued international policy focus, further research on mangrove ecosystem services and values, and improved mangrove restoration that produces positive ecological impacts (Friess *et al.*, 2020), and the support of local communities as stewards (Jape *et al.*, 2024). This aligns with the United Nations "Decade of Ocean Science for Sustainable Development" (Guan *et al.*, 2023) and "Decade on Ecosystem Restoration" (UNEP, 2020) to support efforts to reverse the decline in ocean health. Mangrove ecosystems are vital to a network of functionally connected ecosystems, including saltmarshes, seagrass beds, and coral reefs (Tomlinson, 2016). This interconnectedness not only enriches biodiversity but also provides a wide range of benefits that support the livelihoods of millions of people (Costanza *et al.*, 2017). The benefits of mangroves include the provision of habitat (Tomlinson, 2016), nurseries for fish and invertebrate species (Carrasquilla-Henao and Juanes, 2017), coastal protection (Menendez *et al.*, 2020), and climate mitigation (Himes-Cornell *et al.*, 2018). Despite this wide range of benefits, mangroves remain vulnerable ecosystems, especially to increasing human impacts, such as aquaculture expansion (Elwin *et al.*, 2019), urban development, marine pollution, and global warming (Friess *et al.*, 2019).

Ecosystem health and benefits may vary spatially and temporally (Roces-Diaz *et al.*, 2014), and the differences in cultures and livelihoods may influence how people experience ecosystems (Satterfield *et al.*, 2013), which can then shape their perceptions of the ecosystem as a whole. For example, the differences in how people interact with ecosystems, their socio-cultural values, and personal factors such as age or environmental awareness can significantly shape the link between local communities and ecosystems (Ronnback *et al.*, 2007). In addition, how the concept of a 'healthy ecosystem' may be perceived by people or how local communities benefit from the ecosystem can vary across geographical locations (Scholte *et al.*, 2015). As such, engaging local communities is a key component for successful conservation efforts worldwide (Saunders *et al.*, 2020).

At a regional level, countries that are signatories to international agreements and initiatives will have to fulfil their targets by involving local members of the communities and their perceived views of the ecosystem for better conservation efforts (Satterfield *et al.*, 2013; Scholte *et al.*, 2015; Blum and Herr, 2017; Diaz *et al.*, 2018). However, local community involvement in conservation strategies across the Arabian region remains limited. For example, the United Arab Emirates (UAE) has country-level sustainable and environmental plans, such as for UAE Sustainable Fisheries (2016), the National Marine and Coastal Environment Monitoring (2016), and the Coastal Oil Spill Cleanup Guide (2017) (UAE-SDG, 2023). There do not, however, appear to be plans involving local communities in mangrove conservation strategies, and to date, there has been no assessment of how local people experience mangroves in the UAE. Prior studies have indicated that engaging local communities in the planning and execution of conservation initiatives can lead to successful outcomes (Saunders *et al.*, 2020; Beeston *et al.*, 2023).

This study sought to investigate how people in the southern Arabian Gulf perceive the importance, health, and conservation of mangrove ecosystems, through semi-structured interviews guided by the following research questions: How do people perceive the importance and applications of mangrove ecosystems? How do people assess the health of mangroves? What are people's perspectives on potential threats to mangroves? And How do people recognize any challenges that may impede conservation efforts? The research aimed to understand local perceptions on the significance of mangrove habitats in the region and how these perceptions compare to previous scholarly findings on these issues.

5.2 METHODS

A qualitative research methodology was used, with data collected using semi-structured interviews (Creswell and Poth, 2016) and explored using thematic analysis (Clarke and Braun, 2013). Qualitative research offers valuable explanatory power and rich, in-depth information (Dejonckheere and Vaughn, 2019).

5.2.1 Study area

The study was conducted in Abu Dhabi, United Arab Emirates, along the southern Arabian Gulf coastline (Figure 5.1). Abu Dhabi Emirate has a total coastline of around 750 km^2 and a population of approximately 9.8 million as of 2021 (MOEC, 2023). Around 80% of the population resides in the Emirate's coastal region (MOEC, 2023), taking advantage of its proximity to the sea and the diverse marine ecosystems, such as mangrove habitats, saltmarshes, and coral reefs. Mangrove ecosystems play a crucial role in the coastal environment of the Emirates, providing cultural value and fisheries services to local communities (Almansoori *et al.*, 2024), as well as protection against coastal erosion (Brander *et al.*, 2012; Lopez-Angarita *et al.*, 2016). As of 2021, Abu Dhabi Emirate's mangrove habitats covered an area of approximately 111 km^2 (Almansoori *et al.*, 2021).

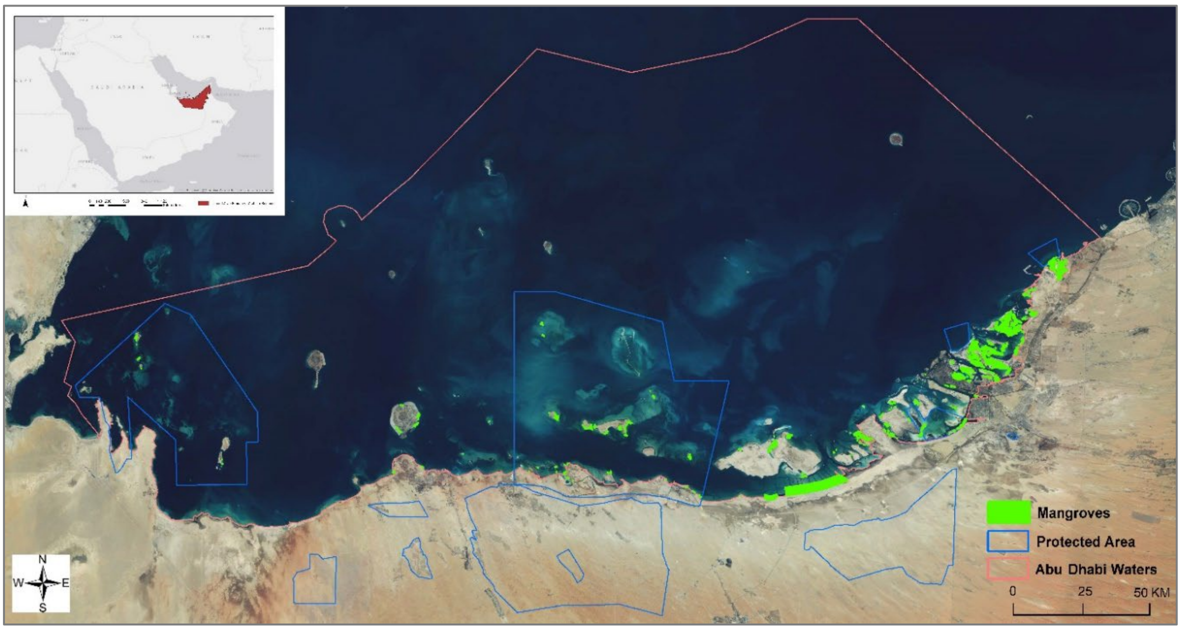


Figure 5. 1. Map of mangrove ecosystems along Abu Dhabi Emirate, in the southern Arabian Gulf.

5.2.2 Data collection

The process of finding participants for the survey was to first identify a broad list of regional organizations to contact for potential participation, including the Environment Agency of Abu Dhabi, UAE Ministry of Climate Change and Environment, Department of Culture and Tourism (Maritime Heritage), Environment and Protected Areas Authority Sharjah, Emirates Nature-WWF, University campuses in the UAE, Abu Dhabi National Oil Company (ADNOC), and TOTAL Energies. Due to cultural barriers in the region and the need to build long-term trust with stakeholders, it was challenging to receive quick responses from stakeholders. Hence, participants who agreed to participate in the survey were fully informed about the purpose of the study and their rights to withdraw at any time and have their information removed from the study. To ensure a good and structured balance of different participants, each participant was randomly selected and assessed for their relative importance in either influencing or being influenced by the issue being investigated, in a simple matrix-style (IUCN-SSC, 2008) (Figure 5.2).

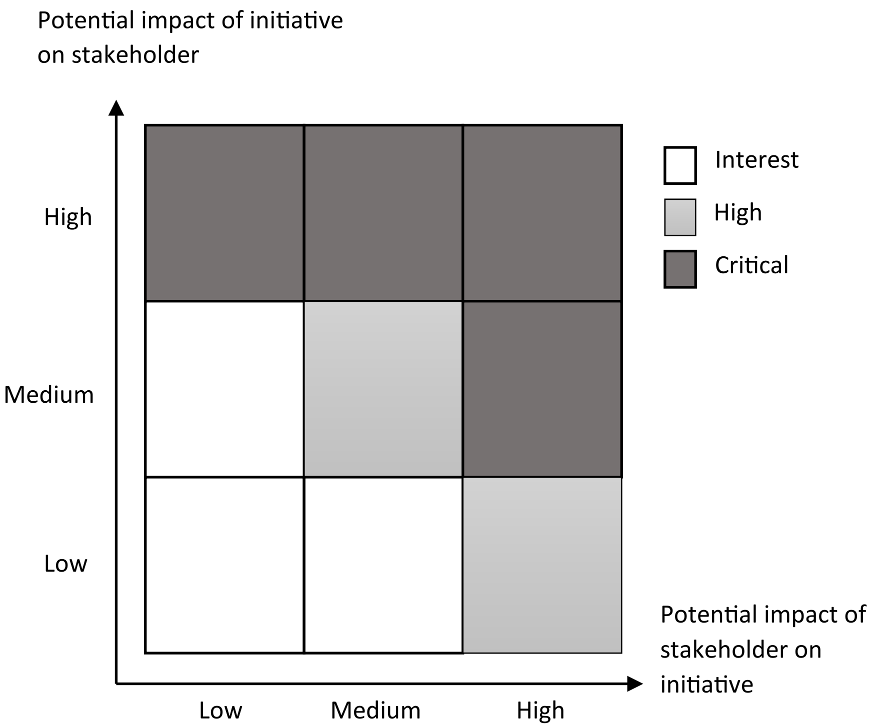


Figure 5. 2. A simple matrix-style used to assess each participant for their relative value adapted from IUCN-SSC (2008).

5.2.3 Semi-structured interviews

Semi-structured interviews were conducted in person and through Zoom video-conferencing between May and June 2023, following the approval of Newcastle University's ethics procedure (Ref: 40431/2023) (details in Appendix D.1). The interviews followed the methods outlined by Creswell and Poth (2016). The selection of questions was designed to allow an overall understanding of the perceptions of regional people on the importance of mangrove habitats (see Appendix D.2 for full transcripts). This semi-guided approach allowed participants to elaborate and explain their perceptions freely, enabling the collection of new qualitative data through an in-depth investigation of the participants' beliefs and ideas about the topic (Dejonckheere and Vaughn, 2019).

Eleven participants were interviewed, including local community members, environmental experts, and representatives from non-governmental organizations, with each interview typically lasting approximately 60 minutes (Table 5.1). The five local community participants were male residents who had been involved in mangrove ecosystems for at least two decades (e.g. for fishing). These interviews were conducted in-person due to the nature of the participants, e.g. cultural respect, limited use of technology, language (Arabic – native language), and authentic involvement to increase their confidence to speak easily (Tesfaye, 2017).

A printed copy of the questions in Arabic was used during the interview, and data was recorded in a notebook and then entered into Word documents. The remaining six participants were interviewed on Zoom video conference platform (details in Appendix D.2). This communication platform allows for an easy approach to video recording and generating transcripts, and a cost-effective way to collect qualitative data, proving satisfactory for this purpose (Archibald *et al.*, 2019; Steele *et al.*, 2022). This approach allowed the recording of all the interviews and transcription directly by Zoom software after consent and the ethical approval of each participant (details in Appendix D.3). Finally, surveys were converted into English for thematic data analysis (Clarke and Braun, 2013).

Group	Description	Number of participants	Potential impact	
			Initiative on stakeholder	*Stakeholder on Initiative*
Local community *(UAE Residents or citezen)*	A group of people who live in a certain area and often share common values, culture, traditions, recreational activities, and services, such as fishermen or residents.	5	High	Medium
Academia *(Staff or Professor at UAE campus)*	A group associated with educational and research institutions, such as universities or educators.	2	Low	High
Non-governmental organizations (NGOs) *(Non-profit or independent from government)*	Refers to an independent, non-profit organization driven by specific goals to address various issues, such as environmental or humanitarian.	1	Low	Medium
Environmental expert *(Specialists in the environment sector)*	An individual who is a professional with specialized knowledge or skills in the fields of ecology, biology, environmental science, policy, management, or engineering.	1	Low	High
Non-environmental expert *(Staff in oil and gas sector)*	An individual who is a professional with specialized knowledge or skills in a wide range of industries and disciplines, who possesses knowledge or skills not directly related to environmental science subjects.	2	Medium	Low
		Total: 11		

Table 5. 1. Description of each participant and relative value using the matrix-style analysis (IUCN-SSC, 2008).

5.2.4 Data Analysis

The interviews were recorded digitally in Microsoft Word, and thematic analysis was used following the six phases proposed by Clarke and Braun (2013) (Figure 5.3a). The initial phase involved thoroughly familiarizing oneself with the data through repeated reading and identifying any preliminary insights. The next phase was generating codes for important data features relevant to the research questions, which subsequently entailed an iterative process of identifying coherent patterns and compiling all coded data for each theme. This was then followed by reviewing the themes to ensure they captured the data, leading to refinement, and then labelling the key themes. Finally, the concluding phase involved writing the data extracts into an objective narrative about the data, contextualizing it in relation to existing literature. The analysis involved a recurring, iterative process, where the different phases were revisited to ensure the captured information remained relevant. The Delve Qualitative Coding Software was used during the coding and themes phase to organize information (Delve, 2023) (Figure 5.3b).

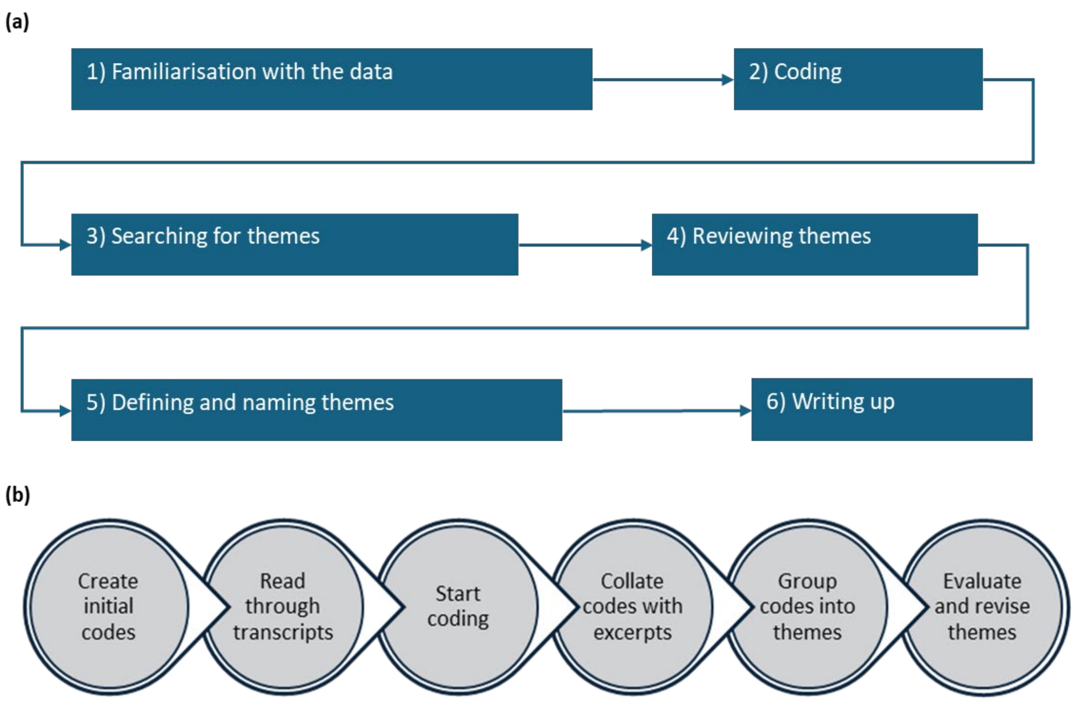


Figure 5. 3. (a) The six phases by Clarke and Braun (2013), (b) The steps used in Delve Software to initiate and evaluate the codes and themes.

5.3 RESULTS

The main themes that emerged were importance, threats, limitation, opportunity, and conservation (Figure 5.4). This section begins by discussing the overall significance and uses of mangrove ecosystems. It then examines how people assess changes in mangrove health and the potential threats facing these ecosystems and concludes with an exploration of conservation-related perspectives.

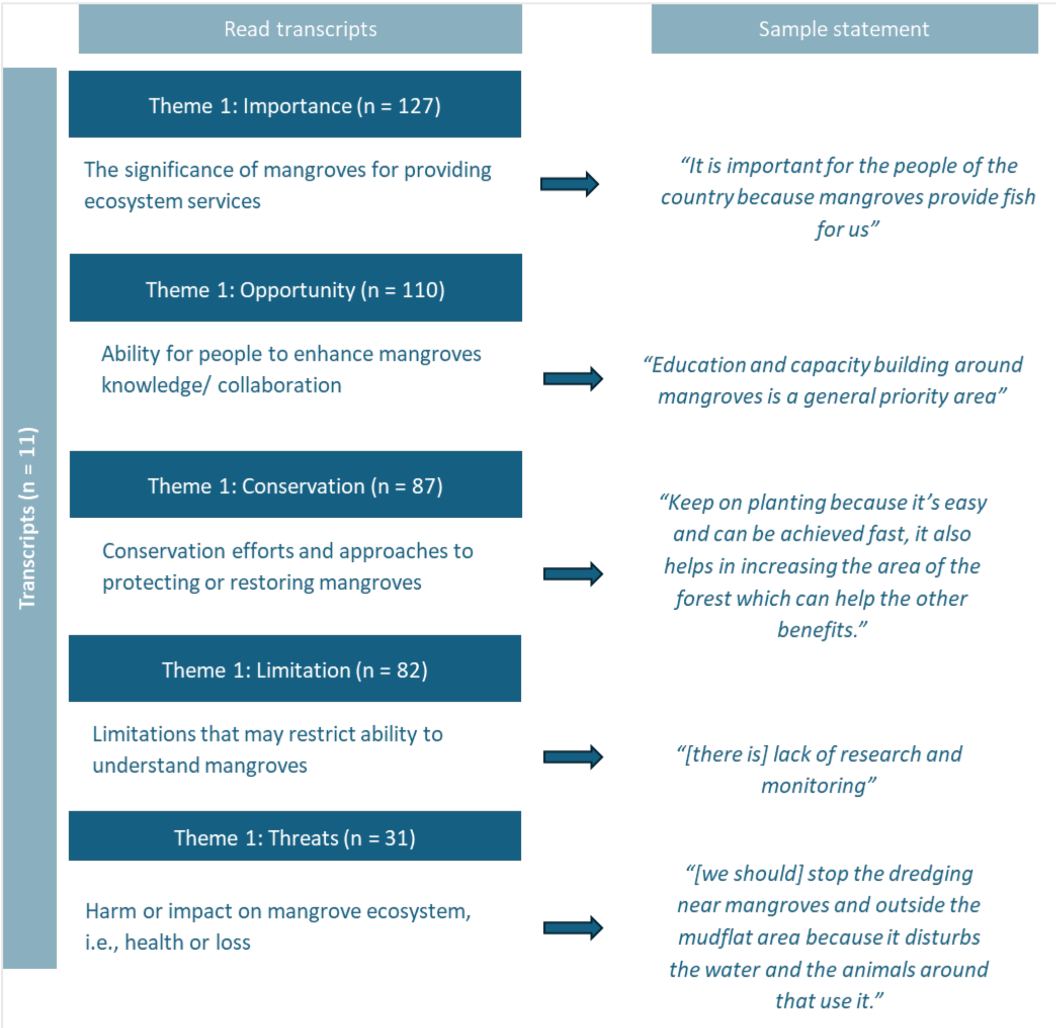


Figure 5. 4. Description of emergent themes and statements of the systematic thematic analysis approach. Information based on eleven transcripts and a total of 434 excerpts based on five groups: A: Academic (n = 2), EE: Environmental expert (n = 1), LC: Local community (n = 5), NEE: Non-environmental expert (n = 2) , and NGO: Non-governmental organizations (n = 1).

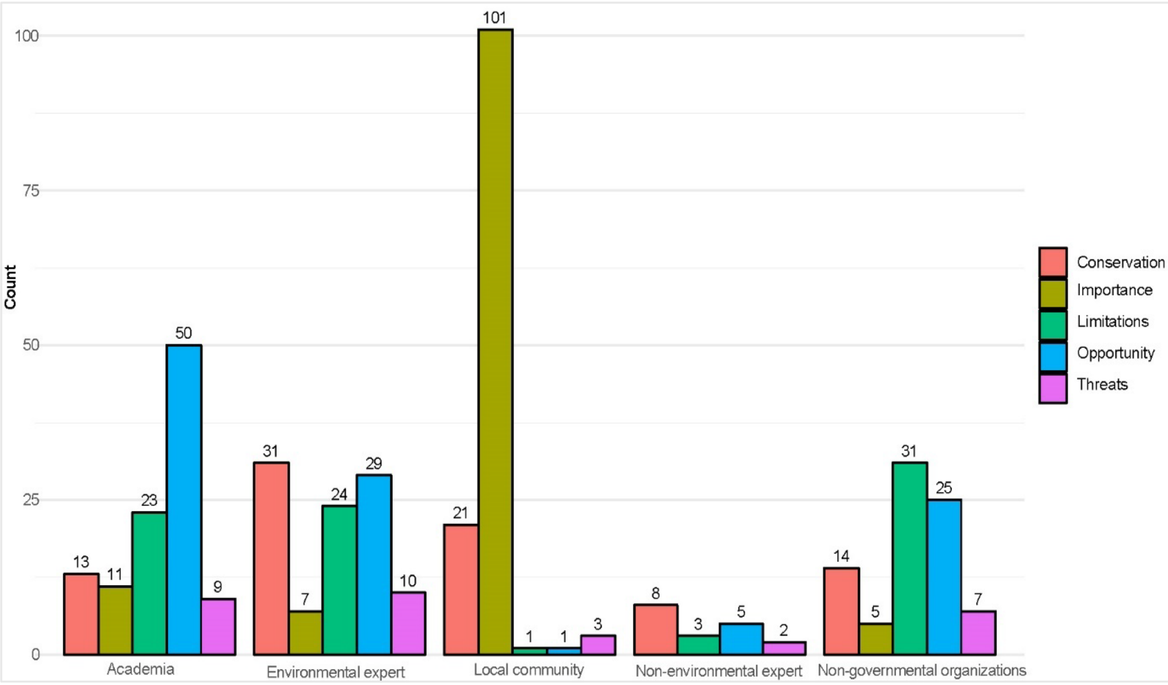


Figure 5. 5. Distribution of themes across groups.

5.3.1 How do people perceive mangrove ecosystems?

Mangrove ecosystems were commonly perceived as one of the most important coastal habitats, providing vital support for biodiversity, ecosystem services, and livelihoods, particularly through fisheries and the supply of material resources. All participants demonstrated a basic understanding of mangrove ecosystems, such as type of plants, where they occur along the coastline, and what services they provide to fauna and people. Though their overall outlook on the importance of mangroves was comparable, there were some variations in how they articulated the significance of these ecosystems. The local community participants emphasized the cultural significance of mangroves and widely recognized their various material uses, such as wood for building boats. They also made clear the importance of mangroves for fishermen and fish populations. For instance, a participant from the local community group stated: "*Mangrove snappers, long-silver biddies, and seabreams are among the fish we catch in mangrove areas*," and another stated: "Y*es, many fish, some are naiser [snapper] and badah [biddy]*". Several other participants from the local community group also expressed how mangroves help other habitats by increasing the number of fish and how that has supported fishermen. For example, local community group participants stated: "*mangroves increase fish, and fish in the coral reefs; we see the increase every day when we fish*", and "*it [mangrove] increases the fish population in the country, and it helps us fisherman to catch more fish*", and "*it is important for the people of the country because mangroves provide fish for us*".

Regarding the mangrove material use, participants from the local community group stated that mangroves were historically important for building materials and feeding livestock, but that mangrove are not used for these purposes. Historically, the material used from mangrove trees included wood for building ship hulls and housing, while the leaves of mangroves were used for feeding livestock such as camels. For example, local community participants mentioned the use of resources by statements, such as: *"everything in the mangrove tree is used because it's a strong tree for building homes and boats"*, and "*they [mangrove leaves] are also used for cattle and livestock like gazelles"*, and *"the material is used for homes"*. The NGO and environmental expert participants shared opinions on the importance of mangroves for other reasons. For instance, an NGO participant stated that mangroves play a role in carbon sequestration by saying: *"The area [mangrove] is rich in organic carbon"*, and an environmental expert participant stated that mangroves play a role in biodiversity and coastal protection: *"...so what is the economic benefit? fisheries resources, flood protection"*.

The non-environmental experts displayed a limited understanding of the importance of mangroves, including their significance to humans and the ecological services they provide, such as nutrient cycling processes. Instead, these participants emphasized the need to restore mangrove habitats through planting efforts, as their awareness was restricted to planting targets. For example, the emphasis on planting mangroves has been expressed as a good, and the main, approach for increasing mangrove cover due to its ease of implementation, as one participant stated: "*so, we keep on planting because it's easy and can be achieved fast, it also helps in increasing the area of the forest which can help with the other benefits*". Another participant from the same group expressed that decision-makers are realizing the importance of increasing mangrove cover due to carbon sequestrations and, for example, stated: *"today policymakers are realizing the importance of mangroves in terms of carbon… the awareness has increased"*. Similarly, a participant from another group (academia) showed that the reason for planting mangroves was their role in carbon offsetting, by stating: *"people now are emphasizing so much on planting for carbon offset"*.

Furthermore, the need for more research on mangrove ecosystems was central to many of the discussions in all groups. There was consensus that there is a scarcity of research on mangrove ecosystems in this geographical region and a feeling that the underlying reasons remain unclear. For example, a participant from the environmental expert group stated: *"…and do you feel like there is still lack of research in this field? Yes, it is affecting us all. So most of the human activities that are negative, yeah, are directly actually affecting"*, and a participant from the NGO group said: *"you know, the scientific understanding is not there*", and *"maybe there is limited resources and funding"*.

5.3.2 General perceptions of mangrove ecosystem health

All participants recognized that increased habitat cover in mangrove areas was a key indicator of a 'healthy mangrove ecosystem.' There was consensus among participants regarding the overall health of the mangrove ecosystem, with the general assumption that a healthy ecosystem is linked to stable habitat cover and ongoing habitat growth. Many participants from the local community group attributed the positive state of mangrove habitat growth to past plantation efforts by the late founder of the United Arab Emirates (Shaikh Zayed bin Sultan), which aligned with habitat change patterns reported in the literature (Almahasheer, 2018).

A participant from the local community group provided detailed insights about the role of Sheikh Zayed toward the initiation of mangrove habitat cover increase across the Emirates, stated: "*yes, I was one of the first group of residents with the late President Sheikh Zayed bin Sultan, who acted fast and ordered the companies to plant mangroves to make the area richer in biodiversity… I then started to notice that it was an important habitat for many other things like reducing some waves, Sheikh Zayed encouraged the plantation, such as collect seeds and plant, that included along the whole coast of Abu Dhabi… started a department [dredging ships] from UAE and Oman to collect the seeds and start to plant, they carry it with a rug, where he wanted them to plant, they planted… the first propagules came from Marawah… Sheikh Zayed kept encouraging the plantation efforts over time until we saw this dense forest*". Other participants from the local community group expressed a similar experience, such as: "*I have seen at least* a *60% increase from all the plantations that our late founder Sheikh Zayed planted many years ago*", and one mentioned that mangrove ecosystem health was linked to habitat size, which stated: *"60% - 100% increase and their size is much larger than I remembered also the density is higher than before"*.

In general, there was a recognition among all the groups that a greater extent of mangrove areas provided a fundamental indicator that an ecosystem is balanced and healthy, but also that there needs to be protection of forests to help maintain the health of mangrove ecosystems. For example, participants from the local community stated: "*We need to keep mangroves healthy for a long time*", and participants from NGOs said: "*Of course, we need marine protected area*", and "*…cost of development and the protection of both, can go together, development and protection and the consideration of the local communities*".

5.3.3 General perceptions of threats to mangroves

Participants from all the groups expressed similar concerns about potential threats to mangrove ecosystems, primarily linked to human activities related to regional economic growth, such as coastal development or global warming (Table 5.2; Figure 5.5). The environmental expert participants cited coastal development threats the most, accounting for nearly a third of all threat mentions, explaining that coastal development activities harm the health of mangrove ecosystems and nearby areas, such as mudflats. According to the environmental expert participant, pollution resulting from development and unregulated activities has a detrimental impact on mangroves. For example, the participant expressed: "*Pollution is very harmful and I see that many of the mangroves die from bad water*", and "*…also when there is no water flow because of construction or a bad land use for some reason, the water flow just stops, and the tree dies very quickly*".

Similarly explained by other participants, for instance, from the academic group indicated that dredging was impacting coastal habitats, as expressed by: "*Stop the dredging near mangroves and outside the mudflat area because it disturbs the water and the animals around that use it, so we have to protect all the area, not just mangroves*". An NGO participant expressed concern that future economic growth could lead to degraded mangrove habitats and health. This participant provided specific insights on the future status of mangroves, emphasizing the importance of involving youth in nature and educating them, stating: "*you think this will not really affect the future plan for mangroves, or because the new generation doesn't actually interact so much [with nature] maybe like the old people who go fishing and still go fishing to this day, maybe the new generation don't interact so much with nature, but this will affect everything*", and "*this youth generation, these too need to be educated right?*".

Group	Mention(s)	Top threats
Environmental Experts	10	Coastal development (n = 8), Global warming (n = 2)
Academia	8	Coastal development (n = 4), Global warming (n = 4)
NGO	7	Coastal development (n = 5), Global warming (n = 2)
Local Community	3	Coastal development (n = 3)
Non-Environmental Experts	2	Coastal development (n = 2)

Table 5. 2. The number of identified threats across groups (n = 30).

Figure 5. 6. Images depicting the signs of threats to mangrove ecosystems along the coastline of Abu Dhabi (United Arab Emirates) as perceived across the survey groups. Mangrove habitat degradation and loss due to human activities (left), dredging and landfilling operations near mangrove areas (top right), and coastal infrastructure, e.g. bridge, near mangroves (bottom right).

5.3.4 Perceptions of challenges towards mangrove conservation

The key insights into how each participant perceived the challenges of mangrove conservation emerged from their personal experiences with mangroves. Thus, perceptions of potential conservation challenges varied among the groups. Members of the local community group were not fully aware of how conservation works and, therefore, were unable to identify any challenges. Participants from other groups, however, were able to communicate some key challenges, including research gaps in mangrove ecology, lack of effective policies and enforcement to address unauthorized human activities, insufficient communication and collaboration between local communities and environmental managers, and scarcity of resources such as funding.

According to three groups (environmental expert, NGOs, and academia), the primary challenge in conserving mangrove ecosystems in the region was the lack of communication between local community members and decision-makers such as environmental managers, as the following statements show: "*The people are also not fully involved in the planning level like restoration planning. They are also not involved in the management practice*", and "*So they should be involved, you know. Yes. So if the local community is involved in mangroves, conservation, it's in big term or success. There is always a gap, you know, between management, by offices for the management, by the local people. That is a gap. That gap should be reduced*". In addition, the environmental expert participant expressed the need to have clear conservation targets or agendas that involve a wider range of stakeholders; as expressed by: "*what is the commitment or what is the mandate? … and I'm talking in general*".

Several ways to address these challenges were discussed, including encouraging scientific knowledge by conducting more research on mangrove ecosystems. The main topics of discussion on scientific research included the role of mangrove habitats for biodiversity, such as their importance for habitats or fisheries, the role of mangroves in climate change mitigation through carbon sequestration, the use of innovative monitoring techniques, and the need to raise public awareness on the importance of mangroves. For example, a participant from the NGO group expressed: *"There should be an increase of research happening here. And I think, highlighting this more and more right? [on mangrove research]*", and another from academia stated: "*the technology, the innovation. Now, every 5 or 2 years, we can see amazing things [to help in monitoring of mangroves]… Okay, it works sometimes.*".

The participants viewed these challenges as opportunities that would enhance conservation efforts. Members of the local community group associated these opportunities with the potential to increase or strengthen the protection of mangroves, as evidenced by the following statements: "*we need to protect them [mangroves] by the protection of the old trees in the areas because they mean a lot to the local community*", and "*we protected it [mangrove forest] a long time ago and never cut it down for no reason, and I believe now the government is protecting it which is good for people and fish*", and "*protect mangroves because they are valuable it helped us [long time ago], and it will help you [future generations]*".

Moreover, the participants across all groups shared a similar outlook on the way forward for mangrove conservation, emphasizing the importance of planting and protecting trees. However, each group provided distinct insights into their approach to restoration. For instance, the local community group described using traditional knowledge and natural regeneration, as illustrated by statements, such as: "*there is a way I used to do near my home for small young mangroves, I take care of them from the algae by manually removing them from the tree and leaves, then also I put a fence around the small saplings to protect them from other things like grazing and wind*". They also noted that: *"…most planting works, with natural regeneration… and the tidal water flushing*". In contrast, participants in the non-environmental expert group discussed restoration through large-scale plantation efforts and national conservation commitments, stating: "*we are just familiar with the 100 million trees that the country has pledged for mangroves. So, for example, you see, a lot, probably, people are kind of bidding on how many plantations they want to reach because we have committed for a hundred million plants. I wouldn't say we are aware what is the commitment or what is the mandate?*", and "*we need to plant, uh, 10 and 100 million mangrove, [such as] Abu Dhabi National Oil Company pledge for 10 million*", and discussed that plantation can help in carbon offset, by stating that: "*Other than planting more mangroves. I think it should continue because this is what we did from the beginning so this is what we need to be ready to focus and try to do, because if we can, if we focus on offsetting*".

5.4 DISCUSSION

This study set out to evaluate how different groups of stakeholders define and assess mangrove ecosystem importance, health, threats, and the potential challenges that may hinder conservation efforts. The results of this study are based on a small sample size and would benefit from further work, such as long-term trust building, before being considered representative of the national population. The study shows that using semi-structured interviews can offer valuable insights and rich narratives on specifics in understanding the link between people and mangrove ecosystems (Dejonckheere and Vaughn, 2019; Nyangoko *et al.*, 2022), which is not currently captured very well by national conservation strategies or frameworks in the same region of the study area. For example, UAE's current frameworks for the marine and coastal environment, such as the Emirates' Strategy for Green Development or the National Strategy for Coastal and Marine Environment, often partially address the social aspects of the relationship between people and nature (UAE-SDG, 2023).

This study provides information that participants generally hold a positive perception of mangrove ecosystems, but their level of knowledge and experience vary. It was most notable that the participants from the local communities, academic institutions, non-governmental organizations, and environmental experts exhibited extensive familiarity with mangrove ecosystems, presumably due to their close interaction with the environment through daily activities or research. The non-environmental group showed limited familiarity and experience with mangroves, discussing mangroves mainly as national-level concerns, referencing large-scale planting commitments, and providing few examples of why or how such plantations could succeed. Such variations in people's perceptions of natural ecosystems have been observed elsewhere (see e.g. Halpern, 2020; Loch and Riechers, 2021), suggesting that participants' knowledge and experience can be attributed to various factors, such as their interactions with ecosystems or simply their level of environmental awareness (Ronnback *et al.*, 2007).

5.4.1 How can local knowledge be used to develop better conservation efforts?

The local community group displayed the most in-depth and direct experience of mangroves, appreciating them not only for the services they provide but also for their cultural and aesthetic significance. The relationship between people and nature creates a sense of connection beyond the typical material approach used to assess ecosystem services (Nyangoko *et al.*, 2020). This suggests that communities in the Arabian region derive relational value from mangroves (Chan *et al.*, 2018). This finding is supported by research showing that local communities identify the cultural services of mangrove ecosystems as most significant (Nyangoko *et al.*, 2020). In this study, the local community group also demonstrated a meaningful relationship with mangroves beyond material benefits, suggesting that they feel a connection to nature and a commitment to protecting them, despite some historical practices being common. However, like many other parts of the world, local knowledge is often overlooked in decision-making and policies (Chan *et al.*, 2012).

The study of local ecological knowledge is relevant to understanding fishery-related ecological issues within mangroves (Mellado *et al.*, 2014) and for effective conservation efforts (Adom, 2018; Beeston *et al.*, 2023). The local community group demonstrated in this study that they benefit from traditional fishing in areas near mangroves, and as previously reported, local knowledge can reduce the need for extensive surveys and guide how conservation resources are used (see e.g. Mellado *et al.*, 2014; Camacho *et al.*, 2020). Local knowledge can enhance conservation efforts by providing detailed information on species distribution and changes over time. For example, fishermen can offer insights into seasonal migration patterns and fluctuations in fish populations. Additionally, local communities can contribute input on specific sites to identify priority areas for mangrove restoration or report on observations of declining mangrove health or increased erosion. Engaging local communities in conservation efforts fosters a sense of ownership and responsibility (Jape *et al*., 2024), because when people see themselves as custodians of their local ecosystems, they are more likely to actively protect and manage them, which leads to more holistic and effective conservation efforts (Adom, 2018; Beeston *et al.*, 2023).

5.4.2 Regional perceptions of mangrove threats

According to environmental experts, NGOs, and academic participants, the key challenges hindering mangrove conservation efforts in the Arabian region are linked to three main limitations: gaps in scientific research, lack of policies, and poor communication between the public and higher management or environmental authorities. This assertion is supported by the evidence gathered in previous chapters (e.g. see Chapter Two and Three). Government authorities could contribute by allocating more funds to research centres and universities to assess how mangroves support local communities and biodiversity, as well as the impacts of anthropogenic and natural stressors on mangrove habitats.

Lack of enforcement and policies could limit the ability of managers to sustain healthy ecosystems and, if addressed, could reduce threats to ecosystems (e.g. Friess *et al.*, 2019). Policies that are strengthened can help mitigate threats to ecosystems by preventing illegal activities, promoting sustainable practices, and safeguarding mangrove habitats, consistent with previous research (Chamberland-Fontaine, 2022). Environmental authorities could enhance regulations, such as limiting dredging activities and enforcing buffer zones, to prevent the loss and degradation of mangrove habitats. This could include issuing violations for industries and establishing marine protected areas (see e.g. Dabala *et al.*, 2023) that ensure mangroves remain undisturbed.

Improved communication between the public and environmental authorities will help bridge the gap of communication between people and decision-makers, which has been shown to provide higher conservation successes (see e.g. Reagans and McEvily, 2003; Crona and Bodin, 2006). Across the Arabian region, different stakeholders, including governments, local communities, and practitioners, could collaborate to address large-scale threats to mangroves (see e.g. Regional Organization for the Protection of the Marine Environment programs; ROMPE, 2024). Providing more evidence-based information can increase the likelihood of positive conservation action (Friess *et al.*, 2019; Dahdouh-Guebas *et al.*, 2020; Elwin *et al.*, 2024).

5.4.3 Raising awareness about science-based approaches to conservation

This study found that all the participants advocated for the plantation of mangrove ecosystems, and while this seems to be a positive outlook for the restoration of degraded and lost areas, excessive plantation efforts may have a negative environmental impact (Peng *et al.*, 2016), such as the introduction of non-native species (Augusthy *et al.*, 2024). All the participants also credited past planting initiatives by the late UAE president, which they consider has increased total mangrove cover over the years, consistent with scholarly reports (e.g. Alhabshi *et al.*, 2007; Almahasheer, 2018). Previous studies have demonstrated that factors such as site capacity or selection, science-based methodology, and land tenure can significantly influence the success of restoration projects (Peng *et al.*, 2016; Wylie *et al.*, 2016; Friess *et al.*, 2019). The large-scale plantation pledge stated by non-environmental experts to plant millions of mangrove saplings (also see e.g. 'UAE's ambitious pledge to plant 100 million mangrove trees by 2030'; MOCCAE, 2024) must be revised to consider multiple factors that may influence the successful establishment and growth of the trees. Thus, it appears that participants' perspectives on the approach to restoring mangroves are limited to the need for planting trees to restore coverage, indicating their understanding of why mangroves need restoration but less certainty about how to achieve successful restoration.

Mangroves are vulnerable ecosystems, susceptible to increasing human stressors such as urban development (e.g. Elwin *et al.*, 2019), and marine pollution (e.g. Friess *et al.*, 2019), factors that can degrade the health of mangroves and, in some cases, lead to the complete loss of these habitats. While deforestation of mangroves worldwide has declined (Bunting *et al.*, 2022), the future of mangroves remains uncertain, especially in the rapidly developing Arabian region, where coastal environments face threats (Sheppard *et al.*, 2010). Without adequate measures and management to investigate underlying threats to mangroves, the drivers of degradation may continue (e.g. Elwin *et al.*, 2019; Friess *et al.*, 2019). To effectively raise awareness about science-based approaches to conservation, environmental authorities in the region must first address the underlying threats to mangroves and understand long-term habitat changes. Additionally, they should employ science-based restoration methods to ensure the success of their conservation efforts (see e.g. Coleman *et al.*, 2008; Ren *et al.*, 2008; Romanach *et al.*, 2018; Hai *et al.*, 2020).

5.4.4 Constraints of the study

The scope of this study precluded an in-depth examination. Instead, it illustrated that people with different backgrounds hold a wide range of valuable perceptions and knowledge about mangrove ecosystems. The study provided information that could be leveraged when planning mangrove restoration or other science-based initiatives. However, results cannot yet be generalized to represent the full range of perspectives on mangrove ecosystems, as relying solely on the perceptions of a limited number of people is insufficient to capture the diverse views about this ecosystem. To enhance this study, future investigations could target one specific group, such as local communities or fishermen, and conduct interviews across the different subregions of Arabia. This would capture the full range of local perceptions regarding the benefits of mangroves, including their importance for fisheries and cultural values (see e.g. Mellado *et al.*, 2014; Camacho *et al.*, 2020). The insights from such studies can then be used to bring local community perceptions to guide the planning of conservation initiatives (Saunders *et al.*, 2020; Beeston *et al.*, 2023).

While capturing the viewpoints of stakeholders can be straightforward, interpreting these perspectives requires thought and care. Several approaches can address this, such as improving data collection techniques through methods like participant observations (Bazen *et al.*, 2021) or a mixed-method approach combining surveys, focus groups, and interviews (Nyangoko *et al.*, 2022). Alternatively, high-level meetings could be organized with management from different stakeholders (e.g. ADNOC and NGOs) and incorporate a series of workshops to better understand their needs and viewpoints (Johnson-Bailey and Cervero, 1997; Elwin *et al.*, 2024). Another approach is conducting more interviews to achieve a larger sample size (Gayo, 2020; Loch and Riechers, 2021). Researchers could spend more time building trust with local communities, organizing small group discussions to collect opinions, and dedicating more time and resources to engage with community leaders and elders. These approaches may enable the acquisition of critical information to ensure consistency of responses.

5.5 CONCLUSION

This study used semi-structured interviews to examine how people perceive mangrove ecosystems, providing valuable insights and rich narratives on the importance and conservation of these ecosystems. While all participants recognized the importance of mangrove ecosystems, their varying levels of knowledge and engagement with these systems revealed a correspondingly mixed understanding of conservation needs and existing efforts. The increased public awareness of the importance and positive socio-ecological contributions of mangroves has led to these ecosystems being considered a high priority for international conservation initiatives (e.g. Friess *et al.*, 2019; Friess *et al.*, 2020; Elwin *et al.*, 2024). Currently, there is a lack of awareness about mangrove ecology and the approach to restoring mangroves across all stakeholder groups in the Arabian region. Addressing the underlying threats to mangroves and understanding long-term habitat changes is essential. Research and education could be a helpful tool that can enable people to understand the ecosystem better, the cultural value and connection of mangroves to people, and the different ways mangrove ecosystems could be restored, particularly by using science-based restoration methods (Beeston *et al.*, 2023).

This study has important implications for understanding mangroves by examining the perspectives of diverse groups of people. However, future research could focus on a specific group, such as local communities or developers along the coastline, as this would be important when planning conservation initiatives to ensure successful outcomes (Saunders *et al.*, 2020; Beeston *et al.*, 2023). It is recommended that conservation initiatives in the region involve multiple stakeholders, especially members of the coastal and local community, at an early stage of the planning process to build strong networks and amplify the voices of local people into positive conservation action. This will allow for recognizing the vital connection between local communities and mangrove ecosystems, and it will better acknowledge that mangrove ecosystems are socio-ecological systems (Elwin, 2019), eventually contributing to successful conservation outcomes.

CHAPTER 6: General Discussion

6.1 Background

Mangroves intricately link a wide array of biological, ecological, and physical components, providing important ecosystem services and playing a crucial role in the lives of coastal communities. Mangroves in the whole Arabian Gulf region cover an area of 209.5 km^2, accounting for less than 0.1% of the global mangrove distribution. Of the total mangrove area in the province, 47% is situated in the southern Arabian Gulf, dominated by one species: *Avicennia marina* (Almansoori *et al.*, 2024). Although mangroves are important to biodiversity and people, Arabian mangrove ecosystems remain among the least studied globally. Mangrove habitats are under substantial pressure in the Arabian region from human activities, particularly coastal development (Sheppard *et al.*, 2010; Almansoori *et al.*, 2024), marine pollution (Friess *et al.*, 2019), and global warming-induced sea-level rise (Hagger *et al.*, 2022). The paucity of research presents substantial challenges in establishing optimal approaches for conservation efforts, such as restoration, and highlights the pressing need for a much more robust scientific-based foundation to support effective conservation strategies and plans in the region.

The primary aim of my thesis was to investigate the role of mangrove habitats in supporting marine species and the perspectives of people and how we can use the available information to target conservation efforts in the Arabian region. Mangroves are crucial coastal ecosystems globally, and in the Arabian region, they are unique, benefiting marine species living at their environmental limits and supporting a diverse and dynamic seascape where other species cannot thrive. As a result, this region serves as a 'natural laboratory' for mangrove research as the climate changes, offering new knowledge about ecological connectivity within increasingly warm and arid climates that mangroves in other parts of the world may face in the future. My research provides a valuable resource for guiding future scientific research on mangrove habitats and highlights priority areas for future conservation attention in the Arabian region.

6.1.1 Synthesis of key findings

Chapter Two established an understanding of mangrove habitats role in supporting species, especially fish populations. However, it reveals significant geographical gaps in research, including the Arabian Peninsula, and limited exploration of other species and microhabitats. Future investigations could include expanding research on other marine species and understudied microhabitats and addressing geographical gaps by prioritizing studies in underrepresented regions. The geographical bias identified in Chapter Two provides a rationale for focusing on underrepresented regions like the Arabian Gulf. The findings emphasized the need for more local research, the specific requirements of which are identified in Chapter Three, such as the key literature trends, research gaps, and geographic disparities identified in the Arabian Gulf mangrove studies. The results show the necessity for developing region-specific mangrove typologies to better represent its unique mangrove ecosystems, as well as the expansion of ecological research, including climate change impacts and coastal connectivity.

Chapter Three established the groundwork for Chapter Four by highlighting the gaps in our knowledge regarding species-specific habitat utilization within southern Arabian mangrove ecosystems. The emphasis on coastal connectivity corresponded with research on fish habitat and its ecological importance in the Arabian region. Chapter Four provided a novel exploration of fish communities in southern Arabian Gulf mangroves. The findings affirm the ecological significance of mangroves discussed in Chapter Five, particularly in sustaining fisheries valued by local communities. Furthermore, Chapter Four underscores the necessity for conservation strategies that preserve habitat complexity and connectivity and address environmental shifts. Building on the ecological findings presented in the previous chapters, Chapter Five underscores the importance of translating scientific and traditional knowledge into effective conservation practices. This chapter highlights perceptions of mangrove ecosystems in Arabia by different groups, identifying gaps in awareness and a preference for tree planting as the primary conservation method. While participants recognize the benefits of mangroves, the findings reveal a limited understanding of alternative, science-based restoration approaches. Insights from Chapter Five emphasize the critical role of traditional knowledge in conservation plans. A summary of key findings of each chapter is presented in Table 6.1.

Chapter	Title	Key findings
2	The importance of mangrove habitat for supporting species: A synthesis of the current literature	• Research on coastal connectivity in mangrove ecosystems has steadily increased over the past four decades. • 65% of studies focused on fish populations with limited focus on other marine species and microhabitats. • Geographical bias exists, with most studies concentrated in the tropical Atlantic and Oceania, while regions such as Asia, Africa, and the Arabian Peninsula are underrepresented. • Greater integration of ecological process understanding and conservation measures is needed, especially in less-studied regions.
3	Mangrove research in the Arabian Gulf: Temporal trends, geographical coverage, and research gaps	• The review revealed a steady increase in mangrove research over two decades, focused on the northern subregion and led by regional researchers. • Research diversity is lacking, with underrepresentation in southern UAE despite significant mangrove presence. • Research focuses on two themes: mangrove ecology (e.g. coastal descriptions and phenology) and spatial mapping of habitats. • Insights suggest a need for local-scale mangrove typologies and an expanded focus on climate change impacts and coastal connectivity.
4	Evaluate the habitat use by fish in mangroves of the southern Arabian Gulf	• Fish abundance and diversity were higher in structural complexity habitats, e.g. mangroves and rocky shores, than in bare habitats, such as mudflats, with the majority of fish at juvenile stages. • Fish communities were strongly influenced by seasonal temperature changes, indicating sensitivity to environmental fluctuations. • This study provides the first detailed exploration of fish communities in southern Arabian Gulf mangroves but highlights the need for further research on mangrove-fishery relationships and local community benefits.

5	Regional perspectives on the conservation of mangroves in Arabia	• Five key themes emerged: ecosystem services, threats, conservation approaches, protection limitations, and future opportunities. • Participants valued mangroves, though awareness levels varied: local communities had traditional knowledge of mangrove products and fisheries, while non-environmental groups lacked basic understanding. • Participants perceived mangrove tree planting as the main restoration method and were unaware of alternative approaches. • Future research could focus on a specific group, such as local communities, to fully capture their traditional knowledge and involve them in conservation projects. Research and education can equip people with a deeper understanding of mangrove ecosystems and empower them to explore diverse, science-based approaches for restoring these environments beyond just planting targets.

Table 6. 1. The aim and key findings of each Chapter.

In the following section, I will discuss how my research can contribute to the conservation of Arabian mangroves. Due to the broad scope of mangrove research, my thesis revealed research gaps that could benefit from further investigation. Therefore, I will conclude by recommending key areas of future work and directions for mangrove research, offering hope for achieving conservation goals.

6.2 How my thesis contributes to the conservation of Arabian mangroves

The effects of human activities on our ecosystems have increased significantly in recent decades, and the need for conservation is more urgent than ever (e.g. IPBES, 2019). My research is timely because it focuses on a region understudied in mangrove science and situated in one of the world's harshest environments. Here, I have generated a new understanding and knowledge about the southern Arabian Gulf mangrove habitats. I have situated this within the mangrove literature presented in Chapter Two, and my synthesis of regional published literature and datasets in Chapter Three. By mapping the focus of research efforts and identifying gaps, in both Chapters Two and Three, I was able to design ecological and social surveys that examined the connections between Arabian mangroves, local fish populations (as seen in Chapter Four), and people from diverse backgrounds (as presented in Chapter Five). This thesis emphasizes the critical need for an integrated approach to mangrove conservation that combines ecological knowledge (Chapters Two to Four), stakeholder engagement (Chapter Five), and advocacy for evidence-based conservation strategies prioritizing research in this region.

6.2.1 Local knowledge in conservation planning

People and mangroves have long shared a deep connection, with this relationship varying across cultures and individual experiences (see e.g. Roces-Diaz *et al.*, 2014; Elwin *et al.*, 2024). Particularly important is how nature has benefited human livelihoods. In the 1960s, the UAE's population was estimated to be around 4,000 people (Nowell, 1998), and the region holds significant historical and cultural heritage (Heard, 2012). Few visitors, merchants, or mariners ventured into the shallow waters of the inhospitable Arabian coast due to the lack of fresh food supplies, and for centuries, the local population had relied on small boats to search for pearls and fish, utilized camels and date palms for trading, providing employment, wealth, and food (Sheppard *et al.*, 2010; Heard, 2012). The Arabian region's mangroves were among the first reported in the world literature, documented by Nearchus and Theophrastus over 2,000 years ago (Saenger, 2002), and, therefore, could hold incredible historical and ecological insights into past geological records of mangroves (Plaziat *et al.*, 2001). The establishment of the UAE in 1971 and the discovery of crude oil and natural gas brought prosperity to the Emirati people, fuelling the economy rapidly (Heard, 2012) and expanding the population, which has since grown to exceed nine million as of 2022 (UAE-MOFA, 2022). Therefore, the entire coastal environment has become a major contributor to the economy of the Gulf countries (see e.g. Sheppard *et al.*, 2010; Almahasheer *et al.*, 2015).

This research highlighted the cultural significance of mangroves from local people's perspectives, yet relatively few studies have involved local communities in mangrove management projects (but see Satterfield *et al.*, 2013; Reyes-Garcia *et al.*, 2019). We need to explore ways to address these issues to utilize available data better and gather more information if we want to reach national conservation targets. Traditional knowledge regarding the benefits of mangroves to fisheries and other services has been acquired through personal experiences or shared stories passed down through generations. This is particularly true for Arabian culture, where people have long migrated along the coast in search of food, shelter, and trade, forging a deep connection with mangroves (Nowell, 1998; Heard, 2012).

The involvement of local communities is an essential element of mangrove conservation efforts in the region, and an expansion of the approach I used in Chapter Five could be a useful way to gather such data, if it could be expanded in scope (a greater diversity of stakeholders) and depth (more people in each group). For coastal protection and restoration strategies to build resilience, it is imperative that future research not only acknowledges but also incorporates the local and traditional knowledge of residents and stakeholders throughout the project planning process (Martinez, 2021). The involvement of local communities in mangrove management is an essential element of mangrove conservation (Datta *et al.*, 2012; Cebrian-Piqueras *et al.*, 2020), but the evidence from the papers reviewed in Chapter Three is insufficient to prove that local communities have participated in mangrove research in Arabia to date, making it difficult to assess whether our understanding of the relationship between people and nature is too complex to ever be complete.

6.2.2 Implications for management

This research has immediate implications for management to preserve existing mangrove ecosystems and surrounding coastal habitats. It recognizes that mangroves do not function in isolation and require protection, as they are essential for supporting fisheries. With decades of coastal habitat loss driven by urbanization, the global community has now recognized the critical need to conserve these vital ecosystems (Mazor *et al.*, 2021). From a management perspective, the ecological connectivity among these habitats must be considered (Nagelkerken, 2009) to ensure the unrestricted flow of natural processes that sustain life on Earth (CMS, 2020). In the Arabian region, marine protected areas (MPAs) account for approximately 12%, and robust strategies will be needed to achieve the ambitious goal of expanding coverage to at least 30% (UAE-GOV, 2024). Yet, in a broad sense, marine research in the entire Arabian region remains in its early stages of development (but see e.g. Saenger *et al.*, 2004; Alsalam, 2007; Burt, 2013; Vaughan *et al.*, 2019), and while well-placed and well-managed protected areas can provide connectivity between habitats and species, the conservation of species and habitats can only be truly achieved if these protected areas are functionally connected (Trombulak and Baldwin, 2010; Resasco, 2019).

In the Arabian region, future investigations of seasonal and environmental influences on fish communities, as presented in Chapter Four, will support targeted management strategies that account for dynamic environmental conditions (e.g. temperature fluctuations and coastal modifications). Moreover, the global mangrove zonation story map by Twomey (2022), currently covers five main subregions of the Arabian province; mangroves of Kalmat Khor in Pakistan Balochistan (Rasool and Saifullah, 1996), mangroves of Oman (Saifullah and Rasool, 2000), mangroves of Miani Hor lagoon north Arabian Sea in Pakistan (Saifullah and Rasool, 2002), two mangroves sites of Bardestan in Iran (Abuzinada *et al.*, 2008; Safahieh *et al.*, 2012). Hence, the mangrove zonation of the southern Arabian Gulf subregion described in Chapter Three could be included in the global story map platform. This would place the region on a global platform accessible to international practitioners and support local management in restoration efforts for mangrove and coastal ecosystems.

6.3 Recommendations for future work

The findings present novel insights into the importance of mangroves in Arabia for supporting biodiversity and people, which can guide the identification of specific priority areas for future research for the southern Arabian Gulf subregion in the United Arab Emirates (UAE). The following priorities emerge from the findings presented in this thesis: (1) enhance scientific research of mangroves and adjacent coastal ecosystems, (2) seek to involve national perceptions and knowledge in conservation planning, and (3) improve regional and international collaboration (Table 6.2). These priorities are proposed for future work in line with the newly developed Environment Agency of Abu Dhabi's (EAD) strategic objectives for marine biodiversity from 2026 to 2030 (EAD, 2024). This should help drive growth in mangrove research in the region, which will gain international attention in the coming years.

6.3.1 A roadmap for practical action

As mangrove research continues to grow and the pressure of coastal expansion persists, there will be a simultaneous need for further investigation in a region that remains understudied in many ecological aspects of mangrove science. This region continues to face threats from urbanization and rapid economic growth, and studies to understand the impact of these threats on mangroves are urgently needed. In the face of future microclimatic changes, such as shifts in temperature and salinity (Osland *et al.*, 2016), detrimental effects may occur on mangrove habitats. As such, the extreme conditions in which mangroves thrive in Arabia suggest that even a small increase in aridity could lead to drastic changes to these systems, as Berdugo *et al.* (2020) have observed.

The natural spatial configuration of the southern Arabian coastline offers a unique setting for ecological studies such as primary productivity services and fisheries studies (Table 6.2; Target 1.1), in line with the EAD's objective to strengthen monitoring of biodiversity's state to support evidence-based conservation (4A.1). In the context of fisheries studies, many opportunities are presented to further understand species distribution, movement, and their response to minor habitat or climatic changes, e.g. temperature and salinity, which could help in the understanding of how fish respond to habitat fragmentation and whether their responses are similar across other habitats and taxa (e.g. Bostrom *et al.*, 2016). This research highlighted the cultural significance of mangroves from local people's perspectives, yet relatively few studies have concentrated on studying coastal community interactions with mangroves or have involved them in mangrove management projects (but see Satterfield *et al.*, 2013; Reyes-Garcia *et al.*, 2019). Local communities and government stakeholders must collaborate in managing and conserving mangroves, and previous research has suggested that recognizing the rights of local communities can enhance social acceptance and achieve conservation objectives (see e.g. Datta *et al.*, 2010; Majesty and Fadmastuti, 2018; Camacho *et al.*, 2020; Gayo, 2022). As such, engagement with local fishermen could be a useful way to study fisheries in the region, such as through traditional knowledge research (Table 6.2; Target 2.1).

As habitats change due to land use or natural causes, monitoring mangrove ecosystems and adjacent habitats, such as saltmarshes, will be important for future work (Table 6.2; Targets 1.2 and 1.3). Saltmarsh ecosystems are an important critical ecosystem that coexist with mangrove communities in the UAE, but has received little attention to date (EAD, 2024). To achieve this, future studies could examine how mangrove or saltmarsh habitat loss and fragmentation due to land reclamation impact ecosystem health by using field data and remote sensing or mapping techniques (Table 6.2; Targets 1.2). This could involve regular monitoring of salinity levels over long periods and correlating these data with measures of mangrove health, tree mortality rates, and biodiversity species composition. By using transdisciplinary approaches, such as input of different stakeholders (Newton and Elliott, 2016) to identify thresholds where interlinkages between habitats and species are weakened, can provide a useful tool for managers. This will allow for effectively managing the wider seascape and reduce habitat destruction effects, offering lessons for adaptive conservation as the climate changes.

We must explore ways and set solid roadmaps to gain scientific and traditional information and enhance coordination and cooperation among stakeholders at various levels to inform management and develop effective mangrove conservation strategies. The type of critical information required for conservation planning could include the current degradation of mangroves (e.g. Ferreira and Lacerda, 2016), mangrove rehabilitation methods and restoration policies (e.g. Lee *et al.*, 2019). While coastal and marine restoration is relatively new compared with terrestrial restoration (Saunders *et al.*, 2020), the restoration of mangroves has become a global priority and a key focus of initiatives such as the United Nations Framework Convention on Climate Change (UNFCCC), Ramsar Convention on Wetlands, Sustainable Development Goals (SDGs), United Nations Decade for Ecosystem Restoration (Waltham *et al.*, 2020), as well as large international conservation initiatives, such as the Global Mangrove Alliance (https://www.mangrovealliance.org/) and International Blue Carbon Initiative (https://www.thebluecarboninitiative.org/). According to the first-ever global assessment for the IUCN Red List of Ecosystems, more than half of the world's mangrove ecosystems are at risk of collapse by 2050 (IUCN, 2024), and the overall threat categorisation for Mangroves of the Arabian Gulf is Vulnerable (Almansoori *et al.*, 2024: see Appendix B.4).

The conservation and management status of UAE mangroves is primarily based on expert knowledge or baseline marine surveys contracted by developers (Sheppard *et al.*, 2010). Therefore, to meet national targets, e.g. UAE's Climate Change Plan 2017-2050 (MOCCAE, 2023) or National Committee on SDGs (UAE-SDG, 2023), the UAE must take a series of coordinated actions that align with international commitments more explicitly. A practical road map to reach these targets and to maximize the protection of existing mangrove habitats could start by establishing a regional task force dedicated to the research and conservation of mangroves in Arabia to link between regional and national and to deliver on key reports, such as the Climate Change Plan of the United Arab Emirates 2017-2050, and UAE-SDGs (Table 6.2; Target 3.1). The regional task force should also develop a regional conservation action plan incorporating new targets, such as mangrove conservation in land-use planning (Links to Kunming-Montreal Global Biodiversity Framework-KMGBF, Target 1) (Table 6.2; Target 3.2). Such a dedicated team in the region could assess the management status of marine protected areas using a limited set of indicators (e.g. Pomeroy *et al.*, 2005), as demonstrated in the work of Tupper *et al.* (2015). Also, establishing workshops and training programs could foster self-sufficiency in research and development (Van Lavieren *et al.*, 2011). Establishing a 'Majlis' (an Arabic term meaning a place where community members gather) where capacity-building and knowledge sharing events may enable a way to engage with local communities.

Environment Agency of Abu Dhabi's (EAD) strategic objectives for marine biodiversity from 2026 to 2030 (EAD, 2024) relevant to the recommended future work:

- 4A.1. Strengthen monitoring of biodiversity's state to support evidence-based conservation
- 4A.2. Strengthen institutional, regulatory, and policy frameworks for biodiversity and coordinate with stakeholders for effective implementation
- 4A.3. Deliver conservation and restoration programs and ensure sustainable environmental management
- 4A.4. Ensure biodiversity representation, and sustainability of resource values in the protected areas of network of Abu Dhabi
- 4B.2. Adopt innovative research and monitoring in support of habitats restoration and stock regeneration
- 4B.2.1. Conduct further monitoring and assessment programs to expand knowledge of the fisheries and aquaculture sector in Abu Dhabi
- 4.A.2.1 Further mainstream biodiversity conservation into policies, regulations, and national development plans, and advocate for implementation
- 4B.3. Promote fisheries and aquaculture's social, cultural, economic value, and expand engagement and awareness
- 4B.3.3. Seek further engagement of various stakeholders, particularly fisherman

Objective 1: Enhance scientific research of mangroves and adjacent coastal ecosystems			
	Details	**Priority level**[1]	**EAD Strategic Objective**
Target 1.1			
Ecological assessment of mangroves	• Evaluate the ecosystem services of mangroves • Develop a baseline survey of associated marine species in mangrove ecosystems, e.g. fish and crabs	1	4A.1.
Target 1.2			
Monitoring programme of mangrove ecosystems	• Extend the current monitoring sites to include new areas such as offshore islands and urbanized areas • Develop a scientifically-based guidance for restoration of mangroves that ensures post-restoration assessments • Assess direct and indirect impacts of natural and anthropogenetic activities on mangroves, e.g. coastal development • Utilize broad-scale remote sensing data, e.g. multispectral or LiDAR, to estimate tree-level attributes of mangroves	1	4A.1. 4A.3. 4B.2.
Target 1.3			
Distribution and ecology of coastal ecosystems adjacent to mangroves	• Utilize mapping techniques and field-based surveys to develop a detailed spatial distribution map of saltmarsh ecosystems • Conduct baseline ecological survey of saltmarsh ecosystems	2	4A.1. 4A.3.

Table 6. 2. Proposed future work for mangrove ecosystems in the United Arab Emirates, southern subregion of the Arabian Gulf.

[1] Priority level: 1: High (1 to 2 years), 2: Medium (3 to 4 years), 3: Low (5 to 6 years), 4: Very low (7 to 9 years)

Objective 2: Seek to involve national perceptions and knowledge in conservation planning			
	Details	**Priority level**	**EAD Strategic Objective**
Target 2.1			
Engagement with local communities	• Enhance the communication between local communities, especially those by the coastal areas, and decision-makers or government agencies by conducting interviews, workshops, and involvement in conservation planning of mangrove ecosystems • Establish a 'Majlis' (an Arabic term meaning a relaxed sitting place where community members gather) for networking, knowledge sharing, and capacity building	2	4A.1. 4B.2.1 4B.3. 4B.3.3. 4A.3.

Objective 3: Improving regional and international collaboration			
	Details	**Priority level**	**EAD Strategic Objective**
Target 3.1			
Regional task force	• Establish a regional task force dedicated to the research and conservation of mangroves in Arabia • Deliver reports on NBSAPs, Climate Change Plan of the United Arab Emirates 2017-2050, and UAE-SDGs • Submit peer-reviewed publications to help attract more global attention and build knowledge to reach international scientific groups	2	4A.2. 4.A.2.1 4A.3 4A.4.
Target 3.2			
Mangrove conservation action plan	• Develop a national mangrove action plan incorporating requirements for mangrove conservation in land-use planning (Links to KMGBF Target 1) • Develop new MPAs that include existing mangrove areas and identify priority areas most at risk (Links to KMGBF Target 3)	3	4A.2. 4.A.2.1 4A.3 4A.4.

6.4 Conclusion

In a rapidly changing marine environment, ecological connectivity and the ways in which mangroves shape the lives of people must be considered to ensure effective management and conservation of mangroves. However, while data on mangroves is increasingly available globally, information remains limited in the Arabian region. To address these knowledge gaps, my examination of regional publication trends will enable a better understanding of what has been studied and in which subregional areas; this information can guide future research. As habitat and land changes threaten coastal areas, investigations into fish assemblages in mangrove microhabitats and beyond will inform better management of coastal systems and strengthen linkages among habitats for species. As more people live in proximity to coastal areas, it will be imperative to explore the perspectives of these communities. Semi-structured interviews are one way to obtain valuable insights into the experiences of people and how best to involve them in conservation planning to achieve successful outcomes. While exploring the role of mangrove habitats in supporting marine species and shaping human lives can be approached in various ways, using these scientific methods can provide a rich regional synthesis that may not be evident in broader studies.

Based on this thesis, the future priorities for Arabian mangroves include: enhancing scientific research on mangroves and adjacent coastal ecosystems, seeking to incorporate local knowledge in conservation planning, and improving regional and international collaboration. We have many tools available to achieve these priorities, and by setting a practical roadmap supported by local and regional organizations, such as the Environment Agency of Abu Dhabi, a starting point can be established to achieve strategic objectives and prepare for 2030, thereby aiding in the conservation of mangrove ecosystems. Overall, adopting a balanced approach that bridges ecological and social considerations is crucial for strengthening mangrove protection and raising the international profile of Arabian mangroves.

References

Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J. and Sala, E. (2008) 'Mangroves in the Gulf of California increase fishery yields', *Proceedings of the National Academy of Sciences of the United States of America*, 105, pp. 10456-9.

Abuzinada, A.H., Barth, H.J., Krupp, F., Boer, B. and Al-Abdessalaam, T.Z. (2008) 'Protecting the Gulf's marine ecosystems from pollution', *Springer Science & Business Media. Birkhauser*, Basel.

Adame, F., Reef, R., Santini, N., Najera, E., Turschwell, M., Hayes, M., Masqué, P. and Lovelock, C. (2020) 'Mangroves in arid regions: Ecology, threats, and opportunities', *Estuarine, Coastal and Shelf Science*, p. 106796.

Adkins, M., Tobin, A. and Simpfendorfer, C. (2015) 'Large tropical fishes and their use of the nearshore littoral, intertidal and subtidal habitat mosaic', *Marine and Freshwater Research*. 67.

Adkins, M.E., Tobin, A.J. and Simpfendorfer, C.A. (2016) 'Large tropical fishes and their use of the nearshore littoral, intertidal and subtidal habitat mosaic', *Marine and Freshwater Research*, 67(10), pp. 1534-1545.

Adom, D. (2018) 'Traditional Biodiversity Conservation Strategy As A Complement to the Existing Scientific Biodiversity Conservation Models in Ghana', *In Environment and Natural Resources Research*, Canadian Centre of Science and Education, 8:3. p. 1.

Afefe, A. (2021) 'Linking Territorial and Coastal Planning: Conservation Status and Management of Mangrove Ecosystem at the Egyptian - African Red Sea Coast, Aswan University of Journal Environmental Studies, 7(2), pp. 91-114.

AGEDI. (2008) *'Marine and Coastal Environment of Abu Dhabi Emirate'*, UAE: Environment Agency of Abu Dhabi EAD.

Aguilar, C., Gonzalez-Sanson, G., Cabrera, Y., Ruiz, A. and Curry, R.A. (2014) 'Inter-habitat variation in density and size composition of reef fishes from the Cuban Northwestern shelf', *Revista De Biologia Tropical*, 62(2), pp. 589-602.

Alhabshi, A., Youssef, T., Aizpuru, M. and Blasco, F. (2007) 'New mangrove ecosystem data along the UAE coast using remote sensing', *Aquatic Ecosystem Health and Management*, 10(3), pp. 309-319.

Al-Jufaili, S.M., Jawad, L.A., Park, J.M., Al-Sariri, T.S. and Al-Balushi, B.Y. (2021) 'Fish diversity of mangrove ecosystems in Sultanate of Oman', *Cahiers de Biologie Marine*, 62(3), pp. 235-249.

Al-Khayat, J.A., Abdulla, M.A. and Alatalo, J.M. (2019) 'Diversity of benthic macrofauna and physical parameters of sediments in natural mangroves and in afforested mangroves three decades after compensatory planting', *Aquatic Sciences*, 81(1).

Almahasheer, H. (2017) 'Lack of knowledge in Arabian Gulf Mangroves'. [Dataset]. Available at: https://figshare.com/articles/dataset/Lack_of_knowledge_in_Arabian_Gulf_Mangroves/5386846/1 (Accessed: 10 October 2024).

Almahasheer, H. (2018) 'Spatial coverage of mangrove communities in the Arabian Gulf', *Environmental Monitoring and Assessment*, 190(2), p. 85.

Almansoori, A., Castellanos, M., Zager, I. and García, L. (2021) 'Red List of Ecosystems for Abu Dhabi Emirate – Mangrove forests Assessment' *IUCN*, Abu Dhabi, UAE: Environment Agency of Abu Dhabi.

Almansoori, A., Macintosh, D., Almahasheer, H., Suárez, E. and Valderrábano, M. (2024) 'IUCN Red List of Ecosystems: Mangroves of The Arabian Gulf (Preprint)', *EcoEvoRxiv*.

Almardeai, S., Bastidas-Oyanedel, J.R., Haris, S. and Schmidt, J.E. (2017) 'Avicennia marina biomass characterization towards bioproducts', *Emirates Journal of Food and Agriculture*, 29(9), pp. 710-715.

Almaslamani, I., Walton, M., Kennedy, H., Al-Mohannadi, M. and Le Vay, L. (2013) 'Are mangroves in arid environments isolated systems? Life-history and evidence of dietary contribution from inwelling in a mangrove-resident shrimp species', *Estuarine, Coastal and Shelf Science*, 124, pp. 56-63.

Al-mayah A. and Al-Asadi W. (2023). Germination Percentage of Emirati and Iranian Gray Mangrove *Avicennia marina* (Forssk.) Viern Seeds and their Growth Rates in Basrah, 7:130-142.

Alongi, D. (2002) *'Present State and Future of the World's Mangrove Forests'*, Environmental Conservation, 29, pp. 331-349.

Alongi, D. (2015) 'The Impact of Climate Change on Mangrove Forests', Current Climate Change Report, 1, 30-39.

Alsalam, T. (2007) *'Marine environment and resources of Abu Dhabi.'* United Arab Emirates, Abu Dhabi: Environment Agency of Abu Dhabi, pp. 255.

Amezcua, F., Ramirez, M. and Flores-Verdugo, F. (2019) 'Classification and comparison of five estuaries in the southeast Gulf of California based on environmental variables and fish assemblages', *Bulletin of Marine Science*, 95.

Amin, S., Fouad, M. and Zyadah, M. (2018) 'Human, Urban and Environmental-Induced Alterations in Mangroves Pattern along Arabian Gulf Coast, Eastern Province, KSA', *preprints*, 10.20944/preprints201801.0259.v1.

Arachchige, P., Rondon, M., Roy A., Watt, S. , Davies M., Ouerfelli, D., Ewane B., Abulibdeh, A., Abdullah, M., and Al-Awadhi, T. (2024) 'Current status of mangrove conservation efforts in Qatar: A review', *Regional Studies in Marine Science*, 79:103822.

Archibald, M., Ambagtsheer, C., Casey, G. and Lawless, M. (2019) 'Using Zoom Videoconferencing for Qualitative Data Collection: Perceptions and Experiences of Researchers and Participants.', *International Journal of Qualitative Methods*, 18.

Augusthy, S., Nizam, A., and Kumar, A. (2024) 'The diversity, drivers, consequences and management of plant invasions in the mangrove ecosystems', *Science of the Total Environment*, 173851.

Baboli, M.J. and Sahar, K. (2017) 'Grey mangrove *Avicennia marina* (FORSK.) vierh. as a bio-indicator to measure nickel, mercury and cadmium: A case study at Persian gulf port Shoreline, Khuzestan, Iran', *Environmental Engineering and Management Journal*, 16(9).

Badzmierowski M.J., Evanylo G. K., Daniels W. L. and Haering, K.C. (2021) 'What is the impact of human wastewater biosolids (sewage sludge) application on long-term soil carbon sequestration rates? A systematic review protocol', Environmental Evidence, 10 (6).

Barletta, M., Barletta-Bergan, A., Saint-Paul, U., and Hubold, G. (2005) 'The role of salinity in structuring the fish assemblages in a tropical estuary', *Journal of Fish Biology*, 66, pp. 45-72.

Bazen, A., Barg, F. and Takeshita, J. (2021) 'Research Techniques Made Simple: An Introduction to Qualitative Research', *Journal of Investigative Dermatology*, 141(2):241-247.e1.

Beeston, M., Cameron, C., Hagger, V., Howard, J., Lovelock, C., Sippo, J., Tonneijk, F., van MacNaeBijsterveldt, C. and van Eijk, P. (2023) '*Best practice guidelines for mangrove restoration'*.

Beitl, C.M. (2014) 'Navigating Over Space and Time: Fishing Effort Allocation and the Development of Customary Norms in an Open-Access Mangrove Estuary in Ecuador', *Human Ecology*, 42, pp. 395–411.

Bell, J., David; Burchmore, J., Pease, B. and Middleton, M. (1984) 'Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales', *Marine and Freshwater Research*, 35.

Benzeev, R., Hutchinson, N. and Friess, D. (2017) 'Quantifying fisheries ecosystem services of mangroves and tropical artificial urban shorelines', *Hydrobiologia*, 803(1), pp. 225-237.

Berdugo, M., Delgado-Baquerizo, M., Soliveres, S., Hernandez-Clemente, R., Zhao, Y., Gaitan, J.J., Gross, N., Saiz, H., Maire, V., Lehman, et al. (2020) ‘Global ecosystem thresholds driven by aridity’, *Science*, 367, 787–790.

Berkstrom, C., Gullstrom, M., Lindborg, R., Mwandya, A., Yahya, S., Kautsky, N. and Nystrom, M. (2012) 'Exploring ‘knowns’ and ‘unknowns’ in tropical seascape connectivity with insights from East African coral reefs', *Estuarine, Coastal and Shelf Science*, 107, pp. 1-21.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. and Silliman, B.R. (2011) ‘The value of estuarine and coastal ecosystem services, *Ecological Monographs*, 81 (2), 169–193.

Berkstrom, C., Eggertsen, L., Goodell, W., Cordeiro, C., Lucena, M., Gustafsson, R., Bandeira, S., Jiddawi, N. and Ferreira, C. (2020) ‘Thresholds in seascape connectivity: the spatial arrangement of nursery habitats structure fish communities on nearby reefs’. *Ecography*, 43, pp. 882-896.

Bimrah K, Dasgupta R, Hashimoto S, Saizen I. and Dhyani S. (2022) ‘Ecosystem Services of Mangroves: A Systematic Review and Synthesis of Contemporary Scientific Literature’, *Sustainability*, 14(19):12051.

Blaber, S., Brewer, D. and Salini, J. (1989) 'Species composition and biomasses of fishes in different habitats of a tropical Northern Australian estuary: Their occurrence in the adjoining sea and estuarine dependence', *Estuarine, Coastal and Shelf Science*, 29(6), pp. 509-531.

Blaber, S.J. (2009) 'Relationships Between Tropical Coastal Habitats and (offshore) Fisheries', in Nagelkerken, I. (ed.) *Ecological Connectivity among Tropical Coastal Ecosystems*. Springer, Dordrecht, pp. 533-564.

Blaber, S.J. (2000) ‘*Tropical Estuarine Fishes. Ecology, Exploitation and Conservation’*, Oxford: Blackwell Science, pp. 384.

Blum, J. and Herr, D. (2017) ‘*Can restoring mangroves help achieve the Sustainable Development Goals?’* IUCN. [Online]. Available at: https://www.iucn.org/news/forests/201703/can-restoring-mangroves-help-achieve-sustainable-development-goals (Accessed 10 October 2024).

Bostrom, C., Pittman, S J., Simenstad, C., and Kneib, R. (2011) ‘Seascape ecology of coastal biogenic habitats: advances, gaps, and challenges’, *Inter-Research*, 427, pp. 191-217.

Bohnsack, J.A. and Bannerot, S.P. (1986) ‘A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes’, *NOAA Technical Report*, 41, pp. 1-15.

Bradley, M., Nagelkerken, I., Baker, R. and Sheaves, M (2020) ‘Context dependence: A conceptual approach for understanding the habitat relationships of coastal marine Fauna’, *Bioscience*, 70(11), pp. 986–1004.

Bradley, M., Dubuc, A., Piggott, C. V. H., Sambrook, K., Hoey, A. S., Depczynski, M., Langlois, T. J., Gagliano, M., Wilson, S. K., Cure, K., Holmes, T. H., Moore, G. I., Travers, M., Baker, R., Nagelkerken, I. and Sheaves, M. (2024) ‘The fish–mangrove link is context dependent: Tidal regime and reef proximity determine the ecological role of tropical mangroves’, *Fish and Fisheries*, 1–19.

Brander, L., Wagtendonk, A. J., Hussain, S., McVittie, A., Verburg, P. H., de Groot, R. S. and van der Ploeg, S. (2012) ‘Ecosystem service values for mangroves in Southeast Asia: a meta-analysis and value transfer application,’ *Ecosystem Services*, 1(1), 62-69.

Brauman, K.A., Garibaldi, L.A., Polasky, S., Zayas, C., Aumeeruddy-Thomas, Y., Brancalion, P., DeClerck, F., Mastrangelo, M., Nkongolo, N. and Palang, H. (2019) ‘Status and Trends – Nature’s Contributions to People (NCP). In: *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, Ch 2, pp. 309-384. Brondízio, E. S., Settele, J., Díaz, S., Ngo, and H. T. (eds.), IPBES secretariat, Bonn, Germany.

Brenner, M. and Krumme, U. (2007) ‘Tidal migration and patterns in feeding of the four-eyed fish Anableps anableps L. in a north Brazilian mangrove’, *Journal of Fish Biology*, 70: 406-427.

Brown, G., Boer, B. and Sakkir, S. (2008) *'The coastal vegetation of the western and southern Gulf - characterisation and conservation aspects'*, in Abdulaziz H., Hans-Jorg, B., Krupp, F., Boer, B. and Abdessalaam, T. (eds.) Protecting the Gulf's Marine Ecosystems from Pollution. Basel: Birkhäuser.

Brown, C., Harbone, A.R., Paris, C.B. and Mumby, P.J. (2016) 'Uniting paradigms of connectivity in marine ecology', *Ecology*, 97(9), pp. 2447-2457.

Buelow, C. and Sheaves, M. (2015) 'A birds-eye view of biological connectivity in mangrove systems', *Estuarine Coastal and Shelf Science*, 152, pp. 33-43.

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R., Thomas, N., Tadono, T., Worthington, T., Spalding, M., Murray, N. and Rebelo, L. (2022) 'Global Mangrove Extent Change 1996-2020: Global Mangrove Watch Version 3.0', *Remote Sensing*, 14(15), DOI: 10.3390/rs14153657.

Burt, J.A. (2013) 'The growth of coral reef science in the Gulf: a historical perspective', Marine Pollution Bulletin, 72, 289–301.

Burt, J.A., Feary, D.A., Cavalcante, G., Bauman, A.G. and Usseglio, P. (2013) 'Urban breakwaters as reef fish habitat in the Persian Gulf,' *Marine Pollution Bulletin*, 72(2), pp.342-350.

Burt, J. A. (2024) *'A Natural History of the Emirates: An Introduction'*, Springer, Cham, pp. 748.

Camacho, L., Gevana, D., Sabino, L., Ruzol, C., Garcia, J., Camacho, A., Naing, O., Maung, A., Saxena, K., Yiu, E., Takeuchi, K. and Liang, L. (2020) 'Sustainable mangrove rehabilitation: Lessons and insights from community-based management in the Philippines and Myanmar', *In APN Science Bulletin*, 10(1), pp. 18-25.

Chamberland-Fontaine, S., Thomas Estrada, G., Heckadon-Moreno, S., and Hickey, G. M. (2022) 'Enhancing the sustainable management of mangrove forests: The case of Punta Galeta, Panama', *Trees, Forests and People*, 8, 100274.

Chan, K.M., Guerry, A.D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A., Chuenpagdee, R., Gould, R., Halpern, B.S., et al. (2012) 'Where are cultural and social in ecosystem services? A framework for constructive engagement', *Bioscience*, 62, 744–756.

Chan, K.M., Gould, R.K. and Pascual, U. (2018) 'Editorial overview: relational values: what are they, and what's the fuss about?' *Current Opinion in Environmental Sustainability*, 35, pp. A1–A7.

Caputo, A. and Kargina, M. (2022) 'A user-friendly method to merge Scopus and Web of Science data during bibliometric analysis', *Market Analysis*, 10, pp. 82–88.

Castellanos-Galindo, G., Kluger, L., Camargo, M., Cantera, J., Mancera, Blanco-Libreros, J. and Wolff, M. (2020) 'Mangrove research in Colombia: Temporal trends, geographical coverage and research gaps,' *Estuarine, Coastal and Shelf Science*. 248. 106799.

Castellanos-Galindo Saran, A. and White, H. (2018) 'Evidence and gap maps: a comparison of different approaches', *Campbell Systematic Reviews*, 14: 1-38.

Castellanos-Galindo, G., Kluger L., Camargo M., Cantera J., Pineda J., Blanco-Libreros J. and Wolff M. (2021) 'Mangrove research in Colombia: Temporal trends, geographical coverage and research gaps', *Estuarine, Coastal and Shelf Science*, 248, 106799.

Carrasquilla-Henao, M., Natalie, Rueda, M. and Juanes, F. (2019) 'The mangrove-fishery relationship: A local ecological knowledge perspective', *Marine Policy*, 108, p. 103656.

Carrasquilla-Henao, M. and Juanes, F. (2017) 'Mangroves enhance local fisheries catches: a global meta-analysis', *Fish and Fisheries*, 18(1), pp. 79-93.

Carrasquilla-Henao, M., Rueda, M. and Juanes, F. (2022) 'Fish habitat use in a Caribbean mangrove lagoon system', *Estuarine, Coastal and Shelf Science*, 278.

Cebrian-Piqueras, M. A., Filyushkina, A., Johnson, D. N., Lo, V. B., López-Rodríguez, M. D., March, H. E., Oteros-Rozas, Peppler-Lisbach, C., Quintas-Soriano, C., Raymond, C. M., et al. (2020) 'Scientific and local ecological knowledge, shaping perceptions towards protected areas and related ecosystem services', *Landscape Ecology*, 35, 2549–2567.

Chen, C., Peng, C., Yan, H., Wei, M. and Wang, T. (2023) 'Experimental study on the mitigation effect of mangroves during tsunami wave propagation', *Acta Oceanologica Sinica*, 42, pp. 124-137.

Chin, A., Simpfendorfer, C., Heupel, M. (2012) 'Reef sharks and inshore habitats: patterns of occurrence and implications for vulnerability', *Marine Ecology Progress Series*, 460, pp. 115-125.

Chin, A., Heupel, M., Simpfendorfer, C. and Tobin, A. (2013) 'Ontogenetic movements of juvenile blacktip reef sharks: evidence of dispersal and connectivity between coastal habitats and coral reefs', *Aquatic Conservation-Marine and Freshwater Ecosystems*, 23(3), pp. 468-474.

Chong, V., Sasekumar, A., Leh, M. and D'Cruz, R. (1990) 'The fish and prawn communities of a Malaysian coastal mangrove system, with comparisons to adjacent mud flats and inshore waters', *Estuarine, Coastal and Shelf Science*, 31(5), pp. 703-722.

Cipta, I.M., Sobarman, F.A., Sanjaya, H., and Darminto, M.R. (2021) 'Analysis of mangrove forest change from multi-temporal Landsat imagery using Google Earth Engine application: case study: Belitung Archipelago 1990-2020', IEEE Asia-Pacific Conference on Geoscience Electronics and Remote Sensing Technology, pp. 90-95.

CMS. (2020) 'Improving Ways of Addressing Connectivity in the Conservation of Migratory Species, Resolution 12.26 (REV.COP13), Gandhinagar, India', UNEP/CMS/COP13/CRP, 26.4.4.

Cocheret de la Moriniere, E., Nagelkerken, I., van der Meij, H. and van der Velde, G. (2004) 'What attracts juvenile coral reef fish to mangroves: habitat complexity or shade?', *Marine Biology*, 144, 139–145.

Creswell, J.W. and Poth, C.N. (2016) 'Qualitative inquiry and research design: Choosing among five approaches', 2nd ed, Sage publications, pp. 386.

Clarke, K.R. (1993) 'Nonparametric Multivariate Analyses of Changes in Community Structure', *Austral Ecology,* 18. 117-143.

Clarke, V. and Braun, V. (2013) '*Successful Qualitative Research: A Practical Guide for Beginners'*, 1st edition, Sage Publishing, pp. 400.

Clarke, K.R. and Warwick, R.M. (2001) 'Changes in Marine Communities: An Approach to Statistical Analysis and Interpretation', 2nd edn. Plymouth: PRIMER-E, pp. 176.

Coleman, T.L., Manu, A. and Twumasi, Y.A. (2008) 'Application of Landsat data to the study of mangrove ecologies along the coast of Ghana', *Journal of the ISPRS*, 49.

Comte, A. and Pendleton, L.H. (2018) 'Management strategies for coral reefs and people under global environmental change: 25 years of scientific research', *Environment Management*, 209, pp. 462–474.

Crona, B. and Bodin, O. (2006) 'What you know is who you know? Communication patterns among resource users as a prerequisite for co-management', *Ecology and Society*, 11(2).

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S., Kubiszewski, I., Farber, S. and Turner, R. (2014) 'Changes in the global value of ecosystem services', *Global Environmental Change*, 26, pp. 152-158.

Costanza, R., De Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M. (2017). Twenty years of ecosystem services: how far have we come and how far do we still need to go?, *Ecosystem Services*, 28, pp. 1–16.

Curnick, D., Pettorelli, N., Amir, A., Balke, T., Barbier, E., Crooks, S., Dahdouh-Guebas, F., Duncan, C., Endsor, C., Friess, D., Quarto, A., Zimmer, M. and Lee, S. (2019) 'The value of small mangrove patches', *Science*, 363, pp. 239-239.

Dabala, A., Dahdouh-Guebas, F., Dunn, D.C. Everett J.D. , Lovelock, C.E. , Hanson J.O. , Buenafe, K.C.V. , Neubert S., and Richardson, A. J. (2023) 'Priority areas to protect mangroves and maximise ecosystem services', *Nature Communications*, 14, 5863

Dahdouh-Guebas, F., Ajonina, G.N., Amir, A.A., Andradi-Brown, D.A., Aziz, I., Balke, T., Barbier, E.B., Cannicci, S., Cragg, S.M., Cunha-Lignon, M., Curnick, D.J., et al. (2020) 'Public perceptions of mangrove forests Matter for their conservation', *Frontiers in Marine Science*, 7, 603651.

Dasari, H. P., Viswanadhapalli, Y., Langodan, S., Abualnaja, Y., Desamsetti, S., Vankayalapati, K., Thang, L. and Hoteit, I. (2022) ‘High-resolution climate characteristics of the Arabian Gulf based on a validated regional reanalysis’, *Meteorological Applications,* 29. 5.

DasGupta, R. and Shaw, R. (2017) ‘Perceptive insight into incentive design and sustainability of participatory mangrove management: A case study from the Indian Sundarbans’, *Journal Forestry Research*, 28, 815–829.

Das, S. (2017) 'Ecological Restoration and Livelihood: Contribution of Planted Mangroves as Nursery and Habitat for Artisanal and Commercial Fishery', *World Development*, 94, pp. 492-502.

Dasari, H. P., Viswanadhapalli, Y., Langodan, S., Abualnaja, Y., Desamsetti, S., Vankayalapati, K., Thang, L. and Hoteit, I. (2022) ‘High-resolution climate characteristics of the Arabian Gulf based on a validated regional reanalysis’, *Meteorological Applications*, 29, 5, e2102.

Datta, D., Chattopadhyay, R. and Guha, P. (2012) ‘Community based mangrove management: A review on status and sustainability’, *Journal of Environmental Management*, 107 84-95.

Datta, D., Guha, P. and Chattopadhyay, R. (2010) ‘Application of criteria and indicators in community-based sustainable mangrove management in the Sunderbans, India’, *Elsevier* 53(8), pp. 468-477.

Davis, S.E., Lirman, D. and Wozniak, J.R. (2009) ‘Nitrogen and Phosphorus Exchange Among Tropical Coastal Ecosystems’, In: Nagelkerken, I. (eds.) *Ecological Connectivity among Tropical Coastal Ecosystems*. Springer, Dordrecht, pp. 9-43.

De-Abreu, D., Paula, J. and Macia, A. (2017) 'Tropical seascapes as feeding grounds for juvenile penaeid shrimps in southern Mozambique revealed using stable isotopes', *Estuarine Coastal and Shelf Science*, 198, pp. 21-28.

Dejonckheere, M. and Vaughn, L. (2019) 'Semi structured interviewing in primary care research: a balance of relationship and rigour', *Family Medicine and Community Health*, 7(2), p. e000057.

Delve. (2023) ‘*Delve Qualitative Analysis Software’*. Available at: https://delvetool.com/ (Accessed: 10 October 2024).

Devitt, K., Adams, V. and Kyne, P. (2015) 'Australia’s protected area network fails to adequately protect the world’s most threatened marine fishes', *Global Ecology and Conservation*, 3, pp. 401-411.

Donato, D., Kauffman, J., Murdiyarso, D., Kurnianto, S., Stidham, M. and Kanninen, M. (2011) 'Mangroves among the most carbon-rich forests in the tropics', *Nature Geoscience*, 4(5), pp. 293-297.

Diana, R., Kiswanto, K., Hardi, E., Palupi, N., Susmiyati, R., Jaslin, J., Matius, P., Syahrinudin, S. and Karyati, K. (2023) 'Soil carbon stock in different of mangrove ecosystem in Mahakam Delta, East Kalimantan, Indonesia', *E3S Web of Conferences*, 373.

Diaz, S., Pascual, U., Stenseke, M., Martín-L´opez, B., Watson, R. T., Moln´ar, Z., Hill, R., Chan, K. M., Baste, I. A., Brauman, K. A., et al. (2018) ‘Assessing nature’s contributions to people’, *Science*, 359, 270–272.

Dorenbosch, M., Monique, G., Christianen, M., Nagelkerken, I., and Van der Velde, G (2005) ‘Indo-Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs’, *Marine Ecology Progress Series*, 302, pp. 63-76.

Dorenbosch, M., Verberk, W., Nagelkerken, I. and Van der Velde, G. (2007) 'Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves and coral reefs', *Marine Ecology Progress Series*, 334, pp. 103-116.

Dunn, O.J. (1964) ‘Multiple Comparisons Using Rank Sums’, *Techno metrics*, 6(3), 241–252.

Dunne, A., Coker, D., Kattan, A., Tietbohl, M., Ellis, J., Jones, B. and Berumen, M. (2023) ‘Importance of coastal vegetated habitats for tropical marine fishes in the Red Sea’, *Marine Biology*. 170, 90.

Duke, N. (1992) 'Mangrove floristics and biogeography', in Robertson, A. and Alongi, D. (eds.), *Tropical Mangrove Ecosystems Coastal and Estuarine Studies Series*. Washington, D.C. pp 63-100.

Duke, N., Meynecke, J., Dittmann, S., Ellison, A., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K., Field, C., Koedam, N., Lee, S., Marchand, C., Nordhaus, I. and Dahdouh-Guebas, F. (2007) 'A World Without Mangroves?', *Science*, 317, pp. 41-2.

Ebrahimi-Sirizi, Z. and Riyahi-Bakhtiyari, A. (2013) 'Petroleum pollution in mangrove forests sediments from Qeshm Island and Khamir Port - Persian Gulf, Iran', *Environmental Monitoring and Assessment*, 185(5), pp. 4019-4032.

EAD. (2003) *'Long-Term Data for Salinity and Seawater Temperature'*, EAD Internal database. Abu Dhabi, UAE: Environment Agency of Abu Dhabi.

EAD. (2011) *'Environmental Atlas of Abu Dhabi Emirate'*. United Arab Emirates, Abu Dhabi: Environment Agency of Abu Dhabi. [Online]. Available at: https://www.environmentalatlas.ae/ (Accessed: 10 October 2024).

EAD. (2018) *'Mangrove Mapping & Health Assessment from Satellite Imagery for Abu Dhabi Emirate: Version 3'*. Abu Dhabi, UAE: Environment Agency of Abu Dhabi.

EAD. (2019) *'Mangroves of Abu Dhabi Emirate'* [Factsheet]. Abu Dhabi, UAE: Environment Agency of Abu Dhabi, p. 1. [Online]. Available at: https://www.ead.gov.ae/en (Accessed: 10 October 2024).

EAD. (2020) '*Terrestrial, Marine and Intertidal Habitat Classification Schema Document: V3.5*', In: S-Dite, H, (eds.), Environment Agency of Abu Dhabi: Abu Dhabi, UAE, pp. 170.

EAD. (2021) '*Environmental Agency Coastal and Marine Portal Viewer Map'*. [Online]. Available at: https://enviroportal.ead.ae/map/ (Accessed 10 October 2024).

EAD. (2024) '*Development of EAD's Strategic Plan 2026-2030: Marine Biodiversity Compiled Deliverable'*. [Report]. Environment Agency of Abu Dhabi: Abu Dhabi, UAE.

Ellison, A., Farnsworth, E. and Merkt, R. (1999) 'Origins of Mangrove Ecosystems and the Mangrove Biodiversity Anomaly', *Global Ecology and Biogeography*, 8(2), pp. 95-115.

Ellison A. M., Felson A. J. and Friess D. A. (2020) 'Mangrove Rehabilitation and Restoration as Experimental Adaptive Management', *Frontiers in Marine Science*. 7.

El-regal, M. A. and Ibrahim N. (2014) 'Role of mangroves as a nursery ground for juvenile reef fishes in the southern Egyptian Red Sea', *Egypt Journal of Aquatic Research*. 40(1):71–78.

Elwin, A. (2019) '*Social-ecological Resilience of Mangrove-Shrimp Farming Communities in Thailand*', PhD Thesis, University of Reading. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://centaur.reading.ac.uk/85482/1/23863919_Elwin_thesis.pdf. (Accessed 10 October 2024).

Elwin, A., Robinson, E. J., Feola, G., Jintana, V. and Clark, J. (2024) 'How is mangrove ecosystem health defined? A local community perspective from coastal Thailand', *Ocean & Coastal Management*. 251: 107037.

Embabi, N.S. (1993) 'Environmental aspects of geographical distribution of mangrove in the United Arab Emirates', in Lieth, H.A.M., Ahmed A. (eds.) '*Towards the rational use of high salinity tolerant plants: Deliberations about High Salinity Tolerant Plants and Ecosystems'*, Springer Netherlands, pp. 45-58.

Emmanuel, H., Aboobacker, V., Veerasingam, S., Dobbelaere, T., Vallaeys, V. and Vethamony, P. (2023) 'A multiscale ocean modelling system for the central Arabian/Persian Gulf: From regional to structure scale circulation patterns,' *Estuarine, Coastal and Shelf Science*, 282:108230.

EndNote. (2019) EndNote. [Online] Available at: https://endnote.com/ (Accessed: 10 October 2024).

English, S., Wilkinson, C., and Baker, V. (1997) '*Survey manual for tropical marine resources'*, 2 edn. Townsville, Qld, Australian Institute of Marine Science.

Erdelen, W.R. (2007) ‘Foreword’, *Aquatic Ecosystem Health and Management*, 10(3), pp. 255.

Erftemeijer, P., Agastian, T., Yamamoto, H., Cambridge, M., Hoekstra, R., Toms, G. and Ito, S. (2020) 'Mangrove planting on dredged material: three decades of nature-based coastal defense along a causeway in the Arabian Gulf', *Marine and Freshwater Research*, 71(9), pp. 1062-1072.

Etemadi, H., Smoak, J. and Abbasi, E. (2020) ‘Spatiotemporal pattern of degradation in arid mangrove forests of the Northern Persian Gulf’, *Oceanologia*. 63.

Ewel, K., Twilley, R. and Ong, J. (1998) 'Different Kinds of Mangrove Forests Provide Different Goods and Services', *Global Ecology and Biogeography Letters*, 7(1), pp. 83-94.

Faunce, C. S. and Serafy, J. (2006) ‘Mangroves as fish habitat: 50 Years of field studies’, *Marine Ecology Progress Series*, 318, pp. 1-18.

Faunce, C. and Layman, C. (2009) 'Sources of Variation that Affect Perceived Nursery Function of Mangroves', in Nagelkerken, I. (ed.) *Ecological Connectivity among Tropical Coastal Ecosystems*. Springer, pp. 401-425.

FAO. (1994) ‘*Mangrove forest management guidelines’*. Rome: Food and Agriculture Organization of the United Nations. Nairobi.

FAO. (2005) *‘Thematic study ofmangroves of United Arab Emirates Country Profile’*. Rome, Italy: Food and Agriculture Organization of the United Nations Nations, [Online]. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.fao.org/forestry/9377-03b475439571a3115226f1d00ae23b52a.pdf. (Accessed: 10 October 2024).

Feary, D.A., Burt, J.A. and Bartholomew, A. (2011) ‘Artificial marine habitats in the Arabian Gulf: review of current use, benefits and management implications’, *Ocean & Coastal Management*, 54(10, 742-749.

Jape, K.K. and Najar, M.A. (2024) ‘Empowering Local Stewardship of Coastal Ecosystems in Zanzibar: Participatory Models for Habitat Rehabilitation and Resilience. International’, *Journal of advanced multidisciplinary research and studies*, 4(2).

Jelbart, J., Ross, P. and Connolly, R. (2007) 'Fish assemblages in seagrass beds are influenced by the proximity of mangrove forests', *Marine Biology*, 150, pp. 993-1002.

Johnson-Bailey, J. and Cervero, R.M. (1997) ‘Negotiating power dynamics in workshops’, *New Directions for Adult and Continuing Education*, pp. 41–50.

Ferreira, A.C. and Lacerda, L.D. (2016) ‘Degradation and conservation of Brazilian mangroves, status and perspectives’, *Ocean Coastal Management*, 125, pp. 38-46.

Francis, F., Al-Shamsi, A. and Hartmann, S. (2016) ‘Reproductive biology and spawning season of ‘badah’ (*Gerres longirostris*) in Abu Dhabi waters ‘, *Fisheries investigation and monitoring unit*. Abu Dhabi: Environment Agency Abu Dhabi, UAE, pp. 16.

Francis, F., Al-Shamsi, A., Al-Hameli, S. and Hartmann, S. (2019) ‘Reproductive biology and stock assessment of Naiser in Abu Dhabi waters’, *Fisheries investigation and monitoring unit*. Abu Dhabi: Environment Agency Abu Dhabi, UAE, pp. 19.

Francis, F., Al-Shamsi, A. and Pinello, D. (2022) ‘An Assessment of the Stock Status of Seven Commercially Exploited Fish Species in Abu Dhabi’, *Fisheries investigation and monitoring*. Abu Dhabi: Environment Agency Abu Dhabi, pp. 8.

Freedman, D.R., Pisani, R. and Purves, R. (2007) ‘Statistics’, 4 edition. New York: W. Norton & Company, pp. 415-424, 488-495, 523-540.

Friess, D., Rogers, K., Lovelock, C., Krauss, K., Hamilton, S., Lee, S., Lucas, R., Primavera, J., Rajkaran, A. and Shi, S. (2019) 'The State of the World’s Mangrove Forests: Past, Present, and Future', *Annual Review of Environment and Resources*, pp. 89-115.

Friess, D., A., Yando, E., S., Abuchahla, G., M., Adams, J., B., Cannicci, S., Canty, S., W., Cavanaugh, K., C., Connolly, R., M., Cormier, N., Dahdouh-Guebas, F. and Diele, K. (2020) ‘Mangroves give cause for conservation optimism, for now’, *Current Biology*, 30(4).

Friess, D., Gatt, Y., Ahmad, R., Brown, B., Sidik, F. and Wodehouse, D. (2022) ‘Achieving ambitious mangrove restoration targets will need a transdisciplinary and evidence-informed approach’, *One Earth*. 5.

Friis, G. and Burt, J. (2020) 'Evolution of mangrove research in an extreme environment: Historical trends and future opportunities in Arabia', *Ocean & Coastal Management*, 195, p. 105288.

Froese, R. and Pauly, D. (2023) ‘FishBase’. [Online]. Available at: https://www.fishbase.se/search.php. (Accessed 10 October 2024).

Gayo, L. (2022) 'Local community perception on the State Governance of mangroves in Western Indian coast of Kinondoni and Bagamoyo, Tanzania', *Global Ecology and Conservation*, 39, p. e02287.

Gerona-Daga, M.E. and Salmo, S.G. (2022) ‘A systematic review of mangrove restoration studies in Southeast Asia: Challenges and opportunities for the United Nation’s Decade on Ecosystem Restoration’, *Frontiers in Marine Science*, 9.

Ghasemi S., Zakaria M., Abdul-Hamid, H., Yusof, E., Danehkar, A. and Rajpar, M N. (2010) ‘A review of mangrove value and conservation strategy by local communities in Hormozgan province, Iran’, *Journal of American Science*, 6, 329-338.

Ghayoumi, R. Ebrahimi, E., and Mousavi, S.M. (2022) 'Dynamics of mangrove forest distribution changes in Iran', *Journal of Water and Climate Change*, 13 (6): 2479–2489.

Gholami, D.M. and Baharlouii, M. (2019) 'Monitoring long-term mangrove shoreline changes along the northern coasts of the Persian Gulf and the Oman Sea', *Emerging Science Journal*, 3(2):88.

Giarrizzo, T., Krumme, U. and Wosniok, W. (2010) ‘Size-structured migration and feeding patterns in the banded puffer fish *Colomesus psittacus* (Tetraodontidae) from north Brazilian mangrove creeks’, *Mar Ecol Prog Ser*, 419:157-170.

Gillanders, B., Brown, J., Eggleston, D. and Sheridan, P. (2003) 'Evidence of Connectivity between Juvenile and Adult Habitats for Mobile Marine Fauna: An Important Component of Nurseries', *Marine Ecology-progress Series*, 247, pp. 281-295.

Giri, C., Ochieng, E., Tieszen, L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N. (2011) 'Status and distribution of mangrove forests of the world using earth observation satellite data', *Global Ecology and Biogeography*, 20(1), pp. 154-159.

Goldberg, L., Lagomasino, D., Thomas, N, and Fatoyinbo, T. (2020) 'Global declines in human-driven mangrove loss', *Global Change Biology*, 26(10), pp. 5844-5855.

Grandcourt, E., Alabdessalaam, T., Francis, F., Alshamsi, A., Hartmann, S., Alali, S. and Alali, K. (2008) ‘Reproductive biology and implications for the management of Hamoor (*Epinephelus coioides*) in Abu Dhabi waters’, *Fisheries investigation and monitoring unit*. Abu Dhabi: Environment Agency Abu Dhabi, UAE, pp. 46.

Grandcourt, E. (2008) ‘Fish and Fisheries’, in: Al-Abdessalaam, T.Z., (eds.) *Marine Environment and Resources of Abu Dhabi*. Dubai, UAE, Motivate Publishing, pp. 200-255.

Grandcourt, E., Alabdessalaam, T., Francis , F. and Alshamsi, A. (2010) ‘Reproductive biology and implications for management of the spangled emperor, *Lethrinus nebulosus* (Shaari), in Abu Dhabi’, *Fisheries investigation and monitoring unit*. Abu Dhabi: Environment Agency Abu Dhabi, UAE, pp. 31.

Green, B.C, Smith, D.J and Underwood G. (2012) ‘Habitat connectivity and spatial complexity differentially affect mangrove and salt marsh fish assemblages’, *Mar Ecol Prog Ser*, 466:177-192.

Guan S, Qu F. and Qiao F. (2023) ‘United Nations Decade of Ocean Science for Sustainable Development (2021-2030): From innovation of ocean science to science-based ocean governance’, *Frontiers in Marine Science*, 9:1091598.

Gurevitch, J., Koricheva, J., Nakagawa, S. and Stewart, G. (2018) ‘Meta-analysis and the science of research synthesis’, *Nature*, 555, 175–182.

Hai N. T., Dell B., Phuong V. T. and Harper R. J. (2020) ‘Towards a more robust approach for the restoration of mangroves in Vietnam’, *Annals of Forest Science*, 77, 1–18.

Hagger, V., Worthington, T., Lovelock, C., Adame, M., Amano, T., Brown, B., Friess, D., Landis, E., Mumby, P., Morrison, T., O’Brien, K., Wilson, K., Zganjar, C. and Saunders, M. (2022) 'Drivers of global mangrove loss and gain in social-ecological systems', *Nature Communications*, 13(1), p. 6373.

Haig, J., Gwladys I., Sumpton, W., Mayer, D. and Werry, J. (2018) 'Habitat features influence catch rates of near-shore bull shark (Carcharhinus leucas) in the Queensland Shark Control Program, Australia 1996–2012', *Estuarine, Coastal and Shelf Science*, 200, pp. 289-300.

Hajisamae, S. and Chou, L. (2003). Do shallow water habitats of an impacted coastal strait serve as nursery grounds for fish?’, *Estuarine, Coastal and Shelf Science*, 56, 281-290.

Halpern, B.S. (2020) ‘Building on a decade of the Ocean Health index’, *One Earth*, 2, 30–33.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., d'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E. and Fujita, R. (2008) ‘A global map of human impact on marine ecosystems’, *Science*, 319, 5865.

Hampel H., Cattrijsse A. and Vincx M. (2003) ‘Tidal, diel and semi-lunar changes in the faunal assemblage of an intertidal salt marsh creek’, *Estuarine Coastal and Shelf Science* 56(3-4):795-805.

Hamilton, S.E. and Casey, D. (2016) ‘Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century’, *Global Ecology and Biogeography*, 25, 729–738.

Harborne, A., Nagelkerken, I., Wolff, N. H., Bozec, Y., Dorenbosch, M., Grol, M.G. and Mumby, P.J. (2016) 'Direct and indirect effects of nursery habitats on coral-reef fish assemblages, grazing pressure and benthic dynamics', *Oikos*, 125(7), pp. 957-967.

Harzing, A.W. (2007). Publish or Perish. [Online]. Available from: https://harzing.com/resources/publish-or-perish. (Accessed on 10 October 2024).

NBSAPs. (2022) ‘National Reports and NBSAPs’, [Online]. Available at: https://www.cbd.int/reports/search/?country=ae. (Accessed 10 October 2024).

Heard, D. (2012) ‘From Pearls to Oil: How the Oil Industry Came to the United Arab Emirates’, *Abu Dhabi Company for Onshore Oil Operations*, pp. 622.

Hellyer, P. and Aspinall, S. (2005) *‘The Emirates: A natural history’*. United Arab Emirates: Trident Press, pp. 428.

Hemmati, M.R., Shojaei, M.G., Mirghaed, A.T., Farahni, M.M. and Weight, M. (2021) 'Food sources for camptandriid crabs in an arid mangrove ecosystem of the Persian Gulf: a stable isotope approach', *Isotopes in Environmental and Health Studies*, (5):457-469.

Hemingson, C. and Bellwood, D. (2020) 'Greater multihabitat use in Caribbean fishes when compared to their Great Barrier Reef counterparts', *Estuarine, Coastal and Shelf Science*, 239.

Himes-Cornell, A., Pendleton L. and Atiyah P. (2018) ‘Valuing ecosystem services from blue forests: a systematic review of the valuation of salt marshes, sea grass beds and mangrove forests’, *Ecosystem Services*. 30, 36–48.

Hogarth, P. (2015) *‘The Biology of Mangroves and Seagrasses’*, 3 edn, Oxford University Press, pp. 304.

Honda, K., Nakaoka, M., Uy, W. and Fortes, M. (2013) 'Habitat Use by Fishes in Coral Reefs, Seagrass Beds and Mangrove Habitats in the Philippines', *PLoS ONE*, 8(8).

Ho, N., Ooi, J., Amri, A.Y. and Chong, V.C. (2018) 'Influence of habitat complexity on fish density and species richness in structurally simple forereef seagrass meadows', *Botanica Marina*, 61(6), pp. 547-557.

Ho, Y. and Mukul S.A. (2021) ‘Publication Performance and Trends in Mangrove Forests: A Bibliometric Analysis’, *Sustainability*, 13(22):12532.

Howari, F.M., Jordan, B.R. and Bouhouche, N. (2009) 'Field and remote-sensing assessment of mangrove forests and seagrass beds in the northwestern part of the United Arab Emirates', *Journal of Coastal Research*, 25(1).

Hughes, A. and Grumbine R. (2023) ‘The Kunming-Montreal Global Biodiversity Framework: what it does and does not do, and how to improve it’, *Frontiers in Environmental Science*, 11:1281536.

Huijbers, C., Grol, M. and Nagelkerken, I. (2008) 'Shallow patch reefs as alternative habitats for early juveniles of some mangrove/seagrass-associated fish species in Bermuda', *Revista de Biologia Tropical*, 56, pp. 161-169.

Hutchings, P. and Saenger, P. (1987) *‘The Ecology of Mangroves’*. Queensland: University of Queensland Press, pp. 388.

Hutchison, J., Spalding, M. and Zu Ermgassen P. (2014) ‘The Role of Mangroves in Fisheries Enhancement’, *The Nature Conservancy, Wetlands International, University of Cambridge*, pp. 54.

Huxham, M., Dencer-Brown, A., Diele, K., Kathiresan, K., Nagelkerken, I. and Wanjiru, C. (2017) ‘Mangroves and People: Local Ecosystem Services in a Changing Climate. In: Rivera-Monroy, V., Lee, S., Kristensen, E., Twilley, R. (eds.) *Mangrove Ecosystems: A Global Biogeographic Perspective*. Springer, Cham, pp. 245–274.

Hylkema, A., Vogelaar, W., Meesters, E., Nagelkerken, I. and Debrot, A. (2015) 'Fish Species Utilization of Contrasting sub-Habitats Distributed Along an Ocean-to-Land Environmental Gradient in a Tropical Mangrove and Seagrass Lagoon', *Estuaries and Coasts*, 38(5), pp. 1448-1465.

Igulu, M., Nagelkerken, I., Dorenbosch, M., Grol, M., Harborne, A., Kimirei, I., Mumby, P., Olds, A. and Mgaya, Y. (2014) 'Mangrove Habitat Use by Juvenile Reef Fish: Meta-Analysis Reveals that Tidal Regime Matters More than Biogeographic Region', *PLoS ONE*, 9, p. e114715.

IPBES. (2019) ‘Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services’, Diaz, J., Settele, E.S., Brondízio, H.T., Ngo, M. Gueze, J., Agard, A.A., Balvanera, K., Brauman, S., Butchart, K., Chan, L.A., et al. (eds.), *IPBES secretariat*, Bonn, Germany, pp. 56.

IPBES. (2022) ‘Methodological Assessment Report on the Diverse Values and Valuation of Nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services’, Balvanera, P., Pascual, U., Christie, M., Baptiste, B., and González-Jiménez, D. (eds.), *IPBES secretariat*, Bonn, Germany.

Irlandi, E.A. and Crawford, M.K. (1997) ‘Habitat linkages: the effect of intertidal saltmarshes and adjacent subtidal habitats on abundance, movement, and growth of an estuarine fish’, *Oecologia*, 110, 222–230.

IUCN-SSC. (2008) 'Strategic Planning for Species Conservation: A Handbook', *IUCN*, 1.0, p 104.

IUCN. (2024) ‘Red List of Mangrove Ecosystems, IUCN’. [Online]. Available at: https://iucn.org/resources/conservation-tool/iucn-red-list-ecosystems/red-list-mangrove-ecosystems. (Accessed 10 October 2024).

Jamaluddin, I., Chen, Y.N., Ridha, S.M., Mahyatar, P., and Ayudyanti, A.G. (2022) ‘Two Decades Mangroves Loss Monitoring Using Random Forest and Landsat Data in East Luwu, Indonesia (2000–2020)’, *Geomatics*, 2(3), 282-296.

Jawad, L. (2021) ‘*The Arabian Seas: Biodiversity, Environmental Challenges and Conservation Measures’*. 1 edn. Springer International Publishing.

Joly, C.A. (2022) ‘The Kunming-Montréal global biodiversity framework’, *Biota Neotropica*, *22*(04), p.e2022e001.

Kathiresan, K., and Bingham, B. (2001) 'Biology of Mangroves and Mangrove Ecosystems', *Advances in Marine Biology*, 40, pp. 81-251.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E. and Kingsford, R. T. (2020) ‘IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups,’ *International Union for Conservation of Nature*, IUCN.

Khan, M.R. (1982) 'Status of mangrove forests of the United Arab Emirates', *Bulletin of the Emirates Natural History Group*, 17(15), p. 1.

Klain, S. C. and Chan, K. M. (2012) ‘Navigating coastal values: participatory mapping of ecosystem services for spatial planning’, *Ecological Economics*, 82, 104–113.

Koch, M. and Snedaker, S. (1997) 'Factors influencing Rhizophora mangle L. seedling development in Everglades carbonate soils', *Aquatic Botany*, 59(1), pp. 87-98.

Kimirei, I., Nagelkerken, I., Griffioen, B., Wagner, C. and Mgaya, Y. (2011) 'Ontogenetic habitat use by mangrove/seagrass-associated coral reef fishes shows flexibility in time and space', *Estuarine Coastal and Shelf Science*, 92(1), pp. 47-58.

Kimirei, I., Nagelkerken, I., Mgaya, Y. and Huijbers, C. (2013) 'The Mangrove Nursery Paradigm Revisited: Otolith Stable Isotopes Support Nursery-to-Reef Movements by Indo-Pacific Fishes', *Plos One*, 8(6), p. 8.

Kimirei, I., Nagelkerken, I., Slooter, N., Gonzalez, E., Huijbers, C., Mgaya, Y. and Rypel, A. (2015) 'Demography of fish populations reveals new challenges in appraising juvenile habitat values', *Marine Ecology Progress Series*, 518, pp. 225-237.

Kruitwagen, G., Nagelkerken, I., Lugendo, B., Mgaya, Y. and Bonga, S. (2010) 'Importance of different carbon sources for macroinvertebrates and fishes of an interlinked mangrove–mudflat ecosystem (Tanzania)', *Estuarine, Coastal and Shelf Science*, 88(4), pp. 464-472.

Krumme U., Audfroid-Calderon, M. and Echterhoff, A. (2014) ‘Intertidal migration of the four-eyed fish Anableps anableps in North Brazilian mangrove creeks’, *Mar Ecol Prog Ser*, 509:271-287

Kruskal, W.H. and Wallis, W.A. (1952) ‘Use of Ranks in One-Criterion Variance Analysis’, *Journal of the American Statistical Association*, 47, 583-621.

Kusmana, C., Sabiham, S., Abe, O. and Watanabe, H. (1992) 'An Estimation of Above Ground Tree Biomass of a Mangrove Forest in East Sumatra, Indonesia', *Tropics*, 1, pp. 243-257.

Larentis, C., Kotz Kliemann, B. C., Neves, M. P. and Delariva, R. L. (2022) ‘Effects of human disturbance on habitat and fish diversity in Neotropical streams’, *PloS one*, 17(9), e0274191.

Leal, M. and Spalding, M. (2022) *‘The State of the World’s Mangroves 2022’*, Global Mangrove Alliance. [Online]. Available at: www.mangrovealliance.org (Accessed: 10 October 2024).

Le, D., Tanaka, K., Hii, Y., Sano, Y., Nanjo, K. and Shirai, K. (2018) 'Importance of seagrass-mangrove continuum as feeding grounds for juvenile pink ear emperor Lethrinus lentjan in Setiu Lagoon, Malaysia: Stable isotope approach', *Journal of Sea Research*, 135, pp. 1-10.

Lee, Y.L., Rivera-Monroy, V.H., Kristensen, E. and Twilley, R.R. (2017) ‘Mangrove Ecosystems: a Global Biogeographic perspective: Structure, Function, and Services’, In: Rivera-Monroy, V.H., Lee, S.Y., Kristensen, E., Twilley, R.R. (eds.) Springer, Cham, pp. 383–386.

Lee, S.Y., Hamilton, S., Barbier, E. B., Primavera, J. and Lewis III, R. (2019) ‘Better restoration policies are needed to conserve mangrove ecosystems’, *Nature ecology & evolution*, 3(6), 870-872.

Loch, T.K. and Riechers, M. (2021) ‘Integrating indigenous and local knowledge in management and research on coastal ecosystems in the Global South: a literature review’, *Ocean Coast Management*, 212, 105821.

Lopez-Angarita, J., Roberts, C.M., Tilley, A., Hawkins, J.P. and Cooke, R.G. (2016) ‘Mangroves and people: Lessons from a history of use and abuse in four Latin American countries’, *Forest Ecology and Management*, (368)151-162.

Loughland, R., Al Muhairi, F., Fadel, S., Al Mehdi, A. and Hellyer, P. (2004) *‘Marine Atlas of Abu Dhabi’*. Abu Dhabi: Emirates Heritage Club, pp. 277.

Lovelock, C., Feller, I., McKee, K., Engelbrecht, B. and Ball, M. (2004) 'The effect of nutrient enrichment on growth, photosynthesis and hydraulic conductance of dwarf mangroves in Panama', *Functional Ecology*, 18.

Lovelock, C., Cahoon, D., Friess, D., Guntenspergen, G., Krauss, K., Reef, R., Rogers, K., Saunders, M., Sidik, F., Swales, A., Saintilan, N., Thuyen, L. and Triet, T. (2015) 'The vulnerability of Indo-Pacific mangrove forests to sea-level rise', *Nature*, 526(7574), pp. 559-563.

Lugo, A. and Snedaker, S. (1974) 'The Ecology of Mangroves'. *Annual Review of Ecology and Systematics*, Vol. 5, pp. 39-64

Luther, D. and Greenberg, R. (2009) 'Mangroves: A Global Perspective on the Evolution and Conservation of their Terrestrial Vertebrates', *BioScience*, 59(7).

MacNae, W. (1969) 'A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region', Academic Press, *Advances in marine biology*, Vol. 6, pp. 73-270.

Malik, A., Rahim, A., Sideng, U., Rasyid, A., and Jumaddin, J. (2019) 'Biodiversity assessment of mangrove vegetation for the sustainability of ecotourism in West Sulawesi Indonesia', *Journal Aquaculture, Aquarium, Conservation & Legislation*, 12(4).

Manson, F. J., Loneragan, N. R., Skilleter G. A. and Phinn S. R. (2005) 'An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions', *Oceanography and Marine Biology*, 43: 483–513.

Mafi-Gholami, D., Mahmoudi, B. and Zenner, E.K. (2017) 'An analysis of the relationship between drought events and mangrove changes along the northern coasts of the Persian Gulf and Oman Sea', *Estuarine, Coastal and Shelf Science*, 199, pp. 141-151.

Majesty, K I. and Fadmastuti, M. (2018) 'Degree of community participation in mangrove resources management as livelihood support in West Java, Indonesia', *EDP Sciences*, 74, 10005-10005.

Marley, G., Deacon, A., Phillip, D. and Lawrence, A. (2020) 'Mangrove or mudflat: Prioritising fish habitat for conservation in a turbid tropical estuary', *Estuarine, Coastal and Shelf Science*, 240, p. 106788.

Martinez, G. (2021) 'Coastal risk cultures: Local and regional formation of knowledge and action', *Frontiers in Environmental Science*, 9, 578238.

McCain, J.C., Tarr, A.B., Carpenter, K.E. and Coles, S.L. (1984) 'Marine Ecology of Saudi Arabia-A Survey of Coral Reefs and Reef Fishes in the Northern Area, Arabian Gulf, Saudi Arabia,' in: Bittiker, W. and Krupp, F. (eds.), Fauna of Saudi Arabia, Vol. 6, National Commission for Wildlife Conservation and Development, Riyadh, 102-126.

Mcafee, D., Reis-Santos, P., Jones, A., Gillanders, B., Mellin, C., Nagelkerken, I., Nursey-Bray, M., Baring, R., Miot, G., Tanner, J., Connell, S. (2022) 'Multi-habitat seascape restoration: optimising marine restoration for coastal repair and social benefit', *Frontiers in Marine Science*, 9.

Mellado, T., Brochier, T., Timor, J., and Vitancurt, J. (2014) 'Use of local knowledge in marine protected area management,' *Marine Policy*, 44, 390-396.

Menendez, P., Losada, J., Torres-Ortega, S., Narayan, S. and Beck, M.W. (2020) 'The Global Flood Protection Benefits of Mangroves', *Nature Portfolio*, 10(1).

Meynecke, J.O., Lee, S.Y., Duke, N.C. (2008) 'Linking spatial metrics and fish catch reveals the importance of coastal wetland connectivity to inshore fisheries in Queensland, Australia', *Biological Conservation*, 141(4), pp. 981-996.

Micheli, F. and Peterson, C.H. (1999) 'Estuarine vegetated habitats as corridors for predator movements', *Conservation Biology*,13, 869–881.

Moberg, F. and Ronnback, P. (2003) 'Ecosystem services of the tropical seascape: Interactions, substitutions and restoration', *Ocean and Coastal Management*, 46(1-2), pp. 27-46.

MOCCAE. (2023) 'National Climate Change Plan of the United Arab Emirates 2017 – 2050', [Online]. Available at: file:///C:/Users/User/Downloads/National%20Climate%20Change%20Plan.pdf. (Accessed 10 October 2024).

MOEC. (2023) *'An Overview of the United Arab Emirates'*. [Online]. Available at: https://www.moec.gov.ae/en/emirates-of-the-uae#:~:text=United%20Arab%20Emirates,Ras%20Al%20Khaimah%20and%20Fujairah (Accessed: 10 October 2024).

Mohammadizadeh, M., Farshchi, P., Danehkar, A., Mahmoodi-Madjdabadi, M., Hassani, M. and Mohammadizadeh, F. (2009) 'Interactive effect of planting distance, irrigation type and intertidal zone on the growth of grey mangrove seedlings in Qeshm Island, Iran', *Journal of Tropical Forest Science*, 21(2), pp. 147-155.

Mukherjee, N., Sutherland, W J., Dicks, L V., Hugé, J., Koedam, N. and Dahdouh-Guebas, F. (2014) 'Ecosystem Service Valuations of Mangrove Ecosystems to Inform Decision Making and Future Valuation Exercises', *Public Library of Science*, 9(9), e107706-e107706.

Mumby, P., Alasdair; A., Ernesto, A., Lindeman, K., Blackwell, P., Gall, A., Gorczynska, M., Harborne, A., Pescod, C., Renken, H., Wabnitz, C. and Llewellyn, G. (2004) 'Mangroves enhance the biomass of coral reef fish communities in the Caribbean', *Nature*, 427.

Mumby, P. (2006) 'Connectivity of reef fish between mangroves and coral reefs: Algorithms for the design of marine reserves at seascape scales', *Biological Conservation*, 128(2), pp. 215-222.

Murchie, K., Schwager, E., Cooke, S., Danylchuk, A., Danylchuk, S., Goldberg, T., Suski, C. and Philipp, D. (2010) 'Spatial ecology of juvenile lemon sharks (Negaprion brevirostris) in tidal creeks and coastal waters of Eleuthera, The Bahamas', *Environmental Biology of Fishes*, 89(1), pp. 95-104.

Nagelkerken, I. and Van der Velde, G. (2004) 'Relative importance of interlinked mangroves and seagrass beds as feeding habitats for juvenile reef fish on a Caribbean island', *Marine Ecology Progress Series*, pp. 153-159.

Nagelkerken, I, Blaber, S., Bouillon, S., Green, P., Haywood, M., Kirton, L., Meynecke, J., Pawlik, J., Penrose, H., Sasekumar, A. and Somerfield, P. (2008) 'The habitat function of mangroves for terrestrial and marine fauna: A review', *Aquatic Botany*, 89.

Nagelkerken, I. (2009) *'Ecological Connectivity Among Tropical Coastal Ecosystems'*. Springer. Dordrecht, pp. 400.

Nagelkerken, I., Dorenbosch, M., Verberk, W., Morinière, E. and Van der Velde, G. (2000) 'Importance of shallow-water biotopes of a Caribbean bay for juvenile coral reef fishes: Patterns in biotope association, community structure and spatial distribution', *Marine Ecology Progress Series*, 202, pp. 175-192.

Nagelkerken, I., Kleijnen, S., Klop, T., Van den brand, R., Cocheret, E. and Van der velde, G. (2001) 'Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: A comparison of fish faunas between bays with and without mangroves-seagrass beds', *Marine Ecology Progress Series*, 214, pp. 225-235.

Nagelkerken, I., Huebert K., Serafy J., Grol M., Dorenbosch M. and Bradshaw C (2017) 'Highly localized replenishment of coral reef fish populations near nursery habitats', *Marine Ecology Progress Series*, 568.

Nawari, N., Syahza A. and Siregar Y.I. (2021) 'Community-based mangrove forest management as ecosystem services provider for reducing CO2 emissions with carbon credit system in bengkalis district, riau, Indonesia', *Journal of Physics Conference Series*, 12074.

Nelson, D.R., Chaiboonchoe, A., Hazzouri, K.M., Khraiwesh, B., Alzahmi, A., Jaiswal, A., Friis, G., Burt, J.A., Amiri, K. and Salehi-Ashtiani, K. (2022) 'Tissue-Specific Transcriptomes Outline Halophyte Adaptive Strategies in the Gray Mangrove (Avicennia marina)', *Agronomy*, 12(9).

Newton, A. and Elliott, M. (2016) 'A typology of stakeholders and guidelines for engagement in transdisciplinary, participatory processes', *Frontiers in Marine Science*, 3.

Noghabi, A,N., Shojaei, M.G., Farahani, M.M. and Weigt, M. (2022) 'Stable Isotopes Reveal the Food Sources of Benthic Macroinvertebrates in the Arid Mangrove Ecosystem of the Persian Gulf', *Estuaries and Coasts*, 45(7), pp. 2241-2253.

Nowell, J. (1998) 'Now & Then The Emirates - Arabian Historical Series,' Zodiac Publishing, vol 1, pp 128.

Nyangoko, B., Berg, H., Mangora, M., Shalli, M. and Gullstrom, M. (2022) ‘Local perceptions of changes in mangrove ecosystem services and their implications for livelihoods and management in the Rufiji Delta, Tanzania’, *Ocean & Coastal Management*, 219, 106065.

Nyangoko, B.P., Berg, H., Mangora, M.M., Gullstrom, M. and Shalli, M.S. (2020) ‘Community perceptions of mangrove ecosystem services and their determinants in the Rufiji Delta, Tanzania’, *Sustainability*, 13(1), p.63.

Olds, A.D., Connolly, R.M., Pitt, K.A., Pittman, S.J., Maxwell, P.S., Huijbers, C.M., Moore, B.R., Albert, S., Rissik, D., Babcock, R.C. and Schlacher, T.A. (2016) ‘The conservation value of seascape connectivity’, *Global Ecology and Biogeography*, 25: 3-15.

Olds, A., Nagelkerken, I., Huijbers, C., & Gilby, B., Pittman, S. and Schlacher, T. (2018). ‘Connectivity in Coastal Seascapes,’ John Wiley & Sons Ltd. *Seascape Ecology*, pp.261-292.

Orif, M. and El-Maradny, A. (2018) 'Bio-accumulation of Polycyclic Aromatic Hydrocarbons in the Grey Mangrove (*Avicennia marina*) along Arabian Gulf, Saudi Coast', *Open Chemistry*, 16(1), pp. 340-348.

Osland, M.J., Enwright, N.M., Day, R.H., Gabler, C.A., Stagg, C.L. and Grace, J.B. (2016) ‘Beyond just sea-level rise: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change’, *Global Change Biology*, 22, 1–11.

Page M. J., McKenzie J. E., Bossuyt P. M., et al. (2020) ‘The PRISMA 2020 statement: An updated guideline for reporting systematic reviews’, *Journal of Surgery*. 88:105906.

Paleologos, E.K., Welling, B.A. and Amrousi, M.E. (2019) 'Coastal development and mangroves in Abu Dhabi, UAE', *IOP Conference Series Earth and Environmental Science*, 344(1):012020.

Partelow, S., Hornidge, A.K., Senff, P., Steabler, M. and Schluter, A. (2020) ‘Tropical marine sciences: knowledge production in a web of path dependencies’, *PLoS One*, 15 (2).

Patel, D., Katriya, B. and Patel, K. (2014) 'Performance Of Mangrove In Tsunami Resistance', *International Journal of Emerging Technology & Research*, pp. 29-32.

Peng, Y., Zheng, M., Zheng, Z., Wu, G., Chen, Y., Xu, H., Tian, G., Peng, S., Chen, G. and Lee, S.Y. (2016) ‘Virtual increase or latent loss? A reassessment of mangrove populations and their conservation in Guangdong, southern China’, *Marine Pollution Bulletin*, 109(2).

Pimple, U., Leadprathom, K., Simonetti, D., Sitthi, A., Peters, R., Pungkul, S., et al. (2022) ‘Assessing mangrove species diversity, zonation and functional indicators in response to natural, regenerated, and rehabilitated succession’, *Journal of Environmental Management*, 318, 115507.

Pittman, S. and McAlpine, C. (2003) 'Movements of Marine Fish and Decapod Crustaceans: Process, Theory and Application', *Advances in marine biology*, 44, pp. 205-94.

Plaziat, J. (1995) 'Modern and fossil mangroves and mangals: their climatic and biogeographic variability', Geological Society, London, *Special Publications*, 83, pp. 73 - 96.

Plaziat, J., Cavagnetto, C., Koeniguer, J. and Baltzer, F. (2001) ‘History and biogeography of the mangrove ecosystem, based on a critical reassessment of the paleontological record’, *Wetlands Ecology and Management,* 9, 161-180.

Pomeroy, R.S., Watson, L.M., Parks, J.E. and Cid, G.A. (2005) ‘How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas’, *Ocean & Coastal Management*, 48(7-8), 485-502.

Ponton-Cevallos, J., Ramírez-Valarezo, N., Pozo-Cajas, M., Rodríguez-Jácome, G., Navarrete-Forero, G., Moity, N., Villa-Cox, G., Ramírez-González, J., Barragán-Paladines, M., Bermúdez-Monsalve, J. and Goethals, P. (2022) 'Fishers’ Local Ecological Knowledge to Support Mangrove Research in the Galapagos', *Frontiers in Marine Science*, 9.

Price, A., Sheppard, C. and Roberts, C. (1993) ‘The Gulf: its biological setting’, *Marine Pollution Bulletin*, 27, pp. 9-15.

Pullin, A. S. and Stewart, G. B. (2006) ‘Guidelines for systematic review in conservation and environmental management’*, Conservation biology*, 20(6):1647-56.

Ramos, D., Aragones, L. and Rollon, R. (2015) ‘Linking integrity of coastal habitats and fisheries yield in the Mantalip Reef System’, *Ocean & Coastal Management*. 111. 62-71. 10.1016/j.ocecoaman.2015.04.009.

Rasool, F. and Saifullah, S.M. (1996) ‘Mangroves of Kalmat Khor, Balochistan’, *Journal of Botany*, 28(2):143-150.

Reagans, R. and McEvily, B. (2003) ‘Network structure and knowledge Transfer: the effects of cohesion and range’, *Administrative Science Quarterly*, 48(2):240-267.

Reciproco, A., Suarez, J., Padilla, J., Flora, J., Cañada, M., Velasco, C. and Buhong, N. (2023) 'Awareness and Participation in Mangrove Management of Coastal Communities in Baler, Aurora, Philippines', Ecology, *Environment and Conservation*, 29, pp. 928-934.

Reis-Filho, J. A., Giarrizzo, T. and Barros, F. (2016) ‘Tidal migration and cross-habitat movements of fish assemblage within a mangrove ecotone’, *Marine Biology*. 163, 111.

Ren, H., Jian, S., Lu, H., Zhang, Q., Shen, W., Han, W., Yin, Z. and Guo, Q. (2008) ‘Restoration of mangrove plantations and colonisation by native species in Leizhou bay, South China’, *Ecological Research*, 23, pp. 401-407.

Resasco, J. (2019). ‘Meta-analysis on a decade of testing corridor efficacy: What new have we learned?’, *Current Landscape Ecology Reports*, 4:61–69.

Reyes-Garcia, V., Fernández-Llamazares, A., McElwee, P., Molnar, Z., Ollerer, K., Wilson, S. J. and Brondizio, E. S. (2019) ‘The contributions of Indigenous Peoples and local communities to ecological restoration, *Restoration Ecology*, 27:3-8.

Riegl, B. and Purkis, S. (2012) ‘*Coral Reefs of the Gulf: Adaptation to Climatic Extremes in the World’s Hottest Sea*. Springer, pp. 379.

Richards D.R. and Friess D.A (2016) ‘Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012’, *PNAS*, 113 (2) 344-349.

Robards, M. D., Schoon, M. L., Meek, C. L. and Engle, N. L. (2011) ‘The importance of social drivers in the resilient provision of ecosystem services’, *Global Environmental Change*, 21, 522–529.

Robertson, A. and Duke., N. (1987) 'Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia', *Marine Biology*, 96, pp. 197-205.

Robertson, A. and Blaber, S. (1992). ‘Plankton, epibenthos and fish communities’. *Coastal and Estuarine Studies*, 173–224.

Roces-Diaz, J. V., Diaz-Varela, E. R. and Alvarez-Alvarez, P. (2014) ‘Analysis of spatial scales for ecosystem services: Application of the lacunarity concept at landscape level in Galicia (NW Spain)’ *Ecological Indicators*, 36, 495–507.

Romanach S. S., DeAngelis D. L., Koh H. L., Li Y., Teh S. Y., Barizan R. and Zhai L. (2018) ‘Conservation and restoration of mangroves: Global status, perspectives, and prognosis’, *Ocean & Coastal Management*. 154:72-82.

ROMPE. (2024). Regional Organization for the Protection of the Marine Environment – programs. [Online]. Accessed at: https://ropme.org/programs/. (Accessed 28 October 2024).

Rostami, F., Attarod, P., Keshtkar, H. and Nazeri Tahroudi, M. (2022). 'Impact of climatic parameters on the extent of mangrove forests of southern Iran', *Caspian Journal of Environmental Sciences*, 20(4), pp. 671-682.

Ronnback, P., Crona, B. and Ingwall, L. (2007) ‘The return of ecosystem goods and services in replanted mangrove forests: perspectives from local communities in Kenya’, *Environment Conservation*, 34.

RStudio. (2022) ‘RStudio: Integrated Development for R. RStudio’, PBC: Boston, MA. [Online]. Accessed at http://www.rstudio.com/. (Accessed 10 October 2024).

Rypel A.L., Layman C.A. and Arrington, D.A. (2007) ‘Water depth modifies relative predation risk for a motile fish taxon in Bahamian tidal creeks. Est Coasts 30(3):518–525.

Rutter, D., Francis, J., Coren, E. and Fisher, M. (2013) ‘*SCIE systematic research reviews: guidelines’*. UK: Social care institute for excellence.

Saenger, P., Hegerl, E. and Davie, J. (1983) ‘Global status of mangrove ecosystems’. *Commissionon Ecology Papers*. IUCN. *The Environmentalist*, Vol. 3.

Saenger, P. (2002) *‘Mangrove Ecology Silviculture and Conservation’.* Kluwer Academic Publishers. Dordrecht.

Saenger, P., Blasco, A., Youssef and Loughland, R.A. (2004) ‘Mangroves of the United Arab Emirates with particular emphasis on those of Abu Dhabi Emirate’, in: R. A. Loughland, F. S. Al-Muhairi, S. S. Fadel, A. M. Al-Mehdi, and P. Hellyer (eds.) *Marine Atlas of Abu Dhabi*, Abu Dhabi, pp. 58-69.

Saifullah, S.M. and Rasool, F. (2000) ‘Mangroves of Pakistan - Iran border near Gulf of Oman’, *Journal of Botany*, 32(1):227-234.

Saifullah, S.M. and Rasool, F. (2002) ‘Mangroves of Miani Hor lagoon on the north Arabian Sea coast of Pakistan’, *Journal of Botany*, 34(3):303-310.

Safahieh, A., Nabavi, M.B., Vazirizadeh, A., Ronagh, M.T. and Kamalifar, R. (2012) ‘Horizontal zonation in macrofauna community of Bardestan mangrove Creek, Persian Gulf’, *World Journal of Fish and Marine Sciences*, 4(2), pp.142-149.

Sale, P.F., Feary, D., Burt, J.A., Bauman, A., Cavalcante, G., Drouillard, K., Kjerfve, B., Marquis, E., Trick, C., Usseglio, P. and van Lavieren, H. (2011) ‘The growing need forsustainable ecological management of marine communities of the Persian Gulf’, *Ambio*, 40, 4–17.

Saito, H., Bellan, M.F. and Al-Habshi, A. (2003) 'Mangrove research and coastal ecosystem studies with SPOT-4 HRVIR and TERRA ASTER in the Arabian Gulf', International Journal of Remote Sensing.

Salmo, S.G. (2021). ‘Assessment of typhoon impacts and post-typhoon recovery in Philippine mangroves: lessons and challenges for adaptive management’, in: Sidik, F., Friess, D. (eds.), *Dynamic sedimentary environments of mangrove coasts*. Amsterdam, Netherlands, Elsevier, pp. 539–562.

Salimi, E., Sakhaei, N., Nurinezhad, M., Savari, A. and Ghaemmaghami, S.S. (2021) 'Composition, biomass and secondary production of the macrobenthic invertebrate assemblage in a mangrove forest in Nayband Bay, Persian Gulf', *Regional Studies in Marine Science*, 42.

Samara, F., Solovieva, N., Ghalayini, T. and Nasrallah, Z.A. (2020) 'Assessment of the environmental status of the mangrove ecosystem in the United Arab Emirates', *Water*, 12(6):1623

Sambrook, K., Hoey, A., Andrefouet, S., Cumming, G., Duce, S. and Bonin, M. (2019) 'Beyond the reef: The widespread use of non-reef habitats by coral reef fishes', *Fish and Fisheries*, 20(5), pp. 903-920.

Sandilyan, S. and Kathiresan, K. (2015) 'Density of waterbirds in relation to habitats of Pichavaram mangroves, Southern India', Journal of Coastal Conservation, 19(2), pp. 131-139.

Sandoval Londono, L.A., Leal-Florez, J. and Blanco-Libreros, J.F. (2020) ‘Linking mangroves and fish catch: a correlational study in the southern Caribbean Sea (Colombia)’, *Bulletin of Marine Science*, 96(3).

Sannigrahi, S., Qi Zhang, Francesco P., Kumar P., Basu, B., Keesstra, S.,Roy, Wang, Y., Sutton P., Chakraborti, S., et al. (2020) ‘Responses of ecosystem services to natural and anthropogenic forcings: A spatial regression based assessment in the world's largest mangrove ecosystem,’ *Science of The Total Environment*, 715.

Satterfield, T., Gregory, R., Klain, S., Roberts, M. and Chan, K.M. (2013) ‘Culture, intangibles and metrics in environmental management’, *Journal of Environmental Management*, 117, 103–114.

Sarhan, M. and Tawfik, R. (2014) ‘The Economic Valuation of Mangrove Forest Ecosystem Services: Implications for Protected Area Conservation’, *George Wright Society*. 2014, 35, 1–16.

Saunders, M.I., Doropoulos, C., Bayraktarov, E., Babcock, R.C., Gorman, D., Eger, A.M., Vozzo, M.L., Gillies, C.L., Vanderklift, M.A. and Steven, A.D. (2020) ‘Bright spots in coastal marine ecosystem restoration’, *Current Biology*, 30, R1500–R1510.

Scholte, S.S., Van Teeffelen, A.J. and Verburg, P.H. (2015) ‘Integrating socio-cultural perspectives into ecosystem service valuation: a review of concepts and methods’, *Ecology*. 114, 67–78.

Schwenke T. and Helfer V. (2021) ‘Beyond borders: The status of interdisciplinary mangrove research in the face of global and local threats’, *Estuarine, Coastal and Shelf Science*, 250. 107119.

Serafy, J., Shideler, G., Araújo, R. and Nagelkerken, I. (2015) 'Mangroves enhance reef fish abundance at the Caribbean regional scale', *PLoS ONE*, 10(11).

Shriadah, M. (1999) 'Chemical characterization of water and sediments in the mangroves along the Arabian Gulf, United Arab Emirates', *International Journal of Ecology and Environmental Sciences*, 25(1), pp. 85-90.

Shahraki M., Saint-Paul U., Krumme U. and Fry B. (2016) ‘Fish use of intertidal mangrove creeks at Qeshm Island, Iran’, *Marine Ecology Progress Series*, 542, pp. 153-166.

Sheaves, M. (2005) 'Nature and consequences of biological connectivity in mangrove systems', *Marine Ecology Progress Series*, 302, pp. 293-305.

Sheaves, M., Baker, R., Nagelkerken, I. and Connolly, R. (2015) 'True Value of Estuarine and Coastal Nurseries for Fish: Incorporating Complexity and Dynamics', *Estuaries and Coasts*, 38, pp. 401-414.

Sheppard, C., Price, A. and Roberts, C. (1992) *‘Marine Ecology of the Arabian Region Patterns and Processes in Extreme Tropical Environments’*. London. Academic Press, pp. 359.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., Benzoni, F., Dutrieux, E., Dulvy, N., Durvasula, S., et al. (2010) 'The Gulf: A young sea in decline', *Marine Pollution Bulletin*, 60(1), pp. 13-38.

Sheridan, P. and Cynthia (2003) 'Are mangroves nursery habitat for transient fishes and decapods?', *Wetlands*, 23(2), pp. 449-458.

Sherman, R., Fahey, T. and Martinez, P. (2003) ‘Spatial Patterns of Biomass and Aboveground Net Primary Productivity in a Mangrove Ecosystem in the Dominican Republic. *Ecosystems*, 6, 384–398.

Sierra-Correa, P.C. and Cantera, J.R. (2015) ‘Ecosystem-based adaptation for improving coastal planning for sea-level rise: a systematic review for mangrove coasts’, *Marine Policy*, 51, 385–393.

Sievers, M., Brown, C., Tulloch, V., Pearson, R., Haig, J., Turschwell, M. and Connolly, R. (2019) 'The Role of Vegetated Coastal Wetlands for Marine Megafauna Conservation', *Trends in Ecology and Evolution*, 34(9), pp. 807-817.

Siddig, N., Al-Subhi, A. and Al-saafani, M. (2019) ‘Tide and mean sea level trend in the west coast of the Arabian Gulf from tide gauges and multi-missions satellite altimeter’, *Oceanologia*, 61(4).

Simpson, E.H. (1949) ‘Measurement of Diversity’, *Nature*, 163:688.

Singh, R., Semwal, A. and Kumar, N. (2023) *'Status of Coral Reefs, their Ecological Value and Conservation Management'*, 1 edn. pp. 65-78.

Smale, D. A., Moore, P. J., Queiros, A., Higgs, S. and Burrows, M.T. (2018) ‘Appreciating interconnectivity between habitats is key to blue carbon management’, *Frontiers in Ecology Environment,* 16 (2), 71–73.

Soria-Barreto, M., Gelabert-Fernandez, R., Reyna-Ramos E.H. and Brito, R. (2021) ‘The fish community in Gulf of Mexico mangroves, a response to hydrological restoration’, *Latin American Journal of Aquatic Research*, pp. 507-519.

Spalding, M., Kainuma, M. and Collins, L. (2010) *‘World Atlas of Mangroves’*. 1 edn. Routledge.

Staveley, T., Perry, D., Lindborg, R. and Gullstrom, M. (2017) ‘Seascape structure and complexity influence temperate seagrass fish assemblage composition’, *Ecography*, 40: 936-946.

Steele, T.N., Prabhu, S.S., Layton, R.G., Runyan, C.M. and David, L.R. (2022) ‘The Virtual Interview Experience: Advantages, Disadvantages, and Trends in Applicant Behavior. Plastic and reconstructive surgery’ *Global open*, 10(11), e4677.

Sudo, K., Quiros, T., Prathep, A., Luong, C., Lin, H., Bujang, J., Ooi, J., Fortes, M., Zakaria, M., Yaakub, S., Tan, Y., Huang, X. and Nakaoka, M. (2021) 'Distribution, Temporal Change, and Conservation Status of Tropical Seagrass Beds in Southeast Asia: 2000-2020', *Frontiers in Marine Science*, (8).

Su, J., Friess, D.A. and Gasparatos, A. (2021) ‘A meta-analysis of the ecological and economic outcomes of mangrove restoration’*, Nature Communications*,12, 5050 (2021).

Thayer, G., Colby D. and Hettler, W. (1987) 'Utilization of the red mangrove prop root habitat by fishes in south Florida', *Marine Ecology Progress Series*, 35: 25-38, p. 14.

Tomlinson, P. (2016*) ‘The Botany of Mangroves’*. 2 edn. Cambridge: Cambridge University Press, p. 432.

Tran, T.V., Reef, R., and Zhu, X. (2024) ‘Long-term changes of mangrove distribution and its response to anthropogenic impacts in the Vietnamese Southern Coastal Region’, *Journal of Environmental Management*, 370, 122658.

Trettin, C., Stringer, C. and Zarnoch, S. (2016) 'Composition, biomass and structure of mangroves within the Zambezi River Delta', *Wetlands Ecology and Management*, 24.

Trombulak, S.D. and Baldwin, R.F. (2010) ‘Landscape-Scale Conservation Planning’, New York: Springer.

Tupper, M., Asif, F., Garces, L.R. and Pido, M.D. (2015) ‘Evaluating the management effectiveness of marine protected areas at seven selected sites in the Philippines’, *Marine Policy*, 56, pp.33-42.

Twilley, R., and Day, J. (1999) 'The productivity and nutrient cycling of mangrove ecosystem', *Ecosistemas de Manglar en America Tropical*, pp. 127-152.

Twomey, A. and Lovelock, C. (2024) ‘Global spatial dataset of mangrove genus distribution in seaward and riverine margins’, *Sci Data*, 11, 306.

Twomey, A. (2022) ‘*Mangrove Zonation Data: Global collation of mangrove zonation distribution in seaward and riverine margins’*. [Online]. Accessed at https://storymaps.arcgis.com/stories/2e8ea95cd392475cad68475ca47fced2. (Accessed 10 October 2024).

UAE-GOV. (2024) ‘The UN's 2030 Agenda. The United Arab Emirates Government portal’. [Online]. Available at: https://u.ae/en/about-the-uae/leaving-no-one-behind. (Accessed 10 October 2024).

UAE-SDG. (2023) ‘*UAE and the 2030 Agenda for Sustainable Development’*. National Committee on Sustainable Development Goals for United Arab Emirates. [Online]. Accessed at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://fcsc.gov.ae/en-us/Documents/SDG%20Annual%20Report%202023.pdf. (Accessed 10 October 2024).

UAE-MOFA. (2022) ‘UAE information: Facts and Figures’. [Online] Available at: https://www.mofa.gov.ae/en/the-uae/facts-and-figures. (Accessed 10 October 2024).

Unsworth R., Nordlund L. and Cullen-Unsworth L (2018) ‘Seagrass meadows support global fisheries production’, *Conservation Letters*, 12(1):1-8.

UNEP. (2006) ‘Marine and coastal ecosystems and human well-being: a synthesis report based on the findings of the millennium ecosystems assessment’, *United Nations Environment Programme Programme*, Nairobi.

UNEP. (2020) ‘Percentage of total population living in coastal areas. United Nations Environment Programme’, *United Nations Environment Programme Programme*, Nairobi.

UNEP. (2020). The UN Decade on Ecosystem Restoration. *United Nations Environment Programme Programme*, Nairobi.

UNEP-WCMC. (2022). Progress, needs and opportunities for seascape restoration. Cambridge, United Kingdom.

United Nations. (2015) ‘Transforming Our World: the 2030 Agenda for Sustainable Development’. [Online]. Accessed from: https://www.refworld.org/docid/57b6e3e44.html. (Accessed 10 October 2024).

Valiela, I., Bowen, J. and York, J. (2009) 'Mangrove Forests: One of the World's Threatened Major Tropical Environments', *BioScience*, 51, pp. 807-815.

Van Lavieren, H., Burt, J., Feary, D., Cavalcante, G., Marquis, E., Benedetti, L., Trick, C., Kjerfve, B. and Sale, P. (2011) ‘Managing the Growing Impacts of Development on Fragile Coastal and Marine Ecosystems: Lessons from the Gulf’, *United Nations University Press,* pp. 97.

Vasconcelos, R., Eggleston, D., Le Pape, O. and Tulp, I. (2014) 'Patterns and processes of habitat-specific demographic variability in exploited marine species', *ICES Journal of Marine Science*, 71(3), pp. 638-647.

Vargas-Fonseca E., Olds A.D., Gilby B. L., Connolly R.M., Schoeman D. S., Huijbers C. M., Hyndes G.A., et al. (2016) ‘Combined effects of urbanization and connectivity on iconic coastal fishes’. *Diversity and Distributions*, 22: 1328–1341.

Vaughan, G.O., and Burt, J.A. (2016) ‘The changing dynamics of coral reef science in Arabia’, *Marine Pollution Bulletin*, 105, 441–458.

Vaughan, G., Almansoori, N. and Burt, J. (2019) *'The Arabian Gulf'*, in Sheppard, C. (ed.) World Seas: an Environmental Evaluation, 2 edn, *Academic Press*, pp. 1-23.

Vaughan, G. O., Shiels, H. A. and Burt, J. A. (2021) ‘Seasonal variation in reef fish assemblages in the environmentally extreme southern Persian/Arabian Gulf’*, Coral Reefs*, 40, 405–416 (2021).

Verweij, M., and Nagelkerken, I. (2007) ‘Short and long-term movement and site fidelity of juvenile Haemulidae in back-reef habitats of a Caribbean embayment’, *Hydrobiologia*, 592, 257-270.

Vo, Q.T., Kunzer, C., Vo, Q.M., Moder, F. and Oppelt, N., (2012) ‘Review of valuation methods for mangrove ecosystem services’, *Ecological indicators*, 23, pp.431-446.

Waltham, N. J., Elliott, M., Lee, S. Y., Lovelock, C., Duarte, C. M., Buelow, C., et al. (2020) ‘UN decade on ecosystem restoration 2021–2030—what chance for success in restoring coastal ecosystems?’, *Frontiers in Marine Science*, 7:71.

Walton, M.E., Al-Maslamani, I., Skov, M.W., Al-Shaikh, I., Al-Ansari, I.S., Kennedy, H.A. and Le Vay, L. (2014) 'Outwelling from arid mangrove systems is sustained by inwelling of seagrass productivity', *Marine Ecology Progress Series*, 507, pp. 125-137.

Wetherbee, B., Gruber, S. and Rosa, R. (2007) 'Movement patterns of juvenile lemon sharks Negaprion brevirostris within Atol das Rocas, Brazil: a nursery characterized by tidal extremes', *Marine Ecology Progress Series*, 343, pp. 283-293.

Whitfield, A.K. (2017) ‘The role of seagrass meadows, mangrove forests, salt marshes and reed beds as nursery areas and food sources for fishes in estuaries’, *Reviews in Fish Biology and Fisheries*, 27(1).

Wilkie, M. and Fortuna, S. (2005) ‘Forest Resources Assessment (FRA) Thematic Study on Mangroves; Technical Report’. Rome, Italy: *Food and Agriculture Organization of the United Nations*. FAO.

Woodroffe, C. (1992) *'Mangrove Sediments and Geomorphology'*, Tropical Mangrove Ecosystems, pp. 7-41.

Worthington, T. and Spalding, M. (2018) ‘Mangrove Restoration Potential: A Global Map Highlighting a Critical Opportunity’, *Apollo - University of Cambridge Repository*.

Wylie, L., Sutton-Grier, A.E. and Moore A. (2016) ‘Keys to successful blue carbon projects: lessons learned from global case studies’, *Marine Policy*, 65:76–84.

Zahed, M., Rouhani, F., Mohajeri, S., Bateni, F. and Mohajeri, L. (2010) ‘An overview of Iranian mangrove ecosystems, northern part of the Persian Gulf and Oman Sea’, *Acta Ecologica Sinica*. 30:4.

Zahran, M. and Elamier, Y. (2016) *‘Mangrove Forests of the Arab World's Coastal Belts: A Climate Phenomenon’*. Scholars Press.

Zharikov, Y. and Milton, D. (2009) 'Valuing coastal habitats: predicting high-tide roosts of non-breeding migratory shorebirds from landscape composition', *Emu-Austral Ornithology*, 109(2), pp. 107-120.

Zou, H., Li, X., Li, S., Xu, Z., Yu, Z., Cai, H., Chen, W., Ni, X., Wu, E. and Zeng, G. (2023) 'Soil organic carbon stocks increased across the tide-induced salinity transect in restored mangrove region', *Scientific Reports*, 13.

Zu Ermgassen, P., Mukherjee, N., Worthington, T., Acosta, A., Rocha-Araujo, A., Beitl, C., Castellanos-Galindo, G., Cunha-Lignon, M., Dahdouh-Guebas, F., Diele, K., et al. (2020) 'Fishers who rely on mangroves: Modelling and mapping the global intensity of mangrove-associated fisheries', *Estuarine, Coastal and Shelf Science*, 247, p. 106975.

Appendix

Appendices A1-3: Supplementary material to Chapter 2

Appendix A.1: Database information The literature search was performed using Web of Science, Scopus, Science Direct, and Google Scholar Search Engine on 24 June 2020, using the following combination of search terms: [mangroves* OR mangrove ecosystems* OR mangrove habitats* AND biodiversity AND (proximity OR vicinity) OR (connectivity OR movement) AND ("shallow water habitats*" OR "coastal habitats*") AND NOT (lakes* OR freshwater)].

Name	**Hits**
Database: Scopus	129
Database: Web of Science	197
Database: Science Direct	880
Database: Google Scholar	3500
Total records retrieved	4706
Records removed filter by irrelevance to topic	3496
Records retrieved to be sorted	1210
Duplicates removed	30
Records reviewed for relevance by title	1180
Records removed filter by irrelevance to topic	1019
Reviewed by title and abstract	161
Records removed filter by irrelevance to topic	77
Records sought for retrieval	84
Additional records included from reference list	40
Records assessed for eligibility	124
Records excluded (e.g. unable to source full-text, irrelevance)	22
Final articles included in the review	102

Appendix A.2: Meta-data information Manually filled spreadsheet for the meta-data information and full references. [see additional files].

Appendix A.3: PRISMA flow chart Template for PRISMA 2020 flow diagram for new systematic reviews of databases and registers only (Page *et al.*, 2020).

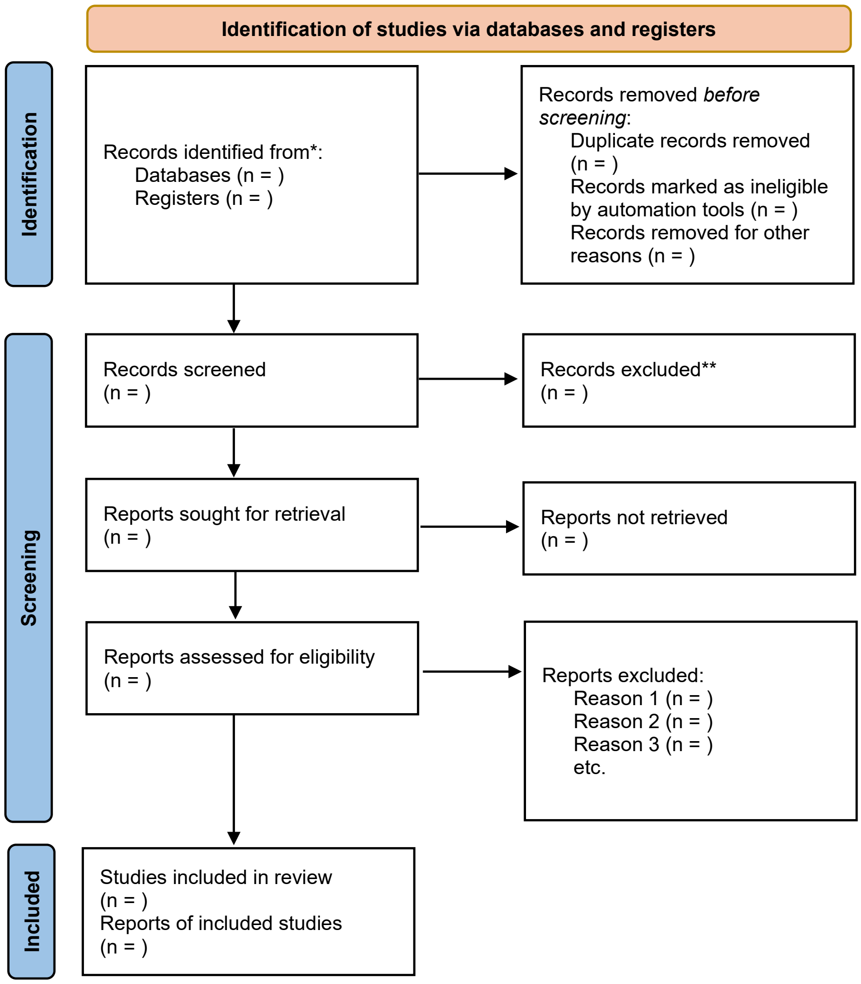


Figure A. 3. 1. Prisma flow chart adapted from Page *et al.* (2020).

Appendices B1-4: Supplementary material to Chapter 3

Appendix B.1: Database information The literature search was performed using the scientific bibliographic databases (Web of Science and Scopus), resource hubs of locally based environmental organizations (EAD and MOCCAE), and the search engine Google Scholar, using the search terms: [mangrove* AND "Arabian gulf" OR "Persian gulf"].

	Hits
Articles identified in search 1 (21 May 2021)	62
Records excluded from search 1 (unpublished records)	16
Final records identified in search 1	46
Articles identified in search 2 (7 June 2024)	541
Excluded in both searches (duplicates and irrelevance to topic)	367
Reviewed for relevance by title	220
Records excluded (filter by irrelevance to topic)	47
Reviewed by title and abstract	173
Articles excluded (Irrelevance to topic)	2
Records sought for retrieval	171
Articles excluded (unable to source full-text)	28
Records assessed for eligibility	143
Articles excluded (Irrelevance to topic)	3
Final articles included in the review	140

Appendix B.2: Meta-data information Manually filled spreadsheet for the meta-data information and full references. [see additional files].

Appendix B.3: Prisma flow chart Template for PRISMA 2020 flow diagram for new systematic reviews of databases and registers only (Page et al., 2020). See Appendix A.3.

Appendix B.4: IUCN Red List of Ecosystems, Mangroves of the Arabian (Persian) Gulf Copy of full article.

Appendices C1-3: Supplementary material to Chapter 4

Appendix C.1: Description of study area used to sample fish in mangroves of the United Arab Emirates, eastern coast in the southern Arabian Gulf

Figure C. 1. 1. Map of the study area for sampling fish in mangroves (yellow polygon) adapted from Google Earth. Located (GPS): Lat: 24.555003° / Long: 54.488596° and Lat: 24.513355° / Long: 54.516956° and Lat: 24.539015° / Long: 54.546968° and Lat: 24.534942° / Long: 54.509870°. Habitats in the area comprise intermixed coastal and marine ecosystems, including saltmarsh, tidal flats, seagrass beds, and rocky shores, covering a total area of approximately 5.4 km^2.

Figure C. 1. 2. The different habitat types of the study area along the Southern Arabian Gulf, Abu Dhabi, United Arab Emirates. Top left; Sparse mangroves with saltmarsh communities during low tide. Top right; Aerial view of mangrove patches with saltmarsh communities along creeks of Jubail Island. Middle left; dense mangroves of Ramhan Island. Middle right; Aerial view of dense mangrove forests without saltmarsh communities along Ramhan Island. Bottom left; Sparse mangroves with saltmarsh communities during high tide. Bottom right; mangroves near rocky shores along Ramhan Island.

Appendix C.2: Description of the fish sampling procedure, data analysis, and Fish ID list

Sampling date	Time of sampling	Tide phase	Water level (m)	Site name (code)
1/26/2022	07:45	High tide/ Flow	1.6	Jubail (a)
1/27/2022	08:50	High tide/ Flow	1.7	Jubail (b)
1/31/2022	12:40	High tide / Flow	1.9	Ramhan (a)
1/31/2022	13:45	High tide / Ebb	1.5	Ramhan (b)
2/4/2022	15:15	High tide/ Flow	2.0	Jubail (a)
2/5/2022	15:45	High tide / Flow	1.8	Jubail (b)
2/11/2022	09:00	High tide / Flow	1.6	Ramhan (a)
2/11/2022	09:50	High tide/ Ebb	0.9	Ramhan (b)
3/2/2022	13:00	High tide / Flow	2.0	Jubail (a)
3/13/2022	09:20	High tide / Flow	1.8	Jubail (b)
3/14/2022	10:30	High tide / Flow	1.7	Ramhan (a)
3/14/2022	11:25	High tide/ Ebb	0.9	Ramhan (b)
5/23/2022	06:00	High tide / Flow	1.8	Jubail (a)
5/23/2022	07:15	High tide/ Ebb	1.3	Jubail (b)
5/31/2022	14:30	High tide / Flow	1.6	Ramhan (a)
5/31/2022	15:20	High tide/ Ebb	0.9	Ramhan (b)
6/9/2022	09:00	High tide / Flow	1.5	Jubail (a)
6/9/2022	10:05	High tide/ Ebb	1.2	Jubail (b)
6/28/2022	13:45	High tide / Flow	1.7	Ramhan (a)
6/28/2022	14:40	High tide/ Ebb	1.4	Ramhan (b)
8/27/2022	14:15	High tide / Flow	1.6	Jubail (a)
8/27/2022	15:20	High tide/ Ebb	1.2	Jubail (b)
8/28/2022	14:45	High tide / Flow	1.7	Ramhan (a)
8/28/2022	15:35	High tide/ Ebb	1.2	Ramhan (b)
9/19/2022	08:45	High tide / Flow	1.2	Jubail (a)
9/19/2022	09:35	High tide/ Ebb	0.8	Jubail (b)
9/20/2022	10:20	High tide / Flow	1.2	Ramhan (a)
9/20/2022	11:15	High tide/ Ebb	0.8	Ramhan (b)

Notes: No samples were taken during April and July.

Table C. 2. 1. Dates of sampling period and tidal regimes.

Log 1 Abundance category	Number of fish	Average count
1	1 to 2	Per fish counted
2	3 to 5	Per fish counted
3	6 to 15	11
4	16 to 25	21
5	> 26	26
Log 2 Size category	**Size range**	**Average size**
1	3 to 8	6
2	9 to 14	12
3	15 to 20	18
4	21 to 26	24
5	> 27	27

Table C. 2. 2. Standardized Log categories for sampling fish abundance and total length in mangroves, adapted and modified from English et al., 1997.

Family	Species	Common name	Code
Apogonidae	*Apogonichthyoides taeniatus*	Twobelt cardinal	ATA
Apogonidae	*Taeniamia fucata*	Orangelined cardinalfish	AFU
Apogonidae	*Ostorhinchus fleurieu*	Flower cardinalfish	AFL
Ariidae	*Netuma bilineata*	Bronze/Roundsnout catfish	ABL
Ariidae	*Netuma thalassina*	Giant catfish	ATH
Ariidae	*Plicofollis layardi*	Thinspine sea catfish	ATN
Ariommatidae	*Ariomma indicum*	Indian driftfish	AID
Batrachoididae	*Colletteichthys dussumieri*	Flat toadfish	AUS
Batrachoididae	*Colletteichthys occidentalis*	Arabian toadfish	BCO
Batrachoididae	*Allenbatrachus grunniens*	Grunting toadfish	BAG
Belonidae	*Strongylura leiura*	Banded needlefish	SLI
Belonidae	*Strongylura strongylura*	Spottail needlefish	SSR
Belonidae	*Tylosurus crocodilus crocodilus*	Houndfish	TCC
Carangidae	*Atule mate*	Yellowtail scad	AMB
Carangidae	*Gnathanodon speciosus*	Golden trevally	GSP
Carangidae	*Scomberoides commersonnianus*	Talang queenfish	SCO
Carangidae	*Scomberoides lysan*	Doublespotted queenfish	SLY
Carangidae	*Scomberoides tol*	Needlescaled queenfish	STO
Chanidae	*Chanos chanos*	Milkfish	CAO
Clupeidae	*Herklotsichthys quadrimaculatus*	Bluestripe herring	HQU
Clupeidae	*Nematalosa nasus*	Bloch's gizzard shad	NNA

Clupeidae	*Herklotsichthys lossei*	Gulf herring	HLO
Cynoglossidae	*Cynoglossus puncticeps*	Speckled tonguesole	CPU
Cynoglossidae	*Cynoglossus kopsii*	Shortheaded tonguesole	CKO
Cynoglossidae	*Cynoglossus arel*	Largescale tonguesole	CAE
Cyprinodontidae	*Aphanius dispar dispar*	Arabian pupfish	ADS
Dasyatidae	*Brevitrygon walga*	Scaly Whipray	DHW
Dasyatidae	*Himantura leoparda*	Leopard Whipray	DKL
Dasyatidae	*Himantura uarnak*	Reticulate Whipray	DHV
Dasyatidae	*Maculabatis arabica*	Arabian Whipray	ZMR
Dasyatidae	*Maculabatis gerrardi*	Whitespotted Whipray	DHG
Dasyatidae	*Maculabatis randalli*	Arabian Banded Whipray	DMR
Dasyatidae	*Pastinachus ater*	Broad Cowtail Ray	ZPA
Dasyatidae	*Pastinachus sephen*	Cowtail Ray	DYP
Dasyatidae	*Pateobatis fai*	Pink Whipray	DHF
Dasyatidae	*Urogymnus asperrimus*	Porcupine Ray	RUA
Elopidae	*Elops machnata*	Tenpounder	EMA
Engraulidae	*Thryssa baelama*	Baelama anchovy	TBA
Engraulidae	*Encrasicholina devisi*	Devis' anchovy	EDE
Engraulidae	*Stolephorus indicus*	Indian anchovy	SID
Gerreidae	*Gerres infasciatus*	Nonbanded whipfin mojarra	GIN
Gerreidae	*Gerres longirostris*	Strongspine silver-biddy	GLO
Gerreidae	*Gerres oyena*	Common silver-biddy	GOY
Haemulidae	*Diagramma pictum*	Painted sweetlips	DPI
Haemulidae	*Pomadasys kaakan*	Javelin grunter	PKA
Hemiramphidae	*Hemiramphus far*	Black-barred halfbeak	HFA
Hemiramphidae	*Hemiramphus marginatus*	Yellowtip halfbeak	HMR
Hemiramphidae	*Hyporhamphus sindensis*	Sind halfbeak	HIN
Hemiramphidae	*Rhynchorhamphus georgii*	Long billed half beak	RGE
Leiognathidae	*Gazza minuta*	Toothpony	GMI
Leiognathidae	*Leiognathus equulus*	Common ponyfish	LEQ
Lethrinidae	*Lethrinus lentjan*	Pinkear emperor	LLE
Lethrinidae	*Lethrinus nebulosus*	Spangled emperor	LNE
Lutjanidae	*Lutjanus argentimaculatus*	Mangrove red snapper	LAR
Lutjanidae	*Lutjanus ehrenbergii*	Ehrenberg's snapper	LEH

Lutjanidae	*Lutjanus fulviflamma*	Blackspot snapper	LFU
Microdesmidae	*Parioglossus raoi*	Rao's hover goby	PRA
Monodactylidae	*Monodactylus argenteus*	Silver moony	MAR
Mugilidae	*Planiliza subviridis*	Greenback mullet	LSU
Mugilidae	*Ellochelon vaigiensis*	Squaretail mullet	MES
Mugilidae	*Moolgarda seheli*	Bluespot mullet	VSE
Mullidae	*Upeneus tragula*	Freckled goatfish	UTR
Nemipteridae	*Scolopsis ghanam*	Arabian monocle bream	SGA
Nemipteridae	*Scolopsis taeniata*	Blackstreaked monocle bream	STA
Platycephalidae	*Platycephalus indicus*	Bartail flathead	PIN
Polynemidae	*Polydactylus sextarius*	Blackspot threadfin	PSE
Pomacanthidae	*Pomacanthus maculosus*	Yellowbar angelfish	PMB
Rhinobatidae	*Glaucostegus halavi*	Halavi Guitarfish	RBH
Sciaenidae	*Johnius belangerii*	Belanger's croaker	JBE
Sciaenidae	*Johnius carutta*	Karut croaker	JCA
Sciaenidae	*Johnius dussumieri*	Sin croaker	JSI
Sciaenidae	*Johnius borneensis*	Sharpnose hammer croaker	JBO
Sciaenidae	*Protonibea diacanthus*	Blackspotted croaker	PDI
Scombridae	*Rastrelliger kanagurta*	Indian mackerel	RAS
Serranidae	*Epinephelus epistictus*	Dotted grouper	EEP
Serranidae	*Epinephelus bleekeri*	Bleeker’s grouper	EBE
Serranidae	*Epinephelus coioides*	Orange spotted grouper	ECO
Sillaginidae	*Sillago sihama*	Silver sillago	SSH
Sillaginidae	*Sillago arabica*	Arabian sillago	SAA
Soleidae	*Brachirus orientalis*	Oriental sole	BOR
Soleidae	*Pardachirus marmoratus*	Finless sole	PMA
Soleidae	*Solea stanalandi*	Stanaland's sole	SST
Soleidae	*Zebrias captivus*	Convict zebra sole	ZEA
Sparidae	*Acanthopagrus latus*	Yellowfin seabream	ARA
Sparidae	*Acanthopagrus berda*	Picnic seabream	ABE
Sparidae	*Acanthopagrus sheim*	Spotted yellowfin seabream	ACS
Sparidae	*Crenidens crenidens*	Karanteen seabream	CCS
Sparidae	*Rhabdosargus sarba*	Goldlined seabream	RSA
Sphyraenidae	*Sphyraena jello*	Pickhandle barracuda	SJE

Sphyraenidae	*Sphyraena acutipinnis*	Sharpfin barracuda	SAC
Sphyraenidae	*Sphyraena flavicauda*	Yellowtail barracuda	SFL
Sphyraenidae	*Sphyraena obtusata*	Obtuse barracuda	SOB
Sphyraenidae	*Sphyraena putnamae*	Sawtooth barracuda	SPU
Teraponidae	*Pelates quadrilineatus*	Fourlined terapon	PGU
Teraponidae	*Terapon jarbua*	Jarbua terapon	TJA
Teraponidae	*Terapon puta*	Smallscaled terapon	TPU
Triacanthidae	*Triacanthus biaculeatus*	Shortnose tripodfish	TBC
Siganidae	*Siganus luridus*	Dusky spinefoot	SLU
Siganidae	*Siganus canaliculatus*	White-spotted spinefoot	SCA

Table C. 2. 3. A pre-determined fish species ID list supplied by fisheries experts at the Environment Agency of Abu Dhabi (Grandcourt 2008; Francis et al., 2022).

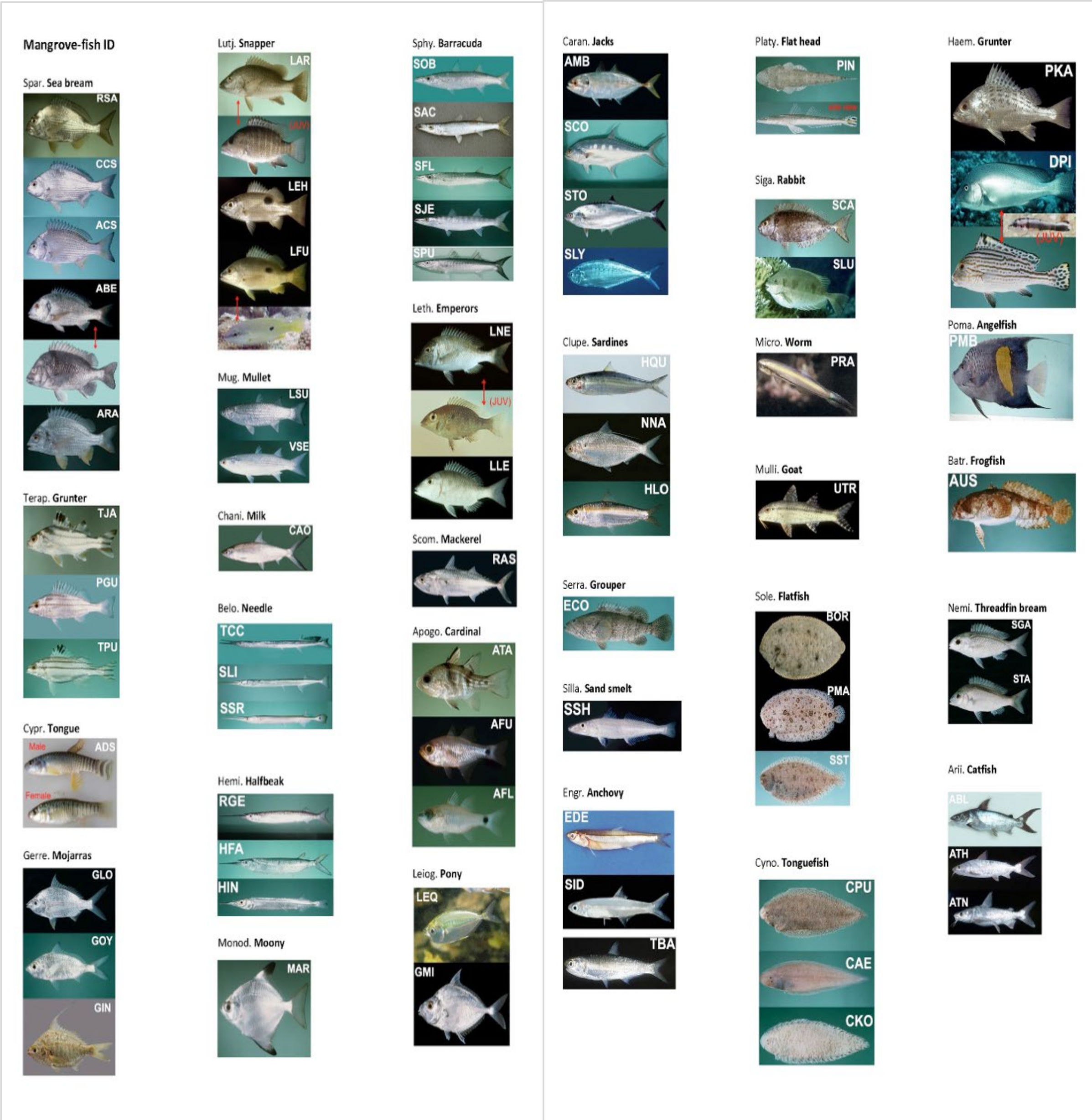


Figure C. 1. 3. Mangrove fish ID photos.

Fish abundance & size datasheet Date:______ Time:___ Site name:___ Station:___ Transect no:___

		Abundance						Size				
		1--2	**3—5**	**6--15**	**16--25**	**>26**		**3--8**	**9--14**	**15--20**	**21--26**	**>27**
Spar. **Sea breams**												
	RSA						RSA					
	CCS						CCS					
	ACS						ACS					
	ABE						ABE					
	ARA						ARA					
Terap. **Grunters**												
	TJA						TJA					
	PGU						PGU					
	TPU						TPU					
Cypr. **Tongue**												
	ADS						ADS					
Gerre. **Mojarras**												
	GLO						GLO					
	GOY						GOY					
	GIN						GIN					
Lutj. **Snapper**												
	LAR						LAR					
	LEH						LEH					
	LFU						LFU					

Mug. **Mullet**												
	LSU						LSU					
	VSE						VSE					
Chani. **Milk**												
	CAO						CAO					
Belo. **Needle**												
	TCC						TCC					
	SLI						SLI					
	SSR						SSR					
Hemi. **Halfbeak**												
	RGE						RGE					
	HFA						HFA					
	HIN						HIN					
Sphy. **Barracuda**												
	SOB						SOB					
	SAC						SAC					
	SFL						SFL					
	SJE						SJE					
	SPU						SPU					

		Abundance						Size				
		1–2	**3—5**	**6–15**	**16–25**	**>26**		**3–8**	**9--14**	**15–20**	**21–26**	**>27**
Serra. **Grouper**												
	ECO						ECO					
Sand smelts												
	SSH						SSH					
Engr. **Anchovy**												
	EDE						EDE					
	SID						SID					
	TBA						TBA					
Platy. **Flat head**												
	PIN						PIN					
Leiog. **Pony**												
	LEQ						LEQ					
	GMI						GMI					
Siga. **Rabbit**												
	SCA						SCA					
	SLU						SLU					
Micro. **Worm**												
	PRA						PRA					
Mulli. **Goat**												
	UTR						UTR					

Sole. **Flat Fish**												
	BOR						BOR					
	PMA						PMA					
	SST						SST					
Cyno. **Tongue**												
	CPU						CPU					
	CAE						CAE					
	CKO						CKO					
Haem. **Grunts**												
	PKA						PKA					
	DPI						DPI					
Poma. **Angel**												
	PMB						PMB					
Batr. **Frog**												
	AUS						AUS					
Nemi. **Threadfin bream**												
	SGA						SGA					
	STA						STA					
Arii. **Catfish**												
	ABL						ABL					
	ATH						ATH					
	ATN						ATN					
Shark												
Ray												

		Abundance						Size				
		1--2	**3—5**	**6--15**	**16--25**	**>26**		**3--8**	**9--14**	**15--20**	**21--26**	**>27**
Leth. **Emperors**												
	LNE						**LNE**					
	LLE						**LLE**					
Scom. **Mackerel**												
	RAS						**RSA**					
Moony												
	MAR						**MAR**					
Apogo. **Cardinal**												
	ATA						**ATA**					
	AFU						**AFU**					
	AFL						**AFL**					
Jacks												
	AMB						**AMB**					
	SCO						**SCO**					
	STO						**STO**					
	SLY						**SLY**					
Clupe. **Sardines**												
	HQU						**HQU**					
	NNA						**NNA**					
	HLO						**HLO**					

Figure C. 1. 4. Fish abundance and size sample data sheet.

Appendix C.3: Supplementary results

Figure C. 1. 5. Underwater field photos of fish species observed during sampling in mangroves of the Southern Arabian Gulf. Top left; *Lutjanus argentimaculatus*. Top right and bottom; *Epinephelus coioides*.

Figure C. 1. 6. Field photographs during the underwater visual census sampling (left) and habitat survey (right) of Amna Almansoori in mangroves of Abu Dhabi, United Arab Emirates, southern Arabian Gulf.

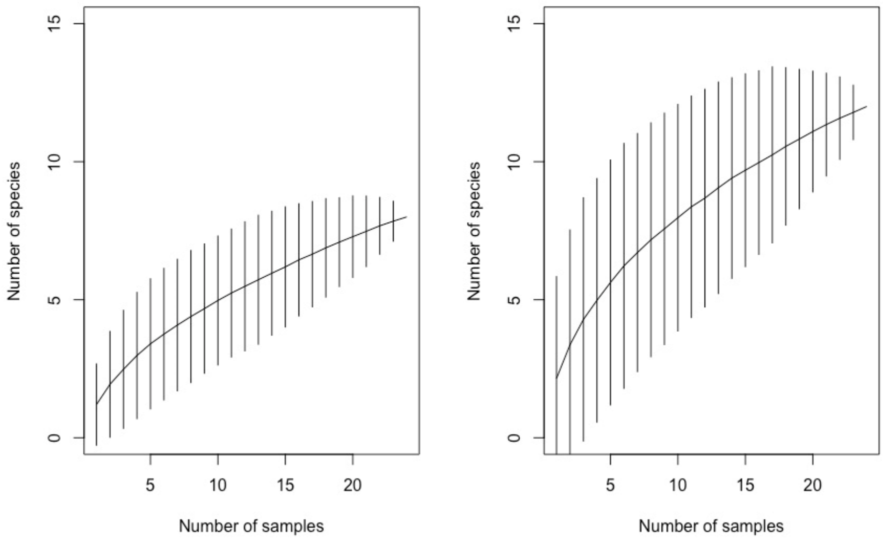


Figure C. 1. 7. Species accumulation curve across study stations; JA+JB (left) and RA+RB (right).

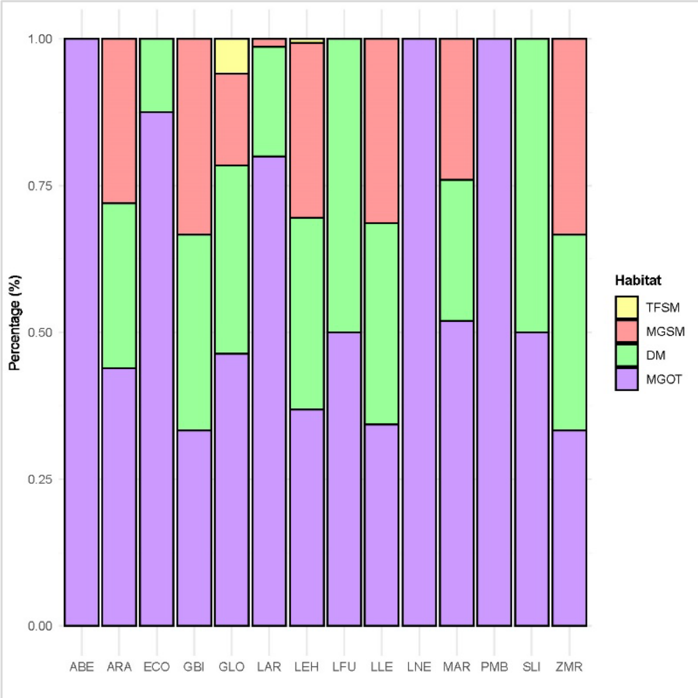


Figure C. 1. 8. Cumulative (%) of species among habitats.

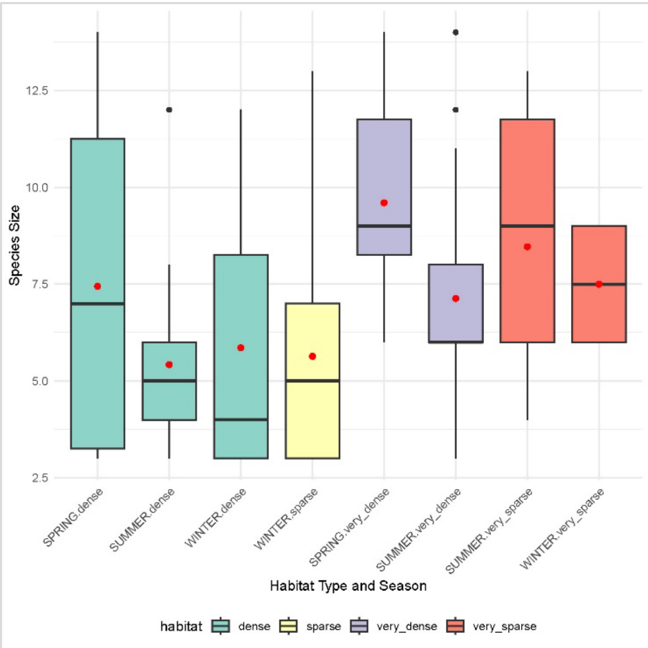
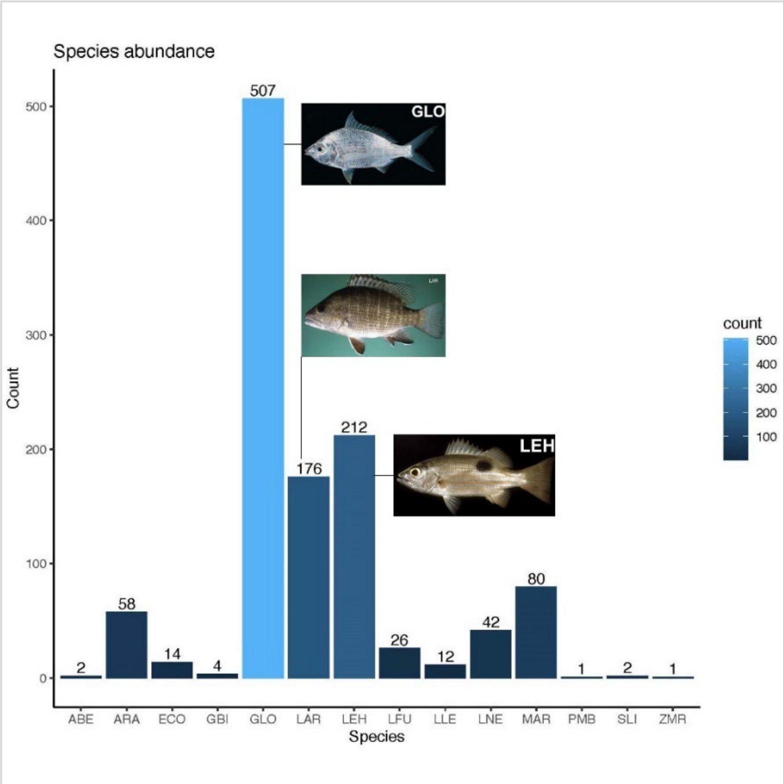


Figure C. 1. 9. Mean fish species size across habitats and seasons.



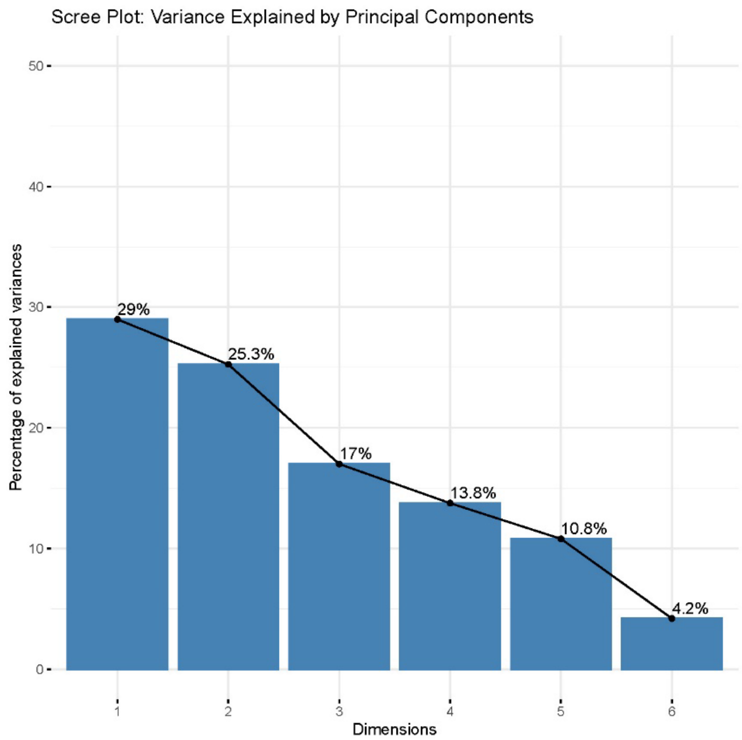


Figure C. 1. 10. (above) Total fish species abundance. (below) PCA results: Scree plot variance explained by principal components

Appendices D1-3: Supplementary material to Chapter 5

Appendix D.1: Newcastle University's ethics policy and procedure (Ref: 40431/2023)

From: Policy & Information Team, Newcastle University
To: Amna Almansoori (PGR)
Subject: Ethics Form Completed for Project: Evaluating mangrove habitats as part of an interconnected coastal mosaic for supporting biodiversity in the Southern Arabian Gulf AMNA ALMANSOORI
Date: Thursday, December 14, 2023 12:32:05 PM

External sender. Take care when opening links or attachments. Do not provide your login details.

Ref: 40431/2023

Thank you for submitting the ethical approval form for the project 'Evaluating mangrove habitats as part of an interconnected coastal mosaic for supporting biodiversity in the Southern Arabian Gulf' (Lead Investigator: AMNA ALMANSOORI). Expected to run from 06/01/2020 to 15/12/2023.

Your project already has ethical approval in place and your faculty representative has agreed to accept this approval in lieu of a new application. Based on your answers, the University Ethics Committee grants its approval for you to start working on your project. Please be aware that if you make any significant changes to your proposal then you should complete this form again, as further review may be required. This confirmation may be used within a research portfolio as evidence of ethical approval. Please note: this confirmation will be the only correspondence you should expect to receive as evidence of ethical approval. There will be no other confirmation provided. You may now proceed with research. If you have any queries, please review the internal and external ethics FAQ pages before contacting res.policy@ncl.ac.uk.

Best wishes

Research Policy Intelligence and Ethics Team,

Research Strategy & Development
res.policy@ncl.ac.uk

Figure D. 1. 1. Ethics Form Completed for Project Ref: 40431/2023.

Appendix D.2: Description of participants

No.	Background	Group	Date of interview	Duration of interview	Place of interview
1	UAE Resident	Local community	6 Feb 2023	55 minutes	In-person
2	UAE Resident	Local community	8 Feb 2023	50 minutes	In-person
3	UAE Resident	Local community	19 Feb 2023	60 minutes	In-person
4	UAE Resident	Local community	20 Feb 2023	60 minutes	In-person
5	UAE Resident	Local community	21 Feb 2023	50 minutes	In-person
6	Professor	Academic	22 May 2023	60 minutes	Zoom
7	Marine science expert	NGO staff	24 May 2023	55 minutes	Zoom
8	Professor	Academic	25 May 2023	60 minutes	Zoom
9	Marine science expert	Environmental expert	31 May 2023	55 minutes	Zoom
10	Oil & Gas Industry	Non-environmental staff	8 June 2023	50 minutes	Zoom
11	Oil & Gas Industry	Non-environmental staff	9 June 2023	60 minutes	Zoom

Table D. 2. 1. Background, expertise level on mangroves, and interview date of each participant.

Appendix D.3: Transcripts of interviews (n = 11)