

Chapter 14

Insects and Diseases of Mediterranean Forests: A South African Perspective

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Abstract The Mediterranean climate zone (MCZ) covers approximately 94,000 km² along the southern and western tip of South Africa. Roughly coinciding with the Cape Floristic Province encompassing Fynbos, Renosterveld and Succulent Karoo biomes, the area has very few native forests. Most occur in sparse patches on south-facing slopes and in a few areas of contiguous Afromontane forest. Plantations in this region, as well as the pests and diseases that damage them, comprise primarily exotic species in the genera *Pinus*, *Eucalyptus* and Australian *Acacia* (wattle), both as planted crops and as wilding escapes. At least 22 of 43 insect pests are present on plantation trees in South Africa and 16 of 33 pathogens are present in the MCZ, some causing serious damage. A small number have also been intentionally introduced for biological control of invasive wattles. This chapter summarizes current knowledge on the insects and pathogens of *Pinus*, *Eucalyptus* and Australian *Acacia* in the MCZ South Africa. Special attention is given to examples where the biology, life history or expression of damage or disease differs from the summer rainfall areas of the country.

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14.1 Introduction: The Mediterranean Climate Zone in Southern Africa

As in other parts of the world, precise definitions or delineation of the Mediterranean climate zone (MCZ) are elusive in southern Africa (Blumler 2005; Kruger 2014). Characteristic Mediterranean climate conditions – hot, dry summers and cool, wet winters – occur principally in the Western Cape province of South Africa in the southwest corner of the country (Rundel 1998; Schulze 2007, Fig. 14.1). Many authors extend the boundaries of MCZ to the east as far as Port Elizabeth (Eastern Cape) where rain can fall year round, and midway to the Namibian border along the Atlantic coast, where conditions are highly seasonal, but exceedingly arid (20–290 mm per annum with most areas receiving <10 mm, though additional moisture enters the system as coastal fog; Mucina and Rutherford 2006). The core of the MCZ is centered on the areas of the southwestern Cape Province where annual rainfall ranges from 366 to 1607 mm, with more than 75 % falling in winter (April–September in the Southern Hemisphere; Cowling et al. 2005, Fig. 14.2).

The historical climate, geological history and natural ecology of the MCZ in South Africa are most similar to that of the southwest coast of Australia (Rundel 1998). Both have remained relatively stable geologically and climatically for millions of years, and are characterized by ancient, highly leached, nutrient-poor soils

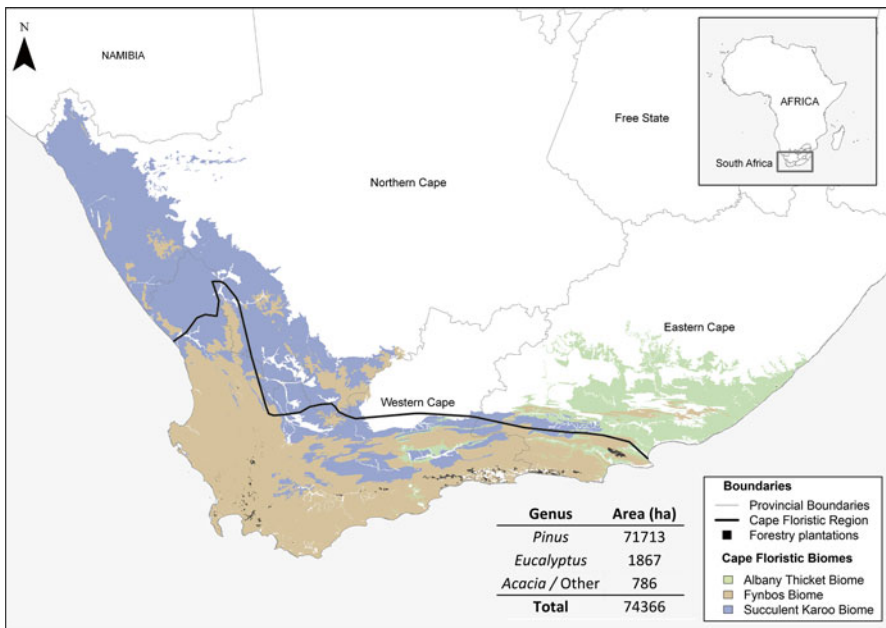


Fig. 14.1 Map of southern Africa showing the three major biomes that broadly occur within the Mediterranean climate zone (MCZ). The *bold line* corresponds to the Cape Floristic Province and roughly delineates the MCZ

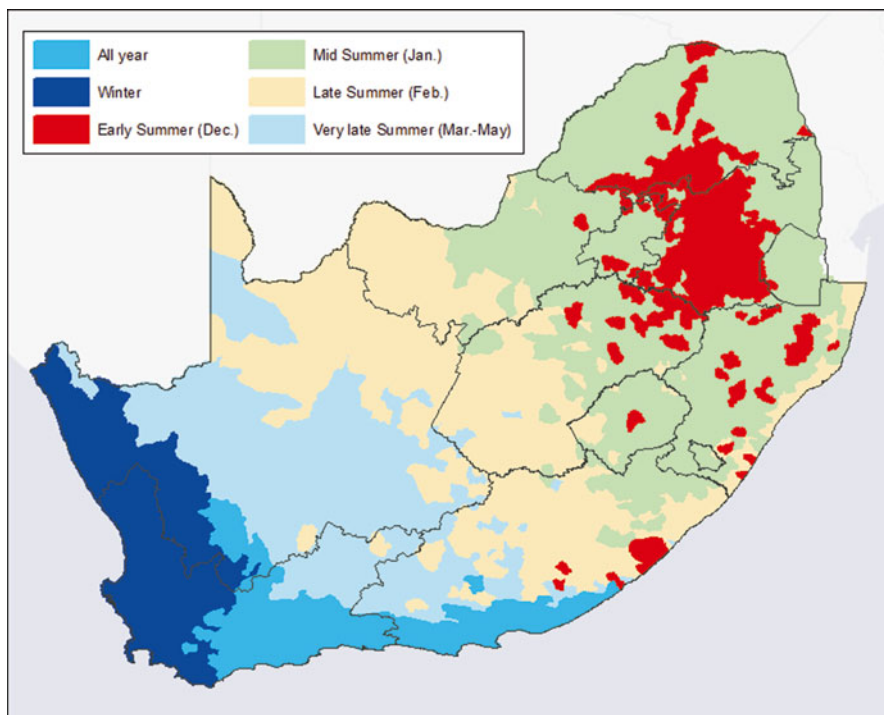


Fig. 14.2 Rainfall seasonality in South Africa [Data from Schulze (2007)]

and by frequent fires (every 10–15 years in the case of South Africa, considerably more frequent than Chile, California or the Mediterranean basin; Rundel 1998). The MCZ roughly corresponds to the Cape Floristic Region (CFR), which harbors astonishing plant diversity: over 9000 species in nearly 1000 genera and an endemism rate approaching 70 %, but with very few trees (Rouget et al. 2003). The dominant vegetation types of the CFR are shrubs and perennial herbs that fall broadly into the Fynbos or Renosterveld types. Fynbos, or “fine leaved” in Afrikaans, comprises diverse sclerophyllous, fire-adapted and mostly-evergreen plants in the Proteaceae, Ericaceae and Restionaceae. The Renosterveld derives its name from the “renosterbos”, Afrikaans for rhinoceros bush (*Elytropappus rhinocerotis*), but in fact is dominated by perennial grasses and numerous species in the Asteraceae, of which the rhinoceros bush is one (Rouget et al. 2003; Mucina and Rutherford 2006; Kruger 2014). At the northern reaches of the CFR is the Succulent Karoo, characterized by dwarf vegetation in the families Mesembryanthemaceae, Crassulaceae and Aloaceae, as well as diverse and abundant geophytes, which spend at least part of their annual life cycle underground as dormant corms, tubers or bulbs (Born et al. 2006; Mucina and Rutherford 2006).

One stark difference between the MCZ in South Africa compared with the rest of the world is the almost complete lack of forests. Small patches of Afromontane

forest occur scattered around the CFR, primarily on south-facing ridges and along steep ravines. One larger contiguous swath that occurs within the region – the Knysna/Tsitsikamma *forest* along the southern Cape coast – occupies 568 km² in an area with patchy, but continuous year-round rain that falls predominately in the summer months (Midgley et al. 1997). Such forests, while they occur broadly within the MCZ, clearly experience conditions uncharacteristic of Mediterranean climates and represent a distinct ecozone.

14.2 Mediterranean Afforested Landscapes: Past and Present

When Europeans first established permanent settlements in 1652 in what was to become the Western Cape of South Africa, they encountered a landscape with limited timber resources that were depleted quickly (Olivier 2009; Bennett and Kruger 2013). Perhaps as a result, afforestation linked to the planting of exotic species commenced almost immediately. Land proprietors were prompted by decree to plant 100 young oaks on all holdings as early as 1689, though it was not until around 1820 that the first commercial plantation is known to have been established (Olivier 2009). By the early twentieth century, numerous species of *Pinus*, *Eucalyptus* and Australian *Acacia* were actively being cultivated for timber, tannins, and fuelwood, as well as for shade and as windbreaks. Several of these species, notably *Pinus pinaster* (maritime pine), *Acacia melanoxylon* (Tasmanian Blackwood), as well as *A. mearnsii*, *A. longifolia* and *A. cyclops* (black, long-leaf and red-eyed wattle) and several eucalypts, have become aggressive invaders in the region (Richardson 2000; Richardson et al. 2011; Richardson and Rejmánek 2011). Many form dense stands that outcompete fynbos and grassland vegetation and can inhibit indigenous tree regeneration on harvested or burned sites (Bennett and Kruger 2013). Tree invasions represent a major threat to biodiversity in the region, a fact which has caused considerable conflict and controversy around exotic plantation forestry since the early twentieth century (Bennett and Kruger 2013). Forest growers, in adherence with government regulations and requirements set by sustainable forest certification authorities, have modified planting and management practices considerably. In many cases this has meant utilizing species that are less prone to escape, enforced buffer zones around riparian areas to limit effects on streamflow, and limited the extent of exotic plantations (Bredenkamp et al. 2012). Nevertheless, current trends appear to favour reductions in planted area, at least partly due to conservation concerns (Anonymous 2012).

Conflicts aside, nearly all forests within the core of the winter rainfall zone in the MCZ are exotic plantations and areas of natural recruitment of *Pinus*, *Eucalyptus* and Australian *Acacia*. A handful of other tree species are particularly invasive in the region, including *Hakea sericea*, *Sesbania punicea* as well as *Prosopis* species to the north in the Succulent Karoo (Moran et al. 1999; Van den Berg et al. 2013).

In 2014, the reported forest plantation cover in the region was 74,366 ha and was mostly pine (71,713 ha; principally *Pinus radiata*). There was only a modest *Eucalyptus* (1,867 ha) component, and *Acacia mearnsii* and other species of minor importance (e.g., poplar) contributed only 786 ha (DAFF 2014). Taken together, this area represents just less than 1 % of the land area of the MCZ. The contribution of exotic escapes to total forested land area is difficult to calculate as little of the invaded landscape is characterized by closed canopy or contiguous forest, but rather as distributed patches of trees with some dense thickets occurring along riparian zones (Rouget et al. 2002; Le Maitre et al. 2000).

14.3 Pests and Diseases of Forests in the South African MCZ

Very little is known about the insects and diseases of the southern Afromontane forest in the MCZ of South Africa. In light of limited knowledge and scant occurrence of major biotic threats to these forests, the proportionally small land area contributed and the fact that climate conditions associated with the biome are uncharacteristic of other Mediterranean forests, we focus this review exclusively on cultivated plantation forestry trees and forestry trees imported for cultivation that later escaped and spread, all of which are non-native to the region. Forest plantations and areas of natural recruitment by exotic species in the genera *Pinus*, *Eucalyptus* and *Acacia* support a number of insects and pathogens of both native and exotic origin, many of which are shared with and/or have relevance to the other MCZ's in the rest of the world.

Detailed knowledge of patterns of distribution and abundance specific to the MCZ within South Africa is lacking. Tables 14.1 and 14.2 summarize the insect and pathogen threats of current and historical importance in southern Africa. We divide these taxa into those that are unique or endemic to the MCZ, those that are known to be widespread with clear impacts in the MCZ, and those that are known from South Africa but not specifically documented in the MCZ (or where only anecdotal reports exist). Perhaps surprisingly in light of the climatic distinctiveness of the MCZ relative to the rest of South Africa, the majority of insect threats appear to be shared across the whole country, particularly those of exotic origin. More subtle differences (e.g., in behaviour, abundance and/or phenology) do exist, however, and are treated in greater detail below.

14.3.1 Forest Insects in the MCZ

Of the 43 insect pests of *Pinus*, *Eucalyptus* and Australian *Acacia* found in South Africa (Table 14.1), 26 (60 %) have been reported or are assumed present on hosts within the MCZ. Distributional data are difficult to interpret, however, as sporadic attacks by native insects often go unreported. All of the most serious pests of *Pinus*

Table 14.1 Insect pests of plantation trees in South Africa, with focus on the Mediterranean Climate Zone (MCZ)

Scientific name(s)	Common name	Trees affected ^b	Feeding guild	Native/introduced	Presence in MCZ
<i>Achaea lienardi</i>	Wattle semi-looper	<i>Acacia</i>	Defoliator	N	No report
<i>Agrotis</i> spp.	Cutworms	<i>Acacia</i> , <i>Eucalyptus</i> <i>Pinus</i>	Establishment pest	N	Assumed present
<i>Blastopsylla occidentalis</i>	Eucalyptus shoot psyllid	<i>Eucalyptus</i>	Sap-sucker	I	No report
<i>Catamonus</i> sp.	Catamonus weevil	<i>Acacia</i>	Defoliator	N	No report
<i>Cinara cronartii</i>	Black pine aphid	<i>Pinus</i>	Sap-sucker	I	Confirmed present (Prinsloo and Uys 2014)
<i>Cleora herbuloti</i>	Pine looper	<i>Eucalyptus</i> , <i>Pinus</i>	Defoliator	N	Assumed absent (Hepburn and Leodolf 1964)
<i>Colaspoxoma</i> spp.	Green bronze beetle	<i>Eucalyptus</i> , <i>Pinus</i>	Establishment pest Defoliator	N	Assumed absent (van Webb 1974)
<i>Coryphodema tristis</i>	Cossid moth	<i>Eucalyptus nitens</i>	Wood borer	N	Not present (Gebeyehu and Hurley 2005)
<i>Ctenarytaina eucalypti</i>	Blue gum psyllid	<i>Eucalyptus</i>	Sap-sucker	I	No report
<i>Dasineura rubiformis</i>	Black wattle gall midge	<i>Acacia</i>	Gall former	I ^a	Confirmed present (Impson et al. 2013)
<i>Drosophila favohirta</i>	Eucalypt nectar fly	<i>Eucalyptus</i>	Pollen feeder	I	Confirmed present (Tribe 1991a)
<i>Ellimenistes laeviscollis</i>	Grey weevil	<i>Eucalyptus</i> , <i>Acacia</i>	Establishment pest Defoliator	N	No report
<i>Eulachnus rileyi</i>	Pine needle aphid	<i>Pinus</i>	Sap-sucker	I	Confirmed present (Prinsloo and Uys 2014)
<i>Euprocis terminalis</i>	Pine brown tail moth	<i>Pinus</i>	Defoliator	N	Assumed absent (Tooke 1938; Prinsloo and Uys 2014)

<i>Eutricha capensis</i>	Brown lappet moth	<i>Acacia Eucalyptus Pinus</i>	Defoliator	N	Confirmed present (van Webb 1974)
<i>Glycaspis brimblecombei</i>	Red gum lerp psyllid	<i>Eucalyptus</i>	Sap-sucker	I	Confirmed present (authors, pers. obs.)
<i>Goniipterus</i> n. sp. 2	Eucalyptus weevil	<i>Eucalyptus</i>	Defoliator	I	Confirmed present (Tooke 1953; Mapondera et al. 2012)
<i>Gynanisa maia</i>	Wattle emperor moth	<i>Acacia</i>	Defoliator	N	No report
<i>Hylastes angustatus</i>	Pine bark beetle	<i>Pinus</i>	Establishment pest Bark borer	I	Confirmed present (Tribe 1990b)
<i>Hylurgus ligniperda</i>	Red-haired pine bark beetle	<i>Pinus</i>	Bark borer	I	Confirmed present (Tribe 1991c)
<i>Imbrasia cytherea</i>	Pine emperor moth	<i>Acacia, Pinus</i>	Defoliator	N	Confirmed present (van Webb 1974)
<i>Imbrasia tyrrhea</i>	Willow tree emperor moth	<i>Eucalyptus, Pinus</i>	Defoliator	N	Confirmed present (Prinsloo and Uys 2014)
<i>Kotochalia junodi</i>	Wattle bagworm	<i>Acacia</i>	Defoliator	N	No report
<i>Leptocybe invasa</i>	Blue gum chalcid	<i>Eucalyptus</i>	Gall former	I	Confirmed present (authors, pers. obs.)
<i>Lygidolon laevigatum</i>	Wattle mind	<i>Acacia</i>	Sap-sucker	N	No report
<i>Monochelus calcaratus</i>	Lesser wattle chafer	<i>Acacia</i>	Defoliator	N	No report
<i>Odonionopa sericea</i>	Fruit nibbler	<i>Eucalyptus, Pinus</i>	Defoliator	N	Mainly in MCZ (Tribe 1991b)
<i>Oosomus varius</i>	Diamond-back pine snout beetle	<i>Eucalyptus, Pinus</i>	Defoliator	N	Exclusively in MCZ (Tribe 1991b)
<i>Ophelimus maskelli</i>	Eucalyptus gall wasp	<i>Eucalyptus</i>	Gall former	I	No report
<i>Orthotomicus erosus</i>	Mediterranean pine engraver beetle	<i>Pinus</i>	Bark borer	I	Confirmed present (Tribe 1990a)

(continued)

Table 14.1 (continued)

Scientific name(s)	Common name	Trees affected ^b	Feeding guild	Native/introduced	Presence in MCZ
<i>Pegylis sommerii</i>	Wattle chafer	<i>Acacia</i> , <i>Pinus</i>	Defoliator	N	Confirmed present (du G. Harrison 2014)
<i>Phorocantha recurva</i> and <i>P. semipunctata</i>	Eucalyptus longhorn beetle	<i>Eucalyptus</i>	Wood borer	I	Confirmed present (van Webb 1974)
<i>Pinus boernerii</i>	Pine woolly aphid	<i>Pinus</i>	Sap-sucker	I	Confirmed present (Bruzas 1983)
<i>Pissodes nemorensis</i>	Deodar weevil	<i>Pinus</i>	Bark borer	I	Confirmed present (van Webb 1974)
<i>Pseudobunaea irius</i>	Poplar emperor moth	<i>Acacia</i> , <i>Eucalyptus</i> <i>Pinus</i>	Defoliator	N	Assumed absent (Hepburn 1966)
<i>Sirex noctilio</i>	Sirex woodwasp	<i>Pinus</i>	Wood borer	I	Confirmed present (Tribe 1995)
<i>Spondylitaspis plicatuloides</i>	Shell lerp psyllid	<i>Eucalyptus</i>	Sap-sucker	I	No report
<i>Thaumastocoris peregrinus</i>	Bronze bug	<i>Eucalyptus</i>	Sap-sucker	I	Confirmed present
<i>Trachymela tincticollis</i>	Eucalyptus tortoise beetle	<i>Eucalyptus</i>	Defoliator	I	Exclusively in MCZ (Tribe 2000)
Various species	Grasshoppers and crickets	<i>Acacia</i> , <i>Eucalyptus</i> <i>Pinus</i>	Establishment pest	N	Assumed present
Various species	Termites	<i>Acacia</i> , <i>Eucalyptus</i>	Establishment pest	N	Confirmed present (van Webb 1974)
Various species of Scarab beetle larvae	Whitegrubs	<i>Acacia</i> , <i>Eucalyptus</i> <i>Pinus</i>	Establishment pest	N	Assumed present
<i>Xyleborus</i> spp. <i>Xyleborinus</i> spp.	Ambrosia beetles	<i>Pinus</i>	Wood borer	I	Confirmed present (Mandelshtam and Danielsson 2004)

^aIntentionally introduced for the biological control of invasive weeds

^b“Trees affected” column reflects examples of moderate to several and/or recurring damage occur and do not include native or occasional hosts

Table 14.2 Pathogens^a of plantation trees in South Africa, with a focus on the Mediterranean Climate Zone (MCZ)

Scientific name(s)	Disease name/type	Plantation species affected	Other host records	Native/introduced	Presence in MCZ
<i>Armillaria fuscipes</i> <i>Armillaria species</i>	Armillaria root rot	<i>Eucalyptus</i> , <i>Pinus</i>	Several native South African tree species; non-native fruit tree species, oak	N I	No report of <i>A. fuscipes</i> , but several reports of <i>A. mellea</i> on non-plantation hosts (Doidge et al. 1953)
<i>Aulographina eucalypti</i>	Aulographina leaf spot	<i>Eucalyptus</i>	–	I	Assumed
<i>Camptomeris albizziae</i>	Camptomeris leaf spot	<i>Acacia mearnsii</i>	–	I	Yes
<i>Ceratocystis albifundus</i>	Wattle/Ceratocystis wilt	<i>Acacia mearnsii</i> , <i>A. decurrens</i>	Native African tree species in more than ten plant families	N	Yes
<i>Cercoseptoria pini-densiflorae</i>	Needle blight	<i>Pinus</i>	–	I	No report
<i>Chrysosporthe austroafricana</i>	Cryphonectria canker	<i>Eucalyptus</i>	Non-native ornamental <i>Tibouchina</i>	N	No report
<i>Cyclaneusma minus</i>	Cyclaneusma needle spot	<i>Pinus</i>	–	I	Yes (Crous et al. 1991)
<i>Diplodia sapinea</i>	Diplodia canker	<i>Pinus</i>	–	I	Yes (Burgess et al. 2004)
<i>Dothistroma septosporum</i>	Dothistroma needle blight	<i>Pinus</i>	None	I	No report
<i>Erythricium salmonicolor</i>	Pink disease	<i>Acacia mearnsii</i> <i>Eucalyptus</i>	<i>Ekebergia capensis</i> <i>Dais cotonifolia</i> , <i>Podocarpus henkelii</i>	U	No report
<i>Fusarium circinatum</i>	Pine pitch canker	<i>Pinus</i>	Grass species	I	Yes (Coutinho et al. 2007)
<i>Grosmannia alacris</i>	Blue stain and root disease associated with root infecting bark beetles	<i>Pinus</i>	–	I	Yes (Wingfield and Knox-Davies 1980a, b)

(continued)

Table 14.2 (continued)

Scientific name(s)	Disease name/type	Plantation species affected	Other host records	Native/introduced	Presence in MCZ
<i>Holocryphia eucalypti</i>	Holocryphia (Endothia) canker	<i>Eucalyptus</i>	<i>Metrosideros angustifolia</i>	I	Yes on <i>M. angustifolia</i> (Chen et al. 2013)
<i>Lasiodiplodia theobromae</i>	Blue stain Canker	<i>Acacia</i> , <i>Eucalyptus</i> , <i>Pinus</i>	Several native South African tree species; non-native fruit tree species	I	Assumed absent; typically restricted to tropical and sub-tropical areas. (Slippers and Wingfield 2007)
<i>Lophodermium</i> sp.	Needle spotting	<i>Pinus</i>	–	I	Yes (Crous et al. 1991)
<i>Neofusicoccum</i> spp. ^b	Botryosphaeria canker	<i>Eucalyptus</i>	Several native South African tree species; non-native fruit tree species	U	<i>N. australe</i> , <i>N. parvum</i> ; others assumed present (Crous et al. 2000; Slippers et al. 2007, 2009; Van Niekerk et al. 2004)
Ophiostomatoid fungi ^b	Blue stain of pine (roots and bole)	<i>Pinus</i>	Many	I	<i>O. abietinum</i> , <i>P. piliferum</i> , <i>O. stenoceras</i> ; No report for others but assumed present.
<i>Pantoea ananatis</i>	Bacterial blight	<i>Eucalyptus</i>	–	I	No report
<i>Phytophthora boehmeriae</i>	Phytophthora root rot of <i>Acacia</i>	<i>Acacia mearnsii</i>	–	U	No report

<i>Phytophthora cinnamomi</i>	Phytophthora root rot	<i>Eucalyptus, Pinus radiata</i>	Native and non-native plant species (e.g., <i>Quercus</i> , Proteaceae etc.)	I	Yes (Olivier 1951; Van der Merwe and Van Wyk 1973; von Broembsen and Kruger 1985; Oh et al. 2011)
<i>Phytophthora parasitica</i>	Black butt disease (root rot)	<i>Acacia mearnsii</i>	–	U	No report
<i>Pseudophaeoelus baudonii</i>	Pseudophaeoelus root rot	<i>Eucalyptus Pinus</i> species	–	N	No report
<i>Puccinia psidii</i>	Myrtle rust	Not detected on <i>Eucalyptus</i> yet, but present in country	<i>Myrtus communis</i>	I	No report
<i>Quambalaria eucalypti</i>	Quambalaria leaf and shoot blight	<i>Corymbia Eucalyptus</i>	None	I	No report
<i>Ralstonia solanacearum</i>	Bacterial wilt	<i>Eucalyptus</i>	Various vegetable crops	U	No report
<i>Rhizina undulata</i>	Rhizina root rot	<i>Pinus</i>	None	I	Yes (authors, pers. obs.)
<i>Sphaerotheca pannosa</i>	Mildew	<i>Acacia, Eucalyptus, Pinus</i>	Numerous	U	Yes
<i>Teratosphaeria suttonii</i>	Leaf spot	<i>Eucalyptus</i>	None	I	Yes (authors, pers. obs)
<i>Teratosphaeria nubilosa</i>	Mycosphaerella leaf blotch	<i>Eucalyptus</i>	None	I	Yes (Crous et al. 1991)
<i>Teratosphaeria zuluensis</i>	Coniothyrium stem canker	<i>Eucalyptus</i>	None	I	No report
<i>Uromycladium alpinum</i>	Uromycladium rust	<i>Acacia mearnsii</i>	None	I*	Yes (authors, pers. obs)
<i>Xanthomonas vasicola</i>	Bacterial blight	<i>Eucalyptus</i>	Sugarcane	U	No report

*Intentionally introduced for the biological control of invasive weeds

**"Pathogens" listed are only examples of moderate to severe pathogens causing plant death and economic losses and do not include those resulting in only sporadic or negligible damage

^bMultiple species, many previously recorded as *Botryosphaeria dothidea* and *B. ribis*

and *Eucalyptus* are present in the MCZ (with the exception of *Ophelimus maskelli*, which was only recently detected in 2014 near Johannesburg; Bush et al., *in prep.*). The wattle insects in Table 14.1 are largely known from black wattle (*Acacia mearnsii*) plantations from the interior, which together with green wattle (*Acacia decurrens*), comprise the majority of cultivated plantation wattles in South Africa. Many of these insects have not actually been reported in the MCZ, and while they may be present, none is of importance either as a pest species of plantation-grown or escaped wattles, and do not appear to limit the spread of these trees into native areas (Impson, pers. comm.).

Native insects damaging exotic trees appear to be characterized by an over-representation of broad generalists. Fourteen of the twenty-two native insects listed in Table 14.1 are known as pests for at least two genera of exotic trees, though several of these insects are actually groups of related species (e.g., grasshoppers and crickets, cutworms, termites, and white grubs) and are primarily pests of establishment. Of those known to be present in the MCZ, only the Pine and Willow Tree Emperor Moths (*Imbrasia cytherea* and *Imbrasia tyrrhea* respectively) and the brown lappet moth (*Pachypasa capensis*) are pests of mature trees, and in some years cause severe defoliation, particularly on *Pinus* species (van Webb 1974).

The dominance of generalist insects stands in stark contrast to the introduced pests, all of which are restricted to a single host genus. Many are further restricted or show strong preference for a subset of species or clades within those genera (Tooke 1953; Santana and Burckhardt 2007; Dittrich-Schröder et al. 2012). Not surprisingly, there is also a marked discrepancy between the levels of damage caused by exotic and native species, with a small number of the most damaging introduced pests causing the bulk of economic losses. The effects of major *Eucalyptus* pests (i.e., *Leptocybe invasa*, *Gonipterus* spp., *Thaumastocoris peregrinus* and *Glycaspis brimblecombei*), as well as *Sirex noctilio* on *Pinus* are severe. For example, the blue gum chalcid, *Leptocybe invasa*, is the most devastating and widespread pest on *Eucalyptus* in South Africa, and perhaps worldwide (Mendel et al. 2004; Nugnes et al. 2015; Nyeko et al. 2010).

In the MCZ, however, *Eucalyptus* is of relatively minor importance as a forestry crop, and the effects of these insects may be more pronounced for beekeepers who value the pollen and nectar of at least 13 species of *Eucalyptus* as a source of honey. The combination of the success of biocontrol (species swapping) and the diminished importance of *Eucalyptus* has resulted in reduced attention to some pests (e.g., *Phoracantha recurva* and *P. semipunctata*) in the MCZ. This is despite the fact that some were formerly of major consequence and even changed the face of forestry in the region (e.g., the *Gonipterus* leaf weevil, discussed in detail below).

Together with pathogens and fire, these insects represent serious threats to forest plantations countrywide. All are the subject of active research on management and biological control. Research and management to control the spread of the trees themselves (particularly Australian *Acacia*) are also ongoing, and numerous insects and one rust pathogen have been imported and have become established (see Sect. 14.3.3). Impacts also vary widely when considering the MCZ versus the summer rainfall areas, a reflection of a complex interplay among climate, manage-

ment regime (i.e., mainly pulp in the summer rainfall versus mainly timber in the MCZ) and regional variation in the planting and importance of certain host tree species. Climate, however, appears to be a weak driver of the distribution of introduced pests.

Considerable work has been published on the biology and life history of many of the pests from Table 14.1 (Wingfield et al. 2013; Slippers et al. 2014; Nadel et al. 2015). Many have been studied principally in the primary growing areas of the Mpumalanga and KwaZulu-Natal Provinces. Forestry in the MCZ contributes only about 8 % to the total plantation area of the country and is largely dominated by pine (96 % in the region; Fig. 14.1). As such, pests of *Eucalyptus* of major importance elsewhere in South Africa (e.g., *L. invasa*, *T. peregrinus*, *G. brimblecombei*), together with some of the insects specific to wattle, are of only passing interest in the MCZ. However, three pests of pine (*S. noctilio*, *I. cytherea* and *P. nemorensis*) and two of *Eucalyptus* (*Gonipteris* beetles and *T. tinticollis*) have in part shaped forestry in the region and/or exhibit behaviours, ecologies or have distributions that are specific to the MCZ. We focus on these five insects in greater detail in the following section and also include a brief discussion of the native wood-boring moth (*Coryphodema tristis*) present in the region but acting as a forest pest only to the north of its distribution in the summer rainfall zone.

14.3.2 Case Studies: Insects of Relevance to Plantation Forests of the MCZ

14.3.2.1 Sirex Woodwasp: *Sirex noctilio*

The Sirex woodwasp (*Sirex noctilio*; Siricidae; Fig. 14.3a) is Eurasian in origin and was first recorded from South Africa in a *P. radiata* plantation in Tokai, Cape Town in 1994 (Tribe 1995). The presence and apparent age of emergence holes indicated that it was present at least 2 years earlier. The *S. noctilio* life cycle has been written about at length elsewhere (Slippers et al. 2012a). Briefly, *S. noctilio* adults attack primarily stressed trees (though healthy trees are also vulnerable when wasps are at high densities in the invasive range). Female wasps probe trees, placing arthrospores of a symbiotic fungus, *Amylostereum aereolatum* (typically, but see Hajek et al. 2013; Wooding et al. 2013), a phytotoxin, and sometimes one or a few eggs (Madden 1974). Larvae develop within the sapwood for 1–3 years depending on temperature, though no life cycles greater than 1 year have been recorded in South Africa. Within the first few months post-oviposition, trees decline and die (Fig. 14.3b).

The arrival of *S. noctilio* to South Africa was not unexpected given that the wasp had been introduced and was widely distributed across the Southern Hemisphere, infesting plantations of *Pinus* in Mediterranean climates in New Zealand, Australia and South America (Slippers et al. 2014). The wasp's rapid spread and aggressive establishment in the continental and subtropical climates in the east of the country

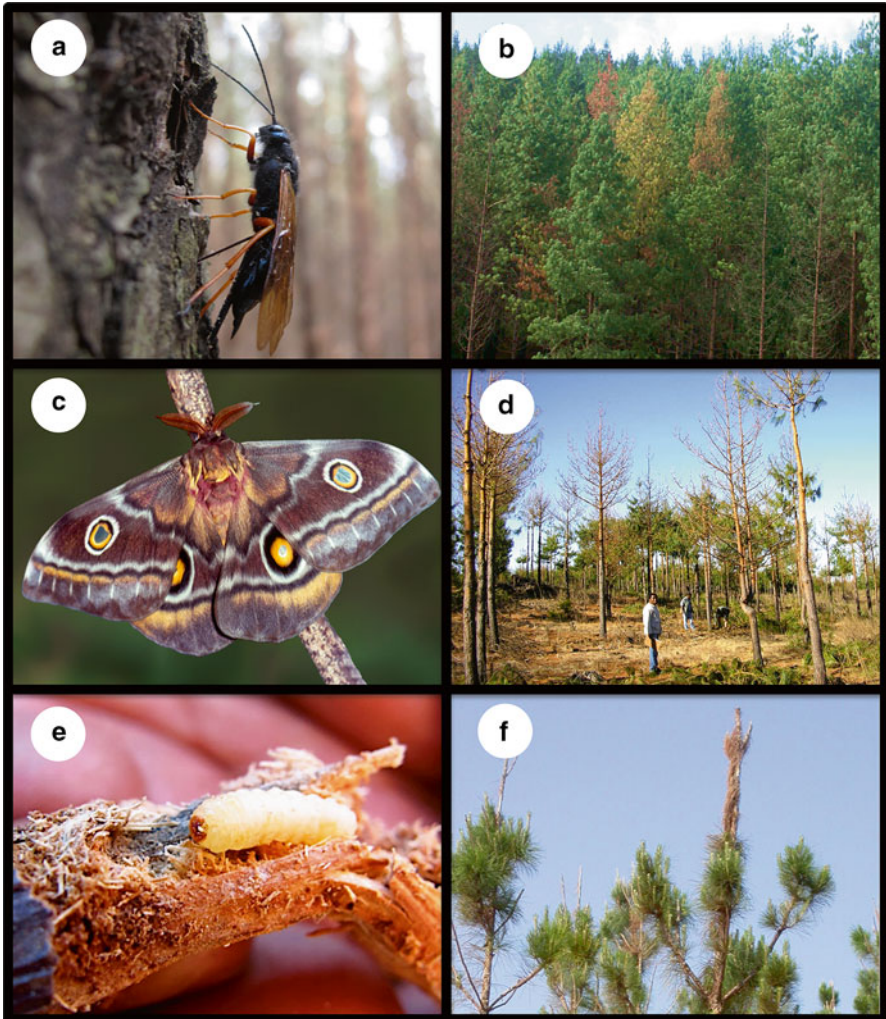


Fig. 14.3 Insects and damage relevant to exotic forestry in the Mediterranean climate zone (MCZ), South Africa. Subfigures are as follows: female *Sirex noctilio* ovipositing on *Pinus patula* (a); dead and dying pines after attack by *S. noctilio* (b); *Imbrasia cytherea cytherea* adult (c) and defoliation (d) *Pissodes nemorensis* larvae if the terminal leader of *Pinus radiata* (e) and associated tip dieback in the Western Cape of South Africa Photos by Jeff Garnas (a), Brett Hurley (b, e and f), Rolf Oberprieler (c), and Stuart Charlton (d)

(dominated by *P. patula*, and to a lesser degree *P. elliottii* and *P. taeda* plantations) and its rapid switch to the altered phenology in the summer rainfall zone, was considerably more surprising (Hurley et al. 2011). *Sirex noctilio* has since established throughout plantations in South Africa, including all plantations in the MCZ and stretching to plantations in northern Limpopo (Lantschner et al. 2014).

Major differences in population dynamics and impact of *S. noctilio* populations exist in the eastern summer rainfall regions of South Africa in comparison to the MCZ (Hurley et al. 2011). For example, climatic differences strongly influence flight phenology, which occurs from late October to December in the east of the country (peaking in November), and from December to April in the Cape (peaking in March/April). In the Cape region, the populations of *S. noctilio* have only rarely reached outbreak levels. Only one relatively mild outbreak (10 % mortality in localized patches) has been recorded to date in the MCZ, recorded near the town of George in 2002. In contrast, outbreaks resulting in up to 35 % tree mortality have been recorded in some *P. patula* plantations in the east of the country (Hurley and Slippers 2007). These differences in population densities and impacts are almost certainly driven largely by vastly different management regimes. In general, commercial pine production is characterized by timber in the MCZ (mainly using *P. radiata* in the MCZ, with regular pruning and thinning that reduces stand stress) and by pulp production in much of the summer rainfall area (dominated by *P. patula* at high planting densities – up to 1600 stems ha⁻¹ – where no density reductions are performed; Hurley et al. 2011). Nevertheless, the influence of climate and pine host species on wasp population dynamics is difficult to discount.

An intensive biological control program has been implemented for *S. noctilio* in South Africa. *Ibalia leucospoides*, a parasitoid of egg and first instar *S. noctilio* larvae, was introduced from Uruguay in 1998 into the Cape (Hurley et al. 2008). This parasitoid has established well throughout the MCZ, parasitizing between 0 % and 50 % of *S. noctilio* larvae in plantations across the region (Hardus Hatting and Brett Hurley, *unpublished data*). Natural spread of *Ibalia leucospoides* into the summer rainfall areas has been slow, and wasps are still collected in the MCZ to be released in plantations in the east of South Africa. While impacts of *Ibalia* on *Sirex* in Cape plantations appear to be considerable, parasitoid effectiveness as a biocontrol agent outside the MCZ is unclear.

Deladenus siricidicola, a parasitic nematode that sterilizes the females of *S. noctilio*, was first introduced in the MCZ in plantations around the Cape peninsula in 1995–1996 (Tribe and Cillié 2004). Nematode-infested logs have since been moved to other plantations in the MCZ along the south coast. The nematode has established in the MCZ, although at rates of background parasitism (i.e., percent occurrence in wasps emerging from un-inoculated trees) ranges from 0 % to 64 % depending on site and year (Slippers et al. 2012b).

The Tree Protection Cooperative Programme (TPCP) at the Forestry and Agricultural Biotechnology Institute (FABI: www.fabinet.up.ac.za) manages a massive programme of inundative control using these nematodes, where close to 1 billion nematodes are reared, transported and inoculated into thousands of *S. noctilio*-infested trees annually, both inside and outside the MCZ (Hurley et al. 2008, 2011). Inoculation success and early establishment of *D. siricidicola* was higher in the MCZ than in the summer rainfall regions of the country (Tribe and Cillié 2004; Hurley et al. 2008). This difference is hypothesized to relate to differences in wood moisture content at time of inoculation between these two regions. Low moisture content at time of inoculation in the summer rainfall regions is

thought to result in poor establishment of the fungus *Amylostereum areolatum*, which serves as a food source for the nematodes in the mycetophagous (fungus-feeding) stage (Hurley et al. 2012).

14.3.2.2 Pine Emperor Moth: *Imbrasia cytherea*

The Pine Emperor Moth (*Imbrasia [Nudaurelia] cytherea*) is a large and striking insect in the emperor moth family (Saturniidae; Fig. 14.3c). Larvae can reach 120–130 mm in length and are intricately and colorfully patterned; adult moths have wingspans of approximately 150 mm with colorfully ringed eyespots on the hindwings (Fig. 14.3d). In addition to their size and appearance, *I. cytherea* is impressive for both its wide host range and its capacity for rapid population growth. Larvae feed on a minimum of 40 native and exotic species across families and orders and are capable of completely defoliating large areas, including plantations of pine, wattle and *Eucalyptus*.

Capable of sustained outbreaks causing severe damage over hundreds of hectares on both wattle and pine (particularly *P. radiata*), this insect represents a serious threat to tree growers in the region. The list of recorded host plants includes the native sugarbush (*Protea repens*), as well as apple, quince, oak and several of the introduced wattles (*A. mearnsii*, *A. cyclops*, *A. longifolia* and *A. saligna*), among numerous other species (Tooke and Hubbard 1941). The species occurs from the southern tip of Africa north into Zimbabwe and is usually treated as comprising two sub-species. These are the dark brown nominate sub-species (*Imbrasia cytherea cytherea*) in the Western Cape and the yellow sub-species (*I. cytherea clarki*) in the Eastern Cape and Highveld area to the north (Geertsema 1971). Pupae are found in the soil, and massive hand collection efforts were made during the 1920's as a means of control in *P. radiata* plantations. In 1924, 230,000 of the insects were manually removed from a single 121-ha infestation of *P. radiata* (together with “100 lbs. of eggs and 163 bags of egg-infested twigs”), but the effort was still insufficient to stop the outbreak (Tooke and Hubbard 1941). Two years later, 50 pigs were enclosed in the same plantation to substitute for hand collection. Pig foraging reduced population density from 150 to 175 pupae per tree to 12. Larval mortality is also incurred due to infection by a suite of small RNA viruses present in populations (Tripconey 1969; Walter et al. 2008), as well as numerous parasitoids of all life stages and several vertebrate predators (Tooke and Hubbard 1941).

In addition to *I. cytherea cytherea* (and *I. cytherea clarki* to the north), the related Willow Tree Emperor moth (*Imbrasia [Gonimbrasia] tyrrhea*) is occasionally problematic in the MCZ on forestry crops (Hepburn 1966; van Webb 1974). Both *I. tyrrhea* and its close relative *Imbrasia [Gonimbrasia] belina* (the so-called Mopane worm) are consumed by humans. The former is consumed locally, largely in Namaqualand (Northern Cape Province) while the latter is harvested in huge numbers from xeric woodlands in the Limpopo Province of South Africa to as far north as the Democratic Republic of the Congo and extensively traded as an important

source of protein (Hrabar et al. 2009). *Imbrasia belina* has also been reported to feed on *P. radiata* (Oberprieler 1986) though only well outside of the MCZ.

14.3.2.3 Deodar Weevil: *Pissodes nemorensis*

Pissodes nemorensis (the deodar weevil) was first discovered in South Africa in 1942 infesting logs of *P. radiata* in Port Elizabeth (Eastern Cape Province) and has now spread throughout the country (van Webb 1974). Throughout most of its range, the beetle attacks dead or dying trees, where larvae typically develop in the phloem and pupate in shallowly excavated chambers on the surface of the xylem (Fig. 14.3e). As a result of this behavior, *P. nemorensis* is generally of little economic consequence for growers of *Pinus* for pulp or timber. However, as in its native range of North America, oviposition and larval development within the terminal leader of vigorously growing trees can also occur (Fig. 14.3f). The corresponding tip death causes fork formation or crooked growth resulting in a reduction in timber values. Interestingly, tip colonization by *P. nemorensis* appears to be considerably more common in the MCZ (Gebeyehu and Wingfield 2003; Prinsloo 2005). Whether this is a result of different insect-host dynamics on *P. radiata* or an indirect effect of climate (i.e., via shifted oviposition phenology) is currently unknown. Efforts to quantify and to improve mechanistic understanding of the drivers of this pattern are currently underway (Mesfin Gossa, unpublished).

Immature stages of the weevil are parasitized by an endemic pteromalid wasp, *Pycnetron pix*, a native parasitoid of the cycad seed weevil (*Antliarhinus peglerae*) (Prinsloo 2005). This parasitoid is regularly recovered at low frequency and has been reported as absent from the MCZ (Prinsloo 2005). However, recent sampling has recovered *P. pix* from *P. radiata* plantations of the Western Cape (Mesfin Gossa, unpublished data). A species of fly in the genus *Gobertina* (Diptera:Stratiomyidae) apparently parasitizing larvae and/or pupae has also been recovered, though its effect on populations is unknown (Gebeyehu and Wingfield 2003).

14.3.2.4 Eucalyptus Tortoise Beetle: *Trachymela tinticollis*

The Eucalyptus Tortoise Beetle (*Trachymela tinticollis*) is a chrysomelid beetle in the Tribe Paropsini discovered in the Cape Peninsula of South Africa in 1982 (Tribe and Cillié 1997). In its native range of southwestern Australia, *T. tinticollis* appears to be a complex of species that can be distinguished on the basis of host preference and subtle aspects of behaviour (Tribe 2000). Initial outbreaks in South Africa were on *Eucalyptus gomphocephala* though the beetles feed on at least 13 species of *Eucalyptus* in the MCZ, including the commercially important *E. grandis* (Tribe and Cillié 1997; Tribe 2000). As with most paropsine beetles, both larvae and adults feed and together are capable of serious defoliation. Feeding takes place in the pre-dawn and dusk hours; adults often hide in bark crevices during the day. Larvae are present between September and February (peaking in November) and adult

dispersal occurs in February and March in the MCZ of South Africa (Tribe and Cillió 1997).

A suite of parasitoids is known from the native range in Australia, including at least five hymenopteran egg parasitoids (plus four hyper-parasitoids), six tachinid fly larval parasitoids and one egg-feeding predatory mite. Four of the wasp egg parasitoids were ultimately imported and released in 1986, including three pteromalids (*Enoggera reticulata*, *E. nassaui* and *Neopolycystus insectifurax*) and the encyrtid *Procheiloneurus* sp. nr. *triguttatipennis*. Only *E. reticulata* successfully established, and within 2 years had spread naturally throughout the range of its host (>1300 km to the east in Port Elizabeth) and achieved up to 96 % parasitism during the oviposition period of *T. tenticollis* (Tribe 2000; Tribe and Cillió 2000). Regarded as a success story in biological control, *T. tenticollis* can still be found in the MCZ, but populations appear to be under strong top-down control. Interestingly, this species has never moved into the summer rainfall zone of South Africa, despite the widespread occurrence of suitable hosts. Rapid colonization throughout the range of *Eucalyptus* in the MCZ would appear to preclude dispersal as a limiting factor in the beetle's distribution, and natural enemies were apparently absent during initial spread. This leads to the hypothesis that the species is limited by climate, though no detailed studies on climate niche or range limitation have been performed to date.

14.3.2.5 Eucalyptus Snout Beetle: *Gonipterus* “*scutellatus*”

The first major insect pest to arrive and establish in South African forestry plantations was the Eucalyptus snout beetle, originally identified and long referred to as *Gonipterus scutellatus*. Recent morphological work (using internal sclerites of the male aedeagus) as well as a region of the cytochrome oxidase (COI) mitochondrial gene has demonstrated that *Gonipterus scutellatus* in fact comprises a complex of at least eight cryptic species (as well as two additional species outside the complex; Mapondera et al. 2012). The species introduced into South Africa, as well as into Italy and France, currently carries the provisional name “*Gonipterus* n. sp. 2” and is currently being described (R. Oberpreiler, *pers. comm.*). Spain and Portugal, parts of South America (Argentina, Chile, Brazil and Uruguay) and North America (California, Hawaii), as well as Western Australia (outside the native range of the beetles) support large populations of *G. platensis*. A third related species, *G. pulverulentus* (once referred to as *G. gibberus*) has been introduced into southeastern South America and is now found in Argentina, Uruguay and Brazil (Rosado-Neto and Marques 1996; Mapondera et al. 2012).

In 1916, “green, slug-like larvae” of what is now known as *Gonipterus* n. sp. 2 were first discovered feeding on *Eucalyptus* just outside of Cape Town. The weevils multiplied rapidly and quickly became a serious pest of *E. viminalis*, *E. globulus*, *E. maideni* and other highly preferred species in the region (Tooke 1953). At the time, these *E. globulus* and *E. viminalis* together comprised 70 % of the *Eucalyptus* plantations in the Cape and were an important source of poles for the mining industry. This led to the search for natural enemies suitable for biological control, and in 1926

the egg parasitoid myrmarid wasp (*Anaphes nitens*) was released. Nearly 50,000 wasps were liberated at 24 sites, including at least 3200 individuals in the Western Cape, all reared from individuals collected from a single source population in Penola, South Australia (Tooke 1953).

By 1930, the establishment success of *A. nitens* was considerable, with parasitism rates reaching upwards of 90–95 % or even higher across the country. Still, *Gonipterus* beetles had profound and lasting effects on forestry both in and out of the MCZ. After what was referred to as a “countrywide defoliation” of *Eucalyptus* (Tribe 2005), several of the most susceptible (and profitable) species, particularly *E. viminalis* and *E. globulus* (the latter also as a result of high susceptibility to *Mycosphaerella* leaf disease – see Pathogens section, this chapter), could no longer be planted in high numbers. In recent years, defoliation rates have increased in several regions of South Africa, which at least in the Highveld, may be due to differences between *Gonipterus* and *Anaphes* in overwintering survival and facultative diapause phenology (Tribe 2005).

14.3.3 *Insects Introduced as Biocontrol Agents Against Exotic Woody Escapes*

The juxtaposition of forestry and exotic invasion linked to many of the same species of woody plants creates considerable conflict and highly divergent perspectives regarding land management and conservation. These issues are particularly acute in the MCZ of South Africa owing to both the diversity and density of woody invaders and the ideal of conservation of the unique and biodiverse ecosystems present there (McConnachie et al. 2015). Considerable effort has been devoted to managing the spread of *Pinus*, *Eucalyptus* and wattle, in some cases using introduced insects (and pathogens) as agents of biocontrol agents. Insects that feed on flowers and seeds are ideal for this purpose, as long as their effects are limited to plant reproduction. To date, only biocontrol agents for control of invasive wattle have been successfully introduced. Nine insects in total have been introduced, as well as a rust fungus (*Uromycladium tepperianum*, see Table 14.2) (Impson et al. 2011). South Africa is the only country to date to have introduced biological controls against Australian wattles, despite the fact that many species are invasive in numerous countries (Impson et al. 2011; Richardson et al. 2011).

All nine insects released for the biological control of invasive acacias between 1982 and 2008 have established. All five species of weevil are in the genus *Melanterius* (*M. acaciae*, *M. ventralis*, *M. servulus*, *M. compactus* and *M. maculatus*) and attack developing seedpods, with larvae feeding on seeds. In several cases these weevils have been estimated to cause either “considerable” or “extensive” damage to hosts, where little or no seed production is observed (Impson et al. 2011). Two species of gall wasp in the genus *Trichilogaster* (*T. acaciaefoliae* and *T. signiventris*) have been similarly successful, eliminating seed production and inducing

galls that act as carbon sinks with the potential to reduce tree growth rate. Finally, two species of cecidomyiid fly in the genus *Dasineura* (*D. dielsi* and *D. rubiformis*) attack single florets forming galls that both preclude pod development due to deformation of the floral ovary and prevent flower abscission (Adair 2004). These midges are multivoltine with up to five generations per year and exhibit an incredible capacity for population growth and spread (Adair 2004, 2005). In all cases, indications of successful control are present at least locally and on some species of wattle. However, given that trees and associated seed banks are long-lived and abundant, the battle against Australian wattle is likely to endure for decades to come.

There has been considerable debate concerning the possible introduction of the cone-infesting *Pissodes validorostri* to control seed production in pine, particularly as a method to curtail invasive spread of the weedy maritime pine (*P. pinaster*). Extensive collections of cones across various species in Europe (including most but not all of the species grown in South Africa) revealed reasonable specificity and clear preference for *P. pinaster* and other Mediterranean pines (Roques et al. 2004). There is, however, evidence that host range expansion and preference changes can occur in this species (Roques et al. 2006), and maturation feeding by adults is more general with respect to pine species (though preference is correlated with larval host; Roques et al. 2004). The specter of a potential association of *P. validorostri* with the Pitch Canker fungus (*Fusarium circinatum*) has led to opposition to the introduction of this insect by the commercial forestry companies (Gebeyehu and Wingfield 2003). Studies under quarantine conditions showed that *P. validorostri* could transmit *F. circinatum* to healthy *Pinus* spp. (Lennox et al. 2009) and the insect has consequently not been released.

14.3.4 Forest Pathogens in the MCZ

In comparison to the rest of South Africa, studies on the diseases of commercial plantation forestry species in the MCZ are limited. This is a reflection of the relative size of the industry in the region (<5 % of landholdings; DAFF 2014) and uncertainty with respect to the future of commercial forestry there (Anonymous 2012). As for insects, the most devastating pathogens of commercial forest trees are introduced. Introduced pathogens represent at least 21 of the 32 (64 %) disease agents or groups of agents listed in Table 14.2. The origin of seven of the remaining microbial pathogens is unknown. Of the four species thought to be native, two (*Armillaria fuscipes* and *Pseudophaeolus baudonii*) are pathogens of *Eucalyptus*, one (*Camptomerris albizziae*) causes a leaf spot of minor to no importance on *Acacia mearnsii*, and one (*Ceratocystis albifundis*) causes a serious canker disease of *A. mearnsii* (Lückhoff 1955; Gibson 1975; Roux et al. 2012).

The pathogens listed in Table 14.2 include only those considered to have had some economic impact on plantation trees in South Africa – few cause widespread damage in the MCZ. Some (i.e., members of the Botryosphaeriaceae) occur commonly as endophytes and represent latent pathogens, causing disease

opportunistically where other stressors are present (Slippers and Wingfield 2007). Still others are obligate associates of insects and usually only weakly or moderately pathogenic (i.e., Ophiostomatoid fungi). Some, however, represent serious threats to plantation forestry in the MCZ. Two important pathogens of pine – *Diplodia sapinea* and *Fusarium circinatum* – dramatically affect plantations of these trees in the region. Additionally, the wattle wilt pathogen, *Ceratocystis albifundus*, occurs on *A. mearnsii* and *A. decurrens*, as well as on commercially cultivated species of the Proteaceae in the region. These three species together with the generalist root pathogen *Phytophthora cinnamomi* are discussed in greater detail below (Fig. 14.4).

The majority of pathology research of plantation species in the MCZ dates back more than 20 years (Laughton 1937; Lückhof 1964; Wingfield and Knox-Davies 1980a, b; Crous et al. 1989, 1991; Zwolinski et al. 1990; Swart and Wingfield 1991). The oldest known diseases from the region are *Diplodia* die-back and canker (Laughton 1937; Lückhoff 1964), *Mycosphaerella* leaf blotch (Crous and Wingfield 1996) and *Rhizina undulata* (Lundquist 1986). In addition there were studies on patches of tree mortality in *P. radiata* and *P. pinaster* plantation areas where bark beetles and associated Ophiostomatoid fungi were implicated (Wingfield et al. 1988). In more recent years, the focus of plantation disease studies in the region has been on the pitch canker fungus, *F. circinatum*, with the first outbreak of pitch canker on established trees in South Africa occurring on *P. radiata* near Cape Town (Coutinho et al. 2007, see below).

Of the most important pathogens of plantation-grown *Acacia mearnsii*, *Eucalyptus* and *Pinus* species in South Africa (Roux et al. 2012), few have been reported as economically damaging in the MCZ (Table 14.2). At least twelve pathogens have been reported from plantation trees in the region, including species of Botryosphaeriaceae on *Eucalyptus* and *Pinus* species, *Harknessia*, *Lophodermium*, several Ophiostomatoid fungi and many others (Table 14.2). However, of these only *D. sapinea* and *F. circinatum* cause economically significant damage in the region. This can partly be explained by the commercial tree species planted in the region and partly by environmental conditions. The important eucalypt canker pathogens in the genera *Chrysosporthe* and *Lasiidoplodia*, for example, are known to be most problematic in tropical and sub-tropical regions (Wingfield 2003; Slippers and Wingfield 2007).

Information regarding the origin of pathogens of plantation species in the MCZ and the rest of South Africa is limited. The wilt pathogen, *C. albifundus*, is hypothesized to be native to Africa, while *D. sapinea*, *F. circinatum* and *P. cinnamomi* are introduced pathogens (see below). In the past few years a number of fungal species related to important plantation forestry pathogens have been recorded from native trees in the MCZ. This is of concern due to the increasing number of examples of the broadening of host range by microbial plant pathogens also in South Africa. In the MCZ, a recent study investigating the potential for pathogen sharing between a native, endemic tree in the Myrtaceae, *Metrosideros angustifolia* and non-native *Eucalyptus* species identified three new species in a previously unknown genus in the Cryphonectriaceae on *M. angustifolia* (Chen et al. 2013). The study shows that at least one of these species, *Holocryphia capensis*, is likely to have been introduced

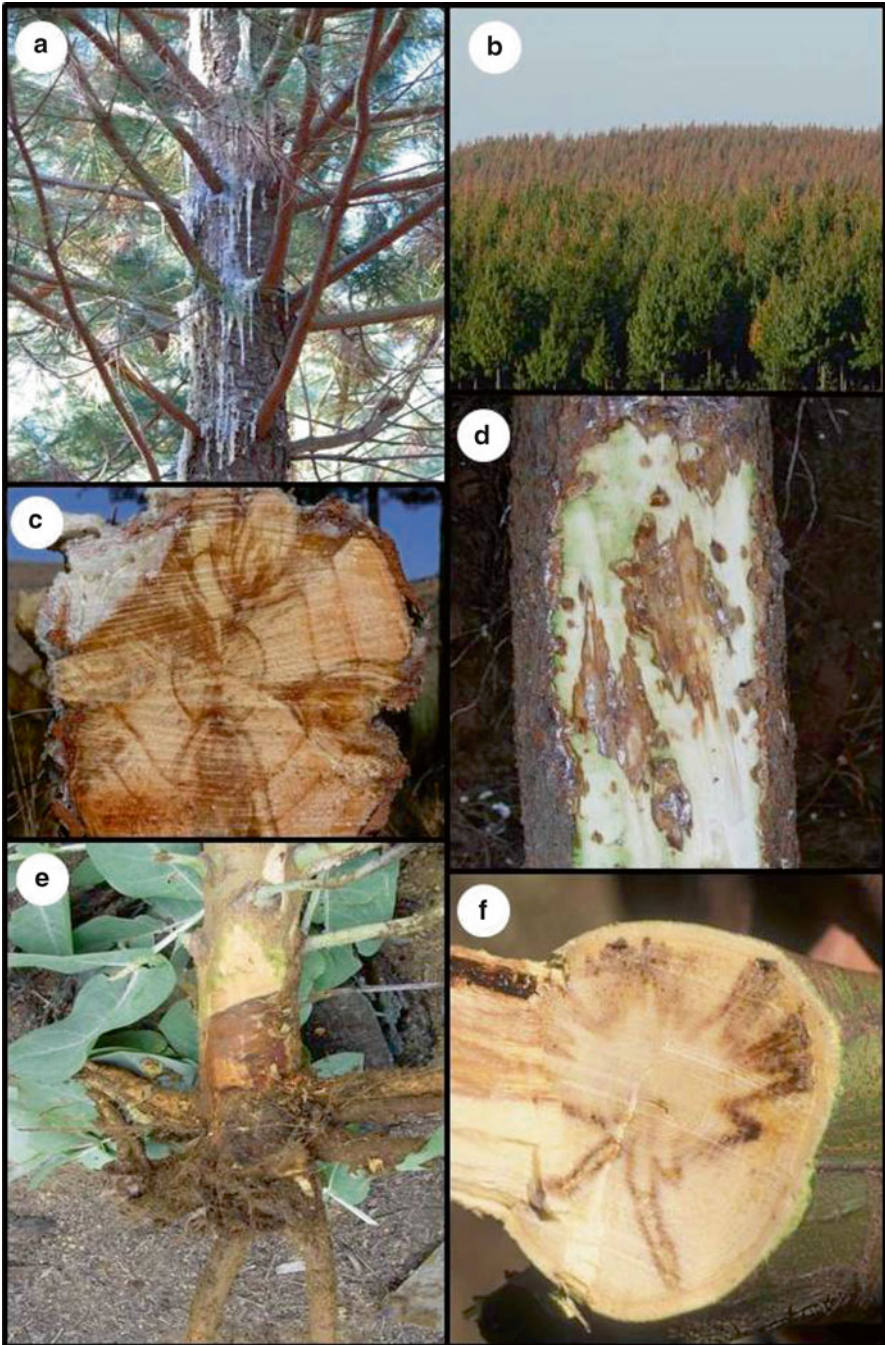


Fig. 14.4 Pathogens and disease symptoms/damage relevant to exotic forestry in the Mediterranean climate zone (MCZ), South Africa. Subfigures are as follows: resin exudation from a *Pinus* sp. infected by the pine pitch canker pathogen, *Fusarium circinatum* (a); hail and *Diplodia sapinea* associated death of *P. patula* (b); pitch/resin soaked wood of a tree infected by *F. circinatum* (c); *Diplodia sapinea* infection of *Pinus* sp. stem associated with hail wounds (d); root and collar rot of a *Eucalyptus nitens* tree caused by *Phytophthora cinnamomi* (e); wood staining (streaking) of an *A. mearnsii* tree infected by the wilt pathogen, *Ceratocystis albifundus* (f)

into the region (Chen et al. 2015 submitted). Similarly, a newly described species in the Cryphonectriaceae, *Knoxdavesia immersiporthe*, has been identified as the cause of a canker disease of native *Rapanea melanophloeos* in the MCZ (Chen et al. 2012).

14.3.5 Case Studies: Pathogens of Relevance to Plantation Forests of the MCZ

14.3.5.1 Wattle Wilt: *Ceratocystis albifundus*

Ceratocystis albifundus has been reported in the MCZ from invasive stands of Australian *Acacia* species, as well as from native Proteaceae where these shrubs are in intensive production systems for the cut-flower industry (Crous et al. 2013). It is, however, considered the most important constraint to the production of *A. mearnsii* in the KwaZulu-Natal Province where it was first described as a pathogen of these trees (Roux and Wingfield 1997).

The wattle wilt pathogen, *Ceratocystis albifundus*, was first described in the 1990s after it was reported as the cause of a wilt and canker disease of jungle and plantation *A. mearnsii* trees in the KwaZulu-Natal Midlands of South Africa (Wingfield et al. 1996). Typical symptoms include a rapid wilt and death of affected trees and staining of the vascular tissue. In some cases, gum-filled blisters can be found in the bark of trees, accompanied by yellowing and cracking of the bark around these blisters (Morris et al. 1993; Roux et al. 1997). Tree death can result within 6 weeks of infection (Roux et al. 1999).

Ceratocystis albifundus has been reported in several countries of Africa, occurring on both native trees (Roux et al. 2007) and exotic Australian wattles (Roux and Wingfield 2013). Natural occurrence of this pathogen on native African hosts in more than eight families (often in the absence of disease), together with high population genetic diversity and structure (Roux et al. 2001a; Barnes et al. 2005), suggests that *C. albifundus* is native to Africa. It has also been reported in association with several insect species in both native and non-native stands of trees (Heath et al. 2009). For example, nitidulid beetles are attracted to sap flow and sometimes breed within mechanical wounds and/or cankers where the adults and larvae encounter a number of pathogens, including *C. albifundus* (Heath et al. 2009). Nitidulid beetles have been shown to carry this fungus on their bodies, though whether or not they are primary vectors between trees is unclear (Heath et al. 2009).

The extensive geographic range of *C. albifundus*, its wide host range (Roux et al. 2007) and its association with generalist insects (Heath et al. 2009) makes *C. albifundus* a potential risk for other continents. It has been recorded from Mediterranean, temperate and subtropical climate zones (Roux et al. 2001b, 2005, 2007; Roux and Wingfield 2009) and has a known host range including more than 10 plant families (Roux et al. 2007). Australia, however, is considered especially vulnerable because of the many Proteaceae and *Acacia* species native to that country.

14.3.5.2 Diplodia or Sphaeropsis Dieback: *Diplodia sapinea*

Diplodia sapinea is one of the best-known pathogens of plantation forestry trees in South Africa (Lundquist 1987), having first been reported from *Pinus* species in the country in the first two decades of the previous century (Laughton 1937; Swart and Wingfield 1991). It is also particularly well known in the MCZ because of the susceptibility of *P. radiata* to infection and the long history of the pathogen in the region (Swart and Wingfield 1991). Infection by this pathogen can result in branch and shoot death, stem cankers and blue stain of the sapwood. Disease symptoms commonly occur in association with hail and pruning wounds (Zwolinski et al. 1990), insect attack (including by the deodar weevil, *P. nemorensis*; Swart and Wingfield 1991; Zwolinski et al. 1995). At least 30 species of *Pinus* at all ages are affected (Swart et al. 1985; Rees and Webber 1988). The high level of susceptibility of *P. radiata* is the primary reason why this species is not planted in summer rainfall areas where hail damage is common (Laughton 1937; Zwolinski et al. 1990; Swart and Wingfield 1991).

Diplodia sapinea was introduced into South Africa (Burgess et al. 2004), most likely with the importation of seeds and planting stock (Wingfield et al. 2001; Burgess and Wingfield 2002; Bihon et al. 2010). It can be isolated from healthy seed (albeit at very low levels) and can be an endophyte in the absence of symptoms on small plants that have been grown in the presence of inoculum, which facilitates cryptic introduction (Bihon et al. 2012). Given the clear association with tree stress and its wide distribution, *D. sapinea* has the potential to increase in importance where drought stress is predicted as a consequence of climate change (Van Staden et al. 2003).

14.3.5.3 Pine Pitch Canker: *Fusarium circinatum*

The pine pitch canker pathogen, *Fusarium circinatum*, was first detected in a single nursery in the Mpumalanga Province of South Africa in the late 1980s (Viljoen et al. 1994). Since then this pathogen has spread to all pine growing nurseries in the country (Steenkamp et al. 2014). It is also a major constraint to plantation establishment, particularly of *P. patula*, killing young seedlings within the first few months after field planting (Morris 2010; Mitchell et al. 2012). More recently *F. circinatum* has become increasingly important as a pathogen of established *Pinus* species in various regions of the country, causing typical pitch canker disease. It is considered the single most important constraint to plantation forestry using *Pinus* species, particularly *P. patula* and *P. radiata*, in the country (Mitchell et al. 2011).

In its nursery manifestation, *F. circinatum* mostly affects the roots of young seedlings, causing root rot and death of plants. In some cases mortality levels of more than 50 % have been reported from nurseries (Morris 2010; Mitchell et al. 2012). A major problem with *F. circinatum* is that it often occurs asymptotically in nursery plants, but when transplanted into the field and subjected to stress, it results in plant

death. A reduction in *P. patula* survival after planting from ~88 % to 64 % has been reported by some companies (Crous 2005; Morris 2010; Mitchell et al. 2012).

During the mid-2000s typical symptoms of pitch canker disease of established *P. radiata* trees were observed in a plantation in the MCZ, near Cape Town, South Africa (Coutinho et al. 2007). The cause of the disease was identified as *F. circinatum* – this represented the first report of pitch canker disease in the country. Since then, pitch canker disease has been recorded from *P. radiata* and *P. greggii* in the Eastern and Southern Cape Provinces of the country. Field symptoms include the death of single branches (flagging), tree tops and entire trees. Affected plants exude copious amounts of resin, and their xylem is soaked with pitch.

Fusarium circinatum is believed to be native to Central America and the southern USA (Gordon 2012), from where it spread to other regions in the USA and several countries worldwide (Wikler and Gordon 2000; Wingfield et al. 2008; Steenkamp et al. 2014). It has been shown to occur in pine seed, and also in association with cone and twig beetles in the United States (Gordon 2012), as well as with *P. nemorensis* (Coutinho et al. 2007). In South Africa, populations of this pathogen have established from multiple introductions (Steenkamp et al. 2014) and the pathogen has spread widely through the movement of infected plant material. Studies of populations of *F. circinatum* on *P. radiata* trees in the MCZ of South Africa suggest that there are no barriers to the movement of the pathogen in the region (Steenkamp et al. 2014). Most recently, *F. circinatum* was found to occur on grass species in the USA and South Africa, providing possible alternative reservoirs of inoculum that could influence disease outbreaks (Swett et al. 2014).

To date, field outbreaks of the disease are most common in coastal and montane areas of the country, characterized by higher frequencies of mist and thus higher humidity. This is similar to the situation reported from the USA (Wingfield et al. 2008). In contrast to the situation elsewhere, only a single mating type (*mat-1*) of *F. circinatum* has been found in the MCZ in South Africa (Steenkamp et al. 2014). Efforts to restrict the movement of the pathogen should therefore continue in order to reduce the chances of sexual recombination and the generation of novel and perhaps more virulent genotypes.

14.3.5.4 *Phytophthora* Root Rot: *Phytophthora cinnamomi*

The oomycete root rot pathogen, *Phytophthora cinnamomi*, has been present in South Africa for many years (Olivier 1951; Van der Merwe and Van Wyk 1973). It has been reported to affect numerous tree hosts, including species of plantation *Eucalyptus* and *Corymbia* trees (Linde et al. 1994, 1999). Some isolates have also been obtained from *Pinus radiata*, *P. pinaster* and *P. patula* in the country, but not associated with serious disease outbreaks on these hosts (Linde et al. 1999). The species has been found to occur in near-pristine, high-altitude mountain streams and on plants in more than five families in native communities in the MCZ (Olivier 1951; Van der Merwe and Van Wyk 1973; Von Broembsen and Kruger 1985). Native plants in the MCZ affected by *P. cinnamomi* include species of Cupressaceae

(*Widdringtonia cedarbergensis*), Ericaceae, Fabaceae, Proteaceae (*Leucadendron* species) and Rosaceae (Olivier 1951; Van der Merwe and Van Wyk 1973; Von Broembsen and Kruger 1985; Linde et al. 1999). It is also a pathogen of ornamental, non-native tree species such as *Quercus cerris* (Oh et al. 2011) and has been reported from Pine nurseries and mature *P. radiata* in the MCZ (Wingfield and Knox-Davies 1980).

Phytophthora cinnamomi is most likely native to Southeast Asia (Zentmeyer 1988) and was introduced to South Africa via trade in living plants (Linde et al. 1999). Population genetic studies ranging from isozyme studies to RFLP and microsatellite studies all suggest Papua New Guinea or surrounding areas as the centre of origin for this pathogen (Hardham 2005). Studies by Dobrowolski et al. (2003) showed high population diversities for isolates from Papua New Guinea and the existence of only three clonal lineages throughout the rest of the world. Populations in South Africa are very similar to those in Australia, where both mating types (A1, A2) of the pathogen have been described (Linde et al. 1997, 1999). The A1 mating type is, however, dominant in the MCZ, while the A2 mating type is broadly distributed (Linde et al. 1997).

Phytophthora cinnamomi causes root rot and basal cankers on affected trees, resulting in stunting and tree death. It is of significant concern to the *Eucalyptus* industry in South Africa, particularly for companies planting cold-tolerant species such as *E. smithii*, *E. nitens*, *E. macarthurii* and *E. fraxinoides* (Linde et al. 1999; Nagel et al. 2013). Temperate and sub-tropical species of eucalypts such as *E. grandis* and others seem to have a higher resistance to infection by *P. cinnamomi*; reports of disease on these trees in the MCZ of South Africa is limited. The majority of problems associated with *P. cinnamomi* in the MCZ occur on native Proteaceae and other fynbos vegetation, as well as on non-native ornamental tree species (Oh et al. 2011) and in some cases grapevine (Van der Merwe and Van Wyk 1973; Linde et al. 1999; Nagel et al. 2013). On plantation species in the MCZ, *P. cinnamomi* has been reported only from *P. radiata*, killing mature trees (age 40–50 years) as well as seedlings from forest nurseries in the region (Wingfield and Knox-Davies 1980a). Although the MCZ in South Africa has not yet experienced the same devastation as seen with native vegetation in Australia, the possibility of increased virulence and damage to native and other vegetation in the region should not be ignored. This is especially important in light of the occurrence of both mating types (A1 and A2) of the pathogen in the MCZ, providing opportunity for sexual recombination and thus the generation of new genotypes.

14.4 Conclusions

Ecologists and evolutionary biologists have long been fascinated by the apparent convergence of plant traits together with ecosystem structure and function across Mediterranean climate zones worldwide. A new age of convergence is now upon us, driven by the introduction and cultivation of non-native trees which are largely

shared (at least at the generic level) across these zones and constitute similar ecologies. Not surprisingly, one result of this homogenization with respect to woody ecosystems (together with facile movement as a consequence of global trade) is that insects and pathogens are broadly shared across continents and geographically distinct but climatically similar biomes (see discussion of drivers in Garnas et al. 2012).

Despite the apparent similarities between MCZ's around the world, important differences in the composition and behaviour of biotic communities do exist. A considerable proportion of sporadic pests and diseases in the region are native species, typically broad generalist that can feed or infect across orders of plants. Some of these are endemic to the MCZ. The distinct climate of the region has generally not been a determining factor for the establishment and spread of exotic pests and diseases, with some exceptions (i.e., *Trachymela tinticollis*, and the possible influence of climate on nematode biocontrol success of *S. noctilio*). The preponderance of threats and by far the most consistently damaging are exotic plantation pests and pathogens, many of which are common around the world. *Gonipterus* weevils, *Mycosphaerella* spp., and *D. sapinea* have had major effects that have altered the face of plantation forestry in the MCZ. Pests and pathogens such as *S. noctilio* and *F. circinatum* continue to seriously threaten what remains of pine plantation forestry in the region.

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