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Review

# A review of factors associated with decline and death of mangroves, with particular reference to fungal pathogens

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ABSTRACT

Mangrove species grow in bays and estuaries in tropical and subtropical latitudes. Mangrove systems are categorized as highly productive, providing crucial environmental functions. Their stability and survival are, however, constantly threatened by anthropogenic activities and there has been an increase in reports of decline and death of these trees globally. Currently, little is known regarding diseases affecting mangroves, particularly those caused by micro-organisms such as fungi. In recent years several studies of the fungi associated with these trees have been conducted and a number of fungal diseases have been identified. However, few studies have been done in South Africa and little is known regarding the health status of mangroves in the country. This review aims to provide a background for further studies of pathogens affecting true mangroves in South Africa. Furthermore, it aims to contribute toward the development of management plans to ensure mangrove health in the country.



**Contents**



## 1. Introduction

The term mangrove refers typically to trees and shrubs growing in estuarine regions throughout the tropical and sub-tropical latitudes of

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the world (Kathiresan and Bingham, 2001). These pan-tropical ecosystems cover approximately 152,000 square kilometers and lie distributed in 123 territories along the coasts of Africa, the Americas, Asia and Australia (Spalding et al., 2010). The Food and Agricultural Organization of the United Nations (FAO) (2007) calculated, for 2005, an area of 3.2 million hectares of mangrove forest in estuaries along the east and west coasts of Africa. In South Africa, mangrove species occur only along the east coast, distributed in 37 estuaries (Adams et al., 2004; Steinke, 1995).

Mangroves have received increasing attention from government and non-government organizations around the world in recent years because of their ecological importance and the crucial environmental and economic services that they provide (Taylor et al., 2003). Mangrove systems protect coastlines from hurricanes and other environmental phenomena, they provide shelter to numerous animal species, and material for human needs (fuel, timber, tannins) (World Rainforest Movement, 2002). Ironically, despite the enormous ecological and economic importance of mangroves, the stability of these ecosystems in many regions is threatened by continued anthropogenic disturbances (Abuodha and Kairo, 2001; Ellison and Farnsworth, 1996) and associated degradation, resulting in their disappearance (World Rainforest Movement, 2002). While there have been reports of diseases of mangroves (eg. Barnard and Freeman, 1982; Teas and McEwan, 1982; Tattar and Scott, 2004; Wier et al., 2000) this is a subject that has received relatively little attention. The aim of this review is thus, to contribute to the knowledge of causes involved in the death and decline of true mangrove trees, with an emphasis on diseases caused by fungi.

## 2. Mangroves

### 2.1. Classification

The exact number of families and genera of mangroves is a matter of debate, depending on how mangroves are classified. Tomlinson (1986) suggested that there are 54 mangrove species belonging to 26 genera, residing in 20 families. Ellison and Farnsworth (2001), on the other hand, estimate that there are between 54 and 70 species including true and associate mangroves, occurring in 20 to 27 genera and residing in 16 to 19 families. Hogarth (2007) grouped true mangroves into 20 genera and 50 species, belonging to 16 families, while Spalding et al. (2010) listed 73 species of true mangroves, including hybrids. The most representative families among mangrove communities are the Avicceniaceae, composed of one genus and eight species, and the Rhizophoraceae containing 16 genera and approximately 120 accepted species (Hogarth, 2007; Prance, 2009; Spalding et al., 2010; Tomlinson, 1986).

Mangroves can be categorized into two groups based on morphological and physiological specializations that allow them to exist in extreme conditions. These are the true mangroves and the mangrove associates (Kathiresan and Bingham, 2001; Lugo and Snedaker, 1974; Tomlinson, 1986; L. Wang et al., 2010). Certain physiological and morphological specializations have been described in order to distinguish true mangroves from associates. True mangroves are characterized by viviparous reproduction, specialized structures such as aerial roots (pneumatophores) for gas exchange, prop-roots to anchor them to unstable soils and glands for salt excretion or exclusion (Hogarth, 2007; Kathiresan and Bingham, 2001; Steinke, 1995; Tomlinson, 1986). Recent advances in the study of mangroves have shown that true mangroves are essentially halophytes, showing a high salt tolerance while mangrove associates are glycophytes with only a certain degree of salt tolerance (L. Wang et al., 2010). In this review we focus exclusively on the true mangroves.

### 2.2. Mangroves of South Africa

Six species of mangroves, belonging to four families, occur in South Africa. These are *Avicennia marina* (Forssk.) Vierth, *Bruguiera gymnorrhiza* (L.) Savigny, *Ceriops tagal* (Perr.) C.B Rob., *Lumnitzera racemosa* Willd, *Rhizophora mucronata* Lam. and *Xylocarpus granatum* König (Adams et al., 2004; Steinke, 1995; Taylor et al., 2003) (Table 1). These species have varying distributions along the east coast of South Africa. In the northern ranges of their distribution, all six species occur, while as one moves south toward the Kei River, this diversity decreases, with only *A. marina* occurring in the southernmost area of distribution, at Nahoon estuary (Spalding et al., 2010; Steinke, 1995) (Fig. 1).

*A. marina* (white or gray mangrove), is a pioneer species and widely distributed along the east coast of South Africa. This species is highly salt tolerant. *B. gymnorrhiza* (black mangrove) is an evergreen tree that generally grows up to 10 m high and is typically associated with wet areas; hence, the root system is well developed. *C. tagal* (Indian mangrove) is less common than other mangrove trees in South Africa and is associated with drier areas. *L. racemosa* (Tonga mangrove) is often found where water inundations are not frequent; thus, it is associated with the landward fringe of mangrove swamps in South Africa. It has a very limited distribution in the country, occurring only in the most northern coastal areas adjacent to the Mozambique border. *R. mucronata* (red mangrove) is less common than *A. marina* and *B. gymnorrhiza*, often associated with muddy soils, and is characterized by aerial roots (prop roots) (Steinke, 1995; Taylor et al., 2003). *X. granatum* (Cannonball mangrove) is found in the Kosi Bay area. It has superficial vertical roots; the bark is smooth and peels in irregular patches (Adams et al., 2004; Tomlinson, 1986) (Table 1).

### 2.3. Reproduction

Pollination of mangroves is mostly carried out by diurnal animals such as birds, bees, butterflies and other small insects and, nocturnally, by bats and moths. Wind pollination, however, plays an important role when flower odor and/or pollinators are absent (Tomlinson, 1986). As a distinctive survival strategy, mangroves exhibit a viviparous or cryptoviviparous reproductive system, increasing their probabilities to establish in the adverse environments where they commonly occur. This unique reproductive adaptation allows seeds to germinate and continue growing while they are still adhered to the maternal plant. In the case of viviparous reproduction (eg. *Rhizophora* species), the seedlings remain on the mother plant for a longer time period than occurs with cryptovivipartiy (eg. *A. marina*). Offspring are eventually dispersed by water, in which they can float for long periods, sometimes months, until they find a suitable substrate in which to establish (Hogarth, 2007; Kathiresan and Bingham, 2001; Tomlinson, 1986).

## 3. Fungi associated with mangroves

The variability of mangrove ecosystems has attracted the attention of several researchers who have contributed extensively to scientific knowledge about fungi associated with mangrove trees (Alias et al., 2010; Cribb and Cribb, 1955; Okane et al., 2001; Jones and Abdel-Wahab, 2005; Koehn and Garrison, 1981; Kohlmeyer and Kohlmeyer, 1971; Kohlmeyer and Schatz, 1985; Lee and Baker, 1973; Liu et al., 2006; Pilantanapak et al., 2005; Steinke, 2000; Steinke and Jones, 1993; Sivakumar, 2013; Tariq et al., 2006a,b; Tan and Pek, 1997; Xing and Guo, 2010). These contributions have been mostly descriptive and focused on the morphology and taxonomy of mangrove fungi (Alias and Jones, 2000; Kohlmeyer and Kohlmeyer, 1971; Jones and Abdel-Wahab, 2005; Sarma and Hyde, 2001; Steinke, 2000). Only a limited number of publications reveal information on fungi causing diseases of mangroves (Barnard and Freeman, 1982; Gilbert and Sousa, 2002; Pegg et al., 1980; Stevens, 1920; Tattar and Scott, 2004; Teas and McEwan, 1982; Wier et al., 2000).

In India and other Asian countries, fungi associated with mangroves are especially well documented (Table 2). Nambiar and Raveendran (2008, 2009a,b), for example, have reported more than 150 fungal species isolated from mangroves in Kerala, South India in the past five

**Table 1**
Mangrove species occurring in South Africa.

| Family | Genus and species | Common name | Location of estuaries |
|---|---|---|---|
| Acanthaceae (Avicceniaceae) | *Avicennia marina* | White/gray mangrove | Kosi bay, Mhlathuze, St Lucia, Mdumbi, Mnyameni, Mtentu, Mtafufu, Mzimvubu, Mgazana, Mtakatye, Mtata, Bulungula, Nqabara, Nxaxo, Mbashe, Xora, Kobonqaba, Gqunube, Kei, Msingazi, Nahoon |
| Rhizophoraceae | *Bruguiera gymnorrhiza* | Black mangrove | Kosi bay, Mtamvuna, Mnyameni, Mtentu, Mzintlava, Mtata, Mzimvubu, Mtafufu, Bulungula, Xora, Mbashe, Msingazi, Nxaxo, Mgazana, Mtakatye |
| | *Ceriops tagal* | Yellow/Indian mangrove | Kosi bay |
| | *Rhizophora mucrunata* | Red mangrove | Kosi bay, Mhlathuze, St Lucia, Mtafufu,Bulungula, Mtakatye, Mtata, Mgazana |
| Combretaceae | *Lumnitzera racemosa* | Tonga mangrove | Kosi bay |
| Lecythidaceae | *Barringtonia racemosa* | Powder-puff tree | Richards Bay, Mapelane |

Steinke (1995); Taylor et al. (2003).
(*Barringtonia racemosa* is considered as a mangrove associate).

years. This is besides the earlier reports of fungi from India where the diversity and frequency of manglicolous fungi were studied (Ananda and Sridhar, 2004; Kumaresan and Suryanarayanan, 2001; Manoharachary et al., 2005; Rani and Panneerselvam, 2009; Sarma et al., 2001; Vittal and Sarma, 2006). A large number of studies have been conducted in East and Southeast Asia (Besitulo et al., 2010; Nakagiri et al., 2001; Ho et al., 1990; Sarma and Hyde, 2001; Vrijmoed et al., 1994; Y. Wang et al., 2010; Xing and Guo, 2010), especially from areas such as China (Jones et al., 1999; Tsui and Hyde, 2004; Xing and Guo, 2010) and Thailand (Hyde, 1990, 1992a; Pilantanapak et al., 2005). Besides the studies conducted in Asia, a number of studies, mostly focussing on the taxonomy of fungi on mangroves, have also been conducted in the Americas (Table 2). Many of these fungi were reported from dead plant parts, often from unidentified mangrove species (Gilbert and Sousa, 2002; Hyde, 1992b; Kohlmeyer and Kohlmeyer, 1971, 1993). In Brazil, data from different studies considered the diversity of Basidiomycetes associated with mangrove trees (Baltazar et al., 2009; Sakayaroj et al., 2012; Trierveiler et al., 2009) and the identification of endophytic fungi based on sequence data, revealing more than 4000 fungi associated with *Rhizophora mangle* L., *Avicennia schaueriana* Stapf & Leechman ex Moldenke and *Laguncularia racemosa* (L) Gaertn.f. (De Souza et al., 2013).

Host-specificity has been studied among different groups of fungi occurring on mangroves, as well as the frequency of fungi and their variation with respect to different substrata such a bark, driftwood, roots, pneumatophores and wood, in living and dying plant material (Alias and Jones, 2000; Kohlmeyer and Kohlmeyer, 1993; Lee and Hyde, 2002; Nambiar and Raveendran, 2008, 2009a,b; Vittal and Sarma, 2006). Kohlmeyer and Kohlmeyer (1993), described host-specificity, mostly in the *Rhizophora* and *Avicennia* groups. They reported specificity of *Leptosphaeria avicennia* Kohlm. & E. Kohlm. and *Mycosphaerella pneumatophora* Kohlm., with bark of living and dying pneumatophores of *Avicennia africana* P. Beauv., as well as *Keissleriella blephorospora* = *Etheirophora blepharospora* (Kohlm. & E. Kohlm.) Kohlm. & Volkm.-Kohlm., occurring on *Rhizophora* species in Hawaii. Some species of *Halophytophthora* have also shown substrate specificity as well as a high level of adaptation to the specific environmental conditions where they occur. For example, *H. avicenniae* (Gerr.-Corn. & J.A. Simpson) H.H. Ho & S.C. Jong, has been isolated repeatedly only from leaves of *Avicennia* in brackish areas of Australia and Japan (Nakagiri, 2000).

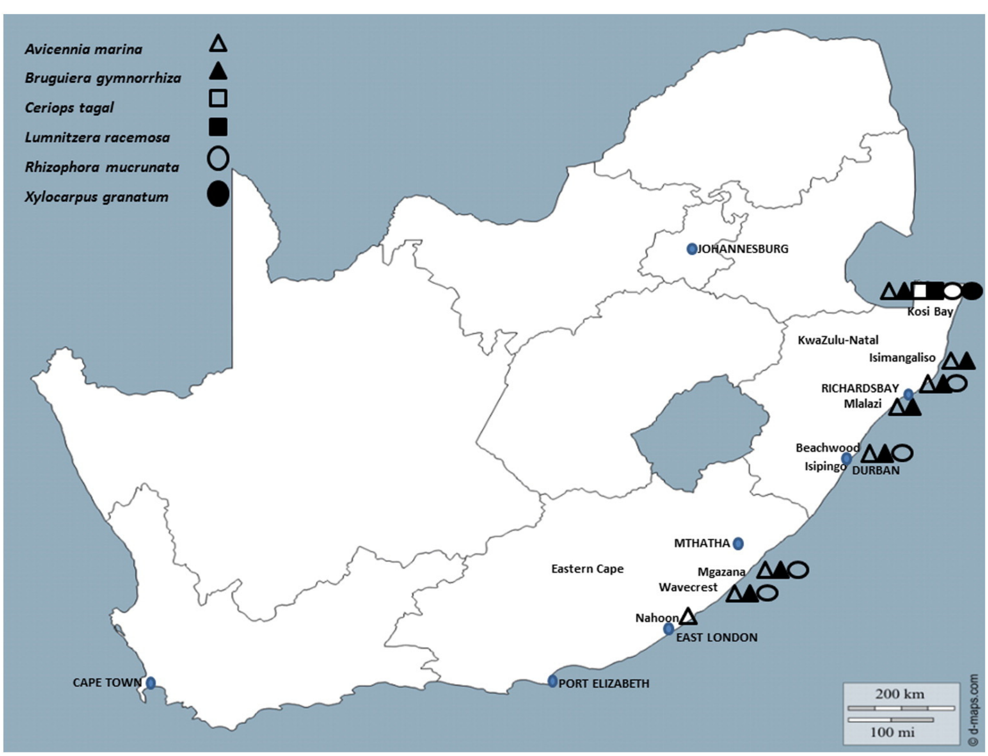


**Fig. 1.** Relative distribution of the six species of mangrove in South Africa.

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**Table 2**
Mangrove species and geographical distribution where fungi have been reported from them.

| Region | Country | Mangrove species | Reference |
|---|---|---|---|
| **New World** | Belize & Trinidad | *Rhizophora mangle* | Kohlmeyer and Schatz (1985) |
| | Brazil | *Avicennia nitida, R. mangle, Lumnitzera racemosa* | De Souza et al. (2013) |
| | Guatemala | *R. mangle, R. racemosa* | Kohlmeyer and Kohlmeyer (1971, 1989) |
| | Hawaii | *A. germinans, R. mangle, R. racemosa, R. stylosa* | Lee and Baker (1973), Kohlmeyer and Kohlmeyer (1971, 1989, 1993) |
| | Mexico | *R. mangle, R. racemosa* | Hyde (1992b) |
| | Panama | *A. germinans, Laguncularia racemosa, R. mangle* | Gilbert and Sousa (2002) |
| | U.S.A | *A. germinans, R. mangle, R. racemosa* | Koehn and Garrison (1981), Kohlmeyer and Kohlmeyer (1971, 1989) |
| **Old World** | Australia | *A. germinans, A. marina, Avicennia* sp., *Osbornia octodonta, Pandanus* sp., *R. stylosa, Rhizophora* sp. | Chalkley et al. (2010), Cribb and Cribb (1955), Kohlmeyer and Kohlmeyer (1991) |
| | China | *Ceriops tagal, R. stylosa, R. apiculata, Bruguiera sexangula* | Xing and Guo (2010) |
| | Hong Kong | *Kandelia candel* | Pang et al. (2008) |
| | India | *Acanthus ilicifolius, A. marina, A. officinalis, Bruguiera cylindrica, Excoecaria agallocha, L. racemosa, R. apiculata, R. mucronata* | Ananda and Sridhar (2004), Gilna and Khaleel (2011), Kumaresan and Suryanarayanan (2001), Manimohan et al. (2011), Maria and Sridhar (2003), Nambiar and Raveendran (2008, 2009), Rani and Panneerselvam (2009), Sarma et al. (2001), Sridhar (2009), Vittal and Sarma (2006) |
| | Japan | *B. gymnorrhiza, R. mucronata, S. alba* | Maekawa et al. (2003), Okane et al. (2001), Hiroto et al. (2010) |
| | Malaysia | *A. marina, Bruguiera parviflora* | Alias and Jones (2000), Alias et al. (2010) |
| | Pakistan | *A. marina, R. mucronata, Aegiceras corniculatum, Ceriops tagal* | Tariq et al. (2006a, 2006b) |
| | Singapore | *R. apiculata, R. mucronata* | Tan and Pek (1997) |
| | South Africa | *R. mucronata, A. marina* | Kohlmeyer and Kohlmeyer (1971), Steinke and Jones (1993), Steinke (2000). Steinke and Hyde (1997) |
| | Thailand | *Nypa fruticans, R. apiculata, S. griffithii* | Chatmala et al. (2004), Hyde (1992a), Pilantanapak et al. (2005), Dethoup and Manoch, 2009; Sakayaroj et al. (2012), Hattori et al. (2014) |

## 4. Diseases of mangrove trees

Considering the ecological importance of mangroves, and the high demand for their timber in many parts of the world, it is ironical that a very limited number of studies have considered the impact of diseases on these trees. This is more so when one considers the substantial level of research that is being conducted on mangroves and the efforts being made to protect mangrove areas. A review of the literature on mangroves show disease reports (Table 3) that include those of branch cankers, leaf spots, leaf loss, die-back and stem rot of these trees (Barnard and Freeman, 1982; Creager, 1962; Sakayaroj et al., 2012; Tattar and Scott, 2004; Teas and McEwan, 1982; Wier et al., 2000). No information was found on the possible impact of fungal pathogens on mangrove recruitment.

The first published study relating to diseases of mangroves was apparently carried out in Puerto Rico by Stevens (1920), who reported a leaf spot on *R. mangle* caused by a fungus belonging to the genus *Anthostomella* (Xylariaceae). Since then, only one other leaf disease has been described, from a mangrove species, namely that caused by *Phyllosticta hibiscina* Ellis and Everh., (Botryosphaeriaceae) resulting in necrosis and death of leaves of *Avicennia germinans* (L.) L. (Black mangrove) in Florida (Olexa and Freeman, 1975).

Stem and branch diseases of mangrove trees consist of several reports where symptoms include galls. Olexa and Freeman (1975) isolated *Cylindrocarpon didymum* (Harting) Wollenw, (Nectriaceae) from galls on *R. mangle* in Florida. Similarly, gall diseases have been reported as the possible cause of mortality of *Rhizophora* species in Gambia (Africa), but the pathogen was not identified (Teas and McEwan, 1982). Kohlmeyer (1969), reported a *Cytospora* sp. (Valsaceae) as a possible causal agent of die-back of *R. mangle* in Hawaii. Similarly, *Cytospora rhizophorae* Kohlm. & E. Kohlm., was repeatedly isolated from stem die-back of *R. mangle* in Puerto Rico (Wier et al., 2000). Damage on other aerial parts includes a report by Creager (1962), who found a new species of *Cercospora* (*Cercospora rhizophorae* Creager) associated with a leaf disease of *R. mangle* in Miami, Florida. Heart wood and butt infections have been reported from mangroves, in several regions (Gilbert et al., 2008). Recently, Sakayaroj et al. (2012), conducted a study in Thailand, in which they found species of *Fulvifomes* (Hymenochaetaceae), associated with heart/butt infections of *X. granatum*.

**Table 3**
Fungi associated with diseases of mangroves.

| Pathogen | Plant organ affected | Symptoms | Host species/family | Location | Reference |
|---|---|---|---|---|---|
| *Anthostomella rhizomorphae* | Leaves | Leaf-spot | *Rhizophora mangle* (Rhizophoraceae) | Puerto Rico | Stevens (1920) |
| *Cercospora rhizophorae* | Leaves | Chlorosis Necrosis Leaf drop | *R. mangle* (Rhizophoraceae) | Florida (USA) | Creager (1962) |
| *Cylindrocarpon didymum* | Prop roots Stems | Galls Canker | *R. mangle* (Rhizophoraceae) | Florida (USA) | Barnard and Freeman (1982); Olexa and Freeman (1978) |
| *Cytospora rhizophorae* | Stem | Die-back Canker | *R. mangle* (Rhizophoraceae) | Puerto Rico | Wier et al. (2000) |
| *Nigrospora sphaerica* | Leaves | Chlorosis | *Avicennia germinans* (Avicenniaceae) | Florida (USA) | Olexa and Freeman (1975, 1978) |
| *Phyllosticta hibiscina* | Leaves | Necrosis | *A. germinans* (Avicenniaceae) | Florida (USA) | Olexa and Freeman (1975, 1978) |
| *Phytophthora* sp. | Roots Pneumatophores Trunk | Leaf loss Trunk rot Death | *A. marina* (Avicenniaceae) | Queensland (Australia) | Pegg et al. (1980) |
| Unidentified fungus | Prop-roots Trunk Branches | Die-Back Galls Canker | *R. mangle R. harrisonii R. racemosa* (Rhizophoraceae) | Gambia (Africa) | Teas and McEwan (1982) |

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Extensive mortality of *A. marina* (White/gray mangrove) along the Gladstone coast of Queensland, Australia, has been attributed to *Phytophthora* (Oomycetes) species (Pegg et al., 1980). The causal agent of the mortality is currently classified in the genus *Halophytophthora* (Ho and Jong, 1990) and resembles *Phytophthora vesicula* = *Halophytophthora vesicula* (Anastasiou & Churchl.) H.H. Ho & S.C. Jong. Symptoms of the disease include chlorosis of the leaves, followed by leaf drop, decay of rootlets and stem rot. Even though there are twelve different species of mangroves in the affected area, only *A. marina* were affected (Pegg et al., 1980). Other studies considering species of *Halophytophthora* are limited to its biology, taxonomy and diversity, more than its virulence (Ho et al., 1990, 1991; Leaño, 2001; Nakagiri et al., 2001; Nakagiri, 2000; Pegg and Alcorn, 1982).

## 5. Damage by Insects

There have been several reports of damage to mangrove species caused by insects. These include publications focused on the impact of insect herbivory on the fitness of trees (Anderson and Lee, 1995; Felller, 2002; Minchinton and Dalby–Ball, 2001; Tavares and Peixoto, 2009). There are also reports of associations between fungi and insects on mangroves (Nieves–Rivera et al., 2002).

Both leaf feeding insects and stem borers have been found to damage mangrove trees, and in some cases this damage resulted in the death of affected trees (Kathiresan, 2003; Mehlig and Menezes, 2005; Tavares and Peixoto, 2009). For example, Felller (2002), reported damage to *R. mangle* in Belize caused by the larvae of the woodborers *Elaphidion mimeticum* Schaeffe and *Elaphidinoides* sp. (Coleoptera). Atkinson and Peck (1994), listed *Coccotrypes rhizophorae* Hopkins (bark and ambrosia beetles, Coleoptera) associated with prop-roots and propagules of *R. mangle* in southern Florida. Several species of Lepidoptera (moths) have also been reported affecting mangrove trees, including *Cleora injectaria* Walker on *A. alba* in Thailand (Piyakarnchana, 1981) and severe defoliation of *A. marina* caused by *Nephopteryx syntaractis* Turner (Lepidoptera) in Hong Kong (Anderson and Lee, 1995). Mehlig and Menezes (2005), reported the defoliation of *A. germinans* in Brazil by the moth *Hyblaea puera* Cramer. Ozaki et al. (1999), conducted a study where *Aulacaspis marina* Takai & Williams (Hemiptera, Coccoidea) was shown to cause the death of trees in mangrove plantations in Indonesia, especially of young saplings. These authors also reported that *R. mucronata, R. apiculata* and *B. gymnorrhiza* are highly susceptible to *Aulacaspis marina* (Table 4).

Nieves–Rivera et al. (2002) reported an association between the fungus *Asteridiella sepulta* (Pat.) Hansf., (Melioliaceae) and the insect *Petrusa marginata* Brunnich (Homoptera/Faltidae). The fungus grows on exudates of *A. germinans* trees where *P. marginata* has been feeding, resulting in sooty mold on leaves in Puerto Rico.

## 6. Other threats to mangroves

The extreme environments in which mangrove trees occur have necessitated special morphological adaptations. Such adaptations include glands in their leaves for salt secretion, and pneumatophores (specialized roots) for respiration in anaerobic soils. Gilbert et al. (2002) found that high salt concentrations in the leaves of *Avicennia* species can inhibit fungal growth and subsequent disease incidence. Nevertheless, environmental stresses can regularly cause disease and death of mangroves. Kirkwood and Dowling (2002) concluded that the large-scale die-back of mangroves in the Pioneer River Estuary in Queensland (Australia) was as a result of the pneumatophores being covered with tidal sediment after an unusually long period of flooding. Similar reports of extreme moisture fluctuations and their negative impact on the survival of mangroves have been made from several regions world-wide, including South Africa (Breen and Hill, 1968). Natural events such as hurricanes also play an important role in the reproduction, distribution and establishment of mangroves. Proffitt et al. (2006), for example, reported the low reproduction rate of *R. mangle* influenced by hurricane Charley in Tampa bay and Charlotte harbor (USA).

**Table 4**
Insects associated with mangrove trees.

| Insect species | Order/Family | Plant part affected | Symptoms | Host species/family | Location | Reference |
|---|---|---|---|---|---|---|
| *Aspidiotus destructor* | Hemiptera/Diaspidiae | Leaves | Leaf loss Seedling death | *Rhizophora mucronata* (Rhizophoraceae) | India | Kathiresan (2003) |
| *Aulacaspis marina* | Hemiptera/Coccoidea | Saplings Seedlings | Death | *Bruguiera gymnorrhiza R. apiculata R. mucronata* (Rhizophoraceae) | Indonesia | Ozaki et al. (1999) |
| *Cecidomyia avicenniae* | Diptera/Cecidomyiidae | Leaves | Galls | *Avicennia germinans* (Avicenniaceae) | Brazil | Gonçalves et al. (2001) |
| *Cenoloba obliteralis* | Diptera/Tephritidae | Fruits Seedlings | Seedling size reduction | *A. marina* (Avicenniaceae) | Australia | Minchinton and Dalby–Ball (2001) |
| *Cleora injectaria* | Lepidoptera/Geometridae | Leaves | Defoliation | *A. alba* (Avicenniaceae) | Thailand | Piyakarnchana (1981) |
| *Coccotrypes rhizophorae* | Coleoptera/Curculionidae | Prop-roots | Unknown | *R. mangle* (Rhizophoraceae) | Florida | Atkinson and Peck (1994) |
| *Elaphidinoides* sp. | Coleoptera/Cerambycidae | Woody and vascular tissues | Canopy loss Death of branches | *R. mangle* (Rhizophoraceae) | Brazil | Felller (2002) |
| *Elaphidion mimeticum* | Coleoptera/Cerambycidae | Woody and vascular tissues | Canopy loss Branch death | *R. mangle* (Rhizophoraceae) | Brazil | Felller (2002) |
| *Euphranta marina* | Diptera/Tephritidae | Fruits | Seedling size reduction | *A. marina* (Avicenniaceae) | Australia | Minchinton and Dalby–Ball (2001) |
| *Hyblaea puera* | Lepidoptera/Hyblaeidae | Leaves Seedlings | Twig death Defoliation | *A. germinans* (Avicenniaceae) | Brazil | Mehlig and Menezes (2005) |
| *Junonia evarete* | Lepidoptera/Nymphalidae | Seedlings | Seedling mortality | *A. germinans* (Avicenniaceae) | Colombia | Elster et al. (1999) |
| *Nephpterix syntaractis* | Lepidoptera/Lymantriidae | Leaves | Defoliation Reduction in reproduction | *A. marina* (Avicenniaceae) | Hong Kong | Anderson and Lee (1995) |
| *Petrusa marginata* | Hemiptera/Flatidae | Leaves | Sooty-mold | *A. germinans* (Avicenniaceae) | Puerto Rico | Nieves–Rivera et al. (2002) |

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## 7. Mangrove health in South Africa

Information on the fungi associated with mangrove trees in South Africa is virtually non-existent. The only studies of mangrove damage or death in the country did not consider microbial pathogens, but focused on environmental processes and human activities such as industrial development, over harvesting, and agriculture (Breen and Hill, 1968; Bruton 1980; Rajkaran et al., 2009; Rajkaran and Adams, 2010; Steinke, 1999). Likewise, nothing has been documented on insects that damage these trees. All reports of fungi associated with mangroves in the country are limited to the taxonomy and morphology of these organisms (Kohlmeyer and Kohlmeyer, 1971; Steinke and Hyde, 1997; Steinke and Jones, 1993) (Table 2). Steinke (2000) reported the percentage of colonization and frequencies of occurrence of fungi isolated from prop roots of *R. mucronata* in the north (Kosi bay), central (Durban) and southern (Mtata) distributions of these trees. These reports provide a valuable foundation for future studies related to marine fungi and their ecological role within mangrove ecosystems in South Africa and other areas of eastern Africa.

A pilot survey in the Beachwood Mangrove Nature Reserve in Durban, by scientific members from Ezemvelo KwaZulu-Natal Wildlife (EKZNW), reported dieback affecting mostly the black mangrove, *B. gymnorrhiza*, and to a lesser extent *A. marina*. Human activities were considered as the possible causes of these deaths (Demetriades, 2009). More recently, other reports of dying mangrove trees have also been made from the Durban area (Pers. comms. Prof. Norman Pammenter and Mr. John Buzzard), suggesting that there are wider scale mangrove deaths than has previously been realized.

## 8. Conclusions

Mangrove trees and the ecosystems they form are important centers of biodiversity as well as protecting our coastlines from storms and flood damage. Despite their ecological importance, relatively few studies have been undertaken on these trees globally. This is especially true for South Africa where virtually nothing is known regarding the health of these trees.

As is true for trees in many other parts of the world, health problems tend to be overlooked until they become so serious that options to manage them are substantially reduced. It is clear that a broad study of the health of mangroves is required in South Africa. This is emphasized by the fact that there have been reports of these trees dying in various areas.

Mangroves are becoming attractive to researchers from many different fields. However, a greater number of mycological studies need to be conducted, since fungi remain relatively unexplored. This is especially in terms of those fungi that might cause diseases of mangrove trees.

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## Further reading

Germoplasm Resources Information network http://ars-grin Accessed February 2011http://www.nhbs.com/hoopoe/index.php/author-interviews/getting-into-mangroves-an-interview-with-mark-spalding/http://www.kew.org/science/tropamerica/neotropikey/families/Rhizophoraceae.htm.