The Conservation, Sustainable Use and Management of Mangrove Habitats in Oman

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Abstract

Mangroves are significant contributors to human wellbeing in many tropical and sub-tropical coastal communities and deliver a wide range of provisioning, regulating, cultural and supporting ecosystem services. Worldwide, the value of these services has been researched, but not in Oman. I explore the role of mangrove ecosystems in Oman dominated by *Avicennia marina* and the value of their services based on perceptions of locals, key utilisers of the ecosystem. I also examine temporal and spatial change in mangrove cover and identify the drivers of environmental change affecting these ecosystems. Perceptions were captured using self-completed questionnaires, aerial extent was estimated from aerial photgraphs and secondary fisheries data were used to evaluate the support of Omani fisheries by mangroves. Carbon sequestration was estimated through a combination of field sampling and reported allometric equations and the service of storm buffering evaluated using data from windroses and mangrove extent. For cultural services assessment, mapping and semi-structured interviews with locals were used. I found that Oman's mangroves are mainly threatened by cyclonic events, both intense marine wave action and flash flooding from the landward side, as well as urbanisation, leading to coastal squeeze with implications for sea-level rise. While mangroves do not appear to highly support commercial fisheries in Oman, they do support ecologically important ecosystem engineers and essential prey for higher tropic levels (including commercially important species). Estimated values of carbon stock ranged from 59.90 to 133.05 t/ha, much lower values for *A. marina* inhabiting more favourable environmental conditions in other parts of the world. Cultural services were highly appreciated by locals, reflecting the influence of both Arabic and Islamic identity in Omani society. Intrinsic, instrumental and relational values of nature were all highlighted by locals. An Ecosystem Based Management approach is advocated for the conservation and sustainable use of mangroves in Oman.

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Author's Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

I also declare that all the figures and tables are generated by me. Any information from other source is clearly referenced and all the sources of data used to generate the maps are clearly acknowledged. All the questionnaires and interviews contents were produced by me, approved by the University of York Ethics Committee, and any guidance studies or toolkits used were referenced. The self-completion questionnaires were distributed and collected back in two sites (Al-Sawadi and Qurayyat) by me, while in Al-Qurum, my nephew (Mr. Abdul Salam Al-Afifi) did help and I provided him a full guidance of the process of distribution and collection with full explanations of the questions and their purpose. In sampling mangroves in Al-Qurum, I was always accompanied by a family member to ensure my safety. The measurements were taken by me or under my supervision at all times. I was occasionally accompanied and assisted with measurements (again under my supervision) by Mr. Sami Al-Shuaibi, a former Biology student. I self-travelled to Qurayyat, conducted and transcribed the interviews.

I have tried to my best of knowledge not to breach rules of intellectual proprieties of any author or organisations.

Zakiya Musallam Mohammed Al-Afifi

To:

My beloved mother, who always sought her literacy dream in me.

Chapter 1

Introduction

1.1. Ecosystems and human well-being

Humanity has always depended on ecosystems and their primary resources which have also played a pivotal role in civilisations, habits, beliefs and traditions (Costanza et al. 2007, Everard 2017). Although the role of ecosystems in improving human well-being has been recognised throughout history, this has been articulated through the concept of 'ecosystem services' in the scientific literature since the 1960s and has fully emerged as an influential concept for both the publics and for policy makers through the Millennium Ecosystem Assessment (MA) in 2005 (Everard 2017).

The MA developed an Ecosystem Services Framework (Figure 1.1) that links all the assets provided by ecosystems (Duke et al. 2014) to community well-being (Fisher et al. 2008, Turner et al. 2008, Everard 2017). The framework presents a qualitative classification of services into provisioning, regulating, cultural and supporting services (MA 2005, Alongi 2009, Brander et al. 2012, Grimsditch et al. 2013, Raffaelli and White 2013, Duke et al. 2014, Thomas 2014, Herr and Landis 2016, Everard 2017). The framework also provides examples for each service provided by an ecosystem for in-depth understanding of the functionality of processes and services within ecosystems.

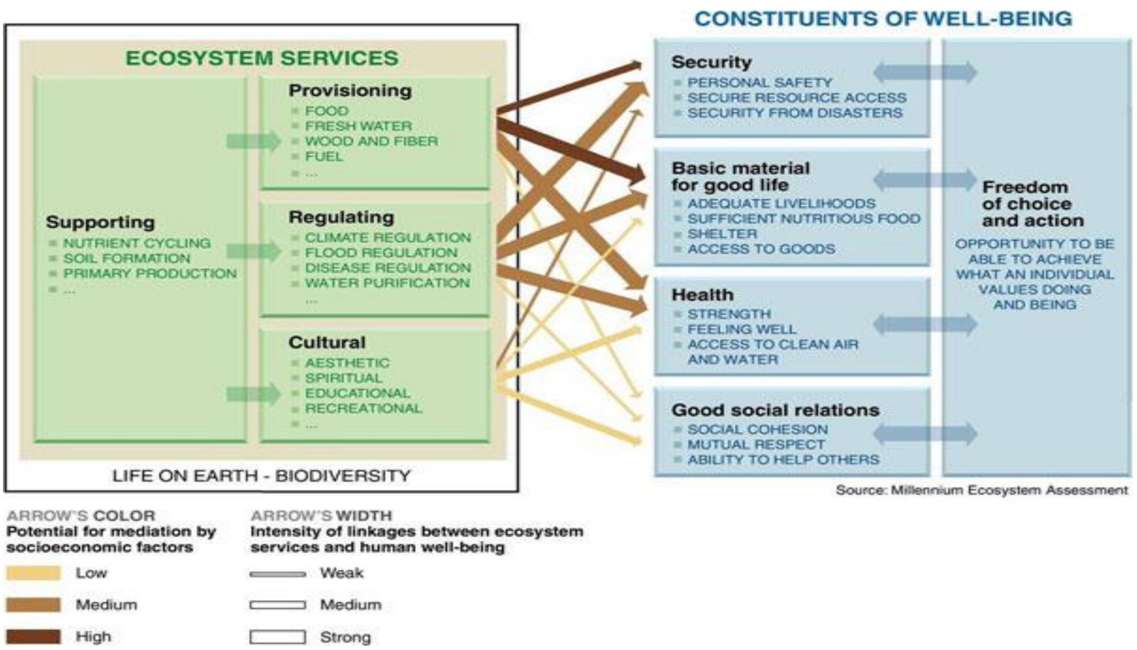


Figure 1.1. Ecosystem services framework developed by and reproduced from MA (2005).

With respect to how functions, services, goods and benefits are related, the literature mostly supports the advocacy of Boyd and Banzhaf (2007) in considering services as the "end product" or the "final service" that humans gain from an ecosystem (Turner et al. 2008, Everard 2017). In other words, *'final ecosystem services are the components of nature, directly enjoyed, consumed, or used to yield human well-being'* (Boyd and Banzhaf 2007, p.619). Based on the latter definition, Fisher et al. (2008) split ecosystem services into intermediate, final and benefits. Figure 1.2, displays a simplified and illustrative relationship between these divisions.

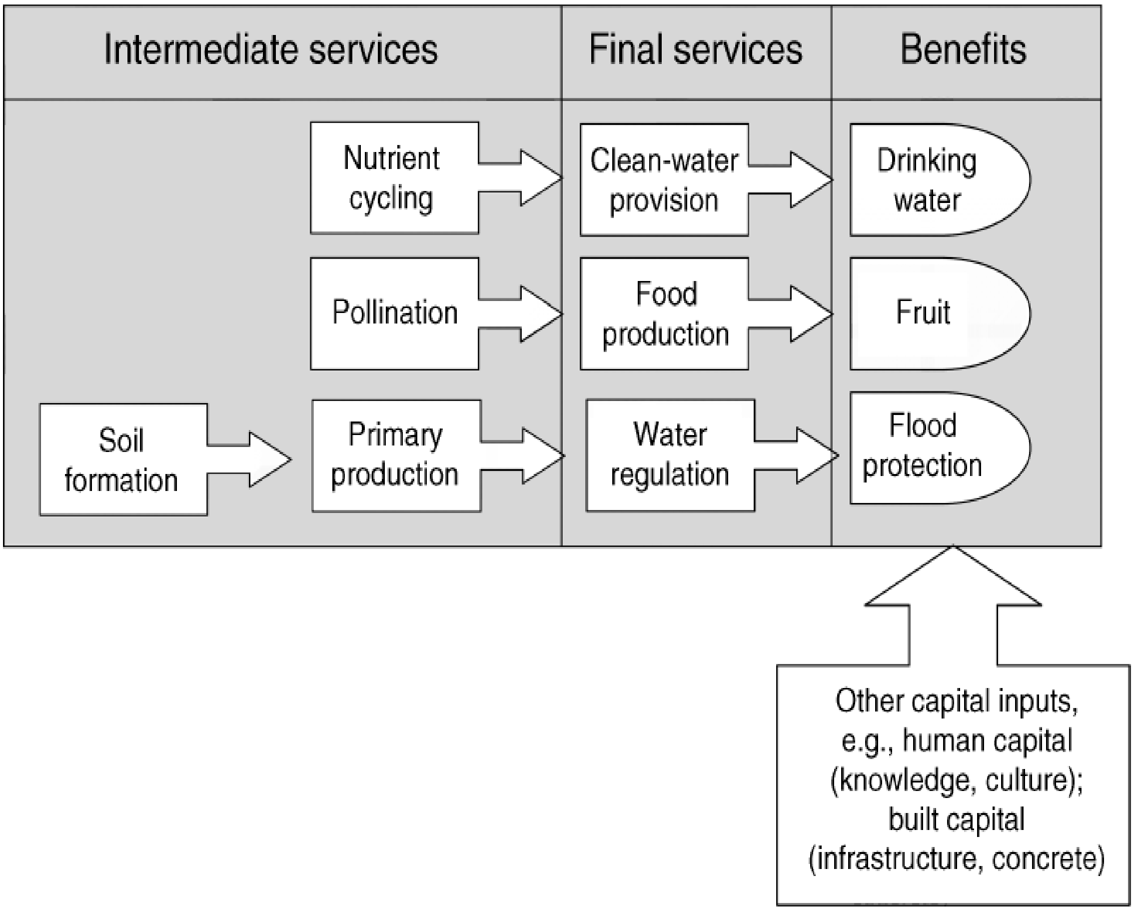


Figure 1.2. The relationships between different divisions of ecosystem service (obtained from Fisher et al, 2008).

There are many variants and developments of the two conceptual frameworks in Figures 1.1 and 1.2 which have developed subsequently, for example, the Cascade Model of Haines-Young and the UKNEA (UK National Ecosystem Assessment) framework (reviewed in Raffaelli and White 2013), and the CICES (Common International Classification of Ecosystem Services) classification of services as used operationally for mapping ecosystem services across Europe as described by the MAES (Mapping and Assessment of Ecosystems and their Services) working group (https://biodiversity.europa.eu/maes). It is expected that such frameworks and classification schemes will evolve towards one that becomes common practice in the coming years – indeed CICES is already on version 4.3. For the purposes of this thesis, the original scheme of the MA will suffice since it is one in common practice and understandood by the publics and the policy community.

This thesis will focus on mangrove ecosystems, which are unique and highly productive but globally threatened coastal ecosystems, providing a wide range of services for human beings. Also, in Oman, my study region, only limited research has been carried out to date on the country's mangrove systems especially in the context of the services they may or may not provide for the Omani population.

1.2. Biological and physico-chemical characteristics of mangrove ecosystems

Mangroves are one of the most productive and ecologically remarkable coastal ecosystems, comprised chiefly of flowering trees and shrubs (Robertson and Alongi 1992, Alongi 2002, 2009, MA 2005, Atheull et al. 2009, Duke et al. 2014) without an understory of shrubs and ferns (Robertson and Alongi 1992, Alongi 2002, 2009). The term "mangrove" can refer to the ecosystem as a whole or the individual tree species, and some authors use the term "mangal" when referring to the ecosystem (McLeod et al. 2009, Kaiser 2011). However, the term mangal is not in widespread use, especially in the non-scientific literature, and I will therefore use the term "mangrove" for both the ecosystem and the individual plants. In almost all places in the text, the sense in which the term is being used will be clear and obvious.

Mangroves are a limited type of forests with an estimated global coverage of 15.2 million ha (Alongi 2002, Atheull et al. 2009, Van Lavieren et al. 2012, Duke et al. 2014) . They occur in 124 countries worldwide (Yee 2010, Kuenzer et al. 2011, Van Lavieren et al. 2012, Duke et al. 2014), within the latitudes of 25–30°S and 25–30°N (Kuenzer et al. 2011) and nearly half of these forests are found in only five countries: Indonesia, Australia, Brazil, Nigeria, and Mexico (Yee 2010). They are the sole evergreen woody halophytes (Alongi 2002, Kuenzer et al. 2011) inhabiting the tropics and subtropics (Alongi 2002, Kuenzer et al. 2011, Van Lavieren et al. 2012, Duke et al. 2014), their distribution co-insides with an ocean isotherm of 20℃ in winter (Alongi 2009) and the species present vary with the prevailing pH and salinity conditions (Wakushima et al. 1994).

Normally, a mangrove tree grows up at mean sea level and can reach a height exceeding one and a half metres (Robertson and Alongi, 1992). Environmental conditions for mangroves become less favourable at higher latitudes and therefore the tropics host the most favourable conditions for mangroves, where the canopy height can range between 30-40m (Kuenzer et al. 2011).

The intertidal environment for mangroves is typically water-saturated with often anaerobic sediment and fluctuating salinities (Robertson and Alongi, 1992, Yee 2010, Kuenzer et al. 2011). In order to thrive in these conditions, mangroves have evolved remarkable morphological and physiological characteristics, for example, aerial root systems to access oxygen from the air and water above the anaerobic sediment, supporting structures in the form of roots and props for anchoring in a loose, muddy environment, variable degrees of viviparous tidally-dispersed propagules, salt-excreting leaves and quick rates of canopy production (Robertson and Alongi 1992, Alongi 2002, Kuenzer et al. 2011, Yee 2010).

In comparison to tropical terrestrial forests, mangroves exhibit relatively low levels of biological diversity and species richness, and simple food webs. Mangrove trees contain 9 phylogenetic orders, 20 families, 27 genera and approximately 70 species. The highest diversity is located in Nigeria, Brazil and in the Indo-Pacific region in Indonesia, Australia (Alongi 2002; 2009, Kuenzer et al. 2011).

1.3. Environmental factors influencing mangroves

Various physico-chemical and biological limiting factors control both the distribution and abundance of mangroves. According to Alongi (2002, 2009), they are limited by temperature at the global level and by changes in rainfall, tides, waves and freshwater input at both the regional and local scale. At the individual level, the growth of mangrove trees is driven, like all plants, chiefly by sunlight, temperature (Alongi 2002; 2009, Yee 2010) and accessibility of water and nutrients, with different species and associated communities distributed in zones down the intertidal gradient according to salinity, soil chemistry and category, predation and competition (Alongi 2002, 2009).

The response of mangrove species to environmental factors is highly variable between regions. For example, mangroves growing in regions with high precipitation are subjected to lower salinity (less salt stress) and therefore are suggested to be more productive and more capable of producing tall trees, up to 40m high with dense canopies (McLeod et al. 2009, Kuenzer et al. 2011). In contrast, mangroves in low rainfall areas are more likely to be less productive, with short trees (1-4m) and a more open canopy (McLeod et al. 2009).

The health of mangrove forests can be affected by both natural and anthropogenic disturbances. It has been argued that the impacts of anthropogenic disturbances last longer than the impacts of natural ones and impose the greater threat for mangroves (Allen et al. 2001). The loss of mangrove forests due to disturbances has been estimated to reach 40% in some countries over the last two decades (Van Lavieren et al. 2012). Worldwide, the loss of mangroves has risen to one-third since the 1950s (Alongi 2002, Duke et al. 2007, Donato et al. 2011).

Natural disturbances can include cyclones (and hurricanes), tsunamis, floods, sea level rise (SLR), infectious diseases (pathogens) and pests (Allen et al. 2001, Alongi 2008, 2009) all of which increase the pressure on mangroves, both now and into the future. It has been suggested that global climate change has resulted in increased natural disturbances, like storms, CO_2 acidification and accelerated sea level rise as a consequence of human activities (McLeod et al. 2009). Both changes in sea level and on storminess frequency and intensity are the main concerns among these disturbances (Allen et al. 2001).

Other anthropogenic disturbances include the expansion of fish and crustacean farms for aquaculture (mangrove clearing/destruction and eutrophication), diversion of freshwater for land irrigation, urban development, agriculture, grazing (e.g. camels and goats), overharvesting of timber, overfishing, mining and introduction of pollutants such as herbicides, pesticides, sewage and hydrocarbons (Allen et al. 2001, Alongi 2009, Yee 2010, Alexandris et al. 2013). Of these various anthropogenic threats to mangroves, it has been suggested that the most significant is shrimp aquaculture, with shrimp farms (McLeod et al. 2009) being responsible for the loss of 20-50% of mangroves around the world (Yee 2010). This is mainly attributed to the perception of mangroves as wastelands with no market value, particularly in developing countries, which can be cleared for aquaculture for private enterprise (De Lacerda 2002, Tam and Wong 2002, Carter et al. 2015).

Alongi (2008, 2009) argues that the observed decline of mangroves could be mainly attributed to the anthropogenic impacts. Turner et al. (2000) argue that local communities have traditionally utilised the mangrove ecosystem for their livelihoods, but a UNEP report in 1994 cited in McLeod and Salm (2006) showed that local communities are now the dominant factor in ecosystem degradation due to overexploitation of the biodiversity and services provided by mangroves. In contrast, Alongi (2002) argues that the major problem is the commercial groups from outside the local communities. Nevertheless, it is clear that mangrove degradation and decline is human- driven, highlighting the need for local, regional and national plans to reduce threats and develop new strategies and practices for more sustainable utilization of mangroves.

1.4. Valuable services and benefits of mangroves

Mangrove ecosystems provide a wide range of services which arise when ecosystem structures and functions contribute directly or indirectly to improvement of the welfare of a society (Fisher et al. 2008, Atheull et al. 2009). Put simply, they are all the material and non-material benefits acquired by people from the ecosystem (MA 2005, Fisher et al. 2008). Based on the approved categorisation of the MA for ecosystem services, mangrove services can be classified into provisioning, regulating, cultural and supporting services (MA 2005, Fisher et al. 2008, Brander et al. 2012, Raffaelli and White 2013, Duke et al. 2014).

1.4.1. Provisioning services

The provisioning services include vital sources of food, medicine, timber fuel and fibres in certain areas (MA 2005, Alongi 2009, Brander et al. 2012, Grimsditch et al. 2013, Raffaelli and White 2013, Duke et al. 2014, Thomas 2014, Herr and Landis 2016) as well as freshwater, genetic resources and animal products used for ornamental resources (MA 2005, Grimsditch et al. 2013, Thomas 2014).

Moreover, mangroves support many floral and faunal communities worldwide, including endangered and protected species (Atheull et al. 2009, Duke et al. 2014). The faunal components of these forests comprise terrestrial, estuarine or marine species (Duke et al. 2014). They provide nurseries and shelters for mammals, reptiles, insects, many crustaceans, shellfish and fish (Alongi 2008, 2009,2011, McLeod et al. 2009), which contribute substantially as a source of income for livelihoods.

It has been estimated that the annual revenues gained from timber products and nursery services can reach US$ 200,000 – US$ 900,000 per ha (McLeod et al. 2009). In addition, revenues can be obtained from ecotourism activities in mangrove forests (Mahmud et al. 2015, Faizal et al. 2017, Kenny 2017). Such activities could include bird watching, angling (Mahmud et al. 2015), locally-guided fishing, walking inside the forests and kayaking (Kenny 2017). In some countries projects of eco-cottages have been established as a source of revenue (Kenny 2017).

1.4.2. Regulating services

The regulating services of mangroves comprise climate regulation, biological control, including human diseases, and pollination (MA 2005, p.58, Kuenzer et al. 2011, Grimsditch et al. 2013, Thomas 2014). Mangroves also defend the coast against erosion and storms/tsunamis and support the accumulation of sediments, trapping and filtering pollutants (Alongi 2009, McLeod et al.2009, Van Lavieren et al. 2012). Mangroves are known to act as storm buffers that reduce wave energy at the shoreline (MA 2005, p.58, Kuenzer et al. 2011, Grimsditch et al. 2013, Herr and Landis 2016), which in turn reduces loss of life and property damage in extreme cases.

These ecosystems are also vital in maintaining climate and air quality by acting as sinks for contaminants and atmospheric carbon (MA 2005, p.58, Alongi 2009, Kuenzer et al. 2011, Van Lavieren et al. 2012, Grimsditch et al. 2013, Herr and Landis 2016) although they occupy only 2.4% of the total area of worldwide tropical forests (Ray et al. 2011). The stored carbon in both biomass and sediments of these coastal ecosystems is commonly referred to as 'blue carbon' (Yee 2010, Grimsditch et al. 2013, Thomas 2014, Herr and Landis 2016). The unique location of mangroves at the land-ocean interface zones increases their potential role in nutrient exchange and in biogeochemical carbon cycling (Mitra et al. 2011).

The level of atmospheric CO_2 has increased from 280 ppmv in 1880 to nearly 370 ppmv in the period to 2000 (McLeod et al. 2009), while the IPCC has projected it to reach to 700 ppmv towards the end of this century (Vanaja et al. 2017). Research shows that the increase in CO_2 level has enhanced the photosynthetic rate of mangroves, which has stimulated growth as well (McLeod et al. 2009). The interest in the potential role of mangroves in carbon sequestration and storage is driven by concerns over global warming (Mitra et al. 2011, Ajonina et al. 2014) and mangroves are among the most carbon rich ecosystems on the planet. McLeod et al. (2009), Mitra et al. (2011) and Ajonina et al. (2014) believe that mangroves have high potential for carbon sequestration and they support the establishment of restoration and conservation plans for mangroves because of their vital role in climate change adaptation and mitigation.

1.4.3. Cultural services

Cultural services are associated with human experience and perception towards the ecosystem, which validate the protection of ecosystems for the publics (Atheull et al. 2009, Duke et al. 2014). These include the non-physical benefits gained from the ecosystem (MA 2005, Clifton et al. 2014) such as cultural diversity, spiritual and religious values, traditional and formal knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values and recreation and ecotourism (MA 2005, Kuenzer et al. 2011, Grimsditch et al. 2013, Herr and Landis 2016, Thomas 2014). Although some scholars find cultural ecosystem services intangible compared to provisioning and regulating services (Sattarfield et al. 2012, Plieninger et al. 2013) and immeasurable in most cases (Chan et al. 2016), they are undeniably valuable to humans (Chan et al. 2012, Chan et al. 2016). Also, most cultural values are catogrised as non-use values, however, cultural and societal human interactions are still needed to recognise and appreciate them (Costanza et al. 2017).

1.4.4. Supporting services

Supporting services, such as nutrient cycling and soil formation, are vital for the assimilation of the other services (Clifton et al, 2014). They differ from the above-mentioned services in their temporal direct/indirect impacts on human life and develop over a long period time (MA 2005). Consequently, some services like biological control can be categorised as a regulating or supporting service, according to the temporal effect on human well-being. Nutrient cycling and primary production are the most cited supporting services (MA 2005, Kuenzer et al. 2011, Grimsditch et al. 2013).

1.4.5. The role of mangroves in the support of neighbouring ecosystems

Mangroves facilitate the presence of other marine ecosystems like seagrass beds, coral reefs and intertidal mud and sand flats due to a direct connectivity with these environments (Duke et al. 2014). Mangroves provide a protected nursery for juvenile fish inhabiting seagrass beds and coral reefs at maturity (Sandilyan and Kathiresan 2012). Also, mangrove plays a major role as a foraging habitat for visiting faunal species from neighbouring ecosystems (Nagelkerken et al. 2008). In addition, mangroves filter pollutants and heavy metals and trap sediment, which improves the health of adjacent ecosystems. For example, inland water discharge purified by mangroves provides cleansed water for coral reef growth (McLeod et al. 2009).

1.5. Ecological indicators as measures of service flow

Benefits gained from an ecosystem like mangroves have been described by Fisher et al. (2008) as anthropocentric. Moreover, the flow of ecosystem services from a natural capital stock varies depending on the biophysical environment and the anthropogenic influences on vegetative cover, land utilisation and climatic changes (Burkhard et al. 2012). Human capital and complementary assets are needed to access these benefits (Jones et al. 2016, Costanza et al. 2017, Riley et al. 2017). Human capital has been defined by Jones et al. (2016, p.154) as "*the productive capacity of human beings and encompasses the stock of capabilities held by individuals such as knowledge, education, training, skills as well as physical and mental characteristics like behavioural habits and physical and mental health*". The flow of service from ecosystem (natural capital) to the beneficiaries (human) is facilitated through other complementary capitals such as produced capital, social capital, cultural and financial capital (Jones et al. 2016, Costanza et al. 2017). Produced capital comprises infrastructure, such as roads, buildings, factories and vessels (Jones et al. 2016, Riley et al. 2017, Costanza et al. 2017). Social capital summarises the relationships resulting from the social networks and connectivity and the stock of contacts among the different groups of the community (Jones et al. 2016, Riley et al. 2017). Cultural capital is more related to holding beliefs and spirituality towards nature (Jones et al. 2016, Costanza et al. 2017). Financial capital facilitates the derivation of services through the funds provided for the activities needed to access the services (Jones et al. 2016, Riley et al. 2017).

Researchers have used indicators to estimate and measure flows of services as well as to monitor the dynamics and conditions within an ecosystem, because most ecosystem services are hard to quantify directly (Burkhard et al. 2012, Egoh et al. 2012). Wood et al. (2010) argues that indicators are an effective tool that can be used by both publics and decision makers for more sustainable management of natural resources, whilst Burkhard et al. (2012) see indicators as useful for valuing ecosystem services at the institutional and decision-making levels. In addition, the MA (2005) asserts that the indicators are essential to monitor environmental changes in ecosystems and the capacity of ecosystems to deliver services. A wide variety of indicators can be used to monitor ecosystem services (Table 1.1).

Wood et al. (2010) and Burkhard et al. (2012) have highlighted the most important criteria for selecting indicators as follows:

a) they should be quantifiable.

b) they should be clear and easily explained.

c) they must be informative.

d) they must respond to environmental change.

In order to function and operate, these indicators need to be SMART (Cromier and Elliotte 2017). SMART indicators seek the achievement of marine management goals (Cromier and Elliotte 2017). Such SMART indicators should be (Cromier and Elliotte 2017, p.29):

a) *specific*: the objectives of the management strategy should be made clear to all stakeholders.

b) *measurable*: this relates to quantification mentioned above, in order to monitor the progress of objectives achievements. These indicators measure the status and changes in the ecosystem resulting from both natural and anthropogenic pressure or activities. They also measure the drivers of this change and the responses of the ecosystem to this change (Wood et al. 2010, Burkhard et al. 2012, Egoh et al. 2012, Cromier and Elliotte 2017).

c) *achievable*: should be credible and avoid conflicts.

d) *realistic*: can be implemented within the allocated resources, such as human, financial, scientific resources and knowledge resources .

e) *time-bounded*: objectives can be achieved with a certain required time period.

Table 1.1. The most commonly used indicators to monitor the flow of ecosystem services. Obtained from Wood et al. (2010), Egoh et al. (2012) and Plieninger et al. (2013).

Service	Values/Benefits	Some potential indicators
Provisioning	Food	Food yield
	Biochemicals	Vegetative cover
	Genetic resource	Vegetative cover
Regulating	Storm protection	Structure of length and width of vegetation
		Response to wave surges
	Air quality maintenance	Amount of extracted pollutants
		Tree cover
	Carbon sequestration	Biomass carbon content
	Erosion control	Rainfall rate (rainfall erosivity)
		Sedimentation rate
		Soil characteristics
	Waste treatment	Pollutants concentration
		Nutrient deposition
	Pollination	Crop yields
Cultural	Spiritual and religious value	Beliefs
	Educational	Accessibility
		Engagement in place-based activities (e.g. planting)
	Recreation and ecotourism	Accessibility
		Accommodation
		Footpaths
		Visitor numbers
	Inspiration	Vegetative cover
		Land use
	Sense of place	Authentic human attachment to the place
	Aesthetic	The beauty of the place
	Cultural heritage	Historical background of site
Supporting	Primary production	NPP (Net primary production)
	Nutrient Cycle	Amount of nutrient cycled in each ha/year
	Soil formation	Top-soil formed every year

1.6. Towards successful management of mangroves

Regardless of their value, mangroves are continuing to be degraded. In fact, mangroves were considered unattractive ecosystems by many governments until the late 1970s; being described by some as '*dangerous*' and '*unpleasant*' places (Tam and Wong 2002, p.225), which led to the underestimation of their value and therefore their overexploitation or even destruction (Tam and Wong 2002). In 1978, the recognition of mangrove benefits as realised value began to increase after a UNESCO initiative to form a group on Mangrove Ecology, followed by another group of Mangrove Ecosystems by the International Union for Conservation of Nature (IUCN) (Tam and Wong 2002). These efforts brought the need to develop more sustainable practices in these ecosystems, including restoration and conservation. In 2010, IUCN listed 11 species of mangroves out of total 70 species on its Red List of Threatened Species, while another 6 species were listed Vulnerable (Yee 2010).

1.6.1. Conservation: a valuable management option

Estuarine ecosystems including mangroves are subjected to human pressure resulting from the activities performed in the ecosystem which ultimately affect the flow of socio-economic services (Borja et al. 2016). Therefore, there is a need to maintain the ecosystems' ecological functions and their socioeconomic contribution to the well-being of communities (Sandilyan and Kathiresan 2012, Borja et al. 2016), motivated by conservation practices (Sandilyan and Kathiresan 2012) and this has been promoted by many governments (Soegiarto 2004). The selection of protected areas creates more resilient ecosystems for mitigation of the effects of climate change, like storminess and sea level rise (Gilman et al. 2008).

Typically, mature and developed ecosystems are more resistant to climate change than immature or less developed ones. In addition, conservation plans should consider the ability of a mangrove forest to migrate landward in response to sea-level rise and adapt to other threats (Gilman et al. 2008, McLeod et al. 2009). Also, it has been documented that mangrove ecosystems are a rich sink of carbon, mainly in their sediments and therefore any degradation in the ecosystem will result in a release of the stored carbon in biomass and sediments back to atmosphere (Grimsditch et al. 2013).

Many studies confirm the effectiveness of protecting existing mangrove ecosystems. For instance, it has been claimed that undamaged, healthy mangrove forests can save the lives of 90% of the coastal population in an event of a cyclone (Sandilyan and

Kathiresan 2012). This protection has an economic value as well. According to research in Thailand, the protection of existing forests costs only US$ 189/ha compared to US$ 946/ha spent on restoring degraded forests (Gilman et al. 2008). Furthermore, Sandilyan and Kathiresan (2012), find that the conservation value of each existing hectare in the Indian State of Orissa is US$ 8,700 while clearing the same area would only generate US$ 5,000.

1.6.2. Restoring the present for the future

Locally and nationally, restoration is considered as one of the core and most valuable options for sustaining the livelihoods of those who rely on mangroves (Alongi 2002) by increasing mangrove ecosystem resilience (McLeod and Salm 2006). Restoration of mangroves has recently received much attention following recognition of their valuable ecological functions (Lewis 2005) – see also section 1.4, above. It has been suggested that restoration is needed for ecosystems impacted by human activities like urbanisation and agriculture which consequently affect the ecological functions of these ecosystems (Elliott et al. 2007).

Commonly, “restoration” refers to reclamation of an adversely affected ecosystem to its previous state (Alexandris et al. 2013). Mangrove restoration usually refers to re-planting mangroves in areas where they previously existed or in areas where there is a threat of degradation (Van Lavieren et al. 2012). For successful restoration, it is recommended to use rapidly growing species of mangroves in monoculture (Alongi 2002) and to culture species from similar ecosystems growing under similar conditions (Elliott et al. 2007). Studies show that successful restoration of mangrove forests usually takes from 15 to 30 years (Lewis 2005). The success of the process is highly influenced by regular tidal action and seed availability (Lewis 2005).

One of the challenges associated with mangroves is that they are generally considered “public goods” with no restrictions on access or property rights (Turner et al. 2000). Consequently, it is hard to convince political and economic interests of the consequences of ecosystem loss and the importance of restoration of these valuable resources (Turner et al. 2000, Van Lavieren et al. 2012). The long temporal scale of restoration is also contrary to political, cultural and economic priorities, but studies have shown that restoration is cost-effective (Alongi, 2002). In general, according to The Economics of Ecosystems and Biodiversity (TEEB) initiative, the cost of sustaining an endangered ecosystem is less than the cost of allowing it to disappear (Alongi et al. 2002, Vo et al. 2012). It has been suggested that the estimated cost of restoring an area ranges from US$ 225/ha to US$ 216,000/ha (McLeod and Salm 2006).

Researchers have considered restoration as an essential pillar for supporting local communities in reducing or confining the threat of cyclones or tsunamis in developing countries with their often high population pressures on their coasts. Danielsen et al. (2005), as cited in Marois and Mitsch (2015), investigated the damage caused by the destructive tsunami in the Indian Ocean in 2004 and the effectiveness of mangroves as storm buffers. The investigation using remote sensing and Geographic Information System (GIS) involved 12 villages on the southeast coast of India with variable mangrove cover. The villages with dense mangrove cover received significantly less destruction compared to those with less cover. The villages with no mangrove defence suffered the most destructive effects of the tsunami.

Herr and Landis (2016), find that restoration is an opportunity for communities to offset their carbon footprints as part of nature-based plan for climate change mitigation. It has also been suggested that restoration along with conservation supports the sustainable harvest of fisheries (Herr and Landis 2016). Restoration also enhances the provisioning of the other services mentioned above.

Although there has been a visible worldwide increase in restoration projects, (Van Lavieren et al. 2012), Alongi (2002) argues that only a few countries like Cuba and Bangladesh have been able to significantly regain their mangroves due to such projects. Conversely, Van Lavieren et al. (2012) find a worldwide visible increase in restoration projects with a noticeable increase in mangrove area. Two of the most successful examples given by the IUCN are Gazi Bay in Kenya and Tanga in Northern Tanzania (McLeod and Salm 2006). In Gazi Bay, a huge area of mangroves was cleared for fuel between 1993 and 1995, but 300,000 mangrove trees were effectively replanted by 2004 as part of rehabilitation program started in 1997. In Tanga, replanting programmes started in 1997, achieving a rehabilitation of 107.4 ha by 2004.

To achieve successful restoration, government policies should be integrated with ecological knowledge and economic incentives (MA 2005, Fisher et al. 2008). Existing areas of mangroves that produce healthy seeds are recommended for protection to supply the seed bank for the restored areas (McLeod and Salm 2006).

1.7. Mangrove Ecosystems in the Middle East: the Omani Experience

The Omani coast extends for approximately 3165 km (MECA 2010, NCSI 2015a) including the coastal islands, and these coasts are met by three water bodies represented by the Arabian Gulf, Oman Sea and Arabian Sea (MECA 2010). Oman is one of the 124 countries which supports mangroves with an estimated forest area of 1100 ha (MECA and JICA 2004, ROPME 2013) and has been designated as the centre for mangrove conservation in the Arabian Peninsula (Grieve et al. 2006). It has been argued that the Omani coastline was extensively occupied by mangroves historically (JICA and MECA, 2004), although today the area is much reduced.

The currently limited distribution of mangroves in Oman has been attributed to several causes: a) the eradication of the trees due to overgrazing, mainly by camels and goats; b) a climate shift towards more arid conditions; c) exposure to extreme tides and winds; d) unsupportive soil properties for mangrove growth and nourishment (Cookson and Shoju 2003). The time-scales for these changes are difficult to be precise about because of the lack of historic records, but as I show in subsequent chapters in this thesis aerial photographs are available from the past several decades and these have been now analysed here. Also, many of the changes in mangrove utilisation by local communities have been profoundly influenced by the shift away from natural resource exploitation to an oil-based economy which has changed dependency on many mangroves services; this will be discussed throughout the thesis.

Mangroves forests in Oman have low species diversity due to the extreme climatic and environmental conditions in the area (ROPME 2013). The area is dominated by *Avicennia marina* with a height varying from 2-10 m (Lézine et al. 2002, JICA and MECA 2004, ROPME 2013). In Southern Oman, relatively small areas of mangroves inhabiting estuaries can reach a height of 6 m (ROPME 2013). The dense canopy of mangroves in Oman is found further east towards and within the Gulf of Oman (Sheppard et al. 1992). Under less favourable environmental conditions, mangroves form isolated patches of dwarf-stunted habitats, with canopies reaching a height of 1–2 m (Kuenzer et al. 2011). *Avicennia marina* is well adapted to high temperatures and the high salinity conditions due to less fresh water input (Lézine et al. 2002). According to the study of JICA and MECA (2004), *Avicennia marina* in Oman occurs at a pH between 7.5 to 8.5 and salinity from 25-48.

Regardless of the relatively limited distribution of mangroves in the Arabian Sea area, they nevertheless play a vital role in the ecology of the region (ROPME 2013). They support the biodiversity of many faunal communities due to their position at the boundary between Africa and Asia (JICA and MECA 2004). In addition, as in other regions, mangroves in Oman support a large variety of other species. It has been estimated they support 51 fish species (Cookson and Shoju 2003) and the number of bird species ranges from 59-159 species per site, whilst 43 species of crustaceans have been reported (JICA and MECA 2004).

The Omani Government recognises the vital role of mangroves in the welfare of the Omani communities, including their role in storm buffering. Consequently, three nurseries (Al-Qurum, Sur and Salalah) of mangroves have been established to produce seedlings for restoration and afforestation programmes (Figure 1.3). Two nurseries started operation in Al-Qurum in August 2000 and November 2000. Another two nurseries were operated in Sur and Salalah in May 2000 and July 2002 respectively (MECA 2010).

Following the establishment of these nurseries, restoration and afforestation programmes in Oman started in 2001 and 500,000 trees were planted over the following 12 years (Balqis 2013). The best season to collect seeds in northern Oman is early July and August, while the southern part of Oman has two seasons, May to June and December to January (JICA and MECA 2004) due to its unique environmental and climatic conditions in summer which is a rainy season accompanied by the monsoon and coastal upwelling. Recent attempts of restoration and afforestation of mangroves in Oman are not the first. Previous attempts were between 1983 and 1985, with intangible results due to lack of knowledge and technical skills. The first successful attempts were not recorded until after 2000 (JICA and MECA 2004).

The literature concerning mangrove ecosystem services reveals a lack of research in the Middle East in general (Duke et al. 2014). In Oman, the most prominent study done on mangroves was conducted by the Japanese International Cooperation Agency (JICA) in 2004 under the supervision of the Ministry of Environment and Climatic Affairs (MECA) of the Sultanate. The study focused mainly on the biological value of mangroves with statistical data concerning the biotic population of mangrove ecosystems. The main highlights from this study were the provisioning services, particularly fisheries, and the shift from past to present in the utilisation of these services by locals. The study also estimated the area of mangroves at the time of the study without observing changes from past to present. Regulating services and cultural services were generally listed for the sites without conducting any studies to examine and study these services in depth. The threats confronting mangroves in Oman were also simply based on observations of the researchers. The socioeconomic survey was dedicated to the awareness of local people of the existing ecosystem and their past and present utilisation of provisioning services of the ecosystem. The study highlighted the socioeconomic services of mangroves and formulated a master plan for the restoration, conservation and management of specific sites based on their socioeconomic characteristics.

1.8. Thesis aim and objectives

The research reported in this thesis anticipates increased interest in the ecosystem services provided by mangroves in the Middle East in general, and in Oman in particular, in relation to human welfare. In addition, Oman plans to create an environmental research centre in the Al-Qurum Natural Reserve (Grieve et al. 2006) and I therefore hope that my work will contribute to the academic, educational and knowledge services offered by this centre. My research specifically aims to explore the role of mangrove ecosystems in Al-Qurum, Al-Sawadi and Qurayyat (Figure 1.3) for human welfare, each mangrove ecosystem having its own distinctive charater.

Al-Qurum has been a natural reserve since 1975 made by the Royal Decree No75/38. It is the only Omani registered Ramsar (Convention on Wetlands) site, where the convention was enforced in Oman on 19 August 2013 (Ramsar 2014). Other studies also indicate that Al-Qurum is one of the most well-developed mangrove ecosystems in Oman based on the recorded populations of crustaceans, molluscs, birds and fish (Fauda and AL-Muharrami 1995) and the height of the trees that can sometimes reach up to 10m (MECA, 2010).

As part of the role of MECA in conserving and restoring mangrove habitats, six months after sowing seeds in the first nursery in Al-Qurum the first seedlings were transported to **Al-Sawadi**. This project in Al-Sawadi started in March 2001 and was accomplished in 2007. After one year, the survival rate of seedlings was 85% and at the end of the restoration period the height of the trees reached up to 2m, despite the limited fresh water input (MECA 2010).

The **Qurayyat** ecosystem is one of the naturally existing mangrove forests in Oman where local people interacted directly with the ecosystem through their traditional livelihoods of fishing and agriculture (JICA and MECA 2004, NCSI 2015b). According to the study of JICA and MECA, the site was managed and monitored by the local authority of the Wali (the person with administrative and political authority given by the Sultan) in the past. The Wali allowed locals to use mangroves for three times per year for a specific period of time extending from two to five days.

The key objectives of my research were to:

a) identify and highlight the contribution of the study areas to community well-being based on the 2005 MA framework for ecosystem services.

b) identify the drivers of environmental change affecting these mangrove ecosystems.

c) provide recommendations for the sustainable management of mangrove forests at the national level in Oman.

Figure.1.3. Locations of mangrove research sites and nurseries in Oman.

1.9. Thesis contents

The format and content of my thesis chapters follow the structure below:

Chapter 1. Introduction

Chapter 2. Contrasting patterns of long-term change in mangrove area at coastal sites in Oman: the role of environmental and anthropogenic drivers

This chapter will use GIS and aerial photographs from different time points to assess the condition of, and any changes occurring to, cyclone-affected mangroves in Al-Qurum and Qurayyat over time (1970-2014) in comparison to “control” (unaffected by cyclones) mangrove sites of Harmul and Mahout, depending on available records, which will link to possible drivers of environmental change.

Chapter 3. Local perceptions of ecosystem services in Oman

This chapter aims to identify the potential services provided by Omani mangroves and to explore how local people perceive and appreciate the ecosystem services flowing from mangrove habitats. This was done through a questionnaire survey at 3 contrasting sites, Al-Qurum, Al-Sawadi and Qurayyat. Specifically, the survey was designed to reveal the relative importance of different mangrove ecosystem services identified by people across a range of socio-economic backgrounds at the three sites as well as their wider appreciation of the benefits that natural systems in general can provide.

Chapter 4. An initial assessment of the role and value of Omani mangroves for fisheries

This chapter assesses the contribution of mangroves in supporting the Omani fisheries. The provisioning service of mangroves as nursery grounds for fisheries was identified and rated significant by many respondents to the first questionnaire (see Chapter 3). This chapter therefore explores that role by utilising secondary data on Omani fisheries.

Chapter 5. How important are carbon sequestration and storm buffering services at Al-Qurum mangroves, Oman?

This chapter focuses on the regulating services of storm buffering and carbon sequestration provided by the Al-Qurum Nature Reserve. GIS was used to assess the potential storm buffering service provided by these mangroves by quantifying the width and length of mangrove belts defending coastal areas against wind and storms in Oman. Data on wind direction were obtained from windroses and the tracks of cyclones from the India Meteorological Department. In-situ transect sampling was used to quantify tree dimensions and density for carbon sequestration calculations using reported allometric equations for *Avicennia marina*.

Chapter 6. Cultural services in Qurayyat: assessing and mapping the local experience

This chapter aims to examine the cultural services provided by mangroves ecosystem at Qurayyat. The questionnaire survey chapter addressed a range of cultural benefits, including material, aesthetic, place/heritage, activities, religious, inspirational, knowledge, social relationships, identity and employment. The survey also used participatory mapping as well as semi-structured interviews to capture the benefits and values provided by Qurayyat mangroves. This site is the most accessed by people in Oman and will potentially be subject to future draconian management by the government including redirecting freshwater supplies for flood protection and preventing public access.

Chapter 7. General discussion and conclusions

This chapter contains a summary of key findings and synthesis of ideas in chapters 2-6 (overview) with greater focus on recommendations for the conservation and management of mangroves in Oman.

Chapter 2

Contrasting patterns of long-term change in mangrove area at coastal sites in Oman: the role of environmental and anthropogenic drivers

2.1. Introduction

Mangrove habitats can play a vital role in improving the well-being of the local communities that access or live near them, for example, through local storm and flood protection, as well as having wider regional and global environmental benefits, such as carbon sequestration and climate regulation (Mitra et al. 2011, Ajonina et al. 2014, Alongi and Mukhopadhyay 2015). Many communities depend on mangroves to generate income and to improve their quality of life, for example from fishing, wildlife tourism, timber for fuel and construction (MA 2005, Alongi 2009, Brander et al. 2012, Raffaelli and White 2013, Duke et al. 2014) and from non-timber forest products (MA 2005, Fisher et al. 2008). Consequently, the ecosystem services delivered by mangrove habitats are of worldwide research interest.

The estuarine and coastal tropical and sub-tropical location of mangroves exposes them to a variety of disturbances caused by human activity, as well as by nature itself (Duke et al. 2007, Alongi 2008, Kuenzer et al. 2011), although their vulnerability is not commonly appreciated (Duke et al. 2007). Industries, urbanisation and population pressure on coastal areas are all major threats to mangroves (Duke et al. 2007), especially in developing countries where there is also extensive harvest of food, timber, fibre and fuel (Alongi 2002, MA 2005, Van Lavieren et al. 2012). Alongi (2008) and Ward et al. (2016) find that the impact of these different kinds of disturbances depends on their frequency, intensity and temporal and spatial scales, with implications for the ecological functioning of mangroves and their ability to deliver the goods and services that underpin human well-being (MA 2005, Alongi 2008, Duke et al. 2007). For instance, it has been argued that unsustainable use of mangroves has led to the degradation of 70% of regulating services (MA 2005), including a decline in the amount of carbon sequestered by mangroves (Marshall et al. 2012). Longer-term anthropogenic climate change impacts such as changes in precipitation, accelerated sea-level rise (ASLR), increasing temperature, inundation and storminess are also affecting mangrove ecosystems (Duke et al. 2007, Alongi 2008).

Donato et al. (2011), estimate that global spatial cover of mangroves has declined by between 30-50% over the past 50 years, with a higher rate in developing countries (Duke et al. 2007). This decline of mangroves is expected to continue in the future, with some mangrove ecosystems under the threat of extinction in 26 out of the 124 countries supporting mangroves (Duke et al. 2007) which will limit the potential direct and indirect services provided by mangroves and result in greater insecurity of local livelihoods dependant on mangroves (Duke et al. 2007, MA 2005, Borja et al. 2016).

In Oman, archaeologists have confirmed the existence of mangroves along the Omani coast stretching back 6000 B.P (Lézine et al. 2002, MECA 2010). Records reveal that in the past mangrove habitats in Oman were more abundant, more widely distributed and not just limited to *Avicennia marina*, as is the case today (Lézine et al. 2002). Today, mangroves are restricted to 18 sites in Oman (MECA 2010).

Research interest in Omani mangroves reflects the threats confronting coastal environments in general, particularly storm surges due to Cyclone Gonu in June, 2007 (Al Najar and Salvekar 2010), the most intense recorded cyclone in the history of the country (Al-Katheri et al. 2008, Al Najar and Salvekar 2010, Fritz et al. 2010, Kwarteng 2010), and Cyclone Phet in June, 2010, considered as the next most intense (Pilarczyk and Reinhardt 2012). These two cyclones formed in the transitional period (June to September) of cyclones in the Northern Indian Ocean (Al Najar and Salvekar 2010, Fritz et al. 2010). Usually, there are two main seasons for storminess in the Northern Indian Ocean, a pre-monsoon season (May) and a post-monsoon one (October to November).

Historically, the cyclones experienced in Oman were less frequent and less intense. Those as intense as Gonu are rare in the Arabian Sea and usually weaken and dissipate before approaching the Omani coast (Fritz et al. 2010). Since 1970, tropical cyclones have intensified worldwide due to increases in sea surface temperature (Mashhadi et al. 2015) and the Intergovernmental Panel on Climate Change (IPCC) predicts further increases in the intensity of storminess and cyclones in the 21st century (Gilman et al. 2008, Kuleshov et al. 2010, Ward et al. 2016).

This chapter focuses on the two main mangrove sites covered in this thesis, Al-Qurum and Qurayyat (the Muscat zone of mangroves) which have experienced cyclones. The chapter makes comparisons with another two sites, Harmul and Mahout which have not been exposed to cyclones, but which experience similar climatic conditions in all other respects. Other non-impacted sites located in the southern part of Oman (Dhofar) zone are radically different climatically (Abdul-Wahab 2003) so do not permit comparisons.

The chapter aims to examine long-term (decadal) changes in the spatial extent of mangroves at all four sites over time in relation to cyclone-related events and local-scale urban development. Other potential and linked factors responsible for the spatial change are also considered, such as fluctuating precipitation and inundation (sea-level rise), which can affect mangroves at a regional scale. There is no consensus in the literature about the impacts of rising temperatures on mangroves. Ward et al. (2016) argue that temperature limits the distribution of mangroves at a regional scale, while Alongi (2002) does not consider temperature as a regional limiting factor of mangroves, considering instead freshwater influx, tidal and wave action as the most significant factors affecting mangrove health and biomass. Therefore, I will not examine temperature as a driving factor of change in this chapter.

The main objectives of this chapter are to:

a) observe the changes in spatial extent over time on mangroves exposed to cyclones in Al-Qurum (1971-2013) and Qurayyat (1980-2014), in comparison to Harmul (1982-2013) and Mahout (1983-2013) which were not exposed to cyclones.

b) examine the role of natural events (cyclones) and human (urbanisation) in shaping the spatial extent of mangroves.

c) comment on the likely response of mangroves in Oman to sea-level rise.

2.2. Methodology

2.2.1. Study sites

All the sites in this study are natural forests of *A. marina* (Lézine et al. 2002, JICA and MECA 2004, MECA 2010) which are adapted to the extreme environmental conditions prevalent in northern Oman such as high salinity, sporadic rainfall and highly variable tidal ranges (JICA and MECA 2004).

2.2.1.1. Cyclone-affected sites

2.2.1.1.1. Al-Qurum Nature Reserve

Al-Qurum is located at the heart of Muscat Governance (23°37'12.88"N, 58°28'33.11"E) in northern Oman (Figure 2.1) and has arid climatic conditions with annual rainfall ranging between 100-150 mm (Al-Shukaili 2011), salinity 25-39 and a pH of 7.5-8.2 (JICA and MECA 2004). The soil at the site is a mixture of silt and mud with sabkha (a phonetic translation of the Arabic word for a salt flat) located at the heart of the habitat (JICA and MECA 2004). Sabkha deposits form on arid coastlines like Oman and are characteristically evaporate-carbonate deposits with some silicates and can be up to a metre deep (Briere 2000). The site is one of the most important for mangrove conservation in Oman due of to its designation as a nature reserve in 1975 and because it hosts two nurseries of mangrove tree samplings which supply seedlings for restoration projects in other parts of the country (JICA and MECA, 2004).

Figure 2.1. Location of cyclone-affected sites (Al-Qurm and Qurayyat) and non-affected sites (Harmul and Mahout). The black dot in the framed map below indicates the location of Oman.

2.2.1.1.2. Qurayyat

This site is also located in Muscat zone (23°16'29.62"N, 58°55'11.91"E), about 80 km south from the capital (MECA 2010, ROPME 2013) (Figure 2.1) and subjected to the same climatic disturbances that confront mangroves at Al-Qurum. According to JICA and MECA (2004), the site has a salinity of 48 and a pH of 8.1. The soil in this site is sandy and aerobic at the open coast, but silty and organic around the estuary with anaerobic conditions (JICA and MECA 2004). Fishing and agriculture used to be the main source of income for locals in Qurayyat who nowadays are supported by jobs in both government and private sectors (JICA and MECA 2004).

2.2.1.2. "Control" sites: not cyclone-affected

2.2.1.2.1. Harmul

Harmul is located in Liwa (24°32'42.42"N, 56°35'0.11"E) in the northern part of Al-Batinah zone (JICA and MECA 2004) (Figure 2.1), about 220 km from Muscat zone (MECA 2010). The mangroves of this zone occur in a sandy-silty environment under a salinity range of 35-43 and a pH range of 7.5-8.2 (JICA and MECA 2004).

2.2.1.2.2. Mahout

Mahout is a small island located in Al-Wusta zone (20°34'30.97"N, 58° 9'43.98"E) (Figure 2.1) fronting the Arabian Sea. Mangroves here grow in sandy-silty soil under a salinity of 38 and a pH of 8.2 (Fouda and Al-Muharrami 1995, JICA and MECA 2004). The island is characterised by a variety of sandy, rocky and mud flats with a small area of salt marsh and sabkha (Fouda and Al-Muharrami 1995). The island is characterised by hosting the largest area of mangroves in Oman and being the only mangrove site which contributes significantly to the harvest of Omani fisheries (JICA and MECA 2004). Mangroves are estimated to occupy 60% of the island leaving a small front beach for the fishermen to launch and land their boats (Fouda and Al-Muharrami 1995).

2.2.2. Spatial changes of mangroves

I used available historical aerial photographs of each site obtained from the National Survey Authority (NSA) in Oman covering the period from 1971-2013 to measure the change in mangrove area. Google Earth was also used for those years post-2002 when aerial photographs were unavailable. Satellite images were also available from 1970 onwards for these sites. Although these images were free and easy to access (Morgan et al. 2010), they failed to provide the high resolution of the aerial photographs. Photographs of the periods 1971-2008 were georeferenced using ArcMap and then digitised using the same software at a scale of 1:0.01 (1cm=10m) by defining the spatial extent of vegetation as polygons, due to the sporadic nature of the cover at the research sites. Ground-truthing of one site (Al-Qurum) was conducted in the summer of July 2016 in order to confirm that vegetation apparent on images was in fact mangroves. Points for ground-truthing were defined in advance and documented by photographs and videos. Access to these points was by either walking or driving around the reserve. Ground-truthing confirmed that elements identified in images were mangrove (trees only) (Figure 2.2 and Figure 2.3).

Point	**Coordinates**
A	23°37'18"N, 58°28'32"E
B	23°37'18"N, 58°28'39"E
C	23°37'37"N, 58°29'1"E
D	23°37'29"N, 58°28'55"E
E	23°37'2"N, 58°28'51"E
F	23°37'3"N, 58°28'59"E
G	23°37'2"N, 58°29'5"E

Figure 2.2. The coordinates and the location of ground-truthed points at Al-Qurum, Oman. Image obtained from Google Earth.

Arc Map software in the GIS tool was used to record changes in mangrove area over time and to explore the degradation in mangrove habitats reported by respondents to a survey described in Chapter 3. The term ‘mangroves’ here refers to the trees only and does not include the other types of vegetation in the ecosystem. The change in the area of the vegetative cover was consequently used as an indicator of a change in mangrove habitat. Commonly, indicators used should be “*quantifiable, sensitive to changes in land cover and temporarily and spatially explicit and scalable*” as suggested by (Burkhard et al. 2012, p.19).

A (Sabkha) | B (Walking path) | C (mangrove connection point with sea and small boats anchorage)

D (Historical site at the back of the reserve) | E (extensive mats of *Sesuvium portulacastrum*) | F (Another extensive cover of *S.portulacastrum*)

G (The back southern part of the reserve, access of freshwater from Wadi Uday, with some grass cover, *S.portulacastrum* and *Prosopis juliflora*)

Figure 2.3. Ground-truthing sites (A-G) visited at Al-Qurum on 18th July 2016 (Photos: author). See Fig. 2.2 for location of sites.

Data on cyclones were obtained from the India Meteorological Department (IMD) in the form of track co-ordinates for each year when cyclones were recorded. These coordinates were then mapped to produce a single track line for each cyclone. Data on cyclone associated weather events such as rainfall, together with wind direction, were obtained from the Public Authority of Civilian Aviation (PACA), Oman. The extent of urbanisation at the sites was determined using aerial photographs from the NSA and mapping data of wadi routes, roads and buildings from the Supreme Council of Planning (SCP) in Oman. Data for mapping were obtained in the form of shapefiles which were imported in ArcMap.

2.3. Results

2.3.1. Changes in spatial extent of mangroves

Al-Qurum showed progressive expansion in vegetation by 83% (35-64 ha) over the first 14 years of data extending from 1971 to 1985, followed by a severe decline of 54% (74-34.7 ha) between 2004 and 2008 and an increase by 19% by 2013 (Figure 2.4).

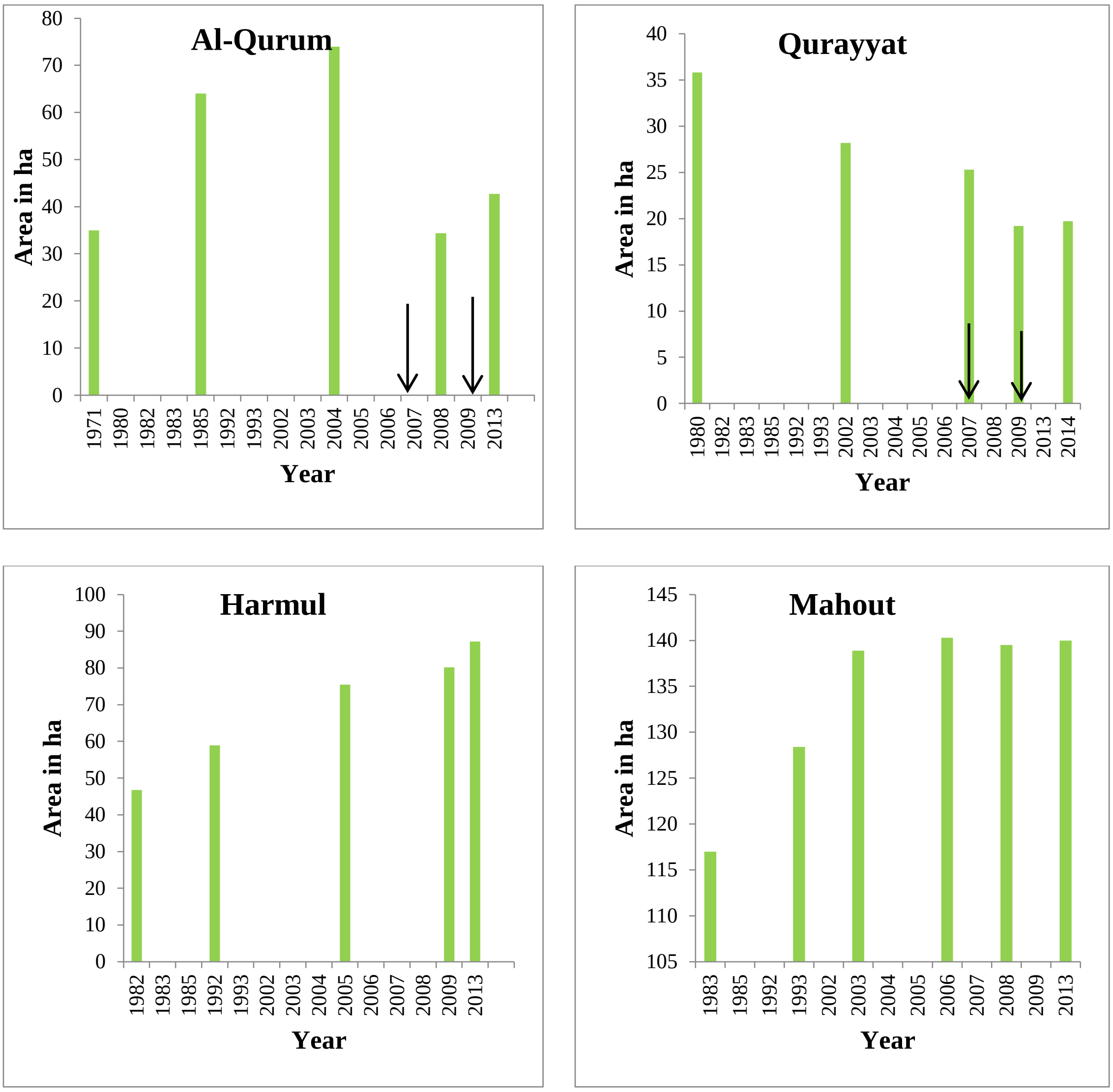


Figure 2.4. Temporal spatial change of mangroves at Al-Qurum and Qurayyat (cyclone exposed sites), and Harmul and Mahout (control sites). Arrows indicate the time periods at which Cyclone Gonu (20007) and Cyclone Phet (2010) occured.

At Qurayyat there was a continuous decline from 35.8 to 19.7 ha between 1980 and 2014 (Figure 2.4). The greatest decline of 32% (28.2-19.2 ha) was from 2002 to 2009 (Figure 2.4), with only a minor increase of 3% (19.2-19.7 ha) to 2014. In contrast to Al-Qurum and Quarayyat, both Harmul and Mahout increased steadily in cover from the early 1980s to 2003, with Harmoul steadily increasing and Mahout remaining stable to 2013 (Figure 2.4). In comparison to the three sites above, Mahout has the largest area of mangrove and showed a steady increase of 20% (117-140 ha) in area between

1983 to 2013 (Figure 2.4). The coverage was relatively stable (138.9-140 ha) from 2003-2013 and the largest area of mangroves in this site was recorded in 2006 (140.3 ha) (Figure 2.4). Overall, it is clear that Al-Qurum, Harmul and Mahout sites all showed a steady increase in mangrove cover from 70s/80s until the early 2000s, while Qurayyat experienced a continuous decline mangrove coverage over the same time period.

2.3.2. Cyclones and storminess at the different sites

a) Cyclone Gonu

Both Al-Qurum and Qurayyat were within the ranges of cyclones Gonu and Phet, whilst Harmul and Mahout were well away from the routes and landfalls of most of the cyclones in a record extending for nearly 40 years, and specifically for the period of 2000-2010, when Gonu and Phet occurred (Figure 2.5). The head of the arrow indicates the direction of the track and the where the arrow stops is the last point in which the dissipation of the effect of the cyclones was monitored, including preciptation. The extent of cyclone land penetration depends on the strength of the cyclone by the time it reaches the land and the amount of precipitation.

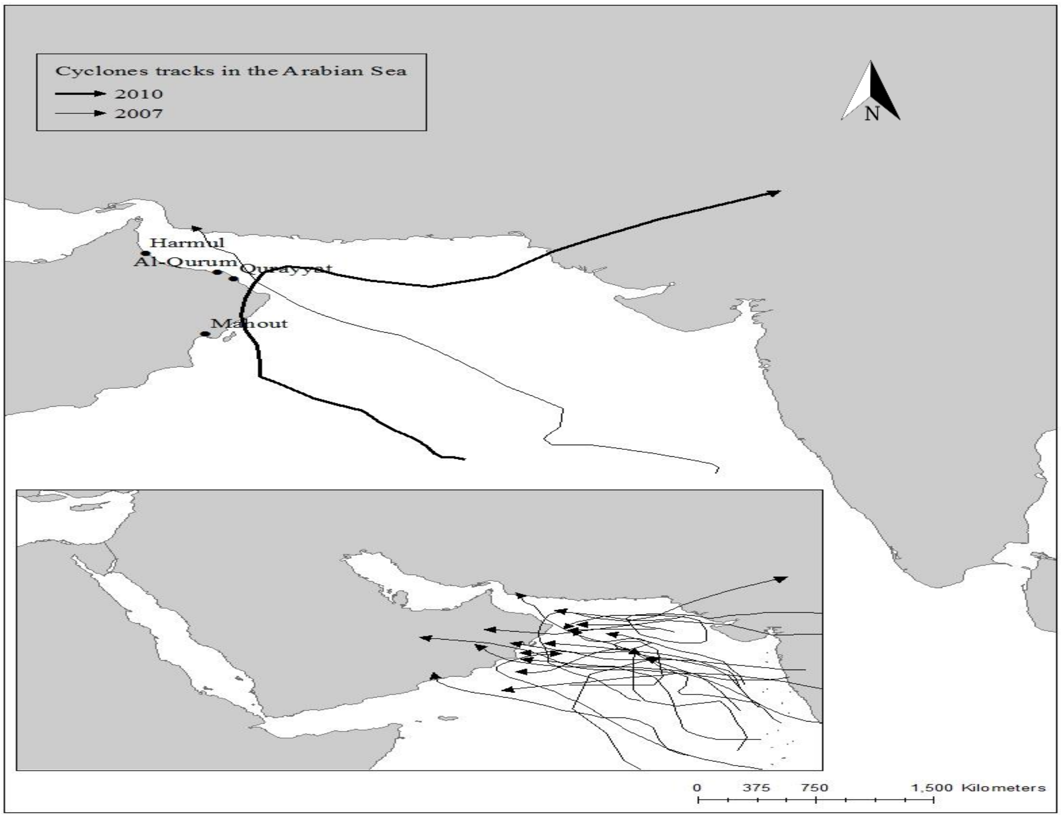


Figure 2.5. Cyclone tracks in the Arabian Peninsula from 1970 to 2010 (frame map below) and the cyclone tracks during 2007 (Gonu) and 2010 (Phet). Track coordinates obtained from the India Meteorological Department (IMD).

Analysis of rainfall records revealed that when Gonu struck Oman, 257 mm were recorded in Al-Qurum 4-6 June 2007 (no precipitation for the most of the year) (Figure 2.6). The highest recorded total precipitation in 2007, excluding June, was in March and reached only 48.4 mm (Figure 2.6).

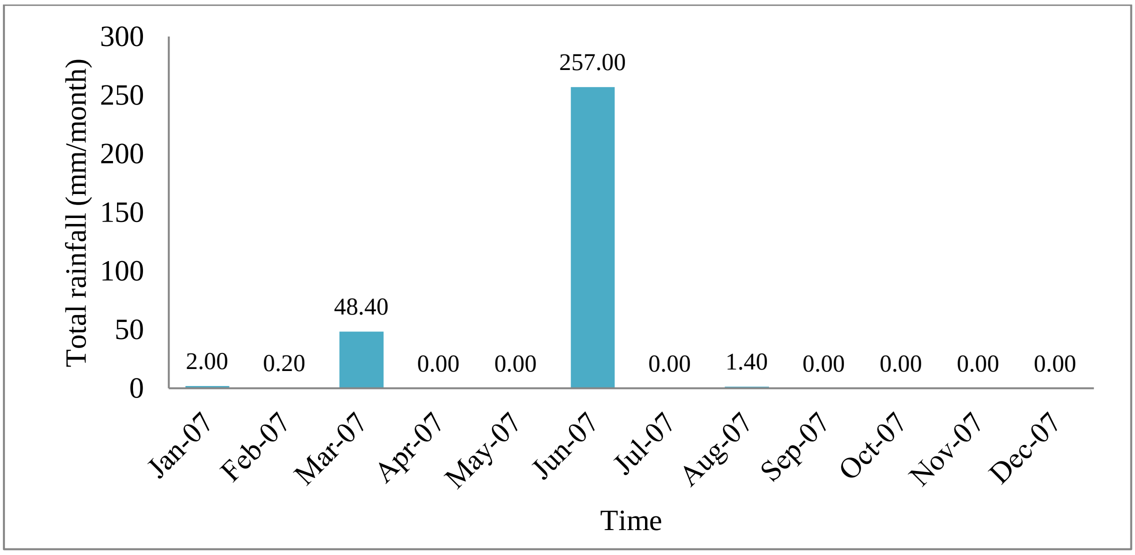


Figure 2.6. The total rainfall recorded in the capital in 2007. Data obtained from PACA (Muscat international airport weather station).

Analysis of PACA rainfall data showed that the highest recorded mean precipitation at Al-Qurum from 2000 to 2016 was in 2007 (Figure 2.7). When 2007 is excluded, the records showed that the mean precipitation at Al-Qurum ranged from 0-12.88 mm/month for the same period of time (Figure 2.7).

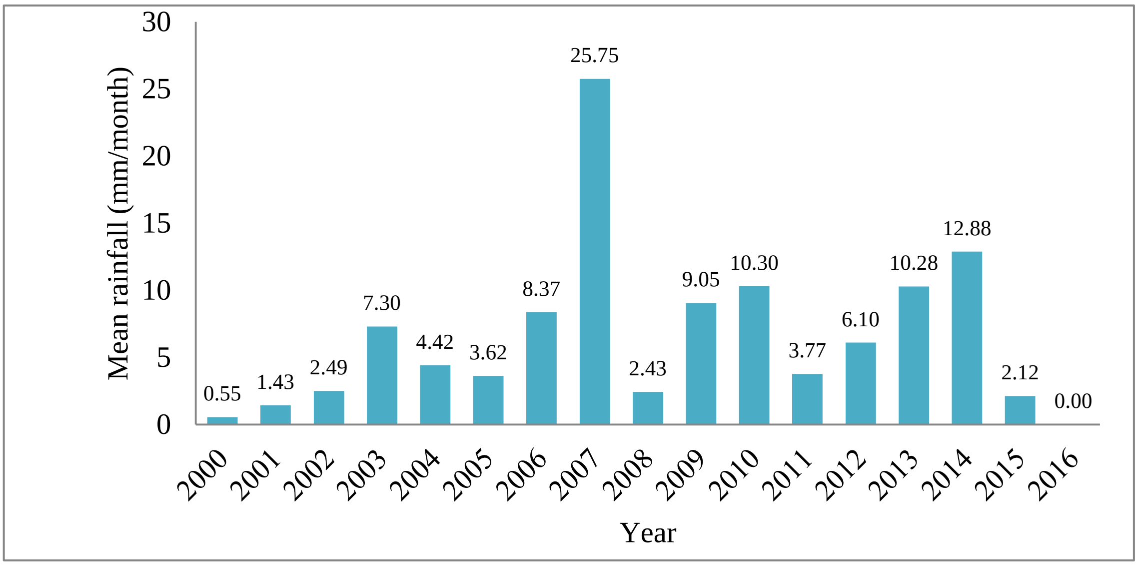


Figure 2.7. Mean monthly rainfall in Al-Qurum each year from 2000 to 2016. Data obtained from PACA (Muscat International Airport weather station).

An even higher level of rainfall was reported in Qurayyat compared to Al-Qurum during Gonu. Rainfall reached 410 mm (no precipitation for most of 2007) (Figure 2.8). In 2007, similarly to Al-Qurum, the highest rainfall record was in March, when excluding June, and reached only 35.8 mm (Figure 2.8).

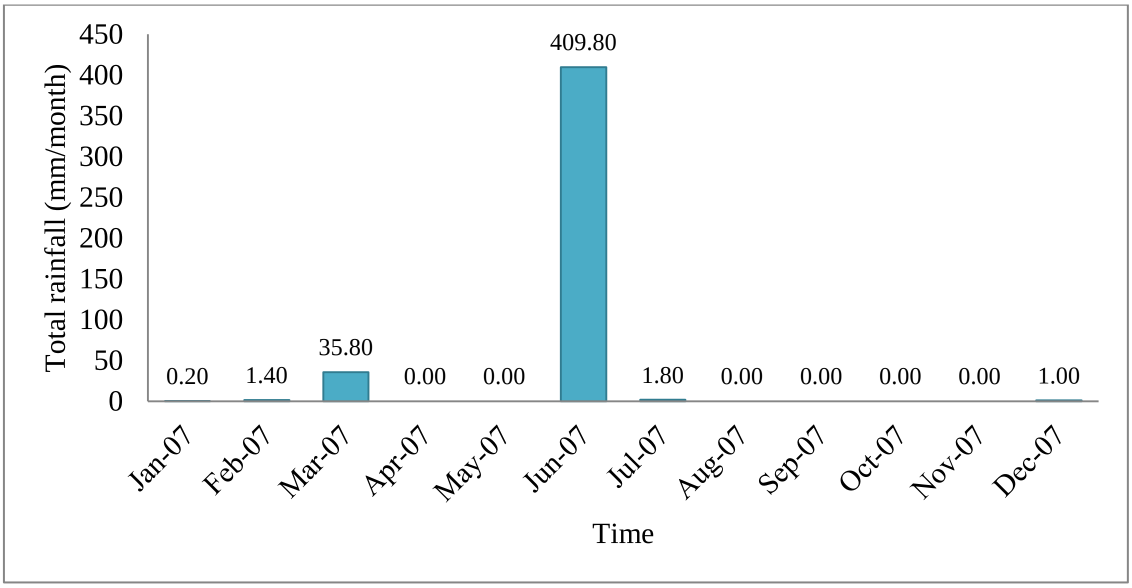


Figure 2.8. The total rainfall recorded in Qurayyat in 2007. Data obtained from PACA (Qalhat weather station).

Again, the analysis of PACA data revealed that the mean precipitation at Qurayyat ranged from 0.07 to 24.87 mm/month from 2000 to 2016, excluding 2007 (Figure 2.9).

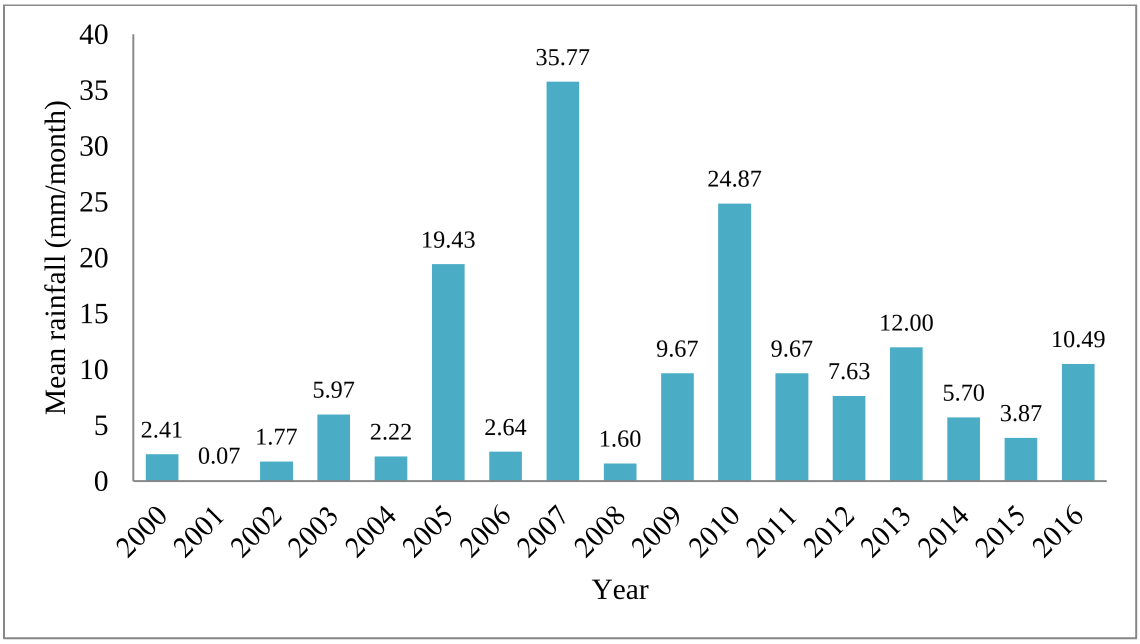


Figure 2.9. Mean monthly rainfall in Qurayyat each year from 2000-2016. Data obtained from PACA (Qalhat and Qurayyat weather stations).

b) Cyclone Phet

The amount of precipitation received by Al-Qurum and Qurayyat during Phet was less than that received during Gonu (Figure 2.10, Figure 2.11). In Al-Qurum, the difference in the recorded rainfall was 65% while in Qurayyat it was 51%. In other words, during Phet, compared to Gonu, precipitation was 65% less in Al-Qurum and 51% less at Qurayyat.

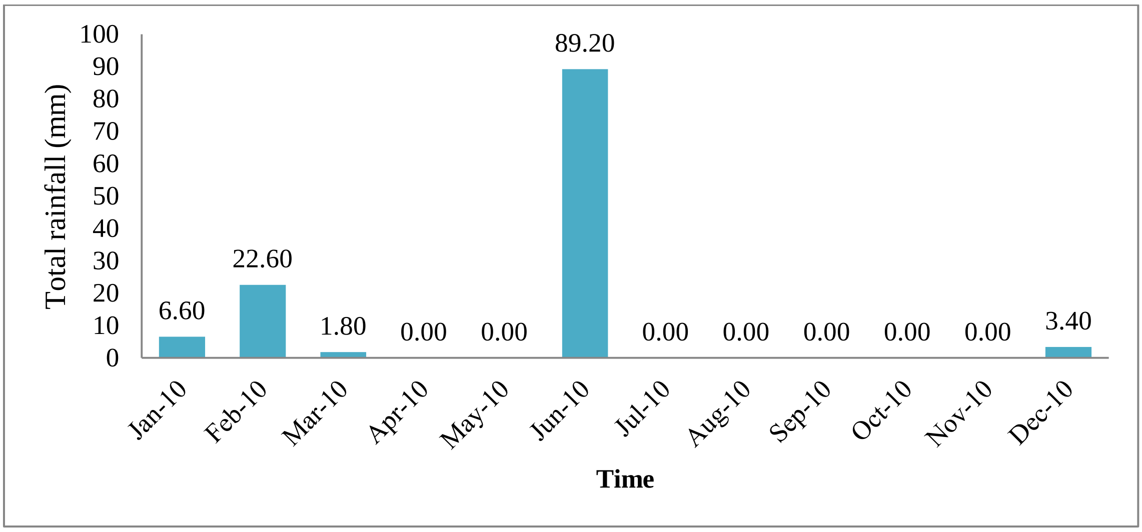


Figure 2.10. The total rainfall recorded in the capital in 2010. Data obtained from PACA (Muscat international airport weather station).

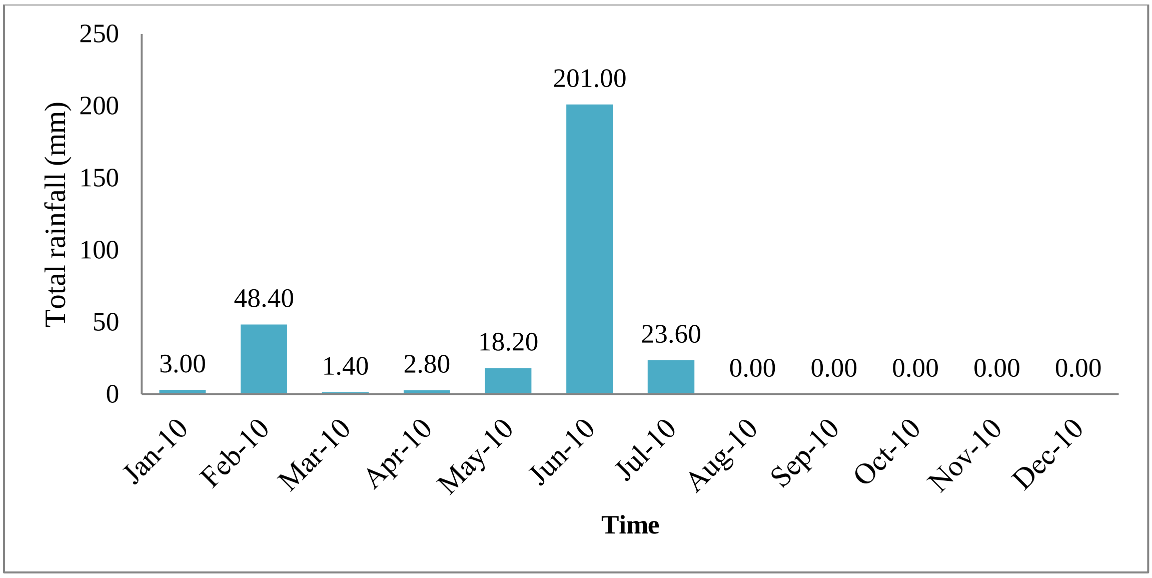
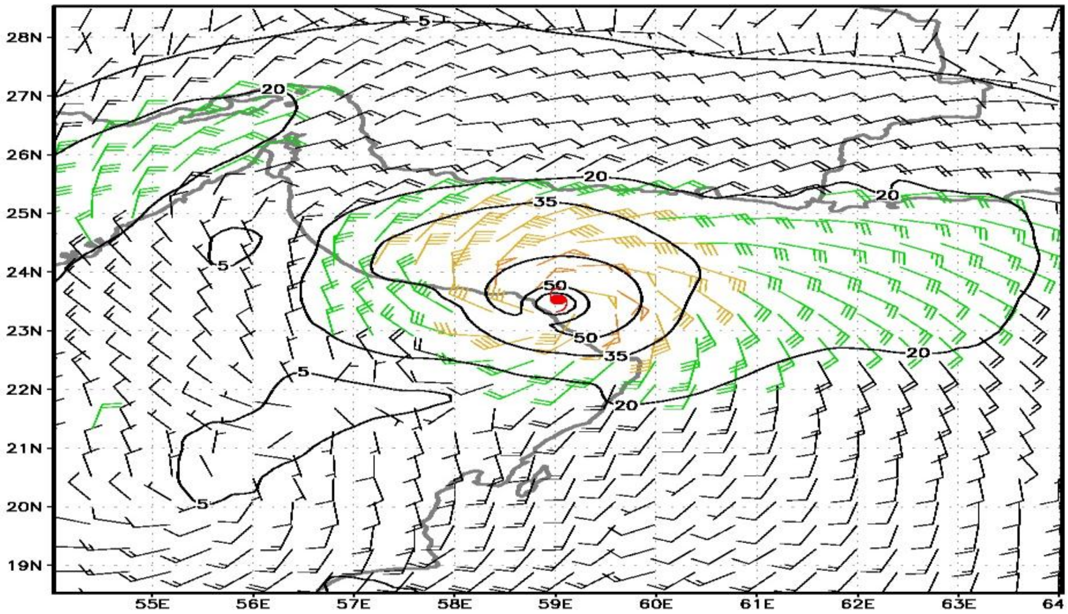


Figure 2.11. The total rainfall recorded in Qurayyat in 2010. Data obtained from PACA (Qalhat weather station).

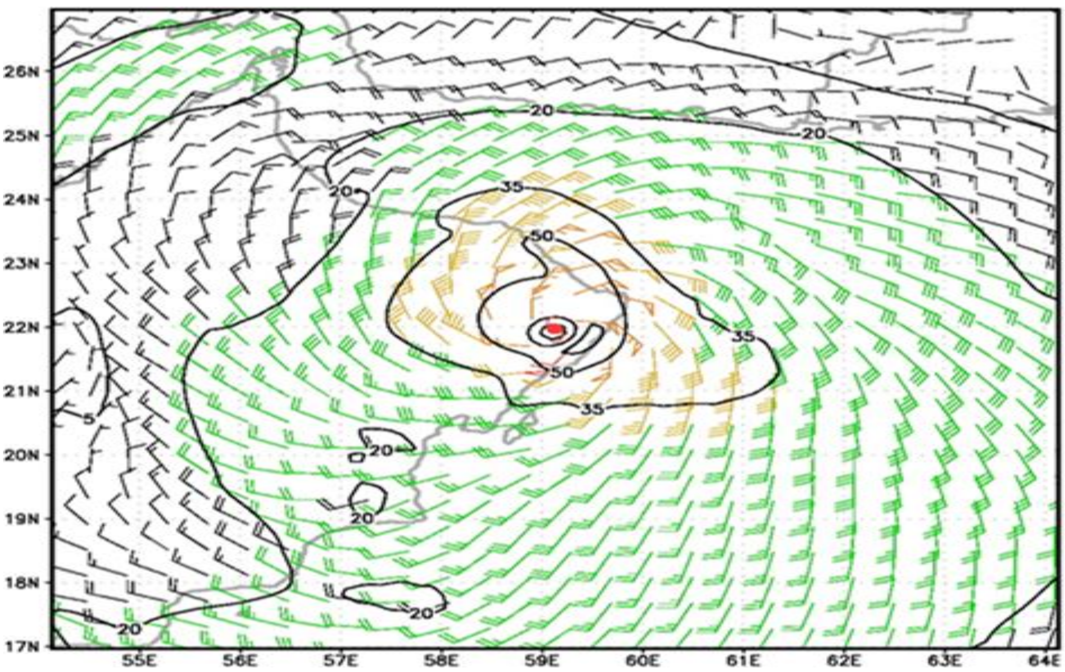
However, in comparison to Gonu, mangroves in the research sites including Harmul and Mahout were not within the path of the eye of cyclone Phet (Table 2.1, Figure 2.12,).

Table 2.1. Study sites coordinates in comparison to the eye of cyclone which was somewhere in the region of 58°-59°E, 23°N during Gonu and 59°E, 21°-22°N during Phet.

Study site	Harmul	Al-Qurum	Qurayyat	Mahout
Coordinates	24°32'42.42"N, 56°35'0.11"E	23°37'12.88"N, 58°28'33.11"E	23°16'29.62"N, 58°55'11.91"E	20°34'30.97"N, 58° 9'43.98"E



a



b

Figure 2.12. Wind direction and intensity during Gonu on 6th June, 2007 at 18 UTC (a) and Phet on 4th June, 2010 at 6 UTC. The arrow heads indicate wind speed increasing from black to green to yellow. The red dot indicates the eye of the cyclone. Obtained from: https://www.nesdis.noaa.gov.

2.3.3. Effects of urbanisation

The aerial photographs of NSA used to generate data for mangrove mapping by the researcher were done by converting the format of vegetation polygons from kml files to shapefiles. For mapping urban development, I used the format of shapefiles provided by SCP (Oman) for mapping. For better comparison of urbanisation level, all the maps were drawn at the same scale as ArcMap which was 1:24,000 (1 cm=0.24 km). The level of housing and infrastructure development in Al-Qurum (2010) (Figure 2.13) was clearly much higher than in Qurayyat (2010) (Figure 2.14). Al-Qurum mangrove is surrounded by roads and buildings and the natural flow of wadis is highly restricted by dense urbanisation. The huge flow of precipitation during cyclones crosses roads and mangroves before reaching its discharge end point, the Gulf of Oman (Figure 2.13).Wadi Uday in Muscat is one of the largest surface hydrolines in Oman which develops during rainy seasons and enters the Gulf of Oman through Al-Qurum mangroves (Al-Hatrushi and Al-Alawi 2010).

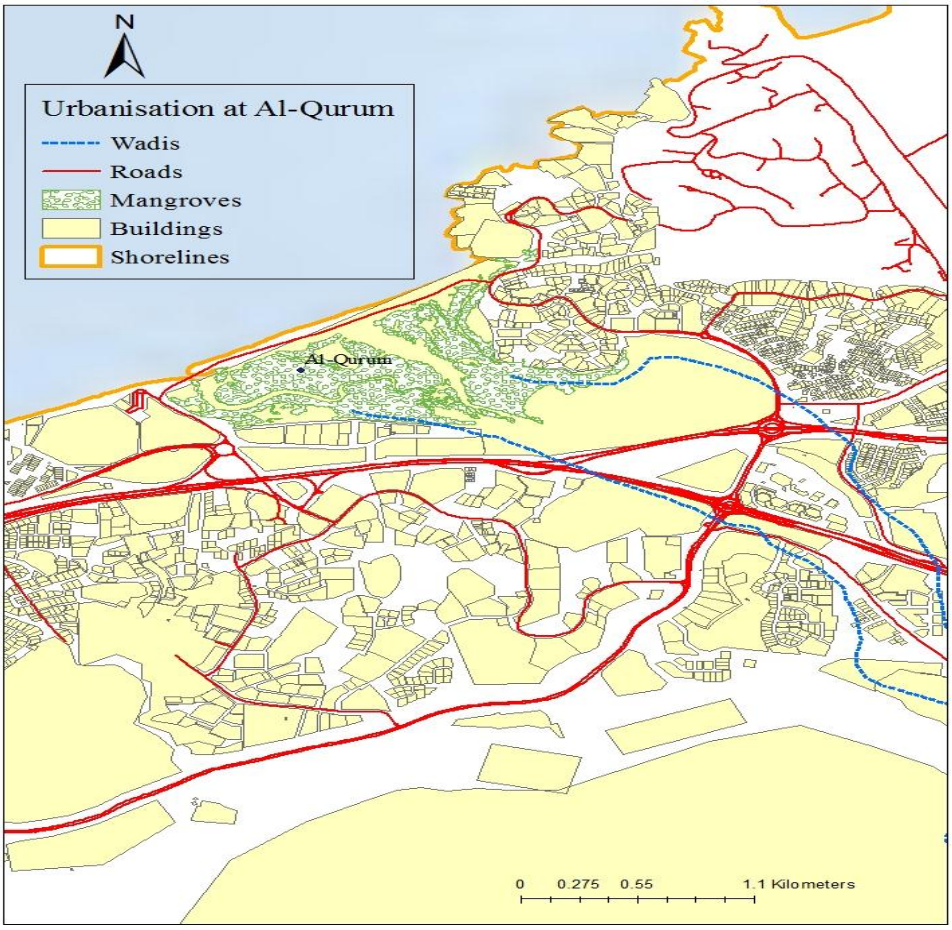


Figure 2.13. Urbanisation at Al-Qurum. Data obtained from NSA and SCP.

In Qurayyat (Figure 2.14), the natural routes of wadis were not blocked, however the residential areas towards the south imposed more restrictions on mangroves. In Qurayyat, wadis are also streaming to the Gulf of Oman (2.14). Wadi Mijlas is one of the major hydrolines in Qurayyat formed during rainy seasons and crosses mangroves on its way to meet the sea (Figure 2.14).

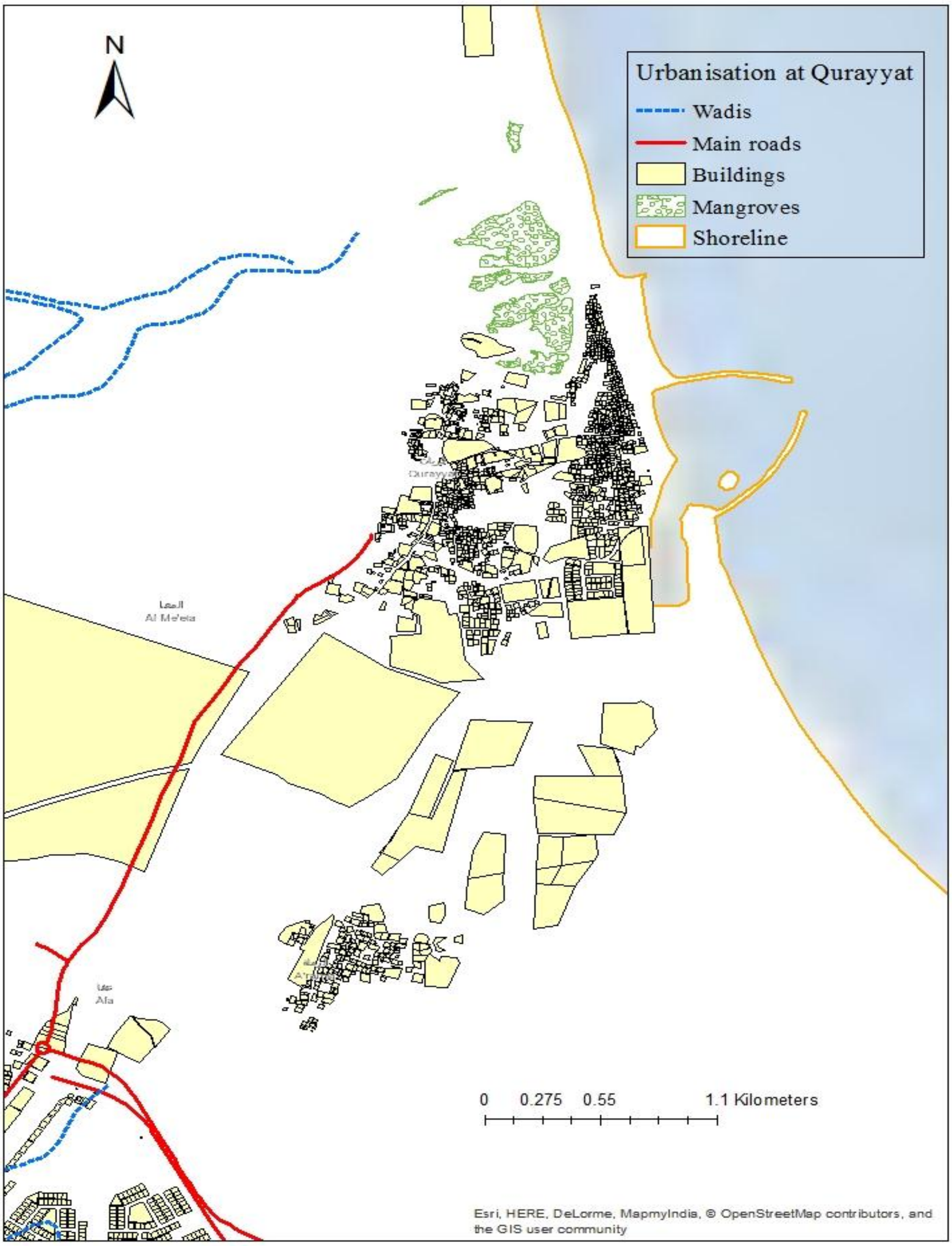


Figure 2.14. Urbanisation at Qurayyat. Data obtained from NSA and SCP.

In comparison, the level of urbanisation at Harmul (2010) (Figure 2.15) was much less than at Al-Qurum. Furthermore, compared to Qurayyat, the buildings were not as close to the mangroves and the routes of wadis were less impeded by dense buildings and infrastructure than at Al-Qurum.

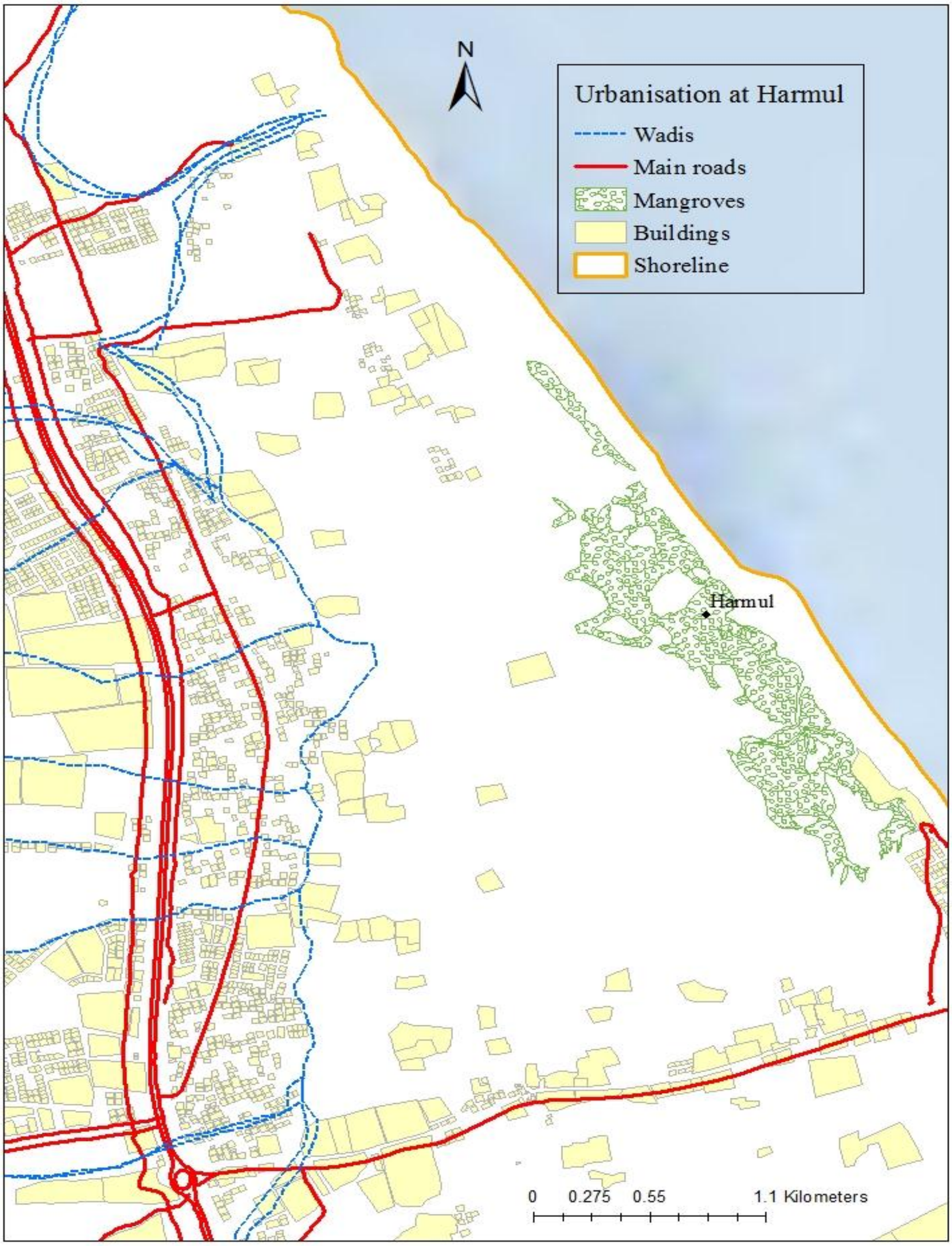


Figure 2.15. Urbanisation at Harmul. Data obtained from NSA and SCP.

At the scale of 1:24,000, Mahout (Figure 2.16) did not show any level of urbanisation apart from a few small roads. This was true when an even larger scale map (framed below in Figure 2.16) of 1:500,000 (1 cm=5 km) was constructed.

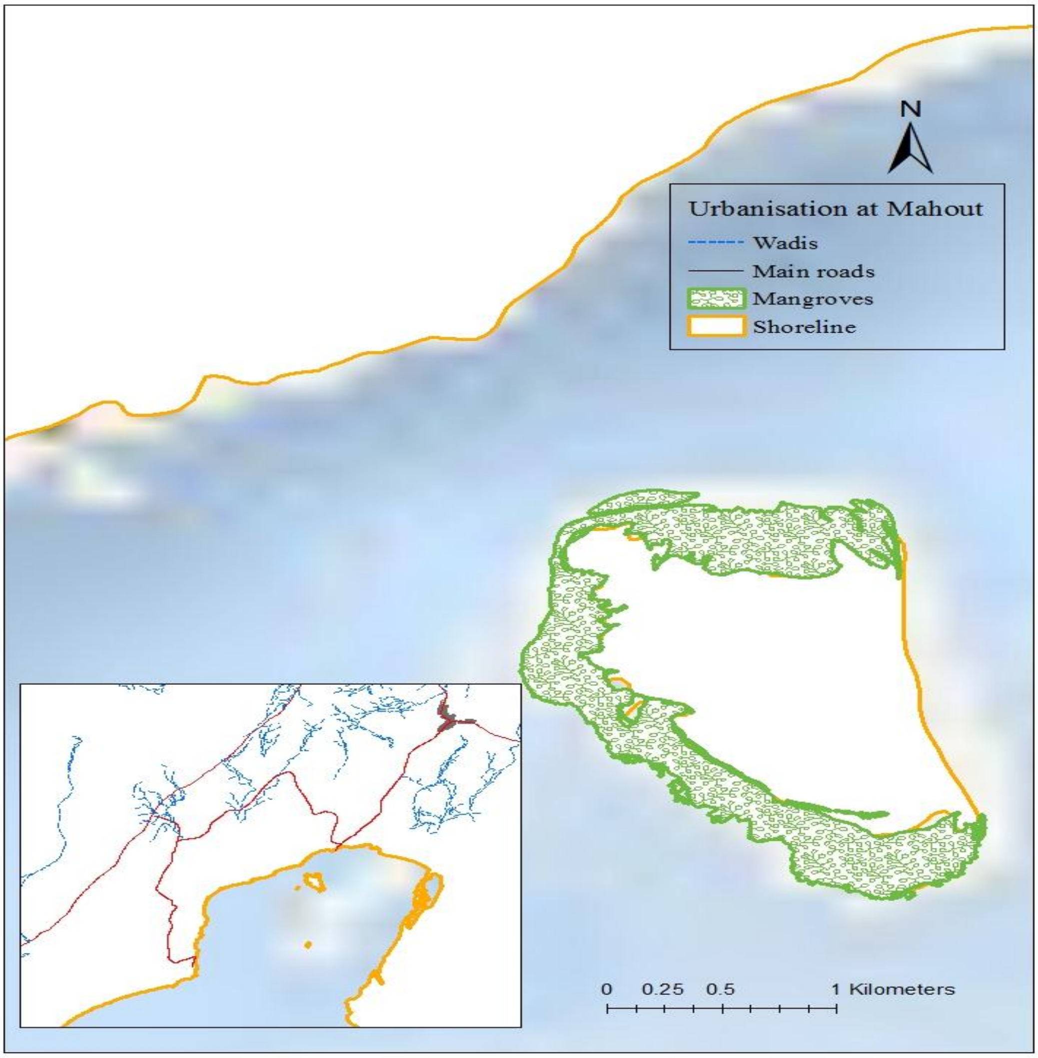
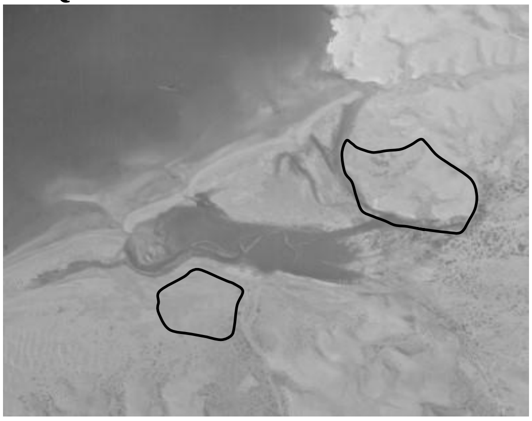


Figure 2.16. Urbanisation at Mahout. Data obtained from NSA and SCP.

In summary, Al-Qurum had the highest level of urbanisation and Mahout (2010) had almost no urbanisation. At Al-Qurum, the heavy level of urbanisation took place between 1970 and 2013 (Figure 2.17). In 1970, Al-Qurum was only occupied by mangrove habitat, but by 1982, infrastructure such as buildings and roads was already built close to the mangroves. By 2008, mangroves were squeezed by buildings and roads from all directions and more buildings were constructed by 2013. In comparison to Al-Qurum, there was very little growth in urbanisation at Qurayat between 1981 and 2008 (Figure 2.17). The area represented by polygongs in aerial photographs was quantified in terms of the buildings occupying the space which also indicates the level of urbansiation.

Al-Qurum



1970 (zero)

1982 (4.42 ha)

2008 (9.42 ha)

2013 (16.95 ha)

Qurayyat

1981 (4.21 ha)

2008 (6.54 ha)

Figure 2.17. The level of urbanisation in Al-Qurum between 1970 and 2013, and in Qurayyat between 1981 and 2008 as shown in aerial photos by NSA, Oman.

2.3.4. Sea-level Rise (SLR)

The level of urbanisation around mangroves has an effect on the response of mangroves to SLR (Torio and Chmura 2013). The most extensive records of sea level available for my study sites were obtained from the tidal gauge of Permanent Service for Mean Sea Level (PSMSL) organisation, available online at http://www.psmsl.org/. The longest instrumental sea-level record from Oman is from 1987 and spans the years 1987 to 1993 and 2009 to 2014 for my sites. The longest record in the wider region is from Aden, Yemen, and goes back to 1879. To examine the reliability of applying trends in the Aden data to my study sites in Oman, I examined the relationship between sea-level records in Muscat (for the period they existed) and those from Yemen (Figures 2.18). The scatterplot showed no significant correlation between the data of Muscat and Aden (Spearman's correlation coefficient = -0.101, N=29, p = .604).

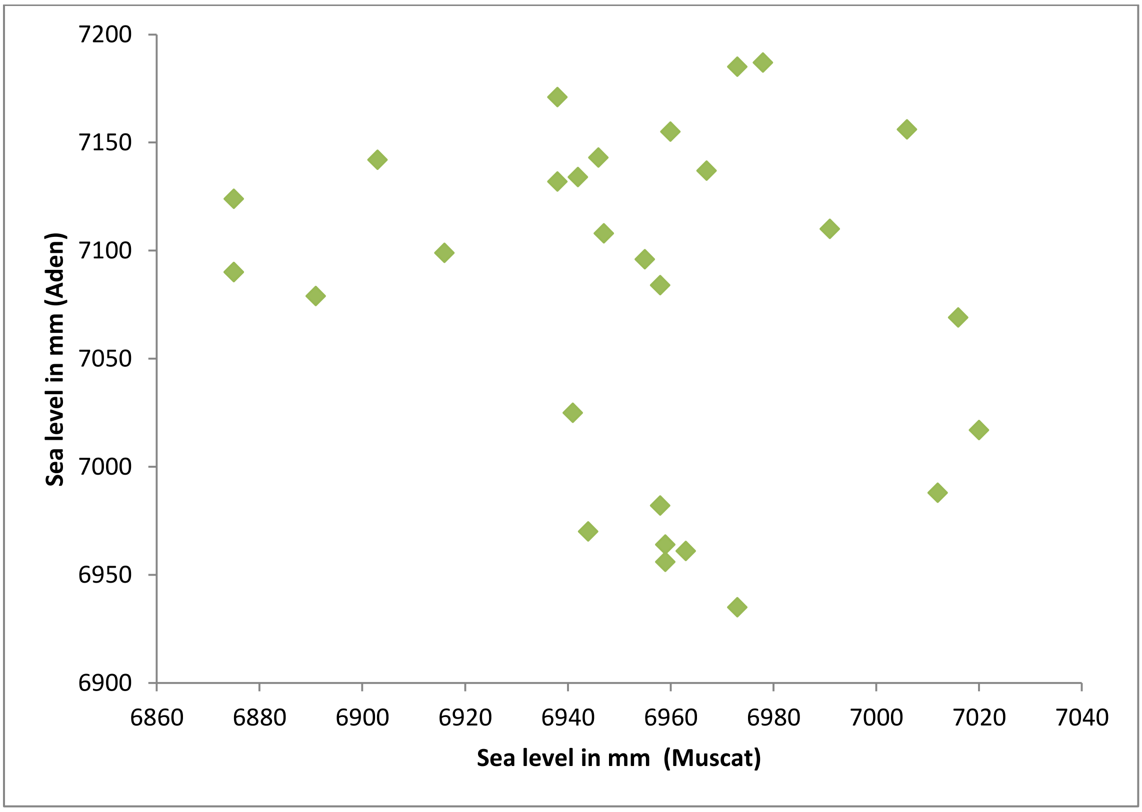


Figure 2.18. Scatterplot of monthly sea level (mm) in Aden and Muscat for the available records from 2009-2013, N=29.

As a result of the above analysis, the shorter time series data from Oman were used. The most extensive records of sea-level available from my study sites (obtained from 2 stations) were plotted (Figures 2.19 and 2.20) and a linear regression analysis performed to see if there was an increasing trend over time. The analysis showed no significant trend over time for either the first period (R^2=0.013, p=0.383) or the second period (R^2 <0.001, p=0.892). The data used here are Revised Local Reference (RLR), and available without a zero bench mark as further explanined at https://www.psmsl.org/data/obtaining/rlr.php.

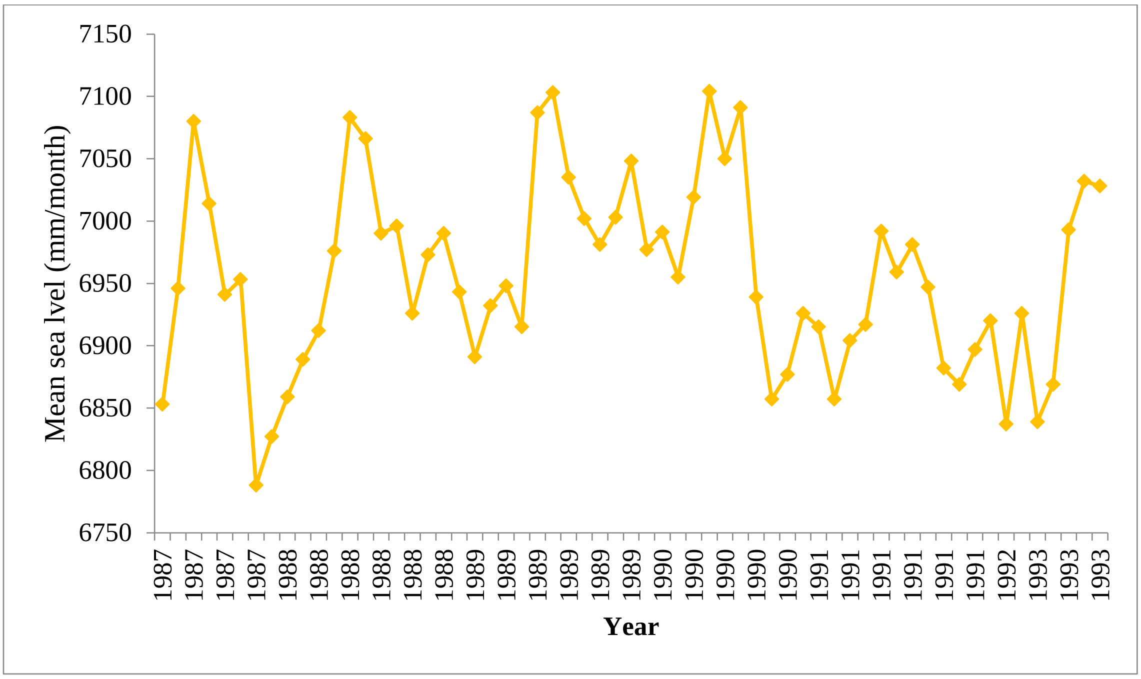


Figure 2.19. Mean sea level trends for available data in Muscat (1987-1993).

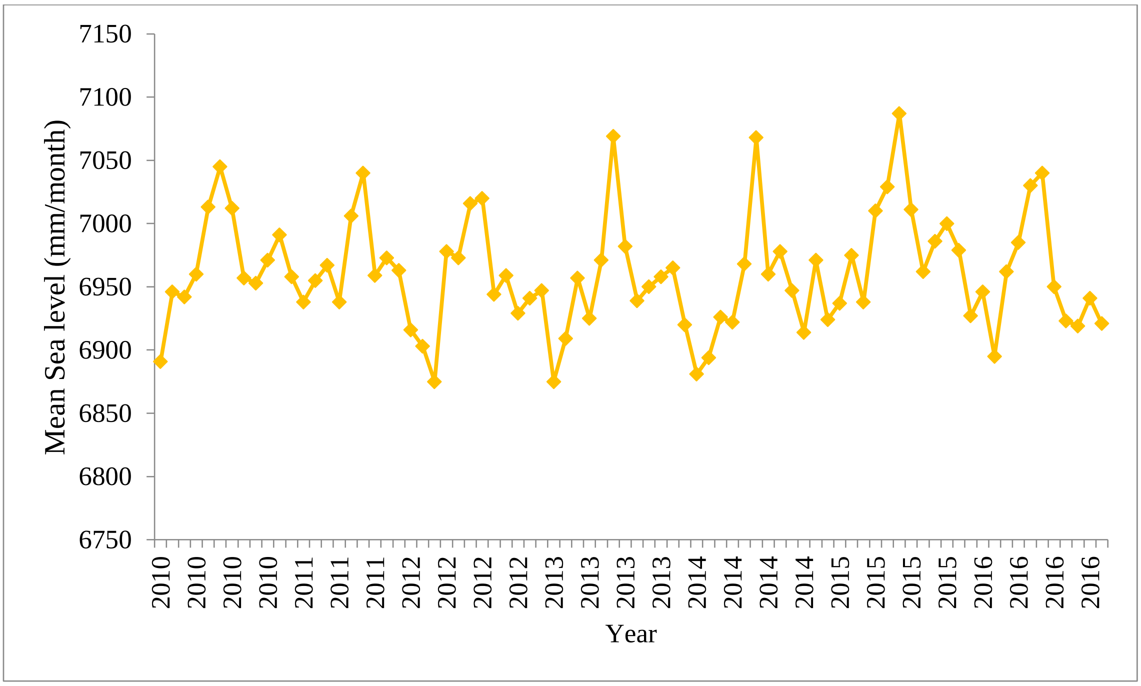


Figure 2.20. Mean sea level trends for available data in Muscat (2009-2010).

The environment at both Al-Qurum and Qurayyat was also documented photographically to assess the long-term effects of the SLR. In Al-Qurum, elevated sediments occupied the back boundaries of the reserve (Figure 2.21).

Figure 2.21. Elevated environment at the southern boundaries of the Al-Qurum reserve in 2016. Photograph by author.

At Qurayyat, the mangrove site had heavy sedimentation at the shore (Figure 2.22).

Figure 2.22. Heavy sedimentation at the Qurayyat site. Photograph by author.

2.4. Discussion

2.4.1. Changes in spatial extent of mangroves

My analyses have revealed wide variations in the amount and direction of change in spatial extent of mangroves in northern Oman. Since 2007, the declines seen in Al-Qurum and Qurayyat can be mainly attributed to cyclone Gonu, which struck the north-eastern coasts of Oman in June 2007 (Al-Kathiri et al. 2008, Al Najar and Salvekar 2010, Blount et al. 2010, Kwarteng 2010) and where Al-Qurum and Qurayyat were within the eye of Gonu. Small changes in area (<5%) at all the sites cannot be interpreted confidently as real because they fall within the error range expected when calculating polygons using the GIS tool (Goodchild 1994).

2.4.2. Cyclones and storminess at the different sites

A reduction in water quality due to run-off during cyclones may also lead to soil toxicity resulting from high concentrations of sulphides (Erftemeijer and Hamerlynck 2005, Gilman et al. 2008). Also, storminess and wave surges can lead to defoliation and death of mangrove trees (Gilman et al. 2008, Mashhadi et al. 2015). In addition, cyclonic events can lead to radical changes in ecosystem hydrology, soil characteristics, deposition rate and sedimentation elevation, which consequently pose a threat to the new seedlings that support the process of recovery of the ecosystem (Gilman et al. 2008, Ward et al. 2016).

2.4.2.1. Cyclone Gonu

Gonu was a category 5 cyclone and was characterised by strong winds reaching 130 km/h (Al Najar and Salvekar 2010, Azaz 2010b), with waves reaching 12 m in height (Al Najar and Salvekar 2010, Kwarteng 2010), unusual for the Gulf in Oman where waves do not usually exceed 1.5 m. The Gulf of Oman is usually calm in comparison to the Arabian Sea (Kwarteng et al. 2016). High precipitation associated with this cyclone reached 900 mm on 5th June (Al Najar and Salvekar 2010, Kwarteng 2010) and in some parts of Oman this caused floods 3 m high (Pilarczyk and Reinhardt 2012). It has been estimated that this severe event affected 20,000 people around Oman (Al Najar and Salvekar 2010), left 50 people dead (Al-Kathiri et al. 2008, Azaz 2010b, Fritz et al. 2010, Kwarteng 2010, Pilarczyk and Reinhardt 2012) with a further 27 missing, despite the evacuation of more than 70,000 people before the cyclone struck (Azaz 2010b, Kwarteng 2010). The economic cost of Gonu was estimated at US$4 billion (Al-Katheri et al. 200, Al Najar and Salvekar 2010, Azaz 2010a,b, Blount et al. 2010, Pilarczyk and Reinhardt 2012).

In the Muscat zone (Al-Qurum and Qurayyat), the high precipitation associated with the cyclone caused the flooding of valleys emptying into the Gulf of Oman (Azaz 2010b, Fritz et al. 2010, Al Najar and Salvekar 2010, Kwarteng 2010, Pilarczyk and Reinhardt 2012), including the mangrove locations at Al-Qurum and Qurayyat. The rainfall records in this study were obtained from PACA which has only 75 weather stations around the country, compared to the greater range covered by the Ministry of Regional Municipality and Water Resources (MRMWR), with its 315 stations throughout Oman (MRMWR, 2016). According to MRMWR, the northern Oman mountains received rainfall between 97 and 943 mm (Kwarteng 2010) on June 5th and 6th. Hydrological studies suggest that the water table increased greatly during Gonu (Abdalla and Al-Abri 2011).

According to the PACA data, rainfall reached 257 mm in Al-Qurum. Fritz et al. (2010) point out that the steep slopes of mountains increased the speed of water flow and consequently increased the flooding hazard produced by the cyclone. The high speed and volume of water with a natural route blocked with roads, bridges, buildings and other infrastructure resulted in major damage and destruction (Fritz et al. 2010, Kwarteng 2010) and extended to other utilities such as desalination plants, electricity supply systems and telecommunications, as well as tree uprooting and coastal erosion (Azaz 2010b, Kwarteng 2010, Pilarczyk and Reinhardt 2012). Many parts (including Al-Qurum) turned to lakes while roads and valleys turned to rivers (Azaz 2010b, Kwarteng 2010).

The destruction of shoreline-parallel roads in front of mangroves in Al-Qurum was also attributed to the storm surge and not solely to floods (Fritz et al. 2010). JICA and MECA (2004) argue that the road and the bridge had already caused damage to mangroves even before the event of Gonu. The alterations of the natural route of Wadi Uday (the freshwater supply to mangroves) have also caused floods in many residential and recreational areas. Alterations are due to a combination of the wadi being channeled by urbanisation and building on the actual flood plain (Al-Hatrushi and Al-Alawi, 2010). The floods beside the storm surge were found to be the main factors responsible for the shoreline-parallel roads in front of mangroves in Al-Qurum (Fritz et al. 2010).

Gonu also had serious impacts on Qurayyat (Kwarteng et al. 2016). As part of Muscat zone, it also received a high level of rainfall. According to PACA rainfall data, Qurayyat received total rainfall of 409.80 mm in June, the month of Gonu. Infrastructure was also severely affected including the road connecting Qurayyat with the capital (Al-Hatrushi and Al-Alawi 2010). The heavy precipitation also led to the flow of wadis across mangroves towards the Gulf of Oman, further disturbing mangroves (trees were uprooted and seriously damaged) already suffering stress from the storm surge (Figure 2.23). Prior to Gonu, the extent of mangroves at Al-Qurum, Harmul and Mahout had increased over recent decades (although this hadn't occurred at Qurayyat). The increase in mangrove cover at most study sites was probably due to radical changes in Omani economic and social structure post-1970. In 1970, a new government took over the country and focused on an oil-based economy. That in turn led to the generation of regularly paid positions in the government and reduced livelihood dependence on natural ecosystems such as mangroves (Mansur and Treichel 1999).

Figure 2.23.The impact of Gonu on mangroves in Qurayyat. Photos taken by Fatma Al-Sinani, former representative of Qurayyat Municipal Council.

Despite the damage caused by cyclone Gonu, my analysis suggests a degree of resilience and recovery in Omani mangroves, particulary in Al-Qurum and seen as an increase in the area of vegetative cover in 2013 compared to 2008. Alongi (2008) argues that mangroves can develop and recover at considerable speed, recovery rate being dependent on the temporal and spatial scale of disturbances. Elliott et al. (2007) also find that ecosystems such as mangroves inhabiting the variable environment of estuaries have higher degrees of post-disturbance recovery compared to ecosystems inhabiting less variable environments.

In contrast to Al-Qurum, the mangrove ecosystem at Qurayyat appeared less resilient after Gonu, possibly because it was in decline even before the cyclone struck. The pre-Gonu study by JICA and MECA (2004) attributed the decline in mangroves Qurayyat to lack of proper management, animal grazing and deterioration in water quality in the estuary due to sedimentation. These factors have been identified elsewhere as key causes of decline in ecological system resilience (Walker et al. 1997, Gunderson 2000, Lotze et al. 2006).

A major difference between Qurayyat and Al-Qurum is that the latter is a protected reserve whilst the former is accessed by the general publics. Locals in Qurayyat were thought to be highly dependent on mangroves in the past (JICA and MECA 2004), which has been confirmed by my own surveys (chapter 6). The Qurayyat mangroves were traditionally managed by the local authority where the harvest of mangroves was allowed for only 7 days a year. According to locals, this system (also reported by JICA and MECA 2004), was efficient and kept the mangroves in the area healthy, but was deactivated in the early 1980s after which mangroves started to deteriorate. General ecological resilience theory points out that the absence of multi-disciplinary (adaptive) management and the dependence on command and control management regimes (which Qurayyat is following now), leads to the deterioration of ecosystem resilience (Gunderson 2000, Folke 2006). Reduced biodiversity is also expected to contribute to a loss of ecosystem resilience, especially with the loss of any keystone species (Walker et al. 1997, Gunderson 2000). In Qurayyat, locals already reported the disappearance of mangrove whelk and a substantial decline in crabs and shrimps (Chapter 6) so that further research is needed to establish the role of these species in contributing to mangrove ecosystem resilience.

Interestingly, the sites not impacted by cyclones, Harmul and Mahout, are not designated as nature reserves and they are also open to publics, but they did not experience the decline seen at Qurayyat. The problem of sedimentation was documented in Harmul by JICA and MECA (2004), due to the construction of Sohar Port, 2.5 km away. However, Harmul did not experience the decline that Qurayyat did and therefore heavy sedimentation may not be a significant factor contributing to mangrove degradation in Qurayyat.

Mahout was not affected by Gonu and according to JICA and MECA (2004), the site is also accessed by the publics where the most practiced activities include angling and fodder harvest. The mangroves at Mahout Island are designated by MECA as one of the healthiest ecosystems in Oman based on fisheries production and because no local impacts have been reported by JICA and MECA (2004), despite some human use in the past. No recent studies have been conducted in Mahout, but the island is currently uninhabited due to the movement of most locals to nearby areas with better job opportunities, education, health care, electricity and drinking water facilities (Atheer 2017), so human impact is expected to be low. It seems likely therefore that the continued decline in mangrove at Qurayyat was due to Gonu and that the earlier decline is because of inappropriate management (further discussed in Chapter 6).

2.4.2.2. Cyclone Phet

Phet did not make landfall on the Omani coastline close to the mangroves studied here and winds had reduced to 20 kt (37 km/h) by the time they reached Muscat (Chaudhuri et al. 2015). An example of the reduced impact of Phet is that the capital-to-Qurayyat road, which temporarily replaced the one completely destroyed during Gonu, remained intact (Al-Hatrushi and Al-Alawi 2010). Phet left 15 dead in Oman and 3 missing (Gulf News 2010). It has been argued that the economic impact of this cyclone has not been properly assessed in Oman (Pilarczyk and Reinhardt 2012), but the cost evaluated for the wider Arabian Gulf and the Bay of Bengal was US$ 78 million. Similar to Gonu, Phet left its mark on Ras Al-Hadd and Sur located in the tip of the Eastern Region (Al-Sharqiya) of Oman (Pilarczyk and Reinhardt 2012, Chaudhuri et al. 2015) which is located 100 km south of Muscat (Pilarczyk and Reinhardt 2012).

The track of cyclones documented by NASA showed that after Phet, 4 cyclones formed in the Arabian Sea, Nilofar (October 2014), Chapala (October 2015), Megh (November 2015), Ockhi (December 2017) and Mekunu (May 2018). Nilofar attained category 4, turned away from the Omani coasts and made its landfall in India on 31st October 2014 as a tropical depression (Sarker 2017). Chapala also made landfall on the island of Socotra, Yemen, on 31st October 2015 shortly followed by Megh which hit Yemen on 7th November 2015 (Kennedy et al. 2016, Kumar 2016). Both Chapala and Megh were classified as category 3 cyclones but Megh was considered more disastrous than

Chapala because it crossed over Socotra directly (Kumar 2016). According to NASA, Ockhi was classified as a tropical storm which affected the Indian coast and Mekunu was a category 3 cyclone, made its landfall in south-west coasts of Oman.

2.4.3. Effects of variable precipitation on mangroves in Oman

As shown above, heavy precipitation is a serious problem during cyclones in Oman. Beside the threat of heavy precipitation during cyclones, mangroves in Oman can also be impacted by fluctuations in precipitation. In typical conditions, freshwater supply is required for healthy mangrove ecosystems (Gilman et al. 2008). In Oman, surface-running wadis, which develop during rains, are considered the main freshwater supply for mangroves (Kwarteng et al. 2009). Some wadis run only for hours or days, even in the event of heavy rains, due to dry ground and high temperatures (Kwarteng et al. 2009) and usually the groundwater re-charging dams constructed by MRMWR limit the amount of water reaching coasts (Kwarteng et al. 2009).

Globally, precipitation is predicted to increase in high latitudes and to decrease in subtropical regions by 25% by 2050 because of climate change (Gilman et al. 2008). The IPCC projected significant changes in precipitation around the world with variations among regions (Gilman et al. 2008, Ward et al 2016). These changes are influencing temperature, evaporation and transpiration and consequently affect the health and productivity of mangroves (Ward et al. 2016). It is expected that precipitation is more likely to decrease in the Middle East with a projected increase in temperature and therefore an increase of salinity stress on mangroves (Ward et al. 2016).

Oman is located in the Arabian Peninsula, which is characterised by its arid climate, defined by spatially and temporally variable scarce precipitation (Kwarteng et al. 2016). On average, the annual precipitation recorded all over the country is 117 mm (Kwarteng et al. 2009, Kwarteng et al. 2016). The northern parts of Oman receive the least amount of rainfall with an annual average of only around 76.9 mm, mainly between December and April, while the southern parts influenced by the southwest Indian monsoon in summer receive an average annual precipitation of 181.9 mm (Kwarteng et al. 2009, Kwarteng et al. 2016).

Accordingly, this low precipitation trend is predicted to affect the health and growth of mangroves. Low freshwater supply to mangroves in a region of desert climate is also expected to increase salinity stress, reduce the growth rate of trees and increase mortality rate in seedlings, pushing mangroves to the edge of suitable environmental conditions and consequently expected to lead to a decline in their area (Gilman et al. 2008). Also, decreased freshwater input to mangroves changes their floral composition as well as soil and water characteristics which may also affect their overall growth and productivity (Gilman et al. 2008). These stressors could be compounded by temperature increase which can reduce the photosynthetic rate of *Avicennia marina* and therefore limit the growth and productivity of mangroves (Kathiresan and Bingham 2001). However, as stated above, Alongi (2002) argues that the effect of temperature as a limiting factor of mangroves is more noticeable on a global scale rather than a regional one.

A. marina is recognised for its tolerance to salinity stress and high temperatures (Clough 1984, Fouda and Al-Muharrami 1995, Cookson and Lepiece 1997, Lézine et al 2002, JICA and MECA 2004). Deposits of pollen grains discovered by archaeologists reveal the long history of existence of mangroves in Oman which goes back to 6000 B.P (Lézine et al 2002) when climatic conditions were more humid and supported the nourishment of both *Rhizophora* and *Avicennia* (Lézine et al. 2002). The shift in climatic conditions to more arid conditions limited the existence of *Rhizophora* to southern Oman where the climate is more humid while *Avicennia* secured its existence in other parts of northern Oman including the nature reserve in Al-Qurum (Lézine et al 2002). However, it is difficult to judge the future of this species due to urban expansion and immediate stresses such as cyclones which are more important in controlling the future of mangroves.

2.4.4. Urbanisation

Climate change related factors (extreme events) are seen by many researchers as the major threat limiting mangroves (Ward et al. 2016). In a country like Oman, climate change disasters such as cyclones and flooding are rare events (Kwarteng 2010, Pilarczyk and Reinhardt 2012). Therefore, it is not usual for decision makers to take such things into account in their development plans (Kwarteng 2010), unlike other countries where risk assessment procedures take into account climate change. Thus, urban planning in Oman did not acknowledge the mitigating effects of mangroves on extreme weather events, such as cyclones, and urbanisation itself reduces their effective role for storm protection through physical clearance and by releasing polluting effluent during high precipitation.

Mangroves have been acknowledged for their defensive role, mitigating the effect of storms. But urbanisation makes it hard for mangroves to play this role. In addition, effluents are released to mangroves during high precipitation events (Nóbrega et al. 2016). Urbanisation, infrastructure and tourism development are considered the chief reasons for mangrove loss in the Middle East (Van Bochove et al. 2014) and consequently the degradation of regulating services as well.

Based on my own observations, development in Al-Qurum is mainly in the form of roads, hotels, coffee bars and houses. All the natural routes of rainwater to the sea are impeded by roads and bridges and the level of urbanisation around mangrove areas is significantly higher than at Qurayyat. Al-Hatrushi and Al-Alawi (2010) found that most of the flooded areas along the natural route of Wadi Uday to the Gulf of Oman were 31.91% recreational, 31.08% residential and 10.29% transport facilities. Urbanisation can affect the health of mangroves by reducing the supply of freshwater, even during normal levels of precipitation.

In Qurayyat, the freshwater flow route is not blocked and occasional and low levels of rainfall normally provide the only freshwater supply to the mangroves. However, cyclone Gonu generated high rainfall at this site (409.80 mm in June, PACA). As a result, infrastructure in the area was severely affected, including the road connecting Qurayyat with the capital (Al-Hatrushi and Al-Alawi 2010). Mangrove trees were uprooted and seriously damaged and many houses in the fishing villages in Qurayyat were completely destroyed (ITNsource 2007). The government sheltered affected people until it could build new houses (ITNsource 2007).

In Harmul and Mahout, urbanisation does not appear have had an adverse effect on mangroves, particularly not at Mahout which is considered to be one of the healthiest mangrove ecosystems in Oman (JICA and MECA 2004). According to NCIS (2015), the town of Liwa town (where Harmul located) has 917 families and Mahout has 181, whereas in the town of Bawshar town (where Al-Qurum located) there are 18,123 families and at Qurayyat town there are 751, reflectingthe different degrees of urbanisation at the four sites.

2.4.5. Sea-level rise (SLR)

Gilman et al. (2008) argue that climate-induced accelerated SLR might be the most serious threat to mangroves and Ward et al. (2016) described it as a ‘major threat’. The continuous submergence of the aerial root system of mangrove trees can lead to oxygen deficiency, inactive water transport in leaves and a low rate of photosynthesis (McLeod and Salm 2006), which can result in the death of mangrove trees (McLeod and Salm 2006, Ward et al 2016) and thus change the structure and composition of the ecosystem (Gilman 2008, Ward et al. 2016). Inundation also adversely affects carbon sequestration, and leaves soil-stored carbon to an unpredictable fate (Marshall et al. 2012, Crooks et al. 2014).

SLR is spatially variable (Srinivasu et al. 2017). For example, it is found to be 3 times higher than the global mean in western tropical Pacific and found to be noticeably less than the global mean in south-western tropical Indian Ocean and eastern tropical Pacific (Han et al. 2010, Merrifield and Maltrud 2011, Srinivasu et al. 2017). Satellites are suggested to provide reliable and better estimates for SLR (Srinivasu et al. 2017). A recent study by Thompson et al. (2016) based on satellites (1993-2014) revealed that the trends of Sea Surface Height (SSH) in the western part of Equatorial and Northern Indian Ocean (ENIO), where Oman is located, were comparable to the global mean rates. In the first decade (1993-2003) of the analysis by Thompson et al. (2016), there was a drop in SSH in eastern ENIO compared to the mean global rate. In the second decade (2004-2014), Thompson et al’s. (2016) analysis showed increasing SL with rates in ENIO of up to 5-10 mm/yr in some regions.

Another analysis conducted by Srinivasu et al. (2017) for the same periods (1993-2003) and (2004-2014) supported the findings of Thompson et al. (2016) and found an increase in SLR in the northern Indian Ocean in the second period in comparison to the first one. According to Srinivasu et al. (2017), the SLR estimate for the second period ranged from 5.58±0.23 to 6.11±0.26 mm/yr, while in the first period there was a drop in SLR, where the rate was (0.37±0.26 mm/yr).

To examine the threat of SLR to Oman mangroves, long-term historical sea-level data are needed, but no long-term records were available specifically for Oman, whilst my analysis of the shorter (last 20 years) time series for Muscat did not reveal any directional trend. For the wider region, tidal records exist for Yemen, but these are mostly missing for the years covered in this study (early 1980s to date) and in any case, there does not appear to be a correlation between sea level in Oman and Aden (Yemen). By comparison, Alothman et al. (2014) estimated SLR was 2.2 mm/yr for the Arabian Gulf, at the tip of the northern part of Oman using the available tide gauge data, which is less than the mean global rate of SLR (3.2±0.4 mm/yr) (Thompson et al. 2016, Srinivasu et al. 2017). However, worldwide projections are for an increase in SLR along 70% of coastlines (Gregory 2013) and to attain between 0.28 m and 0.98 m by the end of this century according to the IPCC (2013).

Mangrove ecosystems can be resilient to climate change effects such as SLR under certain conditions (Gilman et al. 2008, Crooks et al. 2014, Lovelock et al. 2015, Ward et al. 2016). Alongi (2008) argues that mangrove migration inland should be able to keep pace with sea-level rise if not blocked by urban development (coastal squeeze). Coastal squeeze occurs when a fixed structure (often the result of urbanisation e.g. seawall, roads, buildings) prevents coastal ecosystems from migrating inland as the sea rises (Torio and Chmura 2013). Consequently, ecosystems such as mangroves can become 'squeezed' and the intertidal area reduced (McLusky and Elliott 2004, Torio and Chmura 2013 Winterwerp et al. 2013, Phan et al. 2015). Also, mangroves become more vulnerable and their delivery of services, such as storm buffering and erosion control will be affected as well as their capacity to act as a nursery areas for other species (Torio and Chmura 2013).

Several authors have emphasised the significant role of elevated sediments, supplied by freshwater input for mangroves to keep pace with SLR (Gilman et al. 2008, Lovelock et al. 2015, Ward et al 2016). Therefore mangroves inhabiting areas of rich sedimentation are more likely to survive and cope with a rise in sea level (McLeod and Salm 2006, Ward et al. 2016). Mangroves can trap sediments (Kathiresan and Rajendran 2005, Alongi 2008, Ward et al. 2016) by reducing wave energy and by accumulating algal mats or debris (Ward et al. 2016). Although sediment trapping can lead to a landward migration rate by mangroves of 0.7-20.8 mm/yr, Ward et al (2016) point out that this is site-specific. The tidal environment of mangroves deposits sediments, but it can also cause erosion, especially with the daily fluctuations of tides (Alongi 2008).

At Al-Qurum, research by JICA and MECA (2004) indicated the presence of elevated sediments in the reserve, as was confirmed by the site visits in this study. However, property development around mangroves, which is also clearly seen in historical aerial photographs, means that any sea-level rise would be expected to result in coastal squeeze (McLeod and Salm 2006, Fujii and Raffaelli 2008, Torio and Chmura 2013, Crooks et al. 2014, Phan et al. 2015) and therefore an overall reduction in mangrove forest area. In Qurayyat, heavy sedimentation which was observed in this study and documented in JICA and MECA (2004), could be explained by the findings of McLusky and Elliott (2004) who suggest that heavy sedimentation in estuaries can result from low energy intertidal zones or low energy freshwater supply.

With this accumulation of sediment, mangroves here may be less vulnerable to SLR and able to grow at a suitable elevation (Lovelock et al. 2015). However, sedimentation can still affect the hydrology and consequently the biological life of an estuary (McLusky and Elliott 2004). The 2008 aerial photograph of Qurayyat shows that the mangroves are surrounded by mountains, roads and agricultural lands. Urbanisation and steep topography may affect the health of this ecosystem by causing coastal squeeze.

Thus, despite the potential resilience of mangroves to SLR through landward migration or through sediment trapping or vertical accretion, urbanisation may consequently impede these processes and increase environmental stress on mangroves. Furthermore, urbanisation may also limit the supply of sediments from wadis, which is already the case in Al-Qurum. Worryingly, there is a plan to construct a new dam in Qurayyat which will further block freshwater and sediment supply to the site (Chapter 6). Urbanisation may also alter hydrographic patterns in estuaries (McLusky and Elliott 2004, p.93), which limit the supply of nutrients and consequently affect the productivity of the ecosystem (McLusky and Elliott 2004).

2.5. Conclusion

In summary, my analysis of vegetative cover of four mangrove forest sites over several decades revealed different dynamics at different sites, with Harmul and Mahout appearing more stable than Al-Qurum and Qurayyat. These patterns of change are consistent with storminess (from the sea) and high precipitation (freshwater flowing from the land) associated with cyclones, which are expected to increase in frequency and intensity due to climate change.

The effects of cyclones on mangrove sites in Oman have been found to be exacerbated by encroaching urbanisation which is blocking the natural routes of wadis. These wadis are also narrowly channeled and therefore cause destructive floods. Furthermore, large-scale construction projects such as harbours appeared to be increasing sedimentation that is impeding natural tidal action in estuaries, as seen at Harmul and Qurayyat and consequently affecting the health of ecosystem. Future coastal development needs to acknowledge the role played by mangroves in mitigating the impacts of severe weather events, such as cyclones, by planning urban development and infrastructure so that the services of flood protection afforded by mangroves are not compromised.

Chapter 3

Local perceptions of mangrove ecosystem services in Oman

3.1. Introduction

Mangrove ecosystems have widely been acknowledged for their contribution in improving communities' wellbeing (Mitra et al. 2011, Ajonina et al. 2014, Alongi and Mukhopadhyay 2015) and this has been reported in different parts of the world (MA 2005, Alongi 2009, Brander et al. 2012, Raffaelli and White 2013).

In spite of the considerable amount of published literature on ecosystem services and greater understanding about the role of mangroves in improving the well-being of communities, a UNEP survey reveals that the contribution of the Middle East in this area is considerably limited (Van Bochove et al. 2014). In particular, the services and benefits which might flow from the natural capital of mangrove ecosystems in Oman are poorly documented. Studies conducted in the 1990s by Fauda and Al-Muharrami (1995, 1996) were amongst the first to highlight the role of mangrove communities in Oman. Their main focus was to describe the biological community structure of mangroves and human activities at Mahout Island, one of the most significant mangrove sites in the country. Provisioning services were the most prominent benefits identified in the socio-economic survey they conducted (Fauda and Al-Muharrami 1995), particularly fisheries, which they attributed to the direct link of provisioning services to human well-being as well as the poor scientific knowledge and understanding about the value of regulating services, such as carbon sequestration. Also, the Oman coast had not been exposed to severe cyclone episodes events immediately before the 1990s, so the storm buffering role of mangroves was not appreciated, even though cyclones have been indicated as the most destructive natural phenomenon over longer time scales in Oman (Al-Badi et al. 2009, Charabi and Al-Hatrushi 2010, Fritz et al. 2010, Pilarczyk and Reinhardt 2012).

The MA provides a comprehensive list of potential services from mangroves (MA 2005, Fisher et al. 2008, Brander et al. 2012, Raffaelli and White 2013, Duke et al. 2014), but it is not known, firstly, whether all of these are significant for Oman and, secondly, how the Oman publics perceive them. For instance, Holt et al. (2011) found that whilst local communities surrounding a temperate North Sea estuary were able to identify and appreciate many provisioning and cultural ecosystem services, regulating services were poorly recognised or understood. Similarly, Lamarque et al. (2011) found that the identification of ecosystem services is influenced by human needs and the contribution of these services to well-being, revealing the values people hold, which is essential for better management and policy decisions.

A more recent and extensive study of Omani mangroves was conducted by the JICA and MECA (2004) (as introduced in Chapter 1). That study focused mainly on the biological importance of mangroves. Also, a socio-economic survey was conducted by JICA and MECA (2004), aimed to generally list and identify the ecosystem services of mangroves in Oman without a particular focus on local appreciation and perceptions towards the services and the ecosystem itself.

Accordingly, this chapter aims to reveal the relative importance of different mangrove ecosystem services identified by people across a range of socio-economic backgrounds at three sites: Al-Qurum, Qurayyat and Al-Sawadi (Figure 1.3, Section 1.7, Chapter 1). The specific objectives of the research were:

a) to explore how local people perceive and appreciate the ecosystem services flowing from natural systems in general, and from mangrove habitats in particular.
b) to perceive the relative significance of ecosystem services provided by mangroves.
c) to explore the type of activities practiced by respondents in the context of services provided by mangroves.

3.2. Methodology

The study was done through a questionnaire survey at three contrasting sites, the Nature Reserve of Al-Qurum (23°37'12.88"N, 58°28'33.11"E), the afforested site of Al-Sawadi (23°45'48.32"N, 57°47'42.19"E) and the publically-accessed site of Qurayyat (23°16'29.62"N, 58°55'11.91"E). The questionnaire was designed to reveal the relative importance of different mangrove ecosystem services identified by people across a range of socio-economic backgrounds at the three sites, as well as their wider appreciation of the benefits that natural systems can provide.

I used a self-completion questionnaire (Appendix 3.1) which I conducted from July to mid-September 2015. The questionnaire focussed more on cultural and regulating services, due to the tendency of people to be aware of the more tangible provisioning services (Holt et al. 2011, Lamarque et al. 2011). The formatting and structure of the questionnaire followed Atheull et al. (2009) and Wang et al. (2011).

Atheull et al. (2009) carried out a similar analysis on communities associated with mangroves in Cameroon around the Wouri estuary and the Douala-Edea reserve, while Wang et al. (2011) carried conducted a survey around slough and wetlands in Calgary, Canada. Atheull et al. (2009) sought to assess the value of mangroves to local communities through eliciting the perception and appreciation of people towards the services provided, but the questionnaires and interviews mainly involved loggers and households that utilise the system and have local knowledge of mangrove ecosystems. Wang et al. (2011) reflect more on the perceived importance of ecosystem services by individuals, stakeholders and the community, and like Atheull et al. (2009), the stakeholders had a professional experience in wetlands ecosystems. Given the broad similarity of these studies to my own, their questionnaire designs formed a sound basis for my own, although some questions were rephrased for the Oman context.

The questionnaire was relatively short with few open questions and more closed ones, to stimulate active participation in the study because they are easy to complete, they ensure respondent comfort and they reduce the risk of quitting a question without providing an answer (Bryman et al. 2008). Both types of questions were formatted and designed in an easily understandable way for different respondents with different socio-economic backgrounds. Due to the restriction to summer time for conducting the study, cooler and late afternoons were the best times to conduct the study and thus semi-structured interviews could not be used because they require more time compared to the short questionnaire: repondents might highly be unwilling to participate and spend most of their afternoon for the interviews. To avoid influencing responses, respondents were not given any information about mangroves or their benefits as ecosystems.

To view respondents' opinions and appreciation towards nature in general and mangroves in particular, respondents were asked to list the benefits of nature and estuarine trees specifically. They were also asked if they have noticed any kind of changes to these trees over time. To perceive their significance, the study provided a list of services provided by ecosystems and asked respondents to rank them from highest to the least significant. The study also provided a list of activities commonly practiced in nature and asked respondents to identify the activities they practice, where they usually practice them and how often they visit the site. The respondents were also asked to provide information on their socio-economic characteristics: sex, age group, level of education and profession.

The questionnaire was self-distributed and responses collected *in situ* by the researcher. The difficulty of answering questions by some respondents, and the risk of missing data, was minimised by the presence of the researcher at a proper distance to reduce her influence on respondents. Commonly, postal or mail methods are used to distribute self-completion questionnaires where respondents return their responses by post or deposit them in a designated location (Bryman et al. 2008). Although mailing of questionnaires has advantages in terms of time and money, processing and data collection (Oppenheim 2000), this approach has disadvantages in the Omani context. First, there is a high risk of low response rates, because the culture of using electronic mail is mainly adopted by academic and business sectors. Postal mail is mainly used for billing and many people in Oman don't have their own mail boxes. Second, a large percentage (76.6%) of the population in Oman aged 60 and above are illiterate (NCSI 2015b), particularly women, and therefore there is a risk of missing an important sector. Third, there is no opportunity for explanation, correcting misunderstanding and completion of the questionnaire (Kumar 2011, Oppenheim 2000).

Each site was visited for three days during afternoons with questionnaires distributed between late July and mid-September 2015 (Table 3.1). Respondents were approached as they were encountered by the researcher but sample size was greatly influenced by the interest of the selected respondents in contributing to the study. Any person who had access to the research site has "*an equal and independent chance of selection in the sample*" (Kumar 2011 p.199). As suggested by Bryman et al. (2008), the purpose of the study and the significance of their contribution were disclosed to the respondents, the questions were all explained and then respondents were left alone to answer the questions to reduce the influence of researcher. The respondents were informed about the right of anonymity, clarification of any question and how the data were to be used. The questionnaire had been approved by the Ethics Committee of Environment, University of York. Arabic was used for the questionnaire and for any dialogue with respondents, translation of the questionnaire from the original English approved by

York being checked by an Arabic scholar (Mr Younis Al-Anqoudi). The questionnaire was not tested beforehand because it was initially planned only as a pilot study.

Differences between sites in the relative frequency of responses were analysed where appropriate using chi-square contingency table analysis on the raw data, not the percentages presented in the figures. This statistical procedure assumes that the frequency of expected values equal to or less than 5 is greater than 20% of the total number of expected values, otherwise the test might suffer a type-one error. Where this was the case, adjacent rows had to be pooled or, if this was not sensible, removed all together. The final data categories used for the chi-square analysis are shown in corresponding tables in the results section.

Table 3.1. The schedule of questionnaire distribution at the three sites.

Site	**Sample size**	**Date of collection**
Al- Qurum	37	16th, 17th,and 18th July, 2015
Al- Sawadi	38	27th , 28th and 29th July, 2015
Qurayyat	32	24th , 31st August, 2015 and 9th September 2015
Total	107	

3.3. Results

Note: the percentage of responses presented here does not include invalid or missing data for individual questions. Accordingly, the sample size for each question could be less than the total number of questionnaires completed (Table 3.1).

3.3.1. Socio-economic characteristics of respondents

When respondents were asked about their place of residence, approximately three-quarters of the respondents in Al-Qurum and Al-Sawadi were visitors to the sites, while all the respondents in Qurayyat were residents (Table 3.2).

Table 3.2. Origin of respondents where N= 37 in Al-Qurum, 38 in Al-Sawadi and 32 in Qurayyat, July to September 2015.The actual number of responses is shown in brackets.

Site	**Al-Qurum**		**Al-Sawadi**		**Qurayyat**	
Respondents	Inside	Outside	Inside	Outside	Inside	Outside
%	24.3 (9)	75.7 (28)	26.3 (10)	73.7 (28)	100 (32)	0 (0)

Overall, for all three sites combined, most of the respondents were between 21 and 40 years old and three-quarters of the respondents interviewed were males (Table 3.3).

Roughly half of the respondents had not received a university level education and most were in governmental sector employment (Table 3.3). Sixty-two% of the respondents had regular employment, 3.1% worked in fisheries and only 1% practiced farming. Retired people accounted for 2.1% and 12.5% and 11.5% were students and unemployed, respectively. This section of the questionnaire received a 100% response rate, except for profession, where the response rate was 89.7%. The percentage of unemployed represents non-working housewives and job seekers.

Table 3.3. Responses of socio-economic characteristics of respondents, all sites combined. The actual number of responses is shown in brackets.

Variable	**% (N)**
Gender	
Male	75.7 (81)
Female	24.3 (26)
Total	*100.0 (107)*
Age	
< 20	15.0 (16)
21-30	48.6 (52)
31-40	26.2 (28)
41-50	8.4 (9)
51-60	1.9 (2)
61-70	0 (0)
Total	*100.0 (107)*
Level of education	
School level	49.6 (53)
Diploma	25.5 (27)
Higher education	24.3 (26)
Illiterate	0.9 (1)
Total	*100.0 (107)*
Profession	
Government sector	39.6 (38)
Private sector	8.3 (8)
Free business	9.4 (9)
Oil and gas industry	1.0 (1)
Engineer	1.0 (1)
Fishing	3.1 (3)
Farming	1.0 (1)
Student	12.5 (12)
Military	7.3 (7)
Electrician	3.1 (3)
Unemployed	11.5 (11)
Retired	2.1 (2)
Total	*89.7(86)*

With respect to the frequency of visits, around 27% of Al-Qurum respondents visited the site once a week, while in Al-Sawadi the most frequently recorded visit was twice a year (39%), and in Qurayyat, the most frequently recorded visits were daily (37.5%) and once a week (37.5%) (Figure 3.1). Statistical comparison of visit frequency between the three sites by a chi-square contingency test is constrained by the low number of respondents at each site (30 or less), so data had to be pooled into the following categories: daily, weekly, monthly/yearly to satisfy the assumptions of the test (less than 20% of expected values < 5). This analysis showed that there was statistically significant heterogeneity between the sites (chi-square = 21.96, df=4, p<0.001), with fewer daily and more yearly visits than expected at Al-Sawadi, and more than expected daily visits at Quayyat (80.6% of the total chi-square).

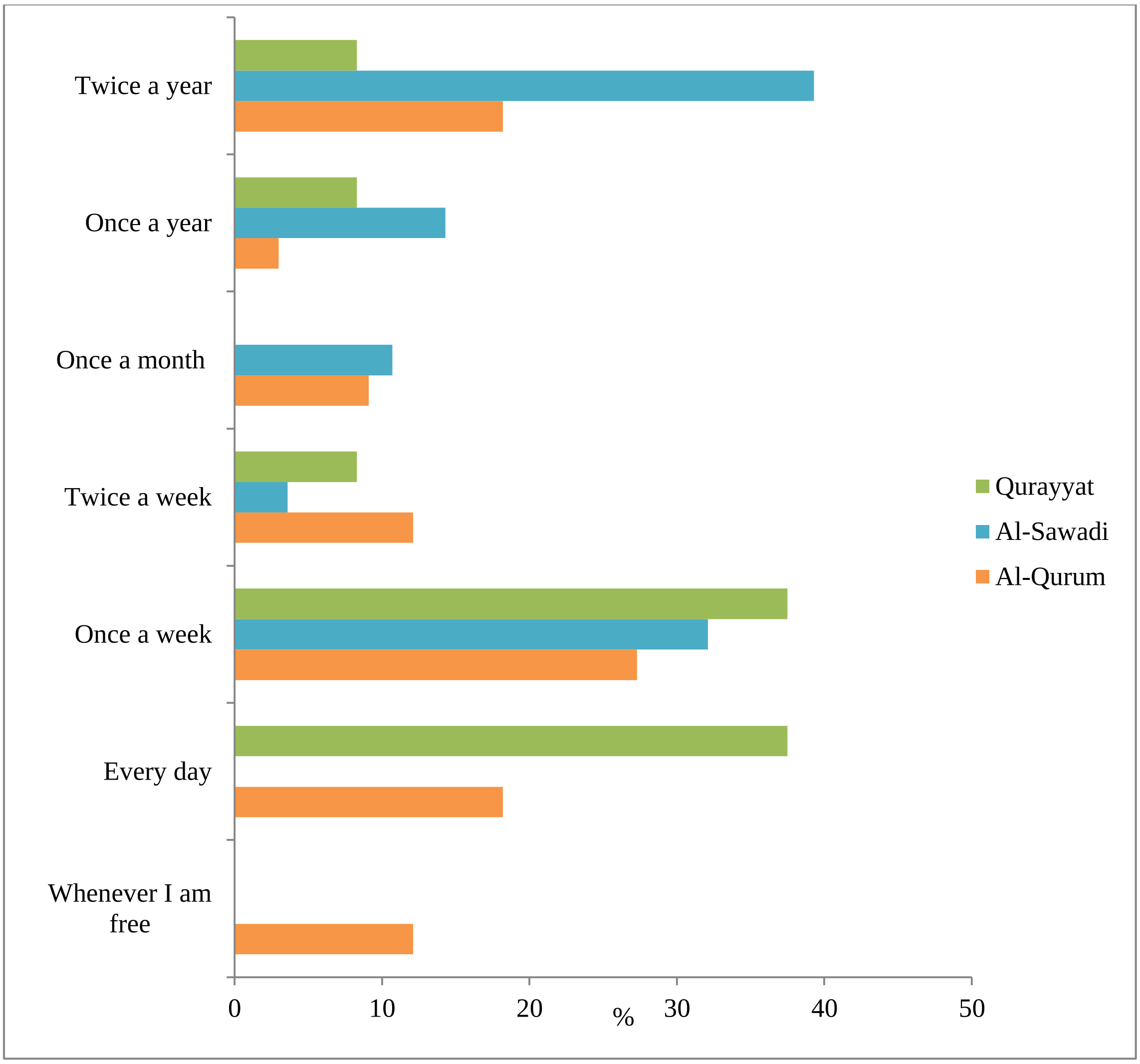


Figure 3.1. Frequency of visits by respondents to the three sites, where N= 33 in Al-Qurum, 28 in Al-Sawadi and 24 in Qurayyat, July to September 2015.

3.3.2. Respondent opinions and attitudes towards nature in general and towards mangrove habitats in particular

3.3.2.1. Public awareness of mangrove habitats and benefits

When respondents were asked the open question, what does the term "Al-Qurum" (the Arabic name for mangroves) imply, 80% replied it was a tree and about half replied it was coastal (Table 3.4). Around 16% identified the term as the capital city. The table also suggested variation of responses among the three contrasting sites. Statistical comparison of the meaning of term "Al-Qurum" between the three sites by a chi-square contingency test was again limited by the low number of responses (more than 20% of the expected values were great than 5), so some data had to be excluded to satisfy the needs of the test, such that only the first 4 responses in Table 3.4 were included in the test. The analysis showed there was no statistical significant difference between the sites (chi-square= 2.97, df=6, p>0.5).

Table 3.4. Meaning of the term "Al-Qurum" to respondents at each of the sites, July to September 2015. The actual number of responses is shown in brackets.

Meaning of the term "Al-Qurum"	**All sites (%)**	**Al-Qurum (%)**	**Al-Sawadi (%)**	**Qurayyat (%)**
It's a tree	79.4 (85)	89.2 (59)	68.4 (26)	81.3 (26)
It grows along coasts	43.9 (74)	48.6 (52)	39.5 (15)	43.8 (14)
It grows in estuaries	26.2 (28)	27.0 (29)	15.8 (6)	37.5 (12)
It's a city	15.9 (17)	13.5 (14)	18.4 (7)	15.6 (5)
It's adapted to saline environment	8.4 (9)	10.8 (12)	2.6 (1)	12.5 (4)
It has aerial root system	1.9 (2)	5.4 (6)	0 (0)	0 (0)
It's a nature reserve	1.9 (2)	2.7 (3)	0 (0)	3.1 (1)
It's a unique ecosystem	0.9 (1)	2.7 (3)	0 (0)	0 (0)
It shows horizontal zonation	0.9 (1)	2.7 (3)	0 (0)	0 (0)
It grows in deserts	0.9 (1)	2.7 (3)	0 (0)	0 (0)

When respondents were asked the open question about the benefits of estuarine trees, the most commonly mentioned services were nurseries for fish and other marine species, birds nesting and soil erosion prevention (Table 3.5). Statistical comparison of the perceived benefits of estuarine trees between the three sites, by a chi-sqaure contingency test was again constrained by the low rate of response. The data had to be pooled into the following categories - provisioning services, regulating services and cultural services - to meet the test assumptions. This analysis showed that there was a statistically significant difference between the sites (chi-square = 15.62, df=4, p<0.001), with more people identifying provisioning services than expected and less identifying cultural services than expected in Al-Sawadi (72%). Also, fewer people identified cultural services than expected in Al-Qurum.

3.3.2.2. Perceptions of changes to estuarine trees (mangroves)

Respondents were also asked about changes they may have noticed in these trees over time. Over half of the respondents had not noticed any change, while one-third perceived a decline in the number of trees. None of the respondents specified the period of time over which the change took place (Table 3.6).

Table 3.5. Benefits of estuarine trees (mangroves) identified by respondents at each of the sites, July to September 2015. The actual number of responses is shown in brackets.

Benefits of estuarine trees	%	Al-Qurum	Al-Sawadi	Qurayyat
Provisoning				
Nursery for fish & marine organisms	29.0 (31)	43.2	15.8	28.1
Source of medication	5.6 (6)	2.7	5.3	9.4
Fodder for animals	4.7 (5)	2.7	5.3	6.3
Supply of wood	1.9 (2)	0	0	6.3
Nest sites for birds	17.8 (19)	24.3	7.9	21.9
Nesting sites for bees	1.9 (2)	0	0	6.3
Regulating				
Preventing soil erosion	15.9 (17)	24.3	5.3	18.8
Heat trap (cools the air)	5.6 (6)	0	7.9	9.4
Storm buffer	2.8 (3)	2.7	5.3	0
Balance of nature	1.9 (2)	2.7	0	3.1
Water purification	1.9 (2)	2.7	2.6	0
Cultural				
Attracts tourists	3.7 (4)	0	10.5	0
Nice natural scene	9.3 (10)	5.4	15.8	6.3
Supporting				
Supporting coral reefs	1.9 (2)	5.4	0	0

Table 3.6. Responses of changes in estuarine trees at all sites, July to mid-September 2015. The actual number of responses is shown in brackets.

Changes in trees in the area	%	Al-Qurum	Al-Sawadi	Qurayyat
No noticeable change	52.3 (56)	54.1	71.1	28.1
Decrease in vegetative cover	32.7 (35)	29.7	15.8	56.3
Increase in vegetative cover	15.0 (16)	16.2	13.2	15.6

3.3.2.3. Public perceptions towards natural benefits

When respondents were asked about benefits that nature might provide, 50% said that nature helps them to relax, 35.5% said the natural scene attracts them and 23.4% said that nature is a source of meditation in God's creation (Table 3.7). In addition, the main regulating service identified by the respondents was the maintenance of air quality (23.4%).

Statistical comparison of the perceived benefits of nature between the three sites by a chi-square contingency test was again constrained by the low number of responses at each site and data had to be pooled into the categories of provisioning services, regulating services and cultural services to fit the assumptions of the test. The analysis showed that there was statistically significant heterogeneity between the sites (chi-square =16.89, df=4, $p<0.005$). In Al-Qurum, more people identified provisioning and regulating services than expected and fewer people identified cultural services than expected, while fewer identified provisioning services than expected and more identified cultural services than expected in Qurayyat (76 % of the total chi-square).

Table 3.7. The benefits of nature identified by respondents at all sites, July to September, 2015. The actual number of responses is shown in brackets.

Services and benefits of nature	%	Al-Qurum	Al-Sawadi	Qurayyat
Provisioning				
Shelter for living organisms	8.4 (9)	10.8	13.2	0
Food supply	3.7 (4)	5.4	5.3	0
Medicine source	2.8 (3)	2.7	2.6	3.1
Source of wood	1.9 (2)	5.4	0	0
Water supply	1.9 (2)	2.7	2.6	0
Ornamentals source	1.9 (2)	5.4	0	0
Regulating				
Air quality maintenance	23.4 (25)	29.7	23.7	15.6
Oxygen supply	14.0 (15)	27.0	5.3	9.4
Protects soil from erosion	2.8 (3)	5.4	2.6	0
Environmental changes control	1.9 (2)	2.7	2.6	0
Carbon sequestration	0.9 (1)	2.7	0	0
Cultural				
Helps to relax	50.5 (54)	27.0	63.2	62.5
Attractive natural scene	35.5 (38)	40.5	28.9	37.5
Meditation in God's creation	23.4 (25)	24.3	23.7	21.9
Good health maintenance	13.1 (14)	2.7	2.6	37.5
Tourists attraction	5.6 (6)	5.4	7.9	3.1
Source of education	1.9 (2)	2.7	2.6	0
Supporting				
Supports life on Earth	0.9 (1)	2.7	0	0

3.3.3. Significance of ecosystem services provided by mangroves

In the preceding section, respondents revealed their perceptions of the benefits that mangroves may provide through answering open questions. The following sections analyse responses to lists of ecosystem services (modified from the MA) provided to them, where they were asked to rank them in order of importance. A large percentage of the respondents considered all the services "highly significant" (code 3 or 4) even though they had not listed many of them in the open question section (Figures 3.2 – 3.4).

In Al-Qurum (Figure 3.2), over 80% of the respondents considered the role of nature in keeping the air clean as a highly significant benefit. Over 60% of them ranked the beauty and relaxation value as highly significant. Also, other services such as water purification and soil erosion prevention were highly ranked by more than 60% of responses. More than 50% ranked carbon sequestration as highly significant as well.

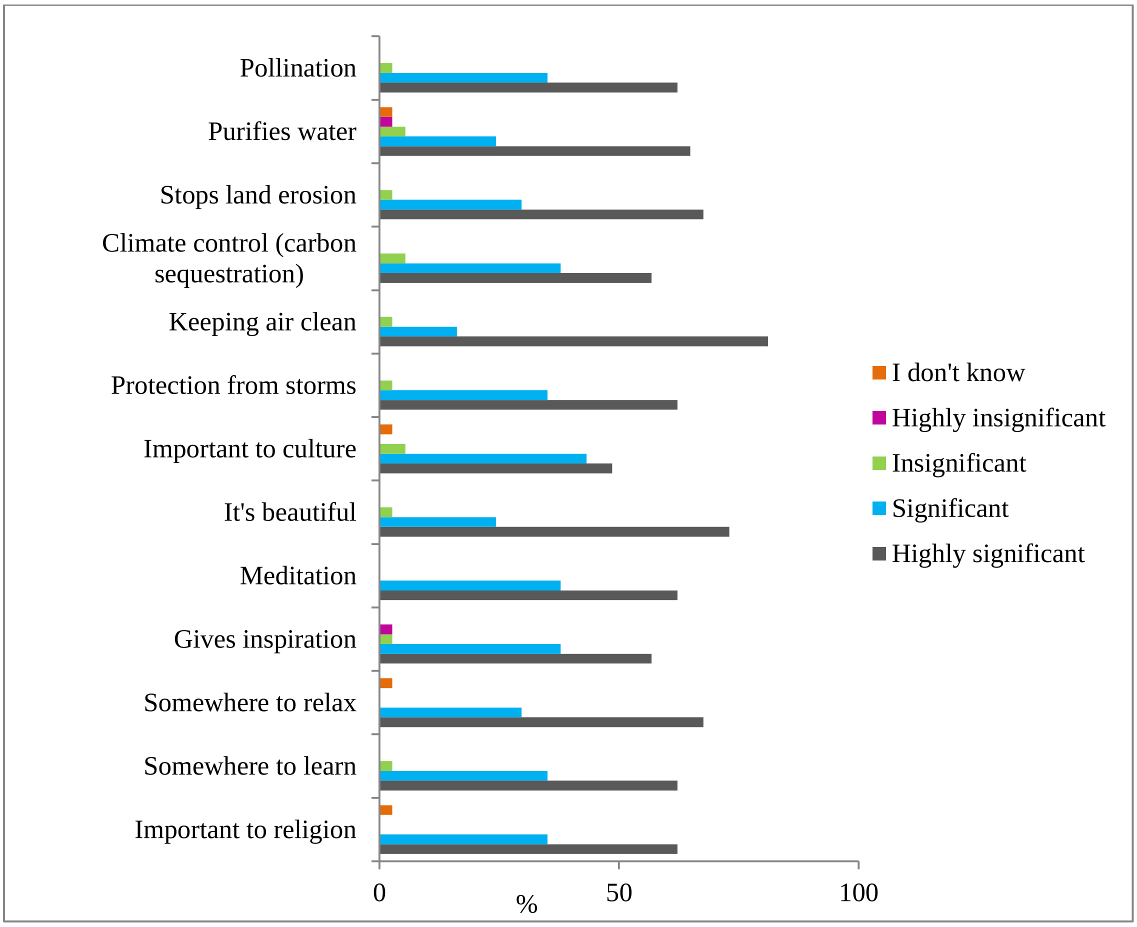


Figure 3.2. Ranking by respondents of the benefits of mangroves, in Al-Qurum, N=37, July 2015.

At Al-Sawadi, roughly 80% of respondents considered the value of relaxation as highly significant (Figure 3.3), and over 70% ranked beauty and keeping the air clean as highly significant. Just under 60% of respondents considered services such as water purification and beauty. The least significant (40%) were religious, inspirational and educational services.

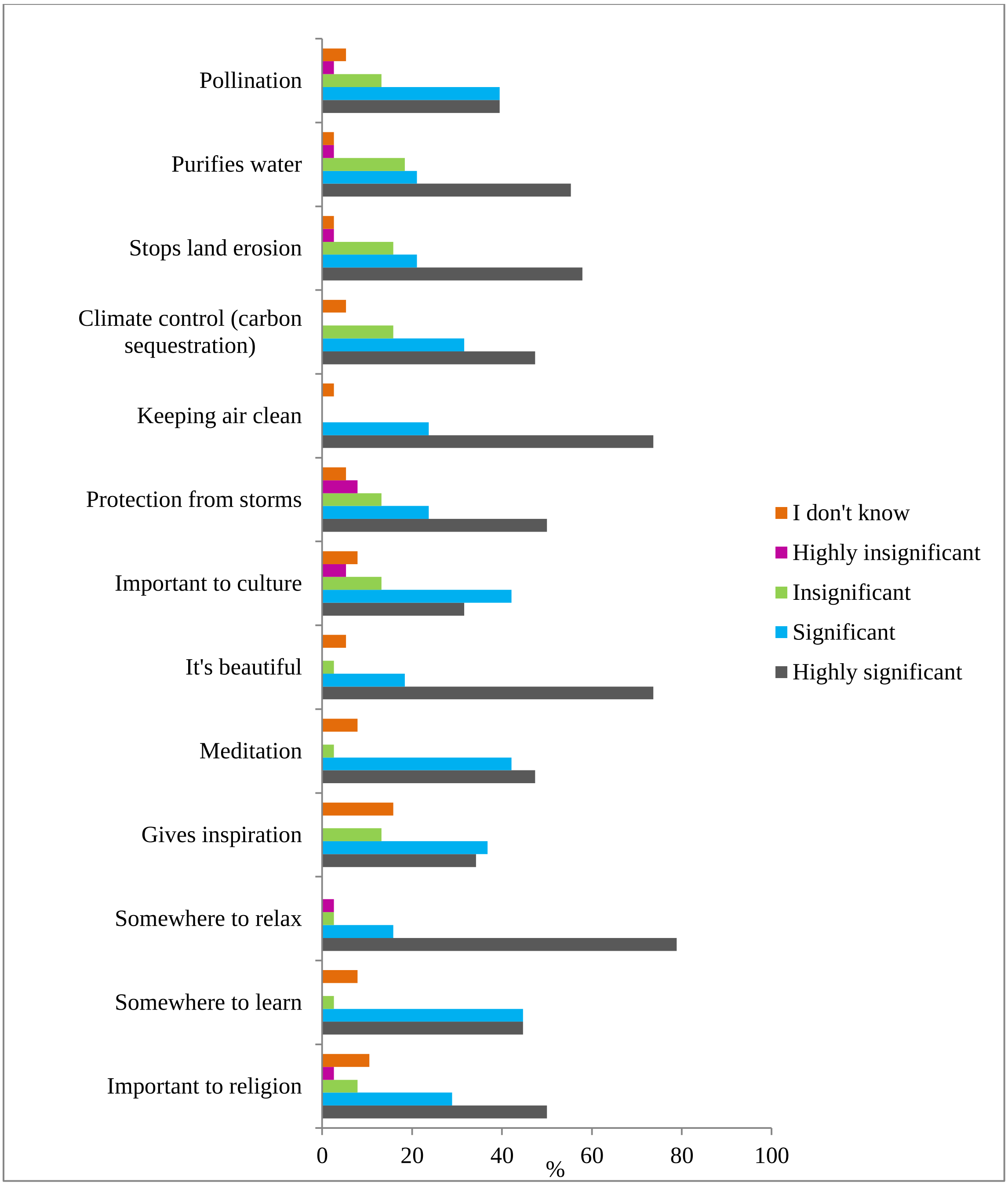


Figure 3.3. Ranking by respondents of benefits of mangroves in Al-Sawadi, N=38, August 2015.

The most highly ranked services for respondents in Qurayyat were beauty and clean air (more than half) with religious, cultural and inspirational values ranked least (Figure 3.4). Statistical comparison using chi-square analysis confirmed that there was no statistical difference between the three sites in terms of how services were ranked (chi-square = 7.44, df =26, p>0.5, not significant).

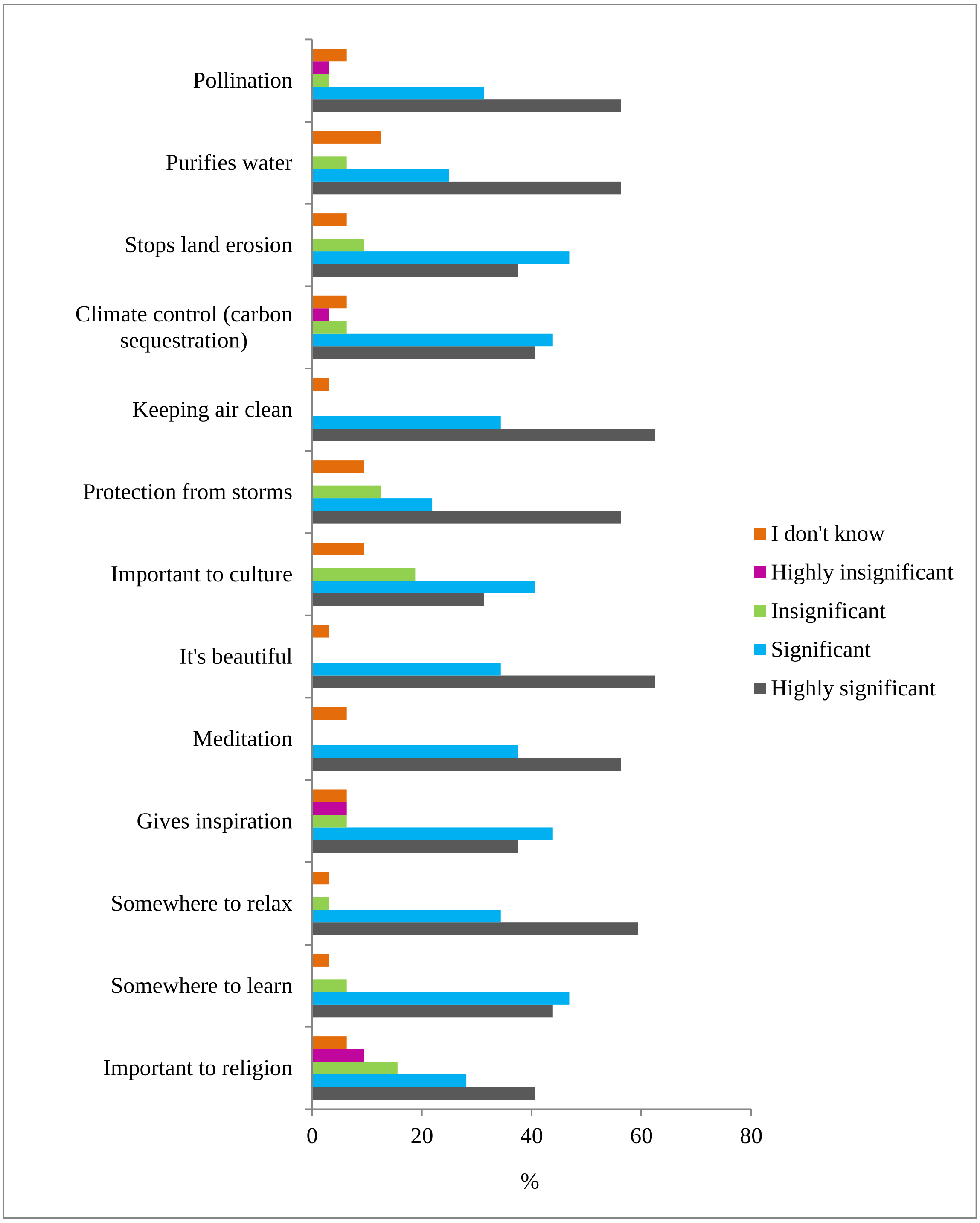


Figure 3.4. Ranking by respondents of the benefits of the mangroves in Qurayyat, N=32, August to September 2015.

3.3.4. Activities at the sites

When respondents were asked about the activities they practiced in the mangrove areas, over one-third of respondents stated that they visited the area for walking (38.3%), relaxation (35.5%) and bird watching (34.6%), with around a quarter (23.4%) visiting for angling. The least practiced activities by respondents were the collection of timber wood, the harvest of animal fodder and staying in hotels, each of which accounted for less than 5% (Table 3.8).

Table 3.8. Activities practiced in mangrove areas by all 107 respondents, at three sites, July to September 2015. The actual number of responses is shown in brackets.

Order	**Activity**	**(%)**
1	Walking	38.3 (41)
2	Relaxation	35.5 (38)
3	Bird watching	34.6 (37)
4	Angling	23.4 (25)
5	Inspirational purpose	20.6 (22)
	Meeting friends or neighbors	20.6 (22)
6	Playing ball sports	18.7 (20)
7	Visiting restaurants and coffee bars	15.9 (17)
8	Fishing for the household	12.1 (13)
	Horse riding	12.1 (13)
9	Pharmaceutical products harvest	11.2 (12)
	Camping	11.2 (12)
10	Collecting firewood	10.3 (11)
	Collecting charcoal wood	10.3 (11)
	Cycling	10.3 (11)
11	Educational purpose	9.3 (10)
	Spiritual purpose	9.3 (10)
	Ornamental products collection	9.3 (10)
12	Commercial fishing	5.6 (6)
13	Collecting timber wood	4.7 (5)
14	Animal fodder harvest	3.7 (4)
15	Staying in hotels	0.9 (1)

When analysed by site, more than 35% of those visiting Al-Qurum did so for enjoying a meal or coffee in the restaurants or coffee bars next to where the mangroves are located, while over 30% visited the area for bird watching and walking (Figure 3.5). None of the respondents visited the area to harvest animal fodder, to collect any kind of wood or to fish commercially. At Al-Sawadi, less than 30% of respondents visited the area for relaxation (Figure 3.5), whilst between 10% and 20% visited the area for walking, inspirational purposes and meeting neighbours and friends. None of the respondents intended to stay in hotels, to harvest animal fodder, or used the area for educational purposes, for collecting all kinds of wood, horse riding or visiting restaurants and coffee bars. At Qurayyat, around 70% of respondents visited the area for walking and over 60% visited the area for relaxation and bird watching (Figure 3.5). None of respondents visited the area to stay in a hotel.

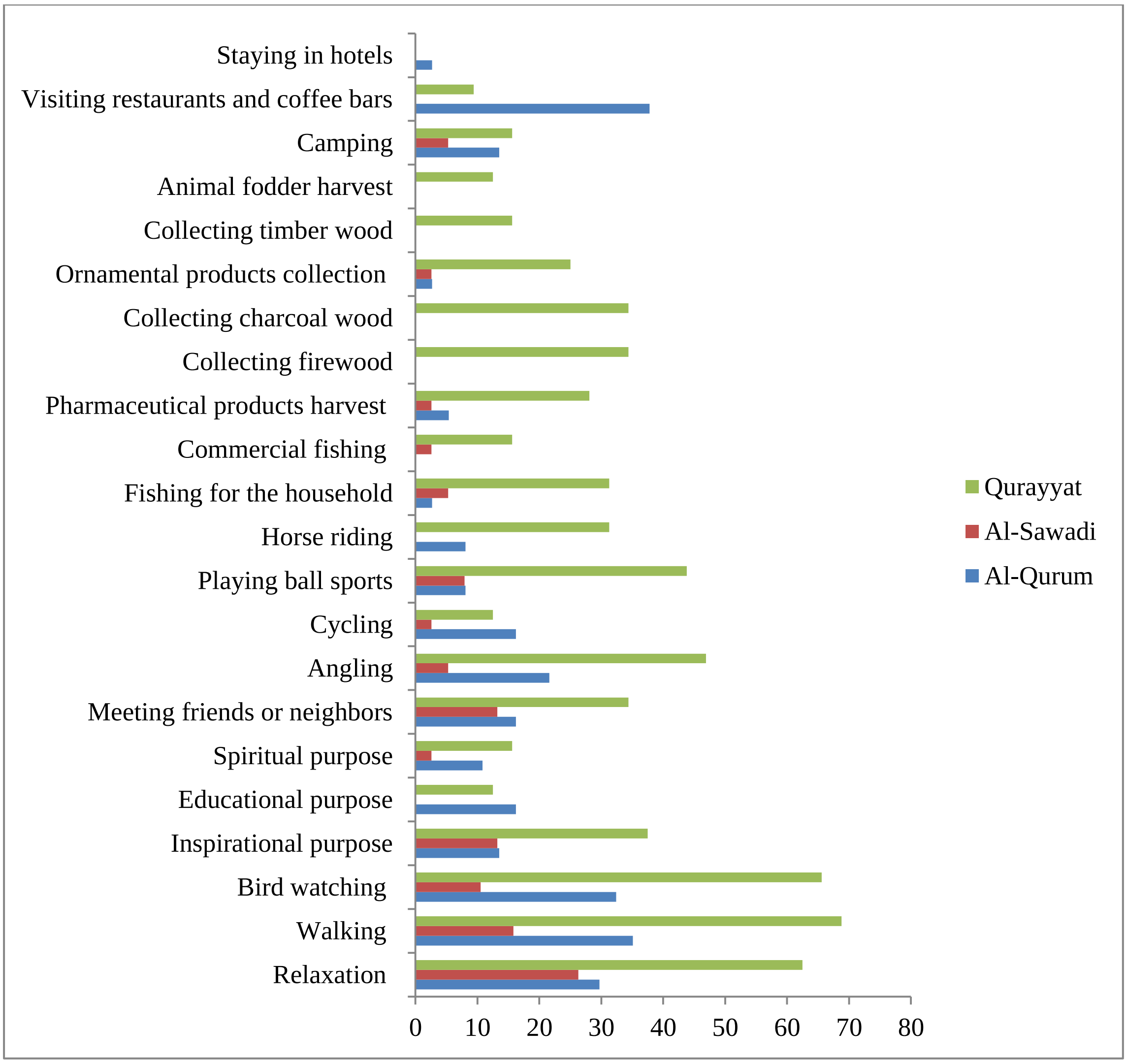


Figure 3.5. Activities practiced in mangrove areas by the respondents, where N=37 in Al-Qurum, 38 in Al-Sawadi and 32 in Qurayyat.

Statistical comparison between the sites by chi-square analysis required the removal of several activities from the analysis that had overall low response rates and hence low expected values (cycling, educational purpose, spiritual purpose, ornamental products collection, commercial fishing and staying in hotels) in order to satisfy the assumptions of the test. The revised analysis revealed significant heterogeneity between the sites (chi-square=57.42, df=30, $p<0.005$), with Al-Qurum having significantly more restaurant and coffee bar visits than expected and the other two sites significantly less, whilst firewood and charcoal collection was higher than expected at Qurayyat (55% of total chi-square).

3.4. Discussion

3.4.1. Overview

The results of the questionnaire survey indicated that:

a) when not prompted by a list of services, fish nurseries, bird habitat, erosion prevention and scenic importance were identified as important services.
b) when given a list of services to rank, cultural and aesthetic services were highly ranked.
c) provisioning services that are important in mangroves in many other parts in the world, such as timber, non-timber products and fodder, did not figure highly.

I now go on to explore in more detail the significance of the findings and the possible explanations behind them.

3.4.2. Socio-economic characteristics of respondents

Most respondents (75%) were male. Al-Qurum and Qurayyat, in particular, were mainly recreational destinations for young men. Women usually accompany families when visiting recreational places, consistent with the cultural practices of the Omani community. Also, interest and willingness to participate in the study was highly influenced by gender. When approached by the researcher, females showed less interest in participating and therefore the gender ratio in this questionnaire does not fully represent the population in these particular areas and the country in general, but it is a true reflection of the higher proportion of males visiting the area. My observations during the survey indicated that more males actually visited Al-Qurum and Qurayyat, whereas at Al-Sawadi approximately equal numbers of males and females visited, but more males completed the questionnaire due to cultural reasons (see above). Around 50% of respondents in this study were between 20 and 40 years old. According to NCIS (2015), the population of males of this age in Al-Qurum and Al-Sawdi is not significantly higher than females in the same age group, although the population of females in this age group in Qurayyat is slightly higher than males, but not significantly.

3.4.3. Respondent opinion and attitudes towards nature in general and mangrove habitats in particular

3.4.3.1. Public awareness of mangrove habitats and benefits

It is apparent from Table 3.4 that the respondents in Al-Qurum and Qurayyat were more knowledgeable about mangroves as a term and a habitat than at Al-Sawadi, although some simply thought it was the name of the city. Interestingly, although the findings were not statistically significant they also suggested that the respondents in Qurayyat were the most aware of the mangrove environment among the three sites. More respondents pointed out that mangroves are halophytes (salty plants as the term expressed in Arabic) inhabiting estuaries. In Qurayyat, the freshwater input to the system is not affected by infrastructure and tourism development as in Al-Qurum and the site is accessible by publics (JICA and MECA 2004). This may account for greater awareness of the mangroves. However, it should be noted that the numbers involved were small and that chi-square analysis did not reveal any significant differences between-sites.

As Table 3.5 indicates, respondents were more knowledgeable of the provisioning services of mangroves such as fisheries, bird nesting, bio-medical products and animal fodder supply. The findings also suggested that soil erosion prevention, air cooling and heat trapping are the most significant regulating services provided by mangroves, when identified without prompting. In addition, several cultural services were identified, such as the attractiveness of the natural scenery and tourism. None of the respondents identified the least visible, yet important supporting services such as nutrient cycling, primary production and soil formation. This is consistent with the findings of Holt et al. (2011) for a temperate North Sea estuary, probably due to the less obvious influence of supporting services of ecosystems on human wellbeing making them hard for people to appreciate (Raffaelli and White, 2013).

3.4.3.2. Perceptions of mangrove change

Unfortunately, when asked about changes over time, none of the respondents defined a time period for the recorded changes. Respondents at Qurayyat recorded the highest proportion of declines in mangrove habitat, consistent perhaps with the fact that they were largely residents of the site (Table 3.2) and visit it more often compared to respondents at the other sites (Figure 3.1). Activities such as fishing, harvest of fodder, timber and firewood were only recorded in Qurayyat, also reflecting a closer association between Qurayyat respondents and the site. Atheull et al (2009) also found that regular users of an ecosystem were more knowledgeable about its importance and thus more aware of any changes taking place. In the past, Qurayyat was managed by the local authority where the time and period of harvest was defined by locals, but it is now less managed (JICA and MECA 2004). Such a traditional management of resources supports the sustainable flow of ecosystem services and thus can contribute to the human welfare (Kumar and Kumar 2008).

JICA and MECA (2004), recorded degradation only at Qurayyat out of 18 sites surveyed in their study due to overgrazing by animals and insufficient management. A study done by Parvaresh (2011),in Iranian coasts close to the northern tip of Oman showed that camels pose the main grazing threat to mangroves. Another study conducted in Aden, Yemen, which shares the borders with southern Oman also found that camel grazing is one of the major threats faced by mangroves (Nagi and Abubakr 2013). Personal observations at Quarayyat in 2015 indicated that most grazing animals such as camels, cattle and horses are currently kept in fenced areas, with only a few goats released to graze, although even these small numbers may still pose a threat to mangroves (Parvaresh 2011).

I also noted that vehicles occasionally drive through the mangrove habitat to gain access to the beach and a football pitch, potentially posing further threats to this site. In studies by Atheull et al. (2009) and Wang et al. (2011), more than half of the respondents (56%) reported a decline in mangrove habitats and the majority reported the decline as a severe one due to poor legislation in managing the process of mangrove utilisation.

Less frequent visits were recorded in Al-Qurum and Al-Sawadi compared to Qurayyat. Although most of the respondents (54.1% and 71.1% respectively) did not report a change in mangroves over time, more of the remaining responses indicated a decrease (56.3%), particularly in Qurayyat. Tourism infrastructure development, housings and roads (JICA and MECA 2004) could have significantly affected the health of these ecosystems (Alongi, 2008 and 2009) as explained in more detail in chapter 2. Atheull et al. (2009) argue that economic development of coastal areas is the main cause of worldwide deterioration in mangrove habitats, along with urbanisation and population growth (Alongi, 2001). In addition, natural disturbances such as cyclones, floods, storms and tsunamis can destroy coastal habitats, with recovery potentially taking decades (Alongi 2002). In the Arabian Sea, 'Gonu' was considered the worst cyclonic event in the history of the area, which struck the Omani coast in June 2007 (Al-Badi, Ashrafi et al. 2009, Charabi and Al-Hatrushi 2010, Fritz, Blount et al. 2010, Pilarczyk and Reinhardt 2012).

This was a category 5 cyclone with high precipitation of 610 mm between 3rd-7th June (Fritz et al. 2010), resulting in floods and strong winds and waves (Krishna and Rao 2009, Al Najar and Salvekar 2010, Fritz et al. 2010); extensive damage to coastlines (300 km) and flooding of wadis (temporary rivers in Oman) (Fritz et al. 2010). A second severe cyclone 'Phet' impacted Oman in June 2010, which was classified as Category 3 cyclone (Pilarczyk and Reinhardt 2012). The most severe effects of 'Gonu' and 'Phet' were recorded in Muscat (where Al-Qurum and Qurayyat are located) beside Sur where inundation reached up to 5 m (Al Najar and Savekar 2010, Fritz et al. 2010). The noticeable decline in mangrove habitats reported by respondents in Al-Qurum and Qurayyat could well be explained by the impact these two cyclones in particular (see chapter 2).

3.4.3.3. Public perception of natural benefits of mangroves

Comparison of Table 3.5 (which deals with mangrove benefits elicited through open questions) and Table 3.7 (which deals with natural benefits elicited through closed questions) revealed that respondents were more knowledgeable about the benefits of nature in general than specifically of mangroves. They were able to identify 18 benefits of nature in general compared to 14 benefits of mangrove trees. Also, respondents were more aware of the cultural and regulating services from nature in general compared to questions specifically about services from mangroves, where respondents focused more on provisioning services. The most identified services of nature were relaxation, attractiveness of natural scenes, meditation and air quality maintenance, compared to those benefits identified specifically for mangroves, mainly limited to fisheries, bird biodiversity and the prevention of soil erosion.

The top provisioning service provided by mangroves, as perceived by respondents, was linked to fisheries (fish nursery service). Oman has a coastline of 3165 km (NCSI, 2015b) which supports significant fisheries. Omani exports of fisheries represented 63% of the total production in 2014. Thus, it is not surprising that fisheries figure highly as a benefit of mangroves. The value of mangroves for the Omani fisheries is discussed in Chapter 4.

Although some respondents at all sites identified fodder as a service (Table 3.5), the overall percentage was very low. Similarly, mangroves as a source of wood were recorded only in Qurayyat. A survey carried out by JICA and MECA (2004) showed that mangrove habitats supported local Omani communities significantly in the past by providing fodder for grazing animals, firewood, timber and commercial fishing. Fouda and Al-Muharrami (1995) suggested that this use was unsustainable because mangroves were over-exploited by locals for wood and fodder. The lack of importance of wood and fodder revealed in my survey suggests a shift in livelihood dependence on mangroves by local Omanis.

Atheull et al. (2009) and Van Bochove et al. (2014) argue that the services and benefits of mangroves valued by people are significantly influenced by the level of dependence of livelihoods on these services, in part reflecting the socio-economic characteristics of the country. The Omani economy is now highly dependent on the oil and gas sector which constitutes 47.4% of Omani GDP (Middle East Online 2016). This shift to governmental sector industries that provides more stable incomes in recent years probably accounts for the lack of recognition of provisioning services such as wood and fodder.

With respect to regulating services, the natural benefits most frequently indicated by respondents were the maintenance of air quality and oxygen supply, although these were not mentioned as being specifically provided by mangroves. The highest responses for regulating services were recorded in Al-Qurum, consistent with the greater awareness of pollution in cities, due to denser population, buildings and transportation (Bolund and Hunhammar 1999). Interestingly, respondents identified more regulating than provisioning services, in contrast to the study of Holt et al. (2011), although the majority of respondents (around 99%) were not aware of the significant role that mangroves play in carbon sequestration. Alongi (2002) suggests that the loss of 35% mangroves habitat world-wide has resulted in the release of $3.8x10^{14}$ gC, a figure which excludes below-ground biomass and forest net canopy production. Likewise, very few respondents recognised the significant role of mangroves for mitigating the effects of storms and cyclones (5% or less across all sites), despite the high recent impact of cyclones 'Gonu' and 'Phet'. The role of mangroves in carbon sequestration and storm mitigation are explored in depth in the next chapter. Yet when provided with a list of services, these were ranked quite highly (Figures 3.2-3.4).

The tendency of respondents to highly appreciate the listed services in this study corresponds with Lamarque et al. (2011) who showed that stakeholders tend to self-identify 'visible' services without the need for a prompt while a ranking exercise reveals the 'invisible' services in which the provided list of these services is expected to prompt the responses. The findings here are also consistent with those of Atheull et al. (2009), where 87% of respondents revealed that mangrove ecosystems are of high importance to their wellbeing. However those respondents were highly knowledgeable of the ecosystem due to their high utilization of it.

Wang et al. (2012) also found that stakeholders highly ranked the list of services provided for them, even for the less tangible cultural services such as inspiration. Regulating services such as carbon sequestration were identified as highly important, and those stakeholders also had a good knowledge of wetlands ecosystems.

With respect to cultural services in this study, respondents most frequently mentioned relaxation, followed by the attractiveness of natural scenery, both for nature in general and mangroves in particular. Respondents also frequently identified meditation as a cultural benefit; aesthetic and spiritual values are often the benefits most frequently mentioned by respondents, a reflection of belonging to a place (Rodwell, 2013). Although cultural values are not linked to community well-being directly, they are highly significant and irreplaceable and therefore will decline if the ecosystem is degraded (Plieninger et al, 2013).

The MA (2005) argues that the cultural perception of humans towards nature and ecosystems is strongly influenced by changes in the condition of ecosystems. In the present study, the responses for cultural services probably reflect the influence of the Islamic identity of the respondents. The values and directives of Islam stem from the two main sources, the Quraan (the Holy Book) and the Sunnah or Hadith (statements or actions reported about the Messenger of God, Prophet Mohammed (peace be upon him). Muslims value nature through the appreciation of its beauty and God's creation. In fact, Muslims believe that "*God expresses himself through non-linguistic forms of communication which is through nature*" as stated by Chowdhury (2013, p.8). The Prophet Mohammed stated "*Allah being beautiful Himself, loves beauty" (Saheeh Muslim).* Chowdhury (2013) confirms that the different cultural benefits of nature are well appreciated in Islamic culture and heritage based on what was stated in the Quraan and Sunnah (Hadith) in both an implicit and explicit manner.

3.4.5. Activities at the sites

The activities practiced by respondents at each site are the services that people actually use, including intangible services such as like cultural ones, reflecting their personal interests and likes. Cultural services associated with recreation were practiced more often than inspirational or spiritual ones, consistent with the findings of Plieninger et al. (2013). These authors showed that after aesthetic services and social relations, most of respondents identified the recreational services of walking and bicycling more frequently than inspirational and spiritual ones.

The activities undertaken by respondents differed between sites, as expected according to location and their distinctive characteristics (the three sites differed in their demography and level of development) (Van Bochove et al. 2014). Al-Qurum is located in a central part of Muscat, the capital of Oman. Most of the respondents visited this area for recreational activities, including relaxation, walking and eating in restaurants and coffee bars, which form part of the cultural values of the site. It could be argued that views of mangroves are an incentive to visit the area.

Al-Qurum is considered as one of the prime recreational destinations for tourist and residents in Muscat (JICA and MECA 2004). Bolund and Hunhammar (1999) argue that citizens of cities tend to value highly the recreational services of nearby nature, which may relieve the stress of the urban environment. This is consistent with the results of a socio-economic survey included within the study by JICA and MECA (2004), confirming that Al-Qurum has high tourism potential and high recreation and aesthetic values. Similarly, that study found that the site has high potential educational value, especially for teaching school children about conservation and the importance of the natural environment. In the present study, the highest percentage of responses recorded for the educational value of mangroves was for Al-Qurum.

The lowest level of activities recorded among the three study sites was at Al-Sawadi. Despite the high potential of the site for providing services to people, its location limited realisation of that potential (JICA and MECA, 2004). Al-Sawadi is distant from residential areas and paved roads leading to the coast, with most tourists and residents visiting the Al-Sawadi area to spend time on its beach and islands which are distant from the mangroves. Only a few people were seen walking in the evening in the mangrove area during my surveys. This study also found that most of the activities practiced by respondents at Al-Sawadi were recreational. The potential of this site as a prominent tourism destination is also limited by the abandoned unfinished resort, the Blue City. The details of the project can be found on (http://www.aktor.gr/oman_projects/arthro/blue_city-11858981/).

Although Qurayyat is part of Muscat Governance, the rate of development is low compared to other areas of Muscat and people there enjoy most of their times in the coastal part of the town (Chapter 6). Most of the activities practiced by locals in the mangrove area were recreational, similar to the other two sites, but broader in range. The only activity not practiced at Qurayyat was staying in hotels, only to be expected given the lack of a hotel close to the mangrove area. Some of the locals revealed that there was a plan by the Ministry of Tourism to develop tourism and recreational projects in the areas, but it conflicted with local aspirations due to fears of losing their cultural identity. This is consistent with JICA and MECA (2004), which suggested that Qurayyat has high potential for tourism. Although, that study stated that there was no potential for collecting wood or for harvesting natural medicines in mangroves, my survey showed that some families in the area are in fact utilizing these services. In addition, all the respondents I surveyed in Qurayyat were residents, so it is not surprising that their lives were linked more closely with their local ecosystem than at the other sites.

3.5. Some reflections on the study

This survey aimed to increase knowledge of mangrove services in Oman by soliciting views of people on the benefits of ecosystem services. However, the interpretation of the data collected needs to take into account the following aspects:

a) There was a marked imbalance in respondent gender ratio that does not represent the society present in the research areas. Despite my aim to randomly select respondents, males were more interested in participating than females and most visitors were males. Also, most of the respondents were aged 40 and younger.

b) The study is likely to have been richer if it had included the views and perceptions of the older generation, but most of older age group showed no interest in participation due to being illiterate.

c) The questionnaire done in Al-Sawadi would have been more representative if conducted in the mangrove area, but people rarely visited the site because of its distance from residential areas and facilities. Therefore, respondent perceptions were likely based on their general knowledge of mangroves, not particularly those at Al-Sawadi.

d) The study had to be conducted in summer due to costs of time and money and work opportunity, but this is the hottest time of year so less people were likely available to interview at the sites.

e) Some features of the questionnaire may have been lost or weakened by the translation from English to Arabic. The questionnaire was reviewed and translated to Arabic by an Arabic language proofreader, in the presence of the researcher to minimise errors, but some may remain.

f) The study could have considered the distance of the respondents from the research site to examine the influence of the distance on perceptions of and appreciation towards the ecosystem and to examine the presence of distance-decay phenomenon.

3.6. Conclusions

The purpose of this study was to examine the perceptions and attitudes of publics towards ecosystem services of nature in general, and of mangroves in particular, for three contrasting sites in Oman. Additionally, the study aimed to highlight the significance of the services as perceived by respondents and the types of activities practiced by them in mangrove areas at the three sites.

The low direct utilisation of mangroves for provisioning services observed at the 3 sites could be due to recent changes in the socio-economic characteristics of the Omani community. Mangrove habitats can offer important support for poor communities, especially for provisioning services such as food and wood (Van Bochove et al. 2014). In the past, many Omani communities, including coastal ones, were poor and more dependent on fisheries and animal husbandry, with mangrove habitats playing a significant role in supporting the wellbeing of the Omani community (JICA and MECA 2004). The move towards an oil-based economy has reduced this dependence on mangroves. Despite the less dependence of communities on most of the provisioning services, the support of mangroves for fisheries at the three sites was highly recognised. I will therefore explore the role of mangroves to support fisheries in Oman in the next Chapter (4).

The Omani publics surveyed were more aware of nature benefits in general than specifically for mangroves. Regulating and cultural benefits in general were better identified and thus appreciated by the publics than provisioning services. In contrast, provisioning services of mangroves were more appreciated than regulating and cultural services. Generally, cultural services were more appreciated than regulating services both for nature in general, and mangroves in particular. Another main finding of this study was that the activities practiced at mangroves sites were mostly cultural, especially recreational ones.

The results presented in this study facilitate improvements in understanding the attitude of people towards ecosystem services of mangroves and thus could help to implement better policies for more sustainable use and management of these resources (Plieninger et al. 2013) in Oman. It is clear from this study that the potential services provided by an ecosystem and their associated values are site specific (Bolund and Hunhammar 1999). The activities practiced by people at a site were also influenced by the location and characteristics of the area. There was therefore no single site where the complete range of different services could be explored. For these reasons, I will focus on a single site to examine regulating and the cultural services separately in the following chapters. I have excluded the restoration site, Al-Sawadi, due to its early stage of development.

Most people visited Al-Qurum to enjoy walking or having a meal in the area located between the sea and the mangrove nature reserve where walking paths and restaurant and coffee bars are found. Al-Qurum is located in a central urbanised area and was also impacted by ‘Gonu’ (2007) and ‘Phet’ (2010), where the most severe effects of these cyclones were recorded (Al Najar and Salvekar 2010, Fritz et al. 2010). The highest responses for regulating services were recorded in Al-Qurum, consistent with the greater awareness of pollution in cities, due to denser population, buildings and transportation. I will therefore focus in a later chapter (5) on Al-Qurum to explore the role of mangroves in carbon sequestration and storm buffering.

Qurayyat was also severely impacted by those cyclones, with inundation reaching up to 5 m (Al Najar and Salvekar 2010, Fritz et al. 2010). However, due to time limitations the regulating services of this ecosystem will not be further studied in depth and instead

I will focus in chapter (6) more on cultural services at Qurayyat which is publically accessible and recommended by the study of JICA and MECA (2004) for better management plans. In comparison with Al-Qurum Nature Reserve, the respondents at Qurayyat were all residents of the site and visited the site more frequently. More than 70% of Qurayyat respondents visited the site at least once a week. The study has also found that Qurayyat has the highest records of practiced activities and these had a more cultural dimension.

Chapter 4

An initial assessment of the role and value of Omani mangroves for fisheries

4.1. Introduction

Coastal populations, especially in rural communities, are globally increasing and expected to increase pressure on fish stocks, on which many depend for their livelihood and wellbeing (Islam and Haque 2004, Le Vay et al. 2008, Khalfallah et al. 2016). Fishing is not simply a profession or a source of income (Belwal et al. 2015), but it also shapes the cultural and social features of coastal communities (Blaber 1997, Bonfil and Abdallah 2004, Belwal et al. 2015). Fishing activities commonly differ among practitioners, ranging from recreational to subsistence to commercial (Blaber 1997, Dahdouh-Guebas et al. 2000, Hawkins and Roberts 2004, Cooke and Cowx 2006, Belwal et al. 2015), with both licenced and unlicensed full- and part-time fishers (Belwal et al. 2015). The catch of subsistence fisheries is totally consumed by the household and not sold in the market (Blaber 1997). Artisanal fishing refers to the catch partially sold in market, with the remainder going to household consumption (Blaber 1997). All of the catch is sold in commercial fisheries (Blaber 1997). Different methods are used for fishing in tropical and subtropical developing countries compared to industrialised countries (Blaber 1997), ranging from small scale traditional methods and small boats (Hawkins and Roberts 2004), to large scale commercial vessels such as trawlers (Cooke and Cowx 2006).

Fisheries are often sustained by ecosystems like estuaries, mangroves, mudflats, seagrass beds and coral reefs (Hamilton and Snedaker 1984, Laegdsgaard and Johnson1995, Bonfil and Abdallah 2004, Aburto-Oropeza et al. 2008). In more developed regions of the world, there is less dependence on subsistence fisheries, but mangroves can still support important recreational fisheries (Hamilton and Snedaker 1984).

It has been argued that there is no defined number of species that utilise mangroves at some stage in their life cycle (Hamilton and Snedaker 1984, Spalding 2015), however, the list is estimated to include more than 2,000 species of both invertebrates (crabs, molluscs, shrimps and prawns) and fish (Hamilton and Snedaker 1984) and many of these species are commercially fished. Researchers generally classify the faunal inhabitants of mangroves based on attributes such as their adaptation to salinity and habits such as residency, breeding and feeding behaviour (Blaber 1997, Rönnbäck 1999). With respect to salinity tolerance, most studies report that mangrove-associated species are mainly represented by those adapted to a wide range of salinities (euryhaline) (Tzeng and Wang 1992, Blaber 1997). Residency is usually used to define mangrove-associated fish as either permanent or temporary resident species (Blaber 1997, Rönnbäck 1999). Permanent residents usually spend their life entirely in mangroves, while temporary residents either rely on the mangroves at certain stages of their lives or incidentally utilise the habitats (Blaber 1997, Rönnbäck 1999). Some temporarily mangrove-associated species utilise mangroves as nurseries at the larval and juvenile stages of their life cycle, while others visit the estuaries for foraging; with most using mangroves at specific critical stages of their life cycles and to escape predation (Hamilton and Snedaker 1984, Tzeng and Wang 1992, Blaber 1997, Manson et al. 2005b, Spalding 2015). For example, shrimps use coastal waters as spawning grounds, while mangroves are used later as nursing grounds for juveniles (Laegdsgaard and Johnson 1995, Wolanski and Sarsenski1997). Another example given by El-Regal and Ibrahim (2014) is the use of mangrove habitats by coral reef fish in the Red Sea as shelter during the juvenile stage. The morphological structure of mangroves roots provides breeding grounds for fish by trapping sediments to form settlement grounds for larvae and also enhance their chances of escaping predation (Blaber 1997, Dehghani 2014, El-Regal and Ibrahim 2014,). Mangrove roots also form an attachment substrate for shellfish, such as oysters and mussels (Rönnbäck 1999, Blaber 1997).

Different researchers have different mangrove-association schemes for species and this has arguably led to disparate reporting (Tzeng and Wang 1992, Hamilton and Snedaker 1984, Spalding 2015). This disparity has also been suggested to be influenced by the diversity of mangrove species themselves in different parts of the world, as well as the use of different survey methods (Tzeng and Wang 1992, Spalding 2015).

The harvest of mangrove-associated fish and shellfish species has been reported in many tropical and sub-tropical areas (Islam and Haque 2004) at subsistence and commercial levels. It has been estimated that the global annual revenues of all ecosystem services flowing from mangroves reaches US$ 1,648 billion (Aburto-Oropeza et al. 2008), with a net present value (NPV) of fisheries ranging from US$708 to US$ 987/ha (Barbier et al. 2011). This NPV number represents offshore artisanal fisheries in particular.

The time spent in mangroves by fish and invertebrates inhabiting neighbouring ecosystems (e.g. mudflats, seagrass beds and coral reefs) is thought to be highly linked to the commercial harvest of these species (Laegdsgaard and Johnson 1995, Aburto-Oropeza et al. 2008). This is due the important role of mangroves in increasing the population of these species (Laegdsgaard and Johnson 1995, Aburto-Oropeza et al. 2008, Dehghani 2014 and El-Regal and Ibrahim 2014).

For example, modelling studies show that mangrove habitats contribute significantly to maintaining the health and population of reef fish communities (Barbier et al. 2011) as many reef species utilise mangroves during the early stages of their life cycle (El-Regal and Ibrahim 2014). The same studies also suggest that mangroves can directly reduce the impacts of overexploitation of reef fisheries (Barbier et al. 2011). Mangroves and reefs are clearly highly connected and considered to have similar levels of physical complexity (Wolanski and Sarsenski 1997). In addition, mangroves may act as a physical barrier protecting reefs and seagrass beds from river flushes and siltation (Whitfield 2017).

Commonly, mangrove-associated species are threatened by many factors including unsustainable catches (Pauly et al. 1998, Le Vay et al. 2008). Populations may also be threatened if mangrove habitats are degraded, lost or modified, for example, by aquaculture operations (Nurkin1994, Duke et al. 2007, Le Vay et al. 2008), leading to an overall decline in biodiversity and consequently the socio-economic value of the species (Laegdsgaard and Johnson 1995, Islam and Haque 2004, Le Vay et al. 2008, Barbier et al. 2011). The increasing demand for marine food has led to large-scale development of the aquaculture sector especially for crustaceans, but also for fish such as sea bass (Naylor et al. 2000). Consequently, many mangrove habitats have been converted to prawn ponds (Hamilton and Snedaker 1984, Chong et al. 1994, Rönnbäck 1999, Barbier and Strand 1998, Barbier 2006, Aburto-Oropeza et al. 2008), particularly in South-east Asia (Yee 2010). This conversion to aquaculture has significantly contributed to the market value of mangrove fisheries, but has also led to the degradation of the mangrove ecosystems in many countries (Rönnbäck 1999, Naylor et al. 2000, Barbier 2006). Aquaculture is responsible for the degradation of 52% of mangroves world-wide, with 38% alone in Asia (Barbier 2006, Yee 2010).

The conversion of mangrove habitat to fish ponds is mainly driven by the perception among some of mangroves as “wastelands” that can be converted to increase cash supply, fuelled also by ignorance of the broader ecological value of mangroves for services such as storm protection and a lack of awareness that the health of fisheries is dependent on the health of the mangrove system itself (Hamilton and Snedaker 1984, Rönnbäck 1999, McLusky and Elliott 2004). Aquaculture has also led to the decline of mangrove ecosystem health through pollution and the introduction of pathogens and invasive species (Naylor et al. 2000, Black 2001, McLusky and Elliott 2004). As a result, ponds cease functioning and are finally abandoned after 5-10 years in the best cases (Rönnbäck 1999, Black 2001). It has been estimated that 70% of ponds have been abandoned in Thailand, although they were once considered highly productive (Rönnbäck 1999). The ecosystem will consequently fail to deliver other services, such as regulating services, particularly carbon sequestration, storm buffering and prevention of soil erosion (Van Wesenbeeck et al. 2015, Ahmed and Glaser 2016).

Scientifically, tropical and sub-tropical estuaries are less researched than temperate estuaries at the global level and therefore less is known about their fish communities and fisheries, despite the great number of estuaries in these parts compared to temperate regions (Blaber 1997, Blaber 2002, Debroas et al. 2009, Elliott and Whitfield 2011) and the worldwide interest in their resources (Blaber 1997). Most of the research conducted on estuarine fisheries, including mangroves, has focused on their economic importance, which is in turn tightly linked to the productivity of mangroves (Blaber 1997).

The relatively less attention on mangrove fisheries (compared to open marine fisheries) may be influenced by the location of estuaries themselves (Elliott and Whitfield 2011). Usually, scientists interested in freshwater habitats consider estuaries as part of marine habitats, while marine scientists may be attracted by more diverse habitats such as coral reefs or the open ocean (Blaber 1997, Debroas et al. 2009, Elliott and Whitfield 2011). Also, estuaries and mangroves are characterised by muddy, highly turbid environments, which also poses the threat of hidden predators including crocodiles (Blaber 1997, Badola et al. 2012). It is also hard to travel through mangroves due to the structure of the vegetation, therefore they are physically harder to sample and survey (Blaber 1997, Patil et al. 2014).

Whilst aquaculture is an important activity in mangroves in many parts of the world, I could find no indication in the literature or in the records of JICA and MECA (2004) for the practice of aquaculture in the 18 mangrove sites along the Omani coastline (JICA and MECA 2004). This lengthy coastline (compared to Oman's neighbours) occupies the east of the Arabian Peninsula between the latitudes of 16° and 27°N, extends for 3156 km (Al-Jufaili et al. 2010, Khalfallah et al. 2016) and is inhabited by 90 fishing villages (Al-Jufaili et al. 2010). Oman is surrounded by 3 water bodies: the Arabian Sea, the Arabian Gulf and the Gulf of Oman (Randall 1995, Al-Jufaili 2010, Belwal et al. 2015). The continental shelf area of Oman is estimated to cover 54,000 km^2, while Oman's Exclusive Economic Zone (EEZ) extends over 536,000 km^2.

Fisheries are considered a basic element of support to the Omani economy after oil and gas industries (Belwal et al. 2015). In fact, before the 1962 discovery of oil in Oman, fisheries were considered the second main source of income after agriculture (Belwal et al. 2015). Since that time, people have sought full-time jobs in the government sector and many have abandoned fishing as a profession or for subsistence living (Khalfallah et al. 2016). At the current time of writing (June 2018) a drop in oil prices might affect the dependence of the national income on oil, similar to how the drop in oil prices from 1986 to 1989 affected the national economy at that time (Khalfallah et al. 2016). The Omani government aims to reduce dependence on oil and increase its fisheries production (Belwal et al. 2015, Khalfallah et al. 2016) by 5.6% according to the initiative of Economic Vision 2020 (Belwal et al. 2015). The vision aims to reach its target through constructing more harbours for the fishing industry, encouraging greater involvement of private sectors, the acquisition of modern trawlers and enhanced research in the fisheries sector (Belwal et al. 2015).

Industrial fisheries were established in Oman in the early 1980s; reports from the period 1950-1979 showed that the catch of fisheries were exclusively artisanal (Khalfallah et al. 2016). According to more recent records, Omani exports of fisheries were 125,690 t in 2013, mainly represented by pelagic, demersal and crustacean fisheries (Belwal et al. 2015). The mean annual income from the Omani fisheries has been estimated at 60 million Omani Rials (≈US$ 156 million).

Despite this renewed interest in Omani fisheries, Al-Jufaili et al. (2010) reveal that there are very few and limited publications with respect to the marine species of Oman, with only finfish publications reported. More recently, a 2017 FAO report of the 10th meeting of the Regional Commission for Fisheries (RECOFI) Working Group on Fisheries Management (WGFM), which involved 5 members from Iraq, Oman, Qatar, Saudi Arabia, and UAE, indicated that fisheries research in Oman mainly focuses on reproductive biology, fisheries stock assessment and management (http://www.fao.org/documents/card/en/c/80d98981-2de6-4887-9c03-cc862c0b42c8/).

With respect to mangrove-associated fisheries in Oman, I have only found two small-scale studies. One is part of the study of JICA and MECA (2004), which surveyed both fish and crustaceans in Al-Qurum and Mahout out of the 18 designated mangrove sites in the whole country. The other (unpublished) study only surveyed fish in Al-Qurum and was conducted by Al-Kiyumi in 2015. These limited studies will be discussed further in the Discussion section of the present chapter.

Due to the smaller scale of fishing activities in mangroves, in comparison to offshore fishing, it is common for both researchers and governments to under-report data (Spalding 2015). It has also been suggested that most of the catch in mangroves is not released to the market, being consumed at the level of households and families of artisanal fishermen (Spalding 2015). Also, it is argued that there are no unequivocal data on the contribution of mangroves to offshore fisheries (Spalding 2015), although the significant contribution of mangroves elsewhere to these fisheries stocks has been claimed by many researchers (Blaber 1997, Islam and Haque 2004). In fact, worldwide interest in fisheries data mainly targets large-scale fisheries of commercial value (Khalfallah et al. 2016).

Given the extremely limited information on the role of mangroves in supporting Omani fisheries, this chapter sets out to:

a) provide an updated list of fishery and non-fishery species of finfish (bony and cartilaginous) and shellfish (shrimps, lobsters, crabs, molluscs) in Oman from a range of sources.
b) assess the importance of Omani mangroves to those species / species groups which are mangrove-associated, based on the proportion of species associated.
c) assess the degree of subsistence and commercial fisheries that are dependent on mangroves in Oman on the basis of monetary value.

4.2. Methodology

To provide an updated survey of fishery and non-fishery finfish and shellfish species in Oman (Appendix 4.1), I brought together as much information as I could find of relevance to mangrove-associated species (Table 4.1). The species lists in the Appendices do not include freshwater species, but refer to those finfish and shellfish that are reported as both of fishery and non-fishery importance. For the sake of completeness, the lists also include finfish species in Oman reported by Al-

Abdessalaam (1995), Randall (1995) and Al-Jufaili et al. (2010), although the remainder of this chapter focusses more on those species for which a fishery exists.

Table 4.1. Secondary data sources used in this study. All these references include a mixture of both fishery and non-fishery species.

Reference	**Groups covered**
Al-Abdessalaam (1995)	Bony fishes, sharks, rays, crabs, shrimps, lobsters and octopuses
Randall (1995)	Bony fishes, sharks and rays
JICA and MECA (2004)	Mainly shrimps, molluscs and crabs
Al-Jufaili et al. (2010)	Bony fishes, sharks and rays
MAF and MSFC (2012)	Crabs

Unfortunately I could find no recent references to Oman marine molluscs and therefore included only the two gastropod (snail) species reported by JICA and MECA (2004), *Cerithidea decollate* and *Terebralia palustris* and the two cephalopod (octopuses) reported by Al-Abdessalaam (1995), *Octopus aegina* and *Sepia pharaonis* . For instance, a Google search for "marine molluscs of Oman" reveals only papers on limited museum collections from the 1920s by James Cosmo Melvill and palaeological studies, although an initiative is about to be launched by the Marine Sciences and Fisheries Centre in Muscat to survey mollusc stocks in Omani waters (https://www.muscatdaily.com/Archive/Oman/Marine-sciences-centre-studying-mollusc-varieties-stocks-in-Oman-s-waters-3f0j). No data from that survey are available as yet.

To avoid the double counting of species, the FishBase website (www.fishbase.org) was used as a reference for scientific (Latin) names. The study followed a simple classification system of species which could be easily tracked by both specialist and non-specialists in the marine field. The study classified species into bony fishes (Teleosts), sharks and rays (Elasmobranchs), crabs (Brachyura), shrimps (Caridea), lobsters (Astacidea) and molluscs, including Gastropods and octopuses (Cephalopoda) (Appendix 4.1).

To assess the importance of Omani mangroves to these species, I explored the literature to define whether they are mangrove-associated, estuarine-associated or neither (Appendix 4.1). To search for the degree of mangrove association of species, the scientific name (sometimes with synonyms) was submitted to both Google and Google Scholar search engines followed by the term mangroves or estuaries. The FishBase site was also included in the search along with IUCN lists of endangered and threatened species. Some species were found as estuarine-associated, without a particular reference to mangroves, while some species which were not identified as estuarine or mangrove-associated were generally categorised as utilisers of other habitats. Any missing indication of a species as mangrove-associated does not therefore mean that the species is not a mangrove inhabitant. Researchers generally classify the faunal inhabitants of mangroves based on attributes including their adaptation to salinity, and habits such as breeding and feeding and migration, but I was not able to follow this classification system because of the paucity of data from this region. The study also did not define in depth the life history stages at which the species are hosted by mangroves, mainly due to limited and inconsistent availability of data.

To assess the importance of mangroves for supporting subsistence and commercial fisheries, the search was conducted based on both Omani and worldwide interest in these fisheries (Appendix 4.2). I have searched the literature for these values using mainly the FishBase website and by checking for published papers in Google Scholar if this was not clear from the website. I used the scientific names (sometimes synonyms) followed by the term commercial or subsistence value or use. The subsistence value in this study is restricted to household consumption in particular, while the commercial value mainly refers to supplying the catch to markets, but excluding the aquarium trade and gamefish.

The commercial value of mangrove-associated species was also determined for Oman using the latest report (2015) released by the Omani Ministry of Agriculture and Fisheries Wealth (MAF) using a) the total landing in tons including the use of different harvest methods and techniques; b) the total monetary value in million US$, and the percentage of mangrove-association among each group. The first representation of these data included the groups of bony and cartilaginous fisheries, while the second representation included shrimp, lobsters and molluscs.

4.3. Results

4.3.1. Overview

The lists I collated comprise mainly bony fishes (1091 species), followed by sharks and rays (92 species), crabs (57 species), octopuses (2 species) and shrimps and lobsters (5 species) (Appendix 4.1, Table 4.2).

Table 4.2. Number of fishery and non-fishery species in major taxonomic groups in Oman, with their degree of mangrove association. Data sources in Table 4.1.

Species	**Total number**	**Mangrove-associated number and percentage**
Bony fishes	1091	280 (26%)
Sharks and rays	92	21 (21.7%
Crabs	57	24 (42.1%)
Shrimps and lobsters	5	3 (60%)
Molluscs	Unknown	2

4.3.2. Species mangrove-association

Clearly, a large number of species utilise mangroves (Table 4.2), although a smaller proportion of finfish are mangrove-associated compared to crustaceans: 3 out the 5 shrimp species are mangrove associated. The majority of bony fishes, crabs, sharks and rays were found to be inhabitants of other marine environments (excluding estuaries and mangroves). For example, for bony fishes the percentage of association with other habitats was 62% (Figure 4.1). For crabs, the inhabitants of other habitats was 54.4% and for sharks and rays, more than half were found living in other habitats 57.6% (Figure 4.1). Two of the 5 shrimps and lobsters listed (40%) live in other habitats (Figure 4.1).

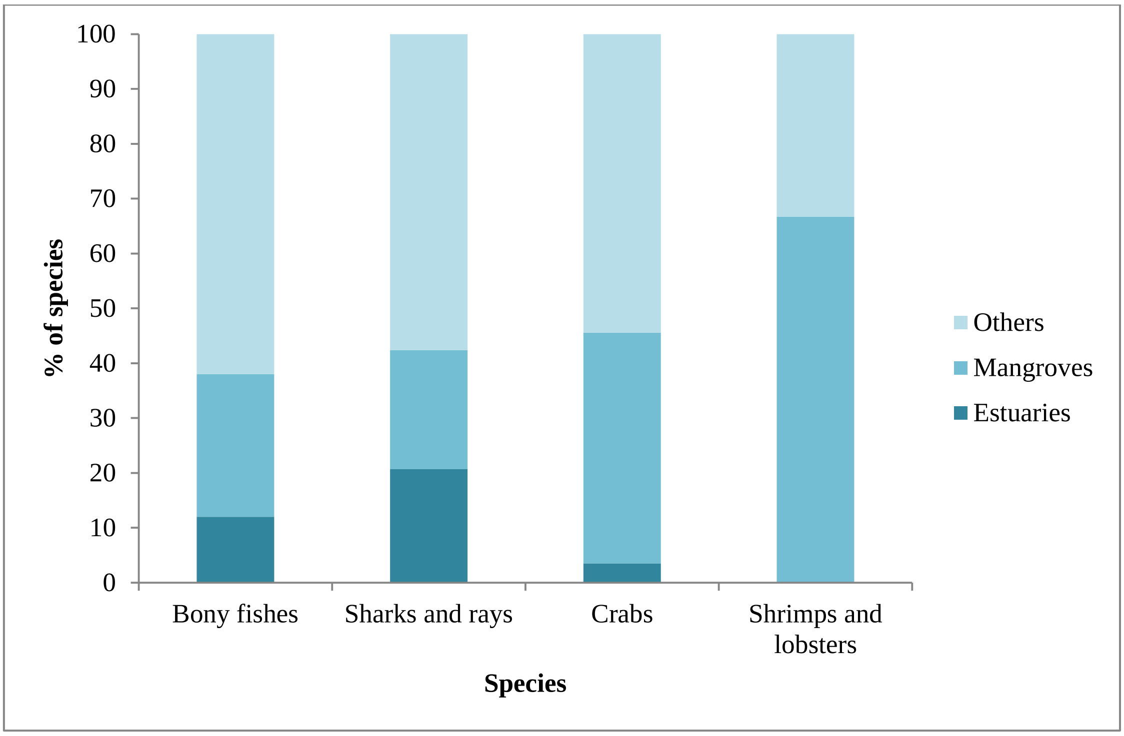


Figure 4.1. Association of Oman marine species with mangroves, estuaries and other habitats.

4.3.3. Commercial value of mangrove-associated species

Analysis of the data on mangrove-associated species by subsistence or commercial use revealed that all the groups were mainly used commercially compared to for subsistence, except for crabs where the subsistence use was 25%, more than commercial use at 20% (Figure 4.2). The majority of bony fishes, sharks and rays, shrimps and lobsters and molluscs species were exploited commercially (not just for subsistence) with percentages of 71.8%, 100%, 66.7% and 100% and respectively (Figure 4.2).

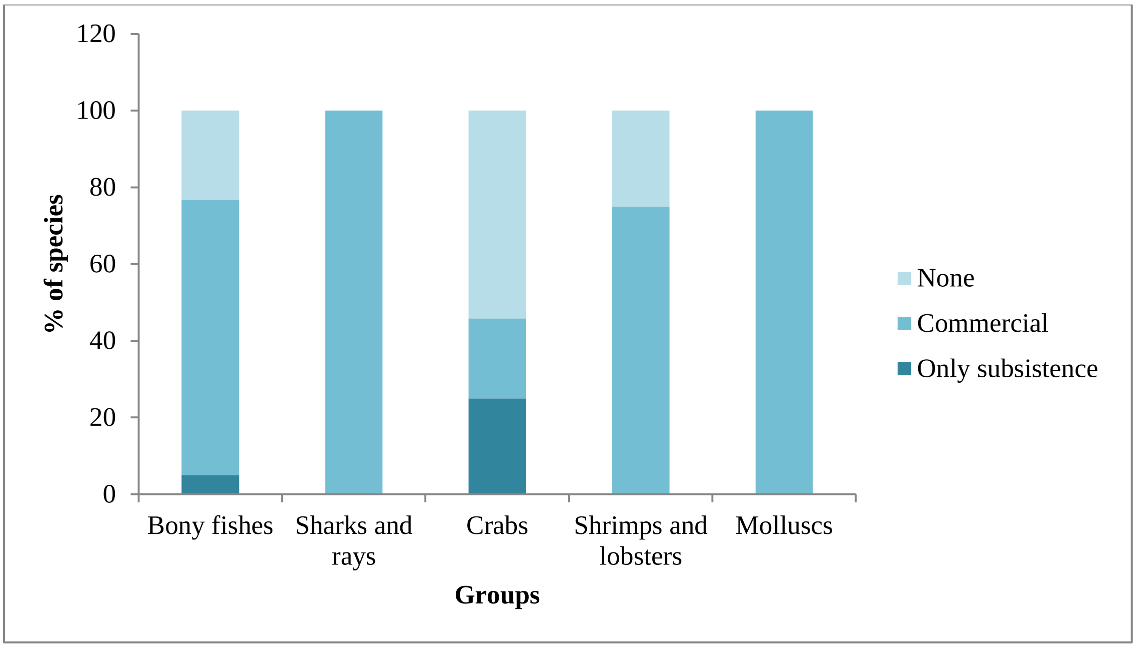


Figure 4.2. Contribution of species groups to subsistence and commercial harvests within Oman or globally.

4.3.4. Commercial mangrove-associated species in Oman

The greatest contributors to fisheries harvest in Oman were determined (Figures 4.3 and 4.4) from the latest fisheries statistics available (MAF 2015). Figure 4.3 shows that the total landings comprised mainly sardines (Clupeidae, *Sardinella longiceps*) (82,654 tons), yellowfin tuna (*Thunnus albacares*) (14,957 tons), longfin tuna (*Thunnus tonggol*) (13,954 tons), small jacks (*Decapterus kurroides*, *Megalaspis cordyla*, *Parastromateus niger*) (11,021 tons) and emperors (Serranidae, *Epinephelus areolatus*, *Epinephelus chlorostigma*, *Epinephelus tauvina*) (10,517 tons). Sharks (Carcharhinidae, *Sphyrnidae*) contributed more to the total landing (6851 tons) compared to rays (Dasyatidae, Myliobatidae, Batoidimorpha, Rhinobatidae) (1218 tons). Although sardines represent the largest biomass, they were not the top economic contributors. In terms of value (expressed in million US$) (Figure 4.3), yellowfin tuna (52.36) and longtail tuna (52.73) were the top contributors, followed by kingfish

(*Scomberomorus commerson*) (28.31), large jacks (*Alectis indica*, *Carangoides armatus*, *Caranx ignobilis*, *Caranx heberi*, *Elagatis bipinnulata*, *Gnathanodon speciosus*, Carangidae) (27.01), emperors (26.75) and then sardines (20.78). With respect to cartilaginous fisheries, sharks (US$ 19.74 million) remain more valuable than rays (US$ 5.45 million) (Figure 4.3).

With respect to mangrove-association, all species in the groups queenfish and cobia in Oman were found to be mangrove-associated, with higher total landing and value for queenfish (*Scomberoides commersonnianus*) (3550 tons, US$ 6.75 million) than cobia (Rachycentridae) (165 tons, US$ 0.72 million). Fifty percent of emperors and 42.9% of sardines were found to be mangrove-associated. Yellowfin tuna, longtail tuna and kingfish has zero association with mangroves. Barracuda (*Sphyraenidae*, *Sphyraena barracuda*, *Sphyraena jello*) and needlefish (Belonidae) have high percentages of mangrove-association (75% and 80% respectively). Their total landing and economic contribution were relatively low (6808 tons and US$ 12.73 million for barracuda and 954 tons and US$ 1.64 million for needlefish). A higher percentage of rays was identified as mangrove-associated (35%), compared to sharks (21.10%).

The total monetary value of mangrove-associated bony and cartilagenous fisheries is summarised in Table 4.3, extracted from Figure 4.3. The table shows the percentage contribution compared to the total contribution of those fisheries in Oman as stated by MAF (2015).

Table. 4.3. The contribution of mangrove-associated bony and cartilaginous fisheries to the total value of these fisheries in Oman based on MAF (2015) statistics.

% of association	Total monetary value in million US$	% of Total value
0%	192.12	47%
< 25%	69.35	21%
25-49%	47.53	12%
50-74%	48.48	12%
75-99%	25.46	6%
100%	7.47	2%

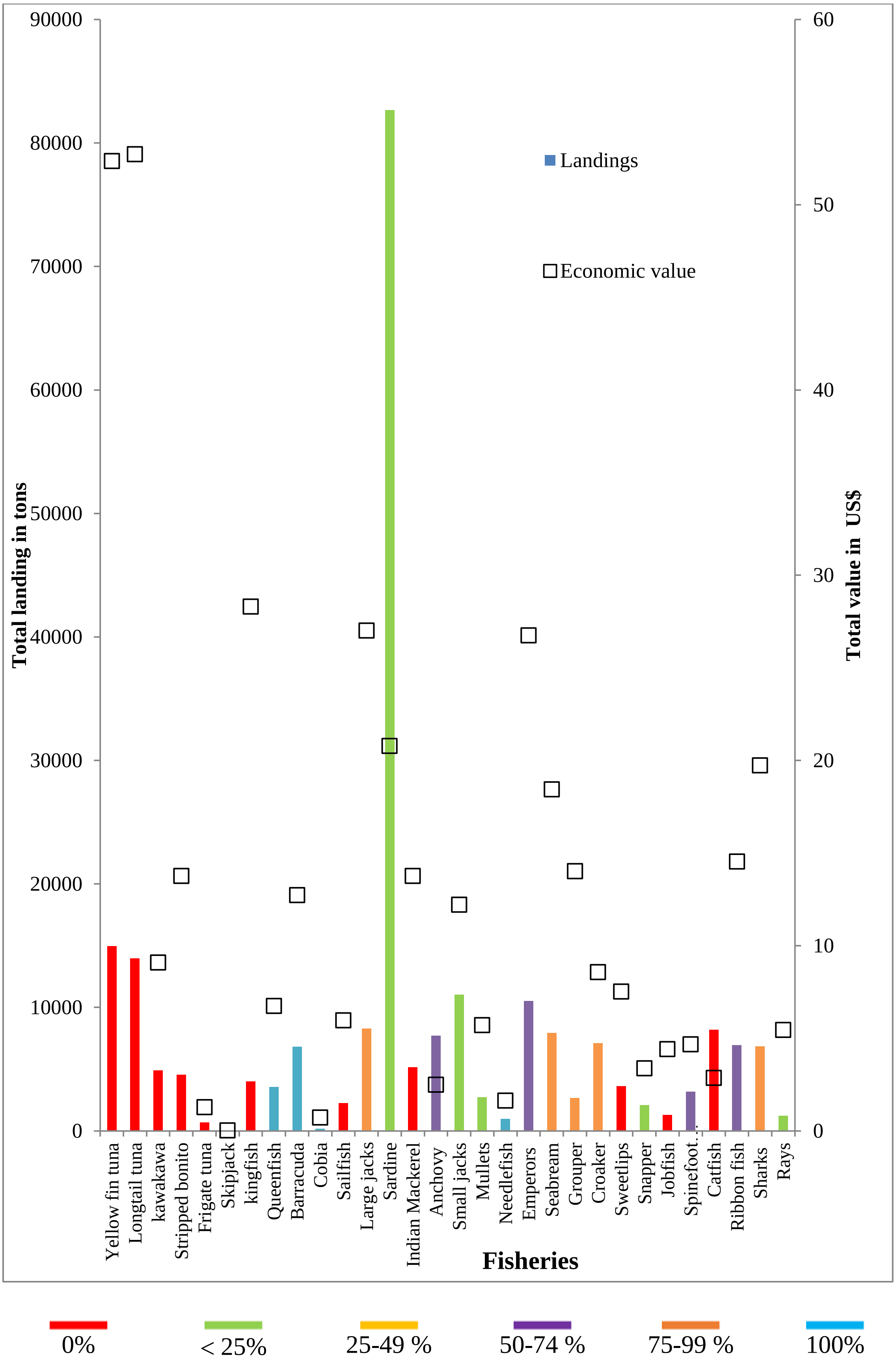


Figure 4.3. Total landings in tons (left) of the highest contributors to harvest of bony and cartilaginous fisheries in Oman, with their total monetary value in million US$ (right column). The colour coding of bars indicates the percentage of species belonging to specific groups identified by the author as mangrove-associated.

With respect to shrimps (*Penaeus indicus*, *Penaeus semisulcatus*, Penaeidae), lobsters (Palinuridae, *Panulirus homarus*, *Panulirus versicolor*, *Scyllarides squammosus*) and molluscs (abalone *Haliotis* spp.) (Figure 4.4), cuttlefish and squid (Sepiidae, *Sepia pharaonic*, Loliginidae) had the highest contribution in terms of landings (9633 tons) and economic value (US$ 22.08 million). Lobsters were the next largest contributors with 614 tons and US$ 10.91 million. There were no data available for abalone due to the prohibition of fishing this species in 2015 as part of MAF plans for sustainable fisheries. With respect to mangrove-association, shrimps were found to be 100% associated, but with a relatively low contribution to both landings (599 tons) and value (US$ 5.2 million).

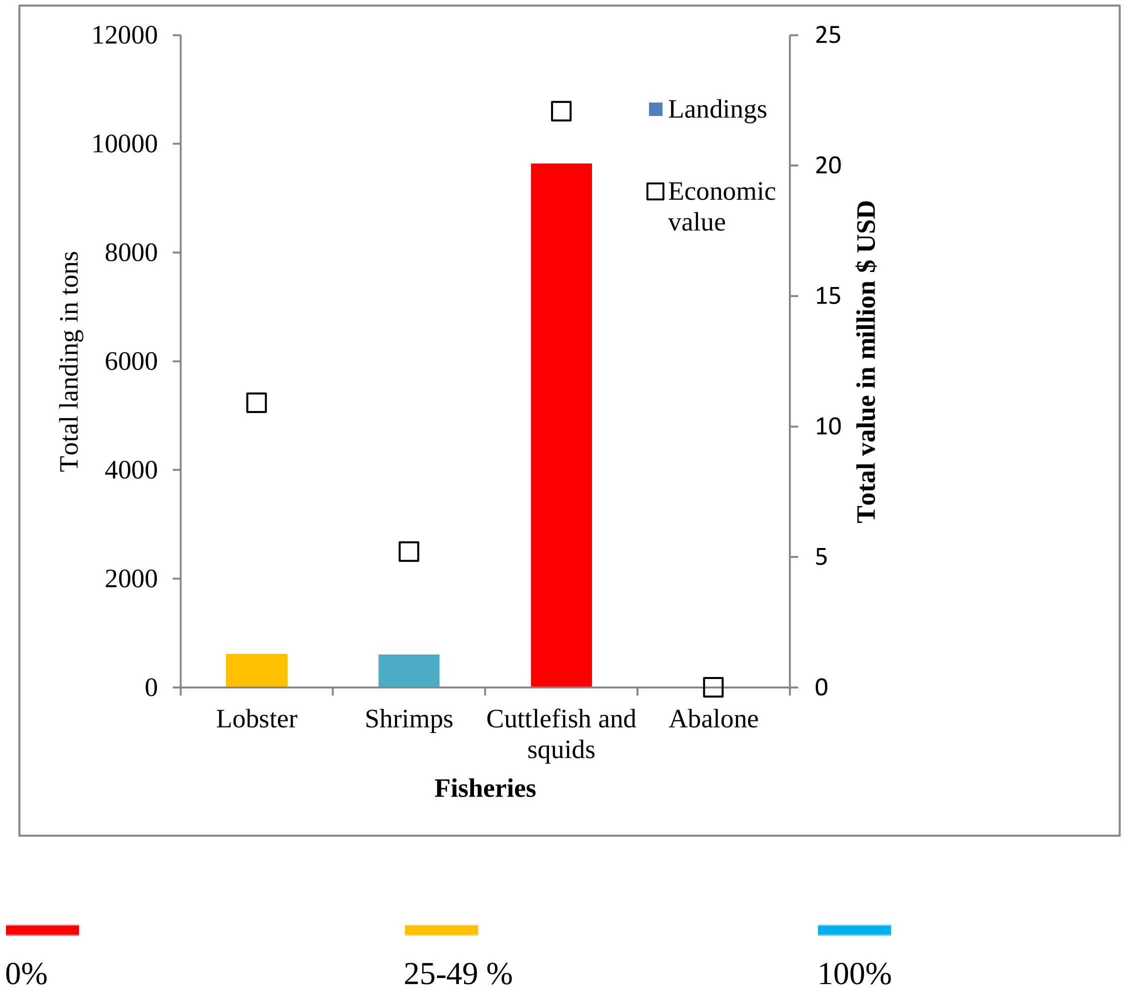


Figure 4.4. Total landings in tons (left) of the highest contributors of shrimps, lobsters and molluscs fisheries to harvest in Oman, with their total monetary value in million US$ (right column). The colour coding of bars indicate the percentage of species identified by the author as mangrove-associated.

The reports of fisheries in Figures 4.3 and 4.4 were listed by the MAF Fisheries Statistics Book (2015) as the percentage contribution of these species to total landings in tons around the country. According to that source, the contributions were 27% for large pelagics, 43% for small pelagics, 23% for demersal, 3% for sharks and rays, 2% for crustaceans and 1% for other unidentified fish.

4.4. Discussion

4.4.1. Overview

It has been estimated that tropical and subtropical estuaries may host up to 200 fishery and potential fishery species (Blaber 1997). Many researchers have attempted to explain the linkage of these species to mangroves (Islam and Haque 2004), with most highlighting the importance of two main factors; the mangrove ecosystem carrying capacity (a function of mangrove area and productivity) and the productivity of the fisheries themselves (Nickerson 1999, Islam and Haque 2004). In Chapter 2 of this thesis, I examined the spatial change of 4 mangrove ecosystems in northern Oman and revealed that the total area of each ecosystem is much less in comparison to other mangroves in the world with more favourable environmental conditions. Healthy conditions of the ecosystem also contribute to the fish stock size through high primary productivity, and favourable physical variables such as salinity, system hydrology, water quality, temperature, and potential to escape predation (Islam and Haquem 2004, Blaber1997).

Commonly, estuaries, including mangroves, exhibit less species richness compared to other ecosystems and this applies equally to fishery species (McLusky and Elliott 2004, Elliott and Whitfield 2011). This low diversity is often compensated for by an increase in abundance and biomass of those species present (McLusky and Elliott 2004, Elliott and Whitfield 2011). This is consistent with the findings of my analysis: less species were identified as mangrove-associated compared to other habitats, except for shrimps and lobsters. Low species diversity is attributed to the physiological stress mainly caused by variable salinity and the relative youth of estuarine environments, compared to other oceanic bodies, with less time available for species to adapt (McLusky and Elliott 2004).

In terms of species, Omani fish and fisheries are dominated by bony fish followed by sharks and rays (Table 4.2), as also shown by Al-Jufaili et al. (2010), considered to be the most up-to-date report of bony fish, sharks and rays fish in Oman. I found that bony and cartilaginous fish comprised 1,184 species, compared to the 1,179 species reported by Al-Jufaili et al. (2010). Although Al-Jufaili et al. (2010) listed new species, it also dropped some species reported in Randall (1995) and Al-Abdessalaam (1995). I also removed the synonyms included by Al-Jufaili et al. (2010) and the species mentioned occasionally twice.

At the global level, and particularly in Oman, there is a lack of data documenting the definite number of species inhabiting or utilising mangroves, however, there is consensus that mangroves are relatively poor in species richness, but those species are highly abundant (Snedaker 1984, Robertson and Duke 1987, Spalding 2015). It has also been suggested that the different means of utilisation of mangroves by fishes has led to inconsistency in reporting the species themselves, as mentioned earlier (Tzeng and Wang 1992, Hamilton and Snedaker 1984, Spalding 2015).

4.4.2. Species mangrove-association

Bony and cartilaginous fish

Although the percentage of mangrove-associated bony fish in Oman was only 26% of the total in Omani waters, this comprised 280 species, nearly 10 times the reported total species of crabs, shrimps and lobsters (Table 4.2). Robertson and Duke (1987), find that fish density in mangroves is relatively high. Mangrove ecosystems are also favoured by sharks and rays as nursery habitats (Compagno 2001). Fewer sharks and rays were mangrove-associated (21 species or 21.7% of the total) (Table 4.2) (Figure 4.1). Whitfield (2017) found that mangroves in the East and West Atlantic, East Pacific and Indo-West Pacific are inhabited by a minimum of 100 species of bony and cartilaginous fish. Rönnbäck (1999) reported that around 200 bony and cartilaginous species have been associated with mangroves in Australia and India, whilst Islam and Haque (2004) report 177 species for Bangladesh mangroves. Other reports expect the number to reach a total of 400 different means utilisers of mangroves of the same groups (Islam and Haque 2004).

The reports by Rönnbäck (1999) and Whitfield (2017) are actually based on sampling, in contrast to this study which was based on what has been reported in the literature regarding species mangrove-association. The high numbers of species reported by my study are the potential number, not necessarily the actual number inhabiting mangroves in Oman. However, it does show the high capacity of mangroves to nurse and support these species.

Regarding mangrove fish and fisheries, most of the research which was based on sampling in Oman was conducted at Al-Qurum Nature Reserve, probably due to its location close to Muscat and therefore easy accessibility. In an unpublished study conducted by Al-Kiyumi in 2015 on juvenile fish at Al-Qurum, species diversity and abundance were reported, classification according to families ranging from 6-9 in different sampling creeks. The earlier study of JICA and MECA (2004) only conducted fish sampling in Al-Qurum and Mahout Island, out of the 18 designated mangrove sites around the country. This study reported 9 families of bony fish in these ecosystems and no sharks or rays. The main fish identified by JICA and MECA were killifish (Cyprinodontidae), terapon (Terapontidae), silverbiddy (Gerreidae), glass fish (Ambassidae), mullet (Mugilidae), goby (Gobiidae), tilapia (Cichlidae), seabream (Sparidae) and whiting (Sillaginidae) .

Invertebrates

Crabs were the most diverse group of invertebrates in Omani mangroves, where 42% of them were found by this study as mangrove-associated. Crabs are known to dominate in mangrove estuaries (Robertson and Duke 1987, Ashton et al. 2003, MAF and MSFC 2010) due to their adaptation to a wide range of salinities (MAF and MSFC 2012). Robertson and Duke (1987) find crabs have higher densities in mangroves compared to other habitats. The majority of crabs prefer to live in muddy substrates and some of them are tree climbers and active swimmers (Robertson and Duke 1987, MAF and MSFC 2012). I identified 24 crab species as mangrove-associated, compared to a sampling study conducted in the Sematan mangrove ecosystem in Malaysia by Ashton et al. (2003), which reported 31crab species.

My study indicated that a higher percentage of shrimps and lobsters (60%) are present in mangrove habitats in comparison to other habitats (Figure 4.1), which is consistent with the findings of Robertson and Duke (1987), indicating the preference by shrimps for mangrove habitats over other nearshore habitats for most of the year. However, it is possible that the total number of shrimp in the region is an underestimate because of inadequate sampling. Primavera (1998) conducted a comparison of shrimp populations in mangroves and non-mangrove ecosystems showing high densities of shrimps particularly juveniles in mangrove habitats in comparison to tidal flats (without mangroves). Another report by Islam and Haque (2004) in the Sundarbans showed a higher percentage of shrimps that are mangrove-associated, represented by nearly 30 species in comparison to less than 15 species each in nearby marine and freshwater habitats.

My study found a low diversity of mangrove-associated shrimp species in Oman. Despite the low diversity, shrimps have been reported to contribute significantly to the faunal stock in mangroves (Islam and Haque 2004). It has also been reported that shrimps are abundant in mangroves in comparison to other neighbouring ecosystems such as mudflats (Chong et al. 1994, Islam and Haque 2004), attributable to the greater availability of food (Blaber 1997). It has also been suggested that food is more available and diverse for juveniles in mangrove ecosystems compared to nearshore habitats (Blaber 1997). Run-off supplies mangroves with the nutrients utilised by shrimps (Blaber 1997) and this could explain the low diversity of shrimps in Oman due to the lower nutrient supply (compared to other mangrove areas in the world) resulting from infrequent rainfall (Chapter 2).

The molluscs identified by JICA and MECA (2004) as mangrove inhabitants were the mangrove snail (*Cerithidea decollate*) and the mangrove whelk (*Terebralia palustris*) and classified as native inhabitants of mangroves (Kabir et al. 2014). This number is obviously an underestimate, as oysters, mussels, cockles, and other gastropods all inhabit mangroves and numbers of sessile molluscs utilise mangrove roots as a substratum (Blaber 1997, Kabir et al. 2014). In a study conducted by Pawar (2012) in the mangrove ecosystem of Uran on the west coast of India, 55 species of molluscs were reported. The study of Ashton et al. (2003) also reported 44 molluscs species in the ecosystem. Thirty-four molluscs species were reported by Macintosh et al. (2002) in Ranong mangrove ecosystem, Thailand, and in another extensive study conducted by Lozouet and Plaziat (2008), which involved sampling 42 coastal stations in the central Philippines that supported mangroves, they reported 204 species of molluscs. Molluscs in mangroves are not only considered as a source of food but they are also a valuable contributor to the ecological functioning of the ecosystem (Kabir et al. 2014). They are a linkage point to assimilate energy from primary producers to secondary consumers (Kabir et al. 2014). Gastropod distribution and diversity in mangroves is influenced by tidal elevation and light and humidity, which primarily affect the growth of algae which is often the main food for these molluscs (Nagelkerken et al 2008, Kabir et al. 2014). Soil high in salinity (Kathiresan et al 1997, Kabir et al. 2014) or with low nitrogen, like the environment where *Avicennia marina* grows (Kabir et al. 2014), are also suggested to reduce the development of algae. This might explain the low diversity of gastropods and molluscs in general in sampled sites in Omani mangroves (Kathiresan et al 1997, Kabir et al. 2014).

The different composition of Omani mangrove-associated marine fauna, compared to other estuaries, is not surprising. Salinity was considered as a limiting factor in more researched areas of estuaries in the developed world, and also suggested to influence the faunal composition of fish in mangroves (Blaber 1997, Manson et al. 2005a, Kabir et al. 2014). Commonly, fish in mangroves are euryhaline and able to adapt to salinities ranging from 1-35 (Blaber 1997). Other environmental variables such as temperature and precipitation are suggested by Manson et al. (2005a) to influence faunal species composition in mangroves. In Oman, temperatures can be extreme and precipitation can be low and variable which would likely explain why faunal communities appear so different from other parts of the world.

When examining the differences in the composition of faunal communities between different mangrove ecosystems, researchers also consider the habitat complexity of each ecosystem (Blaber 1997). These structural differences have been reported to influence the means of utilisation of the ecosystem by mangrove species (Blaber 1997). Notwithstanding this, fish communities in mangroves share broadly similar features and characteristics (Blaber 1997). The different sampling techniques and strategies used for fish in mangroves create uncertainty in assessing the value of mangroves for supporting nearshore fish populations compared to other habitats lacking mangroves (Robertson and Duke 1987, Manson et al. 2005a, Anneboina and Kumar 2017, Sheaves 2017). Only a few studies provide good evidence on this role by comparing fish densities between mangroves and non-mangrove habitats (Robertson and Duke 1987). The occasional existence of nearshore habitats such as seagrass beds within or close to mangroves makes it difficult to judge whether the preference of species is for mangroves or seagrass (Robertson and Duke 1987). Also, survey timing is thought to influence the results (Robertson and Duke 1987). For example, the latter study found that at certain times there were no significant differences in the abundance of fish between mangroves and seagrass beds, but in other times there is a preference of mangroves.

4.4.2. Commercial value of mangrove-associated species

Fish of commercial interest differ between countries, so what might end up as a bycatch in fisheries in one country might be of commercial importance in another (Blaber 1997).

For example, a study conducted in India by Anneboina and Kumar (2017), showed that the landing biomass of fish linked to mangroves was much less than in freshwater fisheries regardless of the high extent of mangrove forests in the area, due to consumer preference for freshwater fish. Although it has been suggested that most of the fish entering estuaries are not of commercial interest, due to their size or simply unwanted by consumers, other species are highly commercial (McLusky and Elliott 2004). Many parts of the world have reported the contribution of mangroves to the commercial value of fisheries (Manson et al. 2005a, Dehghani 2014, El-Regal and Ibrahim 2014, Sheaves 2017). Although fishing in mangroves is often mainly artisanal (Rasolofo 1997, Whitfield 2017), in countries like Bangladesh, artisanal fisheries contribute 85–95% of the catch, which is supported by the existence of mangrove habitats (Whitfield 2017). In parts of the developed world, like Florida USA, early studies estimated that 80% of both recreational and commercial fisheries are largely supported by mangroves (Hamilton and Snedaker 1984, Rönnbäck 1999). It has also been estimated that 67% of the gross commercial harvest in eastern Australia is of mangrove-dependent species (Hamilton and Snedaker 1984, Rönnbäck 1999).

The importance of mangroves as feeding and protection grounds for fisheries is due to their ability to support large populations with a consequent high commercial value (Blaber 1997, El-Regal and Ibrahim 2014, Anneboina and Kumar 2017). Species in mangroves have a higher potential to escape predation in comparison to open water (Robertson and Duke 1987, Islam and Haque 2004 Manson et al. 2005b), due to the structural complexity created by the vegetation, reduced visibility to predators because of the generally high turbidity and the shallow water depths that prevents the movement of large fish (Robertson and Duke 1987, Blaber 1997, Manson et al. 2005b). Thus, *Avicennia marina* (the dominant mangrove species in Oman) would provide a predation refuge for juveniles to escape predation (Robertson and Duke 1987, Whitfield 2017) and in a study done in the Pagbilao mangroves (Philippines), most species were found to be sheltered by the pneumatophores of *Avicennia marina* compared to the prop roots of *Rhizophora* (Rönnbäck et al. 1999, Whitfield 2017).

The description of mangroves as playing a “critical” role in coastal fisheries has been recently criticised by some researchers, regardless of the common acceptance of this role worldwide. Manson et al. (2005a) and Sheaves (2017) are among these researchers who argue that there is a lack of robust and sufficient evidence of the role of mangroves in sustaining coastal fisheries. Multiple hypotheses (e.g. availability of food, protection from predation and protection from wave disturbance) emerged to explain the role of mangroves in supporting fish populations and protecting vulnerable juveniles and consequently assuming a correlation between mangroves and fisheries (Blaber 1997, Rönnbäck 1999, Manson et al. 2005a, Spalding 2015, Sheaves 2017). Although these hypotheses were widely accepted, Manson et al. (2005a) and Sheaves (2017) find them poor in empirical testing and only a few studies have actually quantified the actual value of mangroves to fisheries.

Sheaves (2017) criticised what he calls the "75% Rule" that implies a percentage of 75 or even higher of fisheries catch is mangrove-dependent. Sheaves (2017) described these reports of high percentages as claims lacking sense and logic due to the absence of scientific empirical evidence. He also recognised that some researchers avoided being explicit in reporting these claims in their studies, not specifying whether they are referring to species richness, abundance or biomass (Sheaves 2017). Different groups of researchers have different interests in mangroves and Sheaves (2017) suggests that if the interest is in the commercial value then statements based on biomass would be more relevant. However, biomass does not always capture the monetary value of a fishery. Therefore, I calculated the the economic value of mangrove-associated fisheries directly.

Correlations between mangrove and fisheries have often been based mainly on the high abundance of juvenile species in mangroves compared to neighbouring habitats (Manson et al. 2005a, Manson et al. 2005b). A study by Manson et al. (2005b) finds the report of high mangrove fisheries correlation was also based on high catches related to the extent of the mangroves themselves, with most of these results reported for shrimps and prawns. Manson et al. (2005a) also found that the strong mangrove-fisheries relationship is not applicable to offshore fisheries.

The contribution of mangroves to fisheries has also been questioned by other researchers. One of the main questions raised by researchers was: "to what extent do these fisheries depend on mangroves?" (Manson et al. 2005, Sheaves 2017). They assert that a species relying on mangroves should spend at least one stage of its life cycle in mangroves and therefore this means that the use of terms such as association or utilisation to describe mangrove fish-linkages does not actually imply an obligatory relationship between species and mangroves.

While some species spend their entire life in mangroves, such as the prawn *Penaeus merguien* (Rönnbäck et al. 2002, Manson et al. 2005a, Manson et al. 2005b), others can actually inhabit other neighbouring communities, even in the absence of mangroves. Therefore mangroves are not the only important habitat for some species (Manson et al. 2005a, Manson et al. 2005b). Sheaves (2017) argues that the role of mangroves in supporting fisheries should be properly investigated. In some cases, the connectivity of mangroves with other communities, such as coral reefs or seagrass beds, adds a value to the role of mangroves in fisheries production and therefore another question emerges: "if these neighbouring communities are absent, will the role of mangroves be affected?" (Sheaves 2017). For those species spending their entire lifecycle in mangroves, most are found to be small in size and short in life (Blaber 1997, Manson et al. 2005b) and weak direct contributors to fisheries (Manson et al. 2005b).

One of the frequently reported fish species-dependency on mangroves is their use as breeding grounds and nurseries for juveniles (Manson et al. 2005b), Hutchison et al. 2014, Anneboina and Kumar 2017). According to Manson et al. (2005b), the reports of the nursery role of mangroves in most studies could be open to criticism. Manson et al. (2005b), advocates more strict definitions of nurseries, as by Beck et al. (2001, p.635) which states that:" *a habitat is a nursery for juveniles of a particular species if its contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than production from other habitats in which juveniles occur.*" So, according to this definition, mangroves should be more successful in their contribution to species recruitment and production, compared to other habitats. That brings us again to the necessity for more empirical assessment of this role. Beck et al. (2001) and Manson et al. (2005b), argue that most of the work done on juveniles in mangroves has focused on abundance and fewer studies have considered other factors such as viability and growth. According to them, the neglect of these factors makes abundance a poor indicator of the contribution of mangroves to mature fish populations.

Sheaves (2017) also emphasised the difference of environmental settings in different areas of mangroves around the world. Therefore, a report of high mangrove-fisheries correlation in one region does not necessarily mean the same is the case in other regions. There is an argument that most of the work of mangrove-fisheries correlations was conducted in the Caribbean and that most of Indo-Pacific conclusions of the significant role of mangroves in fish production were actually based on the Caribbean studies, conducted in a physically different environment. The diversity of plants and floral composition among mangrove ecosystems themselves provide different community physical structure, different attributes and probably different means of support to fisheries (Sheaves 2017). For example, mangroves in Oman are dominated by *A. marina* which has a different physical structure (e.g. roots) from other mangrove species and therefore the opportunities for species to obtain food and refuge might differ.

Bony and cartilaginous fish

All sharks and rays identified here as mangrove-associated had commercial value. Sharks and rays are often included within both artisanal and commercial fisheries, particularly in the developing world (Barker and Schluessel 2005). In the Sundarbans, Bangladesh, the largest continuous mangrove habitat in the world as described by Islam and Haque (2004), 120 bony and cartilaginous fisheries species were identified as commercially important compared to 222 species identified at the global level as commercially valuable comprising 201 species of bony fish and 21 species of sharks and rays (Islam and Haque 2004). In a sampling study conducted in Madagascar mangroves by Laroche et al. (1997), where salinity levels are as high as in Oman (30.7-34.1), 44 species were identified as having commercial importance out of 60 species caught. Manson et al. (2005b) find that the empirical studies correlating the high catch of these fisheries with the extent of mangrove remain few.

Invertebrates

Raga (2006) found that mangroves are one of the important spawning and nursing grounds for crabs. Also, the fact that crabs are highly diverse in both their morphology and ecology makes them good candidates for commercial exploitation (MAF and MSFC 2012). *Portunus sanguinolentus*, *Portunus segnis*, *Scylla serrata* and *Charybdis feriata* reported in this study (Appendix 4.2) are considered the most commercially important crabs in Oman (MAF and MSFC 2012). Mud crabs (*Scylla* spp.) also have considerably high commercial value (Rönnbäck 1999, Le Vay et al. 2008), particularly in the Indo-Pacific (Le Vay et al. 2008).

The crabs in this study had the least commercial value compared to other fisheries, with 54.2% of them having no subsistence or commercial value, although very few species of crabs (mainly xanthids) are toxic, and therefore are not edible (MAF and MSFC 2012). Even in the absence of economic values, crabs are significantly important from an ecological perspective. For example, they create a link in the food chain between the primary producers at the lowest level and higher consumers at the top of the chain

(Ashton et al. 2003, Kristensen 2008). Crab burrowing and tunnelling (bioturbation) activities also increase aeration in sediments and therefore increase the potential for nutrient cycling and exchange (Ashton et al. 2003, Kristensen 2008).

Shrimps and lobsters were found to be highly commercial in this study, and are considered as an important contributor not only to the national income but also to the income of artisanal fishermen and their families (Al-Mamry et al. 2015). Robertson and Duke (1987) and Raga (2006), also find mangroves as a significant contributor to commercial shrimp populations. In Oman, shrimp is also a valuable economic resource for suppling local and overseas markets, which has been estimated to be worth US$5 million per annum (Al-Mamry et al. 2015). In south-east Asia, it has been estimated that the shrimp catch is up to 100% sustained by mangroves (Singh al. 1994, Rönnbäck1999). The shrimp *Penaeus indicus* in my study is one of the most commercial in the world (Primavera 1998, Rönnbäck 1999, Islam and Haque 2004) and specifically prefers mangroves (Robertson and Duke 1987). Another species in this study *Penaeus semisulcatus* has a variable range of habitat preferences (Manson et al. 2005). It utilises mangroves, but in the absence of mangroves it can convert to other estuarine habitats such as seagrass beds, mudflats and saltmarshes (Haywood et al. 2005, Manson et al. 2005). Penaeids are argued to have the highest commercial values among mangrove-associated fisheries due to their abundance and high market price (Rönnbäck 1999). Most reports find a good correlation between their catch and mangrove extent (Manson et al. 2005a, Manson et al. 2005b).

The two gastropod species reported in mangroves in this study have high commercial value in some parts of the world (Appukuttan and Ramadoss, 2000), although I have not found any reports indicating the commercial values of these molluscs in Oman. In one of the questionnaire surveys carried out of this thesis (Chapter 6), locals indicated that they used to harvest and consume the molluscs reported here for their household consumption and called them *Cono cono*. Commonly, most molluscs in mangroves are harvested extensively at the subsistence level (Rönnbäck 1999), but also to supply markets (Rönnbäck 1999).The degradation in mangrove habitats is suggested to lead to declines in mollusc populations and therefore decrease their contribution to market value (Rönnbäck 1999). Similarly, degradation of the Qurayyat ecosystem and declines in molluscs populations are reported in this study (Chapter 6).

4.4.3. Commercial mangrove-associated species in Oman

As in other parts of the world, landing tonnages of commercial fisheries species in Oman are not necessarily correlated with their economic value: some species are priced more than others. For example, the total landing of sardines is significantly higher than the total landing of tuna, but tuna prices significantly exceed the price of sardines. For bony and cartilaginous fish, cobia and queenfish, which were considered 100% mangrove-associated, had significantly lower total landings and prices compared to others. On the other hand, a lower percentage of barracuda was identified as mangrove-associated, but had a higher total landing and economic value. Also, invertebrates had a lower landing biomass compared to bony and cartilaginous fish, but a higher economic value. At the global level, not only in Oman, the contribution of invertebrates to the total landing biomass is less than that of vertebrates, but invertebrates are often high value (Jennings et al. 2009, Howarth et al. 2014).

The top commercial mangrove-associated species reported by Raga (2006) include bony fish (mullets, rabbitfish and emperors), crabs, shrimps and oysters. According to the data presented in this study, 50% of emperors in Oman were mangrove-associated with the 4th highest economic value in the countries fisheries. The proportion of rabbitfish (spinefoot) identified as mangrove-associated in Oman was higher than groupers (65.5%) with an economic value substantially less than for groupers. Thirty-three percent of mullets were identified as mangrove-associated, with an economic value relatively higher than rabbitfish, but significantly less than the value of groupers.

Among invertebrates, the highest economic value was for cuttlefish and squid, but none of the species in this group were mangrove-associated. Abalone is also not mangrove-associated. Abalone had a total landing and economic value of zero in 2015 due to the ban on the abalone harvest during that year and previously during 2008, 2009 and 2010 by MAF in order to increase the yield (MAF 2015). Abalone production is restricted to the southern parts of Oman and the harvest season usually ranges from 11-21 days (MAF 2015). Although it is known that abalone are commercially valuable, no statistics are provided by MAF for their commercial value. Lobsters and shrimps had similar landings, but the value of lobsters was noticeably higher compared to shrimps. Remarkably, crabs were not included within the statistics of MAF in terms of either total landings or value, despite the fact that some crabs in Oman are known to be commercially valuable.

Although this study suggests that many of mangrove-associated species are not of high commercial value in Oman, this does not mean they are not important in the diets of higher consumers which themselves are of commercial value (Robertson and Duke 1987, Sheaves 2017). In Australia, which has extensive mangrove forests compared to Oman, studies of Robertson and Duke (1990) and Sheaves et al. (2016) showed that the few fish species of mangroves contribute directly to economic value and most of the species existing in mangroves visit mangroves for foraging on these mangrove species. Even in the absence of the economic value, these fisheries are certainly ecologically important in shaping the structure and function of the ecosystem (Rasolofo 1997), as well as contributing to a broader range of ecosystem services.

4.5. Conclusion

Although, mangroves in Oman are not as extensive as mangroves in other parts of the world under less stressful and more favourable conditions, this does not necessarily limit their potential to support fisheries. It has been proposed by many scholars that the physical structure of *A. marina,* the dominant mangroves in Oman, provides high potential to support fisheries. The study also showed that the mangroves-fisheries link cannot simply be assumed from theories of foraging, breeding and predation escape and that there is an urgent need for more research to test and quantify mangroves-fisheries linkages. Sheaves (2017) argues that statements and questions related to the contribution of mangroves should not be addressed ambiguously, without clearly specifying which dimensions of fish biology are being discussed (abundance, diversity, biomass, health, etc.). Anneboina and Kumar (2017) also assert that empirical assessment of the role of mangroves in supporting fisheries should consider the extent of mangroves, the fish diversity present and the methods used for harvest.

Although this study showed that many fish species (bony and cartilaginous) have the potential to be sheltered by mangroves during at least one stage of their lives, the present study was not based on sampling and therefore cannot be directly and uncritically compared with other studies; there are many physical and structural factors of an ecosystem that could influence the appropriateness of different mangroves for supportingfisheries.

At the economic level, Blaber (1997) finds that mangroves remain an important source of fisheries for local communities and therefore are monetarily valuable, particularly in developing countries. A common problem in developing countries is being rich in natural, but poor in financia, resources compared to developed countries (Blaber 1997), which consequently leads to an increased pressure on resources such as fisheries (Blaber 1997). This pressure is influenced by the increase in human populations and therefore increases demand on fisheries for both subsistence and commercial use (Blaber 1997, McLusky and Elliott 2004).Changes and shifts in fisheries methods and instruments are also expected to increase the pressure (Blaber 1997). In Oman, such pressures are captured by the MAF (2015) statistical fisheries book which records registered subsistence and artisanal fishermen, along with the registration of commercial fishing activities. The ministry also keeps records of the total landing and controls the fishing seasons for specific threatened species such as abalone.

To study fisheries-mangrove relationships, new paradigms are needed instead of relying on previous studies that simply correlate mangroves with fisheries production (Manson et al. 2005b). This will also influence the development of management strategies (Manson et al. 2005b, Sheaves et al. 2016). Scientific knowledge of species composition and abundance will also help to develop better management plans for sustainable utilisation of fisheries resources (Pawar 2012, Whitfield 2017). This study has provided more evidence for the need of ecosystem-based approach to fisheries management and follows the recommendation of Barbier et al. (2011) that fisheries management strategies should mainly focus on the ecosystem itself and not only be limited to the monetary target of increasing fisheries yield, due to the dependence of fisheries harvest on the health of ecosystem.

Chapter 5

How important are carbon sequestration and storm buffering services at Al-Qurum mangroves, Oman?

5.1. Introduction

Mangrove forests are one of the most productive ecosystems on Earth (Kuenzer et al. 2011, Mitra et al. 2011), and are found across 75% of the tropics and subtropics (Alongi 2002, Komiyama and Poungparn. 2008, , Mitra et al. 2011 , Duke et al. 2014, Ghasemi et al. 2016). They provide all four of the main categories of ecosystem services - provisioning, regulating, cultural and supporting (MA 2005, Fisher et al. 2008, Kuenzer et al 2011, Brander et al. 2012, Raffaelli and White 2013, Duke et al. 2014). Amongst the regulating services, the most important are erosion protection, water purification, storm buffering (Green et al. 1998, Wells and Ravilious 2006, Kuenzer et al. 2011, Van Bochove et al. 2014), climate regulation, and sediment deposition (MA 2005, Wells and Ravilious 2006, Van Bochove et al. 2014). Climate regulation (carbon sequestration) and storm buffering (flood hazard mitigation) are considered to be the most significant of these (MA 2005, Kuenzer et al. 2011, Mitra et al. 2011, Brander et al. 2012, Van Bochove et al. 2014), which UNEP strongly links to the security of livelihoods of those dependant on mangroves (Van Bochove et al. 2014).

Carbon sequestration

Globally, mangrove ecosystems play a significant role in the carbon cycle (Mitra et al. 2011, Crooks et al. 2014) through the process of carbon sequestration by trees in their above ground biomass (AGB) which includes leaves, stems and branches, below ground biomass (BGB) which comprises roots, dead biomass, and the microbial communities in the sediment (Komiyama and Poungparn 2008, Kuenzer et al 2011, Yee 2010, Grimsditch et al. 2013, Crooks et al. 2014, Patil et al. 2014, Sitoe et al 2014). Mangroves are considered the richest carbon sink of all tropical forest types (Patil et al. 2014, Schile et al. 2017) (Figure 5.1), while the MA (2005, p.7) describes them as a ‘net sink’ of carbon sequestration. The efficiency of mangroves in sequestering carbon can vary over space and time, with the amount of mangrove primary production and the complex nature of carbon storage in sediment affected by different rates of sediment deposition, erosion and transformation as well as soil type, local climate and topography (Alongi 2011, Mitra et al. 2011).

The amount of carbon stored in sediments by a particular mangrove ecosystem can therefore range widely from 0.5% to up to 40% of the total carbon stored by mangrove in an area (Patil et al. 2014), although these estimates remain uncertain (Chave et al. 2005, Sitoe et al. 2014), particularly for the amount of carbon stored as BGB. A report released by United Nations Food and Agriculture Organisation (FAO) in 2005 suggests that estimates of carbon sequestered by tropical forests are unreliable, due to their reliance on predictions that are not always underpinned by scientific measurements (Gibbs et al. 2007).

Estimating mangrove biomass

When assessing the role of mangroves in carbon sequestration, tree biomass is first estimated (Betts 2006, Camacho et al. 2014, Patil et al. 2014). The highest AGB in mangroves has been estimated for *Rhizophora apiculata* in Malaysia, which reached 460 t/ha (Komiyama and Poungparn 2008). Significant AGB has also been reported in Indonesia and French Guyana, with up to more than 300 t/ha (Komiyama and Poungparn 2008), while the lowest estimate of AGB, reported in *Rhizophora mangle* forest in Florida, USA, was only 7.9 t/ha (Komiyama and Poungparn 2008).

A diversity of methods have been developed by different researchers to estimate both AGB and BGB (Betts 2006, Komiyama and Poungparn 2008, Chave et al. 2005, Ray et al. 2011, Patil et al. 2014, Ghasemi et al. 2016), ranging from the traditional field measures to more sophisticated recent techniques such as mathematical modelling and remote sensing (Proisy et al. 2003, Camacho et al. 2014, Patil et al. 2014, Ghasemi et al 2016, Igu and Marchant 2016). This variety of approaches contributes to the uncertainty in estimating biomass and subsequently in quantifying carbon sequestration and storage (Chave et al. 2005).

Traditional approaches range from destructive harvest methods (Camacho et al. 2014, Patil et al. 2014, Ghasemi et al. 2016) to less disturbing field measurements (Proisy et al. 2003, Camacho et al. 2014, Patil et al. 2014, Ghasemi et al. 2016). Cutting methods involve the clearance of vegetation in a sampled area of around one-acre (= 0.4 ha), which is time and labour intensive and harmful to the ecosystem itself (Patil et al. 2014). Also, it is not easily achieved due to the muddy environment and weight of the wood, particularly in dense forests (Komiyama and Poungparn 2008).

Field measurements which are non-destructive include measuring tree height (H), trunk diameter at breast height (DBH) and species density or wood specific gravity (*p*) (Chave et al. 2005, Betts 2006, Ray et al. 2011, Camacho et al. 2014, Patil et al. 2014, Igu and Marchant 2016). These measures then use appropriate allometric equations to quantify biomass (Chave et al. 2005, Camacho et al. 2014, Patil et al. 2014, Ghasemi et al. 2016). Although this method is advantageous over the destructive harvest method and could be operated for monitoring the health of the forest, as indicated by changes in biomass (Komiyama and Poungparn 2008), it requires the use of the correct site-specific and species-specific allometric equations and there is significant physical effort spent in making the measurements (Komiyama and Poungparn 2008). Traditional sampling methods can also be used to verify estimates made by modelling or remote sensing (Patil et al. 2014, Igu and Marchant 2016).

The shape and size of sampling plots also varies among studies. The shape can be rectangular, square or round, all of which can be of different sizes (Ray et al 2011, Marshal et al. 2012, Patil et al. 2014, and Camacho et al. 2014). Ideally, plots should be large enough, representative and the measurements of H and DBH should be taken as accurately as possible (Chave et al. 2005). The height at which diameter is measured for DBH should be 1.3 m (Chave et al. 2005, Ray et al. 2011) and the measurements of H and DBH should be taken above any buttresses present (Chave et al. 2005). Most studies only measure plants with a DBH greater than 5 cm (Ray et al. 2011, Patil et al. 2014, Igu and Marchant 2016) due to the low biomass content of smaller plants, which are thought to account for less than 5% of the total biomass (Lewis et al. 2009, Marshall et al. 2012, Igu and Marchant 2016).

Other studies use regression models to estimate biomass (Koprivica et al. 2010, Ghasemi et al. 2016). Similar to allometric equations, these models use field measurements of all or two of DBH, H and wood density variables (Koprivica et al 2010, Ray et al. 2011, Ghasemi et al. 2016). These equations can be used also to estimate BGB (Koprivica et al. 2010, Patil et al. 2014).

The use of remotely sensed data to quantify the carbon stored by AGB of mangroves (Proisy et al. 2003, Patil et al. 2014) has recently increased due to its advantage over conventional methods in terms of time and physical effort (Patil et al. 2014). The most common sources of data are Landsat, Radar images (Proisy et al. 2003), Laser Imaging Detection and Ranging (LIDAR), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Interferometric Synthetic Aperture Radar (InSAR) (Patil et al. 2014, de Araujo Barbosa et al. 2015). Remote sensing can also be advantageous over traditional methods due to its much more extensive coverage of the vegetative area (Marshall et al. 2012). Although it has its limitations, this technique can be enhanced by ground-truthing (Marshall et al. 2012).

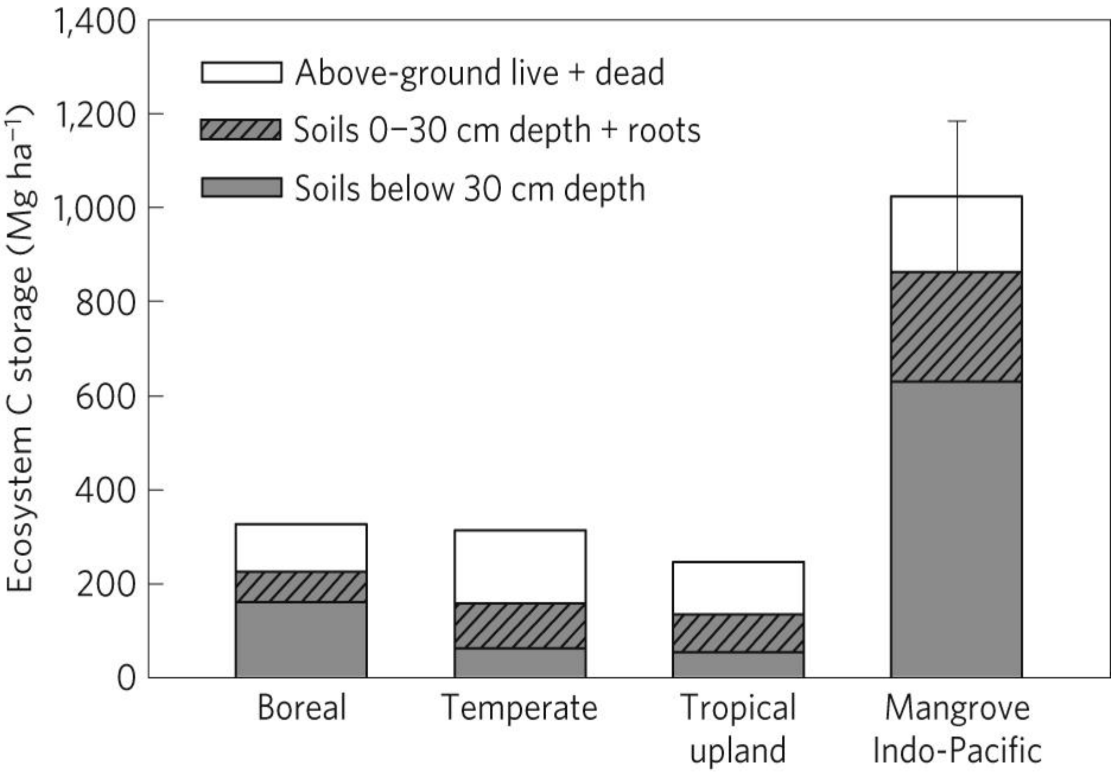


Figure 5.1. Estimates of amount of carbon sequestered by different forests, (Mgha^{-1} = t/ha). Obtained from Donato et al. (2011).

Storm buffering

In addition to serving as a carbon sink, mangroves also provide a physical buffer that can ameliorate the impacts of storms, hurricanes, surges and, in extreme cases, tsunamis (Kathiresan and Rajendran 2005, Wells and Ravilious 2006, Das and Vincent 2009, Alongi 2011, Kuenzer et al 2011, Duke et al. 2014). For instance, in the 2004 Boxing Day tsunami that originated near Ache, Indonesia, there is much compelling evidence that fewer lives were lost where there was more mangrove vegetation present (Kathiresan and Rajendran 2005, Das and Vincent 2009). Wells and Ravilious (2006) suggest that in Sri Lanka mangroves could also catch the debris swept by energetic waves and therefore reduce the damage cause by debris. They also suggest that mangroves saved people from being pulled into the sea by receding large waves. Wells and Ravilious's (2006) survey of 24 estuaries in Sri Lanka revealed that the quality of life of local communities with fringing mangroves was less adversely affected by flooding than communities lacking fringing mangroves.

Duke et al. (2014) note the increasing interest in the role of mangroves as a buffer against storms, cyclones, winds and waves, reducing the energy of storms and reducing death rates and property loss. Das and Vincent (2009) argue that mangroves are more effective against storm surges than tsunamis, because of the short wavelengths and surface-restricted energy of storm surges which models have shown to be more attenuated by mangroves than the long waves present in a tsunami. The defensive role of mangroves also shelter juvenile fish and crustaceans, which use these areas as nursery grounds against waves and storm surges. This will in turn provide benefits for nearby fisheries (Van Bochove et al. 2014), expanded on in Chapter 4.

Regulating services in Oman

Although the role of coastal habitats such as mangroves in delivering regulating services significantly contributes to human wellbeing, this role has only been recently emphasised (Herr and Landis 2016), with a focus largely on South America, South-east Asia and with only a few studies in sub-tropical Africa (Marshall et al. 2012). There is little information on regulating services of coastal systems in the Middle East in general, and in Oman in particular. This is despite the known existence of Omani mangroves extending back 6000 B.P (Fouda and Al-Muharrami 1995, Lézine et al 2002, MECA 2010) and the large investment in restoring and conserving intertidal ecosystems in Oman and neighbouring countries (Schile et al. 2017).

UNEP claims that there are fewer than 10 published papers from the Middle East on this topic (Van Bochove et al. 2014) and even fewer published studies on carbon sequestration by mangroves in the region (Ward et al. 2016). Indeed, according to a summary of projects conducted globally on blue carbon, no projects on this subject where conducted in the Middle East till 2013 (Bredbenner 2013, Thomas 2014). Generally, more studies have been conducted on mangroves and carbon in the wetter tropics than arid regions (Schile et al. 2017). This is surprising considering that Omani mangroves are a key element of the climate change adaptation policies of the Omani government. However, the term “blue carbon” has not been used yet in Oman, unlike the neighbouring states of Bahrain, UAE and Saudi Arabia (Herr and Landis 2016).

There are no previously published studies on the significance of Oman mangroves for carbon sequestration. Two studies (Fouda and Al-Muharrami 1995, JICA and MECA 2004) reported mangrove tree height (H) and diameter (DBH), which are the basic measures needed for carbon quantification (Chave et al. 2005, Betts 2006, Ray et al.

2011, Camacho et al. 2014, Patil et al. 2014, Igu and Marchant 2016), but they were only used to assess mangrove abundance and health.

In the Arabian Gulf region where Oman is located, a broad-scale study in blue carbon was conducted in the United Arab Emirates (UAE) by Schile et al. (2017) to quantify the biomass and carbon storage of coastal ecosystems comprising mangroves, seagrass beds and salt marshes. Biomass estimates of *Avicennia marina* were included, which allow comparisons with the present study, although the allometric equations used differ from those used here.

Similarly, whilst there is increasing concern in Oman about the threat from storm activity, particularly after cyclones Gonu and Phet, there is no literature on how mangroves might mitigate that threat.

Accordingly, this chapter aims to investigate the potential role of mangroves at Al-Qurum for carbon sequestering and storm buffering, using a combination of field sampling and GIS mapping. These services were among the top reported regulating services in Al-Qurum from a questionnaire survey (Chapter 3), compared to Al-Sawadi and Quarayyat. Specifically, this chapter:

a) estimates the AGB and carbon stock of *A. marina* at Al-Qurum using field sampling and by applying allometric equations.
b) examines the potential role of mangrove belts at Al-Qurum in defending the coast, using GIS mapping.

5.2. Methodology

5.2.1. Study area

Al-Qurum is located at the heart of Muscat Governance at 23°37'12.88"N, 58°28'33.11"E in Northern Oman (Figure 5.2) with arid climatic conditions with annual rainfall ranging between 100-150 mm (Al-Shukaili, 2011). The mangrove ecosystem is characterised by the dominance of *A. marina* (Lézine et al. 2002, JICA and MECA 2004, MECA 2010) which is adapted to extreme environmental conditions such as high salinity and highly variable tidal ranges (JICA and MECA 2004). The soil in the site is a mixture of silt and mud with sabkha located at the heart of the habitat (JICA and MECA, 2004). The site is one of the most important for mangroves in Oman due of its designation as a nature reserve in 1975 and because it hosts two nurseries of mangrove tree saplings which supply seedlings for restoration projects in other parts of the country (JICA and MECA, 2004).

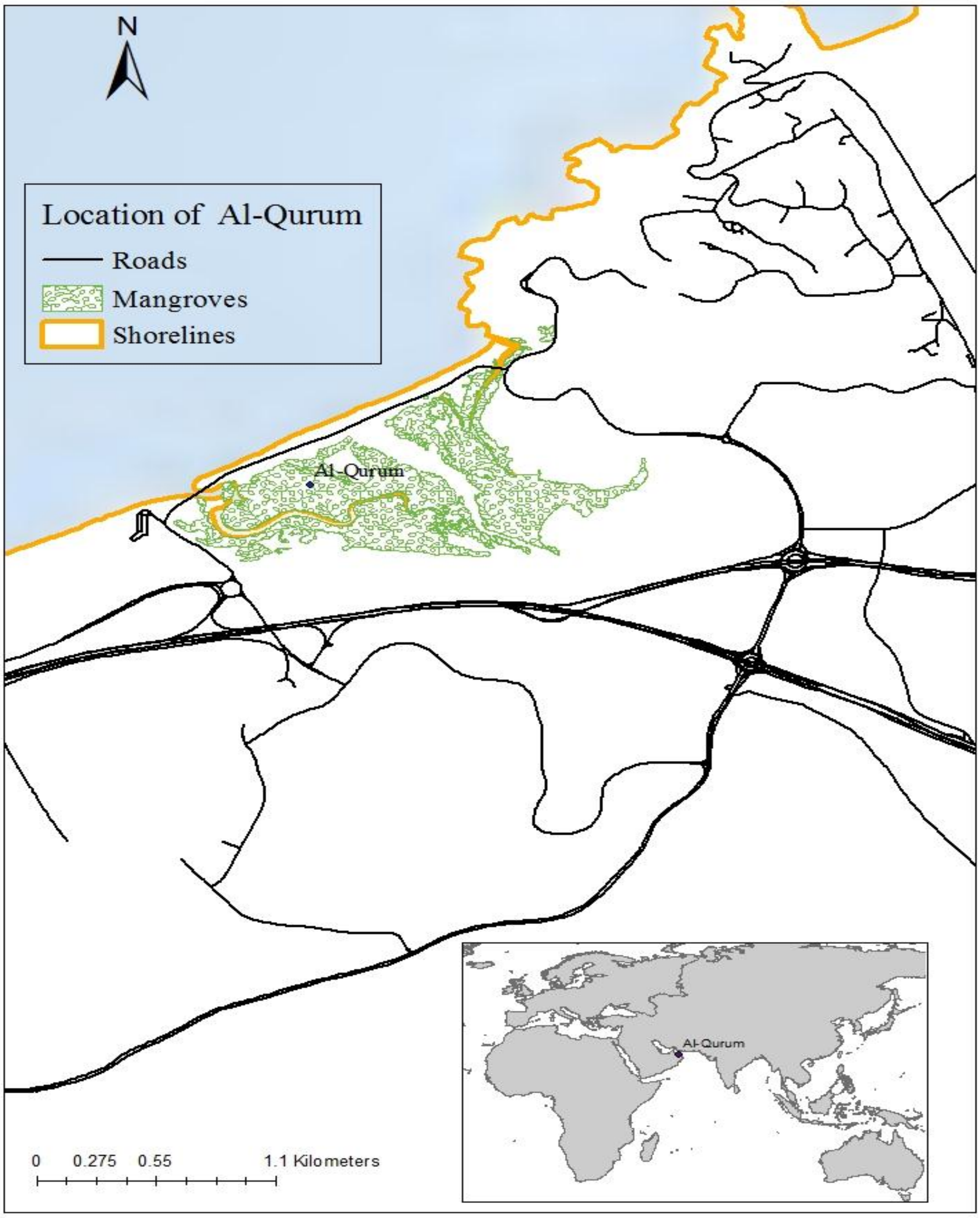


Figure 5.2. Location of Al-Qurum in Oman.

5.2.2. Quantification of AGB and carbon

This study used field sampling to estimate AGB only. Few equations have been developed for BGB, due to the exhaustive physical efforts needed to extract the roots from soil and then weighing them (Komiyama and Poungparn2008). Although mangrove soil stores significant amounts of carbon (Donato et al. 2011, Grimsditch et al. 2013, Patil et al. 2014), these sediments are very variable and dynamic (Donato et al. 2011, Grimsditch et al. 2013), meaning that quantification of soil carbon was beyond the scope and resources of this study.

Due to the patchy nature of mangroves at Al-Qurum I sampled along seven transects perpendicular to the shoreline, with plots spaced along each transect, the number depending on the width of the mangrove zone (Figure 5.3). A prior GIS analysis indicated the total extent of mangroves to be 42.7 ha in 2013, a relatively small area, and so 15 plots of 5 m x 5 m (25 m^2) were sampled in total. For larger forests, plots of 10 m^2, 20 m^2, 30 m^2 are commonly used (Patil et al. 2014, Ray et al 2011, Marshal et al. 2012).

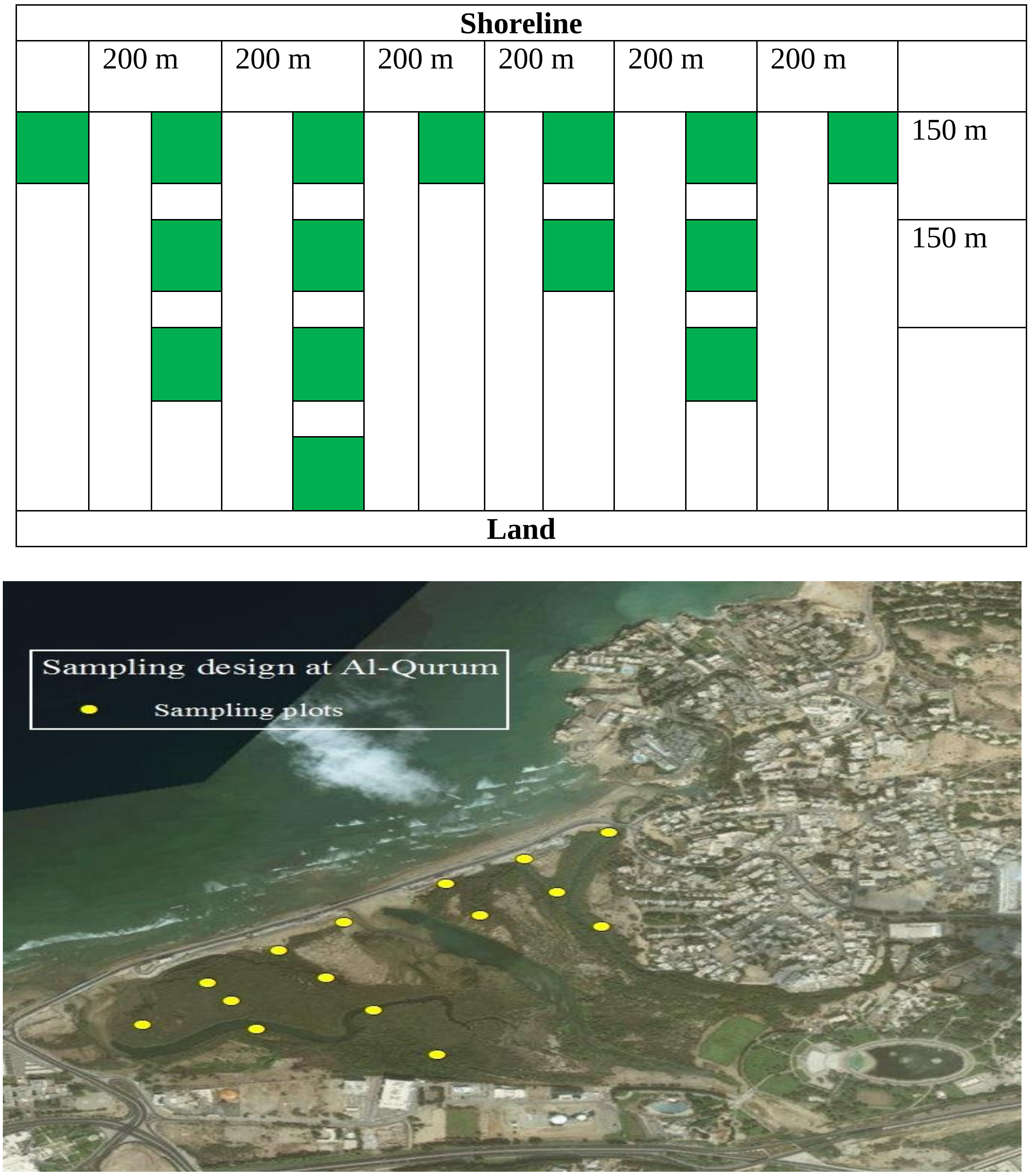


Figure 5.3. Sampling scheme for mangrove AGB at Al-Qurum, plots in green (see Figure 5.2 above for distance scale).

AGB was estimated from measurements of H and DBH (Chave et al. 2005, Betts 2006, Ray et al. 2011, Camacho et al. 2014, Patil et al. 2014, Igu and Marchant 2016). Only trees with circumference ≥ 10 cm, where the DBH was ≥3cm were included. Every tree of these dimensions was measured within each plot (Ray et al. 2011, Patil et al. 2014, Igu and Marchant 2016). H was measured using a stiff measurement tape from the base to the tip of the tree (Igu and Marchant, 2016) and DBH was measured using a tape at a height of 1.3 m (Ray et al. 2011) (Figure5.4).

Figure.5.4. The author taking measurements of H and DBH and marking trees to record that they had been measured.

One of the complications associated with measuring DBH is the stem-branching habitat of *A. marina*. Therefore the diameter of each branch (≥3 cm) was recorded, as proposed by JICA and MECA (2004) and Patil et al. (2014). To avoid duplications and missing any trees in a plot, each tree was marked directly after measurement, as suggested by Patil et al. (2014) (Figure 5.4).

Allometric equations have commonly been developed for single-trunk trees, but they have also been widely used for multi-stemmed trees such as *A. marina* (Komiyama and Poungparn 2008). Equations were taken from the literature for tropical forests and for *A. marina* from different parts of the world, including South-east Asia, Australia, Africa, India and China, reported in Komiyama and Poungparn (2008), and Patil et al. (2014).

The first equation (Table 5.1) reported in Patil et al. (2014) and developed by Kirui (2006) was considered the most appropriate for this study [Total AGB= 0.637 $(DBH)^{1.6479}$]. This equation was developed for Kenyan *A. marina*, which is expected to live in climatic conditions most similar to those in Oman (compared to SE Asia, India or Australia). This equation resulted in biomass values within the range reported by Comley and McGuinness (2005) for different measurements of DBH in *A. marina*.

I also applied another equation developed by Chave et al. (2005) for more general use in the the pantropics (Table 5.1). This equation used a value of ρ which represents the wood specific gravity (WSG) in g/cm^3. According to the global wood density database, the WSG of *A. marina* ranges from 0.52 (South America), 0.65 (South-east Asia), 0.732 and 0.689 (Australia) (Chave et al. 2009, Zanne et al. 2009) and therefore I used the maximum, minimum and mean value (0.64775 g/cm^3) of WSG.

Table 5.1. Allometric equations used for AGB estimates in this study.

	AGB equation	**Developed for**	**Used by**
1	$AGB=0.637 (DBH)^{1.6479}$	*A. marina*	Kirui (2006)
2	$AGB=0.0673x(\rho D^2H)^{0.976}$	pantropics	Chave et al. (2005)

The biomass of individual trees within a single plot was summed to obtain the total biomass in kg for the 25 m^2 plot. This figure was then scaled up to give a value of t/ha. The mean biomass value in all 15 plots was computed for each equation. The calculated mean was then converted to the amount of carbon stored by multiplying by 0.5, a value representing the average amount of carbon stored in woody tropical ecosystems (Chave et al. 2005, Camacho et al. 2014, Marshall et al. 2012, Igu and Marchant 2016).

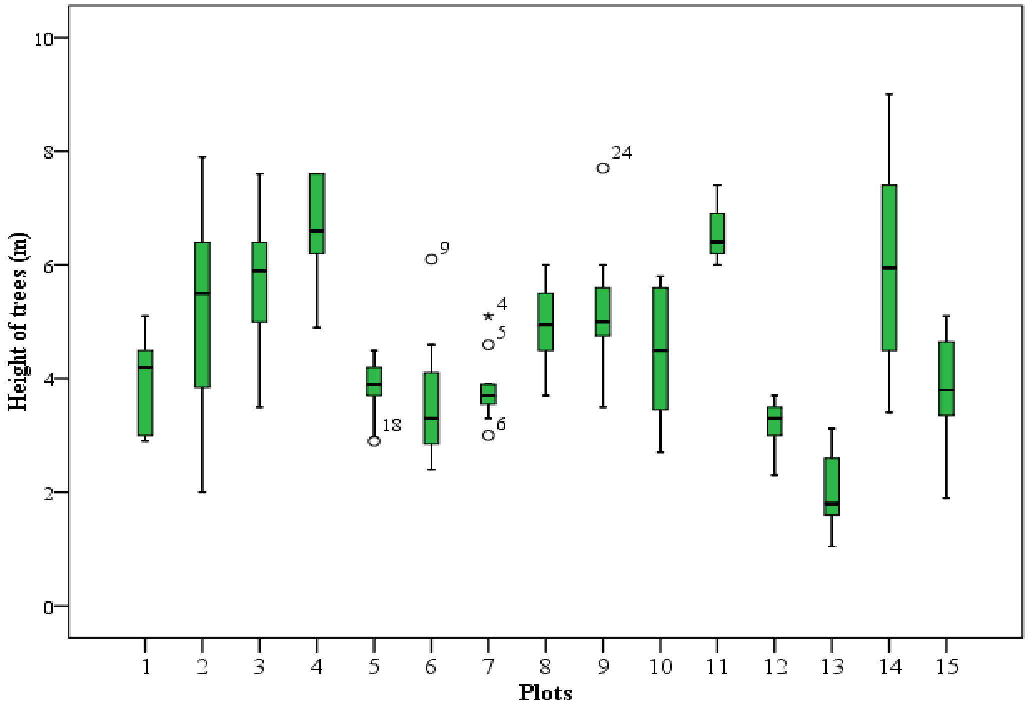
5.2.3. Storm buffering potential

The potential of mangroves to deliver the regulating service of storm buffering was assessed as the width of vegetative cover perpendicular to the prevailing wind direction (Wood et al. 2010). The width and length of the mangrove belt from low to high shore was measured using GIS for mangrove areas exposed to prevailing winds (data from wind roses from the meteorological station at Muscat for the years 1985 to 2009) and to cyclones (PACA 2016). GIS was performed using ArcMap, based on historical aerial photographs obtained from the National Survey Authority (NSA), Oman, and the most recent historical aerial photograph of Al-Qurum (2013).

3. Results

5.3.1. H and DBH ranges of Avicennia marina

The 15 plots sampled contained a total of 245 trees with an average of 16.33 trees per plot (SE±2.46). The height of sampled trees ranged from a minimum of 1.05 m to a maximum of 9 m, while the mean height ranged between plots from 2.03 m to 6.60 m (Figure 5.5, a). Trees exceeding 6 m in height were reported in less than 50% of the plots. A correlation analysis of the spatial pattern of H showed a degree of correlation between recorded heights and distance from the coast (R=0.568, p=0.027). Spatial representation of this relationship showed an increase in the value of H with distance from the coastline (Figure 5.5b).



(a)

(b)

Figure 5.5. Box-plot of heights of trees sampled (m) in the 15 plots (a) with spatial representation of mean H with distance from coast (b).

The values of DBH ranged from a minimum of 3.2 cm to a maximum of 20.7 cm (Figure 5.6). Only 26% of the plots had DBHs exceeding 15 cm and in 39% of the plots half of the DBHs were less than 10 cm (Figure 5.6).

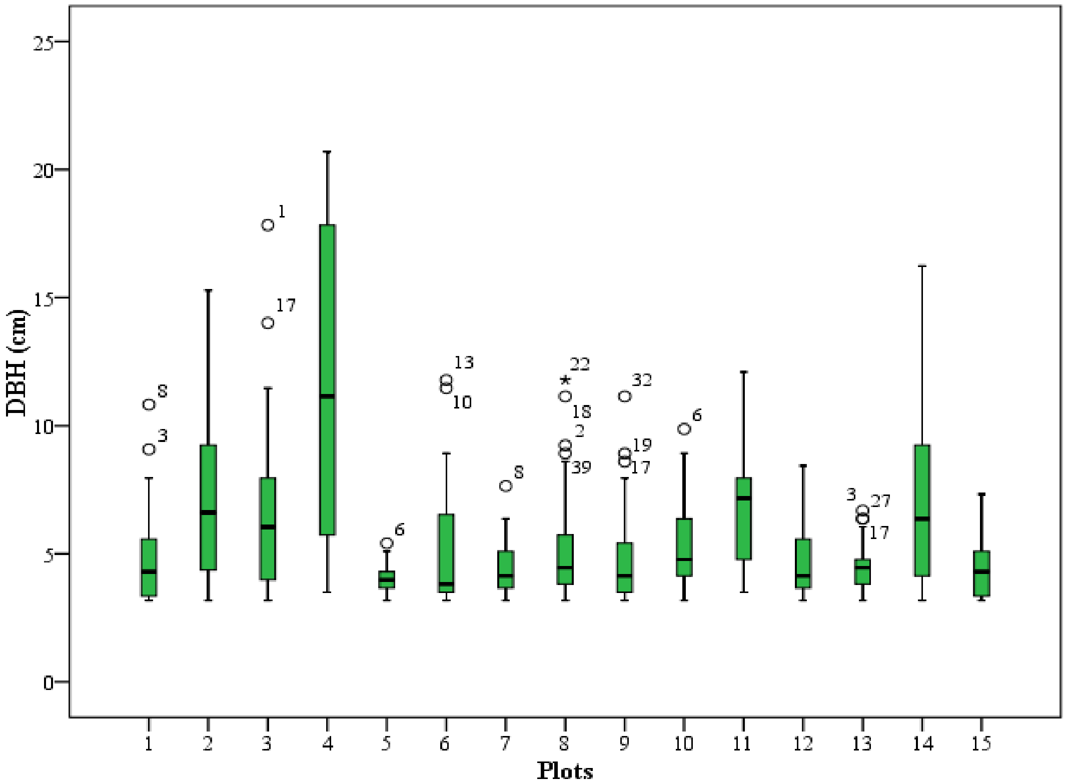


Figure 5.6. Box-plot of tree DBH values (cm) for the 15 plots.

There was a positive relationship between H and DBH across all the fifteen plots (Figure.5.7, R^2 =0.40, p<0.001, N=245).

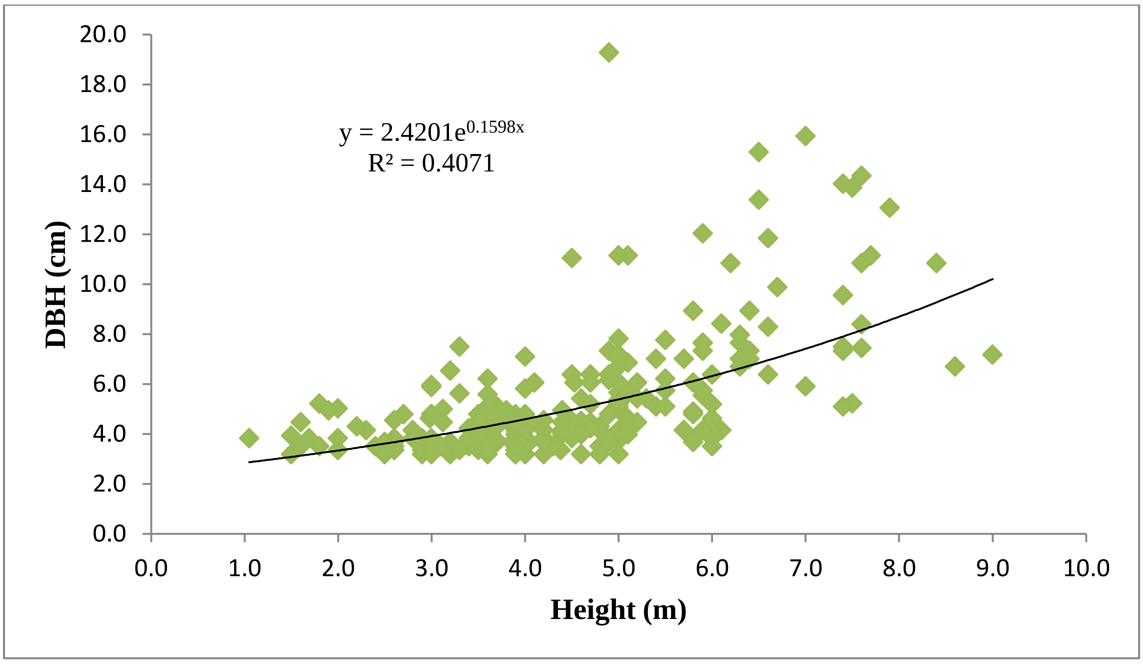


Figure 5.7. The relationship between height and DBH for all trees measured in the fifteen plots.

5.3.2. AGB estimates and carbon stock in Avicennia marina

The two different equations used to calculate AGB produced somewhat different results. Using the Kirui (2006) equation, AGB estimates ranged from 74.20 t/ha to 290.37 t/ha (Figure 5.8) with a mean of 157.11(±20.04 SE) t/ha across the 15 plots. In comparison, when using the Chave et al. (2005) equation with mean global WSG, the AGB estimate ranged from 24.60 t/ha to 284.04 t/ha (Figure 5.8) with a mean of 106.92 (±21.92 SE) t/ha.

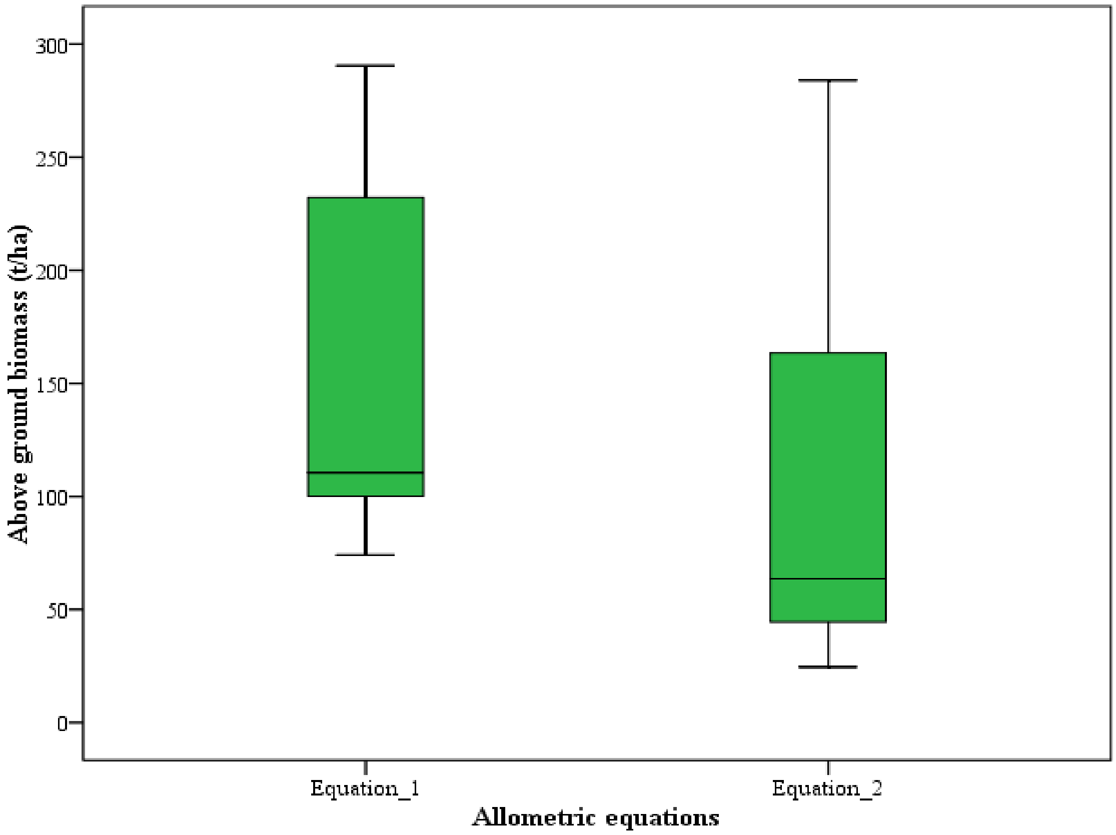


Figure 5.8. AGB estimates (t/h) in all the fifteen plots. The first equation is by Kirui (2006) and the 2nd by Chave et al. (2005).

According to the equation of Chave et al. (2005), and by using the global minimum, maximum and means of WSG of *A. marina*, the AGB estimates were also somewhat variable (Figure 5.9). When using the minimum global WSG, the AGB ranged from 19.85 t/ha to 229.22 t/ha with a mean of 86.34 (±17.71 SE) t/ha, while when using the maximum global WSG, the AGB ranged from 27.72 t/ha to 320.04 t/ha with a mean of 120.55 (±24.74 SE) t/ha.

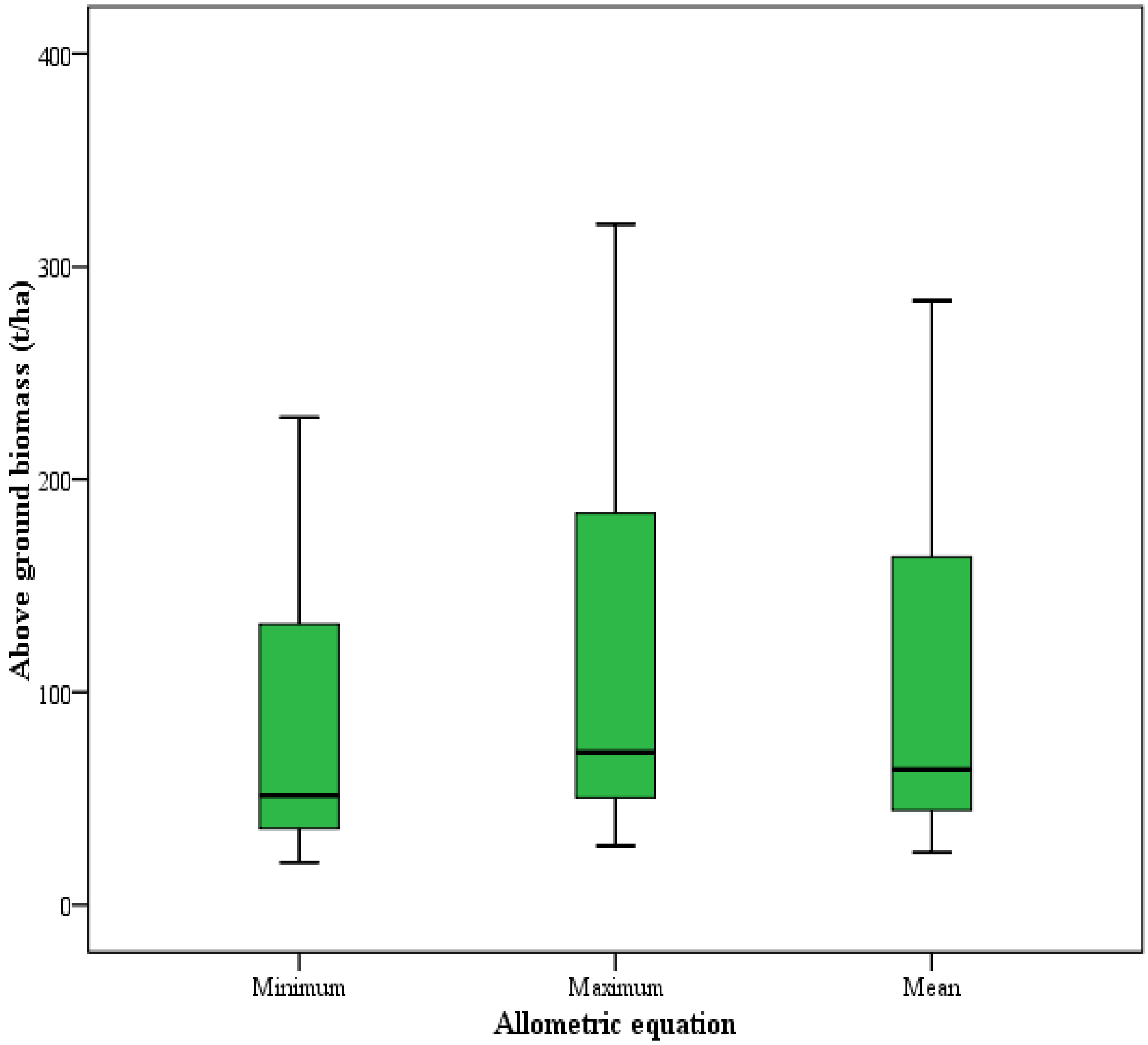


Figure.5.9. AGB estimates derived using the Chave et al. equation using the minimum, maximum and means of global WSG of *A. marina*.

The estimated values of carbon stock given by the equations ranged from 59.90 t/ha to 133.05 t/ha (Table 5.2). The equation of Chave et al. (2005) estimated less carbon stock in comparison to the equation of Kirui (2006).

Table 5.2. Amount of carbon sequestered by Al-Qurum mangroves. Note that ρ represents the maximum, minimum and mean global value for *A. marina* (see text).

	Equation	**Mean carbon stock in t/ha**
1	$AGB=0.637\ (DBH)^{1.6479}$	78.55
2	$AGB=0.0673x(\rho\ D^2H)^{0.976}$	43.17(ρ=0.52), 60.27(ρ=0.732), 53.46 (ρ=0.64775)

5.3.3. Protective role of mangroves against waves and storminess

To interpret the protective role of mangroves against waves and storminess, two factors (as suggested by Ward et al. (2016) were considered: a) the direction of the storminess and b) the direction of the prevailing wind. A report released by PACA (Public Authority of Civil Aviation) in Oman (May, 2016) shows the windrose of Muscat for the period 1985-2009 where the prevailing wind is mainly coming from a north-eastern direction and, much less so, from the south-west (Figure 5.10).

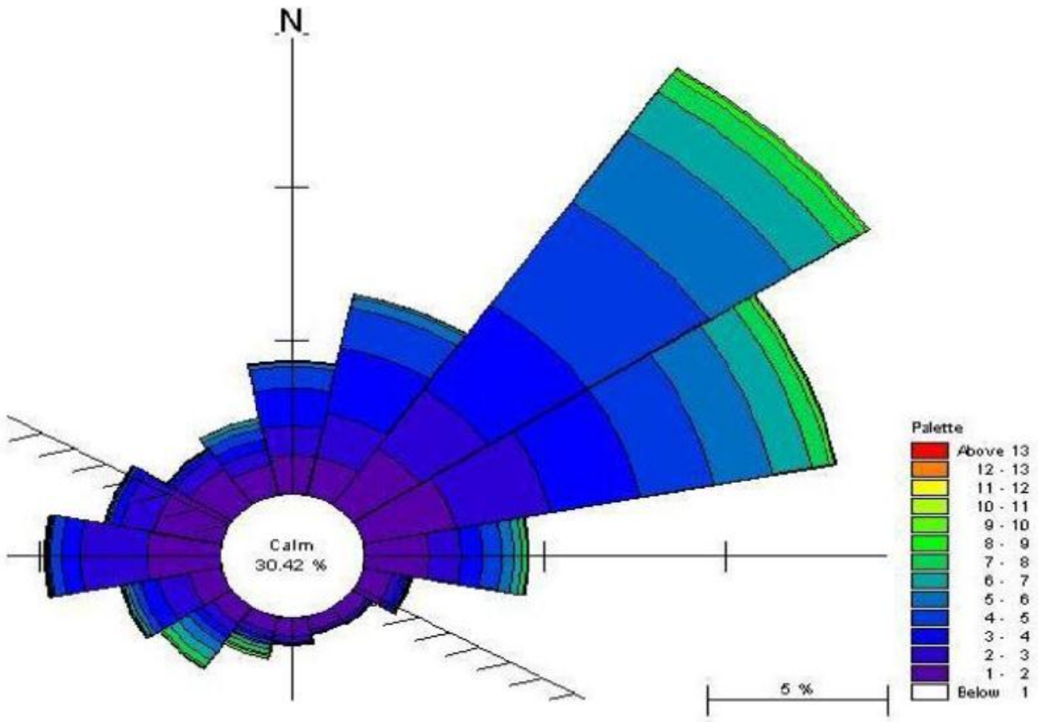


Figure 5.10. Windrose of Muscat in the period of 1985-2009 in m/s, with wind prevailing coming from north-east direction. Obtained from PACA, 2016.

For cyclones (storms), as mentioned in Chapter 2, the most recent destructive recorded in the northern Indian Ocean and the Arabian Sea was Gonu which severely impacted the north-eastern coasts of Oman in June, 2007 (Al-Kathiri et al. 2008, Al Najar and Salvekar 2010, Pilarczyk and Reinhardt 2012). Cyclone Phet in June 2010 was less intense than Gonu, but still considered destructive (Pilarczyk and Reinhardt 2012).

The track of cyclone Gonu (Figure 5.11) showed that it developed in the northern Indian Ocean on the 3rd of June, 2007 and lasted for 5 days, impacting the eastern Omani coasts on the 5th (Al-Sharqia Governorate) before heading north towards the capital and Al-Qurum on the 6th.

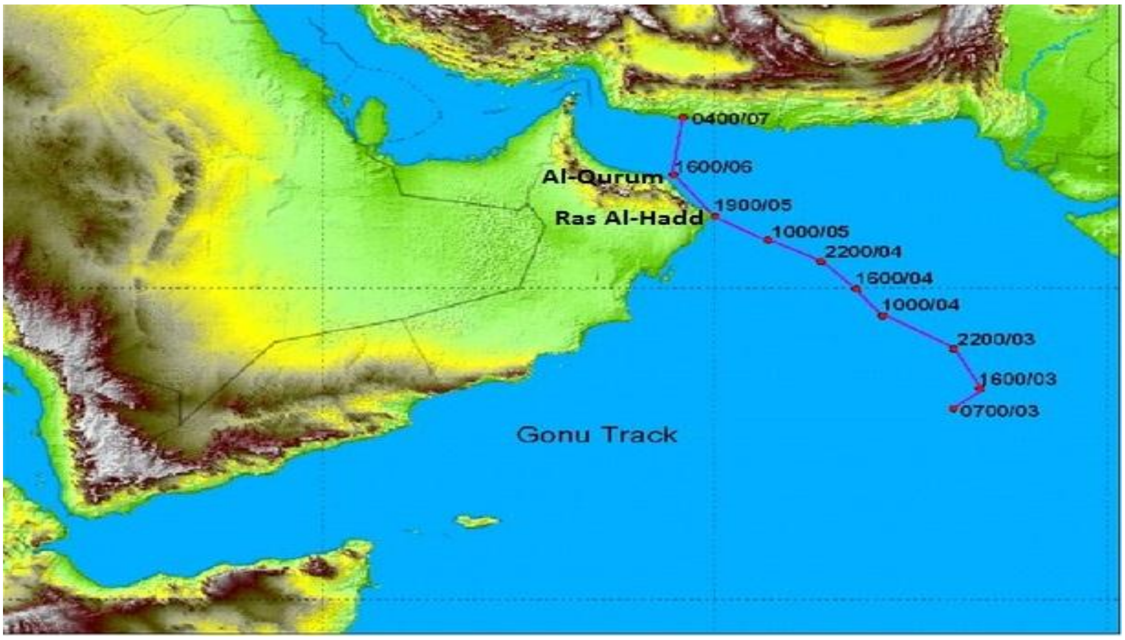
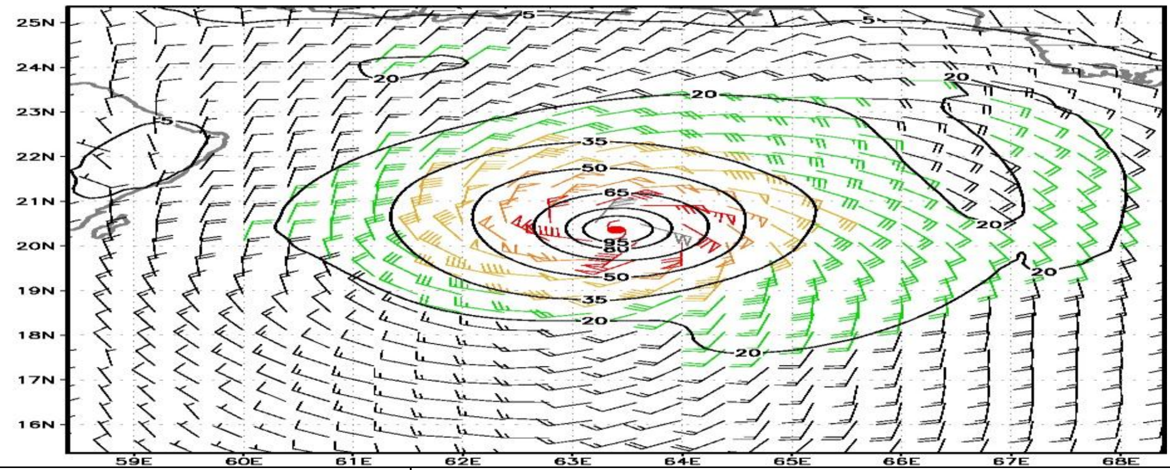


Figure 5.11. The track of cyclone Gonu in June 2007, indicating that it made its 1st landfall in Ras Al-Hadd, the most eastern tip of Oman and moved towards Al-Qurum for its 2nd landfall. Map obtained from Al Najar and Salvekar (2010).

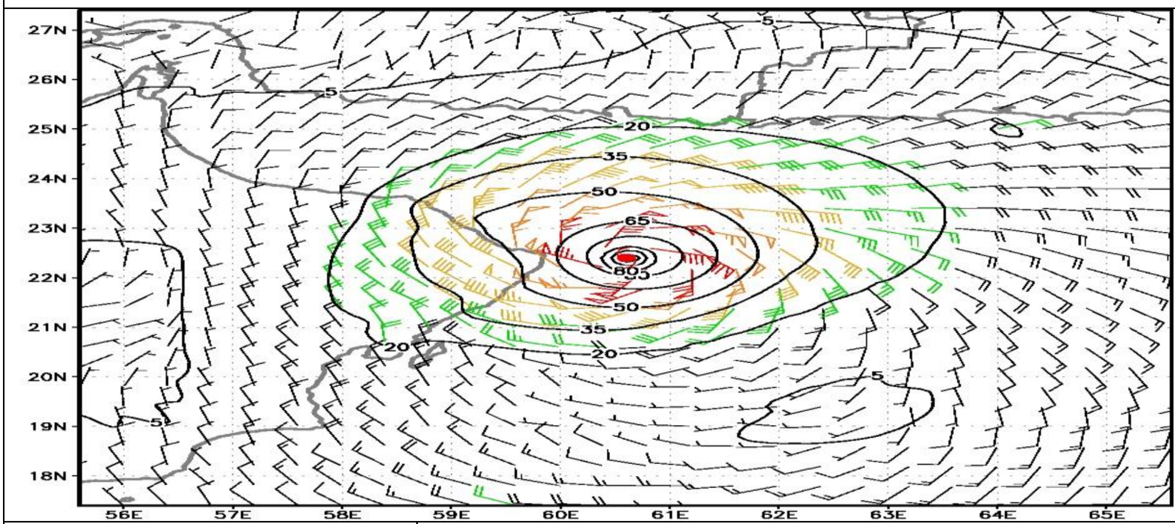
Figure 5.12, provides more details of the eye of the cyclone Gonu, its wind direction and speed. While approaching the Omani coasts on June 4th (Figure 5.12, a), the prevailing wind direction was from the north-west, wind speed reached 95 knots (176 km/hr) and the eye of the cyclone was located within longitudes 36° and 64°E and latitudes 20° and 21°N, which is out of the range of Al-Qurum. On June 5th (Figure 5.12, b) the cyclone was at the eastern tip of Oman where it made its first landfall with wind speed at the eye reduced to 80 kt (148 km/hr). The wind direction shifted gradually to the north-west and the eye remained out of the range of Al-Qurum. On June the 6th (Figure 5.12, b), Gonu made its second landfall in Muscat Governorate where Al-Qurum is located and retained its north-west wind direction. Although Gonu was less intense on June 6th, with wind speed of 50 kt (93 km/hr), the eye of the cyclone was closer to Al-Qurum, within longitudes 58°-59° E and latitudes 23°-24 N°, within range of Al-Qurum. A summary of the quantification of windspeed during Gonu at each of the sites indicating the relative severity of the cyclone is shown in Table 5.3.

Table 5.3. Summary of the strength of the effects of Gonu on study sites based on wind speed on 4th, 5th and 6th June 2007, respectively .

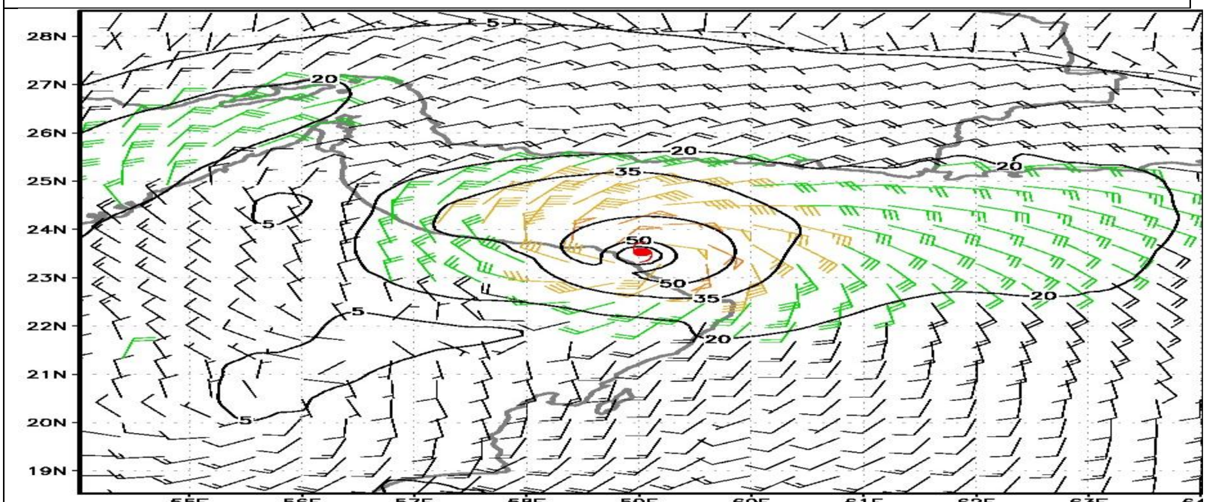
Site	Coordinates	Wind speed on 4th, 5th, 6th June 2007
Harmul	24°32'42.42"N, 56°35'0.11"E	5 kt (9.3 km/h), 5 kt (9.3 km/h), 5 kt (9.3 km/h)
Al-Qurum	23°37'12.88"N, 58°28'33.11"E	5 kt (9.3 km/h), 20 kt (37 km/h), 50 kt (93 km/h)
Qurayyat	23°16'29.62"N, 58°55'11.91"E	5 kt (9.3 km/h), 35 kt (65 km/h), 50 kt (93 km/h)
Mahout	20°34'30.97"N, 58° 9'43.98"E	5 kt (9.3 km/h), 5 kt (9.3 km/h), 5 kt (9.3 km/h)



4th June, 2007 at 18:00 UTC (a)



5th June, 2007 at 18:00 UTC (b)



6th June, 2007 at 12:00 UTC (c)

Figure 5.12. Wind direction and speed of cyclone Gonu from June 4th to 6th 2007. The arrow heads indicate the wind speed increasing from black to green to yellow. The red dot indicates the eye of the cyclone, while Al-Qurum located at 23°N and 58°E. Obtained from: https://www.nesdis.noaa.gov.

Cyclone Phet made landfall on the Omani coast in the same month three years after Gonu. The track of the cyclone (Figure 5.13) shows that it developed in the north Indian Ocean from the 1st to the 6th of June and made its first landfall at the same place as Gonu.

c

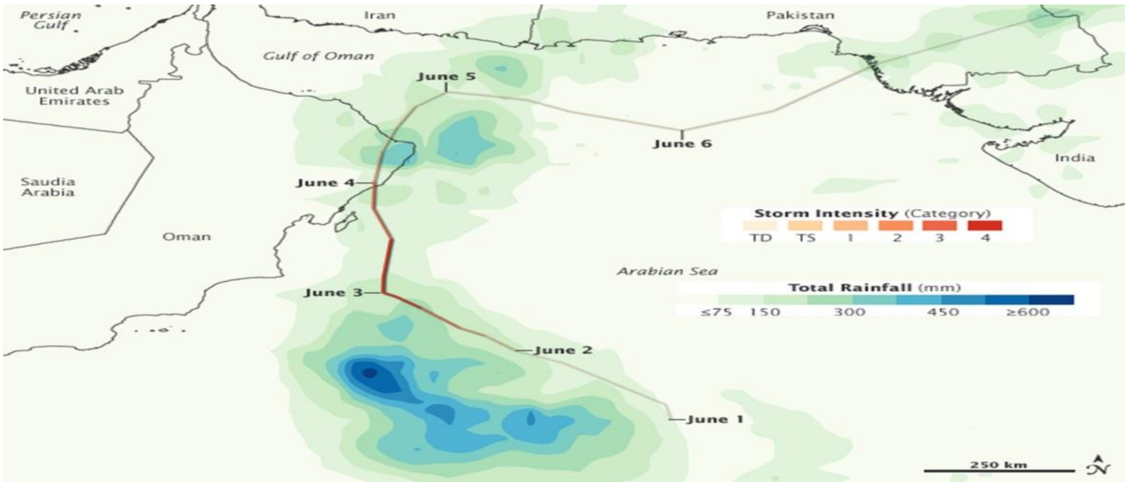
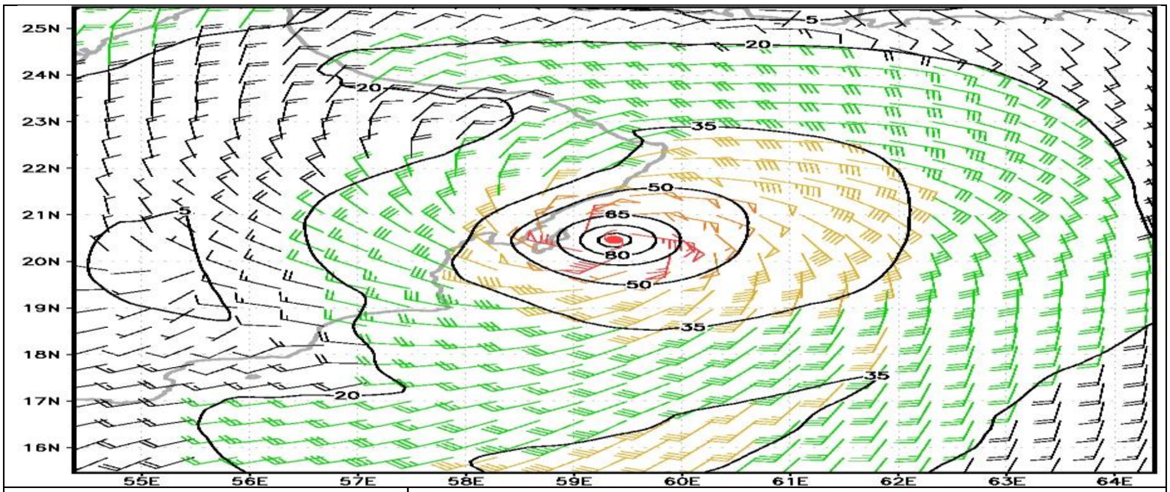


Figure 5.13. Track of cyclone Phet in 2010, which shows that Phet deflected away from Al-Qurum after it made its 1st landfall. Obtained from: https://www.nasa.gov.

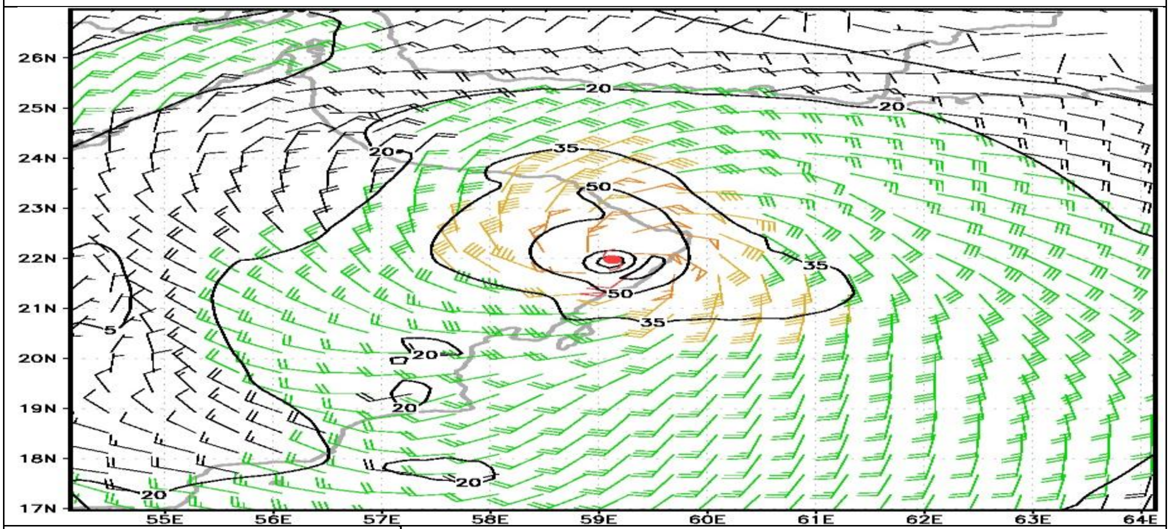
Figure 5.14 shows that cyclone Phet approached the Omani coast on June 3rd 2010 (Figure 5.14, a) with an eye wind speed of 80 kt (148 km/h) and a southwest direction. The eye of the cyclone was within longitudes 59°-60° E and latitudes 20°-21° N, out of the range of Al-Qurum. On June 4th (Figure 5.14, b), the cyclone made its first landfall with a wind speed reduced to 50 kt (93 km/hr) and changed wind direction from southwest to north-west. The cyclone longitudes and latitudes were still out of the range of Al-Qurum. On June 5th (Figure 5.14, c), cyclone Phet migrated away from the Omani coast, retained its north-west wind direction, but dropped its speed to 20 kt (37 km/h) at its eye. The eye did not make its landfall close to mangroves in Al-Qurum (Chaudhuri et al (2015), therefore the impact of Phet on Al-Qurum mangroves will not be discussed further. A summary of the quantification of windspeed during Phet at each of the sites, indicating the relative severity of the cyclone, is shown in Table 5.4.

Table 5.4. Summary of the strength of the effects of Phet on study sites based on wind speed on 3rd , 4th and 4th June 2010, respectively .

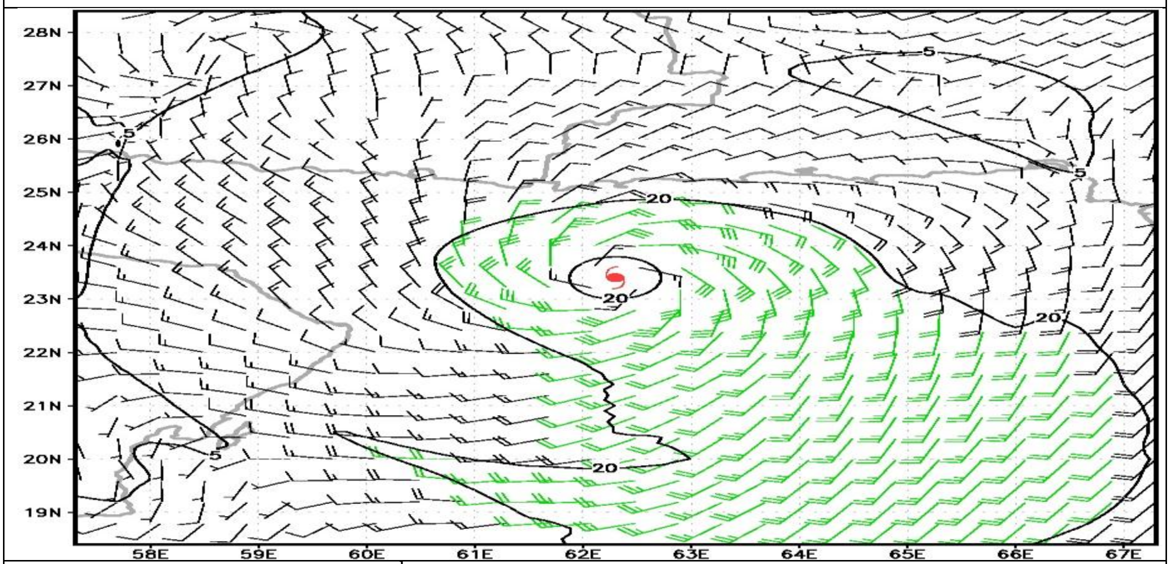
Site	Coordinates	Wind speed on 4th, 5th, 6th June 2007
Harmul	24°32'42.42"N, 56°35'0.11"E	5 kt (9.3 km/h), 5 kt (9.3 km/h), 5 kt (9.3 km/h)
Al-Qurum	23°37'12.88"N, 58°28'33.11"E	5 kt (9.3 km/h), 20 kt (37 km/h), 5 kt (9.3 km/h)
Qurayyat	23°16'29.62"N, 58°55'11.91"E	5 kt (9.3 km/h), 20 kt (37 km/h), 5 kt (9.3 km/h)
Mahout	20°34'30.97"N, 58° 9'43.98"E	20 kt (37 km/h), 20 kt (37 km/h), 5 kt (9.3 km/h)



3rd June, 2010 at 18:00 UTC (a)



4th June, 2010 at 06:00 UTC (b)



5th June, 2010 at 18:00 UTC (c)

Figure 5.14. Wind direction and speed of cyclone Phet from 3rd to 5th, June. The arrow heads indicate the wind speed increasing from black to green to yellow. The red dot indicates the eye of the cyclone, while Al-Qurum located at 23°N and 58°E. Obtained from: https://www.nesdis.noaa.gov.

The prevailing wind directions of the windrose and both cyclones were used to identify which belts of mangroves were relevant for potential wind / storm protection and their length and width was defined using GIS (Table 5.5). The prevailing wind direction is from the north-east which is along belt C (Figure 5.15), while the direction of prevailing wind for both cyclones was fronting the shoreline of belts B and C (Figure 5.15).

Table 5.5. Mangrove belt length and width in relation to prevailing wind directions for the windrose data and cyclones in Muscat. Points (B) and (C) are indicated in Figure 5.15, below.

Direction of wind	**Length of mangrove belt (m)**	**Width of mangrove belt (m)**
north-east (C)	550	30-250 (range)
south-west (B)	750	410

Figure 5.15. Main source of freshwater to mangroves (A), mangrove belts (B,C) and the centre point of meeting of floods and storm surge (D). Note that the width of B and C is indicated above in Table 3.4. Image obtained from Google Earth.

5.4. Discussion

5.4.1. Estimation of AGB and carbon stock

5.4.1.1. H and DBH ranges of *Avicennia marina*

The ranges of H and DBH which have been used to estimate the AGC at this site reflect its location in an arid zone characterised by low annual rainfall and high salinity, as elaborated in chapter two. In other parts of the world the height of *A. marina* usually could exceed 16 m (Komiyama and Poungparn 2008), however in this study less than half of the sampled plots had trees exceeding 6 m in height. DBHs in this study ranged from 3.2 to 20.7 cm while those reported for *A. marina* in Patil et al. (2014) ranged from 35 to 50 cm in Australia, while in Thailand the maximum DBHs ranged from 45 to 49 cm and had a mean of to 35.5 cm in Indonesia.

Mangroves in the above countries appear to be more productive under more favourable conditions than those found in the Arabian Peninsula. For example, in Indonesia, some areas can receive an annual precipitation of 3250 mm (Komiyama et al. 2005), while in Sri Lanka, the annual precipitation ranges from 1000-1100 mm, both of which are significantly higher than in Oman (100-150 mm) (Al-Shukaili, 2011).

Despite the apparently unfavourable environmental conditions in Oman, significant stands of mangroves were still able to survive at the study site. However, it has been argued that this results in patchy habitats with low canopy mangroves (Kuenzer et al. 2011), as I also observed. The study in the UAE by Schile et al. (2017) used similar methodology to this study (only included trees with >3 cm DBH at H of 1.3 m), but they did not report the full range of H and DBH in their study so direct comparisons are difficult.

5.4.1.2. AGB estimates and carbon stock in *Avicennia marina*

Worldwide, it has been suggested that mangrove biomass ranges from 300 to 1000 t/ha (Grimsditch et al. 2013). In this study, the estimates of AGB dropped below the range in other parts of the world, despite the fact that the study dealt with a mature forest. This was not unexpected, given the apparently unfavourable environmental conditions in Oman. Harsh climatic conditions are likely to limit the growth of mangroves and therefore the AGB (Kirui 2006, Marshall et al. 2012, Schile et al. 2017). Also, Schile et al. (2017) argue that the extreme temperatures, limited rainfall and high salinity in the Arabian Peninsula push mangroves to their tolerance limits. Furthermore, it has been found that AGB is inversely related to latitude (Komiyama and Poungparn 2008, Yee 2010, Kuenzer et al. 2011, Alongi and Mukhopadhyay 2015), so that it might be expected that Omani mangroves will have less biomass than their close to equator equivalents. Beside climate and latitude, variability in other environmental conditions including soil characteristics, the age of the forests and geology could significantly influence the primary production of these ecosystems and therefore reduce the amount of sequestered carbon (Kirui 2006, Marshall et al. 2012, Schile et al. 2017).

In the present study, the Kirui (2006) and the Chave et al. (2005) equations gave a mean AGB value falling below 300 t/ha (Table 5.6). Some AGB estimates for *A. marina* reported in Patil et al. (2014) exceed those reported here. For example, Dharmawan and Siregar (2008) recorded AGBs in Indonesia were more than twice the values reported for Al-Qurum (Table 5.6). The estimates of a fringe forest by Amarasinghe and Balasubramaniam (1992) for AGB in Sri Lanka were found comparable to the ones reported here (Table 5.6). Likewise, a primary forest of *A. marina* in Australia (Table 5.6) had ABG estimates similar to the estimates of this study (Briggs 1977, Komiyama et al. 2005).

Table 5.6. Comparison of *A. marina* ABG (t/ha) recorded in this study with those in other parts of the world. *Numbers in brackets indicate standard errors.*

Equation used	**This study AGB (t/ha)**	**Other reported AGB (t/ha)**	**Country**	**Reported in**
Kirui (2006)	157.11(20.04)	364.90	Indonesia	Dharmawan and Siregar (2008)
		193	Sri Lanka	Amarasinghe and Balasubramaniam (1992)
Chave et al. (2005)	86.34 (17.71), (ρ= 0.52)	144	Australia	Briggs 1977 and Komiyama et al. 2005
	120.55 (24.74), (ρ= 0.732)	243.6 (26.9)	UAE	Schile et al. (2017)
		144.8 (181.1)		
	106.92 (21.92), (ρ= 0.64775)	180.5 (34.8)		
		97.9 (20.2)		

In the study of Schile et al. (2017), the AGB estimates of *A. marina* forests in 4 sites (Table 5.6) in the Gulf of Oman were within the range of estimates reported in my study. Although Schile et al. (2017) did not state the condition of their sites, or whether they are conserved, degraded or used by the publics, the sites are all natural and mature forests such as Al-Qurum. The estimates of this study resulting from the Kirui (2006) and Chave et al. (2005) equations are therefore considered comparable to the study of Schile et al. (2017).

The use of different sampling methods can also influence estimates of carbon stocks in mangroves, even producing different estimates for the same species (Komiyama and Poungparn 2008, Marshall et al. 2012). Others argue that the allometric equations developed in previous studies are both site- and species-specific (Komiyama and Poungparn 2008). The sampling design and procedure in this study was similar to the one used by Schile et al. (2017) for UAE mangroves. Although they used a different allometric equation obtained from Clough et al. (1997), it was also developed for multi-stemmed mangroves such as *A. marina.* Therefore, the results of Schile et al. (2017) could be used to defend and validate the results obtained here using Kirui (2006) allometric equation which was developed for *A. marina* specifically.

Komiyami et al. (2008) argued that the formulation of equations is more species-specific than site-specific, giving more weight to the use of the Kirui (2006) equation in this study, rather than the Chave et al. (2005) pantropical equation. Further, the use of DBH only to estimate AGB is suggested to provide valid estimates of the amount of stored carbon without the necessity to include height, as reported by Clough and Scott (1989, in Kirui et al. 2006). In the present study, the equation designed by Kirui (2006) for *A. marina*, in which only the DBH has been used, provided results comparable to the Schile et al. (2017) UAE study. In this study, the Chave et al. (2005) equation comprising both H and DBH was also applied. I found a significant correlation between H and mean DBH, although it was quite variable (r-squared only 0.40), implying that using DBH on its own may be relatively imprecise. I therefore used the Chave et al. equation to improve the reliability of my estimates. Chave et al. (2005) support the use of both H and DBH, which are suggested to improve the estimates of AGB along with WSG values. Although the study here does not use a WGS specifically for Middle Eastern *A. marina*, the use of both H and DBH is suggested to improve the estimates.

This relatively low productivity in Oman does not actually limit the capacity of mangroves to sequester carbon when compared to terrestrial ecosystems (Schile et al. 2017). Sediments will still build up and vertically accrete, allowing mangroves to store unlimited amounts of carbon (Schile et al. 2017).

5.4.2. Defensive role of mangroves against winds, waves and storminess

Commonly, vegetation is likely to reduce the wind speed (Youssef et al. 2012, Das and Crépin 2013), with seaward mangroves being the most effective (Das and Crépin 2013). The windrose data for Muscat revealed that the prevailing wind in the capital was mainly in two directions, north-east and (much less) south-west. The north-east mangrove belt (C, Figure 5.15) was only 32.5 m wide and located behind a residential area. It would therefore only be expected to reduce winds confronting the western part of the reserve. The south-western belt was much wider (400 m) and should therefore provide more protection from wind for the eastern part of the reserve and the residential area located behind it (Das and Crépin 2013).

At the seafront, mangroves intercept wind-driven wave energy, where wide belts of mangroves are expected to reduce the speed of the waves (Kathiresan and Rajendran 2005, Alongi, 2008). It has been argued by Alongi (2008) that a mangrove belt should be a minimum of 100 m in width to provide significant protection against wave energy, reducing it by 13 to 60% depending on the density of the vegetation (Duke et al. 2014), and to be highly efficient in defence compared to hard infrastructure (Herr and Landis 2016). According to the Muscat windrose, the seafront mangrove belts in this study were not facing the prevailing wind and therefore were less exposed to wave energy. However, in events like storms (such as cyclones) and tsunamis, mangroves are commonly expected to reduce the energy of waves and consequently reduce the threat to human lives from associated major flooding (Kathiresan and Rajendran 2005).

The area of mangroves at Al-Qurum in 2004 (3 years prior to Gonu) reached 74 ha (JICA and MECA, 2004), potentially enough to provide protection from storms, but the vegetation is fragmented (Figure 4.9), which likely affected its efficiency for storm defence (Raffaelli and White 2013). So when struck by Gonu, the seafront mangrove belts in this study appeared to provide protection for infrastructure utilities parallel to them. The main reported damage in the site was the breakdown of shoreline-parallel roads, utilities and a bridge (Fritz et al. 2010) where no mangroves existed. The storm surges and floods resulting from high precipitation, met at this point of destruction (Fritz et al. 2010) combined with the high wind intensity reaching 130 km/h (Al Najar and Salvekar 2010).

In other parts of the world, observations of the role of mangroves as storm buffers revealed that mangroves can serve to protect many features, not only utilities. For example, a study conducted at 18 sites in the Bay of Bengal following the 2004 Tsunami revealed that greater vegetative cover of mangroves saved more lives (Kathiresan and Rajendran 2005). The same study showed that where there was mangrove cover of 10 ha, 0-5 deaths were recorded, while sites with much less cover of 0.1-0.5 ha had 7-93 deaths recorded. Nevertheless these observations have been criticised for their small sample sizes and have led people to question the significance of the storm buffering service of mangroves, as argued by Wells and Ravilious (2006). Also, Alongi (2008) argues that the significance of mangroves as a storm buffer has not been empirically tested and that arguments for this role are based on circumstantial observations, However, he did concede that mathematical modelling has indicated that mangroves can diminish wave energy, such as the hydraulic experiment conducted by Harada et al. (2002) which revealed that mangroves are effective at reducing both the speed and height of waves.

The efficiency of mangroves to perform as a storm buffer is not simply due to area. Ward et al (2016) point out that location of mangrove forests, storm direction, wind intensity and the tidal range of the ecosystem, particularly in regions of meso- and macro-tides, are all important variables. The efficiency of defense also depends on soil texture and the presence of adjacent habitats such as seagrass and corals (Alongi 2008).

Different mangrove species are also thought to vary in their effectiveness as storm buffers. Kathiresan and Rajendran (2005) claim that *Rhizophora* is more effective in mitigating the speed and height of storm waves than *Avicennia* found exclusively in northern Oman in general and at Al-Qurum in particular. Mathematical modelling has shown that 150 m of *Rhizophora* forests can diminish the wave energy by 50% (Alongi 2008). It has been suggested that *Rhizophora* which is supported by its stilt roots is better able to defend coasts than *Avicennia* which is commonly characterized by pneumatophores that are less tolerant to intense waves and long inundation duration (Kathiresan and Rajendran 2005). In spite of their greater inundation tolerance, 30 to 80% of *Rhizophora* died in the Andaman Islands after the 2004 tsunami due to prolonged inundation (Alongi 2008). *Avicennia spp* can recover from storm disturbances by developing new shoots from epicormic buds (Alongi 2008, Ward et al. 2016).

5.5. Conclusion

Although mangroves in this study are all of the same species and occupy a single site, there might be a significant difference in their characteristics, even between individual trees and on a small spatial scale (Lovelock et al. 2015). Despite this variation, the designation of the site as a nature reserve is likely contributing significantly to improving the level of services provided by the site (MA 2005, Crooks et al. 2014) including carbon sequestration and storm buffering.

Although the carbon stock at this study site was much less than in mangrove forests in other parts of the world, this does not undervalue mangroves as the richest natural carbon sink (refer to Figure 5.1). Management and conservation plans contribute to protect these mangrove ecosystems from degradation, which could otherwise lead to oxidation of sediment carbon and release of carbon to the atmosphere (Grimsditch et al. 2013). Further, it has been suggested that conservation is an effective nature-based solution for climate change mitigation (Herr and Landis, 2016, Schile et al. 2017). The conservation of mangroves as a blue carbon sink does not only contribute effectively to the achievement of carbon offset goals, but it also contributes to the health of the ecosystem and the ecosystem services it provides (Thomas 2014), as elaborated in chapters 4 and 6.

Due to being an efficient carbon sink, the efforts of conservation, reforestation and afforestation are considered contributors to carbon markets (Yee 2010, Alongi 2011, Crooks et al. 2011, Mcleod et al. 2011). To increase the capacity of projects aiming to offset carbon, real commitments and practically enforced laws should be applied without compromising the right of livelihoods to utilise the natural resources in a sustainable manner (Yee 2010).

With respect to storm buffering services, mangroves in this study had a limited role in defending Al-Qurum against storminess, due to the absence of a continuous wide belt at the sea front, however this is not the single threat facing mangroves during these events. Flooding is another threat, due to high precipitation and mangroves at the eastern and western sides of the reserve can provide some protection for the residential areas behind them. The designation of the area as a nature reserve was suggested to increase the capacity of mangroves to recover from cyclones and recover spatial extent, as shown in Chapter 2.

Chapter 6

Cultural services in Qurayyat: assessing and mapping the local experience

6.1. Introduction

Nature supports human well-being on this planet through the material and non-material commodities and benefits it provides. One such non-material benefit is cultural ecosystem services (CES) (MA 2005, Raffaelli and White, 2013).

One of the earliest definitions of CES was given by Costanza et al. (1997), who introduced them, as the "*aesthetic, artistic, educational, spiritual and/or scientific values of ecosystems*" (Chan et al. 2011, p.1), whilst the MA (2005, p.40) defines CES as *"the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences"*. These definitions reflect the significant influence of nature on knowledge acquired by humans, beliefs, culture and social relations (MA 2005, Chan 2016). Current scholars frequently use the definition of Chan et al (2012, p.9), in which CES are stated as *"ecosystems' contributions to the non-material benefits (e.g., capabilities and experiences) that arise from human–ecosystem relationships"*.

Although many have attempted to study the cultural benefits that communities can acquire from nature, very few have categorised these benefits (Chan and Satterfield 2016). Chan et al. (2016) categorise the values of nature into instrumental, intrinsic and relational values. Instrumental values reflect the pleasure and satisfaction acquired by humans when engaged with nature, while intrinsic values underline the value of nature independently of human appreciation (Chan et al. 2016). Relational values are a newly emerging class which collectively comprises the cultural identity of the place, social relationships between humans, their social responsibilities towards each other and moral-based responsibilities towards other non-human components of a place. It has been argued that cultural ecosystem services are '*inherently relational* 'and *'poorly instrumental'* (Chan et al. 2016, p.3).

Ecosystem services are becoming used by both researchers and policy makers to identify and implement the management plans for a natural site (Martín-López et al.2012). The services provided by nature in meeting human needs play an important role in the decision-making and management plans (Bryan et al. 2012, Chan et al. 2012, Plieninger et al. 2013). It has been argued that the cultural values that humans acquire from nature were not considered in decision-making until the MA (2005) focused on their significant contribution to human wellbeing (Peh et al. 2013, Merriman and Despot-Belmonte 2016).

Although some scholars find cultural ecosystem services intangible compared to provisioning and regulating services (Sattarfield et al. 2012, Plieninger et al. 2013) and immeasurable in most cases (Chan et al. 2016), they are undeniably valuable to humans (Chan et al. 2012, Chan et al. 2016) and hard to capture in monetary terms (Hernández-Morcillo et al. 2013, Plieninger et al. 2013). Some communities have become less dependent on provisioning and regulating services for their wellbeing and the demand for cultural services has correspondingly increased to support their economy (Plieninger et al. 2013) so that these services should be considered in management and conservation plans (Chan et al. 2011).

The cultural values of ecosystems can be captured through people's preferences, perceptions, experience, norms and beliefs towards nature through perception studies (questionnaires and interviews) (Watson et al. 2011, Martín-López et al. 2012, Hernández-Morcillo et al.2013, Plieninger et al. 2013, Brown and Fagerholm 2015), as well as by spatial participatory mapping (Watson et al. 2011, Plieninger et al. 2013). Perception studies mostly reflect the preferences of individuals, while mapping can be used as a tool to spatially quantify and localize the services provided for an entire community (Bryan et al. 2010, Rayan 2011, Plieninger et al. 2013, Van Berkeland Verburg 2014, Brown and Fagerholm 2015) and can be used to implement management plans (Bryan et al. 2010, Brown and Fagerholm 2015).

Mapping of human-nature spatial relationships assists in understanding CES contributions to human wellbeing (Brown and Fagerholm 2015). The UK National Ecosystem Assessment (UKNEA) found that mapping is also a useful tool for observing temporal changes in CES across space (Watson et al. 2011). The cartographic representation of CES using stakeholders' perception improves the comparison between the different services obtained from an ecosystem and facilitates management and the discussion of trade-offs (Plieninger et al. 2013). Public Participation GIS (PPGIS) and Participatory GIS (PGIS) are popular, newly emerging methods for engaging publics, exploring their perceptions (Cinderby et al. 2011, Cinderby et al. 2012, Rich et al. 2015) and capturing CES (Brown and Fagerholm 2015). These methods were defined by

Brown and Fagerholm (2015, p.3) as *"spatially explicit methods and technologies for capturing and using spatial information in participatory planning processes"*. The general term of participatory mapping is used when individuals play a role in making a map using their qualitative and geographic information (Brown and Fagerholm 2015). PPGIS and PGIS provide opportunities to explore the allocation of ecosystem services at a spatial scale (Cinderby et al. 2012) and are expected to lead to better formations of policies and decision-making (Forrester et al. 2015) to manage ecosystems and their resources.

Some toolkits have also been used as participatory tools in understanding CES, such as the Toolkit for Ecosystem Services Site-based Assessment (TESSA) (Peh et al. 2013, Ivory 2014, Merriman and Despot-Belmonte 2016), and this has influenced the design of the present study. TESSA is designed to facilitate the identification of ecosystem services by using accessible and easy to use methods for stakeholders participating in a study (Peh et al. 2013, Merriman and Despot-Belmonte 2016). TESSA is also based on collecting primary data *in situ* using, for example, questionnaires and interviews and visual illustrations such as pictures and drawings (Peh et al. 2013, Ivory 2014). TESSA uses the knowledge of local people to define the main stakeholders benefiting from the ecosystem (Peh et al 2013, Merriman and Despot-Belmonte 2016). It is advantageous in its low cost participatory approach which can be easily applied by non-experts (Peh et al 2013, Merriman and Despot-Belmonte 2016) and its application can help to understand spatial human-nature relations for more effective land-use planning (Peh et al 2013, Merriman and Despot-Belmonte 2016).

It has been argued that management plans which are underpinned by ecosystem services often lack attention to ecosystem disservices (Lyytimäki and Sipilä 2009, Shackleton et al. 2016). Ecosystem disservices have been simply defined by Shackleton et al. (2016) as "*the threats and unpleasant and unwanted impacts formed by or within an ecosystem and negatively impact the human wellbeing*". Shackleton et al. (2016) claim that the MA has overlooked ecosystem disservices and the publications on disservices are much fewer than those for services.

Despite the significant increase of publications on CES, particularly after the MA (Hernández-Morcillo et al. 2013), the material benefits of nature have remained the central focus of most studies (Martín-López et al.2012) and even where the importance of non-material benefits of nature and their importance in well-being improvement have been highlighted, few studies have attempted the assessment of these benefits due to methodological challenges (Plieninger et al. 2013). Most studies have emphasised the importance of cultural ecosystem services using a monetary approach (Martín-López et al.2012, Hernández-Morcillo et al.2013, Plieninger et al. 2013), mainly for recreation and tourism, because the latter are relatively easy to identify, classify and assess compared to other services linked to knowledge, appreciation and behaviours (Hernández-Morcillo et al. 2013). In fact, only 38 indicators relate to CES out of a total of 344 indicators designed by the MA for ecosystem services overall (Hernández-Morcillo et al. 2013).

In the Middle East in general, and in Oman in particular, CES have been poorly researched (Van Bochove et al. 2014). A few publications exist in Arabic discussing the human-nature relationship from a religious perspective, without incorporating the science related to the ecosystem services approach, and nothing has been published on non-material services of mangrove ecosystems. The study of JICA and MECA (2004), which is the main Omani reference for the present study, overlooked the CES of mangroves in Oman. This chapter extends a previous study of people perceptions towards ecosystem services provided by Omani mangroves (Chapter 3), which showed more linkages between cultural services and the wellbeing of locals in Qurayyat, consistent with the argument of the MA (2005) that this linkage is region-specific. In this chapter I aim to assess a wider range of CES provided by the mangrove ecosystem at Qurayyat and perform participatory mapping of the services as well as disservices associated with that place. A survey was conducted to elicit in-depth views of locals regarding the cultural ecosystem services provided by this ecosystem (Appendix 6.1).

The study has the following objectives:

a. to better understand the CES provided by Qurayyat mangroves.

b. to elicit the individual preferences for landscape attributes in mangroves in relation to CES.

c. to examine the cultural disservices provided by mangroves.

d. to elicit individual views on current and potential future site management.

e. to evaluate the utility of emerging frameworks for understanding cultural services, such as those of Chan et al. (2016), in the Omani context.

6.2. Methodology

The study was conducted in Qurayyat, part of Muscat zone (23°16'29.62"N, 58°55'11.91"E). Fishing and agriculture were once the main source of income for locals in Qurayyat, but nowadays many people are supported by jobs in both government and private sectors (JICA and MECA 2004).

The study followed a participatory approach, which involved interviewing locals, eliciting views, preferences and observations (Gilbert 2008). The study also used participatory mapping to assess cultural ecosystem services as perceived by locals. The survey was based on the studies of Plieninger et al. (212), Chan et al. (2011, 2012a, 2012b), Rajmis et al. (2009) and the TESSA toolkit applied by Ivory (2014) and Merriman and Despot-Belmonte (2016). The survey design was also informed by a project within the BESS programme in the UK by Wessex-BESS consortium, available online at (http://www.ppgis.manchester.ac.uk/bess/). The questions of the latter survey were modified for the Omani context and aimed at people visiting mangroves at Qurayyat. The categories of cultural benefits examined in this survey were: material, aesthetic, place/heritage, activities, religious, inspirational, knowledge, social relationships, identity, employment.

The survey was relatively short with more open-ended questions. Although open-ended questions might result in ambiguous responses which cost time in analysis (Gilbert 2008), they do not restrict answers given by respondents and can often provide more information (Gilbert 2008).

Respondents were mainly asked how frequently they visit the site and to identify the type of activities they once practiced or still practice at the site from a list provided. Participatory mapping was used to as a tool to localise those activities. Respondents were also provided with a list to identify their motivations for visiting the site.

To elicit the individual preferences for landscape attributes in mangroves in relation to CES, photographs were also used as a tool in this study. Seven different landscape images, including mangroves, were captured by the researcher and used to elicit preferences of respondents for different landscapes (Figure 6.1). Bryman (2015) has referred to the use of photography in qualitative research as *"photo-elicitation"*, providing a visual aid to stimulate the engagement of respondents (Bryman 2015). Also, photographs are a supportive tools for remembering places, people and events (Bryman 2015). To meet the objective, participatory mapping was used again to highlight individual preferences for landscape attributes, as well as any disservices provided by the sites.

To examine the cultural disservices of mangroves, respondents were asked to localise on a map their disliked spots and provide reasons for such choices.

To elicit individual perceptions of site management, respondents were asked of their awareness of the manager of the site and what they thought of the plan of Ministry of Regional Municipality and Water resource (MRMWR) to build a dam at the route of fresh water supply to mangroves.

Al-Sahil, sandy coast in a residential and historical site.

Hawiyat Najm, a small lake occupying deep depression.

Hail Al-Ghaf, an oasis surrounded by mountains with green fields.

Dhabab, coastal area with sandy and rocky beaches.

Wadi Dyqa, the largest surface water reservoir in Oman.

Mangroves, study site.

Al-Khawbar, sand dunes with lagoon comprising

Figure 6.1. Different landscapes in Qurayyat including mangroves, the study site. Photos by author.

grass, shrubs and trees.

A small selection of local residents was approached to ask about their willingness to participate in the study. To participate in the study, the respondent chosen had to have visited the ecosystem at some time in the past, irrespective of when or how often. The initial respondents were then asked to propose someone else who would fulfil these characteristics (snowball sampling) (Gilbert 2008, Bryman 2015). Although this type of sampling is mainly used for minor groups (Gilbert 2008) which are not easily accessible (Bryman 2015), it was more culturally suitable for me as a female researcher conducting the study alone. Snowball sampling may also increase the chance of collecting more responses compared to approaching people at random. Also, this method is likely to be better for reaching the actual beneficiaries of CES, necessary to identify, map and localise the services for better policy implementation, as suggested by Brown and Fagerholm (2015). Sampling was stopped when it became very difficult to find more people willing to participate and / or no more visitors to the site could be found. This provided a total of 34 respondents.

Data were collected by conducting face-to-face semi-structured interviews on site or at respondents' homes, depending on respondent preference. This approach is the most commonly used for qualitative interviews (Arksey and Knight 1999, Barbour 2013). The data were collected between 31st January 2017 and 3rd April, 2017, during morning and afternoons, which are culturally the best times for visits and also avoids the hot Oman's summer. This method also provided a chance to capture the views of elderly and / or illiterate people who were excluded in the self-administered questionnaire described in Chapter 3. The respondents were informed of the purpose of the study and the confidentiality of the information they gave. They were also familiarised with the map before mapping-based questions were asked.

This type of qualitative interview focused on respondent views, perspectives, feelings and behaviours which were the main interest of the research and thus I obtained responses rich in detail (Arksey and Knight 1999, Barbour 2013, Bryman 2015). The decentralised format of the interviews allowed the exchange of knowledge between the researcher and the respondents, gave more freedom for the respondents to reveal their understandings and provided the researcher with a chance to clarify any ambiguous responses (Arksey and Knight 1999).

The interviews were recorded digitally and later transcribed. Recording supports in-depth analysis of the data. Bryman (2015, p.479) points out that audio recorded interviews help in fulfilling researcher interests in both 'what people say' and 'the way they say it'. The data were then coded and analysed using Microsoft Excel and SPSS. Participatory mapping was done using the Arcmap tool in ArcGIS. Full transcription of data was time-consuming, but it ensured the intact responses of respondents (Bryman 2015). Where answers to open questions were given, these were in Arabic. To report some of these here in the Results section, I have translated them into English to the best of my ability and the reader should be aware that there may be minor inaccuracies in translation; However, I do believe that the sense of the statements has not been altered or compromised.The interview and approach were approved by the University of York's Environment and Geography Ethics Committee prior to its implementation in the field.

6.3. Results

6.3.1. Socio-economic characteristics of respondents

In total, the interviews comprised 34 respondents, none of whom particpated in the questionnaire in chapter 3, with a slight gender bias of 18 males (52.9%) compared to 16 females (47.1%) (Table 6.1). Respondents mainly belonged to the age groups 31-40 years (29.4%) and 51-60 years (26.5%) (Table 6.1). The majority had received a high school level education (47.1%), while 32.4% received above school level education (Diploma, College and University level) and 20.6% were illiterate (Table 6.1).

A significant proportion (35.3%) of respondents were not currently employed and were mainly housewives (Table 6.1). Government sector was the most common employment of respondents (32.4%), with far fewer working in private firms (2.9%) (Table 6.1). A reasonable percentage of respondents, all males, were running their own businesses (14.7%) (Table 6.1). A small proportion (5.9%) of respondents stated fishing as their main profession, while 8.8% were retired (Table 6.1). The percentage 'no occupation' represents non-working housewives and job seekers.

Table 6.1. The socio-economic characteristics of respondents. The actual number of responses is shown in brackets.

Variable	**% (N)**
Gender	
Male	52.9 (18)
Female	47.1 (16)
Age	
18-20	0.0 (0)
20-30	11.8 (4)
31-40	29.4 (10)
41-50	17.6 (6)
51-60	26.5 (9)
61-70	11.8 (4)
>71	2.9 (1)
Level of education	
School level	47.1 (16)
Diploma	17.7 (6)
Higher Education	14.7 (5)
Illiterate	20.6 (7)
Occupation	
No occupation	35.3 (12)
Government sector	32.4 (11)
Private sector	2.9 (1)
Free business	14.7 (5)
Fishing	5.9 (2)
Retired	8.8 (3)
Prefer not to say	0.0 (0)

6.3.2. Frequency of visits

Most respondents were very high users of the site, visiting the mangrove area daily (more than 50%) within the last 12 months. 11.8% had not made a visit in the last 12 months (Figure 6.2).

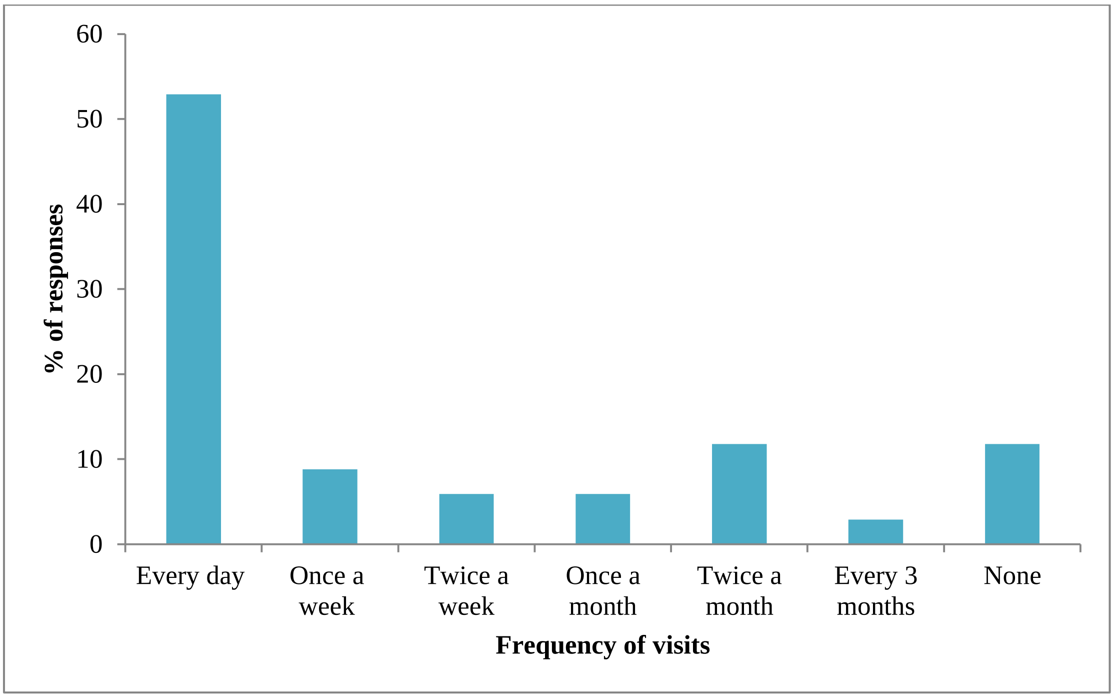


Figure 6.2. The frequency of visits to the mangrove area.

6.3.3. Identification, understanding and mapping of cultural services

The activities practiced by respondents were categorised into past (when respondents were much younger or children), present, and both past and present, for better understanding of the services provided by the mangroves over time. The practice of some activities was abandoned over time while some activities were not popular. For example, cycling was not practiced by 88.2% of the respondents and the rest had cycled only during their childhood. Horse riding and creative activities were not popular either as 14.7% and 5.9% only practice them at present (Table 6.2). Some activities were more popular in the past, during childhood or youth, such as swimming (67.6%), playing with children or friends (52.9%) and fishing (50%) (Table 6.2). At present, many respondents were involved in nature conservation and monitoring (70.6%), compared to far fewer in the past (5.9%) (Table 6.2).

Table 6.2. Activities practiced by respondents in mangrove area in different times. The highest percentage of each activity is underlined. The actual number of responses is shown in brackets.

Activity	**% non-practice (N)**	**% only past practice (N)**	**% only present practice (N)**	**% present and past practice (N)**
Wildlife watching	23.5 (8)	5.9 (2)	0.0 (0)	<u>70.6</u> (24)
Walking	2.9 (1)	14.7 (5)	2.9 (1)	<u>79.4</u> (27)
Cycling	<u>88.2</u> (30)	11.8 (40	0.0 (0)	0.0 (0)
Horse riding	<u>85.3</u> (29)	0.0 (0)	14.7 (5)	0.0 (0)
Fishing	35.3 (12)	<u>50.0</u> (17)	0.0 (0)	14.7 (5)
Swimming	23.5 (8)	<u>67.6</u> (23)	0.0 (0)	8.8 (3)
Nature conservation/ monitoring	11.8 (4)	5.9 (2)	<u>70.6</u> (24)	11.8 (4)
Teaching/ informing people about the area	<u>55.9</u> (19)	0.0 (0)	44.1 (15)	0.0 (0)
Playing (with children, with friends)	23.5 (8)	<u>52.9</u> (18)	0.0 (0)	23.5 (8)
Running	<u>55.9</u> (19)	32.4 (11)	2.9 (1)	8.8 (3)
Spiritual/ faith based activities	14.7 (5)	17.6 (6)	11.8 (4)	<u>55.9</u> (19)
Playing ball sports	44.1 (15)	<u>47.1</u> (16)	0.0 (0)	8.8 (3)
Creative activities (e.g. painting, photography, sculpture, filming)	<u>67.6</u> (23)	14.7 (5)	5.9 (2)	11.8 (4)

Whilst some activities were abandoned over time, many activities remain highly practiced, such as walking (79.4%), wildlife watching (70.6%) and spiritual/faith-based activities (55.9%). On the paper map provided, respondents marked the points of practice for each of these the activities.

There were two main walking routes followed by respondents which were the shoreline and the paved area sandwiched between houses and mangroves (Figure 6.3).

Figure 6.3. The walking routes followed by respondents in the mangrove area. The area towards the top right is the shoreline. The two other main walking routes are paved areas.

The main wildlife watching spots were located on the walking path of respondents with a higher density at the northern part of the site (Figure 6.4).

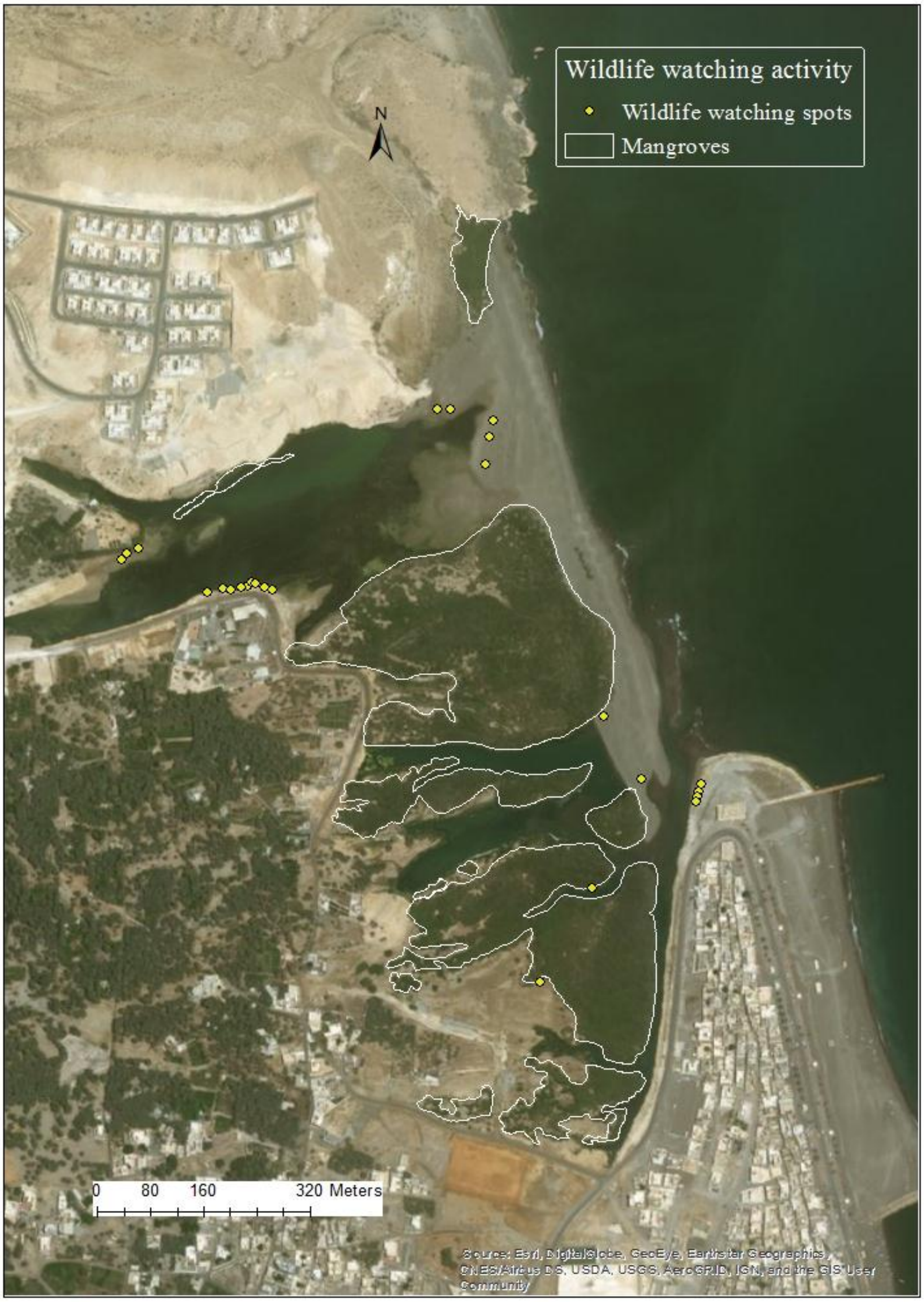


Figure 6.4. The wildlife watching spots by respondents in mangrove area.

The spiritual and faith-based activities were also highly practiced at the northern part of the area (Figure 6.5).

Figure 6.5. The spots of spiritual and faith-based activities in mangrove area.

With respect to gender, wildlife watching, walking and spiritual/faith-based activities were still at the top of the list of past and present practices for both males and females. However, some activities such as horse riding were exclusively male (Figure 6.6), while cycling, fishing, swimming and running were either not practiced by females or the practice was restricted to their childhood (Figure 6.7).

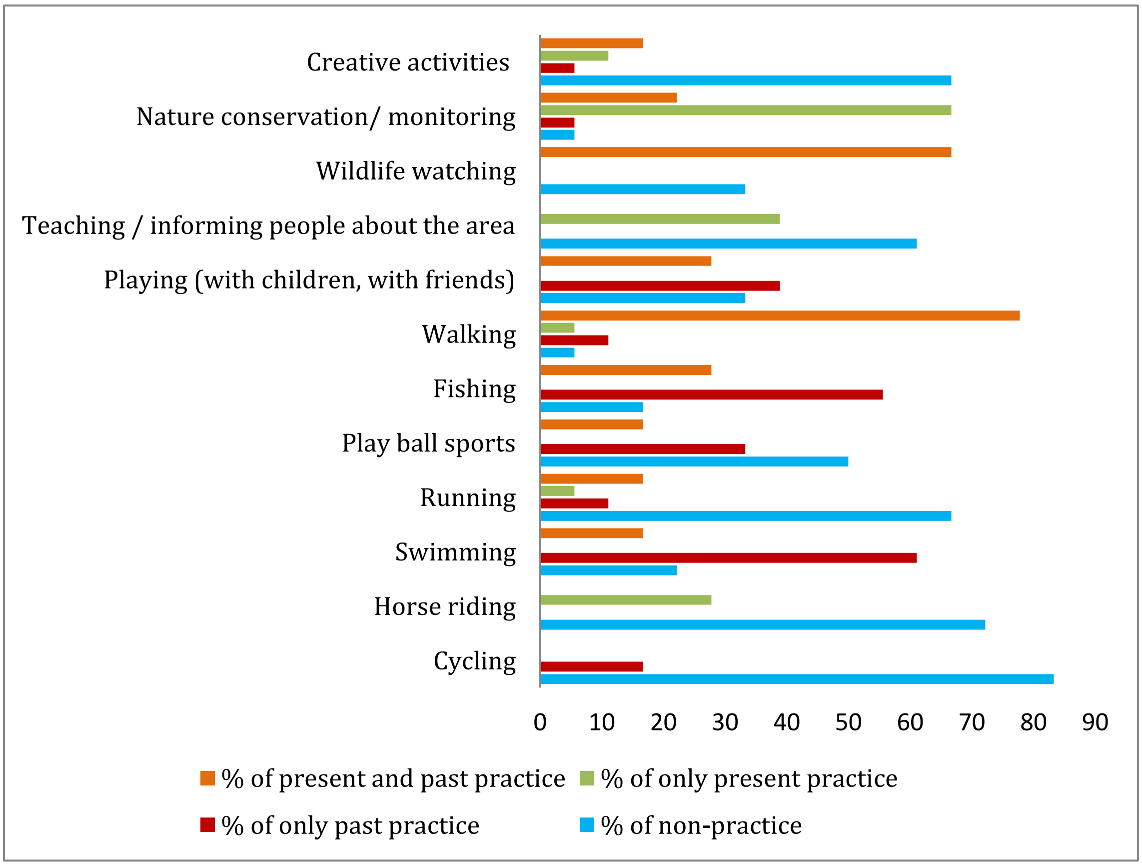


Figure 6.6. Activities practiced by males in the mangrove area.

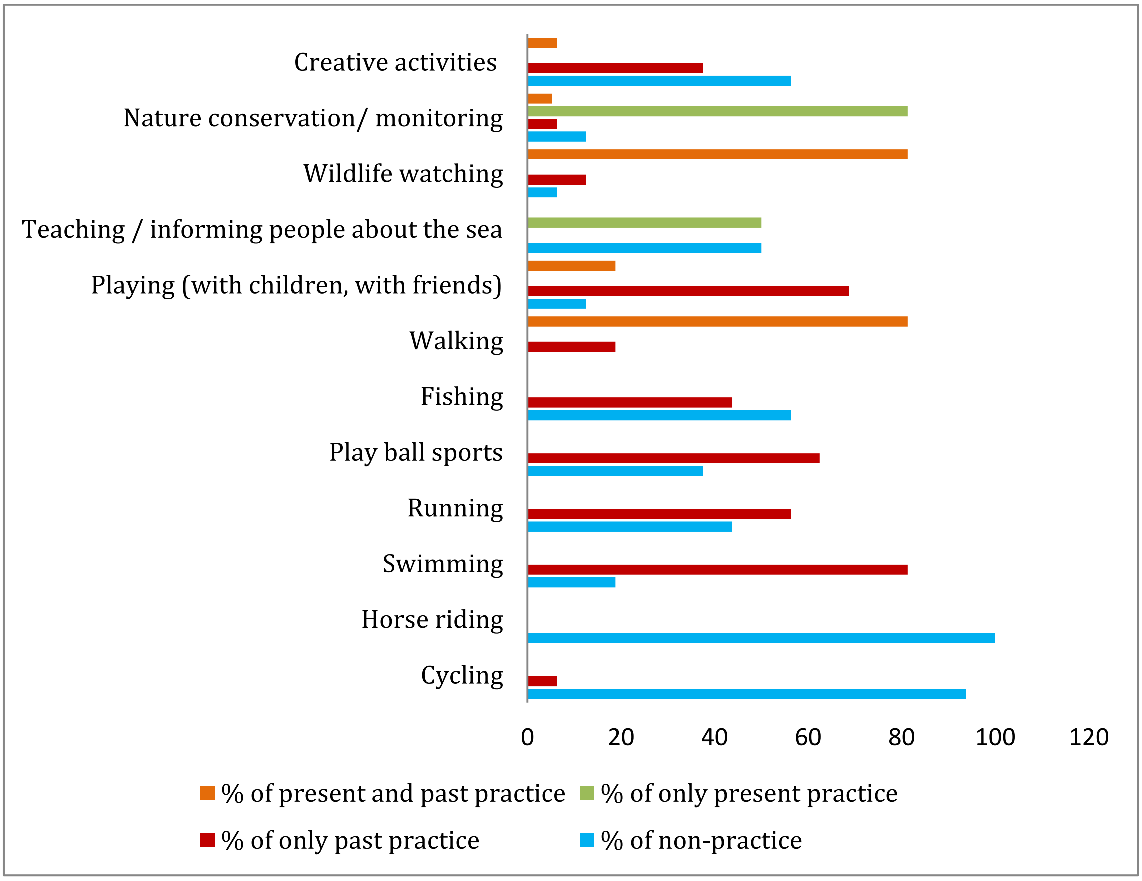


Figure 6.7. Activities practiced by females in the mangrove area.

Although the function of mangroves as fisheries nurseries was greatly emphasised by respondents in Qurayyat in an earlier study (chapter 3), fishing was not the top activity practiced by respondents in the mangrove area of this study. For example, 50% of respondents listed fishing as a past practice, and only 14.7% still fish (Table 6.2). The main past and present fishing zones in the area are marked below (Figure 6.8).

Figure 6.8. Main fishing zones in the mangrove area.

Some respondents also suggested that the mangroves are not as healthy as in the past and that some types of fish have disappeared. For example, it was stated there has been a marked decline in the catch of shrimps and crabs and of conical molluscs (*Cono cono*) which have completely disappeared. One elderly man stated: "*I used to fish crabs, blue crabs and a type of snail called Cono cono, which live on mud".* Another elderly man also stated: "*Mangroves, dense mangroves, we used to walk inside them, and catch shrimps and crabs, since we were little kids. The government employment opportunities at that time were very scarce, so when we do not fish in the sea, we head to estuaries for crabs. There were also shrimps in mangroves, lots of shrimps especially after wadis* *flow. These mangroves were existing here long time back even before the days of grandfathers of our grandfathers".* Another elderly man stated: "*I used to fish in the estuary, with nets or with fishing rods".*

Girls also used to fish in the estuary. One young lady stated: "*We used to use our scarves for fishing, so I hold the scarf from one end and my friend will hold it on the other end, then we drop it in water and then lift it after sometime, we used to get shrimps and sometimes crabs and sometimes we used to use fishing rods".*

When the activities above are merged into a single map it reveals that there are common spots where respondents practice these activities (Figure 6.9). For example, the main spots for wildlife watching and spiritual/faith based activities are commonly walking routes for respondents. The fishing zones are also adjacent to some spots of the other activities.

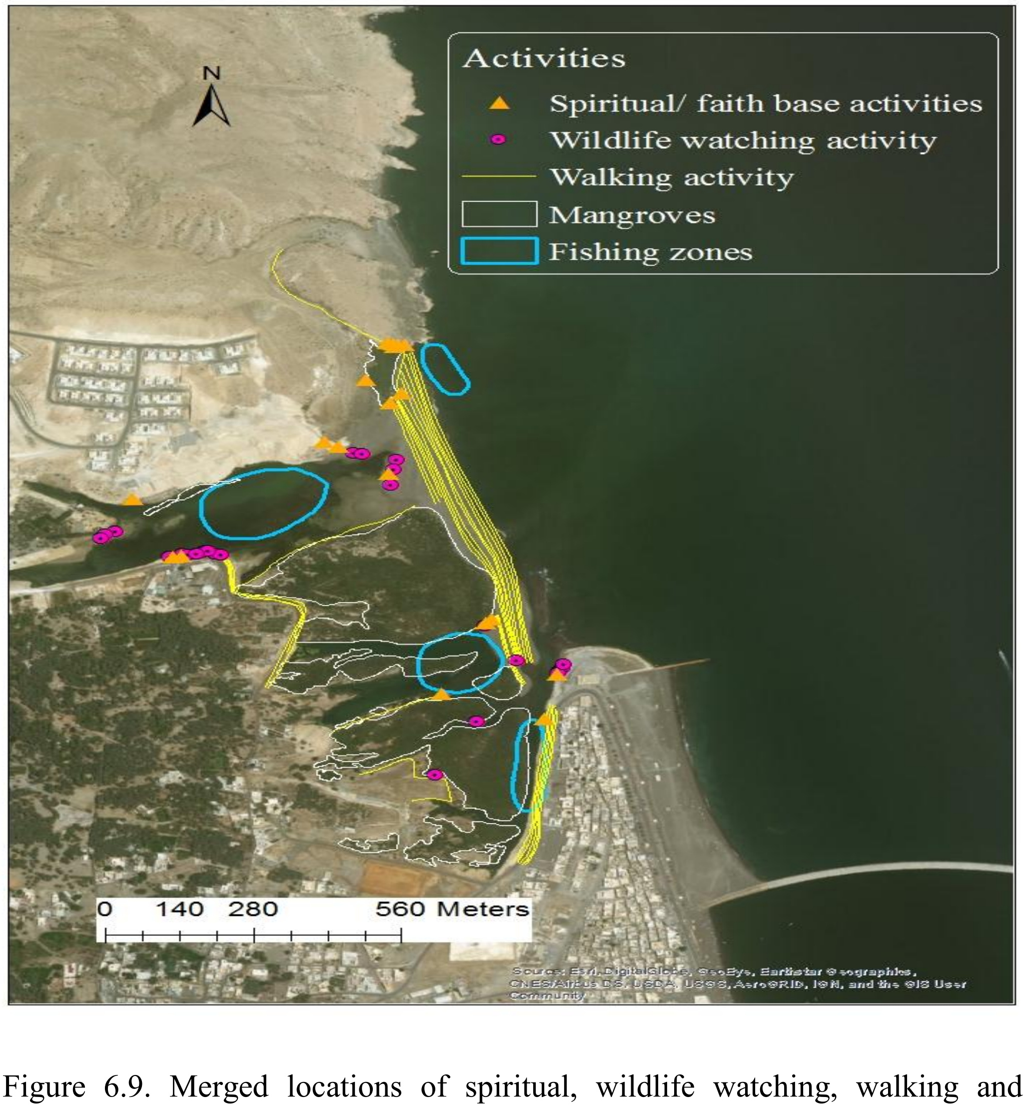


Figure 6.9. Merged locations of spiritual, wildlife watching, walking and fishing activities.

Respondents' visits to the area were mainly driven by the need "to experience the beauty of nature" (49.1%), while the practices of family business like fishing and boat making were the least common reason to visit the area (35.3%). Also, a small percentage (5.9%) mentioned other motivations like the safe nature of the environment (Figure 6.10). For example, regarding boat industry, one elderly man stated: *"Even sailors of Sur (coastal Omani town, southern Qurayyat known for being an ancient trade centre and still keeping ships industry), used to come to Qurayyat to get the timber supply to make ships".*

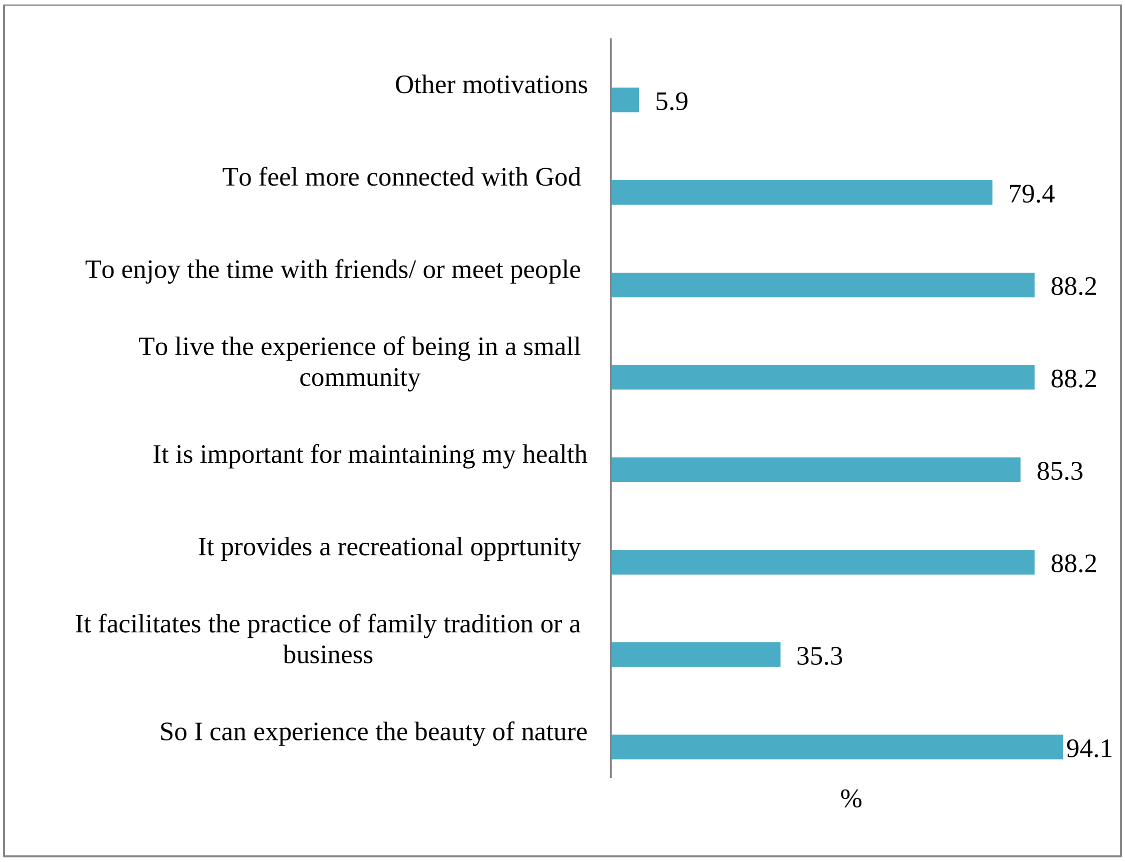


Figure 6.10. Motivations of respondents to visit the area.

6.3.4. Individual preferences for landscapes

In their preferences for different landscapes in Qurayyat (Figure 6.11), the majority of respondents ranked mangroves as the second preferred landscape in Qurayyat (32.4%), 29.4% ranking it as their first preferred landscape (Figure 6.11).

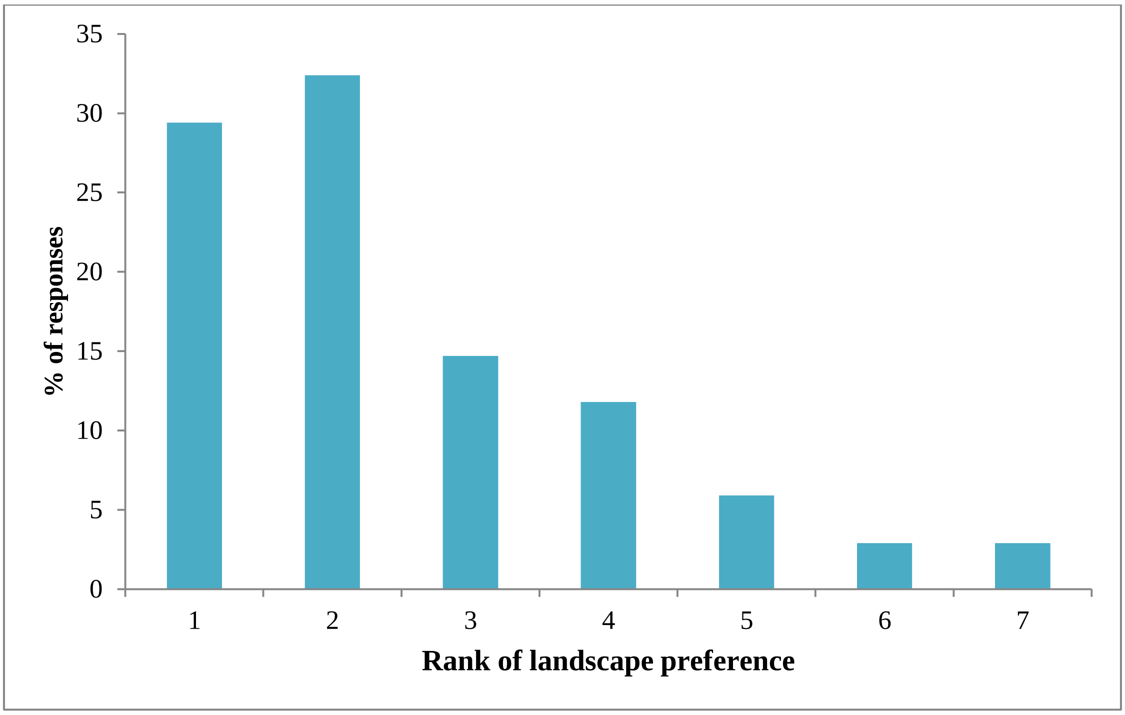


Figure 6.11. Mangrove landscape preference ranked by respondents.

Frequency analysis confirmed that the most frequent rank is for Al-Sahil and then mangroves (Table 6.3).

Table 6.3. Mode of responses of preferences of each landscape. In some cases (Hail Al-Ghaf and Wadi Dyqa) equal numbers of people ranked ecosystems differently.

Landscape	**Brief description**	**Mode**
Al-Sahil	Sandy coast in a residential and historical site.	1
Mangroves	Study site.	2
Dhabab	Coastal area with sandy and rocky beaches.	3
Al-Khawbar	Sand dunes with lagoon comprises grass, shrubs and trees.	4
Hail Al-Ghaf	Oasis surrounded by mountains with green fields.	3,4,5,6
Wadi Dyqa	The largest surface water reservoir in Oman.	4,6,7
Hawiyat Najm	Small lake occupying a deep depression.	7

Respondents were also asked to mark their favourite spots (Figure 6.12).

Figure 6.12. Respondents' favourite spots in mangroves.

Favoured spots were linked to childhood memories of respondents (68%) and more than half of the respondents (55.9%) loved the view of the spot overlooking the mangroves, coast and the wildlife, mainly birds (Figure 6.13). More than a third of the respondents favoured spots that allowed them to conduct activities such as walking (38.2%) and meditation (35.3%) (Figure 6.13).

One elderly lady stated: "*I love this spot. It reminds me of my childhood. I love mangroves since I was a kid. Mangroves have lovely views. They wanted to clear mangroves (referring to authorities), but we did not like the plan. They can take anything, we don't mind, but not mangroves. We rely on mangroves for living since we were kids*". Also, one elderly man stated: "*Mangroves have nice spots, this one has a wide and clear field of view, you can see birds, the mountain and the whole valley meeting the coast*". A young man also stated: "*Here, between mangroves and the mountain, you see lots of birds, you see ducks, flamingo, gulls and in winter, lots of migrating birds meet here*".

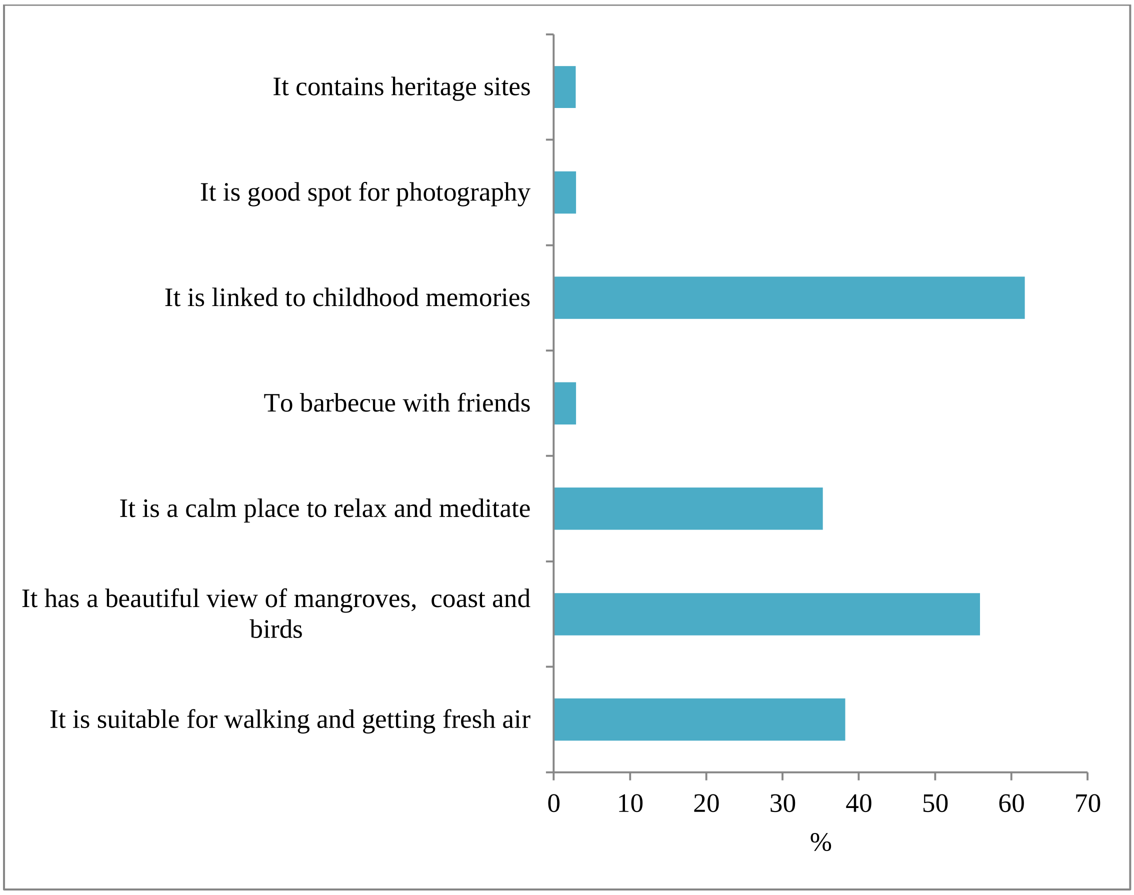


Figure 6.13. Attributes influencing the choice of favourite spots at mangroves.

When these different attributes were mapped (Figure 6.14), it is clear that respondents chose similar spots for different attributes. For example, a favourable spot for walking on the beach is also favoured due to its linkage to childhood memories, due to its beautiful view and also due to its calmness for relaxation and meditation.

Figure 6.14. The localisation of different favourites spots with different attributes.

Most of the respondents spent more than two hours on their last visit to their favourite spots in mangroves (41.2%), and 23.5% had a visit of 1-2 hours (Figure 6.15). 23.5% did not respond. One elderly man stated: *"Sometimes I spend 3 to 4 hours especially if I am chatting with friends, we sit under the shades, especially if weather is cool we could stay from moring to noon"*.

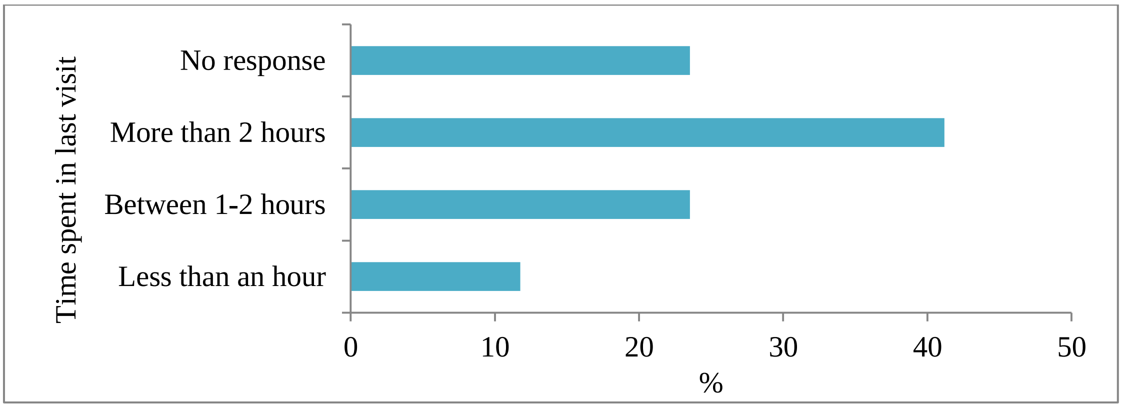


Figure 6.15. The time spent by respondents in their last visits to their favourite spots.

6.3.5. Disservices of mangroves

The respondents also marked some spots they did not like at the site, reflecting disservices. Disliked spots are scattered throughout the site, but mainly at the eastern side, the only permanent entry of seawater to the trees and the west-northern part where freshwater from wadis meets the sea (Figure 6.16).

Figure 6.16. Disliked spots indicated by respondents.

Less attributes where given by respondents for their disliked spots. The main perceived negative attribute at the site was the household and construction trash dump (20.6%). A similar percentage of respondents (8.8%) were upset about perceived eutrophication at the site, the blockage of tidal passage by heavy sedimentation and the decline in vegetative cover (Figure 6.17).

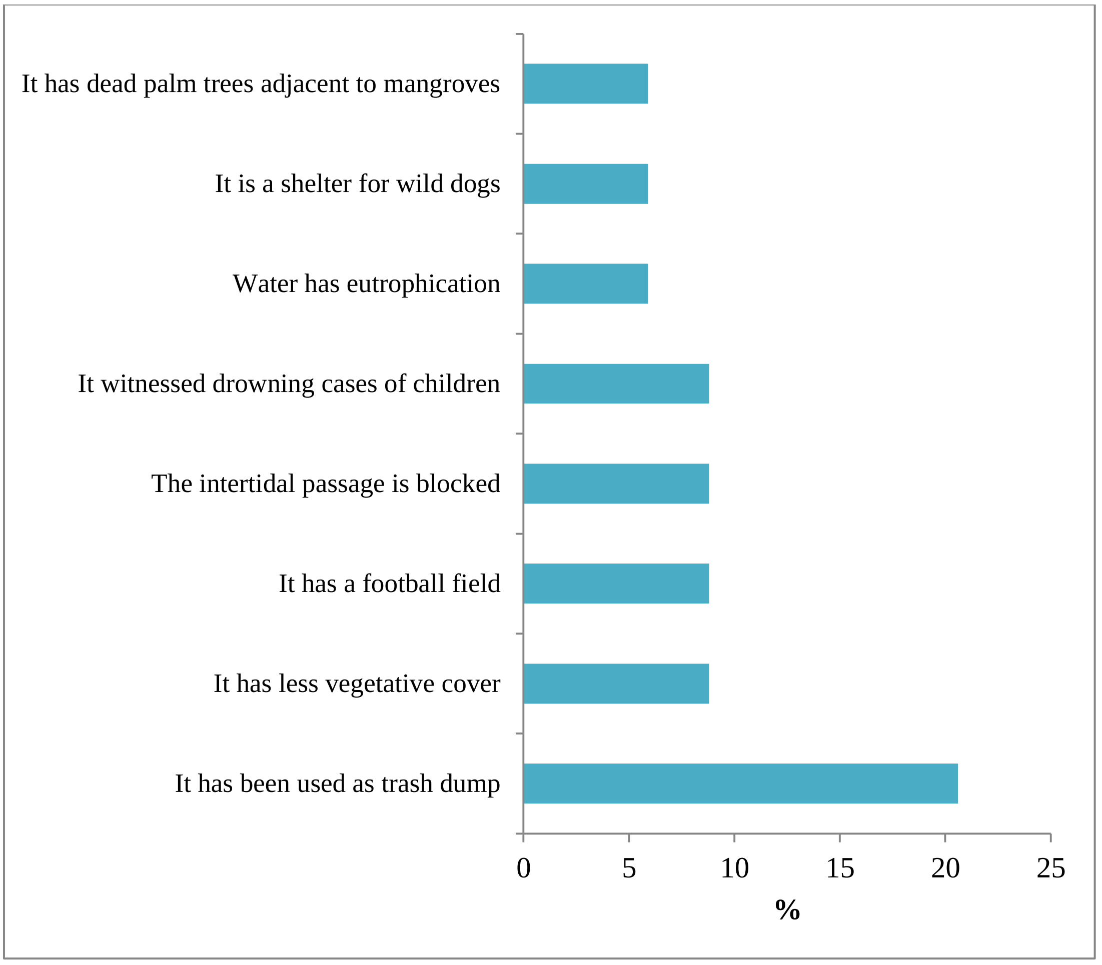


Figure 6.17. Attributes influencing the choice of disliked spots at mangroves.

When the different attributes of ecosystem disservices were mapped, it is clear that a single attribute influences the choice of different spots (Figure 6.18), whilst a single favourite spot had many attributes (Figure 6.18). Also, compared to the favourite spots, the reasons for people disliking spots were more diverse, but there were less people disliking spots overall.

Figure 6.18. The localisation of different disliked spots as identified by respondents with different attributes influencing the choice of the spots.

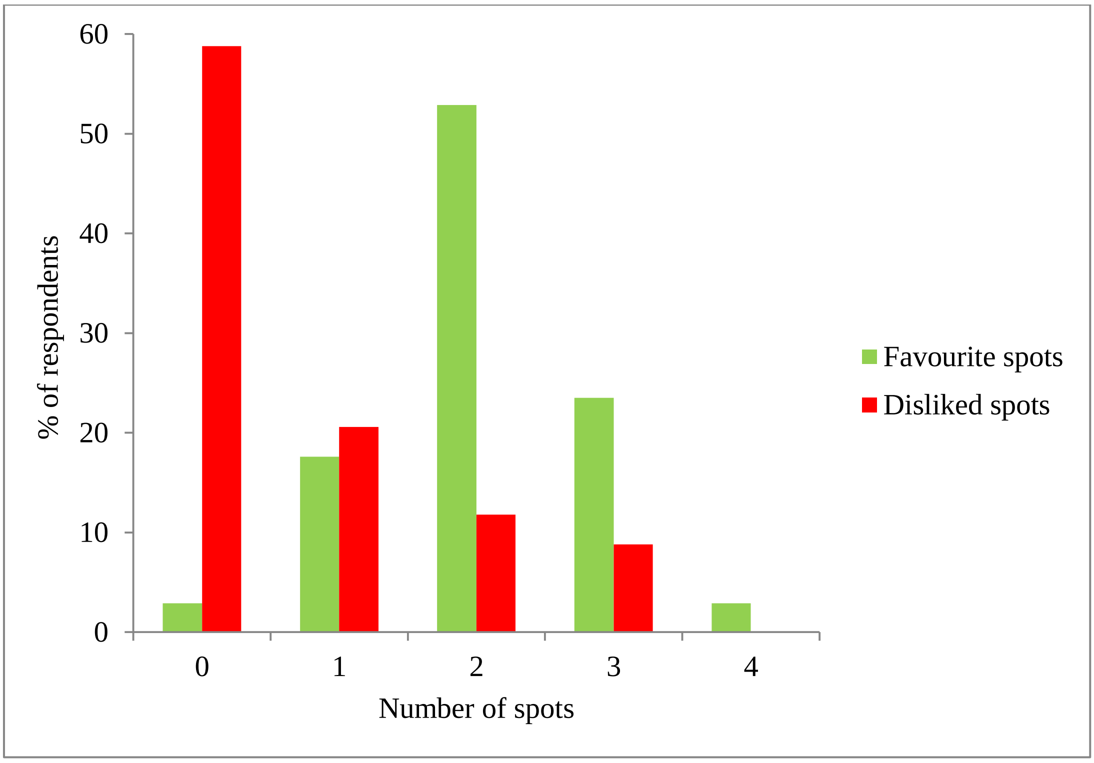


Figure 6.19. Number of both favourite and disliked spots identified by respondents.

As shown in Figure 6.19, there were respondents who did not identify any spots they do not particularly like. When analysed according to age group (Figure 6.20), the highest percentage (35%) was in the age group (51-60) followed by 30% in the age group (31-40), the highest number of respondents.

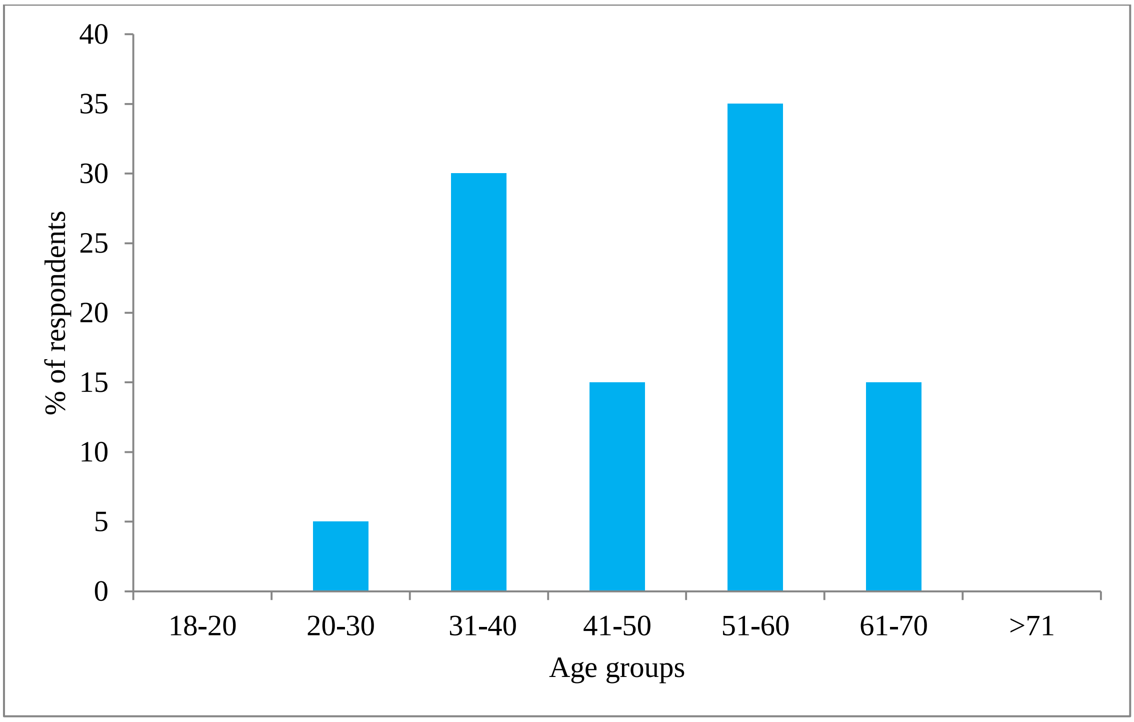


Figure 6.20. The age groups of respondents who did not dislike any spot.

6.3.6. Perceptions of site management

All respondents except one were aware that the site is managed by the Ministry of Environment and Climatic Affairs (MECA), but they all agreed on the need for better management. Many respondents (38.2%) were concerned about garbage in the area turning the mangroves into an unpleasant site. One elderly man stated: "*The Ministry of Environment does not care about mangroves, because it abandoned them and does not allow anyone to cut it. In the past, when we used to cut mangroves under the traditional system, we used to remove all the garbage and clear the dead mangroves. New more shoots emerge after cutting and new seedlings grow. The area was greener and we enjoyed it a lot. But now the Ministry of Environment is only documenting Qurayyat as a site for mangroves without any extra care".*

If better managed in the future, 32.4% pictured it as a tourism destination with resorts, while others specifically pictured the place with parks, rowing boat facilities, restaurants and cafes (Figure 6.21). A number of respondents (23.5%) wished the area had more green cover. All these visualised images were linked with peoples' interests in mangroves and the pleasure they acquired from this ecosystem and therefore imply an instrumental value of nature. Interestingly, some respondents advocated traditional management of the site (26.5%), which reflects the relational value of nature, detailed in the discussion section. 35% of respondents appreciated the intrinsic value of mangroves by requesting defined protective boundaries of mangroves. The respondents also pointed out that a better site will encourage them to regularly visit the mangroves and to spend more time there, and increase the opportunity for the area to be a top tourist destination in Qurayyat, thereby creating job opportunities for locals.

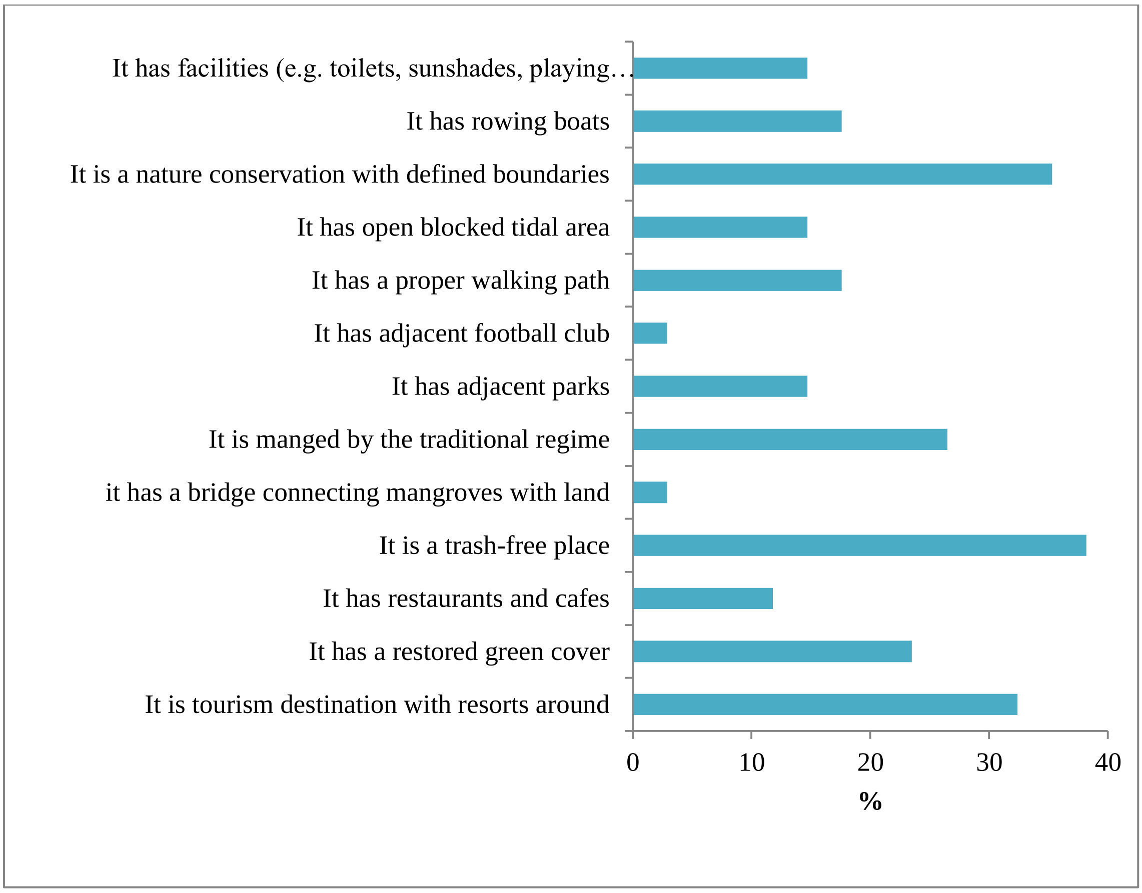
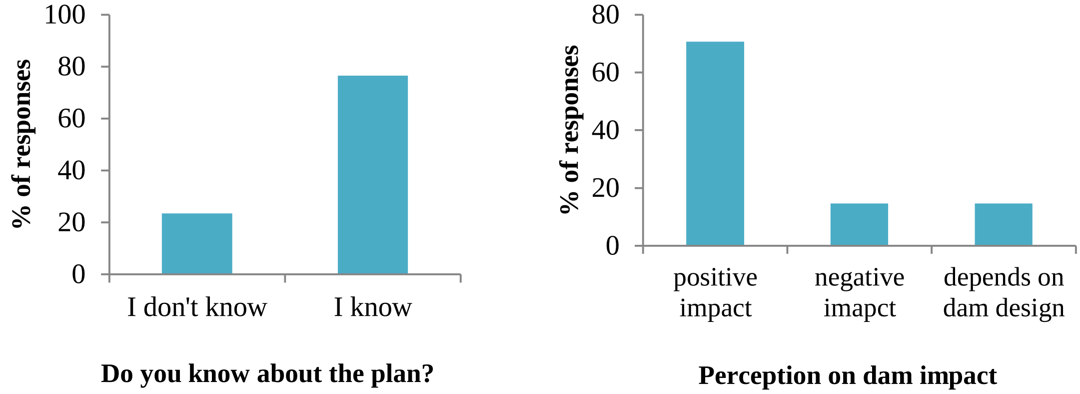


Figure 6.21. The picture of mangroves by respondents as a better place.

The majority of locals (76.5%) were aware of a government plan to build a dam at Wadi Mijlas, the main freshwater supply to the mangroves in Qurayyat (Figure 6.22a). When asked about the impact of the dam on mangroves, the highest percentage (70.6%) of respondents believed that the dam will have a positive impact on mangroves (Figure 6.22b) by preventing uprooting of plants during high-energy flows of wadis. They thought seawater was more vital for more mangroves to thrive than freshwater and some of them said spring water is an additional supply of freshwater to mangroves. Some respondents (14.7%) believed that the dam will negatively (Figure 6.22b) impact mangroves, while the same percentage suggest that the design of the dam will define the whether or not it will negatively impact mangroves.

Those who stressed the negative impacts were aware of the dynamic role of freshwater for mangroves to thrive in their environment. They were also aware of the importance of nutrients and sediments supplied by wadis for mangroves to nourish and support the food chain in this ecosystem. Those who referred to the design of the dam, pointed out that if the main role of the dam is to re-charge groundwater aquifers, then no freshwater will be discharged to mangroves unless the precipitation is heavy, which is an unusual event in the area, and therefore mangroves will be exposed to high salinity.



a b

Figure 6.22. The awareness of people about the plan of dam construction (a) and their perception towards the dam impact (b).

An interview with one of the managers at the (MRMWR) (Appendix 6.2) revealed that the plan to build a dam has been approved. The work on the plan started in 2007 following the impact of cyclone Gonu when high precipitation (detailed in chapter 2) caused massive floods in Qurayyat. The original plan was based only on channelling the route of the wadi and was changed to a dam construction. According to the plan, the capacity of the reservoir will be 150 million m^3 and equipped with controlled discharging channels when the reserved water exceeds the capacity of the dam. Also, the manager showed no objection to the release of some water to mangroves if requested by the Ministry of Environment and Climatic Affairs. These channels are designed to discharge up to approximately 750 m^3/s. The managers also revealed that the MECA approved the Environmental Impact Assessment report of the project. The plan of the dam construction has not been followed to date due to the financial cost which has been described as huge but never exactly revealed by the manager.

6.4. Discussion

My results revealed an appreciation of cultural services provided by the site by most respondents, although some activities had shifted from the past to the present. The site was frequently visited by the respondents, mainly for walking, but a broad range of other activities were also engaged in. A negative shift in the health of the mangrove site was also reported by most respondents, which was perceived to be due to the management system. The section below discusses these findings in more detail and reflects on the relevance of emerging concepts and frameworks for understanding cultural ecosystem services, specifically those developed by Chan et al. (2016).

6.4.1. Socio-economic characteristics of respondents

In this study, most of the interested respondents were older than 30 which might indicate that younger respondents did not have a rich experience to share about coastal systems of mangroves and therefore were less interested in participating, or that they could not meet the main criterion for survey selection, i.e. visitors to the area, or that those asked to propose new respondents (the snowballing approach) simply did not identify younger people.

6.4.2. Frequency of visits

The majority of respondents visited the mangroves frequently, with a high rate of daily visits. Proximity to the mangroves appears to be the main reason for frequent visits. Some of the respondents working in the capital revealed that they make mangrove visits during the weekends. The frequent visits reflect respondents' appreciation of the site, but the small sample may not be representative of the overall population of Qurayyat given that the main criterion for selection was that they visited the site. It is not known; therefore, how many people do not visit the site, that could only be revealed through a household survey of Qurayyat. However, although the sample size was small, it did reveal the substantial importance of mangroves for those people.

6.4.3. Identifying, understanding and mapping cultural services

The activities performed by people reflect the services flowing from the mangrove ecosystem (Chan et al. 2012, Chan et al. 2016). The categorisation of activities to different time periods showed temporal shifts in the types of services provided by mangroves. The UKNEA points out that social changes in communities have caused a remarkable shift in the dependence of humans on ecosystems for their wellbeing for the last 60 years (Watson et al. 2011), and Martín-López et al. (2012) argue that the capacity of an ecosystem to deliver its cultural benefits is mainly driven by the interests of individuals which change over time. Hernández-Morcillo et al. (2013) suggest that the shift in the nature of practices performed by respondents is because CES tend to be place and time dependent due to changes in an individual's perceptions, norms and behaviours as their economic and social conditions change.

In the respondents surveyed at Qurayyat, the decline in dependence on mangroves to support fishing as a family business or a traditional profession was clearly seen.

Around half of the respondents declared fishing in mangroves as a past practice, compared to only 14.7% currently. This shift reflects change in the social and economic status of communities who use mangroves, in line with the rest of the country when people generally shifted from agriculture and fisheries based income to regularly paid professions in the government or the private sectors (NCSI, 2017).

While some activities were less practiced in recent years, walking, wildlife watching and the spiritual faith-based activities were at the top of both past and present practice for both genders. Respondents declared that walking helps them to improve their physical and mental health and relieves the stress of life.

Both wildlife watching and the spiritual faith-based activities appear to have been strongly influenced by the cultural and Islamic identity of the respondents. Wildlife and spirituality are both valued by the two sources of Islamic teachings, *Quraan* (the Holy Book), which is referred to here as Surat, and *Sunnah* (All actions, phrasing, biography or morals reported about Prophet Mohammed) here referred to as Hadith. Muslims value nature through the appreciation of its beauty and God's creation. In fact, Muslims believe that "*God expresses himself through non-linguistic forms of communication which is through nature*" as stated by Ghowdhury (2013, p.8). The Prophet Mohammed stated "*Allah being beautiful Himself, loves beauty*" (Saheeh Muslim).

Different types of ecosystems are mentioned in the Quraan reflecting the appreciation of diversity of life on the planet such as in plants, birds, marine animals, insects and livestock (AlKhayyat 2010). Allah has mentioned in Surat Al-Nahl "*We spread the earth, and placed stabilisers in it, and in it We grew all things in proper measure* (19). *And in it We created livelihoods for you, and for those for whom you are not the providers* (20). *There is not a thing but with Us are its stores, and We send it down only in precise measure* (21)". It also was stated in Surat Al-Nahl "*And whatsoever He created for you on earth is of diverse colours. Surely in that is a sign for people who are mindful"* (13). The teachings of Islam also encourage humans to spiritually engage with nature and appreciate its values (Snoubar 2011). Allah has called people to deeply think of the creation on the planet and believe in the creator himself. He has stated in Surat Al-Ana'am that "*And it is He who sends down water from the sky. With it We produce vegetation of all kinds, from which We bring greenery, from which We produce grains in clusters. And palm-trees with hanging clusters, and vineyards, and olives, and pomegranates-similar and dissimilar. Watch their fruits as they grow and ripen. Surely* *in this are signs for people who believe"* (99). In Sunnah, the Prophet Mohammed has asked people to praise and glorify Allah when seeing any symbol of nature (Snoubar 2011). In fact, the feeling of nature spirituality is part of Muslims' beliefs in Allah as stated in Surat Yunus *"Say, 'Look at what is in the heavens and the earth.' But signs and warnings are of no avail for people who do not believe"* (101).

The mapping of walking, wildlife watching and spiritual faith-based activities showed that the majority of respondents performed their activities at specific locations, which resembles the findings of Plieninger et al. (2013), in which the cultural services of the ecosystem displayed intensity in specific spots. For some activities, gender of the respondents was a factor in the change of practice over time. For example, females never practiced horse riding and those who practiced cycling, fishing, swimming did so during their childhoods, when cultural influences on gender is less in Oman. Martín-López et al. (2012) also find that the activities reflecting the services of an ecosystem may be influenced by the cultural code of the place. Household income may also have an influence. For example, horse riding is a recent emerging sport for affluent young men (Martín-López et al. 2012, Hernández-Morcillo et al. 2013).

The motivations to visit the mangroves reflect the services provided by the ecosystem (Plieninger et al. (2012). They found that the experience of the beauty of an ecosystem (which motivated more than 90% of respondents to visit mangroves in this study) is related to aesthetic ecosystem services, to live the experience of being in a small community (88.2%) related to a sense of place service. Plieninger et al. (2012) also find the enjoyment of time with friends and meeting people (88.2%) relates to social-relations service and that the feeling of connection with God (79.8%) relates to a spiritual service.

6.4.4. Individual preferences for landscapes

Using photos or maps to elicit perceptions is critical for localising the landscapes or locations most appreciated by people (Plieninger et al. 2013). The mangroves in this study were ranked as the 2nd most preferred landscape in Qurayyat after Sahil (the coastal area located between the mangroves and the port in Qurayyat). This high ranking of mangroves appears to reflect a high appreciation by locals, living in close proximity to this landscape, although as stated earlier the respondents surveyed may not be representative of the wider population in Qurayyat.

The majority of respondents linked their appreciation of mangroves to being a valuable part of their childhood memories. William (1995) argues that, the appreciation of an ecosystem may not be interpreted as a service as such, but represents a part of a person's life, culture or experience. Also, Martín-López et al. (2012) argue that preference is linked to the knowledge and perception of people towards the place. In this study, respondents had less preference for the distant landscape which they are less knowledgeable about. In some cases, respondents may never have visited some of the landscapes illustrated in the photographs and this lack of experience may have caused them to rate those landscapes lower.

For mangroves, many respondents had favourable spots, where again the links to their childhood and the beauty of the place were strongly influential. The time spent by respondents in these spots was high and indicated a very strong connection (Figure 6.10). In the past, some respondents used to play with their friends, fish, collect crabs and molluscs, harvest shrimps, collect wood and animal fodder in these favourite spots. Some of these are provisioning services which act as a channel or conduit for CES (Chan and Satterfield 2016). In their study, provisioning services such as fishing play an important role in socio-ecological relationships. For example, one respondent stated: *"We used to walk inside mangrove forest since we were kids, we used to harvest shrimp, crabs, huge crabs and fish. We used to spend our times in mangroves when we were not fishing in the sea. All kids were gathered and cooked the shrimps and crabs they harvested and eat them on spot"*. One girl also said: *"My grandfather used to make local nets for fishing called mahlaq and used to make them from mangrove branches. I used to help him in making these nets and fishing with his other grandchildren. He used to tell us stories when we were in mangroves as well"*. In addition, a young lady stated: *"I walk close to mangroves with my daughter and sister every couple of weeks or every three weeks in early mornings. I had memories with my grandmother when I was a kid. I used to collect mangrove fruits with her to feed them to goats. We used to walk inside the forest and sometimes searching for honey combs"*.

6.4.5. Disservices of mangroves

Mangroves in Qurayyat combined joy, danger and sadness for the people interviewed. For example, many respondents most enjoyed the places where they had their first swimming experience, but sadly at some of the same places they witnessed children drowning.

I co-incidentally interviewed three parents who had lost their children in mangroves and one mother who saved her child at the last minute. One of the male interviewees stated: *"Mangroves is the place where I lived very beautiful days in my life with all the sweet and sad moments. I used to fish and collect crabs and conical molluscs 'Cono cono' from mangroves when I was a kid. In my childhood, I used to spend most of my day in mangroves, I have survived drowning many times in the estuary and I lost one of my sons there when he was 6 years old"*. One elderly lady also stated: *"I was born here and will never leave this place. I love this land, its gravels, its sand and sea"*. She also stated: *"The only problem with mangroves is the drowning of kids, my son was about to die in the estuary, but thankfully he was saved by a fisherman in the last minute"*.

Another example of disservices was that the majority of respondents described mangroves as "*beautiful*" and that they enjoyed the view of trees, coast and birds. On the other hand, they expressed dissatisfaction with eutrophication and trash. One male respondent stated *"This elevated area overlooking mangroves gives you a feeling of living in a unique, charming place, with fresh air, wide field of view and helps you to deeply think*". He also added *"I don't like this passage; people throw their households garbage here"*. These findings are similar to those of Plieninger et al. (2013) which showed that people enjoy harvesting wild products of nature at a place where they also feel disturbed or threatened, for example by wild animals inhabiting the same area. The attributes representing the ecosystem disservices in Figure 6.17 are not only used for interpretation of user dissatification towards the ecosystem, but they could also hamper ecosystem functioning and consequently affect the supply of sevices (Lyytimäki and Sipilä 2009, Shackleton et al. 2016). For example, the blocked mouth of the estuary in Qurayyat affects the hydrology and the interaction of the estuary with the wider coastal system, and is therefore expected to affect the provisioning role of the estuary as a nursery ground.

Despite the presence of disservices, people were more positive than negative towards the site. The density of their favourite spots was more than the disliked spots and many single spots were favoured for more than 2 attributes. Also, the age analysis of both services and disservices at the site revealed that elderly people (aged 51-60) had more appreciation for the site and considered each single spot in the ecosystem equally favourably.

6.4.6. Perceptions of site management

The concepts and frameworks developed by the cultural ecosystem services research group at UBC, Canada (see Chapter Introduction) have been extremely useful for understanding and interpreting how people respond to the mangrove system at the site. For instance, the pictures that respondents visualised for mangroves combined all the three values (intrinsic, instrumental and relational) of nature stated by Chan et al. (2016), who argue that both intrinsic and instrumental values of nature are pivots for conservation even in the absence of non-material rewards. Chan et al (2016) also argue that relational values motivate decision-making for management plans, while Tengberg et al (2012) find that local knowledge could significantly support policies for management. Without these concepts, it would have been difficult to articulate the motivations and responses of those surveyed.

While interviewed, some respondents shared their experience with the traditional management regime of mangroves, a system still in place until the early 1980s (JICA and MECA 2004) when mangroves were monitored and managed by the head of the local authority at that time. My study found that mangroves used to be guarded by soldiers working for the Wali (Head of the local authority as assigned by the Sultan). Locals would be called to harvest mangroves 7-10 days per year under the soldiers' supervision. In particular, women used to meet there and harvest wood. This traditional system was part of the social regimes in the area and improved wellbeing by supplying people with wood for cooking. Locals also suggested that this practice, including trimming mangroves and collecting dead wood, kept mangroves clean and healthy for years. This indicated a moral responsibility towards the ecosystem (see also Chan et al 2016). Relational values were also represented by the awareness of all respondents of the unique environment in which mangroves grow and their appreciation of mangroves as part of Qurayyat identity, because the mangroves have been there for hundreds of years. This corresponds with Daniel et al.'s (2012) argument regarding the link between ecosystems and the identity of a community. The identity arises from the sense of the place and social, cultural and personal experience (William 1995). Satterfield et al. (2013) and Plieninger et al. (2013) find that the cultural identity and inherited knowledge acquired from an ecosystem, support better management plans for the place itself. They also advocated the collaboration of researchers and policy makers with locals to support management and conservation plans.

6.5. Conclusion

This study has attempted to understand, map, and localise the CES of mangroves in Qurayyat through human perceptions and the types of activities people performed in the site. The high frequency of visits by respondents living close to mangroves and their ranking of its landscape as the 2nd best landscape in Qurayyat indicated a high appreciation of mangroves by the locals interviewed.

The study also revealed a change in supply and demand of CES between the past and the present. The most practiced activities, which are suggested to reflect the services, in both the past and present were wildlife watching, walking and spiritual/faith-based activities. The localisation of respondents' favourite spots was mainly linked to the intrinsic value of mangroves themselves as part of their childhood memories. It was also linked to the spirituality of these places, which was further influenced by the Islamic culture and religious background of the respondents.

It is clear that cultural ecosystem services have become relatively more important than provisioning or regulating services to people at this site, and probably throughout Oman, as the economy has shifted from one that exploited natural resources (agriculture and fisheries) to one dominated by oil-based industries and government work (see Chapter 3). Most people now work in sectors not closely associated with the natural environment so that visits to natural areas like mangroves become increasingly important in their lives for their well-being. This makes it increasingly important that a there is a focus on cultural services in future decisions about the site.

This change in supply and demand could assist to prioritise decision-making when developing management plans and policies (Brown and Fagerholm 2015). Mapping of locals' activities and favourite spots can be used as a starting point for decision-makers to decide where and what to invest in the ecosystem to ensure the delivery of the services (Everard, 2017). The plans of management and conservation should be human-centric and not based solely on the views of decision makers (Chan et al. 2016). The relational values in which cultural ecosystem services fit strongly should be considered in the plans (Chan et al. 2016).

Chapter 7

General discussion and conclusions

7.1. Thesis summary and key findings

Estuaries have played an essential role for humanity through the ages, encouraging settlement of cities and towns on their banks (McLusky and Elliott 2004, Elliott and Whitfield 2011) due to the wide range of services they provide to society. This study has aimed to examine the significance of estuarine mangroves for the wellbeing of Omani communities. In Oman there are 18 mangrove sites documented by the Ministry of Environment and Climatic Affairs and this study has focused on two contrasting sites, Al-Qurum and Qurayyat.

The study began by observing changes in the spatial extent of mangroves between the 1970s and 2014, based on the availability of records and aerial photographs. This analysis was done for the two main study sites (Al-Qurum Nature Reserve and Qurayyat) and two "control" sites (Harmul and Mahout), which were not exposed to cyclones during the study period. All the four sites are in the northern part of Oman and therefore expected to experience broadly similar environmental conditions. This analysis showed a steady change in the spatial extent of mangroves over time taking into consideration the absence of cyclonic destructive impact in these sites. Al-Qurum showed a progressive increase in cover, which declined after Cyclones Gonu 2007 and Phet 2010, but Qurayyat showed a decline even before the cyclonic events.

The continuous decline in Qurayyat was probably due to the degradation in the conditions of the ecosystem as a consequence of inadequate management regimes based on my own observations, interviews with locals and the study of JICA and MECA (2004). Although mangroves are known for their ecological resilience, degradation in conditions such as water quality (as at Qurayyat), means that mangroves struggle to endure other pressures (Kuenzer et al. 2011). Although there is a time gap of 14 years between this study and the study of JICA and MECA (2004), the problems reported in 2004 still exist, including the closed mouth of the estuary, eutrophication and a decline in diversity and trees.

Urbanisation was found to impose another major threat to mangroves and will likely restrict their ability to respond to projected increases in sea-level rise. Urbanisation has also been found to increase the chances of flooding during cyclones, which are accompanied by unusual high levels of precipitations, by blocking natural routes of rainwater to the sea (Al-Hatrushi and Al-Alawi, 2010 Fritz et al. 2010 Kwarteng et al. 2016). As a consequence, mangroves are likely to get squeezed by flooding on the land side and by wave energy from the coastal side. In conjunction with these conditions, mangroves in northern Oman were found to live under stressful climatic conditions such as scarce precipitation, high temperatures and consequently high salinity levels.

In the context of all these conditions, the study examined the capacity of mangroves in Al-Qurum and Qurayyat to supply services to Omani communities. To determine which of the many services that mangroves provide in general and which listed by the MA (2005) are of most importance to the Omani community, self-completed questionnaires were used to elicit people's knowledge and their perception towards these ecosystems. This analysis revealed a shift in mangrove utilisation in Oman since 1970s away from direct use in the form of fisheries catch, wood and charcoal source, and animal fodder, in contrast to other countries where coastal communities have been documented to be highly dependent on such services. Compared to Al-Qurum, more respondents in Qurayyat were knowledgeable of these provisioning services and they had a higher appreciation for these services in the past when they used to harvest wood for cooking and fruits for feeding their animals. Their subsistence fishing also used to be highly dependent on mangroves, but now they are more dependent on offshore fishing.

An examination of the role of mangroves in supporting fisheries in Oman revealed that only a small proportion of subsistence and commercial fisheries are supported by mangrove-associated species. However, this does not undervalue the ecological role of these species, particularly molluscs and crabs. These species along with other small-sized fish are important in the diet of higher consumers and considered as important engineers in the ecosystem. Estuaries, including mangroves, may be less diverse than other marine ecosystems, but those species present are often in high abundance and biomass. Reports of high percentages of fisheries supported by mangroves in other areas of the world have been subjected to criticism. More research is needed on fisheries dependence on estuaries and mangroves rather than simply extrapolating from a few previous studies.

With respect to regulating services, storm buffering and carbon sequestration were more acknowledged in interviews with respondents in Al-Qurum. Commonly, it has been noticeable that cyclones, whilst not frequent, are becoming more intense in Oman.

Mangroves are thought to mitigate the coastal effect of cyclones by dissipating wave energy, but freshwater floods resulting from the unusual high precipitation are a major additional stress in Oman. Nevertheless, mangroves are still able to diminish cyclone-associated wave and wind energy. The existence of mangroves provides the regulating service of soil protection and reduces the amount of carbon released from the soil to atmosphere. Carbon sequestration was one of the top regulating services identified by respondents in this study. Although the carbon stocks of mangroves in Al-Qurum were found to be much lower than those in other tropical areas of the world that experience more favourable environmental conditions, mangrove ecosystems are likely the richest carbon sinks in Oman and as such are considered valued contributors to climate change mitigation.

In most studies, cultural services are the least recognised by people compared to provisioning and regulating services (Herr and Landis 2016). However, in this study cultural services were the top listed services by respondents, with more appreciation by locals in Qurayyat than Al-Qurum and Al-Sawadi. This study has revealed an ecosystem-local interaction and connection mainly influenced by the Arabic and Islamic identity of the community. The cultural values of the Qurayyat ecosystem revealed an appreciation of locals for all intrinsic, instrumental and relational values of nature (Chapter 6). Mangroves have been playing a key role in shaping the social lives of people living next to them for millennia, which is reflected in the spiritual value attributed to mangrove trees and their role in the past in supplying the community of Qurayyat with provisioning benefits like wood, animal fodder, fisheries, charcoal and natural medicines.

Mangroves are threatened by various natural and anthropogenic disturbances, which consequently impact their spatial extent. Mangrove spatial decline has been reported in different parts of the tropical and sub-tropical world and is estimated to have reached 35% between 1980 and 2000 (MA 2005, Giri 2008), due to multiple factors. Worldwide, mangrove ecosystems are commonly declining due to anthropogenic activities like aquaculture, changes in land use due to agriculture and urban development, tourism, diversion of freshwater supply away from mangroves and forest clearance for timber, charcoal, furniture, wood and other direct resources (Barbier 1993, Alongi, 2002, Giri et al. 2011). Climate-change related factors including tsunamis, cyclones and sea-level rise were also identified as major threats confronting mangroves (Gilman et al., 2008, Giri et al. 2011).

This study did not find any indication of unsustainable direct use of mangroves, such as clearance for aquaculture or heavy harvest of wood and fruits, in Oman.

In recent decades Omani communities have shifted to more regular-payment forms of income in both private and public sectors and are therefore less dependent on nature for their wellbeing. Instead, urbanisation and climate-change related factors were identified as the main threats confronting the study areas here. The next section addresses what is needed to minimise the impact of these threats.

7.2. Management approaches towards mangroves at the study sites

Although mangroves are frequently exploited by humans or destroyed due to both natural and anthropogenic factors, they are considerably resilient (McLusky and Elliott 2004, Elliott and Whitfield 2011). It has been suggested that the study of pristine ecosystems facilitates the understanding of the disruption in services flow in other ecosystems utilised by humans (Ashton et al. 2003). Worldwide, different regimes and strategies of ecosystem management of mangroves have been followed, amongst which designation of these ecosystems as nature reserves and restoration and rehabilitation are the most commonly used approaches. These are also followed in Oman.

There is consensus among the researchers for the need to conserve mangroves. The conservation of mangroves not only benefits countries at their local scale, but also provides global benefits (Yee 2010). Tam and Wong (2002) find that conservation plans for mangroves can apply different regimes, depending on the ecological conditions at each site, and that conservation strategies could range from aiming exclusively to ensure the ecological value of the ecosystem (like Al-Qurum) to more flexible sustainable use of ecosystem services (like Qurayyat in the past).

When this thesis began, Al-Qurum ecosystem was considered a strict nature reserve, with access prohibited except for research or educational purposes. However, on 23rd October 2017, the Ministry of Environment and Climatic Affairs (MECA) announced in the *Al-Watan* local newspaper that some nature reserves in Oman, including Al-Qurum Nature Reserve, will be handed over to investors in the ecotourism sector. According to the statements of the MECA to the newspaper, this decision will not affect the provisioning and cultural services of the reserve. Nothing was mentioned about regulating services. The MECA also state that this step is to help diversify the national economy resources, especially after the extreme drop in oil prices since 2014, which is the main source of income for Oman. Although tourism is considered as the fastest growing sector of economy in the world, including in nature reserves, its impacts on the environment are inevitable, particular for mass, poorly planned tourism in developing countries (Ray and Ebrary 2012). The MECA did not provide any information on any assessments for this integrated development-conservation project and nothing has been mentioned as to whether the investor will build the planned mangrove research and education centre in the reserve.

Protected areas have been designated mainly to maintain and / or restore biodiversity and ecosystem integrity. On the other hand, ecotourism could impact the biodiversity on site (Ray and Ebrary 2012). Ray and Ebrary (2012) argue that inadequate, improper planning of tourism in conservation areas is highly likely to lead to conflict with the main aims of reserves, however they also argue that if ecotourism is well planned, it could be used to support conservation. They further argue that educating visitors about the value of conservation could reduce the impacts of ecotourism activities on reserves.

The Al-Qurum reserve, as revealed by this research, is already under stressful conditions inhabiting a restricted space in the capital, surrounded by infrastructure development despite its high value role in carbon sequestration and other ecosystem services. Tam and Wong (2002) find urban development has already led to over exploitation of mangroves and a higher level of development around mangroves is expected to increase the level of exploitation of, and damage to, mangroves. Also, any changes in land use due to unplanned investments might lead to the release of stored carbon and contribute to climate change (Yee 2010, Herr and Landis 2016).

Some conservation regimes do not entirely prohibit the utilisation of ecosystems but aim for sustainable use, as recommended by Tam and Wong (2002). That was the approach used in Qurayyat (pre-1980s) where the local authority was protecting mangroves and only permitting locals to harvest wood at specific and limited times of the year. That system was successful according to the statements I obtained from locals I interviewed and who also witnessed those days. Locals also revealed that at that time fishing in mangroves was actively practiced and included fish, crabs, molluscs and shrimps. Besides being a place for human settlements, estuaries also provide a dynamic connection between the coast and interiors (McLusky and Elliott 2004). The locals in Qurayyat also revealed, when interviewed, that mangroves were the connecting point to travel between the coasts and the palm fields when the date season starts in summer (June-August) from point A through point B to point C (Figure 7.1). The mouth at point B used to be open which made the ecosystem healthier as well. So locals used the estuary to facilitate their shift between fishing and agriculture practices, which were the main source of income for Qurayyat before oil investments in 1970s (JICA and MECA 2004). The use of estuaries for transport can be problematic due to the need for dredging to maintain navigation channels (McLusky and Elliott 2004). The existence of a close harbour might be a reason for high sedimentation and the mouth is only opened during heavy flush of wadis as indicated by locals. In large estuaries, dredging can be problematic because it contributes to the removal of some of the species in the ecosystem (McLusky and Elliott 2004).

Figure 7.1 The route followed by locals from point A to C through B in Qurayyat to move in the past from the coast to the interior for date palm fields. Image obtained from Google Earth.

In Qurayyat, the locals inhabiting the area of mangroves were highly appreciative of the services provided by the ecosystem, particularly cultural values. Locals have also declared their willingness to take part in any management plan for a more sustainable use of mangroves that would help restore its condition. Smith and Berkies (1992) suggest that local engagement in development-conservation plans could effectively lead to the improvement in ecosystem conditions and consequently in the services provided, especially if locals are aware of their rights and responsibilities. Tam and Wong (2002) also promote publics engagement in management regimes. They find public awareness of the value of ecosystems is fundamental to maintaining the supply of services.

7.3. Can management approaches perform better?

Understanding of the services supplied by mangroves essentially assists in shaping the management plans for the ecosystems (Ashton et al. 2003). It has also been suggested that mangrove management strategies and regimes cannot be successfully implemented without the interpretation of human-ecosystem relationships in terms of the anthropogenic impacts on the ecosystem (Dahdouh-Guebas 2002, Halpern et al. 2008). Understanding impacts will assist in assessing the ecosystem resilience to such threats and the capacity to cope with them (Dahdouh-Guebas 2002). A better understanding of human-nature relationship results in more sustainable utilisation of resources (Cinderby et al. 2011).

Many management plans of ecosystems have been commonly routine and conventional including conservation plans (Tallis et al. 2010). They also neglect the importance of connectivity between ecosystem components and humans in the resilience and service provisioning of the ecosystem (Leslie and McLeod 2007). The weaknesses of these plans include the failure of inclusion all objectives and interested stakeholders in the ecosystem itself (Tallis et al. 2010).

Due to their complex structure and functions, estuarine environments require holistic approaches for management, which consider this complexity without neglecting the various interests of different stakeholders in the ecosystem (Borja et al. 2016, Elliott et al. 2017). For example, Convention on Biological Diversity's (CBD's) Ecosystem Approach (Everard 2017) and subsequent developments like Drivers-Activities-Pressure-State changes-Impacts (on Welfare)-Responses (as Measures) Framework [DAPSI(W)R(M)] (Elliott et al. 2017). The CBD's Ecosystem Approach comprises 12 principles (Borja et al. 2016, Elliott et al. 2017, Everard 2017) aimed to promote the conservation of ecosystem functions and biological diversity but also recognise and acknowledge that economic aspects need to be considered (Everard 2017). The Ecosystems Approach is also based on the consideration on various types of knowledge in developing the management plans including indigenous, local and scientific knowledge (Elliott et al. 2017, Everard 2017). The DAPSI(W)R(M) Framework was developed for better understanding of ecosystem complexity (Elliott et al. 2017) and developed from the Drivers, Pressures, State changes, Impacts and Responses (DPSIR) Framework (Elliott et al. 2017) which is considered more relevant to estuaries compared to the broader CBD Ecosystem Approach (Elliott and Whitfield 2011). It provides better understanding of human-needs based activities which consequently impact communities' welfare and therefore require responses (Elliott et al. 2007, Elliott et al. 2017). These responses are suggested to be ethically, socially, economically, politically, administratively and culturally valid through different measures (Elliott et al. 2017). The measures are communications and agreements between different stakeholders like policy makers, locals, indigenous people and environmental agencies (Elliott et al. 2017).

Another comprehensive approach is Ecosystem-based Management (EBM) (Pikitch et al. 2004, Leslie and McLeod 2007, Halpern et al. 2008, Tallis et al. 2010). EBM has many points of contact with the CBD Ecosystem Approach (Everard 2017) and the DAPSI (W)R(M) Framework (Elliott et al. 2017). EBM does not exclusively target the species of interest in an ecosystem, yet it considers the interactions of these species with other elements including humans and it also includes the impacts of activities within the ecosystem (Leslie and McLeod 2007, Halpern et al. 2008). This approach requires the inclusion of diverse kinds of knowledge to manage the ecosystem (Leslie and McLeod 2007, Halpern et al. 2008, Tallis et al. 2010). In general, linkage of local, traditional and scientific knowledge with the authorised management system leads to more sustainable use of coastal habitats (Slocombe 1998, Francis and Bryceson 2001) and to better decisions and outcomes (Forrester et al. 2015).

Some scholars consider that local traditional knowledge is as crucial as scientific knowledge to set the basis for management legislation of ecosystems (Francis and Bryceson 2001, Rich et al. 2015). The absence of traditional management systems could lead to the decline of habitats (Francis and Bryceson 2001). In Qurayyat, for example, local engagement could invest the traditional knowledge to improve the health of the mangroves and this could help all fish and shellfish population to recover. This could in turn allow the return of the traditional and recreational fishing in the area. In fact, it has been found that most of the examples of marine EBM are based on fisheries (Pikitch et al. 2004, Halpern et al. 2008, Tallis et al. 2010). To ensure sustainable fisheries, it is vital to also manage habitats the target fish species depend upon (Leslie and McLeod 2007, Pikitch et al. 2004, Halpern et al. 2008). The EBM of fisheries does not conventionally target an increase of yield of catch, but instead it is perceived as an integrated approach considering species at all trophic levels, socio-economic factors and the structure of the ecosystem (Pikitch et al. 2004, Leslie and McLeod 2007, Halpern et al. 2008).

Initially, EBM design should include both spatial and temporal measures within and among species and ecological-human interactions (Leslie and McLeod 2007). EBM also requires defined targets and objectives supported by the availability of adequate data (Slocombe 1998, Pikitch et al. 2004, Leslie and McLeod 2007, Tallis et al. 2010). It has been proposed by some researchers that interviewing ecosystem utilisers provides valuable data for setting the targets of management plans (Pikitch et al. 2004, Tallis et al. 2010). Rich data from utiliser could also facilitate more in-depth understanding of how ecosystems respond to different regimes of management (Pikitch et al. 2004). In the case of fisheries-related management, EBM may utilise information on the natural history of species or habitats or simply depend on general knowledge (Pikitch et al. 2004, Leslie and McLeod 2007).

Generally, the objectives of EBM are directed to:

a) use indicators to maintain the ecosystem and to avoid or minimise the magnitudes of ecosystem deterioration in the ecosystem (Slocombe 1998, Pikitch et al. 2004, Leslie and McLeod 2007). These indicators need to cover ecological, social and economic aspects (Leslie and McLeod 2007).

b) reduce the impact of irreversible changes in the ecosystem (Pikitch et al. 2004, Leslie and McLeod 2007).

c) maximise the socio-economic benefits without neglecting the ecosystem itself (Pikitch et al. 2004, Barbier et al. 2008).

d) obtain adequate levels of knowledge of the ecosystem for a greater understanding of human-ecological interactions (Pikitch et al. 2004, Leslie and McLeod 2007).

EBM is also suggested to improve the services and benefits of an ecosystem including production increase of both ecosystem species (e.g. mangroves products) and associated species (e.g. fisheries) (Temmerman et al. 2013) across both temporal and spatial scales (Leslie and McLeod 2007). The provision of other services like carbon sequestration, storm buffering and cultural services will also be enhanced (Temmerman et al. 2013). EBM is also designed to improve the conservation plans of an ecosystem through linking different views including those of conflicting stakeholders (Imperial and Hennessey 1996, Leslie and McLeod 2007, Barbier et al. 2008) who are the main beneficiaries of the ecosystem (McLusky and Elliott 2004). In mangrove ecosystems the main conflicting groups are coastal communities (wider and mangrove-dependent) and investors who are seeking economic profit mainly from conversion of these habitats to shrimp ponds (Barbier et al. 2008).

EBM has been developed for better understanding of human-ecological interactions and is considered crucial for managing marine ecosystems (Pikitch et al. 2004, Leslie and McLeod 2007, Halpern et al. 2008, Tallis et al. 2010). The understanding of this interaction provides better evaluation of human impacts on the ecosystem (Leslie and McLeod 2007, Halpern et al. 2008). Proper management of mangroves will assist in maintaining a sustainable supply of services especially for communities which are highly and directly dependent on mangroves for their wellbeing (Smith and Berkes 1993). The engagement of all stakeholders in EBM should result in actions described by Leslie and McLeod (2007, p.541) as 'credible, enforceable and realistic'. EBM deals with complex human-environment interactions (Slocombe 1998, Tallis et al. 2010) and whilst it might be hard to avoid the conflicts of interest between different stakeholders, it is not impossible to create dialogue between these groups and outline the management plan (Leslie and McLeod 2007). Slocombe (1998) prefers to address this complexity instead of ignoring or underestimating it.

EBM could also encounter problems of obtaining restricted-access government files (Imperial and Hennessey 1996, Slocombe 1998, Tallis et al. 2010) whilst the need to generate huge quantities of data is both costly and time consuming (Imperial and Hennessey 1996). The prohibition of information access by government could significantly reduce the data available for planning (Tallis et al. 2010). Another problem with EBM is the need for the allocation of financial resources for modelling, administrative planners, developing tools for monitoring conditions in the ecosystem, staff training, etc. (Slocombe 1993, Imperial and Hennessey 1996). The achievement of EBM goals should be tracked and assessed at a variety of temporal and spatial scales (Leslie and McLeod 2007).

The implementation of EBM has been more noticeable in the developed world (Leslie and McLeod 2007). Oman as a developing country is expected to face challenges of EBM implementation for mangrove management.

Based on my background as an Omani researcher and my experience with institutions and communities, the management system in Oman is summarised in the diagram below (Figure 7.2). The diagram only involves a visualisation of mangrove ecosystems managed by MECA. (https://meca.gov.om/en/), whose legislative and management plans are derived from two sources: a) Royal Decrees and, b) Ministerial decisions by the Minister. At the environmental level, the Royal Decrees in Oman are issued only by His Majesty the Sultan, and mainly focus on the designation of nature reserves and to regional and international agreements. MECA is responsile for enforcement of these decrees and laws. As a researcher, I found that MECA was cooperative in terms of facilitating the process of research and supplying researchers with the assistance, advice and data needed to conduct research. However, there is still a weak response from the Ministry with respect to involving the researcher in decision-making. Beside researchers, the Environment Society of Oman (ESO), the only registered environmental NGO in Oman, also plays a dynamic role in engaging MECA in their activities. According to their social media channels, ESO is strongly connected to MECA in terms of organisation of their events and campaigns. ESO also plays a highly actrive role in involving other groups such as researchers, students and communities in their activities. Some of their campaigns highlighted the threats of plastic and abandoned fishing nets on the marine environment. Until recently, ESO does not appear to have had an influential role in management decisions of MECA, except from the support of ESO in running its campaigns like the plastic ban, trash-free beaches and saving green turtles from fishing nets. MECA also receives complaints from communities regarding environmental issues, but decisions are taken based on the vision of the Ministry. There is growing willingness of researchers and academic institutions to involve local communities in research and get their opinion regarding the environmental management and to pass these on to MECA. Unfortunately, MECA remains slow to respond to the recommendations of researchers for better management plans.

This study has shown the significance of mangrove ecosystems to people and the need to involve them as key stakeholders in decision-making. Mangroves are dynamic ecosystems and therefore there is a need to consider all the components of the ecosystem in any management plans. Any suggested management plans should sense the natural and human-caused threats to the ecosystem supported by a satisfactory level of information regarding the components of the ecosystem, their interaction and any changes occurring in the habitat (McLusky and Elliott 2004).The effects of any changes in the ecosystem should also be monitored at both temporal and spatial scales (McLusky and Elliott 2004). The use of SMART indicators for the quantification of services for better understanding of their links to the wellbeing and security of communities and better understanding of the flow of services is strongly advisable. SMART indicators should also be achievable within the allocated resources, especially financial ones as recommended by Cromier and Elliott (2017).

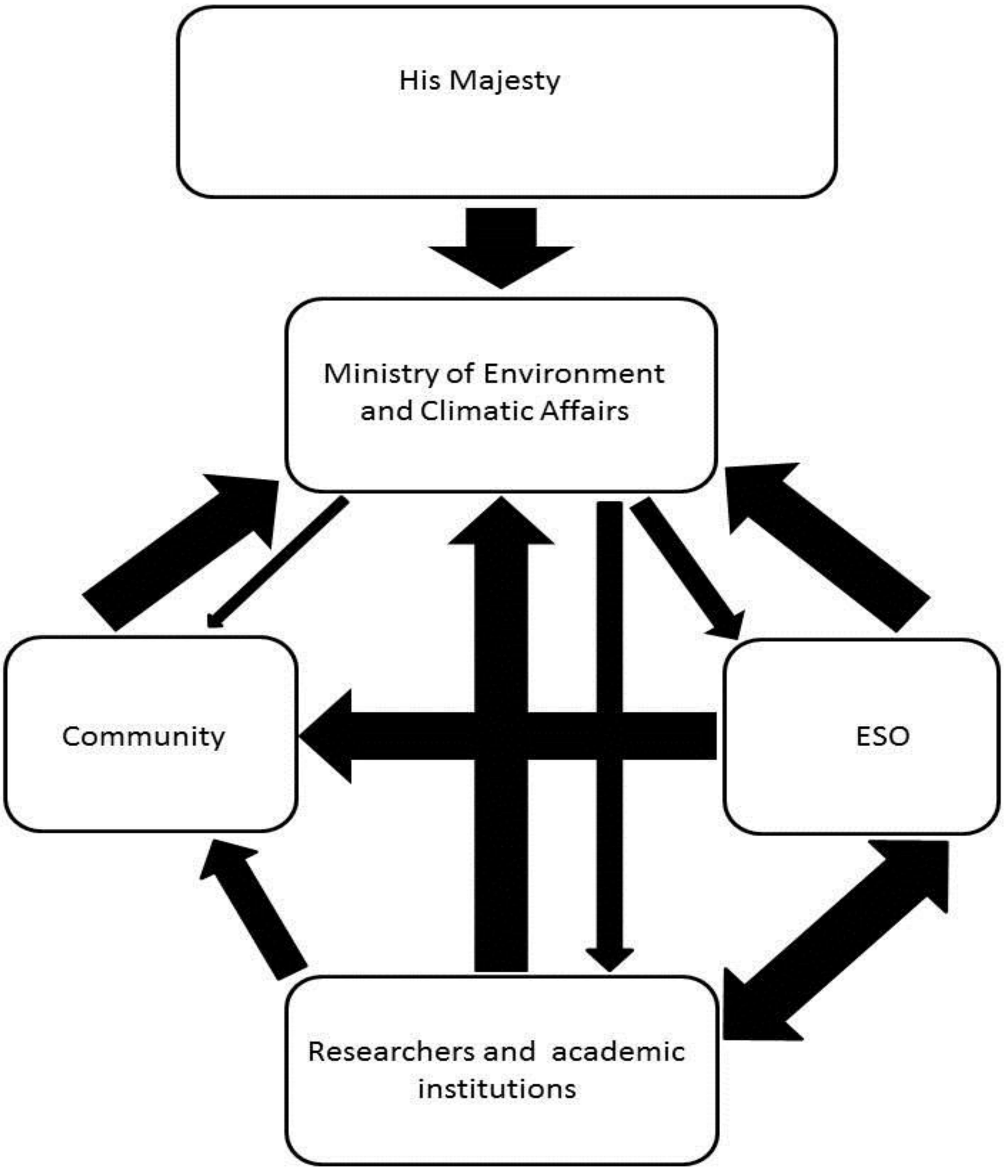


Figure 7.2. Flow chart for ecosystem management in Oman with indications of the different stakeholders involved. The width of the heads of arrows indicates the strength of linkage between stakeholders while the direction of the arrow indicates the direction of the flow in the system.

In conclusion, this thesis has demonstrated the importance of mangrove ecosystems for local communities and the nation of Oman. In reference to the MA (2005) framework used here, there is a shift in the Omani context in the intensity of linkage between the services and the human wellbeing (Figure 7.3). For example, the provisoing services of food, wood, timber and fuel supply are less significant in the contribution of wellbeing of the Omani communities.

This study has particularly highlighted the cultural services of mangrove ecosystems. These are commonly less tangible and less appreciated in other parts of the world compared to the services of fisheries support, storm buffer and carbon sequestration. In a semi-arid country like Oman, nature is expected to be highly appreciated and more activities of cultural and spiritual importance are expected to be practiced where green covers exist. The decline of mangroves have been reported in different places around the world and continuing this study in other sites of Oman will assist to better understand, manage and restore these valuable habitats.

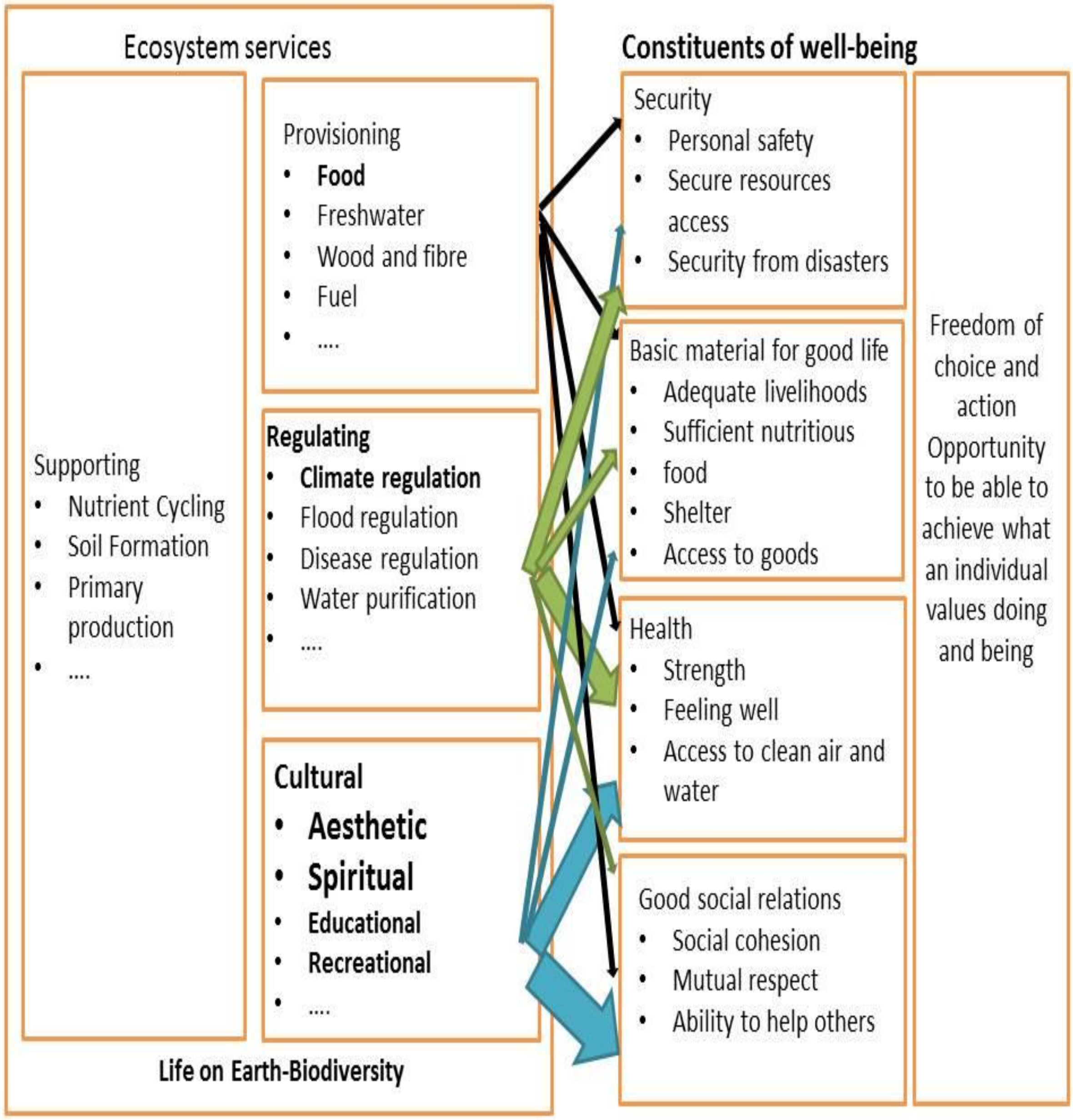


Figure 7.3. Visualisation of the MA Framework for Omani mangroves based on the findings of this study. The services in **Bold** indicate the most significant services and the width of arrows indicate the degree of link of these services to the constituents of wellbeing of the Omani community.

7.4. Recommendations and suggestions for further work

This study recommends extending its approach to other mangrove ecosytems in Oman for a better understanding of their contribution to the wellbeing of the Omani communities. The study recommends avoid summer time to collect research data (due to the heat), particularly those related to public views and perceptions. Due to the high degree of illiteracy among the older generation in Oman (60 years and older), the study recommends using interviews instead of self-administered questionnaires as used initially in this study.

With respect to the contribution of mangroves to fisheries in Oman, the study recommends following an empirical approach by sampling ecosytems at different times of the year. This would also require the sampling of neighbouring ecosytems like mud flats, coral reefs and seagrass beds for better identification of the role of mangroves as nursery grounds, feeding grounds or as refugia.

A revised approach by policy makers regarding the management of mangroves is also recommended by this study. An involvement of locals in decision making should be a key requirement for management plans in Oman. The gap between policy and science needs to be reduced and the gap between locals and policy makers needs to be bridged. This study believes that the engagemnet of both scientific and local knowledge is helpful for better understaning of the flow of services in the ecosystem and consequently framing proper management plans needed for the sustainable use of these services.

Appendices

Appendix 3.1. Self-completion questionnaire conducted from July to mid- September 2015 in the 3 contrasting mangrove sites of Al-Qurum, Qurayyat and Al-Sawadi.

Questionnaire No [ ]

Date: / /2015

Name of site: ☐Al-Qurum ☐Mahout ☐Al-Swadi

1. Opinion and attitudes towards nature in general and mangroves in particular

1.1. What does the term "Al-Qurum" mean to you?

____

____

____

____

1.2. Can you identify any benefits of estuarine trees? If yes, please list them.

____

____

____

____

1.3 Have you noticed any changes in these trees since visiting this area? If yes, what kind of changes and over what period of time?

____

____

____

____

1.4. What benefits can we get from nature? List the ones you know.

a.______________________________

b.______________________________

c.______________________________

d.______________________________

e.______________________________

f.______________________________

g.____

h.____

i.____

j.____

2. Significance of ecosystem services provided by mangroves

2.1. How important to you are the things that nature provides for you?

Benefit	Highly significant	Significant	Insignificant	Highly insignificant	Don't know
Important to my religion					
Somewhere to learn					
Somewhere to relax					
Gives inspiration					
Meditation					
It's beautiful					
Important to culture					
Protects us from storms					
Keeps the air clean					
Controls the climate					
Stops land erosion					
Purifies the water					
Pollination					

3. Public activities at sites

3.1. Do you live in ☐Al-Qurum ☐Al-Sawadi ☐Mahout?

If YES, how long have you been here? ____________________

If NO, where do you come from? ________________________

3.2. What kind of activities do you or have you practiced here?

Activity	Active practice in mangroves area?	Everywhere?	No practice
Commercial fishing			
Fishing for the household			
Collecting timber wood			
Collecting firewood			
Collecting charcoal wood			
Pharmaceutical products harvest			
Ornamental products collection			
Animals' fodder harvest			
Staying in hotels			
Visiting restaurants and coffee bars			
Camping			
Walking			
Cycling			
Horse riding			
Playing ball sports			
Relaxation			
Meeting friends or neighbours			
Bird watching			
Angling			
Educational purposes			
Spiritual purposes			
Inspirational purposes			

3.3. How often do you come to this area? Please be specific.

____

4. Socio-economic characteristics

4.1. Gender ☐Male ☐Female

4.2. Age ☐<20 ☐21-30 ☐31-40 ☐41-50 ☐51-60 ☐51-60 ☐61-70

4.3. Level of Education

☐Primary ☐Preparatory ☐Secondary ☐Diploma ☐High Diploma

☐Bachelor ☐MSc/MA ☐MPhil/Ph.D/Eng.D ☐Illiterate

4.4. What is your profession?

____

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Appendix 4.1. An updated survey of fishery and non-fishery finfish and shellfish species in Oman (Mang: mangroves inhabitant, Estu: estuaries inhabitant, R: rarely).

Bony Fish (Teleosts)				
	Scientific name	Common name	Mang	Estu
1	*Abalistes stellatus*	Starry triggerfish	-	yes
2	*Ablabys binotatus*	Redskinfish	-	-
3	*Ablennes hians*	Flat needlefish	yes	yes
4	*Abudefduf notatus*	Yellowtail sergeant	-	-
5	*Abudefduf saxatilis*	Sergeant-major	yes	
6	*Abudefduf sexfasciatus*	Scissortail sergeant	-	-
7	*Abudefduf sordidus*	Blackspot sergeant	yes	
8	*Abudefduf vaigiensis*	Indo-Pacific sergeant	yes	yes
9	*Acanthocepola abbreviata*	Bandfish	-	-
10	*Acanthocybium solandri*	Wahoo	-	-
11	*Acanthopagrus berda*	Goldsilk seabream	yes	yes
12	*Acanthopagrus bifasciatus*	twobar seabream	yes	
13	*Acanthopagrus latus*	yellowfin seabream		yes
14	*Acanthopagrus* sp.	Seabream	-	-
15	*Acanthoplesiops indicus*	Scottie	-	-
16	*Acanthurus dussumieri*	Eyestripe surgeonfish	yes	yes
17	*Acanthurus gahhm*	Black surgeonfish	yes	
18	*Acanthurus leucosternon*	Powderblue surgeonfish	yes	
19	*Acanthurus mata*	Mata Surgeonfish	yes	yes
20	*Acanthurus sohal*	Sohal surgeonfish	yes	yes
21	*Acanthurus tennentii*	Doubleband surgeonfish	yes	yes
22	*Acanthurus triostegus*	Convict surgeonfish	yes	
23	*Acanthurus xanthopterus*	Yellowfin surgeonfish	yes	yes
24	*Acentrogobius audax*	Mangrove goby	yes	
25	*Acentrogobius dayi*	Day's goby		yes
26	*Acentrogobius nebulosus*	Shadow goby	yes	
27	*Acentronura tentaculata*	Shortpouch pygmy pipehorse	-	-
28	*Acropoma japonicum*	Glowbelly	yes	
29	*Aethaloperca rogaa*	Redmouth grouper	-	-
30	*Albula argentea*	Longjaw bonefish	-	-
31	*Albula glossodonta*	Roundjaw bonefish	yes	
32	*Alectis ciliaris*	African pompano	-	-
33	*Alectis indica*	Indian threadfish	yes	
34	*Alepes djedaba*	Shrimp scad	-	-
35	*Alepes kleinii*	Razorbelly scad	-	-

36	*Alepes melanoptera*	Blackfin scad	-	-
37	*Alepes vari*	Herring scad	yes	yes
38	*Alloblennius parvus*	Dwarf blenny		yes
39	*Allenbatrachus grunniens*	Grunting toadfish	yes	yes
40	*Alticus kirkii*	Kirk's blenny		yes
41	*Aluterus monoceros*	Unicorn leatherjacket filefish		yes
42	*Aluterus scriptus*	Scribbled leatherjacket filefish		yes
43	*Amanses scopas*	Broom filefish	-	-
44	*Ambassis gymnocephalus*	Bald glassy		yes
45	*Ambassis natalensis*	Slender glassy	yes	yes
46	*Amblyeleotris aurora*	Pinkbar goby	-	-
47	*Amblyeleotris diagonalis*	Diagonal shrimp goby	-	-
48	*Amblyeleotris downingi*	Downing's shrimpgoby	-	-
49	*Amblyeleotris periophthalma*	Periophthalma prawn-goby	-	-
50	*Amblyeleotris sungami*	Magnus' prawn-goby	-	-
51	*Amblyeleotris triguttata*	Triplespot shrimpgoby	-	-
52	*Amblyeleotris wheeleri*	Gorgeous prawn-goby	-	-
53	*Amblygaster sirm*	Spotted sardinella	yes	
54	*Amblygobius albimaculatus*	Butterfly goby	yes	yes
55	*Amblygobius nocturnus*	Nocturn goby	yes	yes
56	*Amphiprion clarkii*	Yellowtail clownfish		yes
57	*Amphiprion omanensis*	Oman anemonefish		yes
58	*Amphiprion sebae*	Sebae anemonefish		yes
59	*Anampses caeruleopunctatus*	Bluespotted wrasse	-	-
60	*Anampses lineatus*	Lined wrasse	-	-
61	*Anampses meleagrides*	Spotted wrasse	-	-
62	*Anguilla* sp.	Eel	-	-
63	*Antennablennius adenensis*	Aden blenny	yes	
64	*Antennablennius australis*	Moustached rockskipper	yes	
65	*Antennablennius bifilum*	Horned rockskipper	yes	
66	*Antennablennius hypenetes*	Arabian blenny	yes	
67	*Antennablennius simonyi*	Simony's blenny	yes	
68	*Antennablennius variopunctatus*	Orangedotted blenny	yes	
69	*Antennatus coccineus*	Scarlet frogfish	-	-
70	*Antennarius commerson*	Commerson's frogfish	-	-
71	*Antennarius indicus*	Indian frogfish	-	-
72	*Antennatus nummifer*	Spotfin frogfish	-	-
73	*Antennarius pictus*	Painted frogfish		yes
74	*Antigonia rubescens*	Indo-Pacific boarfish	-	-
75	*Anodontostoma chacunda*	Chacunda gizzard shad	yes	yes
76	*Anyperodon leucogrammicus*	Slender grouper	yes	

77	*Aphanius dispar*	Arabian pupfish	yes	yes
78	*Aphareus furca*	Small toothed jobfish	-	-
79	*Aphareus rutilans*	Rusty jobfish	-	-
80	*Apistus carinatus*	Ocellated waspfish	yes	
81	*Apogon coccineus*	Ruby cardinalfish	-	-
82	*Apogon dhofar*	Dhofar cardinalfish	-	-
83	*Apogon semiornatus*	Oblique-banded cardinalfish	-	-
84	*Apogonichthyoides nigripinnis*	Bullseye	-	-
85	*Apogonichthyoides pseudotaeniatus*	Doublebar cardinalfish	-	-
86	*Apogonichthyoides taeniatus*	Twobelt cardinal	yes	
87	*Apogonichthyoides timorensis*	Timor cardinalfish	-	-
88	*Apolemichthys xanthotis*	Yellow-ear angelfish	-	-
89	*Aprion virescens*	Green jobfish	-	-
90	*Argyrops filamentosus*	Soldierbream	-	-
91	*Argyrops spinifer*	King soldier bream	yes	
92	*Argyrosomus amoyensis*	Amoy croaker	-	-
93	*Argyrosomus heinii*	Arabian sea meagre		yes
94	*Argyrosomus hololepidotus*	Southern meagre		yes
95	*Argyrosomus regius*	Meagre		yes
96	*Ariomma indicum*	Indian driftfish		yes
97	*Arius maculatus*	Spotted catfish	yes	yes
98	*Arnoglossus arabicus*	Arabian flounder	-	-
99	*Arnoglossus aspilos*	Spotless lefteye flounder	-	-
100	*Arnoglossus tapeinosoma*	Drab flounder	-	-
101	*Arothron hispidus*	White-spotted puffer	yes	yes
102	*Arothron immaculatus*	Blackedged puffer	yes	yes
103	*Arothron meleagris*	Guineafowl puffer		yes
104	*Arothron nigropunctatus*	Blackspotted puffer	-	-
105	*Arothron stellatus*	Stellate puffer	yes	yes
106	*Aspidontus taeniatus*	False cleanerfish	yes	
107	*Asterropteryx semipunctata*	Starry goby		yes
108	*Astronesthes martensii*	Snaggletooths	-	-
109	*Atherinomorus lacunosus*	Hardyhead silverside	yes	
110	*Atractoscion aequidens*	Geelbeck croaker	yes	
111	*Atropus atropos*	Cleftbelly trevally		yes
112	*Atule mate*	Yellowtail scad	yes	
113	*Aulostomus chinensis*	Chinese trumpetfish	-	-
114	*Auxis rochei*	Bullet tuna	-	-
115	*Auxis thazard*	Frigate tuna	-	-
116	*Balistoides viridescens*	Titan triggerfish	-	-
117	*Bathygobius meggitti*	Meggitt's goby	-	-

118	*Benthosema fibulatum*	Spinycheek lanternfish	-	-
119	*Benthosema pterotum*	Skinnycheek lanternfish	yes	yes
120	*Beryx decadactylus*	Alfonsino	-	yes
121	*Beryx splendens*	Splendid alfonsino	-	yes
122	*Bifax lacinia*	Two-faced toadfish	-	-
123	*Blenniella periophthalmus*	Blue-dashed rockskipper	-	-
124	*Bodianus axillaris*	Axilspot hogfish	-	-
125	*Bodianus diana*	Diana's hogfish	-	-
126	*Bodianus macrognathos*	Giant hogfish	-	-
127	*Boleophthalmus dussumieri*	Dussumier's mudskipper	yes	yes
128	*Bolinichthys longipes*	Popeye lampfish	-	-
129	*Boops lineatus*	Striped boga	yes	
130	*Bothus mancus*	Flowery flounder	-	-
131	*Bothus myriaster*	Indo-Pacific oval flounder	-	-
132	*Bothus pantherinus*	Leopard flounder	yes	yes
133	*Brachirus orientalis*	Oriental sole		yes
134	*Brachypleura novaezeelandiae*	Yellow-dabbled flounder		yes
135	*Brachypterois serrulata*	Sawcheek scorpionfish		yes
136	*Brachysomophis cirrocheilos*	Stargazer snake eel	-	-
137	*Brachysomophis crocodilinus*	Crocodile snake eel	-	-
138	*Bregmaceros nectabanus*	Smallscale codlet	yes	
139	*Brotula multibarbata*	Goatsbeard brotula	yes	yes
140	*Bryaninops natans*	Redeye goby	-	-
141	*Bryaninops tigris*	Black coral goby	-	-
142	*Bryx analicarens*	Pink pipefish	-	-
143	*Caesio caerulaurea*	Blue and gold fusilier	-	-
144	*Caesio lunaris*	Lunar fusilier	-	-
145	*Caesio varilineata*	Variable-lined fusilier	-	-
146	*Calotomus carolinus*	Carolines parrotfish		yes
147	Callionymus carebares	Indian deepwater dragonet	-	-
148	*Callionymus erythraeus*	Smallhead dragonet	-	-
149	*Callionymus filamentosus*	Blotchfin dragonet	-	-
150	*Callionymus hindsii*	Hinds' dragonet	-	-
151	*Callionymus margaretae*	Margaret's dragonet	-	-
152	*Callionymus marleyi*	Sand dragonet	-	-
153	*Callionymus muscatensis*	Muscat dragonet	-	-
154	*Callionymus persicus*	Persian dragonet	-	-
155	*Callogobius amikami*	Clown goby		yes
156	*Callogobius bifasciatus*	Doublebar goby		yes
157	*Callogobius plumatus*	Feather goby		yes
158	*Calloplesiops altivelis*	Comet	-	-

159	*Cantherhines dumerilii*	Whitespotted filefish	-	-
160	*Cantherhines pardalis*	Honeycomb filefish	-	-
161	*Canthidermis macrolepis*	Largescale triggerfish	-	-
162	*Canthigaster coronata*	Crowned puffer	-	-
163	*Canthigaster rivulata*	Brown-lined puffer	-	-
164	*Canthigaster solandri*	Spotted shaprnose puffer	-	-
165	*Canthigaster valentini*	Valentin's sharpnose puffer	-	-
166	*Carangoides armatus*	Longfin trevally		yes
167	*Carangoides bajad*	Orangespotted trevally	-	-
168	*Carangoides coeruleopinnatus*	Coastal trevally	-	-
169	*Carangoides chrysophrys*	Longnose trevally	yes	-
170	*Carangoides equula*	Whitefin trevally	-	-
171	*Carangoides ferdau*	Blue trevally	-	-
172	*Carangoides fulvoguttatus*	Yellowspotted trevally	-	-
173	*Carangoides gymnostethus*	Bludger		yes
174	*Carangoides hedlandensis*	Bumpnose trevally	-	-
175	*Carangoides malabaricus*	Malabar trevally	-	-
176	*Carangoides praeustus*	Brownback trevally	-	yes
177	*Carangoides talamparoides*	Imposter trevally	-	-
178	*Caranx heberi*	Blacktip trevally	-	yes
179	*Caranx ignobilis*	Giant trevally		yes
180	*Caranx lugubris*	Black jack	-	-
181	*Caranx melampygus*	Bluefin trevally	yes	yes
182	*Caranx sexfasciatus*	Bigeye trevally	yes	yes
183	*Centriscus scutatus*	Grooved razor-fish	-	-
184	*Centropyge acanthops*	Orangeback angelfish	-	-
185	*Centropyge acanthops*	Orangeback angelfish	-	-
186	*Centropyge multispinis*	Dusky angelfish	-	-
187	*Cephalopholis argus*	Peacock hind	-	-
188	*Cephalopholis aurantia*	Golden hind	-	-
189	*Cephalopholis boenak*	Chocolate hind	-	-
190	*Cephalopholis formosa*	Bluelined hind	-	-
191	*Cephalopholis hemistiktos*	Yellowfin hind	-	-
192	*Cephalopholis miniata*	Coral hind	-	-
193	*Cephalopholis nigripinnis*	Blackfin grouper	-	-
194	*Cephalopholis sexmaculata*	Sixblotch hind	-	-
195	*Cephalopholis sonnerati*	Tomato hind	-	-
196	*Chaetodon auriga*	Threadfin butterflyfish	yes	
197	*Chaetodon austriacus*	Blacktail butterflyfish	-	-
198	*Chaetodon citrinellus*	Speckled butterflyfish	-	-
199	*Chaetodon collare*	Redtail butterflyfish		yes

200	*Chaetodon decussatus*	Indian vagabond butterflyfish	-	-
201	*Chaetodon dialeucos*	Oman butterflyfish	-	-
202	*Chaetodon gardineri*	Gardner's butterflyfish	-	-
203	*Chaetodon jayakari*	Indian golden-barred butterflyfish	-	-
204	*Chaetodon larvatus*	Hooded butterflyfish	-	-
205	*Chaetodon leucopleura*	Somali butterflyfish	-	-
206	*Chaetodon lunula*	Raccoon butterflyfish	-	-
207	*Chaetodon melannotus*	Blackback butterflyfish	-	-
208	*Chaetodon melapterus*	Arabian butterflyfish	-	-
209	*Chaetodon nigropunctatus*	Black-spotted butterflyfish	yes	
210	*Chaetodon semilarvatus*	Bluecheek butterflyfish	-	-
211	*Chaetodon trifascialis*	Chevron butterflyfish	-	-
212	*Chaetodon vagabundus*	Vagabond butterflyfish	yes	
213	*Champsodon omanensis*	Oman gaper	-	-
214	*Chanos chanos*	Milkfish	yes	yes
215	*Cheilinus chlorourus*	Floral wrasse	-	-
216	*Cheilinus fasciatus*	Redbreasted wrasse	-	-
217	*Cheilinus lunulatus*	Broomtail wrasse	-	-
218	*Cheilinus trilobatus*	Tripletail wrasse	-	-
219	*Cheilinus undulatus*	Humphead wrasse	-	-
220	*Cheilio inermis*	Cigar wrasse	-	-
221	*Chelidonichthys kumu*	Bluefin gurnard		yes
222	*Cheilodipterus arabicus*	Tiger cardinal	-	-
223	*Cheilodipterus macrodon*	Large toothed cardinalfish		yes
224	*Cheilodipterus novemstriatus*	twospot cardinalfish	-	-
225	*Cheilodipterus persicus*	Persian cardinalfish	-	-
226	*Cheilodipterus quinquelineatus*	Five-lined cardinalfish	-	-
227	*Cheilopogon atrisignis*	Glider flyingfish	-	-
228	*Cheilopogon cyanopterus*	Margined flyingfish	-	-
229	*Cheilopogon furcatus*	Spotfin flyingfish	-	-
230	*Cheilopogon nigricans*	Blacksail flyingfish	-	-
231	*Cheilopogon suttoni*	Sutton's flyingfish	-	-
232	*Cheimerius nufar*	Santer seabream		yes
233	*Chelonodon patoca*	Milkspotted puffer		yes
234	*Chelon planiceps*	Tade gray mullet		yes
235	*Chelon tricuspidens*	Striped mullet		yes
236	*Chilomycterus reticulatus*	Spotfin burrfish	-	-
237	*Chirocentrus dorab*	Dorab wolf-herring	yes	
238	*Chirocentrus nudus*	Whitefin wolf-herring	yes	
239	*Chlidichthys cacatuoides*	Cockatoo dottyback	-	-

240	*Chlorophthalmus corniger*	Spinyjaw greeneye	-	-
241	*Chlorurus sordidus*	Daisy parrotfish	yes	
242	*Chlorurus strongylocephalus*	Steephead parrotfish	yes	
243	*Choerodon robustus*	Robust tuskfish	-	-
244	*Choeroichthys brachysoma*	Short-bodied pipefish	yes	
245	*Choridactylus lineatus*	Lined stingfish	-	-
246	*Choridactylus multibarbus*	Orangebanded stingfish	-	-
247	*Chromis dimidiata*	Chocolatedip chromis	-	-
248	*Chromis flavaxilla*	Arabian chromis	-	-
249	*Chromis pembae*	Pemba chromis	-	-
250	*Chromis weberi*	Weber's chromis	-	-
251	*Chromis xanthopterygia*	Yellowfin chromis	-	-
252	*Chrysiptera annulata*	Footballer demoiselle	-	-
253	*Chrysiptera sheila*	Sheila's damselfish	-	-
254	*Chrysiptera unimaculata*	Onespot demoiselle	-	-
255	*Cirrhilabrus rubriventralis*	Social wrasse	-	-
256	*Cirrhitichthys calliurus*	Spottedtail hawkfish	-	-
257	*Cirrhitichthys oxycephalus*	Coral hawkfish	-	-
258	*Cirrhitus pinnulatus*	Stocky hawkfish	-	-
259	*Cirripectes castaneus*	Chestnut eyelash-blenny	-	-
260	*Cirripectes filamentosus*	Filamentous blenny	yes	
261	*Clinus* sp.	Whipfish	-	-
262	*Cociella crocodilus*	Crocodile flathead	Yes-R	
263	*Colletteichthys dussumieri*	Flat toadfish		yes
264	*Conger cinereus*	Longfin African conger	yes	
265	*Cookeolus japonicus*	Longfinned bullseye	-	-
266	*Coris aygula*	Clown coris	-	-
267	*Coris caudimacula*	Spottail coris	-	-
268	*Coris cuvieri*	African coris	-	-
269	*Coris formosa*	Queen coris	-	-
270	*Coris nigrotaenia*	Blackbar coris	-	-
271	*Coryogalops adamsoni*	Adamson's goby	-	-
272	*Coryogalops anomolus*	Anomolous goby	-	-
273	*Coryogalops bulejiensis*	Thinbarred goby	-	-
274	*Coryogalops monospilus*	Onespot goby	-	-
275	*Coryogalops tessellatus*	Tessellated goby	-	-
276	*Coryphaena equiselis*	Pompano dolphinfish	-	-
277	*Coryphaena hippurus*	Common dolphinfish	-	-
278	*Corythoichthys amplexus*	Brown-banded pipefish	yes	
279	*Corythoichthys flavofasciatus*	Network pipefish	yes	
280	*Corythoichthys haematopterus*	Messmate pipefish	yes	

281	*Cosmocampus banneri*	Roughridge pipefish	-	-
282	*Cosmocampus investigatoris*	Investigator pipefish	-	-
283	*Crenidens crenidens*	Karanteen seabream	-	-
284	*Crenimugil crenilabis*	Fringelip mullet		yes
285	*Crenimugil heterocheilos*	Half fringelip mullet	-	-
286	*Crenimugil seheli*	Bluespot mullet		yes
287	*Cryptocentroides arabicus*	Arabian goby	-	-
288	*Cryptocentroides insignis*	Insignia prawn-gob	yes	
289	*Cryptocentrus fasciatus*	Y-bar shrimp goby	-	-
290	*Cryptocentrus lutheri*	Luther's prawn-goby	-	-
291	*Cryptocentrus strigilliceps*	Target shrimp goby	-	-
292	*Ctenochaetus striatus*	Striated surgeonfish	yes	
293	*Ctenochaetus strigosus*	Spotted surgeonfish	yes	
294	*Cubiceps whiteleggii*	Shadow driftfish	-	-
295	*Cupiceps* sp.	Fathead	-	-
296	*Cyclichthys orbicularis*	Birdbeak burrfish	-	-
297	*Cyclichthys spilostylus*	Spotbase burrfish	-	-
298	*Cynoglossus acutirostris*	Sharpnose tonguesole	-	-
299	*Cynoglossus arel*	Largescale tonguesole		yes
300	*Cynoglossus bilineatus*	Fourlined tonguesole	yes	
301	*Cynoglossus carpenteri*	Hooked tonguesole	-	-
302	*Cynoglossus kopsii*	Shortheaded tonguesole	-	-
303	*Cynoglossus lachneri*	Lachner's tonguesole	-	-
304	*Cynoglossus puncticeps*	Speckled tonguesole	yes	
305	*Cypselurus naresii*	Pharao flyingfish	-	-
306	*Cypselurus oligolepis*	Largescale flyingfish	-	-
307	*Cyttopsis rosea*	Rosy dory	-	-
308	*Dactyloptena orientalis*	Oriental flying gurnard	-	-
309	*Dascyllus marginatus*	Marginate dascyllus	-	-
310	*Dascyllus trimaculatus*	Threespot dascyllus	-	-
311	*Decapterus kurroides*	Redtail scad	-	-
312	*Decapterus macarellus*	Mackerel scad	-	-
313	*Decapterus macrosoma*	Shortfin scad	-	-
314	*Decapterus russelli*	Indian scad	-	-
315	*Decapterus tabl*	Roughear scad	-	-
316	*Dermatolepis striolata*	Smooth grouper	-	-
317	*Diademichthys lineatus*	Urchin clingfish	-	-
318	*Diagramma pictum*	Painted sweetlips	-	yes
319	*Diaphus arabicus*	Lanternfish	-	-
320	*Diaphus meadi*	Mead's lanternfish	-	-
321	*Diaphus thiollierei*	Thiolliere's lanternfish	-	-

322	*Diaphus* spp.	Lanternfish	-	-
323	*Dinoperca petersi*	Lampfish	-	-
324	*Diodon holocanthus*	Longspined porcupinefish	yes	
325	*Diodon hystrix*	Spot-fin porcupinefish	yes	
326	*Diodon liturosus*	Black-blotched porcupinefish		yes
327	*Diplodus capensis*	Cape white seabream		yes
328	*Diplodus cervinus*	Zebra seabream	-	-
329	*Diplodus kotschyi*	One spot seabream	-	-
330	*Diplogrammus pygmaeus*	Pygmy dragonet	-	-
331	*Dipterygonotus balteatus*	Mottled fusilier	-	-
332	*Doryrhamphus aurolineatus*	Orangestripe pipefish	-	-
333	*Doryrhamphus excisus excisus*	Bluestripe pipefish	yes	
334	*Drepane longimana*	Banded drepane	yes	
335	*Drepane punctata*	Spotted sicklefish	yes	
336	*Dussumieria acuta*	Rainbow sardine	yes	
337	*Dussumieria elopsoides*	Slender rainbow sardine	-	-
338	*Echeneis naucrates*	Live sharksucker		yes
339	*Echidna nebulosa*	Starry moray	yes	yes
340	*Ecsenius nalolo*	Nalolo blenny	yes	
341	*Ecsenius pulcher*	Gulf blenny	yes	
342	*Ego zebra*	Bighead goby	-	-
343	*Elagatis bipinnulata*	Rainbow runner	-	-
344	*Eleutheronema tetradactylum*	Fourfinger threadfin		yes
345	*Ellochelon vaigiensis*	Squaretail mullet	yes	yes
346	*Elops machnata*	Tenpounder	yes	yes
347	*Enchelycore pardalis*	Leopard moray eel	-	-
348	*Encrasicholina devisi*	Devis' anchovy		yes
349	*Encrasicholina heteroloba*	Shorthead anchovy	yes-R	
350	*Encrasicholina punctifer*	Buccaneer anchovy	yes	
351	*Engyprosopon grandisquama*	Largescale flounder	-	-
352	*Grammatobothus polyophthalmus*	Threespot flounder	-	-
353	*Enneapterygius abeli*	Yellow triplefin	-	-
354	*Enneapterygius hollemani*	Holleman's triplefin	-	-
355	*Enneapterygius melanospilus*	Spotfin triplefin	-	-
356	*Enneapterygius pusillus*	Highcrest triplefin	-	-
357	*Enneapterygius ventermaculus*	Blotched triplefin	-	-
358	*Ephippus orbis*	Orbfish	-	-
359	*Epibulus insidiator*	Sling-jaw wrasse	-	-
360	*Epinephelus areolatus*	Areolate grouper	-	-
361	*Epinephelus bleekeri*	Duskytail grouper		yes
362	*Epinephelus bruneus*	Longtooth grouper	-	-

363	*Epinephelus chlorostigma*	Brownspotted grouper	-	-
364	*Epinephelus coeruleopunctatus*	Whitespotted grouper	yes	
365	*Epinephelus coioides*	Orange-spotted grouper	yes	
366	*Epinephelus diacanthus*	Spinycheek grouper	-	-
367	*Epinephelus epistictus*	Dotted grouper	-	-
368	*Epinephelus fasciatus*	Blacktip grouper	-	-
369	*Epinephelus faveatus*	Barred-chest grouper	-	-
370	*Epinephelus flavocaeruleus*	Blue-and-yellow grouper	-	-
371	*Epinephelus fuscoguttatus*	Brown-marbled grouper	-	-
372	*Epinephelus gabriellae*	Multispotted grouper	-	-
373	*Epinephelus hexagonatus*	Starspotted grouper	-	-
374	*Epinephelus indistinctus*	Somali grouper	-	-
375	*Epinephelus lanceolatus*	Giant grouper	yes	yes
376	*Epinephelus latifasciatus*	Striped grouper	-	-
377	*Epinephelus longispinis*	Longspine grouper	-	-
378	*Epinephelus malabaricus*	Malabar grouper	yes	yes
379	*Epinephelus marginatus*	Dusky grouper	-	-
380	*Epinephelus merra*	Honeycomb grouper	yes	
381	*Epinephelus morrhua*	Comet grouper	-	-
382	*Epinephelus multinotatus*	White-blotched grouper	-	-
383	*Epinephelus poecilonotus*	Dot-dash grouper	-	-
384	*Epinephelus polylepis*	Smallscaled grouper	-	-
385	*Epinephelus radiatus*	Oblique-banded grouper	-	-
386	*Epinephelus retouti*	Red-tipped grouper	-	-
387	*Epinephelus rivulatus*	Halfmoon grouper	-	-
388	*Epinephelus stoliczkae*	Epaulet grouper	-	-
389	*Epinephelus tauvina*	Greasy grouper	yes	
390	*Epinephelus tukula*	Potato grouper	-	-
391	*Epinephelus undulosus*	Wavy-lined grouper	-	-
392	*Erythrocles schlegelii*	Japanese rubyfish	-	-
393	*Escualosa thoracata*	White sardine	-	-
394	*Etelis carbunculus*	Deep-water red snapper	-	-
395	*Etelis coruscans*	Deepwater longtail red snapper	-	-
396	*Etrumeus sadina*	Red-eye round herring		yes
397	*Eupleurogrammus glossodon*	Longtooth hairtail	yes	
398	*Eupleurogrammus muticus*	Smallhead hairtail		yes
399	*Euthynnus affinis*	Kawakawa	-	yes
400	*Eviota guttata*	Spotted dwarfgoby	-	-
401	*Eviota pardalota*	Leopard dwarfgoby	-	-
402	*Eviota prasina*	Greenbubble dwarfgoby	-	-
403	*Eviota sebreei*	Sebree's dwarfgoby	-	-

404	*Exocoetus monocirrhus*	Barbel flyingfish	-	-
405	*Exocoetus volitans*	Tropical two-wing flyingfish	-	-
406	*Favonigobius melanobranchus*	Blackthroat goby	yes	yes
407	*Favonigobius reichei*	Indo-Pacific tropical sand goby	yes	yes
408	*Fistularia commersonii*	Bluespotted cornetfish	yes	yes
409	*Fistularia petimba*	Red cornetfish	-	-
410	*Forcipiger longirostris*	Longnose butterflyfish	-	-
411	*Fowleria aurita*	Crosseyed cardinalfish	yes	
412	*Fowleria vaiulae*	Mottled cardinalfish	-	-
413	*Fowleria variegata*	Variegated cardinalfish	yes	yes
414	*Fowlerichthys scriptissimus*	Calico frogfish	-	-
415	*Fusigobius inframaculatus*	Innerspotted sandgoby		yes
416	*Fusigobius neophytus*	Common fusegoby	yes	yes
417	*Gazza achlamys*	Smalltoothed ponyfish	-	-
418	*Gazza minuta*	Toothpony	yes	
419	*Gempylus serpens*	Snake mackerel	-	-
420	*Gerres erythrourus*	Deep-bodied mojarra	yes	yes
421	*Gerres filamentosus*	Whipfin silver-biddy	yes	yes
422	*Gerres longirostris*	Strongspine silver-biddy	yes	yes
423	*Gerres oyena*	Common silver-biddy		yes
424	*Glossogobius callidus*	Tank goby		yes
425	*Gnathanodon speciosus*	Golden trevally	yes	yes
426	*Gnatholepis anjerensis*	Eye-bar goby		yes
427	*Gobiodon citrinus*	Poison goby	-	-
428	*Gobiodon reticulatus*	Reticulate goby	-	-
429	*Gobiopsis canalis*	Checkered goby	-	-
430	*Gomphosus caeruleus*	Green birdmouth wrasse	-	-
431	*Grammistes sexlineatus*	Goldenstriped soapfish	-	-
432	*Grammoplites scaber*	Rough flathead	-	-
433	*Grammoplites suppositus*	Spotfin flathead	-	-
434	*Gunnellichthys viridescens*	Yellowstripe wormfish	-	-
435	*Gymnocranius grandoculis*	Blue-lined large-eye bream	-	-
436	*Gymnomuraena zebra*	Zebra moray	yes	yes
437	*Gymnosarda unicolor*	Dogtooth tuna	-	-
438	*Gymnothorax chilospilus*	Lipspot moray	-	-
439	*Gymnothorax favagineus*	Laced moray	-	-
440	*Gymnothorax flavimarginatus*	Yellow-edged moray	-	-
441	*Gymnothorax flavoculus*	Palenose moray	-	-
442	*Gymnothorax griseus*	Geometric moray	-	-
443	*Gymnothorax herrei*	Herre's moray	-	-
444	*Gymnothorax javanicus*	Giant moray	-	-

445	*Gymnothorax megaspilus*	Oman moray	-	-
446	*Gymnothorax nudivomer*	Yellowmouth moray	-	-
447	*Gymnothorax phasmatodes*	Ghost moray	-	-
448	*Gymnothorax pictus*	Paintspotted moray	-	-
449	*Gymnothorax pseudothyrsoideus*	Highfin moray	-	-
450	*Gymnothorax undulatus*	Undulated moray	yes	yes
451	*Halicampus macrorhynchus*	Ornate pipefish	-	-
452	*Halicampus mataafae*	Samoan pipefish	-	-
453	*Halicampus zavorensis*	Zavora pipefish	-	-
454	*Halichoeres hortulanus*	Checkerboard wrasse	-	-
455	*Halichoeres iridis*	Rainbow wrasse	-	-
456	*Halichoeres lapillus*	Jewelled wrasse	-	-
457	*Halichoeres leptotaenia*	Thinstriped wrasse	-	-
458	*Halichoeres marginatus*	Dusky wrasse	-	-
459	*Halichoeres melas*	Black wrasse	-	-
460	*Halichoeres nebulosus*	Nebulous wrasse	-	-
461	*Halichoeres nigrescens*	Bubblefin wrasse	-	-
462	*Halichoeres scapularis*	Zigzag wrasse	-	-
463	*Halichoeres signifer*	Flag signifer	-	-
464	*Halichoeres stigmaticus*	U-spot wrasse	-	-
465	*Halichoeres zeylonicus*	Goldstripe wrasse	-	-
466	*Halidesmus coccus*	Rooster snakelet	-	-
467	*Halidesmus thomaseni*	Thomasen's snakelet	-	-
468	*Haliophis diademus*	Stars-and-stripes snakelet	-	-
469	*Haliophis guttatus*	African eel blenny	-	-
470	*Harpadon nehereus*	Bombay-duck	yes	yes
471	*Helcogramma fuscopinna*	Blackfin triplefin	-	-
472	*Helcogramma obtusirostris*	Hotlips triplefin	-	-
473	*Helcogramma steinitzi*	Red triplefin	-	-
474	*Heniochus acuminatus*	Pennant coralfish	yes	
475	*Hemigymnus fasciatus*	Barred thicklip	-	-
476	*Hemigymnus melapterus*	Blackeye thicklip	-	-
477	*Hemiramphus archipelagicus*	Jumping halfbeak	-	-
478	*Hemiramphus far*	Spotted halfbeak	yes	yes
479	*Hemiramphus marginatus*	Yellowtip halfbeak	-	-
480	*Hemitaurichthys zoster*	Brown-and-white butterflyfish	-	-
481	*Heniochus acuminatus*	Pennant coralfish	-	-
482	*Heniochus diphreutes*	False moorish idol	-	-
483	*Herklotsichthys lossei*	Gulf herring	Near	-
484	*Herklotsichthys quadrimaculatus*	Bluestripe herring	Near	-
485	*Hetereleotris vulgaris*	Common goby	-	-

486	*Heterelectris zonata*	Goggles	-	-
487	*Hilsa kelee*	Kelee shad		yes
488	*Hippichthys cyanospilos*	Blue-spotted pipefish	yes	
489	*Hippichthys penicillus*	Beady pipefish	yes	
490	*Hippocampus fuscus*	Sea pony		yes
491	*Hippocampus histrix*	Spiny seahorse	-	-
492	*Hippocampus kuda*	Spotted seahorse	yes	
493	*Hipposcarus harid*	Candelamoa parrotfish	yes	
494	*Hirculops cornifer*	Highbrow rockskipper	-	-
495	*Hirundichthys coromandelensis*	Coromandel flyingfish	-	-
496	*Hirundichthys oxycephalus*	Bony flyingfish	-	-
497	*Histiopterus typus*	Sailfin armourhead	-	-
498	*Histrio histrio*	Sargassumfish	yes	
499	*Holapogon maximus*	Titan cardinalfish	-	-
500	*Hologymnosus annulatus*	Ring wrasse	-	-
501	*Hologymnosus doliatus*	Pastel ringwrasse	-	-
502	*Hoplosthethus* sp.	Slimeheads	-	-
503	*Hypoatherina temminckii*	Samoan silverside	-	-
504	*Hyporhamphus dussumieri*	Dussumier's halfbeak	-	-
505	*Hyporhamphus limbatus*	Congaturi halfbeak	-	-
506	*Hyporhamphus sindensis*	Sind halfbeak	-	-
507	*Hyporhamphus unicuspis*	Simpletooth halfbeak	-	-
508	*Iniistius bimaculatus*	Two-spot razorfish	-	-
509	*Istigobius decoratus*	Decorated goby	yes	
510	*Istigobius ornatus*	Ornate goby	yes	
511	*Istiompax indica*	Black marlin	-	-
512	*Istiophorus platypterus*	Indo-Pacific sailfish	-	-
513	*Ilisha compressa*	Compressed ilisha		yes
514	*Ilisha megaloptera*	Bigeye ilisha		yes
515	*Ilisha melastoma*	Indian ilisha		yes
516	*Ilisha sirishai*	Lobejaw ilisha		yes
517	*Iniistius bimaculatus*	Two-spot razorfish	-	-
518	*Iniistius pavo*	Peacock wrasse		yes
519	*Iniistius pentadactylus*	Fivefinger wrasse	-	-
520	*Istiblennius edentulus*	Rippled rockskipper	yes	
521	*Istiblennius flaviumbrinus*	Spotted rockskipper	yes	
522	*Istiblennius pox*	Scarface rockskipper	yes	
523	*Istiblennius spilotus*	Spotted rockskipper	yes	
524	*Jaydia lineata*	Indian perch	-	-
525	*Jaydia queketti*	Spotfin cardinal	-	-
526	*Jaydia truncata*	Flagfin cardinalfish	-	-

527	*Johnius belangerii*	Belanger's croaker		yes
528	*Johnius borneensis*	Sharpnose hammer croaker		yes
529	*Johnius carutta*	Karut croaker		yes
530	*Johnius dussumieri*	Sin croaker		yes
531	*Kajikia audax*	Striped marlin	-	-
532	*Karalla daura*	Goldstripe ponyfish	-	-
533	*Katsuwonus pelamis*	Skipjack tuna	-	-
534	*Kuhlia mugil*	Barred flagtail		yes
535	*Kumococius rodericensis*	Spiny flathead	-	-
536	*Kyphosus bigibbus*	Brown chub	-	-
537	*Kyphosus cinerascens*	Blue sea chub	-	-
538	*Kyphosus vaigiensis*	Brassy chub	-	-
539	*Labroides bicolor*	Bicolor cleaner wrasse	-	-
540	*Labroides dimidiatus*	Bluestreak cleaner wrasse	-	-
541	*Lactarius lactarius*	False trevally	-	-
542	*Lactoria cornuta*	Longhorn cowfish		yes
543	*Laeops guentheri*	Günther's flounder	-	-
544	*Lagocephalus guentheri*	Diamondback puffer	yes	
545	*Lagocephalus lunaris*	Lunartail puffer	yes	yes
546	*Lagocephalus sceleratus*	Silver-cheeked toadfish	-	-
547	*Lamnostoma orientalis*	Oriental worm-eel		yes
548	*Larabicus quadrilineatus*	Fourline wrasse	-	-
549	*Leiognathus equulus*	Common ponyfish	yes	
550	*Leiognathus fasciatus*	Striped ponyfish	yes	
551	*Leiognathus oblongus*	Oblong ponyfish	-	-
552	*Lepadichthys lineatus*	Doubleline clingfish	-	-
553	*Lepidamia multitaeniata*	Smallscale cardinal	-	-
554	*Lepidamia natalensis*	Manyline cardinalfish	-	-
555	*Lepidamia omanensis*	Oman cardinalfish	-	-
556	*Lepidocybium flavobrunneum*	Escolar		yes
557	*Lepidotrigla bentuviai*	Twohorn gurnard	-	-
558	*Lepidotrigla bispinosa*	Bullhorn gurnard	-	-
559	*Lepidotrigla faurei*	Scalybreast gurnard	-	-
560	*Lepidotrigla omanensis*	Oman gurnard	-	-
561	*Lepidotrigla spiloptera*	Spotwing gurnard	-	-
562	*Leptojulis cyanopleura*	Shoulder-spot wrasse	-	-
563	*Leptoscarus vaigiensis*	Marbled parrotfish	yes	
564	*Lestidiops jayakari*	Pacific barracudina	-	-
565	*Lethrinus borbonicus*	Snubnose emperor	-	-
566	*Lethrinus erythracanthus*	Orange-spotted emperor	-	-
567	*Lethrinus harak*	Thumbprint emperor	yes	

568	Lethrinus lentjan	Pink ear emperor	yes	
569	*Lethrinus mahsena*	Sky emperor	-	-
570	*Lethrinus microdon*	Smalltooth emperor	-	-
571	*Lethrinus nebulosus*	Spangled emperor	yes	yes
572	*Lethrinus obsoletus*	Orange-striped emperor	yes	
573	*Lethrinus olivaceus*	Longface emperor	-	-
574	*Lethrinus variegatus*	Slender emperor	yes	yes
575	*Lethrinus semicinctus*	Black blotch emperor	yes	
576	*Lethrinus xanthochilus*	Yellowlip emperor	-	-
577	*Lipocheilus carnolabrum*	Tang's snapper	-	-
578	*Lithognathus mormyrus*	Sand steenbras	-	-
579	*Liza klunzingeri*	Klunzinger's mullet	-	-
580	*Liza persicus*	Persian mullet	-	-
581	*Lobotes surinamensis*	Tripletail	yes	yes
582	*Lobulogobius omanensis*	Oman goby	-	-
583	*Lophiodes mutilus*	Smooth angler	-	-
584	*Lophiomus setigerus*	Blackmouth angler	-	-
585	*Lophodiodon calori*	Four-bar porcupinefish	-	-
586	*Lutjanus argentimaculatus*	Mangrove red snapper	yes	
587	*Lutjanus bengalensis*	Bengal snapper	-	-
588	*Lutjanus bohar*	Two-spot red snapper	yes	
589	*Lutjanus coeruleolineatus*	Blueline snapper	-	-
590	*Lutjanus ehrenbergii*	Blackspot snapper	yes	
591	*Lutjanus erythropterus*	Crimson snapper	-	-
592	*Lutjanus fulviflamma*	Dory snapper	yes	
593	*Lutjanus fulvus*	Blacktail snapper	yes	
594	*Lutjanus gibbus*	Humpback red snapper	-	
595	*Lutjanus johnii*	John's snapper	yes	
596	*Lutjanus kasmira*	Common bluestripe snapper	yes	
597	*Lutjanus lunulatus*	Lunartail snapper	-	-
598	*Lutjanus lutjanus*	Bigeye snapper	-	-
599	*Lutjanus madras*	Indian snapper	-	-
600	*Lutjanus malabaricus*	Malabar blood snapper	-	-
601	*Lutjanus monostigma*	One-spot snapper	yes	
602	*Lutjanus quinquelineatus*	Five-lined snapper	-	-
603	*Lutjanus rivulatus*	Blubberlip snapper	-	-
604	*Lutjanus russellii*	Russell's snapper	yes	
605	*Lutjanus sanguineus*	Humphead snapper	-	-

606	*Lutjanus sebae*	Emperor red snapper	yes	
607	*Lutjanus vitta*	Brownstripe red snapper	-	-
608	*Macolor niger*	Black and white snapper	-	-
609	*Macropharyngodon bipartitus*	Rare wrasse	-	-
610	*Makaira nigricans*	Blue marlin	-	-
611	*Malacanthus latovittatus*	Blue blanquillo	-	-
612	*Malacocephalus laevis*	Softhead grenadier	-	-
613	*Megalaspis cordyla*	Torpedo scad	yes	-
614	*Melichthys indicus*	Indian triggerfish	-	-
615	*Mene maculata*	Moonfish		yes
616	*Megalops cyprinoides*	Indo-Pacific tarpon	yes	yes
617	*Micrognathus andersonii*	Shortnose pipefish	yes	
618	*Mimoblennius cirrosus*	Fringed blenny	yes	
619	*Minous coccineus*	Onestick stingfish	-	-
620	*Minous dempsterae*	Obliquebanded stingfish	-	-
621	*Minous inermis*	Alcock's scorpionfish	-	-
622	*Minous monodactylus*	Grey stingfish	-	-
623	*Mola mola*	Ocean sunfish	-	-
624	*Monocentris japonica*	Pineconefish	-	-
625	*Monodactylus argenteus*	Silver moony	yes	
626	*Monodactylus falciformis*	Full moony	yes	yes
627	*Monotaxis grandoculis*	Humpnose big-eye bream	-	-
628	*Moolgarda pedaraki*	Longfin mullet	-	-
629	*Mugil cephalus*	Flathead grey mullet	yes	yes
630	*Mulloidichthys flavolineatus*	Yellowstripe goatfish	yes	yes
631	*Mulloidichthys vanicolensis*	Yellowfin goatfish	yes	
632	*Muraenesox cinereus*	Daggertooth pike conger		yes
633	*Muraenichthys schultzei*	Maimed snake eel	-	-
634	*Myctophum spinosum*	Spiny lantern fish	-	-
635	*Myersina filifer*	Filamentous shrimpgoby	-	-
636	*Myrichthys colubrinus*	Harlequin snake eel	-	-
637	*Myrichthys maculosus*	Tiger snake eel	-	-
638	*Myripristis murdjan*	Pinecone soldierfish	-	-
639	*Naso fageni*	Horseface unicornfish	yes	
640	*Naso lituratus*	Orangespine unicornfish	yes	
641	*Naso thynnoides*	Oneknife unicornfish	yes	
642	*Naso unicornis*	Bluespine unicornfish	yes	
643	*Naucrates ductor*	Pilotfish	-	-
644	*Nematalosa arabica*	Arabian gizzard shad	-	-

645	*Nematalosa nasus*	Bloch's gizzard shad		yes
646	*Nemipterus bipunctatus*	Delagoa threadfin bream	-	-
647	*Nemipterus japonicus*	Japanese threadfin bream	-	
648	*Nemipterus marginatus*	Red filament threadfin bream	-	-
649	*Nemipterus mesoprion*	Mauvelip threadfin bream	-	
650	*Nemipterus nemurus*	Redspine threadfin bream	-	-
651	*Nemipterus peronii*	Notchedfin threadfin bream	-	-
652	*Nemipterus randalli*	Randall's threadfin bream	yes	
653	*Nemipterus zysron*	Slender threadfin bream	-	-
654	*Neobythites* sp.	Bearded brotula	-	-
655	*Neoepinnula orientalis*	Sackfish	-	-
656	*Neoharriotta pinnata*	Sicklefin chimaera	-	-
657	*Neoniphon sammara*	Sammara squirrelfish	yes	
658	*Neopomacentrus cyanomos*	Regal demoiselle	-	-
659	*Neopomacentrus miryae*	Miry's demoiselle	-	-
660	*Neopomacentrus sindensis*	Arabian demoiselle	-	-
661	*Netuma bilineata*	Bronze catfish	yes	yes
662	*Netuma thalassina*	Giant catfish		yes
663	*Nibea maculata*	Blotched croaker	-	-
664	*Norfolkia brachylepis*	Tropical scaly-headed triplefin	-	-
665	*Novaculichthys taeniourus*	Rockmover wrasse	yes	
666	*Nuchequula gerreoides*	Decorated ponyfish		yes
667	*Odonus niger*	Red-toothed triggerfish	-	-
668	*Oman ypsilon*	Oman blenny	yes	
669	*Omobranchus elongatus*	Cloister blenny		yes
670	*Omobranchus fasciolatoceps*	Barred Arab blenny	yes	
671	*Omobranchus mekranensis*	Mekran blenny	yes	
672	*Omobranchus punctatus*	Muzzled blenny	yes	
673	*Opisthopterus tardoore*	Tardoore		yes
674	*Opistognathus muscatensis*	Robust jawfish	-	-
675	*Opistognathus nigromarginatus*	Birdled jawfish	-	-
676	*Ophiocara porocephala*	Northern mud gudgeon	yes	yes
677	*Oplopomus oplopomus*	Spinecheek goby		yes
678	*Oreochromis aureus*	Blue tilapia		yes
679	*Oreochromis niloticus*	Nile tilapia		yes
680	*Osteomugil cunnesius*	Longarm mullet		yes
681	*Ostracion cubicus*	Yellow boxfish	-	-
682	*Ostracion cyanurus*	Bluetail trunkfish	-	-
683	*Ostracion meleagris*	Whitespotted boxfish	-	-
684	*Ostorhinchus aureus*	Ring-tailed cardinalfish	-	-
685	*Ostorhinchus cookii*	Cook's cardinalfish	-	-

686	*Ostorhinchus cyanosoma*	Yellowstriped cardinalfish	-	-
687	*Ostorhinchus fasciatus*	Broadbanded cardinalfish	yes	
688	*Ostorhinchus fleurieu*	Flower cardinalfish		yes
689	*Ostorhinchus gularis*	Gular cardinalfish		yes
690	*Ostorhinchus holotaenia*	Copperstriped cardinalfish	-	-
691	*Ostorhinchus nigrofasciatus*	Blackstripe cardinalfish	-	-
692	*Otolithes cuvieri*	Lesser tigertooth croaker	yes	
693	*Otolithes ruber*	Tigertooth croaker		yes
694	*Oxycheilinus bimaculatus*	Two-spot wrasse		yes
695	*Oxycheilinus digramma*	Cheeklined wrasse	-	-
696	*Oxyurichthys ophthalmonema*	Eyebrow goby	yes	yes
697	*Oxyurichthys papuensis*	Frogface goby		yes
698	*Pagellus affinis*	Arabian pandora	-	-
699	*Pagellus natalensis*	Natal pandora	-	-
700	*Palutrus meteori*	Meteor goby	-	-
701	*Pampus argenteus*	Silver pomfret		yes
702	*Pampus chinensis*	Chinese silver pomfret		yes
703	*Papilloculiceps longiceps*	Tentacled flathead	-	-
704	*Parablennius opercularis*	Cheekspot blenny	yes	
705	*Parablennius pilicornis*	Ringneck blenny	yes	
706	*Parablennius thysanius*	Tasseled blenny		yes
707	*Paracaesio sordida*	Dirty ordure snapper	-	-
708	*Paracaesio xanthura*	Yellowtail blue snapper		yes
709	*Parachaeturichthys polynema*	Taileyed goby		yes-R
710	*Paracanthurus hepatus*	Palette surgeonfish	yes	
711	*Paracheilinus mccoskeri*	McCosker's flasher	-	-
712	*Paracirrhites forsteri*	Blackside hawkfish	-	-
713	*Paraluteres prionurus*	False puffer	-	-
714	*Paramonacanthus* sp.	Gulf filefish	-	-
715	*Parapercis alboguttata*	Whitespot sandsmelt	-	-
716	*Parapercis hexophtalma*	Speckled sandperch	-	-
717	*Parapercis maculata*	Harlequin sandperch		yes
718	*Parapercis robinsoni*	Smallscale grubfish	-	-
719	*Paraplagusia bilineata*	Doublelined tonguesole	yes	yes
720	*Paraplagusia blochii*	Bloch's tonguesole	-	-
721	*Parapriacanthus ransonneti*	Pigmy sweeper	-	-
722	*Parascolopsis aspinosa*	Smooth dwarf monocle bream	-	-
723	*Parascolopsis eriomma*	Rosy dwarf monocle bream	-	-
724	*Parascolopsis townsendi*	Scaly dwarf monocle bream	-	-
725	*Parastromateus niger*	Black pomfret		yes
726	*Pardachirus balius*	Piebald sole	-	-

727	*Pardachirus marmoratus*	Finless sole	-	-
728	*Parioglossus raoi*	Rao's hover goby	yes	
729	*Parupeneus barberinoides*	Bicolor goatfish	yes	
730	*Parupeneus barberinus*	Dash-and-dot goatfish	yes	yes
731	*Parupeneus cyclostomus*	Gold-saddle goatfish	-	-
732	*Parupeneus heptacanthus*	Cinnabar goatfish	-	-
733	*Parupeneus indicus*	Indian goatfish	-	-
734	*Parupeneus macronemus*	Long-barbel goatfish	-	
735	*Parupeneus margaritatus*	Pearly goatfish	-	
736	*Parupeneus pleurostigma*	Sidespot goatfish	-	-
737	*Parupeneus rubescens*	Rosy goatfish	-	-
738	*Parupeneus trifasciatus*	Doublebar goatfish	-	-
739	*Parexocoetus mento*	African sailfin flyingfish	-	-
740	*Parupeneus macronemus*	Long-barbel goatfish	-	-
741	*Pegasus volitans*	Longtail seamouth		yes
742	*Pelates quadrilineatus*	Fourlined terapon	yes	
743	*Pellona ditchela*	Indian pellona	yes	yes
744	*Pempheris vanicolensis*	Vanikoro sweeper	-	-
745	*Pempheris* sp.	Red sweeper	-	
746	*Pennahia anea*	Donkey croaker	-	-
747	*Pentaprion longimanus*	Longfin mojarra	-	-
748	*Pereulixia kosiensis*	Kosi rockskipper		yes
749	*Periophthalmus waltoni*	Walton's mudskipper	yes	
750	*Petroscirtes ancylodon*	Arabian fangblenny	yes	
751	*Petroscirtes mitratus*	Floral blenny	yes	
752	*Photoblepharon steinitzi*	Flashlight fish	-	-
753	*Photopectoralis bindus*	Orangefin ponyfish		yes
754	*Pinjalo pinjalo*	Pinjalo snapper	-	-
755	*Pisodonophis hoeveni*	Hoeven's snake eel	-	-
756	*Plagiotremus rhinorhynchos*	Bluestriped fangblenny	yes	
757	*Plagiotremus townsendi*	Townsend's fangblenny	yes	
758	*Planiliza macrolepis*	Largescale mullet	yes	yes
759	*Planiliza melinopterus*	Otomebora mullet	yes	yes
760	*Planiliza subviridis*	Greenback mullet	yes	yes
761	*Platax orbicularis*	Orbicular batfish	yes	
762	*Platax pinnatus*	Dusky batfish	yes	
763	*Platax teira*	Longfin batfish	yes	
764	*Platybelone argalus platura*	Keeltail needlefish	-	-
765	*Platycephalus indicus*	Bartail flathead	yes	
766	*Plectorhinchus flavomaculatus*	Lemonfish		yes
767	*Plectorhinchus gaterinus*	Blackspotted rubberlip	-	-

768	*Plectorhinchus gibbosus*	Harry hotlips		yes
769	*Plectorhinchus pictus*	Trout sweetlips	-	-
770	*Plectorhinchus vittatus*	Oriental sweetlips	-	-
771	*Plectorhinchus playfairi*	Whitebarred rubberlip	-	-
772	*Plectorhinchus schotaf*	Minstrel sweetlips		yes
773	*Plectorhinchus sordidus*	Sordid rubberlip	-	-
774	*Plectroglyphidodon dickii*	Blackbar devil	-	-
775	*Plectroglyphidodon johnstonianus*	Johnston Island damsel	-	-
776	*Plectroglyphidodon leucozonus*	Singlebar devil	-	-
777	*Plectropomus maculatus*	Spotted coralgrouper	-	-
778	*Plectropomus punctatus*	Marbled coralgrouper	-	-
779	*Pleurosicya micheli*	Michel's ghost goby	-	-
780	*Plicofollis dussumieri*	Blacktip sea catfish	yes	yes
781	*Plicofollis layardi*	Thinspine sea catfish		yes
782	*Plicofollis polystaphylodon*	Mozambique sea catfish		yes
783	*Plicomugil labiosus*	Hornlip mullet		yes
784	*Plotosus limbatus*	Darkfin eel catfish		yes
785	*Plotosus lineatus*	Striped eel catfish	yes	
786	*Plotosus nkunga*	Stinging eel catfish		yes
787	*Poecilia latipinna*	Sailfin molly		yes
788	*Polydactylus plebeius*	Striped threadfin	yes	yes
789	*Polydactylus sextarius*	Blackspot threadfin		yes
790	*Pomacanthus asfur*	Arabian angelfish	-	-
791	*Pomacanthus imperator*	Emperor angelfish	-	-
792	*Pomacanthus maculosus*	Yellowbar angelfish	-	-
793	*Pomacanthus semicirculatus*	Semicircle angelfish		yes
794	*Pomacentrus aquilus*	Dark damsel	-	-
795	*Pomacentrus arabicus*	Arabian damsel	-	-
796	*Pomacentrus caeruleus*	Caerulean damsel	-	-
797	*Pomacentrus leptus*	Slender damsel	-	-
798	*Pomacentrus sulfureus*	Sulphur damsel	-	-
799	*Pomacentrus trichrourus*	Paletail damsel	-	-
800	*Pomacentrus trilineatus*	Threeline damsel	yes	
801	*Pomadasys aheneus*	Yellowback grunt	-	-
802	*Pomadasys argenteus*	Silver grunt	yes	
803	*Pomadasys argyreus*	Bluecheek silver grunt		yes
804	*Pomadasys commersonnii*	Smallspotted grunter	yes	yes
805	*Pomadasys* kaakan	Javelin grunter	yes	yes
806	*Pomadasys maculatus*	Saddle grunt	yes	yes
807	*Pomadasys multimaculatus*	Cock grunter	yes	yes
808	*Pomadasys olivaceus*	Olive grunt		yes

809	*Pomadasys punctulatus*	Lined grunt	-	-
810	*Pomadasys stridens*	Striped piggy	-	-
811	*Pomadasys taeniatus*	Bronzestriped grunt	-	-
812	*Pomatomus saltatrix*	Bluefish		yes
813	*Plectranthias vexillarius*	Banner anthias	-	-
814	*Plesiops mystaxus*	Moustache longfin	-	-
815	*Plesiops nigricans*	Whitespotted longfin	-	-
816	*Priacanthus blochii*	Paeony bulleye	-	-
817	*Priacanthus hamrur*	Moontail bullseye	-	-
818	*Priacanthus tayenus*	Purple-spotted bigeye	-	-
819	*Priolepis cincta*	Banded reef goby	-	-
820	*Priolepis randalli*	Randall's goby	-	-
821	*Pristiapogon exostigma*	Narrowstripe cardinalfish	-	-
822	*Pristiapogon fraenatus*	Bridled cardinalfish	-	-
823	*Pristipomoides filamentosus*	Crimson jobfish	-	-
824	*Pristipomoides multidens*	Goldbanded jobfish	-	-
825	*Pristipomoides sieboldii*	Lavender jobfish	-	-
826	*Pristipomoides zonatus*	Oblique-banded snapper		yes
827	*Pristipomoides typus*	Sharptooth jobfish	-	-
828	*Pristotis obtusirostris*	Gulf damselfish		yes
829	*Prognichthys brevipinnis*	Shortfin flyingfish	-	-
830	*Protonibea diacanthus*	Blackspotted croaker		yes
831	*Psenopsis cyanea*	Indian ruff	-	-
832	*Psettodes erumei*	Indian halibut	-	-
833	*Pseudocheilinus hexataenia*	Sixline wrasse	-	-
834	*Pseudanthias marcia*	Marcia's anthias	-	-
835	*Pseudanthias townsendi*	Townsend's anthias	-	-
836	*Pseudechidna brummeri*	White ribbon eel		yes
837	*Pseudochromis aldabraensis*	Orange dottyback	-	-
838	*Pseudochromis caudalis*	Stripe-tailed dottyback	-	-
839	*Pseudochromis dutoiti*	Dutoiti	-	-
840	*Pseudochromis leucorhynchus*	White-nosed dottyback	-	-
841	*Pseudochromis linda*	Yellowtail dottyback	-	-
842	*Pseudochromis nigrovittatus*	Blackstripe dottyback	-	-
843	*Pseudochromis olivaceus*	Olive dottyback	-	-
844	*Pseudochromis omanensis*	Oman dottyback	-	-
845	*Pseudochromis persicus*	Bluespotted dottyback	-	-
846	*Pseudochromis punctatus*	Blackback dottyback	-	-
847	*Pseudodax moluccanus*	Chiseltooth wrasse	-	-
848	*Pseudorhombus annulatus*	Ringed flounder	-	-
849	*Pseudorhombus arsius*	Largetooth flounder	yes	yes

850	*Pseudorhombus elevatus*	Deep flounder	yes	
851	*Pseudorhombus javanicus*	Javan flounder	yes	yes
852	*Pseudorhombus malayanus*	Malayan flounder	-	-
853	*Pseudorhombus natalensis*	Natal flounders	-	-
854	*Pseudorhombus triocellatus*	Three spotted flounders		yes
855	*Pseudosynanceia melanostigma*	Blackfin stonefish	-	-
856	*Pseudotriacanthus strigilifer*	Long-spined tripodfish	yes	
857	*Pseudovespicula dracaena*	Draco waspfish	-	-
858	*Psammogobius biocellatus*	Sleepy goby	yes	yes
859	*Pteragogus flagellifer*	Cocktail wrasse	-	-
860	*Ptereleotris arabica*	Arabian dartfish	-	-
861	*Ptereleotris heteroptera*	Blacktail goby	-	-
862	*Ptereleotris microlepis*	Blue gudgeon		yes
863	*Ptereleotris monoptera*	Lyre-tail dart-goby	-	-
864	*Pterocaesio chrysozona*	Goldband fusilier	-	-
865	*Pterois antennata*	Spotfin lionfish	-	-
866	*Pterois miles*	Devil firefish	yes	
867	*Pterois mombasae*	Frillfin turkeyfish	-	-
868	*Pterois radiata*	Radial firefish	-	-
869	*Pterois russelii*	Plaintail turkeyfish	-	-
870	*Pterois volitans*	Red lionfish	yes	yes
871	*Pterygotrigla hemisticta*	Blackspotted gurnard	-	-
872	*Rachycentron canadum*	Cobia	yes	yes
873	*Rastrelliger faughni*	Island mackerel	-	-
874	*Rastrelliger kanagurta*	Indian mackerel	-	-
875	*Remora remora*	Shark sucker	-	-
876	*Rhabdosargus haffara*	Haffara seabream	-	-
877	*Rhabdosargus sarba*	Goldlined seabream	yes	
878	*Rhabdosargus* sp.	Seabream	-	-
879	*Rhabdosargus thorpei*	Bigeye stumpnose		yes
880	*Rhinecanthus assasi*	Picasso triggerfish	-	-
881	*Rhynchorhamphus georgii*	Long billed half beak	-	-
882	*Rogadius pristiger*	Thorny flathead	-	-
883	*Rusichthys* sp	Orangestriped snakelet	-	-
884	*Ruvettus pretiosus*	Oilfish	-	-
885	*Sacura boulengeri*	Boulenger's anthias	-	-
886	*Sarda orientalis*	Striped bonito	-	-
887	*Sardinella albella*	White sardinella	yes	
888	*Sardinella gibbosa*	Goldstripe sardinella	-	-
889	*Sardinella longiceps*	Indian oil sardine	-	-
890	*Sardinella melanura*	Blacktip sardinella	yes	yes

891	*Sardinella sindensis*	Sind sardinella	-	-
892	*Sargocentron caudimaculatum*	Silverspot squirrelfish	-	-
893	*Sargocentron diadema*	Crown squirrelfish	-	-
894	*Sargocentron praslin*	Dark-striped squirrelfish	-	-
895	*Sargocentron rubrum*	Redcoat		yes
896	*Sargocentron seychellense*	Yellow-tipped squirrelfish	-	-
897	*Sargocentron spiniferum*	Sabre squirrelfish	-	-
898	*Saurida gracilis*	Gracile lizardfish	-	-
899	*Saurida longimanus*	Longfin lizardfish	-	-
900	*Saurida nebulosa*	Clouded lizardfish	yes	
901	*Saurida tumbil*	Greater lizardfish	yes	
902	*Saurida undosquamis*	Brushtooth lizardfish	yes	
903	*Scartelaos tenuis*	Indian Ocean slender mudskipper	yes	
904	*Scartella emarginata*	Maned blenny	yes	
905	*Scarus arabicus*	Arabian parrotfish	yes	
906	*Scarus collana*	Red Sea parrotfish	yes	
907	*Scarus falcipinnis*	Sicklefin parrotfish	yes	
908	*Scarus ferrugineus*	Rusty parrotfish	yes	
909	*Scarus frenatus*	Bridled parrotfish	yes	
910	*Scarus fuscopurpureus*	Purple-brown parrotfish	yes	
911	*Scarus ghobban*	Blue-barred parrotfish	yes	
912	*Chlorurus gibbus*	Heavybeak parrotfish	yes	
913	*Scarus niger*	Dusky parrotfish	yes	
914	*Scarus persicus*	Gulf parrotfish	yes	
915	*Scarus psittacus*	Common parrotfish	yes	
916	*Scarus rubroviolaceus*	Ember parrotfish	yes	
917	*Scarus scaber*	Fivesaddle parrotfish	yes	
918	*Scarus zufar*	Dhofar parrotfish	yes	
919	*Scatophagus argus*	Spotted scat	yes	
920	*Scolecenchelys gymnota*	Indo-Pacific slender worm-eel	-	-
921	*Scolopsis bimaculata*	Thumbprint monocle bream	-	-
922	*Scolopsis ghanam*	Arabian monocle bream	-	-
923	*Scolopsis taeniata*	Black-streaked monocle bream	-	-
924	*Scolopsis vosmeri*	Whitecheek monocle bream	-	-
925	*Scomber japonicus*	Chub mackerel	-	-
926	*Scomberoides commersonnianus*	Talang queenfish	yes	yes
927	*Scomberoides lysan*	Doublespotted queenfish	-	-
928	*Scomberoides tala*	Barred queenfish	yes	yes
929	*Scomberoides tol*	Needlescaled queenfish	yes	
930	*Scomberomorus commerson*	Narrow-barred Spanish mackerel	-	-
931	*Scomberomorus guttatus*	Indo-Pacific king mackerel		yes

932	*Scomberomorus lineolatus*	Streaked seerfish	-	-
933	*Scorpaenodes evides*	Cheekspot scorpionfish	-	-
934	*Scorpaenodes guamensis*	Guam scorpionfish	-	
935	*Scorpaenodes scaber*	Pygmy scorpionfish	-	-
936	*Scorpaenopsis barbata*	Bearded scorpionfish	-	-
937	*Scorpaenopsis diabolus*	False stonefish	-	-
938	*Scorpaenopsis gibbosa*	Humpbacked scorpionfish	-	-
939	*Scorpaenopsis lactomaculata*	Whiteblotched scorpionfish	-	-
940	*Scorpaenopsis oxycephala*	Tassled scorpionfish	-	-
941	*Scorpaenopsis venosa*	Raggy scorpionfish	-	-
942	*Scuticaria tigrina*	Tiger reef-eel	-	-
943	*Secutor insidiator*	Pugnose ponyfish	-	-
944	*Selar crumenophthalmus*	Bigeye scad	-	-
945	*Selaroides leptolepis*	Yellowstripe scad	-	-
946	*Seriola dumerili*	Greater amberjack	-	-
947	*Seriola rivoliana*	Longfin yellowtail	-	-
948	*Seriolina nigrofasciata*	Blackbanded trevally	-	-
949	*Siganus argenteus*	Streamlined spinefoot	-	-
950	*Siganus canaliculatus*	White-spotted Spinefoot	yes	
951	*Siganus javus*	Streaked spinefoot	yes	
952	*Siganus luridus*	Dusky spinefoot	-	-
953	*Siganus rivulatus*	Marbled spinefoot	yes	
954	*Siganus spinus*	Little spinefoot	-	-
955	*Siganus stellatus*	Brown-spotted spinefoot	yes	yes
956	*Siganus sutor*	Shoemaker spinefoot	yes	yes
957	*Sillaginopodys chondropus*	Clubfoot sillago	yes	
958	*Sillago arabica*	Arabian sillago	-	-
959	*Sillago attenuata*	Slender sillago	-	-
960	*Sillago indica*	Indian sillago	-	-
961	*Sillago sihama*	Silver sillago	yes	yes
962	*Siphamia tubifer*	Tubifer cardinalfish	-	-
963	*Snyderina guentheri*	Günther's waspfish	-	-
964	*Solea elongata*	Elongate sole	-	-
965	*Solea stanalandi*	Stanaland's sole	-	-
966	*Soleichthys heterorhinos*	Black-tip sole	-	-
967	*Solenostomus cyanopterus*	Ghost pipefish	yes	
968	*Sorsogona melanoptera*	Obscure flathead	-	-
969	*Sorsogona nigripinna*	Blackfin flathead	-	-
970	*Sorsogona prionota*	Halfspined flathead	-	-
971	*Sorsogona tuberculata*	Tuberculated flathead	-	-
972	*Sparidentex hasta*	Sobaity seabream	-	-

973	*Sparus aurata*	Gilthead seabream		yes
974	*Sphyraena acutipinnis*	Sharpfin barracuda	-	-
975	*Sphyraena barracuda*	Great barracuda	yes	
976	*Sphyraena flavicauda*	Yellowtail barracuda	yes	
977	*Sphyraena forsteri*	Bigeye barracuda	yes	
978	*Sphyraena jello*	Pickhandle barracuda	yes	yes
979	*Sphyraena obtusata*	Obtuse barracuda	yes	
980	*Sphyraena putnamae*	Sawtooth barracuda	yes	
981	*Sphyraena qenie*	Blackfin barracuda		yes
982	*Spratelloides delicatulus*	Delicate round herring		yes
983	*Spratelloides gracilis*	Silver-stripe round herring	yes	
984	*Stalix omanensis*	Oman jawfish	-	-
985	*Stephanolepis diaspros*	Reticulated leatherjacket	-	-
986	*Stethojulis albovittata*	Bluelined wrasse	-	-
987	*Stethojulis interrupta*	Cutribbon wrasse	-	-
988	*Stolephorus commersonnii*	Commerson's anchovy	yes	yes
989	*Stolephorus indicus*	Indian anchovy		yes
990	*Stolephorus punctifer*	Buccaneer anchovy	-	-
991	*Strongylura leiura*	Banded needlefish	yes	
992	*Strongylura strongylura*	Spottail needlefish	yes	
993	*Suezichthys caudavittatus*	Spottail wrasse		yes
994	*Suezichthys gracilis*	Slender wrasse	-	-
995	*Sufflamen albicaudatum*	Bluethroat triggerfish	-	-
996	*Sufflamen chrysopterum*	Halfmoon triggerfish	-	-
997	*Sufflamen fraenatum*	Masked triggerfish	-	-
998	*Symbolophorus evermanni*	Evermann's lantern fish	-	-
999	*Synanceia nana*	Red Sea stonefish	-	-
1000	*Synanceia verrucosa*	Stonefish	-	-
1001	*Synaptura commersonnii*	Commerson's sole	-	-
1002	*Synchiropus stellatus*	Starry dragonet	-	-
1003	*Syngnathoides biaculeatus*	Alligator pipefish	yes	yes
1004	*Synodus binotatus*	Two-spot lizard fish	-	-
1005	*Synodus dermatogenys*	Sand lizardfish	-	-
1006	*Synodus indicus*	Indian lizardfish	-	-
1007	*Synodus myops*	Snakefish		yes
1008	*Synodus variegatus*	Variegated lizardfish	yes	
1009	*Synodus macrops*	Triplecross lizardfish	yes	
1010	*Taeniamia fucata*	Orangelined cardinalfish	yes	
1011	*Taeniamia pallida*	Pale cardinalfish	-	-
1012	*Tenualosa ilisha*	Hilsa shad	-	-
1013	*Tenualosa toli*	Toli shad	yes	yes

1014	*Terapon jarbua*	Jarbua terapon	yes	yes
1015	*Terapon puta*	Small-scaled terapon	-	-
1016	*Terapon theraps*	Largescaled terapon	yes	
1017	*Tetrapturus angustirostris*	Shortbill spearfish	-	-
1018	*Tetrosomus gibbosus*	Humpback turretfish	-	-
1019	*Thalassoma hardwicke*	Sixbar wrasse	yes	
1020	*Thalassoma loxum*	Slantband wrasse	-	-
1021	*Thalassoma lunare*	Moon wrasse		yes
1022	*Thalassoma lutescens*	Yellow-brown wrasse	-	-
1023	*Thalassoma purpureum*	Surge wrasse		yes
1024	*Thamnaconus melanoproctes*	Blackvent filefish	-	-
1025	*Thryssa baelama*	Baelama anchovy	yes	
1026	*Thryssa hamiltonii*	Hamilton's thryssa	yes	yes
1027	*Thryssa mystax*	Moustached thryssa	yes	yes
1028	*Thryssa setirostris*	Longjaw thryssa		yes
1029	*Thryssa vitrirostris*	Orangemouth anchovy		yes
1030	*Thryssa whiteheadi*	Whitehead's thryssa	-	-
1031	*Thysanophrys celebica*	Celebes flathead	-	-
1032	*Thysanophrys chiltonae*	Longsnout flathead	-	-
1033	*Thunnus albacares*	Yellowfin tuna	-	-
1034	*Thunnus alalunga*	Albacore	-	-
1035	*Thunnus obesus*	Bigeye tuna	-	-
1036	*Thunnus tonggol*	Longtail tuna	-	-
1037	*Tomiyamichthys latruncularius*	Fan shrimp-goby	-	-
1038	*Torquigener flavimaculosus*	Yellowspotted puffer	-	-
1039	*Tosana niwae*	Threadtail anthias	-	-
1040	*Trachinotus africanus*	Southern pompano	-	-
1041	*Trachinotus baillonii*	Small spotted dart	-	-
1042	*Trachinotus mookalee*	Indian pompano	-	-
1043	*Trachinotus botla*	Largespotted dart		yes
1044	*Trachinotus blochii*	Snubnose pompano	-	-
1045	*Trachurus indicus*	Arabian scad	-	-
1046	*Trachyrhamphus bicoarctatus*	Double-ended pipefish	-	-
1047	*Triacanthus biaculeatus*	Short-nosed tripodfish	yes	yes
1048	*Trichiurus auriga*	Pearly hairtail	-	-
1049	*Trichiurus lepturus*	Largehead hairtail		yes
1050	*Trichonotus arabicus*	Arabian sand diver	-	-
1051	*Trimma winterbottomi*	Winterbottom's goby	yes	
1052	*Trypauchen vagina*	Burrowing goby	yes	yes
1053	*Tylosurus acus melanotus*	Keel-jawed needle fish	yes	
1054	*Tylosurus choram*	Red Sea houndfish	-	-

1055	*Tylosurus crocodilus*	Hound needlefish	yes	
1056	*Ulua mentalis*	Longrakered trevally	-	-
1057	*Umbrina canariensis*	Canary drum		yes
1058	*Umbrina ronchus*	Fusca drum		yes
1059	*Upeneus doriae*	Gilded goatfish	yes	-
1060	*Upeneus japonicus*	Japanese goatfish	yes	
1061	*Upeneus pori*	Por's goatfish	yes	-
1062	*Upeneus sulphureus*	Sulphur goatfish	yes	yes
1063	*Upeneus sundaicus*	Ochrebanded goatfish	yes	
1064	*Upeneus tragula*	Freckled goatfish	yes	
1065	*Upeneus vittatus*	Yellowstriped goatfish	yes	
1066	*Uranoscopus archionema*	Stargazer	-	-
1067	*Uranoscopus dollfusi*	Dollfus' stargazer	-	-
1068	*Uraspis helvola*	Whitetongue jack	-	-
1069	*Uraspis secunda*	Cottonmouth jack	-	-
1070	*Uraspis uraspis*	Whitemouth jack	-	-
1071	*Uroconger lepturus*	Slender conger	yes	yes
1072	*Valenciennea helsdingenii*	Twostripe goby	-	-
1073	*Valenciennea persica*	Gulf goby	-	-
1074	*Valenciennea puellaris*	Maiden goby	-	-
1075	*Valenciennea sexguttata*	Sixspot goby	-	-
1076	*Vanderhorstia mertensi*	Mertens' prawn-goby	-	-
1077	*Variola louti*	Yellow-edged lyretail	-	-
1078	*Velifer hypselopterus*	Salifin velifer	-	-
1079	*Xenisthmus balius*	Freckled wriggler	-	-
1080	*Verulux cypselurus*	Swallowtail cardinalfish	-	-
1081	*Xiphasia setifer*	Hairtail blenny	yes	
1082	*Xiphias gladius*	Swordfish	-	-
1083	*Xyrias multiserialis*	Speckled snake eel	-	-
1084	*Yirrkala omanensis*	Oman snake eel	-	-
1085	*Zanclus cornutus*	Moorish idol	yes	
1086	*Zapogon evermanni*	Evermann's cardinalfish	-	-
1087	*Zebrasoma scopas*	Twotone tang	yes	
1088	*Zebrasoma xanthurum*	Yellowtail tang	yes	
1089	*Zebrias captivus*	Convict zebra sole	-	-
1090	*Zebrias synapturoides*	Indian zebra sole	-	-
1091	*Zenopsis conchifer*	Silvery John dory	-	-
Sharks and rays (Elasmobranchs)				

	Scientific name	Common name	Mang	Estu
1	*Aetobatus narinari*	Spotted eagle ray	yes	yes
2	*Aetomylaeus nichofii*	Banded eagle ray	-	-
3	*Acroteriobatus annulatus*	Lesser sandshark		yes
4	*Acroteriobatus salalah*	Salalah guitarfish	-	-
5	*Alopias pelagicus*	Pelagic thresher	-	-
6	*Alopias superciliosus*	Bigeye thresher	-	-
7	*Alopias vulpinus*	Thresher	-	-
8	*Anoxypristis cuspidata*	Narrow sawfish		yes
9	*Apristurus indicus*	Smallbelly catshark	-	-
10	*Brevitrygon imbricata*	Bengal whipray	yes	yes
11	*Bythaelurus alcockii*	Arabian catshark	-	-
12	*Carcharhinus albimarginatus*	Silvertip shark	-	-
13	*Carcharhinus altimus*	Bignose shark	-	-
14	*Carcharhinus amblyrhynchoides*	Graceful shark	-	-
15	*Carcharhinus amblyrhynchos*	Blacktail reef shark		yes
16	*Carcharhinus amboinensis*	Pigeye shark		yes
17	*Carcharhinus brevipinna*	Spinner shark	-	-
18	*Carcharhinus dussumieri*	Whitecheek shark	-	yes
19	*Carcharhinus falciformis*	Silky shark	-	-
20	*Carcharhinus hemiodon*	Pondicherry shark	-	-
21	*Carcharhinus leucas*	Bull shark		yes
22	*Carcharhinus limbatus*	Blacktip shark	yes	yes
23	*Carcharhinus longimanus*	Oceanic whitetip shark	-	-
24	*Carcharhinus macloti*	Hardnose shark	-	-
25	*Carcharhinus melanopterus*	Blacktip reef shark	yes	
26	*Carcharhinus plumbeus*	Sandbar shark	-	-
27	*Carcharhinus sorrah*	Spot-tail shark		yes
28	*Carcharias taurus*	Sand-tiger shark		yes
29	*Chaenogaleus macrostoma*	Hooktooth shark	-	-
30	*Cephaloscyllium sufflans*	Balloon shark	-	-
31	*Chiloscyllium arabicum*	Arabian carpetshark	yes	
32	*Chiloscyllium griseum*	Gray bamboo shark		yes
33	*Dasyatis* sp.	Oman masked stingray	-	-
34	*Eridacnis radcliffei*	Pygmy ribbontail catshark	-	-
35	*Eusphyra blochii*	Winghead Shark	yes	
36	*Echinorhinus brucus*	Bramble Shark	-	-
37	*Chiloscyllium indicum*	Slender bambooshark	-	-
38	*Glaucostegus granulatus*	Granulated guitarfish	-	-
39	*Glaucostegus halavi*	Halavi guitarfish	-	-
40	*Glaucostegus obtusus*	Widenose guitarfish		yes

41	*Galeocerdo cuvier*	Tiger shark	yes	yes
42	*Gymnura poecilura*	Long-tailed butterfly ray	-	-
43	*Halaelurus boesemani*	Speckled catshark	-	-
44	*Hemipristis elongata*	Snaggletooth shark	-	-
45	*Heterodontus ramalheira*	Whitespotted bullhead shark	-	-
46	*Heterodontus* sp.	Oman bullhead shark	-	-
47	*Himantura uarnak*	Honeycomb stingray	yes	yes
48	*Hypogaleus hyugaensis*	Blacktip tope	-	-
49	*Iago omanensis*	Bigeye houndshark	-	-
50	*Isurus oxyrinchus*	Shortfin mako	-	-
51	*Loxodon macrorhinus*	Sliteye shark	-	-
52	*Maculabatis gerrardi*	Sharpnose stingray	-	-
53	*Mobula birostris*	Giant manta	-	-
54	*Mobula eregoodootenkee*	Longhorned mobula	-	-
55	*Mobula kuhlii*	Shortfin devil ray	-	-
56	*Mobula thurstoni*	Smoothtail mobula	-	-
57	*Narcetes lloydi*	Lloyd's slickhead	-	-
58	*Narcine* sp.	Large-eye electric ray	-	-
59	*Narke* sp.	Electric ray	-	-
60	*Mustelus mosis*	Arabian smooth-hound	-	-
61	*Nebrius ferrugineus*	Tawny nurse shark		yes
62	*Negaprion acutidens*	Sicklefin lemon shark	yes	
63	*Neotrygon kuhlii*	Blue-spotted stingray		yes
64	*Oxymonacanthus longirostris*	Harlequin filefish		yes
65	*Pardachirus morrowi*	Persian carpet sole		yes
66	*Paragaleus randalli*	Slender weasel shark	-	-
67	*Paragaleus* sp.	Arabian weasel shark	-	-
68	*Pastinachus sephen*	Cowtail stingray	yes	yes
69	*Pateobatis jenkinsii*	Jenkins whipray	-	-
70	*Pristis zijsron*	Olive sawfish	yes	yes
71	*Pristis pectinata*	Smalltooth sawfish	yes	yes
72	*Rhina ancylostoma*	Bowmouth guitarfish	yes	
73	*Rhincodon typus*	Whale shark	yes	yes
74	*Rhinobatos punctifer*	Spotted guitarfish	-	-
75	*Rhinoptera javanica*	Flapnose ray	yes	yes
76	*Rhinoptera jayakari*	Oman cownose ray	-	-
77	*Rhizoprionodon acutus*	Milk shark	-	-
78	*Rhizoprionodon oligolinx*	Grey sharpnose shark	-	-
79	*Rhynchobatus djiddensis*	Giant guitarfish		yes
80	*Scoliodon laticaudus*	Spadenose shark		yes
81	*Sphyrna lewini*	scalloped hammerhead	yes	yes

82	*Sphyrna mokarran*	Great hammerhead	yes	
83	*Sphyrna zygaena*	Smooth hammerhead		yes
84	*Squatina africana*	African angelshark	-	-
85	*Stegostoma fasciatum*	Zebra shark	yes	
86	*Triaenodon obesus*	Whitetip reef shark	-	-
87	*Taeniura lymma*	Blue spotted ribbontail stingray	yes	
88	*Taeniurops meyeni*	Round ribbontail ray	yes	yes
89	*Torpedo panthera*	Panther electric ray	-	-
90	*Torpedo sinuspersici*	Variable torpedo ray		yes
91	*Triaenodon obesus*	Whitetip reef shark	-	-
92	*Urogymnus asperrimus*	Porcupine whipray	yes	
Crabs (Infraorder: Brachyura)				
	Scientific name	Common name	Mang	Estu
1	*Arcania* sp.	Purse crab	-	-
2	*Ashtoret lunaris*	yellow moon crab	yes	
3	*Atergatis integerrimus*	red egg crab		yes
4	*Bellidilia undecimspinosa*	Purse crab	-	-
5	*Calappa japonica*	Japanese shame faced crab	-	-
6	*Calappa lophos*	Common box crab	yes	
7	*Calappa gallus*	Rough box crab	-	-
8	*Calappa hepatica*	Hepatic box crab	yes	
9	*Calappa philargius*	Box crab	-	-
10	*Camposcia retusa*	Velcro crab	-	-
11	*Cardisoma carnifex*	Brown land crab	yes	
12	*Carpilius convexus*	Omani coral crab	yes	-
13	*Charybdis annulata*	Swimming crab		yes
14	*Charybdis feriata*	Crucifix crab	yes	
15	*Charybdis hellerii*	Indo-Pacific swimming crab	yes	
16	*Charybdis lucifera*	Swimming crab	yes	
17	*Charybdis miles*	Swimming crab	-	-
18	*Charybdis natator*	Rock swimming crab	yes	
19	*Charybdis sagamiensis*	Swimming crab	-	-
20	*Charybdis smithii*	Deep water swimming crab	-	-
21	*Cryptodromiopsis unidentata*	Sponge crab	-	-
22	*Daldorfia spinosissima*	Parthenopid crab	-	-
23	*Euclosia obtusifrons*	Purse crab	-	-
24	*Encephalloides armstrongi*	Armstrong’s spider crab	-	-
25	*Episesarma* sp.	Tree climbing crab	yes	
26	*Eriphia smithii*	Rough redeyed crab	yes	
27	*Eriphia sebana*	Redeyed crab	-	-
28	*Etisus laevimanus*	Smooth spooner	-	-

29	*Gaillardiellus rueppelli*	Stone crab	-	-
30	*Geograpsus stormi*	Rock crab	-	-
31	*Grapsus albolineatus*	Rock crab	yes	
32	*Grapsus tenuicrustatus*	Lightfoot crab	-	-
33	*Gonioinfradens paucidentatus*	Swimming crab	-	-
34	*Homola* sp.	Carier crab	-	-
35	*Hyastenus diacanthus*	Decorator crab	-	-
36	*Leptodius exaratus*	Stone crab	yes	
37	*Liomera cinctimana*	Reef crab	-	-
38	*Lauridromia dehaani*	Japanese sponge crab	yes	
39	*Macrophthalmus* sp.	Sentinel crab	yes	
40	*Matula victor*	Brown spotted crab	yes	
41	*Metopograpsus* sp.	Climber crabs	yes	
42	*Metopograpsus messor*	Messor’s shore crab	yes	
43	*Mursia bicristimana*	Box crab	-	-
44	*Nanopilumnus heterodon*	Hairy crab	-	-
45	*Naxioides robillardi*	Decorator crab	-	-
46	*Ocypode jousseaumei*	Ghost crab	-	-
47	*Ocypode rotundata*	Ghost crab	-	-
48	*Grapsus albolineatus*	Ghost crab	yes	
49	*Portunus pelagicus*	Sand crab	yes	
50	*Portunus petreus*	Swimming crab	-	-
51	*Portunus sanguinolentus*	Threespot swimming crab	-	-
52	*Portunus segnis*	Blue swimming crab	yes	
53	*Psaumis cavipes*	Stone crab	-	-
54	*Scylla serrata*	Giant mangrove (mud) crab	yes	
55	*Thalamita crenata*	Mangrove swimming crab	yes	
56	*Thalamita dakini*	Swimming crab	-	-
57	*Uca lactea*	Milky fiddler crab	yes	
Shrimps (Caridea) and lobsters (Astacidea)				
	Scientific name	Common name	Mang	Estu
1	*Alpheus* sp.	Pistol shrimp	yes	
2	*Penaeus indicus*	Indian white shrimp	yes	
3	*Penaeus semisulcatus*	Green tiger prawn	yes	yes
4	*Panulirus homarus*	Scalloped spiny lobster	-	-
5	*Panulirus versicolor*	Painted spiny lobster	yes	
6	*Scyllarides squammosus*	Blunt locust lobster	-	-
Molluscs (Gastropods)				
	Scientific name	Common name	Mang	Estu
1	*Cerithidea decollata*	truncated mangrove snail	yes	
2	*Terebralia palustris*	mangrove whelk	yes	

Molluscs, Octopuses (Cephalopoda)				
	Scientific name	Common name	Mang	Estu
1	*Octopus aegina*	sandbird octopus	-	-
2	*Sepia pharaonis*	cuttlefish	-	-

Appendix 4.2. Indication of subsistence (S) and commercial (C) value of finfish and shellfish species in Oman.

Bony Fish (Teleosts)				
	Scientific name	Common name	S	C
1	*Ablennes hians*	Flat needlefish	yes	
2	*Abudefduf saxatilis*	Sergeant-major		yes
3	*Abudefduf sordidus*	Blackspot sergeant		yes
4	*Abudefduf vaigiensis*	Indo-Pacific sergeant	yes	
5	*Acanthopagrus berda*	Goldsilk seabream	yes	
6	*Acanthopagrus bifasciatus*	twobar seabream	yes	
7	*Acanthurus dussumieri*	Eyestripe surgeonfish		yes
8	*Acanthurus gahhm*	Black surgeonfish		yes
9	*Acanthurus leucosternon*	Powderblue surgeonfish		yes
10	*Acanthurus mata*	Mata Surgeonfish		yes
11	*Acanthurus sohal*	Sohal surgeonfish		yes
12	*Acanthurus tennentii*	Doubleband surgeonfish		yes
13	*Acanthurus triostegus*	Convict surgeonfish		yes
14	*Acanthurus xanthopterus*	Yellowfin surgeonfish		yes
15	*Acentrogobius audax*	Mangrove goby	-	-
16	*Acentrogobius nebulosus*	Shadow goby	-	-
17	*Acropoma japonicum*	Glowbelly	-	-
18	*Albula glossodonta*	Roundjaw bonefish		yes
19	*Alectis indica*	Indian threadfish		yes
20	*Alepes vari*	Herring scad		yes
21	*Allenbatrachus grunniens*	Grunting toadfish	-	-
22	*Ambassis natalensis*	Slender glassy	-	-
23	*Amblygaster sirm*	Spotted sardinella		yes
24	*Amblygobius albimaculatus*	Butterfly goby		yes
25	*Amblygobius nocturnus*	Nocturn goby		yes
26	*Antennablennius adenensis*	Aden blenny	-	-
27	*Antennablennius australis*	Moustached rockskipper	-	-
28	*Antennablennius bifilum*	Horned rockskipper	-	-
29	*Antennablennius hypenetes*	Arabian blenny	-	-
30	*Antennablennius simonyi*	Simony's blenny	-	-
31	*Antennablennius variopunctatus*	Orangedotted blenny	-	-
32	*Anodontostoma chacunda*	Chacunda gizzard shad		yes
33	*Anyperodon leucogrammicus*	Slender grouper	yes	
34	*Aphanius dispar*	Arabian pupfish	-	-
35	*Apistus carinatus*	Ocellated waspfish		yes
36	*Apogonichthyoides taeniatus*	Twobelt cardinal	-	-
37	*Argyrops spinifer*	King soldier bream	yes	
38	*Arius maculatus*	Spotted catfish	yes	
39	*Arothron hispidus*	White-spotted puffer	-	yes
40	*Arothron immaculatus*	Blackedged puffer		yes
41	*Arothron stellatus*	Stellate puffer	-	-
42	*Aspidontus taeniatus*	False cleanerfish		yes
43	*Atherinomorus lacunosus*	Hardyhead silverside		yes
44	*Atractoscion aequidens*	Geelbeck croaker		yes
45	*Atule mate*	Yellowtail scad		yes
46	*Benthosema pterotum*	Skinnycheek lanternfish		yes
47	*Boleophthalmus dussumieri*	Dussumier’s mudskipper	-	-
48	*Boops lineatus*	Striped boga	yes	
49	*Bothus pantherinus*	Leopard flounder		yes

50	*Bregmaceros nectabanus*	Smallscale codlet	-	-
51	*Brotula multibarbata*	Goatsbeard brotula		yes
52	*Carangoides chrysophrys*	Longnose trevally		yes
53	*Caranx melampygus*	Bluefin trevally		yes
54	*Caranx sexfasciatus*	Bigeye trevally		yes
55	*Chaetodon auriga*	Threadfin butterflyfish		yes
56	*Chaetodon nigropunctatus*	Black-spotted butterflyfish		yes
57	*Chaetodon vagabundus*	Vagabond butterflyfish		yes
58	*Chanos chanos*	Milkfish		yes
59	*Chirocentrus dorab*	Dorab wolf-herring		yes
60	*Chirocentrus nudus*	Whitefin wolf-herring		yes
61	*Chlorurus sordidus*	Daisy parrotfish		yes
62	*Chlorurus strongylocephalus*	Steephead parrotfish		yes
63	*Choeroichthys brachysoma*	Short-bodied pipefish	-	-
64	*Cirripectes filamentosus*	Filamentous blenny	-	-
65	*Cociella crocodilus*	Crocodile flathead	-	-
66	*Conger cinereus*	Longfin African conger		yes
67	*Corythoichthys amplexus*	Brown-banded pipefish	-	-
68	*Corythoichthys flavofasciatus*	Network pipefish	-	-
69	*Corythoichthys haematopterus*	Messmate pipefish	-	-
70	*Cryptocentroides insignis*	Insignia prawn-gob		yes
71	*Ctenochaetus striatus*	Striated surgeonfish		yes
72	*Ctenochaetus strigosus*	Spotted surgeonfish	-	-
73	*Cynoglossus bilineatus*	Fourlined tonguesole		yes
74	*Cynoglossus puncticeps*	Speckled tonguesole		yes
75	*Diodon holocanthus*	Longspined porcupinefish		yes
76	*Diodon hystrix*	Spot-fin porcupinefish		yes
77	*Doryrhamphus excisus excisus*	Bluestripe pipefish	-	-
78	*Drepane longimana*	Banded drepane		yes
79	*Drepane punctata*	Spotted sicklefish		yes
80	*Dussumieria acuta*	Rainbow sardine	yes	
81	*Echidna nebulosa*	Starry moray		yes
82	*Ecsenius nalolo*	Nalolo blenny	-	-
83	*Ecsenius pulcher*	Gulf blenny	-	-
84	*Ellochelon vaigiensis*	Squaretail mullet	yes	yes
85	*Elops machnata*	Tenpounder		yes
86	*Encrasicholina heteroloba*	Shorthead anchovy	yes	yes
87	*Encrasicholina punctifer*	Buccaneer anchovy	yes	yes
88	*Epinephelus coeruleopunctatus*	Whitespotted grouper	yes	yes
89	*Epinephelus coioides*	Orange-spotted grouper	yes	yes
90	*Epinephelus lanceolatus*	Giant grouper	yes	yes
91	*Epinephelus malabaricus*	Malabar grouper	yes	yes
92	*Epinephelus merra*	Honeycomb grouper	yes	yes
93	*Epinephelus tauvina*	Greasy grouper		yes
94	*Eupleurogrammus glossodon*	Longtooth hairtail		yes
95	*Favonigobius melanobranchus*	Blackthroat goby		yes
96	*Favonigobius reichei*	Indo-Pacific tropical sand goby	-	-
97	*Fistularia commersonii*	Bluespotted cornetfish		yes
98	*Fowleria aurita*	Crosseyed cardinalfish		yes
99	*Fowleria variegata*	Variegated cardinalfish		yes
100	*Fusigobius neophytus*	Common fusegoby	-	-
101	*Gazza minuta*	Toothpony		yes
102	*Gerres erythrourus*	Deep-bodied mojarra		yes
103	*Gerres filamentosus*	Whipfin silver-biddy		yes
104	*Gerres longirostris*	Strongspine silver-biddy		yes

105	*Gnathanodon speciosus*	Golden trevally		yes
106	*Gymnomuraena zebra*	Zebra moray		yes
107	*Gymnothorax undulatus*	Undulated moray		yes
108	*Harpadon nehereus*	Bombay-duck		yes
109	*Heniochus acuminatus*	Pennant coralfish		yes
110	*Hemiramphus far*	Spotted halfbeak		yes
111	*Herklotsichthys lossei*	Gulf herring	-	-
112	*Herklotsichthys quadrimaculatus*	Bluestripe herring		yes
113	*Hippichthys cyanospilos*	Blue-spotted pipefish	-	-
114	*Hippichthys penicillus*	Beady pipefish	-	-
115	*Hippocampus kuda*	Spotted seahorse		yes
116	*Hipposcarus harid*	Candelamoa parrotfish		yes
117	*Histrio histrio*	Sargassumfish	yes	
118	*Istigobius decoratus*	Decorated goby	-	-
119	*Istigobius ornatus*	Ornate goby	-	-
120	*Istiblennius edentulus*	Rippled rockskipper	-	-
121	*Istiblennius flaviumbrinus*	Spotted rockskipper	-	-
122	*Istiblennius pox*	Scarface rockskipper	-	-
123	*Istiblennius spilotus*	Spotted rockskipper	-	-
124	*Lagocephalus guentheri*	Diamondback puffer	yes	-
125	*Lagocephalus lunaris*	Lunartail puffer	-	-
126	*Leiognathus equulus*	Common ponyfish		yes
127	*Leiognathus fasciatus*	Striped ponyfish		yes
128	*Leptoscarus vaigiensis*	Marbled parrotfish		yes
129	*Lethrinus harak*	Thumbprint emperor	yes	yes
130	Lethrinus lentjan	Pink ear emperor	yes	yes
131	*Lethrinus nebulosus*	Spangled emperor	yes	yes
132	*Lethrinus obsoletus*	Orange-striped emperor	yes	yes
133	*Lethrinus variegatus*	Slender emperor	yes	yes
134	*Lethrinus semicinctus*	Black blotch emperor	yes	yes
135	*Lobotes surinamensis*	Tripletail		yes
136	*Lutjanus argentimaculatus*	Mangrove red snapper		yes
137	*Lutjanus bohar*	Two-spot red snapper		yes
138	*Lutjanus ehrenbergii*	Blackspot snapper		yes
139	*Lutjanus fulviflamma*	Dory snapper		yes
140	*Lutjanus fulvus*	Blacktail snapper		yes
141	*Lutjanus johnii*	John's snapper		yes
142	*Lutjanus kasmira*	Common bluestripe snapper		yes
143	*Lutjanus monostigma*	One-spot snapper		yes
144	*Lutjanus russellii*	Russell's snapper		yes
145	*Lutjanus sebae*	Emperor red snapper		yes
146	*Megalaspis cordyla*	Torpedo scad		yes
147	*Megalops cyprinoides*	Indo-Pacific tarpon		yes
148	*Micrognathus andersonii*	Shortnose pipefish	-	-
149	*Mimoblennius cirrosus*	Fringed blenny	-	-
150	*Monodactylus argenteus*	Silver moony		yes
151	*Monodactylus falciformis*	Full moony		yes
152	*Mugil cephalus*	Flathead grey mullet	yes	
153	*Mulloidichthys flavolineatus*	Yellowstripe goatfish		yes
154	*Mulloidichthys vanicolensis*	Yellowfin goatfish		yes
155	*Naso fageni*	Horseface unicornfish		yes
156	*Naso lituratus*	Orangespine unicornfish		yes
157	*Naso thynnoides*	Oneknife unicornfish		yes
158	*Naso unicornis*	Bluespine unicornfish		yes
159	*Nemipterus randalli*	Randall's threadfin bream		yes

160	*Neoniphon sammara*	Sammara squirrelfish		yes
161	*Netuma bilineata*	Bronze catfish	yes	yes
162	*Novaculichthys taeniourus*	Rockmover wrasse		yes
163	*Oman ypsilon*	Oman blenny	-	-
164	*Omobranchus fasciolatoceps*	Barred Arab blenny	-	-
165	*Omobranchus mekranensis*	Mekran blenny	-	-
166	*Omobranchus punctatus*	Muzzled blenny	-	-
167	*Ophiocara porocephala*	Northern mud gudgeon	-	-
168	*Ostorhinchus fasciatus*	Broadbanded cardinalfish	-	-
169	*Otolithes cuvieri*	Lesser tigertooth croaker		yes
170	*Oxyurichthys ophthalmonema*	Eyebrow goby		yes
171	*Parablennius opercularis*	Cheekspot blenny	-	-
172	*Parablennius pilicornis*	Ringneck blenny	-	-
173	*Paracanthurus hepatus*	Palette surgeonfish	-	yes
174	*Paraplagusia bilineata*	Doublelined tonguesole		yes
175	*Parioglossus raoi*	Rao's hover goby		yes
176	*Parupeneus barberinoides*	Bicolor goatfish		yes
177	*Parupeneus barberinus*	Dash-and-dot goatfish		yes
178	*Pelates quadrilineatus*	Fourlined terapon		yes
179	*Pellona ditchela*	Indian pellona		yes
180	*Periophthalmus waltoni*	Walton's mudskipper	-	-
181	*Petroscirtes ancylodon*	Arabian fangblenny	-	-
182	*Petroscirtes mitratus*	Floral blenny	-	-
183	*Plagiotremus rhinorhynchos*	Bluestriped fangblenny	-	-
184	*Plagiotremus townsendi*	Townsend's fangblenny	-	-
185	*Planiliza macrolepis*	Largescale mullet	yes	yes
186	*Planiliza melinopterus*	Otomebora mullet	yes	yes
187	*Planiliza subviridis*	Greenback mullet	yes	yes
188	*Platax orbicularis*	Orbicular batfish		yes
189	*Platax pinnatus*	Dusky batfish		yes
190	*Platax teira*	Longfin batfish		yes
191	*Platycephalus indicus*	Bartail flathead		yes
192	*Plicofollis dussumieri*	Blacktip sea catfish	yes	
193	*Plotosus lineatus*	Striped eel catfish	yes	yes
194	*Polydactylus plebeius*	Striped threadfin		yes
195	*Pomacentrus trilineatus*	Threeline damsel	-	-
196	*Pomadasys argenteus*	Silver grunt	yes	yes
197	*Pomadasys commersonnii*	Smallspotted grunter	yes	yes
198	*Pomadasys* kaakan	Javelin grunter	yes	yes
199	*Pomadasys maculatus*	Saddle grunt	yes	yes
200	*Pomadasys multimaculatus*	Cock grunter	yes	yes
201	*Pseudorhombus arsius*	Largetooth flounder	yes	yes
202	*Pseudorhombus elevatus*	Deep flounder	yes	yes
203	*Pseudorhombus javanicus*	Javan flounder	yes	yes
204	*Pseudotriacanthus strigilifer*	Long-spined tripodfish		yes
205	*Psammogobius biocellatus*	Sleepy goby	-	-
206	*Pterois miles*	Devil firefish	-	-
207	*Pterois volitans*	Red lionfish		yes
208	*Rachycentron canadum*	Cobia		yes
209	*Rhabdosargus sarba*	Goldlined seabream	yes	yes
210	*Sardinella albella*	White sardinella	yes	yes
211	*Sardinella melanura*	Blacktip sardinella	yes	yes
212	*Saurida nebulosa*	Clouded lizardfish		yes
213	*Saurida tumbil*	Greater lizardfish		yes
214	*Saurida undosquamis*	Brushtooth lizardfish		yes

215	*Scartelaos tenuis*	Indian Ocean slender mudskipper		yes
216	*Scartella emarginata*	Maned blenny	-	-
217	*Scarus arabicus*	Arabian parrotfish		yes
218	*Scarus collana*	Red Sea parrotfish		yes
219	*Scarus falcipinnis*	Sicklefin parrotfish		yes
220	*Scarus ferrugineus*	Rusty parrotfish		yes
221	*Scarus frenatus*	Bridled parrotfish		yes
222	*Scarus fuscopurpureus*	Purple-brown parrotfish		yes
223	*Scarus ghobban*	Blue-barred parrotfish		yes
224	*Chlorurus gibbus*	Heavybeak parrotfish		yes
225	*Scarus niger*	Dusky parrotfish		yes
226	*Scarus persicus*	Gulf parrotfish		yes
227	*Scarus psittacus*	Common parrotfish		yes
228	*Scarus rubroviolaceus*	Ember parrotfish		yes
229	*Scarus scaber*	Fivesaddle parrotfish		yes
230	*Scarus zufar*	Dhofar parrotfish	-	-
231	*Scatophagus argus*	Spotted scat		yes
232	*Scomberoides commersonnianus*	Talang queenfish	yes	yes
233	*Scomberoides tala*	Barred queenfish	yes	yes
234	*Scomberoides tol*	Needlescaled queenfish	yes	yes
235	*Siganus canaliculatus*	White-spotted Spinefoot		yes
236	*Siganus javus*	Streaked spinefoot		yes
237	*Siganus rivulatus*	Marbled spinefoot		yes
238	*Siganus stellatus*	Brown-spotted spinefoot		yes
239	*Siganus sutor*	Shoemaker spinefoot		yes
240	*Sillaginopodys chondropus*	Clubfoot sillago		yes
241	*Sillago sihama*	Silver sillago		yes
242	*Solenostomus cyanopterus*	Ghost pipefish	-	-
243	*Sphyraena barracuda*	Great barracuda		yes
244	*Sphyraena flavicauda*	Yellowtail barracuda		yes
245	*Sphyraena forsteri*	Bigeye barracuda		yes
246	*Sphyraena jello*	Pickhandle barracuda		yes
247	*Sphyraena obtusata*	Obtuse barracuda		yes
248	*Sphyraena putnamae*	Sawtooth barracuda		yes
249	*Spratelloides gracilis*	Silver-stripe round herring		yes
250	*Stolephorus commersonnii*	Commerson's anchovy	yes	yes
251	*Strongylura leiura*	Banded needlefish	yes	yes
252	*Strongylura strongylura*	Spottail needlefish	yes	yes
253	*Syngnathoides biaculeatus*	Alligator pipefish	-	-
254	*Synodus variegatus*	Variegated lizardfish		yes
255	*Synodus macrops*	Triplecross lizardfish		yes
256	*Taeniamia fucata*	Orangelined cardinalfish	-	-
257	*Tenualosa toli*	Toli shad		yes
258	*Terapon jarbua*	Jarbua terapon		yes
259	*Terapon theraps*	Largescaled terapon		yes
260	*Thalassoma hardwicke*	Sixbar wrasse		yes
261	*Thryssa baelama*	Baelama anchovy	yes	yes
262	*Thryssa hamiltonii*	Hamilton's thryssa		yes
263	*Thryssa mystax*	Moustached thryssa		yes
264	*Triacanthus biaculeatus*	Short-nosed tripodfish		yes
265	*Trimma winterbottomi*	Winterbottom's goby	-	-
266	*Trypauchen vagina*	Burrowing goby		yes
267	*Tylosurus acus melanotus*	Keel-jawed needle fish		yes
268	*Tylosurus crocodilus*	Hound needlefish	yes	yes

269	*Upeneus doriae*	Gilded goatfish		yes
270	*Upeneus japonicus*	Japanese goatfish		yes
271	*Upeneus pori*	Por's goatfish		yes
272	*Upeneus sulphureus*	Sulphur goatfish		yes
273	*Upeneus sundaicus*	Ochrebanded goatfish		yes
274	*Upeneus tragula*	Freckled goatfish		yes
275	*Upeneus vittatus*	Yellowstriped goatfish		yes
276	*Uroconger lepturus*	Slender conger		yes
277	*Xiphasia setifer*	Hairtail blenny	-	-
278	*Zanclus cornutus*	Moorish idol	yes	
279	*Zebrasoma scopas*	Twotone tang	-	-
280	*Zebrasoma xanthurum*	Yellowtail tang	-	-
Sharks and rays (Elasmobranchs)				
	Scientific name	Common name	S	C
1	*Aetobatus narinari*	Spotted eagle ray		yes
2	*Brevitrygon imbricata*	Bengal whipray		yes
3	*Carcharhinus limbatus*	Blacktip shark		yes
4	*Carcharhinus melanopterus*	Blacktip reef shark		yes
5	*Chiloscyllium arabicum*	Arabian carpetshark		yes
6	*Eusphyra blochii*	Winghead Shark		yes
7	*Galeocerdo cuvier*	Tiger shark		yes
8	*Himantura uarnak*	Honeycomb stingray		yes
9	*Negaprion acutidens*	Sicklefin lemon shark		yes
10	*Pastinachus sephen*	Cowtail stingray		yes
11	*Pristis zijsron*	Olive sawfish		yes
12	*Pristis pectinata*	Smalltooth sawfish		yes
13	*Rhina ancylostoma*	Bowmouth guitarfish		yes
14	*Rhincodon typus*	Whale shark		yes
15	*Rhinoptera javanica*	Flapnose ray		yes
16	*Sphyrna lewini*	scalloped hammerhead		yes
17	*Sphyrna mokarran*	Great hammerhead		yes
18	*Stegostoma fasciatum*	Zebra shark		yes
19	*Taeniura lymma*	Blue spotted ribbontail stingray		yes
20	*Taeniurops meyeni*	Round ribbontail ray		yes
21	*Urogymnus asperrimus*	Porcupine whipray		yes
Crabs (Brachyura),				
	Scientific name	Common name	S	C
1	*Ashtoret lunaris*	yellow moon crab	-	-
2	*Calappa lophos*	Common box crab	yes	
3	*Calappa hepatica*	Hepatic box crab	yes	
4	*Cardisoma carnifex*	Brown land crab	yes	
5	*Carpilius convexus*	Omani coral crab	-	-
6	*Charybdis feriata*	Crucifix crab		yes
7	*Charybdis hellerii*	Indo-Pacific swimming crab	-	-
8	*Charybdis lucifera*	Swimming crab	-	-
9	*Charybdis natator*	Rock swimming crab		yes
10	*Episesarma* sp.	Tree climbing crab	yes	
11	*Eriphia smithii*	Rough redeyed crab	yes	
12	*Grapsus albolineatus*	Rock crab	-	-
13	*Leptodius exaratus*	Stone crab	-	-
14	*Lauridromia dehaani*	Japanese sponge crab	yes	
15	*Macrophthalmus* sp.	Sentinel crab	-	-
16	*Matula victor*	Brown spotted crab	-	-

17	*Metopograpsus* sp.	Climber crabs	-	-
18	*Metopograpsus messor*	Messor's shore crab	-	-
19	*Grapsus albolineatus*	Ghost crab	-	-
20	*Portunus pelagicus*	Sand crab		yes
21	*Portunus segnis*	Blue swimming crab		yes
22	*Scylla serrata*	Giant mangrove (mud) crab		yes
23	*Thalamita crenata*	Mangrove swimming crab	-	-
24	*Uca lactea*	Milky fiddler crab	-	-
Shrimps (Caridea) and lobsters (Astacidea)				
	Scientific name	Common name	S	C
1	*Alpheus* sp.	Pistol shrimp	-	-
2	*Penaeus indicus*	Indian white shrimp	yes	yes
3	*Penaeus semisulcatus*	Green tiger prawn	yes	yes
3	*panulirus versicolor*	Painted spiny lobster	yes	yes
Molluscs (Gastropods)				
	Scientific name	Common name	S	C
1	*Cerithidea decollata*	Truncated mangrove snail	yes	yes
2	*Terebralia palustris*	Mangrove whelk	yes	yes

Appendix 6.1. The survey conducted with locals in Qurayyat between 31st January 2017 and 3rd April, 2017, attached with the map used obtained from Google.

Survey No: Date:

Location of the survey: ☐ Somewhere in Qurayyat ☐Mangrove site

1. To better identify, understand and map the cultural services provided by Qurayyat mangroves

1.1. Have you ever visited the mangroves of Qurayyat before?

1.2. If yes, how frequently have you visited the mangrove site in the last 12 months?

1.3. What activities do you (or have you) done here? Please tick as many as apply

☐ Wildlife watching ☐ Nature conservation/ monitoring
☐Walking ☐Teaching/ informing people about the area
☐Cycling ☐Playing (with children, with friends)
☐Horse riding ☐Running
☐Fishing ☐Spiritual/ faith based activities
☐Swimming ☐Play ball sports
☐Creative activities (e.g. painting, photography, sculpture, filming)

If an activity is missing, please mention it_________________________________

1.4. What motivates you to visit the place? Tick as many as you like.

☐So that I can experience the beauty of nature

☐It facilitates the practice of a family tradition or a business

☐It provides a recreational opportunity

☐It is important for maintaining my health.

☐To live the experience of being in a small community.

☐To enjoy time with friends and / or meet people.

☐To feel more connected with God.

Any other? ____

2. Individual preferences for landscapes

2.1. Looking at the pictures of different places in Qurayyat (shown below), which of these places do you personally enjoy more? Please rank them from the most you enjoy to the least.

2.2. Using the map of mangroves in this area (shown below), can you please circle your favourite spot/s in this area?

2.3. Why are you choosing these spots? Which attributes influence your choice?

2.4. If you think about your last visit, how much time did you spend at these different spots?

3. Disservices of mangroves

3.1. Are there any spots at Qurayyat which you dislike? Can you circle them on this map please?

3.2. Why are you choosing these spots? Which attributes influence your choice?

4. Perceptions of site management

4.1. Do you know if the mangroves at Qurayyat are managed by the Ministry of Environment and Climatic Affairs or not?

4.2. Do you think the mangroves at Qurayyat need to be restored and better managed?

☐Yes ☐No
Go to 4.2 Go to 4.3

4.2. Could you please undertake this activity? Close your eyes and picture yourself in this place and imagine it in a better status, imagine it in the way you would like it to be. Can you tell me about the image you have formed in your mind in terms of how the site would look like? How it might affect your daily life and the activities you practice?

4.3. Do you know about the plan of building a dam?

☐Yes ☐No

4.4. Do you think it will affect the mangroves and your experience of the site? How?

5. Socio-economic characteristics of respondents

5.1. Gender:
☐Male ☐Female

5.2. Age:
☐18-20 ☐20-30 ☐31-40 ☐41-50 ☐51-60 ☐61-70 ☐>71

5.3. Place of residence:
____

5.4. Level of education:

☐School level ☐Diploma ☐High Diploma

☐Bachelor ☐MA, MSc ☐Doctoral

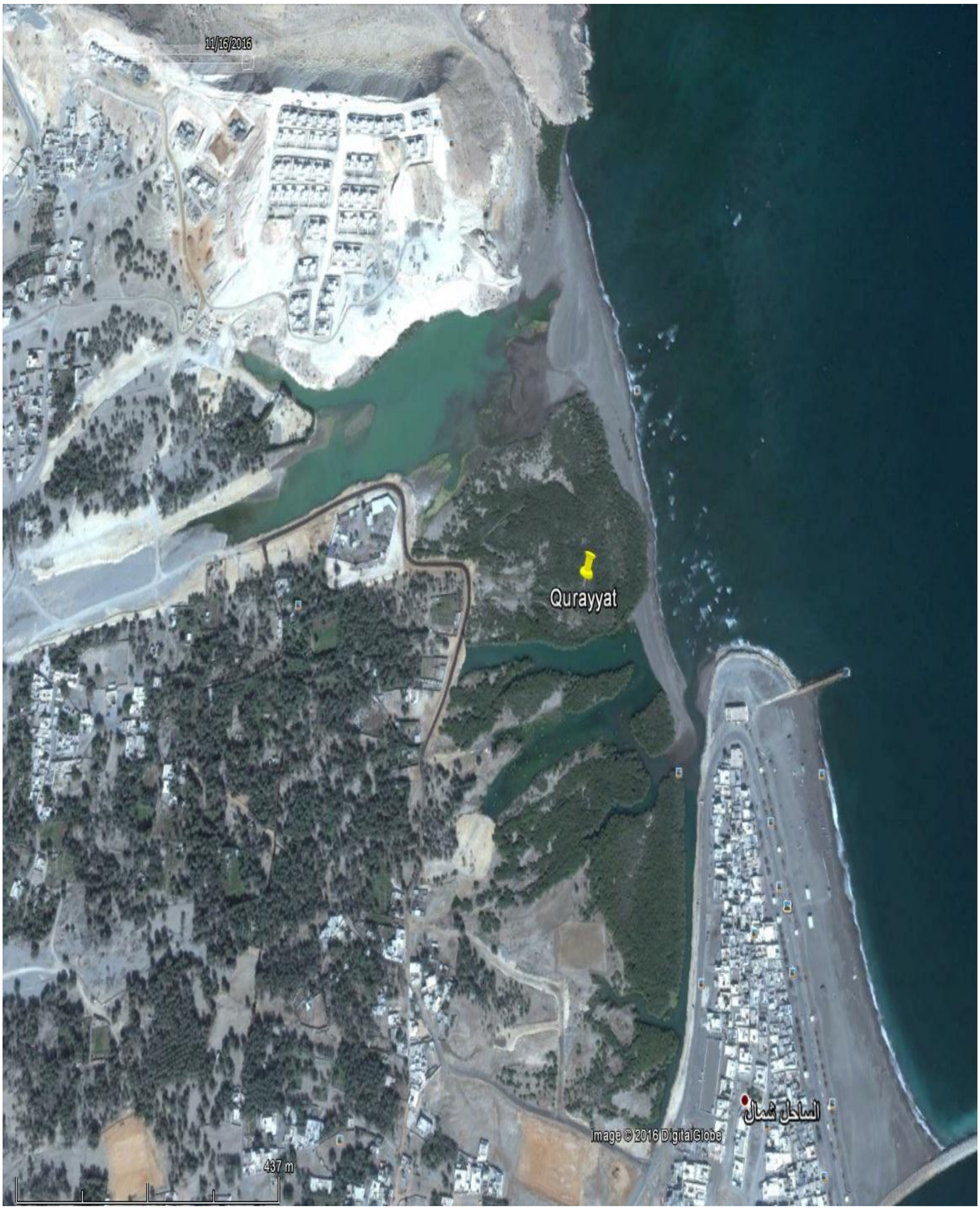
☐Illiterate

5.5. Employment

☐Full-time ☐Part-time ☐Currently unemployed ☐Prefer not to say

5.6. Occupation:

____ ☐Prefer not to say



Appendix 6.2. The interview with a manager in the Ministry of Regional Municipality and Water Resources in Oman conducted on 19th March 2017.

1-When was the plan to construct the dam drawn up?

2- Did you liaise with the Ministry of Environment and Climatic affairs in selecting the location of the dam?

3- When will the dam be constructed?

4- When is the project expected to end?

5-What will be the main purpose of the dam?

6-Will some water be discharged from the dam to the estuary?

7- If yes, how often will it be discharged? What volumes will be discharged?

Abbreviations

AGB	Above ground biomass
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASLR	Accelerated sea level rise
BGB	Below ground biomass
CBD	Convention on Biological Diversity’s
CES	Cultural ecosystem services
CICES	Common International Classification of Ecosystem Services
DBH	Diameter at breast height of a mangrove tree
DAPSI (W)R(M)	Drivers-Activities-Pressure-State changes-Impacts (on Welfare)-Responses (as Mesures) Framework
EBM	Ecosystem-based management
EEZ	Exclusive Economic Zone
FAO	United Nation Food and Agriculture Organisation
GIS	Geographic Information System
H	Height of a mangrove tree
ha	Hectare
IMD	India Meteorological Department (IMD)
InSAR	Interferometric Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
km	Kilometre
LIDAR	Laser Imaging Detection and Ranging
MA	Millennium Ecosystem Assessment
MAES	Mapping and Assessment of Ecosystems and their Services
MAF	Ministry of Agriculture and Fisheries Wealth, Oman
mm	Millimetre
MECA	Ministry of Environment and Climatic Affairs, Oman
MRMWR	Ministry of Regional Municipality and Climatic Affairs, Oman
MSFC	Marine Sciences Fisheries Centre, Oman
NCSI	National Centre for Statistics and Information, Oman
NPV	Net present value

NSA	National Survey Authority
p	Wood specific gravity
PACA	Public Authority of Civil Aviation, Oman
PGIS	Participatory GIS
PPGIS	Public Participation GIS
RECOFI	Regional Commission for Fisheries
RLR	Revised Local Reference
ROPME	Regional Organisation of Protection of Marine Environment (for Arabian Sea)
SCP	The Supreme Council of Planning, Oman
SLR	Sea level rise
SSH	Sea surface height
TEEB	The Economics of Ecosystems and Biodiversity
TESSA	Toolkit for Ecosystem Services Site-based Assessment
UAE	United Arab Emirates
UKNEA	UK National Ecosystem Assessment
UNEP	The United Nation Environment Programme
UNESCO	The United Nations Educational, Scientific and Cultural Organisation
WGFM	Working Group on Fisheries Management
WSG	Wood specific gravity

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