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MANGROVE AS A BIOINDICATOR FOR ENVIRONMENTAL POLLUTION IN THE COASTAL MARINE ENVIRONMENTS-REVIEW

By

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إستعمال المنغروف كدليل أحيائي على التلوث البيئي في البيئات البحرية الساحلية - دراسة مراجعة

فاضل السعدوني و إبراهيم القصاص

قسم الجيولوجيا ، جامعة قطر

إستعمل المنغروف على نطاق واسع كدليل أحيائي لأنواع التلوث المختلفة مثل التلوث بالفلزات الثقيلة والمركبات العضوية والهيدروكربونات فضلاً عن ظروف نضوب الأوزون . وتتركز الملوثات بأنواعها المختلفة في الأوراق والجذور الهوائية ولحاء السيقان والأغصان. كما أن أشجار المنغروف تسهم في حجز الترسبات دقيقة الحبيبات كالأطيان ويؤدي ذلك إلى زيادة كثافة الجذور الهوائية وإستطالتها . ومن المعتاد أن تتركز الملوثات في السنتمترات العليا القليلة.

وتعتمد قدرة التربة على إحتجاز الملوثات على عدة عوامل من بينها نسيج التربة ومحتواها من المادة العضوية ودرجة تأكسدها وملوحتها وعوامل أخرى . إستعملت أشجار المنغروف أيضاً للكشف عن الطفرات الوراثية إذ وجد مثلاً أن للمنغروف الأحمر مواصفات تكاثرية تسمح بإستعماله للكشف عن الطفرات الوراثية الناتجة من التلوث النووي كما إستعمل نقص اليخضور (الكلوروفيل) دليلاً على التلوث النفطي الذي يرتبط أيضاً مع زيادة مطردة في عدد الجذور الهوائية وإتخاذها أشكالاً متفرعة بدلاً من الشكل المستقيم التقليدي وكذلك نشوء أوراق وأثمار مشوهة. كما لوحظ أن معدلات نمو المنغروف قد تدنت بشكل ملموس بعد تعريضها إلى تراكيز عالية من الأشعة فوق البنفسجية .

Key words : *Mangrove, pollution, coastal environments, heavy metals, oil pollution, ozone depletion*

ABSTRACT

Mangrove stand components have been used widely as bioindicators for different types of environmental pollution including heavy metals, organic pollutants and hydrocarbons as as well as in the detection of ozone depletion conditions.

Heavy metals and organic pollutants such as herbicides concentrate in leaves, pneumatophores (aerial roots) and bark of the stems and branches. This is associated with succulence in leaves, which lead eventually to their fall. Heavy metals would be released after the diagenesis of the litter and added to the pollutant budget again. Mangrove stands trap and accumulate fine sediments, which eventually cause the development of high-density pneumatophores. Furthermore, heavy metals accumulate in the few upper centimetres of the mangrove soil layer. The ability of the soil to heavy metals retention depends on their texture, organic matter content, composition, redox potential, pH, salinity and Al, Fe and Mn contents.

Mangrove trees have been used to screen for mutagens in tropical environments and was found that red mangroves have the reproductive traits that allow the detection of nuclear and cytoplasmic mutation in the field in the same way as colonies of bacteria or yeast are screened for mutation in the laboratory. The chlorophyll-deficiency has been used also as a genetic end-point in plant mutation in areas polluted with oil. Oil pollution is associated with increased number of pneumatophores, generation of malformed leaves and fruits and decrease in litter production. Furthermore, mangrove developed highly branched pneumatophores rather that the normal pencil-shaped.

Experimentation on the effect of ultraviolet radiation on the development of the seedlings of the mangrove *Rhizophora* has indicated that their growth was generally reduced with exposure to high UV with shoot elongation.

The integrity of the mangrove ecosystem can be used as a simple bioindicator for a wide range of pollutants with a high efficiency and a minimum cost.

INTRODUCTION

Mangrove stand is one of the most productive organic systems in the world. There are around 46 known species of mangrove in the world, but there is only one species *(Avicennia marina)* in Qatar. This species is the most common worldwide and it is known for its capability to survive under varied climates.

Mangroves are woody, seed-bearing, highly specialised plants ranging in size from shrubs to tall trees. They are found along sheltered intertidal coastlines in association with estuaries and lagoons.

Mangroves are characterised by their ability to grow on land periodically flooded by seawater, and in anaerobic and acidic soils. Although mangroves grow in saline environments, they have the usual requirements for fresh water, nutrients, oxygen and sunlight. Many of the individual species posses unique adaptations which enable them to thrive in an environment where other plants cannot grow. Associated with this vegetation are many species of fish, crustaceans and molluscs, (1).

DISTRIBUTION

Global distribution

Mangrove stands are characteristic vegetation of the upper interidal zone along tropical and subtropical coastlines of the world. Indonesia has the largest remaining area of mangroves.

Mangroves occupy two major belts namely the Eastern Zone, which includes East Africa, India, southeast Asia, Australia and the west Pacific. The term *Indo-West Pacific (IWP)* region has been assigned to this region (2). The second zone consists of West Africa, South

America, the Caribbean, Florida, Central America and Pacific North and South America. The term *Atlantic - Caribbean - East Pacific (ACEP)* has been suggested to this region (20.

Distribution in Arabia

It seems quite possible that rich mangrove forests had occurred along the Arabian Gulf coasts in ancient times. Sumerian inscriptions mention that during the third millennium BC, they imported large quantities of timber from Dilmun (probably present Bahrain) and Magan (present Oman). It could be understood that the timber mentioned in these inscriptions includes mangrove poles. At present, there is no mangrove species suitable for producing poles in the Gulf countries and they are normally imported form East Africa (3).

During the third millennium BC, a drought period dominated the entire region that extends from the Sahara to India. A relatively more humid climate dominated Arabia before the third millennium BC (3). Eratosthenes of Cyrene (272-194 BC) the Alexandrine geographer mentioned that along the whole coast of the Arabian Gulf in the deep parts of the water, grow trees resembling laurel and olive trees. These trees were probably *Avicennia marina.* Furthermore, it was reported that the admiral of Alexandr the Great, described mangrov species in the Arabian Gulf in 325 BC as trees around 14m tall, growing in the sea, and with trunks held up by their roots like polyps (4). Such description would apply to *Rhizophora styosa* recently described from Hudeidah coastal area in Yemen (2).

Regional studies in the Arab countries demonstrate that mangrove species *A.marina* is found along Saudi Arabian Red Sea coast, and on the Arabian Gulf coasts of Saudi Arabia (5,6), Kuwait (7), Qatar (8,9,10,11)

Mangroves have been reported to occur all along the Red Sea Coast of Saudi Arabia but their distribution is not continuous. Earlier, it was thought that they grow only in the southern and central parts but not in the north (12,13), but later studies had revealed them to occur as far as the Jordanian border (14, 15). In general, their growth is very poor as compared to other parts of the world, (16,17). The mangroves of the southern Red Sea coast, however, show better growth than in the north, and are comparable with other favourable areas of the world on a unit area basis, In lagoons, they form fringe forests (18); several kilometres long and as wide as 500 metres (19) and in some cases may even form a single row of trees. These may be classified as dwarf forest (18) because of the narrow tidal zone, the oligotrophic waters, high salinity values and the small size of the mangrove plants.

Only two species of mangroves are known to occur in the Red Sea coastal zone. *Avicennia marina* Forssk is the most dominant and in fact, the only species on the mainland. The other species *Rhizophora mucronata* Lam. is found only in Farasan Archipelago and from

Jizan area (13). Flowering and fruiting seasons also vary with localities. Thus trees flower earlier (March-Augutst) in the south than in the north (October-April) (20).

On Bahrain Island, a few patches of mangrove occur at Ras Sanad, Al-Ak infill and Khor Mugli with a total area of 1 km^2.

In the UAE, mangrove is dominant in some tidal lagoons between Tarif and north of Abu Dhabi Island, near Rams (Ras Al-Khaimah Emirate) and most extensively at Khor Kalba (eastern coast). Despite the fact that all localities of mangrove growth are coastal inlets or lagoons, there are several inlets and lagoons along UAE coasts, which are devoid of mangrove (Khor Dubai, Khor Al-Khan and Khor Sharjah, and a small lagoon north of Fujairah Port). These localities are characterised by features of deep water or encrusted tidal flats, which prevent mangrove growth (21).

In Oman, as in the other Gulf countries, only one species of mangrove *A. marina* occurs. The dense stands in Oman are found further east towards and within the Gulf of Oman (22). At the Qurm, a moderate sized stand has been protected wihtin a reserve. Some dense stands also occur in the region of Strait of Hormuz. There are no significant mangrove stands in Kuwait or Iraq probably due to climatic and biotic reasons.

Distribution in Qatar

Qatar Peninsula being part of the Gulf area, falls within the arid province characterised by hot, arid climate. *Avicennia marina* is the only mangrove species growing naturally in Qatar, and it is locally named «Al-Qurm». It occupies a conspicuous area on the northeast coast of the country, where it mingles with the sabkha frontier vegetation. The area is characterised by mud deposition in an intertidal zone behind a tidal delta that is building up at the norht of Al-Dhakhira Embayment. This area is believed to receive fresh water draining from surface runoff and seeping from groundwater aquifers. Such fresh water flow into the Gulf is an important determinant of the distribution of mangroves in such hypersaline habitat.

Avicennia marina forms a dense population in this particular area, and it is usually observed in shallow water zone, where fine calcareous sandy and muddy sediments are transported by tides. These sediments are relatively rich in organic materials, which produce anaerobic conditions. In Al-Dhakhira area, the sediments are protected by some sandbars partially separating the mangrove vegetation form the open water of the Gulf. In addition to the *Avicennia marina,* there are other halophytic plant communities growing along the shores of Al-Dhakhira area. *Arthrocnemum glaucum,* locally called shnan, growing on the saline flats with fine-textured soil characteriesd by relatively shallow water table. Other plant communities dominated by *Juncus rigidus* or *Aeluropus lagopoides,* locally known as ikrish occurs in the sabkha sediment along the coastal area.

AIM

The purpose of this paper is to review previous attempts to investigate the ability of mangrove trees to accumulate pollutants (mainly heavy metals, herbicides and other organic compounds) to levels that can be determined by chemical analyses, using the same mechanism for salt accumulation in its leaves, roots and bark and the effect of ozone depletion on the development of the mangroves trees. As well as to investigate the characters of mangrove soils that enable them to act as sinks for pollutants and to review the possibility of using the mangrove stands as a bioindicator for the different types of pollution.

MANGROVE STAND AS A BIOINDIACTOR

During the last few decades many plants (as well as organisms), have been used as scanners for any potential environmental pollution and mangrove is one of these plants. The presence of mangrove in sheltered estuaries with little or no water flush makes them vulnerable for different types of pollution.

Mangrove trees as a bioindicator for heavy metals pollution

Early workers have investigated the possibility of using mangroves as a bioindicator for heavy metals pollution in many countries. It was noticed that the mangrove *Avicennia marina* could accumulate high concentration of fluoride particularly in leaves without visible injury (23). In a study the distribution and influence of heavy metals in mangrove forests of the Tamshui Estuary in Taiwan (24,25), it was found that concentration of heavy metals showed a sequential decline from roots to stems; leaves and seedlings and there is a positive correlation between the amount of heavy metals in soils and the tissues. They noticed also that the tolerance of the mangrove *Kandelia candel* seedlings to copper and zinc was much higher than that of rice plants and that *Kandelia candel* can adapt to areas polluted with heavy metals. The heavy metal concentartions in mangrove leaves and soils from the Saudi coast was measured and a correlation was tempted between the concentration of heavy metals in the mangroves and its soil (26). The study of the effect of nickel mining and metallurgical activities in Levisa Bay, Cuba on the red mangroves indicated that *Rhizophora* mangle might be used as a bioindicator of heavy metals pollution (27). It was reported that heavy metals are concentrated at the upper few centimeters of the soil layer.

Arsenic concentration in mangroves from the Goa Coast, India has been investigated and found that Arsenic in younger leaves of mangroves is marginally more than that of mature and yellow leaves, (28).

Other workers attempted to investigate the possible implications of pollution on the development of the tree itself. The herbivory intensity between two polluted and unpolluted communities of mangroves was compared and it was noticed that there is no definite trend regarding the effect of pollution on herbivory intensity, (29).

The mangroves had been used to screen for mutagens in tropical environments of the Caribbean and the Gulf of Mexico. It was suggested that red mangroves have the reproductive traits that allow the detection of nuclear and cytoplasmic mutation in the field in the same way as colonies of bacteria or yeast are secreened for mutation in the laboratory (30). In another work, the chlorophyll-deficiency was used as a genetic end-point indicator in plant mutation in areas polluted with oil in the southwest coast of Puerto Rico, (31).

The distribution of macronutrient (Na, K, Ca, and Mg), heavy metals concentration (Fe, Zn, Mn and Cu) and the anti-herbivory related compounds of seedlings of the viviparous mangrove species *Rhizophora magle L.* was studied at various developmental stages. The results indicated a selective accumulation of K and Cl during growth, which could mean that viviparity, may act as a mechanism to adjust seedlings to the saline mangrove environment. It was indicated also that viviparity may also work as a detoxifying mechanism in *R.mangle* and that anti-herbivory strategies present in seedlings are the same as those found in leaves of mangrove species, (32).

Mangrove stands as a bioindicator for hydrocarbon pollution

Mangrove and oil pollution are two concomitant features. Mangrove is found always in shallow bays, where oil tankers normally stop for loading or unloading, and also because bays are the normal place, where currents dispose their load including oil slacks.

The natural re-establishment of an oil-polluted mangrove soils in a swamp planted with *Avicennia* was investigated by implanting a special program that prevented further pollution of the site and brought clean seawater to the swamp, (33). It was reported that natural recolonisation by small *Avicennia* trees started rapidly after 3 months from the start of the program. The density and growth rate of the plants were more influenced by the nature of the substrate than by the hydrocarbon concentration in the soil.

The response of grey mangrove *(Advicennia marina)* seedlings to spills of crude oil was investigated in glasshouse and field. It was found that fresh oil cause greater leaf loss than aged oil. An experiment on the effects of weathered Bass Strait crude oil on seedling survival was carried out in the field. The results were unequivocal : 96.4% of seedlings treated with weathered Bass Strait oil died wihtin 14 days, while all untreated seedlings survived. A further field experiment also examined the effects of light, canopy gaps and Bass Strait crude oil in the sediment on propagule estabilshment and survival. Establishment and survival were not enhanced by light and canopy effects but crude oil in the sediment inhibited establishment and decreased the number of seedling surviving for several years, (34).

The response of *Avicennia marina* pneumatophores and adventitious roots to oil pollution was investigated in the coasts of Saudi Arabia (35). It was noticed that they developed highly branched pneumatophores rather that the normal pencil-shaped. While, it had been found that mangrove muds served as long-term reservoirs for oil contamination that resulted from the Bahia las Minas (Panama) oil spill for more than five years. A simialr case was reported also from the French West Indies, where it was indicated that mangrove governed the distribution patterns of the hydrocarbons, (37). From a study on the impact of the petroleum pollution on a mangrove community in a coastal ecosystem in Brazil, it was concluded that oil pollution is associated with increase number of pneumatophores, generation of malformed leaves and fruits and decrease in litter production, (38).

MANGROVE SOILS AS AN INDICATOR AND A SINK

Mangrove soil

The high organic production of the mangrove stand, the slow degradation of these organic materials, the slow water flushing and the high salt concentration are important factors that collectively shape the type and zonation of the soils of the mangrove stands and their resultant clay minerals.

Mangrove pneumatophores and trees trap fine mud that in turn enchance their development. The low energy, sheltered environment of the estuary is ideal setting for such entrapment.

Mangrove trees highly influence the nature and rate of sedimentation of their soils. It seems that biological processes have a dominant influence on the fate of clay particles in mangrove swamps. It was noticed that there are three major processes that control the transport of suspended sediments in mangrove swamps of Australia. These include (1) The transport processes in the estuaries and coastal waters draining the swamp, including flocculation, tidal pumping, baroclinic circulation, trapping of the smallest particles in the turbidity maximum zone, and the effect of the mangrove tidal prism. (2) The mechanical and chemical reactions in mangrove water destroying flocs of cohesive sediment in suspension. (3) Biological processes have a dominant influence on the ultimate fate of clay particles in mangroves, (39).

Characteristic features of the mangrove soils

Mangrove sediments have inherited characteristic features from their peculiar environmental conditions. They are characterised by high organic contents, high acidity and certain clay mineral assemblages.

In the Barito estuary, Indonesia, which is an area, characterised by high rainfall and mangrove vegetation associated with fresh water swamps dominated by the *palm Nypa fructicans* and *Melaleuca leucadendron,* the soils were of very fine texture and composed mainly of clay-loam rich in reduced organic matter. This represents a medium in favour of the growth of sulphate reduction bacteria leading to the formation of pyrite and they are potentially acid sulphate soils. The major clay minerals present are illite-smectite, (40).

The rice soils established on mangrove sediments in Senegal are found to be characterised by Fe toxicity, which resulted from deficienty of major plant nutrients such as K and/or P and sometimes Mg. Such soils have a low buffering capacity and a low concentration in available nutrients, and differ from the well-buffered rice soils situated around Gambia River Estuary and in Senegal River Delta, (41), These latter soils contain smectite as the predomintant clays or significant amounts of illites associated with kaolinites. The nutritional disorder rather than either low pH or high Fe_2 content in solution is considered to be essential for iron toxicity in these wetland-rice soils.

The transformation of clay minerals in the mangrove-fringed coastal plains of Sumatra and Borneo was found to be controlled by the acid environment resulting from organic matter decomposition and pyrite oxidation among other factors (42). The mangrove soils reclaimed for a housing project in New Finima, Nigeria are highly plastic, dark-brown organic silty clay with sand as inclusions, (43), Whereas, sediments of the Holocene mangrove swamps of West Africa were found to consist of homogenous sediment dominated by quartz and clay which are associated with halite, pyrite and jarosite. The clay minerals suite consists of smectite and kaolinite. The soils are of chestanut mash colour with buttery consistency in relation with the decomposition of fibrous roots of *Rhizophora* and also with pale yellow jarosite mottles in the top horizons of the tanned profiles due to the oxidation of pyrite. It was suggested that the two main properties of the mangrove soils of West Africa are acidity and salinity, the first is related to the high content of sulphur and the second to the sea influence, (44). In the Kuala Kurau shorelines in Peninsular Malaysia, it was reported that greenish-grey clay is the main component with variable amounts of silt and sand, (45).

The mangrove sediments from the southwest coast of India were made up of silt and sand with minor amounts of clay. They range in size between 0.205-0.098 mm (fine to very fine sand). the sediments are very poorly sorted, negatively to very negatively skewed, and platy to extermely leptokurtic (narrow frequency distribution) in nature. The organic carbon content of the sediments ranges from 0.33% ot 4.93%, which is controlled by the particle size of the sediments, The relative concentrations of heavy metals are Fe>Mn>Cr>Zn>Ni>Cu. All heavy metals other than Fe show an increase in concentration compared to the other parts of the estuarine bed, (46).

Mangrove soils in arid areas are different from those developed under humid climate, This is related to the degradation rate of the contained organic materials, which in turn, depends on other factors such as temperature, moisture and organic activity.

Pollutants retention and biovailability in the mangrove soils

The nature of mangrove soils is of particular importance in the retention of pollutants and also in the biovailability of heavy metals. It is suggeted that the retention ability of mangrove soils depends on their texuture, composition, organic matter contents, redox ptential, pH, salinity, the presence of Al, Fe and Mn, (47, 48, 49, 50).

Mangrove soils as a sink for pollutants

More workers have studied the accumulation of pollutants in mangrove soils in different parts of the world. In a study of the accumulation of heavy metals (Cu, Cr, Cd. Zn, Mn, Co, Pb and Ni) in superficial sediments of mangrove and salt marsh areas in the Sepetiba Bay, Rio de Janeiro, It was found that mangrove sediments have significanly higher concentrations of all metals. The twice-higher content of organic matter found in the latter sediments, their lower oxygenation and the relative position of the 2 communities in relation to wave and tide actions, explain the higher metal concentration found in the mangrove sediments, (51). The concentration of metals was measured in red mangrove forest in Sepetiba Bay, Rio de Janeiro, Barzil. The results indicate that sediments are the main reservoir of the total metal contained in mangrove studied while the *Rhizophora mangle* biomass contained less than 1 percent of reservoir. Within the biotic compartment, perennial tissues accounted for almost all of the metals present in biomass, (52).

In a study on the spatial and temporal distribution of heavy metalas in the sediments of a mangrove swamp in Hong Kong. It is suggested that the total concentrations of Cu, Zn, Mn, and pH did not show any specific trend along the selected transects, althoght the maximum concentration of heavy metals tended to occur at the landward edge. They found also that certain sites contained exceptionally high levels of total metals, (47).

The possibility of using mangrove soils as sinks for pollutatns generated from wastewater was tempted experimentally (50). Leaching experiments, using synthetic wastewater, on two types of mangrove soils from Hong Kong and China were tested to assess their retention capacities. Throughout the experiments, most heavy metals, including Cu, Zn, Cd, Ni and Cr, were not detected in all leachate collected after leaching, indicating that both types of mangrove soils were capable of trapping waste water-generated heavy metals. It was concluded that mangrove soils were good traps to immobilise wastewater-borne phosphorus and heavy metals but they were less efficient in retaining nitrogen from wastewater. The sediment concentrations of NH^{-4}, P, K, and the total organic carbon were consistently higher in the landward locations and decreased gradually towards the sea. The collected sediment samples at the seaward edge of the mangrove plant community had the lowest levels of nutrient and organic matter but no vertical variations in their distribution were detected. Extremely high contents of Cu, Cd, Pb, Cr and Zn were reported at certain locations, suggesting the occurrence of some local contamination. Most of the heavy metals were not in a bioavailable form as the concentrations of extractable metals were relatively low, Pb, Cr and Cd were not detected in leaf samples. Leaf C, N, P, and K contents were similar between the two species and no significant difference was found among locations, although *A.corniculatum* seemed to have lower Mn concentrations than *K. candel L.* No seasonal or temporal changes were found.

The distribution of heavy metals in *Avicennia marina* was investigated at Shenzhen area, China. The study indicates that the Cr, Ni and Mn contents in forest soil are increased from bottom to surface layer (53).

In a study on the metal contamination of the surface sediments in mangrove stand from lagoons in Florianpolis Island, Brazil, the sediments were analysed for a group of pollutant metals. The results indicate higher concentration than the mean elemental composition of sediments for Hg, Pb, Se, As, Sn, U and Ag. They also indicate that the concentrations of these metals follow the variation of fine-grained fraction than that of the organic matter, whereas, both U and Hg were more associated with the organic content of the sediments, (54), In soil horizons with a pH greater than 7 and with reduced conditions, metals are normally present as sulphide-bound species, while in horizons with pH values less than 7 with oxidised conditions, most metals are found as exchangeable or oxide-bound species (55).

MANGROVE TREES AS A BIOINDICATOR FOR OZONE DEPLETION

The effect of ultraviolet radiation on the development of the seedlings of the mangrove *Rhizopora* have been examined by several workers (56, 57) and it was noticed that their growth was generally reduced with exposure to high UV with shoot elongation.

CONCLUSIONS

1. Mangrove is characterisic vegetation of the intertidal zone along the coastlines of the tropical and subtropical areas of the world.
2. The main mangrove species in Arabia is the *Avicennia marina,* which can be found mainly along the coastlines of the Red Sea and the Gulf.

3. In Qatar, the mangrove occupies some parts of the intertidal areas of the northeastern coast mainly in Al-Khor and Al-Dhakhira areas. The mangrove vegetation there intermingles with other halophytic plant communities such as *Arthocneumum glaucum,* which grows on the saline flats with fine-textured soil characterised by relatively shallow water table.
4. Mangrove trees could accumulate high concentration of pollutants (heavy metals and organic pollutants) in its foliage with out visible injury. The concentration of these pollutants showed a sequential decline from roots to stems, leaves and seedlings and there is a positive correlation between the amount of pollutants in soils and the plant tissues.
5. Mangroves subjected to oil pollution were found to develop highly branched pneumatophores rather than the normal pencil-shaped. Furthermore oil pollution is associated with increased number of pneumatophores and the generation of malformed leave and fruits and decrease in litter production. Mangrove muds normally serve as long-term reservoirs for oil contamination for many years.
6. Mangrove had been used by some workers to screen for mutagens in tropical environments of the Caribbean and the Gulf of Mexico. It was concluded that red mangroves have hte reproductive traits that allow the detection of nuclear and cytoplasmic mutation in the field in the same way as colonies of bacteria or yeast are screened for mutation in the lab. The chlorophyll-deficiency of mangrove has been used as a genetic end-point in plant mutation in areas polluted with oil in the southwest coast of Puerto Rico.
7. The exposure of mangrove trees to high UV radiation led to a considerable reduction in their growth and caused in some cases shoot elongation.

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