Proceedings of the X International Symposium on Biological Control of Weeds
4-14 July 1999, Montana State University, Bozeman, Montana, USA
Neal R. Spencer [ed.]. pp. 941-953 (2000)

Biological Control of Alien, Invasive Pine Trees (*Pinus* species) in South Africa

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Abstract

We briefly describe an ambitious, far-reaching initiative, the Working for Water Programme (costing US$70 million per annum and employing 42 000 people), which has strong conservation objectives and the main aim of increasing water supply in South Africa. The plan is to increase water run-off and stream flow by the removal of alien, invasive trees (mainly acacias and *Pinus* species) from catchments and river courses. In this context we discuss the ecological, economic and political dimensions of the biological control of invasive pine trees in South Africa. The emphasis is on the use of seed- and cone-feeding insect and mite agents: (i) because seed reduction has the potential of decreasing the invasiveness of alien plants; (ii) because of the problem of regrowth of the trees, mainly from seeds, in areas previously cleared; and (iii) because the exclusive use of seed- and cone-destroying agents may lessen conflicts of interest between the main role players, namely, conservationists and the Working for Water Programme, on the one hand, and the Forestry Industry, on the other.

Introduction

With the exception of one *Pinus* species, that extends its native range south of the Equator, into Sumutra, all 111 species in the genus originate in the Northern Hemisphere (Price *et al.* 1998). Pines have been cultivated since ancient times, but have only been widely planted in the Southern Hemisphere over the last 200 – 300 years. It is from these plantings that 16 *Pinus* species have become invasive weeds in South America, Australia and New Zealand and in southern Africa (Richardson and Higgins 1998).

In South Africa, plantation forestry contributes about US$300 million, annually, to the economy (about 2% of the GDP) and employs about 100 000 people. Associated industries, based on forestry, produce timber products worth about US$1.6 billion annually (van Wilgen and van Wyk 1999). The most important *Pinus* species in South African forestry are *P. elliottii, P. patula* and *P. taeda*. Lesser amounts of timber are derived from *P. pinaster, P. radiata* and *P. roxburghii*. Inevitably, pine plantations have been the most important source of seeds that have allowed certain of these species to become invasive and problematical (Nel *et. al.* 1998). In South Africa, *P. pinaster, P. radiata* and *P. patula* are the main problem species, together with *P. halepensis* which, although not a forestry species, has been widely planted as an amenity or ornamental tree. Of lesser importance as invasive plants in South Africa are *P. canariensis, P. elliottii and P. pinea* (Henderson 1995). These pine species have invaded conservation areas, displaced native plant species, reduced water run-off in catchment areas and greatly diminished water-flow in rivers (Richardson *et al*. 1992; Le Maitre *et al*. 1996; Richardson *et al.* 1997; Richardson and Higgins 1998; van Wilgen and van Wyk 1999).

Kruger (1977) was probably the first to suggest, in print, that biological control may be useful in the management of invasive pines: "The only feasible means of permanently controlling this source of immigration [invasive *Pinus* species in South Africa] would be through the use of biological control agents for elimination or drastic reduction of seed supplies. This could be achieved without affecting timber resources through careful screening of the control organisms, while seed could be produced [for use in plantation nurseries] from orchards which are sprayed against the specific organism(s)." The suggestion was not followed up at the time. Later, Kay (1994) championed the use of biological control against *P. contorta* in New Zealand: the idea was strongly opposed by foresters and came to nothing, but has recently been revived (Brookerhoff and Kay, in press). In South Africa in 1997, at the behest of the Working for Water Programme, the Plant Protection Research Institute embarked on biological control of pines.

In sharp contrast to most biological control programmes against other alien invasive plants in South Africa and elsewhere, there is an extensive literature and knowledge base on the biology of the genus *Pinus* (Richardson and Rundel 1998) and on the associated diseases and insect fauna of pines (Harrington and Wingfield 1998; de Groot and Turgeon 1998).

The purposes of this paper are:

(i) to consider pines in a wider context of alien invasive tree species in South Africa and to consider the impacts of invasive trees on conservation areas and on water supplies in South Africa;

(ii) to summarise the objectives of the South African 'Working for Water Programme' as a response to these problems;

(iii) to summarise the natural history and ecology of the invasive *Pinus* species that are prospective targets for biological control in South Africa and which assist in an understanding of the establishment, spread and invasiveness of these species;

(iv) to consider the prospects for biological control of invasive pine trees in South Africa through the agency of seed- and cone-feeding insects; and

(v) on the basis of these considerations, to draw some conclusions and to indicate the way forward.

(i) Impacts of invasive tree species in South Africa

Sixty-seven tree species from across the world (Table 1) are listed as alien, invasive weeds in South Africa (Henderson 1995). Of these, 32 are formally and legally recognised or proposed for legal recognition as weeds (their removal is required by law) or as invaders (their spread has to be controlled). Twenty species of trees that are legally recognised as weeds (and one other) have been the subject of, or proposed as targets for biological control (Table 1).

Much of the biological control effort against alien tree species, during the past decade

Table 1.
The number of tree species from the Americas, Europe and Asia and Australia (including one species from New Zealand) that are listed as invasive weeds in South Africa. The number of these species that are legally recognised or proposed for legal recognition (see text) as weeds or as invaders is given. The numbers in parentheses are the numbers of species that have been subjected to, or are proposed subjects for biological control. Data from Henderson (1995).

	AMERICAS	EUROPE/ASIA	AUSTRALIA
Legally recognized or proposed for recognition	10 (5)	8 (3)	14 (12)
Others	7 (1)	17 (0)	11 (0)

in South Africa, has been directed at the acacias and *Hakea,* from Australia, and at *Sesbania*, from South America (see Hoffmann 1991). Jointly, these invasive tree species together with other invasive plants, have had and are having, huge negative impacts on the South African economy and environment. Besides their impact through altered fire regimes and erosion, the main threats are: (a) to the biodiversity of the native flora and fauna; and (b) to South Africa's scarce water supplies.

(a) Loss of biodiversity

Increased extinction rates and loss of biodiversity from alien plant invasions particularly from tree species (the acacias, pines and eucalypts) are most pronounced and have been best explored in, and reported in detail for the species-rich Cape Floral Kingdom. Here there are about 8 600 species of flowering plants and ferns and very high levels of endemicity (70%) (see Richardson *et al*. 1989; Richardson *et al*. 1992; Richardson *et al.* 1996; Richardson *et al.* 1997; Richardson and Higgins 1998; van Wilgen and van Wyk 1999).

(b) Impacts on water supplies

The impacts of alien plants on South Africa's water supplies have been summarised by van Wilgen and van Wyk (1999), whose summary provides the background and rationale for the ambitious South African 'Working for Water Programme'.

Not all alien plant infestations use more water than the natural vegetation that they replace but, as a general rule, trees tend to use more water than grasses or shrubs (Bosch and Hewlett 1982; Dye 1988; Dye 1996; Smith and Scott 1992). The greatest impacts occur when seasonally dormant vegetation is replaced by evergreen plants (Dye *et al.* 1995). Thus, where grasslands or shrublands are invaded by alien trees, the overall water use by the vegetation increases, leaving less water for the streams.

Most of the evidence for this statement comes from catchment experiments in South Africa and elsewhere. These experiments have been established in high-rainfall areas where shrublands or grasslands were afforested with pines or eucalypts. These afforestation experiments can be likened to invasion by alien trees where the end result is the same - the replacement of a low shrubland or grassland with a tall woodland or forest.

Typical examples of the results obtained include an 82% reduction in streamflow (reductions of 115 and 640 mm per year in two small grassland catchments) in the KwaZulu-Natal Drakensberg 20 years after planting with pines (Bosch 1979); a 55% reduction in streamflow (from 600 to 270 mm) in fynbos catchments in the Western Cape 23 years after planting with pines (van Wyk 1987); and the total drying up of streams 6 –12 years after completely replacing grassland catchments with pines and eucalypts in the Mpumalanga Province (van Lill *et al.* 1980).

These results are from small catchments that were heavily afforested, and the impact of alien invading trees on streamflow in larger areas will depend on how much the catchment is actually invaded. Thus, in many cases, the impacts will not be as dramatic. There are nonetheless two important facts to consider here. Firstly, most of the streamflow in South Africa is generated from upper catchments (van der Zel 1981) and these are the areas that are most at risk from invasion. Secondly, it is probable that these areas will become fully invaded if they are not managed – there are many examples of where this has occurred already.

Riparian zones are of special concern. Because more water is available in riparian zones, and because fast-growing alien trees use water whenever it is available, water use by trees in these zones tends to be almost double that of the same trees when they grow away from the rivers (Scott and Lesch 1995, 1996; Scott in press). Riparian zones are not planted by formal forestry for this reason, but often become invaded, by plantation trees, and have to be constantly cleared to prevent these impacts.

While planting trees in catchments reduces streamflow, the reverse is also true – clearing the trees results in equivalent increases. For example, clearing a dense stand of pines and wattles from river banks in Mpumalanga Province resulted in a 120% increase in streamflow (the clearing of a 500 m length of a river increased yield by 30.5 m^3 per day) within a short period after clearing (Dye and Poulter 1995); and clearing pines 30 m on either side of a stream (10% of the catchment) in the Western Cape resulted in a 44% increase in streamflow (over 11 000 m^3 per cleared hectare in the first year) (Scott in press). There are many other observations of this kind where clearing has resulted in streams flowing again, often for the first time in decades. Indigenous riparian vegetation which may eventually replace the invading aliens tends to have smaller leaf areas and has been shown, in at least one experiment (Scott and Lesch 1996) to use less water than vigorous alien trees.

The average changes to streamflow quoted above can be misleading. The effect of alien trees on the amount of water in rivers is more critical in the dry season and in drought years. Because the consequences are more severe at these times, the impact of alien plants on low flows tends to be more important than the average reduction.

The way in which trees use water is reasonably well understood (Dye 1988, 1996; Dye *et al.* 1995). However, there are differences between species. While water use by pines and eucalypts (and to some extent poplars and wattles) has been well measured in South Africa, no data on any other species are available. In addition, the figures for water use by individual trees need to be used carefully. The figure of a eucalypt tree using several hundred litres of water in a single day is often quoted in the popular literature, but this was for an isolated large tree in a riparian zone on a hot day. A more realistic figure would probably be closer to 40 – 50 litres per tree per day on average sites (P. Dye, pers. comm).

Most studies of the impacts of alien plants on water resources have been carried out in high-rainfall catchment areas. Away from these areas, the impacts may depend more on the ability of plants to extract groundwater, which in turn depends on root depth. Some alien plants grow rapidly and establish deep sinker roots while still young. For example, *Pinus radiata* roots can reach a depth of 2.6 m within four years of germination (Dye 1996). Eucalypts also establish deep sinker roots while young, even when the upper soil profile is able to provide all the water the tree needs. *Eucalyptus grandis* (for example) relies heavily on water abstraction from the lower soil profile in order to withstand dry seasons (Dye 1996). *Acacia* and *Prosopis* species roots reach depths of up to 20 m or more.

The results of catchment experiments have been used, together with crude estimates of the extent of invasion, to make a preliminary estimate of the size and significance of the problem in South Africa (Versfeld *et al.* 1998). The current estimate is that invading aliens cover 10 million ha, and use 3.3 billion m^3 of water in excess of that used by native vegetation every year (almost 7% of the runoff of the country). The estimate is based on models which make a number of assumptions (Le Maitre *et al.* 1996), and can therefore be regarded as only preliminary. Nonetheless, the estimate indicates that the reductions are already significant – definitely large enough to warrant intervention. South Africa cannot afford such losses. The water losses will increase as alien plants invade the remaining, uninvaded areas. A lack of action is therefore one of the most serious threats to the sustainability of water yields from South African catchments.

(ii) The South African 'Working for Water Programme'

The 'Working for Water Programme' was launched in South Africa in 1995 aimed at clearing and controlling alien vegetation in conservation areas, water catchments and riparian habitats and providing employment for jobless people. The removal of alien vegetation from catchments and river courses is a highly cost-effective way of delivering additional water. Currently the 'Working for Water Programme' operates on an annual budget of about US$70 million and employs about 42 000 people (see van Wilgen *et al.* 1998, for details). Early on in the implementation of the programme for clearing alien trees from river courses, through mechanical and chemical means (felling and removal or burning of alien plants - most importantly, acacias, pines and eucalypts - and the prevention of copicing by the application of herbicides) it was realised that a major weakness was the re-growth of weed populations, mainly from seeds in the soil, in areas previously cleared. This led the 'Working for Water' authorities to place special emphasis on biological control as an essential element of any long-term integrated control strategy.

(iii) The natural history and ecology of the invasive *Pinus* species targeted for potential biological control

There are seven *Pinus* species that are declared invaders or proposed as declared invaders in South Africa: *P. canariensis, P. elliottii, P. halepensis, P. patula, P. pinaster, P. pinea* and *P. radiata*. An early decision was taken to exclude *P. patula* and *P. elliotti* from further consideration as targets for biological control: this decision was taken because of the paramount importance of these two species in the forestry industry. *Pinus canariensis* and *P. pinea* are far less important as invaders in South Africa than P. *radiata, P. pinaster* or *P. halepensis* and were thus also excluded from further consideration. The attributes of the latter three species, which are relevant to their introduction and invasiveness in South Africa, are summarised in Table 2.

Pinus radiata, P. pinaster and *P. halepensis* have much in common. They are all hard pines in the subgenus *Pinus* and Section *Pinus*. All three are Mediterranean climate, coastal species; all three have been spreading in South Africa for at least 150 years, now invade large areas and are mainly problematic in the 'fynbos' vegetation, in the species-rich, fire-adapted Cape Floral Kingdom (Richardson *et al.* 1990). In common with some other invasive pines; they are functionally alike (Table 2; Richardson *et al*. 1990) in that they are fast growing, with small seeds that have relatively large wings (i.e. low wing loadings which enhance wind-dispersal). Except for *P. halepensis* they have short juvenile periods and all have relatively short intervals (< 3 years) between large seed crops (see the legend to Table 1 for references). Although relatively poorly fire-tolerant as adult trees, all three species are well adapted to high intensity fires (see Table 2 for references and for notes on serotiny, bark-thickness and self-pruning).

The success of *Pinus* species as invaders in the Southern Hemisphere is due to their ability to colonise marginal, nutrient-poor habitats (see Read 1998, for a full account of the role of mycorrhizal fungi, in this regard). The massive reservoir of seeds from forestry plantings of the same species (Nel *et al*. 1998), the strong competitive abilities of the seedlings following fire, and the lack of many of the herbivorous insects and diseases that restrain these *Pinus* species in their native lands, help to explain the prominence of *P. radiata, P. pinaster* and *P. halepensis* as invasive plants in the nutrient-poor, fire-adapted fynbos biome of the south Western Cape Province of South Africa (Richardson, 1990; Richardson *et al*. 1992; Richardson and Higgins 1998). From the viewpoint of prospective biological control of these species, the huge numbers of exceptionally well dispersed seeds is the key consideration for long-term management of these invasive pines.

(iv) The prospects for biological control of invasive *Pinus* species using seed- and cone-feeding agents

In South Africa, there are a number of precedents in which reduction of the fecundity of a perennial tree species and the consequent reduction in its invasiveness has been brought about by suitable, host-specific insects. The best-documented cases include the biological control of the South American species *Sesbania punicea (*Hoffmann and Moran 1995) and the invasive Australian weed *Acacia longifolia* (Dennill and Donnelly 1991). Biological control using seed-feeding insects is particularly appropriate where the target weeds are invasive and problematic in some contexts but are exploited in different circumstances as beneficial plants. For example, the Australian species *Acacia mearnsii* is the basis of a lucrative industry in the Province of KwaZulu-Natal but is also a prolific weed in many parts of the country. A weevil species, *Melanterius maculatus*, has been introduced to reduce seeding and invasiveness of *A. mearnsii*, without affecting its value. Another example is mesquite, *Prosopis* species, from North America, which has many uses as an agroforestry plant but which also invades dry areas in South Africa. Two seed-feeding bruchid species, *Algarobius prosopis* and *Neltumius arizonensis,* have become widely established and abundant, destroying copious quantities of seeds without affecting the useful attributes of the mesquite plants.

The prospects for the biological control of alien invasive *Pinus* species, in South Africa, present similar conflicts and similar solutions seem appropriate. There is a well known and rich guild of cone- and seed-attacking insects on pines in their native habitats in Europe and North America (de Groot and Turgeon 1998) and one or more of these

Table 2.
Attributes of *Pinus radiata*, *P. pinaster* and *P. halepensis* relevant to their introduction and invasiveness in South Africa.
From (1) Agee, J.K. (1998); (2) Barbéro, M. *et al.* (1998); (3) Keely, J. E. and Zedler, P. H. (1998); (4) Lanner, R. M. (1998); (5) Lavery, P. B. and Mead, D. J. (1998); (6) Le Maitre, D. C. (1998); (7) Poynton, R. J. (1977); (8) Price, R. A. *et al.* (1998); (9) Richardson, D. M. and Higgins, S. I. (1998); (10) Richardson, D. M. *et al.* (1992). (*ranges, means and SEs are given for categories/ groups of pines including the three tabulated see (3).)

	P. RADIATA Monterey Pine	***P. PINASTER*** Cluster Pine, Maritime Pine	***P. HALEPENSIS*** Aleppo Pine, Jerusalem Pine
Taxonomy (8)	Subgenus *Pinus* (new World Diploxylon or hard pines) Section *Pinus* Subsection *Attenuatae*	Subgenus *Pinus* (Diploxylon or hard pines) Section *Pinus* Subsection *Pinus*	Subgenus *Pinus* (Diploxylon or hard pines) Section *Pinus* Subsection *Halepenses*
Native Range (7), (2), (5)	Seabord of Central California	Mediterranean Basin including Northern Tunisia, Algeria and Morocco	Coastal areas of Southern Europe, North Africa and Asia Minor
First Imported into South Africa (7), (9)	Second quarter of 19C	End of 17C, 1685-1693? By French Huguenot settlers?	1830?, certainly by mid 19C
Planted Extensively (7), (9), (6)	Plantations established in 1850s	Widely planted by about 1780. First commercial plantings 1825-1830	Widely planted as amenity trees and ornamentals by the 1850s
Main Areas of Forest Cultivation (6)	Western, Southern and Eastern Cape	Western, Southern and Eastern Cape	Not a forestry tree, but widely planted as an amenity/ornamental tree
Recorded as Invasive (7), (9), (10)	From about the late 1800s	Widely spreading in Cape Peninsula by 1772	Spreading in the Caledon District, and probably near Riviersonderend by 1855
Area Invaded and (Biome Invaded) (9), (10)	340 km^2 (Fynbos)	3 256 km^2 (97% in Fynbos)	? km^2 (Fynbos)
Reproductive Age (10)	5 years	6 years	15 years
Reproductive Interval - range 1-24 Years (3)*, (10)	2 ± 1 year	< 3 years	2 ± 1 year
Growth Rate - Scale 1-3 (3)*	2.0 ± 0.2	$2.3 + 0.2$	2.0 ± 0.2
Fresh Seed Mass (10), Range 13-221 mg (3)*	34 mg	45 mg	16 mg
Ratio Seed-wing Length: Seed Mass - Range 0.01-0.17 (3)*	0.17 ± 0.02	0.11 ± 0.01	0.17 ± 0.02
Main Dispersal Agent (10)	Wind	Wind	Wind
Serotiny (10), (4)	Canopy-stored seeds, strongly serotinous	Canopy-stored seeds, weakly serotinous	Canopy-stored seeds, strongly serotinous

	P. RADIATA	*P. PINASTER*	*P. HALEPENSIS*
Bark thickness (Range 1.7-6.2 cm) (3)*	2.9 ± 0.5 cm	3.2 ± 0.1 cm	2.9 ± 0.5 cm
Self-Pruning (Scale 1-10) (3)*	2.4 ± 0.4	6.5 ± 1.0	2.4 ± 0.4
Fire Resilience (3), (1), (10)	Well adapted to frequent, high-intensity fires, adults occasionally survive fires	Adapted to infrequent, high-intensity fires, adults occasionally survive fires	Well adapted to frequent, high-intensity fires, adults very seldom survive fires

insect species may be suitable for the biological control of problematic pines in South Africa. Even on problematic *Pinus* species that have no current commercial value in South Africa, insects that attack the vegetative parts of the plants cannot be considered as potential biological control agents because: (i) with the exception of certain cone- and seed-feeding insects, most insect herbivores associated with pines are oligophagous and feed generally on several species within the genus *Pinus*; and (ii) pine species that are not presently important may become so and it would be prudent not to introduce any insect agents that retard the growth and reduce the value of those plants.

The three *Pinus* species that have been under consideration in South Africa as prospective targets for biological control, *P. radiata, P. pinaster* and *P. halepensis,* present different problems and opportunities, as follows:

- *P. radiata* and pitch canker

In its native range, *P. radiata* has a limited distribution in three patches along the coast of California. Other populations that are regarded as the same species occur on two Californian off-shore islands, but they differ from the mainland forms in having 'leaf' bundles comprising two, not three, needles. (This taxonomic anomaly does not affect our conclusions in the context of biological control of *P. radiata* in South Africa). The reasons for the limited native distribution of *P. radiata* are unknown but it has been widely planted and thrives outside its native range in California, and elsewhere (Lavery and Mead 1998). It is a fire-adapted species in an area that historically had a fire interval that is estimated to have been 230 years.

In 1986, a fungal disease, *Fusarium moniliforme*, known as pitch canker, was first discovered on *P. radiata* at a site, Brighton Beach, in California. This disease which causes extensive die-back ("flagging") of the terminal shoots of *P. radiata* and other pine species, is now widespread in California and poses a real threat to survival of *P. radiata*. Besides the direct damage caused by the disease, the fungus predisposes the trees to attack by other diseases and by pine-feeding insects, so that the rate of mortality of the trees is increased. In South Africa, *F. moniliforme* has been recorded (in 1991 and 1997) on seedlings of *P. radiata, P. patula* and *P. elliottii* growing in nursery situations and on *P. taeda,* in the field. Whether the extremely complex fungus, causing pitch canker in South Africa is the same strain as that now destroying *P. radiata* in California, is not known (Viljoen *et al*. 1997; Harrington and Wingfield 1998).

Pitch canker on *P. radiata* in California is transmitted exclusively by insect vectors and several groups of insects have been implicated, including cone-weevils, bark beetles and cercopids, but it is suspected that all insects that damage the trees through their feeding activities, are potential vectors. Vertical transmission of the disease has been demonstrated for at least one of the cone-feeding beetle species, *Conophthorous radiatae* (Scolytidae).

Although the growth rate of the trees is slowed by the presence of pitch canker, the trees survive for many years (if not attacked by other diseases and by insects) and the quality of the timber is not materially affected. Surveys in California have shown that approximately 3% of the trees in natural populations of *P. radiata* are resistant to pitch canker. The virulence and mode of transmission of pitch canker on *P. radiata* have important implications for the biological control of *Pinus* species in South Africa.

There are many insect herbivore species associated with cones and seeds of *P. radiata* in North America, some of which (such as certain cercopid species and the cone-beetle *C. radiatae)* are damaging and host-specific. However, there is a high probability that the introduction of any of these species into South Africa would increase the threat to *P. radiata* plantations from pitch canker. As long as *P. radiata* continues to be exploited as a significant timber crop in South Africa this risk precludes biological control as an option.

Even if *P. radiata* should become expendable in the future, biological control would not seem to be a viable option. The increase in the reservoir of pitch canker on *P. radiata* combined with the introduction of additional insect vectors, albeit, specific to *P. radiata*, pose an unacceptable risk that the disease may thereby become more prevalent on other, commercially important pine species.

Under these circumstances, other management options would seem to be more appropriate. *Pinus radiata* may conceivably be successfully controlled by chemical and mechanical means (including fire) provided that seeds from trees that grow in plantations do not continually replenish the seed reservoir.

- *Pinus pinaster*

This is a widespread species along the coastal Mediterranean regions of Italy, France and Spain and in Portugal and the Bordeaux region in Western France. In the 1960s and 1970s, large quantities of *P. pinaster* seeds were brought into South Africa for forestry proposes – the majority of these imports came from the Leinia district of Portugal (see Poynton, 1997, for details) a fact which may ultimately be relevant in the context of possible biological control of this species.

Pinus pinaster is extensively exploited as a timber source in France and the herbivorous insects on this pine species are very well known. In stark contrast to the situation in North America, the devastating pine fungal-disease, pitch canker, does not occur in Europe. This fact is of fundamental importance in considering biological control of European pine-species in South Africa, including *P. pinaster*. If this disease does not occur on introduced pines of European origin in South Africa then the prognosis for biological control, using cone- and seed-destroying insect agents, is good.

Bearing in mind the requirement for cone- or seed-destroying insect species as biological control agents, there are three prospective agents on *P. pinaster*: the pyralid moth species *Dioryctria mendasella* and *D. mitatella*, which feed in the cones, but these two species also damage vegetative tissues and may therefore be unsuitable; and the weevil *Pissodes validirostris*. This weevil species is an interesting prospect for biological control of *P. pinaster* because it is prolific and destroys all the seeds in the cones that are attacked. (Adult weevils superficially scour the bark of the host plant without affecting the growth or value of the tree.) However, *P. validirostris* is known to feed on cones from several species in the genus *Pinus* in Europe, including one introduced species (*P. contorta*) and further host-specificity testing, in France, will be essential. It would obviously be critical, during these further tests, to include commercially important species of pines that are grown in South Africa. Host specificity is vital in the context of the risk of wider transmission of pitch canker on pine species in South Africa.

In 1997, an eriophyid mite, *Trisetacus* sp., was identified as the causal agent of extensive destruction of conelets in *P. pinaster* in France. The mite shelters under the bracts of developing conelets, feeding on and destroying the pedicel. This mite species seems to be specific to *P. pinaster* and it is an exciting prospect for use in South Africa.

- *Pinus halepensis*

The native distribution of *P. halepensis* is throughout the coastal regions of the Mediterranean. The species is attacked by several cone- and seed-feeding insects in Europe and the issues associated with biological control of this pine species parallel those for *P. pinaster*. In particular, if the cone-weevil *P. validirostris* proves suitable, following host-specificity tests, for release on P. *pinaster* in South Africa, it may also attack *P. halepensis*, which is one of its known hosts. Should *P. validirostris* not prove to be suitable other potential agents are available, notably the host-specific cecidomyid flies, *Caryphomyia pinicolana*, and *Camistomyi pinicolana.*

(v) Conclusions and the way forward

The purpose of this account has been to discuss the need and prospects for biological control of alien, invasive *Pinus* species in South Africa and to place these deliberations into an ecological, economic and political context. It has been stressed that the prospect of biological control against *Pinus* species in South Africa raises serious challenges. Particularly, the interests of a large, important and lucrative forestry industry must be considered before any insect biological control agents are introduced into South Africa. Consensus must be reached between forestry interests, on the one hand, and conservationists and alien plant managers, on the other, whereby the invasiveness of the alien *Pinus* species can be curbed without affecting the benefits of pine trees in commercial forests. Herbivorous insects that feed on the reproductive tissues of the pine trees, usually the seeds or cones, have the potential to fulfil these requirements.

Thus, we have reached the following conclusions:

- <u>Species of *Pinus* to be considered for biological control.</u> Of the four main invasive *Pinus* species in South Africa, *P. patula* should be excluded from further consideration because of the importance of this species to the forestry industry. *Pinus radiata* should not be considered at this stage because of the risks posed by pitch canker. The two European species, *P. pinaster* (which is becoming less commercially important) and *P. halepensis* (which is of no commercial value in South Africa), should remain as prospective targets for biological control, especially as there is no pitch canker in Europe.
- <u>Pitch canker.</u> Further studies on the taxonomy and host-range of pitch canker disease in South Africa, are essential. Close co-operation with scientists in New Zealand in respect of pitch canker and other pine diseases and their insect vectors, is necessary.

- Seed- and cone-feeding insects. The search for possible biological control agents against invasive *Pinus* species in South Africa must be limited to seed- and cone-feeding insects of *P. pinaster* and *P. halepensis* in Europe. Studies on the cone-weevil *Pissodes validirostris* should receive priority, with secondary consideration going to the cone-pyralids *Dioryctria mendasella* and *D. mitatella* and the mite *Trisetacus* sp. Because the forestry industry in South Africa is dependent on seed orchards to provide propagules to replenish forests, methods will have to be explored to protect pine trees in seed orchards, should it ultimately be decided to introduce biological control agents.
- Parasitoids. Parasitoids of pine-forestry pests have been and will continue to be imported into South Africa. The possible impact of these parasitoids and of native parasitoids, on any prospective biological control agents, should be explored.
- Experiments in progress. In view of the great importance of pines to South African conservation and water supplies it is the role and duty of experts in the field of biological control to make recommendations about the possible importation of insect agents, based on detailed data and evidence. Extensive experiments, to ascertain the facts, are presently underway in France designed to test the *Pinus* host ranges of prospective biological control agents. Preliminary results from these experiments will be reported by Hoffmann *et al*. at a conference entitled "Evaluating indirect ecological effects of biological control" to be held in Monpellier, France from 17-20 October 1999.

Once the facts are known, and prior to the importation of any prospective agents into South Africa, experts will need to make recommendations about how to proceed, which may include abandoning biological control attempts altogether. A recommendation to proceed will need to go to all stakeholders for consensus to be reached as to whether or not biological control of pines in South Africa should ultimately be implemented. The decision to release or not to release biological control agents will be based on assessments of the possible impacts of these agents on commercial forestry relative to the savings and benefits to biodiversity, catchment stability and water resources, and relative to the costs and sustainability of management and control of alien, invasive *Pinus* species in South Africa.

References Cited

Agee, J. K. 1998. Fire and pine ecosystems. *In* Ecology and biogeography of *Pinus*. D. M. Richardson [ed.]. Cambridge University Press. pp. 193-218.

Barbéro, M., R. Loisel, P. Quézel, D.M. Richardson, and F. Romane. 1998. Pines of the Mediterranean Basin. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 153-170.

Bosch, J. M. 1979. Treatment effects of annual and dry period streamflow at Cathedral Peak. South African Forestry Journal. 108: 29-38.

Bosch, J. M., and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evaporation. Journal of Hydrology. 55: 3-23.

Brockerhoff, E., and M. Kay. in press. Prospects and risks of biological control of wilding *Pinus contorta* in New Zealand.

De Groot, P., and J.J. Turgeon. 1998. Insect-pine interactions. *In* Ecology and biogeography of

Pinus, D. M. Richardson [ed.]. Cambridge University Press. pp. 354-380.

Dennill, G.B., and D. Donnelly. 1991. Biological control of *Acacia longifolia* and related weed species (Fabaceae) in South Africa. Agriculture, Ecosystems and Environment, 37: 115-135.

Dye, P.J. 1988. How plants make water flow uphill. African Wildlife. 42: 7-8.

Dye, P.J. 1996. Climate, forest and streamflow relationships in South African afforested catchments. Commonwealth Forestry Review. 75: 31-38.

Dye, P.J., B.W. Olbrich, and C.S. Everson. 1995. The water use of plantation forests and montane grassland in summer-rainfall forestry regions in South Africa. Proceedings of the Seventh South African National Hydrological Symposium. Institute for Water Research, Grahamstown.

Dye, P.J., and T. Poulter. 1995. A field demonstration of the effects on streamflow of clearing invasive pines and wattle trees from a riparian zone. South African Forestry Journal. 173: 27-30.

Harrington, T.C., and M.J. Wingfield. 1998. Diseases and the ecology of indigenous and exotic pines. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp 381-404.

Henderson, L. 1995. Plant invaders of Southern Africa. Plant Protection Research Institute Handbook No 5. Agricultural Research Council. Pretoria, South Africa. 177 pp.

Hoffmann, J.H. [ed.]. 1991. Biological control of weeds in South Africa. Special Issue: Agriculture Ecosystms and Environment. 37: 1-255.

Hoffmann, J.H., and V.C. Moran. 1991. Biological control of *Sesbania punicea* in South Africa. Agriculture, Ecosystems and Environment. 37: 157-173.

Kay, M. 1994. Biological control for invasive species. New Zealand Forestry. 39: 35-37.

Keely, J.E., and P.H. Zedler. 1998. Evolution of life histories in *Pinus*. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp 219-249.

Kruger, F.J. 1997. Invasive woody plants in the Cape fynbos with special reference to the biology and control of *Pinus pinaster*. Proceedings of the Second National Weeds Conference of South Africa. Stellenbosch. pp. 57-74.

Lanner, R.M. 1998. Seed dispersal in *Pinus*. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 281-295.

Lavery, P.B., and D.J. Mead. 1998. *Pinus radiata*: a narrow endemic from North America takes on the world. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 432-449.

Le Maitre, D.C. 1998. Pines in cultivation: a global view. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 407-431.

Le Maitre, D.C., B.W. van Wilgen, R.A. Chapman, and D.H. McKelly. 1996. Invasive plants and water resources in the western Cape Province, South Africa: modelling the consequences of a lack of management. Journal of Applied Ecology. 33: 161-172.

Nel, J.L., B.W. van Wilgen, and C.M. Gelderblom. 1998. The contribution of plantation forestry to the problem of invading alien trees in South Africa: a preliminary assessment. Unpublished Report from CSIR - Enviromentek, Stellenbosch to the Chief Director Forestry, Department of Water Affairs and Forestry, South Africa. pp. (ii) + 26.

Poynton, R.J. 1997. Tree planting in southern Africa. Volume 1. The pines. Report to the Southern African Regional Commission for the Conservation and Utilization of the Soil. (SARCCUS). Department of Forestry, South Africa. pp. xiv + 576.

Price, R.A., A. Liston, and S.H. Strauss. 1998. Phylogeny and systematics of *Pinus*. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 49-68.

Read, D.J. 1998. The mycorrhizal status of *Pinus*. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 324-340.

Richardson, D.M., R.M. Cowling, and D.C. Le Maitre. 1990. Assessing the risk of invasive success in *Pinus* and *Banksia* in South African mountain fynbos. Journal of vegetation Science. 1: 629-642.

Richardson, D.M., and S.I. Higgins. 1998. Pines as invaders in the southern hemisphere. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 450-473.

Richardson, D.M., I.A.W. Macdonald, and G.G. Forsyth. 1989. Reductions in plant species richness under stands of alien trees and shrubs in the fynbos biome. South African Forestry Journal. 149: 1-8.

Richardson, D.M., I.A.W. Macdonald, J.H. Hoffmann, and L. Henderson. 1997. Alien plant invasions. *In* Vegetation of Southern Africa, R.M. Cowling, D.M. Richardson and S.M. Pierce [eds.]. Cambridge University Press. pp. 535-570.

Richardson, D.M., I.A.W. Macdonald, P.M. Holmes, and R.M. Cowling. 1992. Plant and animal invasions. *In* The ecology of fynbos, R. M. Cowling [ed.]. Oxford University Press. Cape Town. pp. 271-308.

Richardson, D.M., B.W. van Wilgen, S.I. Higgins, T.H. Trinder-Smith, R.M. Cowling, and D.H. McKelly. 1996. Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. Biodiversity and Conservation. 5: 607-647.

Richardson, D.M., and P.W. Rundel. 1998. Ecology and biogeography of *Pinus* : an introduction. *In* Ecology and biogeography of *Pinus*, D. M. Richardson [ed.]. Cambridge University Press. pp. 3-46.

Scott, D.F., and W. Lesch. 1995. The water yield gains from clearfelling riparian zone vegetation. Proceedings of the Seventh South African National Hydrological Symposium. Institute for Water Research, Rhodes University, Grahamstown.

Scott, D.F., and W. Lesch. 1996. The effects of clearing and clearfelling of an indigenous forest on streamflow, stormflow and water quality. South African Forestry Journal. 175: 1-14.

Scott, D.F. In press. Managing riparian vegetation to sustain streamflow. Canadian Journal of Forestry Research.

Smith, R.E., and D.F. Scott. 1992. Simple empirical models to predict reductions in annual and low flows resulting from afforestaion. Report FOR- DEA 465. CSIR Division of Forestry Science and Technology. Pretoria, South Africa.

Van der Zel, D.W. 1981. Optimum mountain catchment management in South Africa. South African Forestry Journal. 116: 75-88.

Van Lill, W.S., F.J. Kruger, and D.B. van Dyk. 1980. The effect of afforestation with *Eucaluptus grandis* Hill ex Maiden and *Pinus patula* Schlecht. Et. Cham. on streamflow from experimental catchments at Mokubalaan, Transvaal. Journal of Hydrology. 48: 107-118.

Van Wilgen, B.W., R.M. Cowling, and D.C. Le Maitre. 1997. Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water Programme. Trends in Ecology and Evolution. 13: 378.

Van Wilgen, B.W., and E. van Wyk. 1999. Invading alien plants in South Africa : Impacts and solutions. Unpublished report, CSIR Division of Water, Environment and Forestry Technology, Stellenbosch, South Africa. 15pp.

Van Wyk, D.B. 1987. Some effects of afforestation on streamflow in the Western Cape Province, South Africa. Water S A. 14: 31-36.

Versfeld, D.B., D.C. Le Maitre, and R.A. Chapman. 1998. Alien invading plants and water resources in South Africa: a preliminary assessment. Report TT99/98, Water Research Commission, Pretoria, South Africa.

Viljoen, A., M.J. Wingfield, W.F.O. Marasus, and T.A. Coutinho. 1997. Pitch canker of pines – a contemporary review. South African Journal of Science. 93: 411-413.