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A Review on the Impact of Exotoxicology and Oil Spills in Mangrove of Saudi Arabia

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Mangroves are woody plants and they grow at the interface between land and sea in the region of tropical and sub-tropical latitudes because of conditions like high salinity, extreme tides, strong winds, high temperatures and anaerobic soils. There may be no other group of plant with a highly developed morphological and physiological adaptation to these extreme conditions. Mangroves and mangrove ecosystems were studied extensively but the level of our understanding is still poor. Since the degradation and destruction of mangroves is continuing, there is a critical need to understand them better. As researchers continue to discover certain vital facts about mangroves and their impact in the global ecosystem, the volume of published information has grown enormously and the numbers of workers were increased and drawn to these unique environments. Hence, there is a need for certain periodic reviews of literature. In this review, we emphasize work on mangrove ecosystems and certain fraction of studies in Saudi Arabia.

Key words: Exotoxicology, Oil spills, Mangrove, Saudi Arabia.

Mangarove are woody plants which are found abundantly in regions of tropical and sub-tropical latitudes. Mangrove and their associated microbes constitute the mangal (i.e. The forest community among Mangroves). Mangrove ecosystem is a combination of mangal and their associated abiotic factors. The term "*mangrove*" is referred for plants and their associated microbes in the forest community. In order to avoid confusion, Macnae (1968) had proposed that the term "mangal" should be referred to the forest community while the term "mangroves" should refer to the individual plant species. In 1992, Duke had redefined mangrove as "a tree, a shrub or a palm, generally exceeding one and a half metre in height, which normally grows above sea level in the intertidal zone of marine and coastal environments." This definition was acceptable for most of the species found in the ecosystem of mangroves but ground ferns were probably be considered associates of mangrove rather than true mangroves. The term "mangrove" is also used as an adjective, as in "mangrove tree" or "mangrove fauna". Mangrove forests are sometimes called "tidal forests", "coastal woodlands", or "oceanic rain forests". The word "mangrove" is usually considered a compound in accordance with the Portuguese word "mangue" and the English word "grove". The corresponding French words are "manglier" and "paletuvier"[1] while the Spanish term is "manglar". The Dutch use "vloedbosschen" for

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the mangrove community and "mangrove" for the individual trees. German use follows the English. The word "mangro" is a common name for *Rhizophora* in Surinam[2]. It is believed that all these words originated from the Malaysian word, "manggi-manggi" meaning "above the soil." This word is no longer used in Malaysia, but is used in eastern Indonesia to refer the species of *Avicennia*.

Global distribution of mangrove

Mangroves are distributed in a circum tropical path with its occurrence in 112 countries and their associated territories and in a global scale they cover an area of 150,000 square kilometers (km^2) which is an approximate scale in the region of sheltered coastlines, about 50% of their historic range[3-5, Fig.1]. Global coverage of *Rhizophora* had been variously estimated around 10 million hectares[4-6], 14-15 million hectares[4, 5], and 24 million hectares [5, 6]. Spalding (1997) gave a recent estimate of over 18 million hectares with 41.4% in the region of south and Southeast Asia. In Indonesia the coverage is 23.5%. Mangroves are largely restricted to latitudes between 30° north and 30° south. Northern extensions of this limit occur in Japan (31°22'N) and Bermuda (32°20'N); southern extensions are in New Zealand (38°03'S), Australia (38°45'S) and the east coast of South Africa (32°59'S)[6-8].Mangrove distribution is strongly affected by temperature[9-11] and moisture[10]. Large-scale currents may also influence the distribution by preventing the propagules from reaching some areas[11-14]. Individual mangrove species differ in the length, time of visibility of propagules, establishment of success, growth rate and tolerance limits. These factors appear to be consistent around the world to produce a characteristic distributional range for most species [12, 13 and Table 1].

Mangroves have a broader range of distribution along the eastern coastlines of the America and Africa. Mangroves prefer a humid climate and freshwater inflow for its nutrient and silt. Mangroves grow luxuriantly in alluvial soils. They are abundant in broad, sheltered and low-lying coastal plains where topographic gradients are small and tidal amplitudes are large. Repeatedly flooded but well-drained soils support a proper growth of mangrove with a high diversity of species[15-17]. Mangroves grow poorly in stagnant water[18-20].

Evolution of Mangroves

The evolutionary history of mangroves remains problematic with a variable number of competing theories. Mangroves were expected to be evolved from the terrestrial plants rather than the marine plants. Pollen fossils of mangrove were found below the assemblies of a marine foraminiferan (i.e., in the lower deposition of estuarine environments) suggests the fact that the evolution of these plants from a non-marine habitat to an estuarine habitat[21]. In the distant past, these land plants were adapted to brackish water and became the "core" for the mangrove flora. The diversity of mangroves is much higher in the Indo-West Pacific regions than in the Western Atlantic and the Caribbean regions. There were two competing hypotheses to explain this pattern. The center-of-origin of the first hypothesis indicates that the "taxa of all mangroves were appeared first in the Indo-West Pacific and then they were subsequently dispersed to the other regions". The vicariance hypothesis, on the other hand, states that "all mangroves were originated around the Tethys Sea and due to the continental drift across the different regions of the earth laid the foundation for the creation of distinct faunas".

Ellison *et al.* (1999) had evaluated these two hypotheses using (i) a review about the fossil record of mangarov, (ii) a comparison of fossil distributions of mangroves and its associated gastropods, (iii) an analysis of mangroves and gastropods on the basis of species-area relationships (iv) an analysis of nestedness patterns of individual plants and gastropod communities and (v) an analysis of nestedness patterns of individual plants and individual gastropod species. The evidence from all analyses supports the vicariance hypothesis and it was suggested that the origin of mangroves is Tethyan. This argument set the base for having a much higher range of diversity of mangroves in the region of Indo-West Pacific on the basis of certain conditions to favor diversification. For example, the continual presence of an extensive habitat in wet condition might have allowed more species to make transition from terrestrial to brackish-water habitats. The Atlantic, Caribbean and East Pacific regions were lathogic to the period of drying which could have prevented such adaptation. Ricklefs and Latham (1993) have suggested a limited dispersal to combine with the closure of Tethys connection to the Atlantic Ocean.

Studies of mangrove biochemistry and genetics provided the further evidences for concerning the evolution of mangrove and its dispersal. For example, Dodd *et al.* (1998) found a significant genetic differentiation between mangroves in the eastern and the western provinces of Atlantic region. Three species from the region of western Africa showed a significantly greater diversity for lipid and certain longer carbon chains were its outcome from eastern part of South America and on the basis of these occurances, he suggested the fact that mangroves show a derived characteristic in the western part of Atlantic region and finally he concluded the fact that "Atlantic mangroves had not dispersed from the Tethys via the Pacific region".

Avicennia and *Rhizophora* were probably the first genera to evolve and appear near the end of the Cretaceous period[2]. Mangroves are quite old and it might have possibly occurred after the first angiosperms, around 114 million years ago[8]. Pollen records had provided vital information about the process of subsequent radiation. Fossil pollen was raised from the sediments found in the areas of Leizhou Peninsula and China illustrate that the mangroves were expanded from south to north and reached their northern limit on the Changjiang Delta at the mid-Holocene[22]. A similar study of pollen from the samples of late Holocene in Bermuda suggests that the mangroves were established there before 3000 years when there was a decrease in the rise of sea level from 26 to 7 cm per century[18, 19].

A detailed study about pollen records from Mexico, Antilles, Central America and northern South America[23] indicate that the neotropical environments were first occupied by *Acrostichum*, *Brevitricolpites variabilis*, *Nypa* and *Pelliceria* in the early years of Eocene, which was about 50 million years ago. *Avicennia* appeared late in the region of Miocene, about 10 million years ago. Six mangrove species and three of its associated genera were present in the middle Pliocene, about 3.5 million years ago and fifteen plant genera were present at the Quaternary period. Twelve additional species were added during the Cenozoic to produce the present-day assemblage with 27 genera of mangroves and its associated plants[20, 21].

Continental drift had produced a massive dispersal of genes in the geologically recent times by the processes of evolution. Though mangroves evolved in the tropics, one species, *Avicennia marina*, is found in the temperate latitudes, particularly in the southern hemisphere[22]. This genus is with the origin of western Gondwanan with a subsequent radiation of several taxa. They

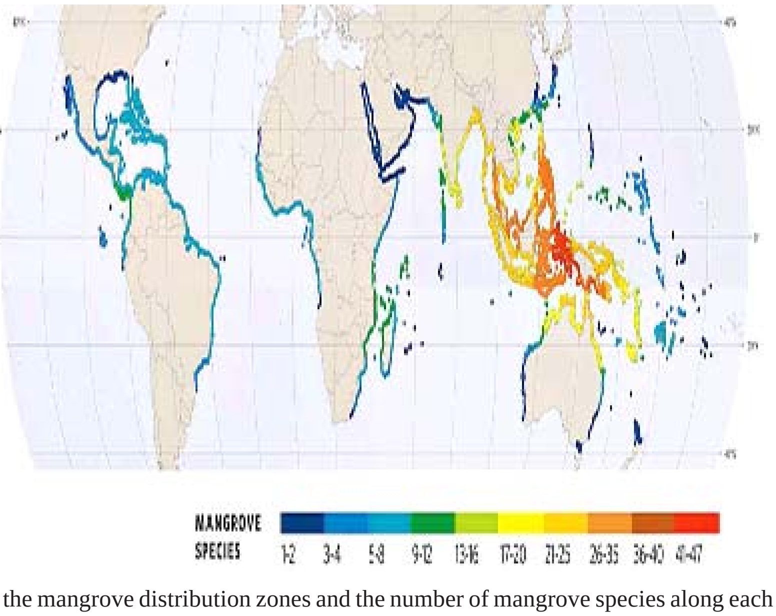

Fig.1. World map of the mangrove distribution zones and the number of mangrove species along each region (Data obtained from the literature "Habitat requirements for mangroves" written by Deltares in 2014.)

were facilitated by the tectonic dispersal of southern continental fragments [23]. Mangrove fossils have clearly provided certain valuable information about the evolution of pre historical mangrove and its dispersal. However, Burnham (1990) cautions that reconstructions were based on organic and it differ substantially on the basis of mangrove parts. (e.g., fruits and seeds vs. leaf litter).

Mangrove ecosystems are dynamic and it is undergoes changes in the time scale of 102 - 104 y[24]. Indeed fossil mangroves are often found in regions where they no longer exist and they are Texas, USA[25, 26], West Africa[27], Hungary[28], India[29, 30], the Chao-Shan Plain of China[31] and Western Australia[32]. Historical changes in mangrove distributions can reveal the details about paleoclimates and the changes in sea-level[33-40]. For example, in the equatorial Pacific Ocean, there were certain alternating reef and mangrove fossils in the region of upper Miocene and lower Pliocene[41].Similarly, Holocene sediments from the Maya Wetland of Belize indicate the fact that the mangrove peats were filled by the lagoon before 4800 y[42]. These patterns might have a reflection on fluctuations in sea level or climatic shifts in large-scale. In Poverty Bay of New Zealand, the presence of *Avicennia marina* and *resinifera* during the early days of mid-Holocene suggests that the area had a frost-free climate[43]. The mangrove fossil record is clearly an area where continued research has a greater potential for providing significant information about the history of these unique plants and the recent history of the earth.

Acute effects of oil toxicology in Mangroves

It is clearly evident that the acute effect of oil toxicity to mangroves has been analysed over the decade from various experiments conducted in laboratory and fields. In particular the seedlings and saplings are highly susceptible to oil exposure. In case of the field studies conducted with *Avicennia marina*, it was found that around 96% of seedlings were exposed to a weathered crude oil were died when compared to the 100% of seedling survival among the unoiled controls[44, 45]. Other studies found that mangrove seedlings could survive in oiled sediments up to the point where the propagules were exhausted upon died plants [Fig. 2, Fig. 3].

Chronic effects of oil toxicology in Mangroves

Mangroves show an immediate response to oiling by curling or yellowing the leaves. In case of the Era and Bahía las Minas spills, tree may survive for a longer time on the nature of exposure but it takes a longer time period to recover to produce the growth of a new leaf. Mangroves could be chronically impacted in several ways by oil spilling. Stressed mangroves could show a fair amount of difference in their rate of growth or the strategy of reproductive timing. They may also develop certain additional adaptations in their morphology to survive either in the physical or in the chemical consequences of contamination. Researches from all around the world have reported

Fig. 2. Chlorosis of red mangroves (after the three week observation) after oil spill of intermediate fuel from the M/T *Solar in* Philippines (Data obtained from the published literature of Ruth Yender in NOAA).

Fig. 3. Arial view of Roosevelt Roads after the Puerto Rico jet fuel spill in 1999 shows the dead mangroves (Data obtained from the published literature of Dan L. Wilkinson and Geo-Marine)

the deformation of red mangrove propagules in *Avicennia* trees after the 1978 Howard Star spill in Tampa Bay (Fig.4 and Fig.5).

Impact of Vegetation and oil toxicology of Mangrove in Saudi Arabia

Mangrove forests are abundantly found in the tidal areas on the Red Sea and the coastal area in Arabian Gulf. *Avicenia marina* trees contribute to its major composition. On the coast of the Red Sea, *Avicenia marina* is also accompanied by *Rhizophora mucronata* and it is rear in the region of Saudi Arabian Gulf [46] because they grow mostly at the end of the fresh water streams and majority of the mangrove forests are found on the eastern coast of the Red sea between Jizan in the south and Dibain in the north. The estimated area of mangroves on the Red Sea shore is about 200-6000 hect., which is very less when compared with the regions in Arabian Gulf. Mangrove ecosystems are limited along the Arabian Gulf and they are confined to the Damman area (Tarut Bay) with well developed communities consisting of *Avicennia marina*.

In the region of Gurmah Island, two mangrove planting sites were established in 1981 in the area of Al Khafji. *Avicennia marina* was the major species with smaller plots of *R. stylosa, R. mangle, Lumnitzera racemosa* and *Bruguiera gymnorrhiza*. In case of mangrove ecosystems, Arabian Gulf was principally affected by the large amount of oil spill which was raised as an outcome of the Gulf War.

In the Darb and Al Raqabah, *Avicennia marina* trees constitute a larger part in the ecosystem and mangroves also occur in the areas of Al Qahmah and Wadi Dhahaban with different ranges of height in different sites. The tallest mangrove trees of height 6 m were located in Al Qahmah. *Avicennia marina* is also overspread in the areas of Rabigh, Jeddah, Jizan and Farasan Island. In case of Farasan Island, *Rhizophora mucronata* was also present.areas of Al

On the coast areas of the Saudi Arabian Gulf, there is no correlation between the concentrations of metal ions in the sediments and the leaves of mangroves on the contaminated soil[47]. In addition to direct killing the mangrove fauna, oil can also have indirect effects on the modification of their habitats. Oil released during the Gulf War (1991) left a black tar layer in the region of mangals along the Saudi Arabian Gulf. The tar layer was created at a higher altitude than the normal temperatures found in soil. The ecological consequences of the higher temperatures, and their effect on epifauna and infauna were not completely understood[48, 49].

The mangrove areas along Rabigh and the delta of Wadi Farrah support dense stands of *Avicennia marina* that extend along 11km of Red Sea coastline from 23° 56'N, 38° 14'E. The site is adjacent to the new industrial city of Yanbu (Yanbu-al-Sinaiyah), which is 25km south of Yanbu al-Bahr. The area also includes coral reefs, sandy beaches, saltmarshes and sabkha.

As the area is surrounded by the largest oil terminal on the Saudi Arabian Red Sea. Oil

pollution poses the main threat to the area, though oil spill contingency planning is well

Fig. 4. Collection of deformed red mangrove propagules from oil sediments contrasted with normally developed propagules from adjacent sediments (Data obtained from the National Ocean Service of United States in 2014).

Fig. 5. Abnormal adventitious roots at the base of a black mangrove tree (Data obtained from the National Ocean Service of United States in 2014).

Fig. 6. Map of Saudi Arabia showing the coastal areas near the red sea having Mangrove species.

advanced and good clean-up and containment facilities are available. Plans exist to build a new marine laboratory and a centre to promote public awareness in environmental issues Mangroves oiled by the 1991 Gulf War spill in Saudi Arabia showed a "tissue death on pneumatophores" and it laid the foundation for a new plant with branched pneumatophores that can grew from lenticels[50-53]. Hence, a compensa-tory mechanism was also found in apparent to the provision of gaseous exchange. As is the case of the spill-affected resources, some indirect impacts on mangroves have been identified. For example, residual oil remaining on the surface of mangrove sediments during the Gulf War spill in Saudi Arabia increased the temperature of the ambi-ent soil to the point where both germination and growth of intertidal plants were adversely affected.

Summary

The general response of a mangrove forest to oiling can be divided into four phases: (i) immediate effects, (ii) structural damage, (iii) stabilization and (iv) recovery. The third and fourth phases may take many more years to occur. There are many species of mangrove which are affected by the oil spills of refineries and metal based oxidation from other industrial waste. Among various species of Mangarov, Rhizophoraceae was found abaundant and well studied in the area of Saudi Arabia. Vegetation in Saudi Arabia is heavily affected because of the Gulf War spill (1991) and the petrochemical industries along the cost of Rabigh and Yanbu, as this area is surrounded by the largest oil refineries on the Saudi Arabian Red Sea. Oil pollution poses the main threat to this area, though oil spill contingency planning is well advanced and good clean-up and containment facilities are available. Though there were many case reports of oil spills on mangarov, the impact made by the "Gulf War spill (1991)" in Saudi Arabia is very high and the recovery will take a minimum of two from the current year but oil spill laid the foundation for a new plant with branched pneumatophores that can grew from lenticels. Since there were very less reports oil spills by other species of mangrove except *Avicenia marina*, it is difficult to analyse the direct and indirect impact of its current environmental hazard and measures of recovery for future. In future, there is a need to develop a biosensor to analyse the level of impact of oil spills on plants.

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