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

**J. Alexander Osorio**

Department of Microbiology and Plant Pathology, DST/NRF Centre of Excellence, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Private Bag X20, Hatfield, Pretoria, 0028, South Africa. Phone: + 27 12 4203938/9. alex.osorio@fabi.up.ac.za

**Michael J. Wingfield**

Department of Microbiology and Plant Pathology, DST/NRF Centre of Excellence, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Private Bag X20, Hatfield, Pretoria, 0028, South Africa. Phone: + 27 12 4203938/9. mike.wingfield@up.ac.za

**Jolanda Roux**

Department of Microbiology and Plant Pathology, DST/NRF Centre of Excellence in Tree Health Biotechnology (CTHB), Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Private Bag X20, Hatfield, Pretoria, 0028, South Africa. Phone: + 27 12 4203938/9

jolanda.roux@up.ac.za

## Highlights

• Mangrove systems are threatened.
• Increasing reports of decline and death of mangrove trees globally
• Little is known regarding microbial diseases affecting mangroves.
• Virtually nothing known about fungi associated with mangroves in South Africa
• This review provides background for studies of mangrove diseases in South Africa.

## 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 is, 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 towards the development of management plans to ensure mangrove health in the country.

***Key words:*** *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, insect pests, Lumnitzera racemosa, opportunistic pathogens, Rhizophora mucronata.*

## 1. INTRODUCTION

The term mangrove refers typically to trees and shrubs growing in estuarine regions throughout the tropical and sub-tropical latitudes of the world (Kathiresan and Bingham 2001). These pan-tropical ecosystems cover approximately 152000 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 they provide 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 2001; Ellison et al., 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 to 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, comprised 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; Wang et al., 2010a). 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 (Wang et al., 2010a). 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 towards 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**).

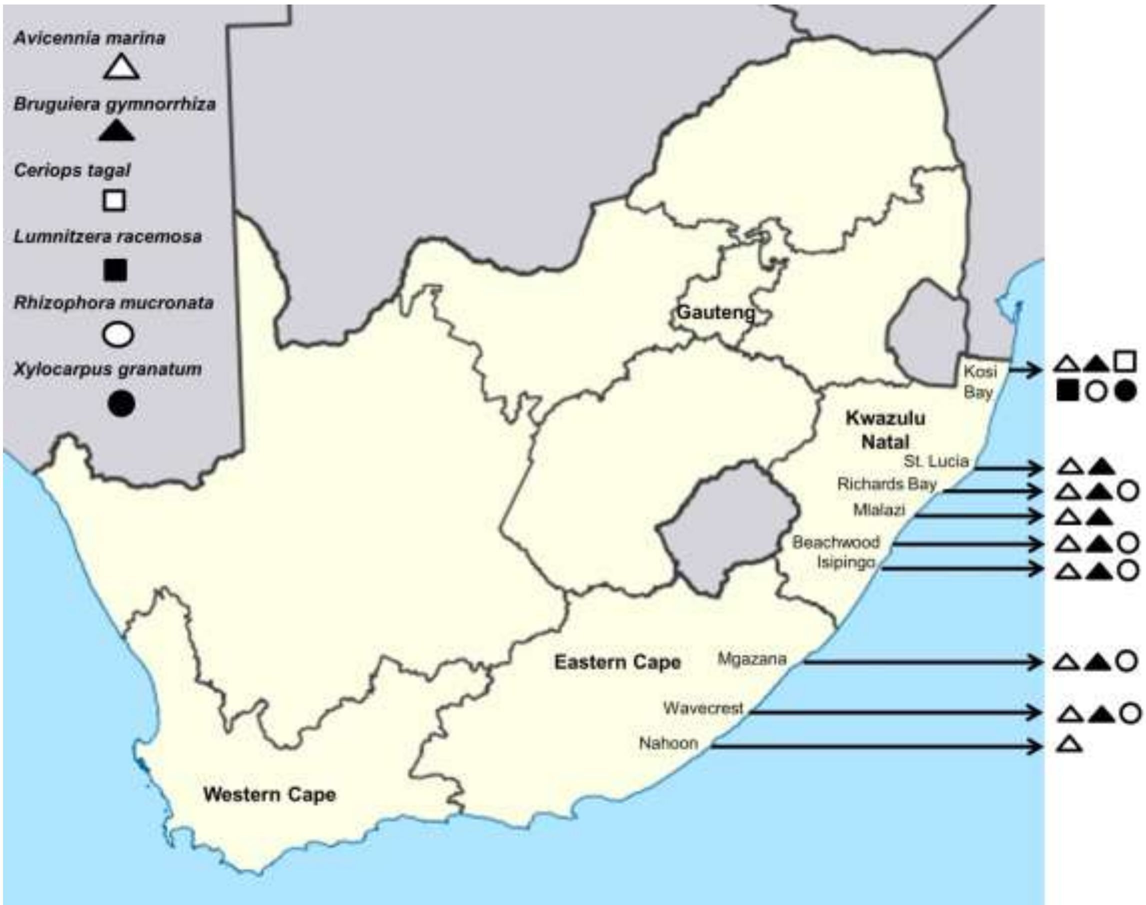


**Figure 1** Geographical distribution of mangrove species in South Africa.

*Avicennia marina* (white or grey mangrove), is a pioneer species and widely distributed along the east coast of South Africa. This species is highly salt tolerant. *Bruguiera gymnorrhiza* (black mangrove) is an evergreen tree that generally grows

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

| Family | Genus and species | Common Name | Location of Estuaries |
|---|---|---|---|
| Acanthaceae (Avicceniaceae) | *Avicennia marina* | White/Grey 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).

up to 10 m high and is typically associated with wet areas; hence, the root system is well developed. *Ceriops tagal* (Indian mangrove) is less common than other mangrove trees in South Africa and is associated with drier areas. *Lumnitzera 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. *Rhizophora 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). *Xylocarpus 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 cryptoviviparity (eg*. Avicennia 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 1953; Izumi et al., 2001; Jones and Abdel-Wahab 2005; Koehn and Garrison 1982; 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, 2006b; 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 et al., 2002; Pegg et al., 1980; Stevens 1920; Tattar and Scott 2004; Teas et al., 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, 2009b), for example, have reported more than 150 fungal species isolated from mangroves in Kerala, South India in the past five 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; Kumeresan 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

**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* | Gilbert et al. (2002), Kohlmeyer & Schatz (1985) |
| | Brazil | *Avicennia nitida, R. mangle, Lumnitzera racemosa* | De Sousa (2013) |
| | Guatemala | *R. mangle, R. racemosa* | Kohlmeyer & Kohlmeyer (1971, 1989) |
| | Hawaii | *A. germinans, R. mangle, R. racemosa, R. stylosa* | Lee & Baker (1973), Kohlmeyer & Kohlmeyer (1971, 1989, 1993) |
| | Mexico | *R. mangle, R. racemosa* | Hyde (1992b) |
| | Panama | *A. germinans, Laguncularia racemosa, R. mangle* | Gilbert et al. (2002) |
| | U.S.A | *A. germinans, R. mangle, R. racemosa* | Koehn & Garrison (1981), Kohlmeyer & 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 & Cribb (1955), Kohlmeyer & Kohlmeyer (1991) |
| | China | *Ceriops tagal, R. stylosa, R. apiculata, Bruguiera sexangula* | Xing & 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 & Sridhar (2004), Gilna & Khaleel (2011), Kumerasan & Suryanarayanan (2001), Manimohan et al. (2011), Maria & Sridhar (2003), Nambiar & Raveendran (2008, 2009), Rani & Panneerselvam (2009), Sarma et al. (2001), Sridhar (2009), Vittal & 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 & 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 & Pek (1997) |
| | South Africa | *R. mucronata, A. marina* | Kohlmeyer & Kohlmeyer (1971), Steinke & Jones (1993), Steinke (1993), Steinke (2000). Steinke & Hyde (1997) |
| | Thailand | *Nypa fruticans, R. apiculata, S. griffithii* | Chatmala (2004), Hyde (1992a), Pilantanapak et al. (2005), Dethoup & Manoch 2009, Sakayaroj et al. (2012), Hattori et al. (2014) |

(Besitulo et al., 2010; Nakagiri et al., 2001; Ho et al., 1990; Sarma and Hyde 2001; Vrijmoed et al., 1994; Wang et al., 2010b; 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 et al., 2002; Hyde 1992b; Kohlmeyer and Kolhmeyer 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, 2009b; 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).

## 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 *Rhizophora 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.

**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<br>Necrosis<br>Leaf drop | *R. mangle* (Rhizophoraceae) | Florida (USA) | Creager (1962) |
| *Cylindrocarpon didymum* | Prop roots<br>Stems | Galls<br>Canker | *R. mangle* (Rhizophoraceae) | Florida (USA) | Barnard & Freeman (1982); Olexa & Freeman (1978) |
| *Cytospora rhizophorae* | Stem | Die-back<br>Canker | *R. mangle* (Rhizophoraceae) | Puerto Rico | Wier & Tattar (2000) |
| *Nigrospora sphaerica* | Leaves | Chlorosis | *Avicennia germinans* (Avicenniaceae) | Florida (USA) | Olexa & Freeman (1975, 1978) |
| *Phyllosticta hibiscina* | Leaves | Necrosis | *A. germinans* (Avicenniaceae) | Florida (USA) | Olexa & Freeman (1975, 1978) |
| *Phytophthora* sp. | Roots<br>Pneumatophores<br>Trunk | Leaf loss<br>Trunk rot<br>Death | *A. marina* (Avicenniaceae) | Queensland (Australia) | Pegg et al. (1980) |
| Unidentified fungus | Prop-roots<br>Trunk<br>Branches | Die-Back<br>Galls<br>Canker | *R. mangle*<br>*R. harrisonii*<br>*R. racemosa*<br>(Rhizophoraceae) | Gambia (Africa) | Teas & McEwan (1982) |

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. mangl*e in Puerto Rico (Wier and Tattar 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 *Xylocarpus granatum.*

Extensive mortality of *A. marina* (White/grey 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; Ho et al., 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 & Lee 1995; Feller 2002; Minchinton & Dalby-Ball 2001; Tavares and Peixoto 2009). There are also reports of associations between fungi and insects on mangroves (Nieves 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, Feller (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 Meneses (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 et al. (2002), reported an association between the fungus *Asteridiella sepulta* (Pat.) Hansf., (Melioliaceae) and the insect *Petrusa marginata* Brunnich

**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<br>Seedling death | *Rhizophora mucronata* (Rhizophoraceae) | India | Kathiresan (2003) |
| *Aulacaspis marina* | Hemiptera/Coccoidea | Saplings<br>Seedlings | Death | *Bruguiera gymnorrhiza*<br>*R. apiculata*<br>*R. mucronata*<br>(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<br>Seedlings | Seedling size reduction | *A. marina* (Avicenniaceae) | Australia | Minchinton & 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<br>Death of branches | *R. mangle* (Rhizophoraceae) | Brazil | Feller (2002) |
| *Elaphidion mimeticum* | Coleoptera/Cerambycidae | Woody and vascular tissues | Canopy loss<br>Branch death | *R. mangle* (Rhizophoraceae) | Brazil | Feller (2002) |
| *Euphranta marina* | Diptera/Tephritidae | Fruits | Seedling size reduction | *A. marina* (Avicenniaceae) | Australia | Minchinton and Dalby-Ball (2001) |
| *Hyblaea puera* | Lepidoptera/Hyblaeidae | Leaves<br>Seedlings | Twig death<br>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<br>Reduction in reproduction | *A. marina* (Avicenniaceae) | Hong Kong | Anderson & Lee (1995) |
| *Petrusa marginata* | Hemiptera/Flatidae | Leaves | Sooty-mold | *A. germinans* (Avicenniaceae) | Puerto Rico | Nieves et al. (2002) |

(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 *Rhizophora mangle* influenced by hurricane Charley in Tampa bay and Charlotte harbor (U.S.A).

## 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, agriculture etc. (Breen and Hill 1968; Bruton 1980; Rajkaran and Adams 2009, 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 were 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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