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Original article

Assessment of coastal salt marsh plants on the Arabian Gulf region

Hanan Almahasheer

Department of Biology, College of Science, Imam Abdulrahman Bin Faisal University (IAU), Dammam 31441-1982, Saudi Arabia

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ABSTRACT

Salt marshes form along coastlines and are very interesting ecosystems due to their function and services. In the future, salt marsh plants might provide food and medicine as crops irrigated via seawater in hyper-arid regions. In the Arabian Gulf, little is known about salt marsh vegetation. Therefore, a targeted search on scientific literature was performed to provide a comprehensive assessment. Hence, current knowledge of the extent and status of salt marsh in the Arabian Gulf region was reviewed, based on literature-based analysis. Then, historic trends of salt marsh publications were carefully inspected. This study provides a list of salt marsh families and their genera and species, with a total of 51 family 179 genera 316 species in the Arabian Gulf. The largest family was Chenopodiaceae followed by Poaceae, Asteraceae. Moreover, this study identified some of the gaps that could help future directions for scientific research, and help making decisions of conservation, management policies and procedures.

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1. Introduction

Salt marshes are one of the most dynamic ecosystems (Zoccarato and Da Lio 2021). They are distributed along 99 countries worldwide, mainly middle to high latitudes (Mcowen et al., 2017). Salt marshes plants have adapted to many different stresses, including salt and heat, as well as low O_2 in waterlogged soil (Silliman 2014). Salt marsh plants involve halophytes, grasses and low shrubs that are adapted to tidal effect (Adam 1993). Moreover, salt marsh habitat acts as a nursery of many aquatic and terrestrial organisms for e.g., Silliman (2014) estimated that there are between100 and 400 individuals of fiddler crabs or snails per m^2 in the salt marsh sediment.

Salt marsh habitat provides a high number of valuable benefits, including shoreline protection (Gedan et al., 2011), as well as, buffers to tsunamis storms, and hurricanes (Shepard et al., 2011), erosion control, water purification, and nursery grounds for many organisms and most importantly to commercial fisheries (Barbier et al., 2011). Moreover, they play an important role in the aquatic food web delivering nutrients to coastal waters (Valiela et al., 2002), as well as services of human well-being e.g., coastal tourism (Jennings 2004). And although vegetated coastal ecosystems (e.g., salt marshes) are smaller than terrestrial forests, their contribution to long-term C sequestration is much greater (Mcleod et al., 2011),

Instead, salt marsh ecosystems are still suffering many threats, e.g., effects of grazing (Bakker 1985, Kiehl et al., 1996), parasitizing (Pennings and Callaway 1996), exploited agriculture, shoreline development and reclamation activities (Bakker et al., 1997), eutrophication (Deegan et al., 2012), pollution (Williams et al., 1994), climate change consequences including sea-level rise (Morris et al., 2002), drought (Silliman et al., 2005), and frequency of intense temperatures (Myers et al., 2019).

The Arabian Gulf is a shallow sea located in a subtropical arid zone (Jones et al., 2012). Vegetated coastal ecosystems along the Arabian Gulf thrive in a hyper-arid and oligotrophic environment, with high levels of seawater temperatures and salinity (Saderne et al., 2020). The majority of Arabian Gulf countries lacked freshwater input (Brown et al., 2018a, 2018b) and were affected by the largest oil spill in history from the 1991 Gulf war (Boer 1996), with 11 million barrels of crude oil that were discharged in the sea (Michel 2011).

In the light of available literature-based conducted here, the aim of this study was first to collect published papers of salt marsh plant in the Arabian Gulf, provide a list of species, genera available in this region, along with their families and the regions where they were found out, as well as identifying the most abundant species and families. And second, to analyze historical trends of salt marsh publications based on countries and categorizing their topics. In order to highlight the less explored research fields and gaps of lit-

E-mail address: halmahasheer@iau.edu.sa
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Table 1
List of publication categories and the number of their sub-categories.

Category	Sub-Category	Number of papers	References
Biological (35)	Bioenergy	3	(Cybulska et al., 2014a, 2014b, Ashraf et al., 2016, Warshay et al., 2017)
	Fauna	5	(Al-Rasheid 1996, AlGhais and Cooper 1996, Van derHave et al., 2002, Al-Zaidan et al., 2003, Barth 2007)
	Flora	10	(Abbas and Eloqlah 1992, Zahran and Al-Ansari 1999, Alaie 2001, Akhani et al., 2003, Akhani 2004, El-Sheikh and Abbadi 2004, Akhani and Deil 2012, Abd El-Wahab, 2016a, Abd El-Wahab, 2016b, Al-Turki et al., 2017)
	Germination	6	(Noaman and El-Haddad 2000, El-Keblawy et al., 2007, El-Keblawy et al., 2016a, 2016b, El-Keblawy et al., 2017, Rao et al., 2017, Rasool et al., 2019)
	Management/ Monitoring/ Conservation	3	(Jones et al., 2012, Langman et al., 2012, El-Keblawy et al., 2015)
	Microbiology and Fungi	4	(Al-Zarban et al., 2002a, 2002b, Obuekwe et al., 2005, Al-Mailem et al., 2010, Bonfá et al., 2011)
	Molecular	4	(Al-Zarba et al., 2002, Al-Zarban et al., 2002a, 2002b, Golding 2012, Jafari et al., 2012)
Chemical (26)	Animal diet	1	(Glenn et al., 1992)
	Chemical analysis	19	(Gunatilaka 1990, Böer 1996, Taha and Alsayed 2000, Abbas 2005, Al-Zaidan et al., 2006, Barth 2006, Yasseen and Al-Thani 2007, Al-Dousari et al., 2008, Yasseen and Abu-Al-Basal 2008, Basyoni and Mousa 2009, Yasseen and Abu-Al-Basal 2010, Fahmy 2013, Zakery-Asl et al., 2014, Al-Taisan 2016, Motamed et al., 2016, Schile et al., 2017, Matinzadeh et al., 2019, Rabaoui et al., 2020, Saderne et al., 2020)
	Pollution	6	(Hayes et al., 1993, Boer 1996, Getter et al., 2005, Krupp and Khushaim 2005, Michel 2011, Ashok et al., 2019)
Physical (6)	Climate study	1	(Kendall et al., 2003)
	Hydrodynamic modeling	2	(Elshorbagy et al., 2003, Azam et al., 2006)
	Remote sensing and/ or Sea Level Rise	3	(Mehrabian et al., 2009, Babu et al., 2012, Lokier et al., 2015)

erature, which will help future environmental researchers, and decision-makers to understand the current knowledge of salt marsh ecosystem in the Arabian Gulf region, to better evaluate conservation and management plans.

2. Methods

A targeted search on scientific literature was performed for Salt marsh plants growing in the Arabian Gulf region, in September 2020. Using equivalent search parameters of two peer-reviewed databases; Scopus (Elsevier) and Web of Science (Clarivate Analytics), whereas Google Scholar was excluded because of the presence of non-peer-reviewed literature and to ensure the validity of the studies. Search parameters were mainly of four categories; Halophyte, Salt marsh, Arabian Gulf, and Persian Gulf (Arabian Gulf, hereafter).

No restriction was carried for years, all documents from 1960 to 2020 for Scopus and 1900–2020 for Web of Science. Yet, English language was the only language accepted for peer-reviewed papers. Any other language was excluded. And all types of documents (e.g., Article papers, books, book chapters, notes, short communications, and correspondence) were included, except for "Review papers" as the aim of this paper was to estimate the total number of families, genera and species of all published papers, although there were not many review papers as there were only three review papers (Cybulska et al., 2014a, 2014b, Brown et al., 2018a, 2018b, Gairola et al., 2018). Moreover, the gray mangrove *Avicennia marina* was excluded from this targeted search. However, when a paper included both salt marsh and mangrove, only salt marsh plants were included. All papers were compiled in EndNote X7.8; duplicated papers were removed. To explore geographic and temporal trends, all papers were investigated separately to extract information (reference type, year of publication, and country), then all papers were classified to categorize and sub-categories referred to the main text of the paper (Table 1). Further information can be found in (Supplementary material S1). Lastly, the number of families, genera and species was extracted from all papers. Descriptive statistics and figures were procured using JMP v.15.

3. Results

A literature-based search conducted here on two databases; Scopus (Elsevier) and Web of Science (Clarivate Analytics), revealed the lack of Salt marsh scientific research on the Arabian Gulf region. Without Salt marsh plants studies preceding 1990 (Fig. 1A), and only 9 papers between 1990 and 2000 followed by a 3-fold increase of scientific publication with 27 papers between 2000 and 2010, then 29 papers from 2010 to 2020 (Fig. 1A).

Historic trends showed that publication started earlier for KSA, UAE, Kuwait, and Bahrain compared to Iran and Qatar (Fig. 1B), yet, no publication was found for Iraq and Oman based on the two datasets Scopus and Web of Science. Similarly, research topics of chemical and biological aspects of the Arabian Gulf salt marsh ecosystem started earlier compared to physical techniques published papers (Fig. 1C).

Total number of published papers investigated in this study was 67 papers, journal articles were the highest, accounting for 88% of the total followed by conference papers with 4.5%, then book chapters with 3% and finally, 1.4% for both notes and short communications (Fig. 2A). Saudi Arabia had the highest number of published papers with 30% of the total, followed by UAE with 25%, Kuwait with 19%, Iran with 15%, while Qatar and Bahrain were 6% and 4.5%, respectively (Fig. 2B).

The total number of salt marsh plants in this study was 316 species detected from the literature-based search conducted, belonging to 179 genera and 51 families, more details about this information can be found in the supplementary information (Table 2 and Supplementary material S2). The most prominent family was Chenopodiaceae, followed by Poaceae, Asteraceae, Brassicaceae, Caryophyllaceae, and the rest of families with less than 10 genera (Table 2). Moreover, the most abundant species in the Arabian Gulf region are *Halocnemum strobilaceum, Suaeda aegyptiaca,* and *Arthrocnemum macrostachyum,* which all belong to the family Chenopodiaceae (Supplementary material S1and S2).

In general, biological topics were the highest (52%), followed by chemical topics (39%), then physical topics (9%) (Fig. 2C). Though, after investigating the collected papers one by one, it appears that

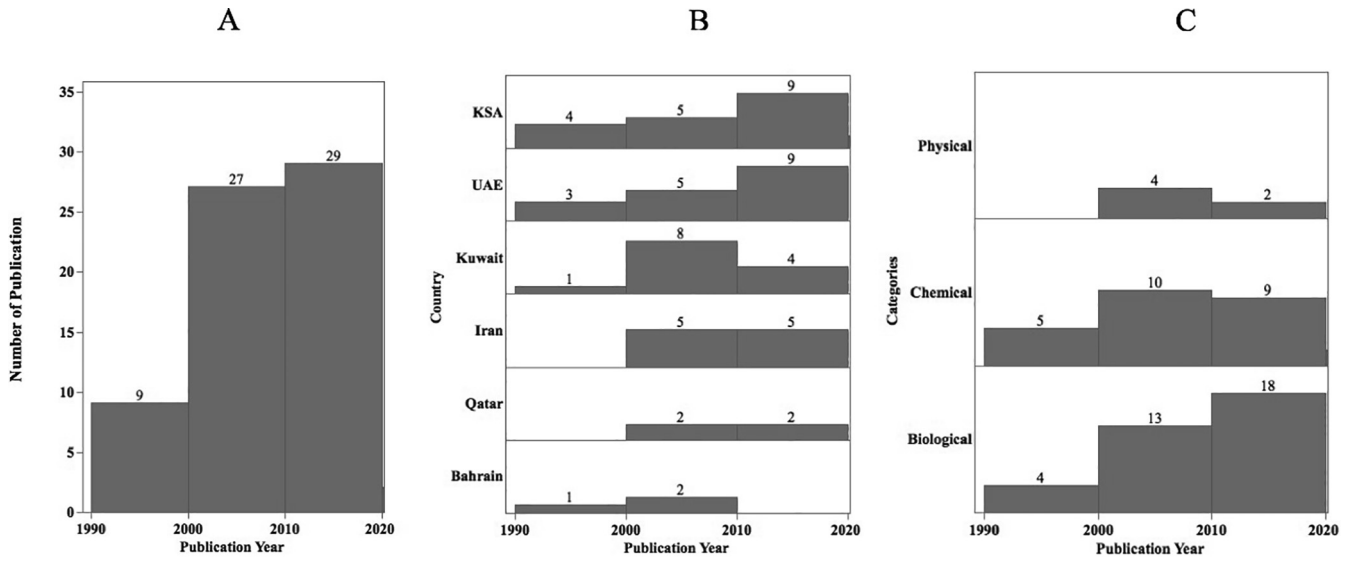

Fig. 1. (A) Historic salt marsh publications in the Arabian Gulf region. (B) Country by publication year in the Arabian Gulf Region. (C) Categories by publication year in the Arabian Gulf Region.

around 28% of the total is a fundamental chemical analysis of salt marsh plant or its surrounding ambiance, i.e., water and sediment. Followed by flora studies with a description of these plant diversity and distribution in different sites or locations of the investigated region, representing 15% of the total. Pollution and factorial germination experiments occupied the third and fourth rank in salt marsh research with 9% for each. Unexpectedly, fauna reports of salt marsh ecosystem were low, with 7.5% indicating the need for experts to gain information on the numerous species that uses salt marsh ecosystem as a nursery. Lastly, new scientific techniques and interest e.g., molecular, microbial and fungi, remote sensing and sea-level rise, management and conservation, bioenergy, hydrodynamic models, climate change, the beneficial uses of salt marsh plants on animal diet were less than 5% of each respectively (Fig. 2D).

4. Discussion

4.1. Biological topics on Arabian Gulf salt marsh

Very few Salt marsh fauna reports were found on the Arabian Gulf region, e.g., ciliates of Saudi Arabia, water-birds of Iran, and macro-fauna of Kuwait, respectively by (Al-Rasheid 1996, Van derHave et al., 2002, Al-Zaidan et al., 2003), and crabs on both UAE and Saudi (AlGhais and Cooper 1996, Barth 2007). Contrarily, the biodiversity and distribution of salt marsh flora were described in many locations e.g., in Iran by (Alaie 2001, Akhani et al., 2003, Akhani 2004, Akhani and Deil 2012), in Kuwait by (El-Sheikh and Abbadi 2004, Abd El-Wahab, 2016a, Abd El-Wahab, 2016b), as well as, Bahrain, UAE, and Saudi respectively (Abbas and Eloqlah 1992, Zahran and Al-Ansari 1999, Al-Turki et al., 2017).

Moreover, factorial salt marsh seeds germination experiments were conducted in UAE as (Noaman and El-Haddad 2000) experimentally germinated six species; *Spartina* sp., *Distichlis palmeri, Paspalum vaginatum, Juncus roemerianus, Salicornia bigelovii* and *Batis maritima*. And (Rao et al., 2017) germinated four species *Distichlis spicata*, *Paspalum vaginatum*, *Sporobolus virginicus* and *S. arabicu*. Whereas, Keblawy et.al germinated one species *Salsola imbricata, Anabasis setifera,* and *Suaeda aegyptiacais* each report respectively (El-Keblawy et al., 2007, El-Keblawy et al., 2016a, 2016b, El-Keblawy et al., 2017). While Rasool et al. (2019) tested the potential germination of *Halopeplis perfoliata*. in Saudi Arabia. Likewise, bioethanol/bioenergy trails of a diverse local salt marsh species were conducted in the UAE (Cybulska et al., 2014a, 2014b, Ashraf et al., 2016, Warshay et al., 2017).

Further, microbiology and fungi were reports were in Kuwait by (Al-Zarban et al., 2002a, 2002b, Obuekwe et al., 2005, Al-Mailem et al., 2010) on Bacteria strain, micro-fungi, and finally halophilic oil-utilizing micro-organisms, e.g., archaea, firmicute and proteobacteria isolated Kuwait salt marshes. And one study of Archaea (Haloarchaea) strains isolated Saudi salt marshes by (Bonfá et al., 2011). While, molecular studies mainly were about bacterial diversity in Kuwait (Al-Zarba et al., 2002, Al-Zarban et al., 2002a, 2002b) and Iran (Jafari et al., 2012) and molecular phylogenetic of mudflat snails in UAE (Golding 2012).

Finally, reports of management/ monitoring/ conservation ranged from sustainable modifications of an artificial coastline in Kuwait to developing multi-metric indices (MMIs) for restoration process and using Seawater to irrigate salt-tolerant landscapes in Saudi Arabia (Jones et al., 2012, Langman et al., 2012, El-Keblawy et al., 2015) respectively.

4.2. Chemical topics on Arabian Gulf salt marsh

An article on animal diet by Glenn et al. (1992) pointed at the potentials of using the dry biomass of *Salicornia bigelovii* as a good candidate to replace Rhodes grass which is the forage component of diets fed to goats in the UAE, because of the aridity of the area where freshwater for forage production is limited, and therefore the saline water resources can be used alternatively for irrigation.

In Bahrain, the extracts of three salt marsh species; *Sesuvium verrucosum, Salsola baryosma, Zygophyllum quatarense* were tested for their cytotoxic activity by (Taha and Alsayed 2000), and only *S. verrucosum* showed a marked significant activity. Moreover, (Abbas 2005) reported significant seasonal dissimilarities in the ash content of *Zygophyllum qatarense* roots and leaves from saline and non-saline habitats in Bahrain island, and the results demonstrated that the change in soil salinity during the different seasons changes the ash content of the plant.

Additionally, various chemical analyses were measured e.g., in Kuwait, isotopic signature δ 13C of salt marsh producers and consumers (Al-Zaidan et al., 2006), chemical analysis of sediment

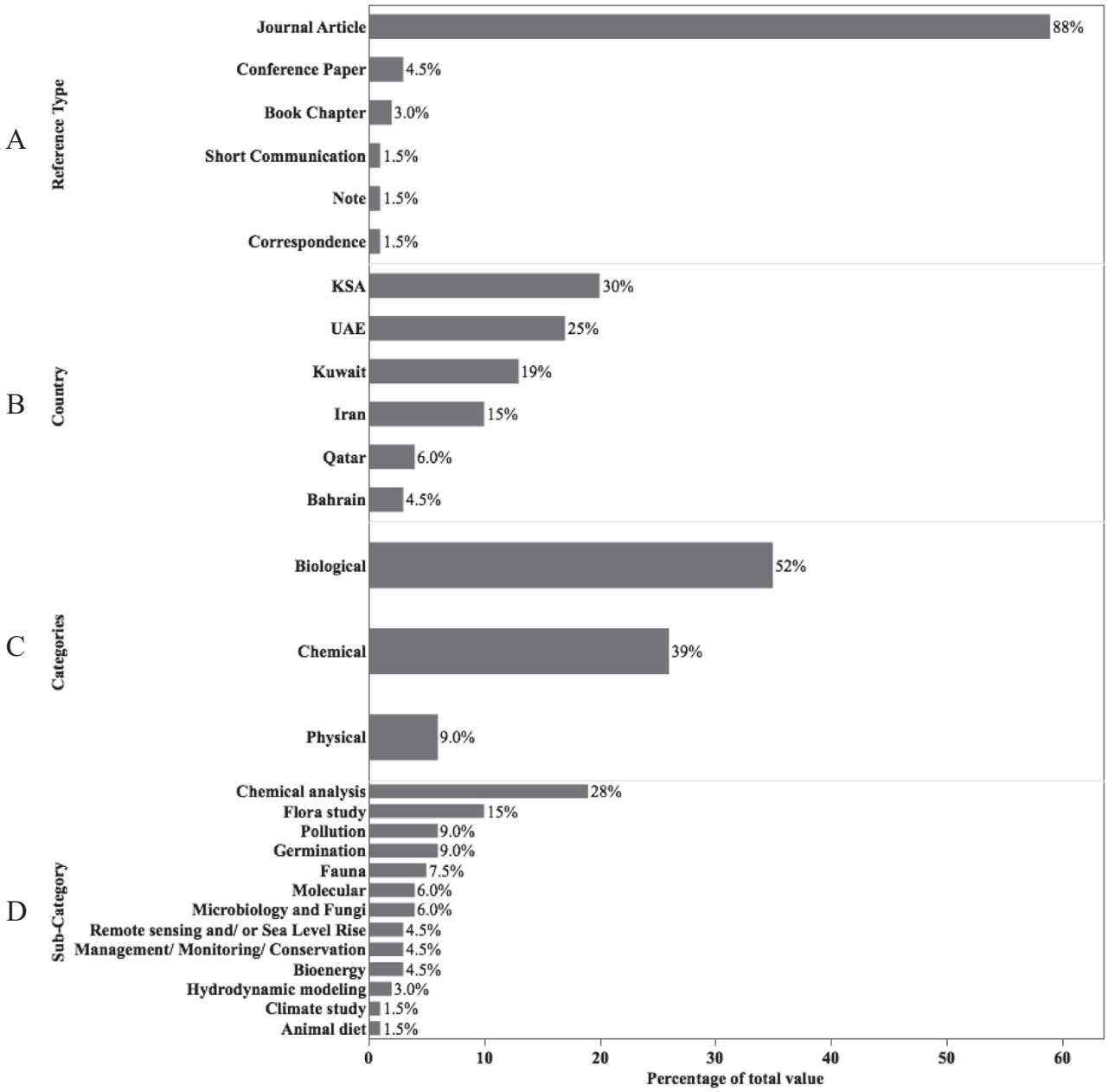

Fig. 2. Publication percentage of total value (A) by reference type (B) by country (C) by categories and (D) by sub category.

(Gunatilaka 1990, Al-Dousari et al., 2008). Whereas chemical reports on Qatar were about both salt marsh plants and sediment (Yasseen and Al-Thani 2007, Yasseen and Abu-Al-Basal 2008, Yasseen and Abu-Al-Basal 2010, Fahmy 2013). Yet, chemical analysis studies in Iran mainly were about plants (Zakery-Asl et al., 2014, Motamed et al., 2016), except for one study on the elemental composition of 108 plants and soil (Matinzadeh et al., 2019). Moreover, carbon stocks of salt marshes and other ecosystems were measured to find that salt marsh total carbon stock in UAE ranged between 31.4 and 205.0 Mg C/ha, (Schile et al., 2017). The importance of carbon sequestration in these vegetated coastal ecosystems, e.g., mangroves, seagrasses and salt marshes generated worldwide interest as these plants have the ability to save the planet via photosynthesis processes by removing large amounts of carbon dioxide from the atmosphere, and the burning fossil fuels which reduce climate heating. In Saudi Arabia, (Böer 1996), (Barth 2006), (Basyoni and Mousa 2009), and (Al-Taisan 2016) studied the chemical characteristics of salt marsh plants and soil along the Saudi Coast. Additionally, the last century's increment of nitrogen and phosphorous sequestration and the increased of elemental burial in salt marshes and other ecosystems along the Saudi coast was highlighted by (Saderne et al., 2020) and (Rabaoui et al., 2020) respectively.

Pollution studies were as the following; Hayes et al. (1993) examined the impacted areas one year after the 1991 Gulf War oil spill on Saudi Arabian shoreline, while (Boer 1996) studied the increase in soil temperature as an effect of the 1991 Gulf War oil spill along the Saudi Arabian shoreline (Getter et al., 2005), (Krupp and Khushaim 2005), and (Michel 2011) conducted shoreline surveys to determine the impacts of the 1991 oil spill on

Table 2
List of salt marsh families and their number of genera and species.

Family	Genera	Species	Family	Genera	Species
Chenopodiaceae	28	77	Bataceae	1	1
Poaceae	24	35	Capparaceae	1	2
Asteraceae	20	33	Cistaceae	1	2
Brassicaceae	10	13	Crassulaceae	1	1
Caryophyllaceae	10	17	Cucurbitaceae	1	1
Fabaceae	9	13	Cuscutaceae	1	0
Zygophyllaceae	7	11	Cynomoriaceae	1	1
Boraginaceae	6	10	Ephedraceae	1	1
Apocynaceae	5	6	Euphorbiaceae	1	1
Cruciferae	4	4	Frankeniaceae	1	2
Aizoaceae	3	6	Fumariaceae	1	1
Polygonaceae	3	3	Geraniaceae	1	3
Convolvulaceae	2	3	Hyacinthaceae	1	2
Cyperaceae	2	5	Juncaceae	1	4
Iridaceae	2	2	Malvaceae	1	1
Orobanchaceae	2	6	Menispermaceae	1	1
Papaveraceae	2	2	Myrtaceae	1	1
Plumbaginaceae	2	5	Neuradaceae	1	1
Ranunculaceae	2	2	Nitrariaceae	1	1
Resedaceae	2	2	Plantaginaceae	1	8
Scrophulariaceae	2	2	Primulaceae	1	1
Solanaceae	2	5	Rhamnaceae	1	1
Tamaricaceae	2	10	Rutaceae	1	1
Alliaceae	1	1	Typhaceae	1	2
Asparagaceae	1	1	Umbelliferae	1	1
Asphodelaceae	1	1	Total: 51 Family, 179 Genera, 316 species		

Saudi Arabian shoreline. Recently, (Ashok et al., 2019) estimated total petroleum hydrocarbons (TPH) in blue carbon vegetated ecosystems along the Saudi Arabian Gulf shorelines.

4.3. Physical topics on Arabian Gulf salt marsh

Industrial impact along UAE coast were assets via three-dimensional hydrodynamic modeling (Elshorbagy et al., 2003, Azam et al., 2006). While a climate study reported microclimate changes through vegetation development of holocene beach ridges in UAE (Kendall et al., 2003). And (Lokier et al., 2015) evaluated the regression related to mid-to late Holocene sea-evel high stand in UAE. While, (Mehrabian et al., 2009) used remote sensing to map vegetation in southwest Iran. And Babu et al., (2012) assessed sea level rise (SLR) scenarios in a Geographic Information System (GIS) along the Saudi Arabia coast.

4.4. Salt marsh plant diversity

Species richness is, in general, less in salt marshes compared to freshwater wetlands as most angiosperms are not tolerant to salt (Pennings and Bertness 2001). However, plants adapt to salt stress differently, e.g., including leaves/roots exerting salt or an increment of salt concertation inside their cells, becoming isosmotic (Silliman 2014). This study found that the most abundant species in the region are *Halocnemum strobilaceum, Suaeda aegyptiaca,* and *Arthrocnemum macrostachyum,* which all belong to the family Chenopodiaceae, since Chenopodiaceae species are often growing in high saline environments (Rozema and Schat 2013, Chenchouni 2017).

Chenopodiaceae was the most prominent family in this study with the greatest number of genera and species, followed by Poaceae, and Asteraceae (Compositae). Similar results of the most abundant salt marsh families and species were found by (Ghazanfar et al., 2014, Öztürk et al., 2019). Many species of Chenopodiaceae are adapted to arid environments and are considered very important as animal forage in the desert, semi-desert, and prairie regions, and used as good windbreaks and soil binders, in addition to their medical uses, e.g., the species *Anabasis aphylla* can be used as an insecticide (Wu et al., 2003).

4.5. Prospective of salt marsh research

Although this study has identified available literature-based research of salt marsh's in the Arabian Gulf region. Yet, other ecological topics which are essential and are gaining scientific interest in other parts of the world are lacking in this region. Therefore, to increase the scientific knowledge and contribute to biodiversity conservation, some significant research opportunities could be as the following; an evaluation of salt marsh dynamics and climate reports, estimations of sea-level rise along the coastlines, the temporal increase of heat and coastal protection. Looking into the evolutionary history and phylogenetic of salt marsh in the region. Building an environmental DNA barcoding (eDNA) database for a complete checklist of salt marsh's flora and fauna in the Arabian Gulf region. In addition to establishing a geographic information system (GIS) map for salt marsh distribution along the Arabian Gulf shoreline. Studies on salt marsh flora and fauna nutritional or trace metals budgets along with their surrounding habitat, i.e., sediment, water and air quality, as well as microbiota and fungi's community. Annual reports on conservation procedures of existing habitat and restoration plans of the degraded habitat of salt marsh plants. Finally, an interesting and important question to be highlighted concerns the use of salt marsh plants as a potential future crop of food and medicine since these plants flourish in seawater and could be used in future agriculture.

5. Conclusion

Although, Arabian Gulf salt marches are located in one of the most hyper-arid regions of the world.

And could be used as a natural laboratory for climate change studies. Nevertheless, it is probably one of the least studied areas worldwide. The collected list of salt marsh plants in this study includes essential information on these plants' diversity and distribution, what has been done in the region, and evidence of the

plant's existence in time and space. This study highlights the research of salt marsh in the Arabian Gulf region over the past three decades. Then specified some insights about what can be done in future salt marsh research in the Arabian Gulf region. This could enable researchers and policymakers to understand some of the most significant research opportunities and set further exhaustive studies to fill our knowledge gaps.

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Declaration of Competing Interest

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Author contribution

Not applicable.

Data availability

The data used to support the findings of this study are included within the supplementary information file(s).

Animal research (Ethics)

Not applicable.

Consent to participate (Ethics)

Not applicable.

Consent to publish (Ethics)

Not applicable.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2021.06.002.

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