CHAPTER SIX

The control of the Sirex woodwasp in diverse environments: The South African experience

---

The woodwasp *Sirex noctilio* was detected in South Africa in 1994, in Cape Town. Within the following 15 years, *S. noctilio* had spread across four of the five main forestry regions. Losses incurred from *S. noctilio* damage increased dramatically as it moved into the Eastern Cape and KwaZulu-Natal provinces, where densely stocked pulpwood stands provided ideal conditions for the population of the wasp to increase. Control strategies developed in Australia and New Zealand were adopted, including the introduction of the parasitic nematode *Deladenus siricidicola* and the parasitic wasp *Ibalia leucospoides*. Adaptations were required for the techniques used to release *D. siricidicola* due to the poor success obtained in the summer rainfall areas. These adaptations increased the effectiveness of the inoculations, although overall inoculation success remained poor. The inoculations spread the nematodes across infested areas; subsequent natural spread of the nematode has resulted in a steady increase in parasitism levels. *Ibalia leucospoides* was successfully released in the Western Cape in 1998, but only recently (since 2006) have there been efforts to release this parasitoid in other infested areas. Monitoring has been crucial for the early detection of infestations and release of biological control agents, and has included field surveys, lure-based traps and more recently trap trees. Plantation management strategies to combat *S. noctilio* have been used to some extent, but are restricted by economic considerations. Although infestations of *S. noctilio* have recently decreased, the movement of *S. noctilio* into the largest pine-growing province and the current inability to quickly establish biological control due to poor inoculation success, emphasizes the fact that *S. noctilio* continues to pose a serious threat to the pine industry in South Africa.

Introduction

The woodwasp *Sirex noctilio* (Siricidae: Hymenoptera) is a major pest in pine plantations throughout the southern hemisphere, where together with its fungal symbiont *Amylostereum areolatum*, it infests and kills *Pinus* spp. *Sirex noctilio* is native to Eurasia and North Africa and was first detected in the southern hemisphere around 1900 in New Zealand (Miller and Clarke 1935). During the next 100 years, *S. noctilio* spread across the southern hemisphere and is now present in Australasia, South America and South Africa (Carnegie *et al.* 2006, Hurley *et al.* 2007). Most recently, an established population of *S. noctilio* was recorded in the United States of America and Canada (Hoebeke *et al.* 2005, de Groot *et al.* 2007).

Due to the long history of *S. noctilio* in New Zealand (since 1900) and Australia (since 1952) (Gilbert and Miller 1952), and the extensive damage that it has caused in these countries (see Rawlings 1955 and Haugen 1990 as examples), management strategies to reduce the impact of *S. noctilio* were well established before the wasp spread to South America and South Africa. These management strategies were strongly focused on the establishment of biological control, although silvicultural measures such as thinning and timely pruning were also seen as important (Madden 1968, Neumann *et al.* 1987). Biological control of *S. noctilio*, which had been very successful in New Zealand and Australia (Hurley *et al.* 2007), was rapidly adopted in South America and South Africa when *S. noctilio* was first detected in these locations.

The control of *S. noctilio* in South America and South Africa has not been uniformly effective, specifically when compared to the success recorded in Australia and New Zealand (Hurley *et al.* 2007). In a detailed examination of *S. noctilio* infestations and their control in the southern hemisphere, Hurley *et al.* (2007) suggested that the integrated control approach for *S. noctilio* might require significant local adaptation in new areas of introduction for effective control to be obtained. The term local adaptation refers to the changes required to the adopted management program, in response to the difference in conditions that can influence the program's success between the local environment and the environment where the specific approach was developed. The aim of this chapter is to provide an overview of the efforts to control *S. noctilio* in South Africa, where the environment has dictated local adaptation of existing control strategies. Information on pine plantations and management, and the history of *S. noctilio* in South Africa is also provided.

Pine forestry in South Africa

South Africa has a low mean rainfall and limited natural forests. Savannah woodland covers 19 % of the land area, and closed canopy forest only 0.5 % (Owen and van der Zel 2000). The arrival and expansion of European colonies in South Africa, and the consequent demand for timber, rapidly placed a strain on the limited supply of wood resources. Thus, from the early 1700s attempts were made to protect natural forests and exotic tree species were introduced to supplement the demand for wood (Owen and van der Zel 2000). In the late seventeenth century, *P. sylvestris*, *P. pinea* and *P. pinaster* were introduced. Numerous pine species were introduced after this, including *P. radiata* (pre-1865), *P. taeda* (pre-1900), *P. patula* (1907) and *P. elliottii* (early 1900s) (Owen and van der Zel 2000). These are currently the four main pine species planted in South Africa (Poynton 1977). The first commercial plantations were established in 1875, where black wattle (*Acacia mearnsii*) was planted to provide railway sleepers, and later as a superior vegetable tanning material. By 1910, 60 000 ha were planted to *A. mearnsii*. Plantations of non-native tree species increased greatly after World War 2; these included species of *Pinus* and *Eucalyptus*. By 1960, 980 000 ha had been planted to non-native species and by 1975 the planted area had risen to 1.1 million ha (Owen and van der Zel 2000).

Plantation forests currently cover about 1.0 % of the land area (about 1.3 million ha) in South Africa, the majority of which is in the Mpumalanga (40.7 %) and KwaZulu-Natal (38.5 %) provinces. The forest industry produces nearly 18 million tons of roundwood per annum, and forest products exports contribute over R12 billion to foreign trade (third only to metal ores and coal), making forestry a major contributor to the South African economy (Godsmark 2008, based on 2007 figures). *Pinus* species make up about 53 % of the planted area, distributed in Mpumalanga (46.6 %), KwaZulu-Natal (21.5 %) and the Eastern and Western Cape (27.8 %). Most of the pine is used for saw timber (68.5 %), followed by pulpwood (30.4 %) and poles (0.9 %) (Godsmark 2008).

South African forests cover a broad range of climatic, soil and altitudinal zones (Figs 1-4). Site-species matching is thus a crucial aspect of South African forestry, although the presence and location of processing plants is also a major factor determining which pine species are planted. In the Western Cape, which is a winter rainfall and all-year rainfall area, *P. radiata* is most commonly planted. In KwaZulu-Natal, Mpumalanga and Northern Province, which are summer rainfall areas, *P. patula* is primarily planted, although *P. taeda* and *P. elliottii* are also widely utilised. *Pinus patula* is mainly planted at altitudes higher than 1000 m.a.s.l. (metres above sea level) due to its snow tolerance and its susceptibility to *Diplodia pinea* at lower altitudes.

Management strategies for *Pinus* spp. differ in the different geographical areas where plantations have been established. In the Western Cape, Eastern Cape and Northern Province, pine trees are predominantly grown for saw timber. In KwaZulu-Natal, pine trees are predominantly grown for pulpwood. In Mpumalanga, there are large areas of pine trees planted for both saw timber and pulpwood. Management for saw timber production includes pruning and thinning, where suppressed trees are removed. In contrast, management for pulpwood production generally does not include thinning, though pruning for access to a height of 2 m is performed, especially in *P. patula* stands. The absence of thinning in pulpwood production stands results in a much higher final stand density (approx. 800 - 1250 stems per hectare [spha]) than in saw timber production stands (approx. 250 spha), at the time of harvest.

Introduction and spread of *S. noctilio* in South Africa

Sirex noctilio was first detected in South Africa in 1962 where it was found in wood at a timber yard in Port Elizabeth (Taylor 1962). Infested material was destroyed and there were no further reports of the wasp in South Africa for the next three decades. In April 1994, *S. noctilio* was reported in *P. radiata* trees in Cape Town (Tribe 1995). It was estimated to have arrived at least two years prior to its detection. The introduction of *S. noctilio* into South Africa was likely from South America or its native range (Slippers *et al.* 2001).

During the next fifteen years, *S. noctilio* spread in a north-easterly direction, following the main pine resources in the country (Fig. 5). Surveys in the Cape region in 1994 detected *S. noctilio* as far as 90 km from Cape Town where it was first detected, infesting mainly *P. radiata* (Tribe 1995). By 1998, *S. noctilio* had been detected as far as Riversdale in the east and Van Rhynsdorp in the north (Tribe and Cillié 2004). In 2001, the wasp was found near Knysna (Brenton-on-Sea). In 2002, *S. noctilio* was detected in the Eastern Cape and KwaZulu-Natal (at Weza) in *P. patula* stands (Hurley *et al.* 2007). In these areas, the wasp rapidly reached epidemic proportions and gradually made its way northwards. By 2009, *S. noctilio* had spread throughout KwaZulu-Natal and was most recently recorded in Mpumalanga (November 2009) - South Africa's main pine growing province (authors, unpublished data). The spread of *S. noctilio* over the last fifteen years has likely been accelerated by accidental human-assisted transport, such as through the movement of infested logs and wood packaging material (Fig. 6A).

Although it was considered a major threat to pine forests in the Western Cape after its detection, *S. noctilio* has caused little damage in this province. The exception was an infestation in the George area where *S. noctilio* caused an average of 10 % mortality in an overstocked area of 12-13-year-old *P. radiata* (Hurley *et al.* 2007). In contrast, soon after the detection of *S. noctilio* in the Eastern Cape and KwaZulu-Natal, serious mortality occurred. The damage peaked in 2004-2006, where mortality in some stands was over 35 % and the mean mortality was 6 % (Hurley *et al.* 2007) (Fig. 6B).

Hurley *et al.* (2007) suggested that differences in management strategies between the provinces had contributed to differences in infestation levels. In contrast to the Eastern Cape and KwaZulu-Natal, the Western Cape does not grow trees for pulpwood and thus does not have large areas of unthinned, heavily stressed stands. In addition to the differences in management strategies, the slow establishment of biological control agents in the Eastern Cape and KwaZulu-Natal also contributed to the epidemic in this area. Infestation levels of *S. noctilio* have declined in KwaZulu-

Natal after 2006, and mean infestation levels in the area were below 1 % in 2009 (authors, unpublished data). Nonetheless, *S. noctilio* is still considered the most serious pest of pine currently in South Africa, based on resulting tree mortality and the threat it poses as it moves in to new pine areas.

Efforts to control *S. noctilio* in South Africa

Biological control: Parasitic nematodes

The nematode *Deladenus* (= *Beddingia*) *siricidicola* Bedding is considered the primary biological control agent for *S. noctilio* (Bedding and Iede 2005). This nematode has a complex life-cycle that includes fungus-feeding and parasitic phases (Bedding 1972). In the fungus-feeding form, *D. siricidicola* feeds on the *S. noctilio* fungal symbiont *A. areolatum*, and has a life-cycle of about two weeks at 22°C, which makes it possible to rear the nematode in Petri-dish cultures in a laboratory environment (Fig. 6C). In the parasitic form the nematode parasitizes but does not kill the larvae of *S. noctilio*, and causes sterility in the female wasp. Infested females act as dispersal agents for the nematode via their parasitized eggs. These attributes of *D. siricidicola*, together with its high specificity and parasitism rates, make it an ideal biological control agent.

Shortly after the detection of *S. noctilio* in Cape Town, efforts were made to introduce the Kamona strain of *D. siricidicola* (Tribe 1995, Tribe and Cillié 2004). In 1995, 250 *S. noctilio*-infested trees were inoculated with 70 million nematodes, and in 1996, 46 *S. noctilio*-infested trees were inoculated with 20 million nematodes (Tribe and Cillié 2004). Inoculations were done on *P. radiata* trees within a 90 km arc of

Cape Town, an area demarcating the boundary of the known occurrence of S. *noctilio* at that time. The standard inoculation method, described in Bedding and Iede (2005) was used. The nematodes were imported directly from Australia. In addition to these inoculations, in 1998 and 2002 *S. noctilio*-infested logs, where *D. siricidicola* parasitism had been confirmed, were transported to *P. radiata* plantations further east, as far as George, with the intention that infected *S. noctilio* females would spread the nematode in that area (Tribe and Cillié 2004). No inoculations were done in the Western Cape from 1997 to 2003.

Results of the nematode inoculations in the Western Cape were reported to be good, although variable. Tribe and Cillié (2004) recorded parasitism of 96.1 % within the inoculated area by 1998. But other studies have revealed more variable success in the province, ranging from 0-64 % (Hurley *et al.* 2007, data from 2001-2002 collections). More recent data reflect average parasitism levels of 53 % (author, unpublished data, based on adult female parasitism) to 64 % (Verleur and Kanzler (2007), based on larval scarring.

Prior to 2001, *S. noctilio* was thought to be well controlled in the Western Cape because it had not caused any serious mortality of pine. Consequently, the South African forest industry did not consider the wasps to be an imminent threat to the majority of the country's pine resources in KwaZulu-Natal and Mpumalanga. The perceived threat of *S. noctilio* increased when it was detected in Knysna in 2001 and then in Umtata, north Eastern Cape and KwaZulu-Natal in 2002 (Fig. 5). In 2003, *S. noctilio* was detected in various plantations in the Eastern Cape and KwaZulu-Natal and heavy infestations were observed. Unfortunately, neither *D. siricidicola* nor any other biological control agents of the wasp had apparently migrated northwards with *S. noctilio*. Again, *D. siricidicola* (Kamona strain) was seen as the most important biological control agent to release in these new epidemic areas, and the first releases started in 2004. This release required a re-negotiation with a private Australian company because the previous licence allowed release of the nematode only below 32°S latitude.

In 2004, a total of 1763 *S. noctilio*-infested trees were inoculated in the Eastern Cape and KwaZulu-Natal, with 178 million nematodes (Table 1). These inoculations were mainly in pulpwood compartments of *P. patula* where infestations were highest. Standard inoculation techniques (Bedding and Iede, 2005) were used. Success from these inoculations was poor, with only 3 % female parasitism obtained. Efforts were made to improve the inoculation success the following year. Particular emphasis was placed on inoculation technique and nematode survival during transport and in wood after inoculation. Operating practices involving nematode transport and inoculations were improved and preliminary studies showed that nematodes had survived well during transport at temperatures between 5-10°C and that they were penetrating and surviving in the wood. Despite these efforts, inoculations in 2005 again resulted in low levels of parasitism (Table 1).

Field trials were established in 2006 to test possible factors influencing success of *D. siricidicola* inoculations. Data from 2005 trials had indicated that the position (bottom, middle or top) of the inoculation in the trees affected inoculation success, which was thought to be due to differences in moisture content between these sections (Verleur and Kanzler 2006). These factors, as well as nematode source (those reared in South Africa as opposed to nematodes sourced from Australia), period of inoculation and inoculation method (conventional method of inoculating felled trees compared to inoculating standing trees) were examined (Hurley *et al.* 2008, Verleur and Kanzler 2008a). The inoculation of standing trees was tested as this targeted the bottom sections of the trees, where inoculation success was highest, was safer and more cost and time effective than having to fell trees for inoculation. Background parasitism, defined as natural spread and establishment of *D. siricidicola*, was also examined.

Results from the 2006 trials confirmed that inoculation success was highest from the bottom section of the tree and in earlier inoculation periods, where moisture content was highest (Hurley *et al.* 2008, Verleur and Kanzler 2008a). However, the correlation between moisture content and parasitism was low; indicating that moisture content was not the only factor influencing inoculation success. Inoculation of standing trees was more cost effective and safer (see Fig. 7). Nematode source was found not to influence inoculation success. Background parasitism was detected at the trial sites, from just over 1 % (Hurley *et al.* 2008) to about 20 % (Verleur and Kanzler 2008a). These results were very encouraging as they showed that despite the low inoculation success (7.2 %, Table 1), the nematodes had, at least to some degree, become established in the plantations.

Mass inoculations of *D. siricidicola* in the Eastern Cape and KwaZulu-Natal were planned for 2007 and 2008. This project was motivated mainly by the evidence of background parasitism, which meant that inoculations, even with low success, could spread the nematode across areas infested with *S. noctilio*, allowing the nematode population to naturally increase over time. Over these two years, 96 063 trees were inoculated with about 7.8 billion nematodes (Table 1). The majority of inoculations were in pulpwood stands where standing trees were inoculated. In saw timber stands, the conventional method of inoculating felled trees was followed. Average female parasitism was 22 % and 35 % from the 2007 and 2008 inoculations, respectively (Table 1). Although the sampling technique for the results in 2007 and

2008 included a higher proportion of bottom logs (where parasitism was higher), the results still showed a general improvement from the initial inoculations in 2004 and 2005, and showed an increase in parasitism over time. The majority of the increase could be attributed to the natural spread of the nematode, as inoculation success remained poor. This was evident from sites receiving their first inoculations where parasitism results were below 10 % (authors, unpublished data). Inoculations continued in 2009, but at reduced levels due to the decrease in infestations of *S. noctilio*. In total, 8 300 trees were inoculated in the Eastern Cape and KwaZulu-Natal with 830 million nematodes. Results from these inoculations were not available at time of writing this review.

The reason for the decline in *S. noctilio* infestations is not known for certain. Increasing levels of parasitism by *D. siricidicola* could have contributed to the decline, but because parasitism has only recently increased and is still not near the over 90 % infestation levels reported by Bedding and Iede (2005), especially from the middle and top sections of the trees, this may not be the main or only cause. Other possible factors include the decreasing supply of suitable hosts, with many suitable hosts previously attacked and killed by *S. noctilio* or removed by clear-felling of highly infested stands (see plantation management section).

Biological control: Parasitic wasps

Parasitic wasps are considered a key component for the control of *S. noctilio* (Taylor 1976). Nine species were released in Australia and of these *Megarhyssa nortoni*, *Ibalia leucospoides* and *Rhyssa persuasoria* were considered the most effective (Taylor 1978, Neumann *et al.* 1987). *Ibalia leucospoides* and *M. nortoni* were introduced into South Africa, but only *I. leucospoides* has become established (Tribe and Cillié 2004) (Fig. 6D).

In 1998, *Ibalia leucospoides* and *M. nortoni* were imported, from Uruguay and Australia respectively (Tribe and Cillié 2004). From the 18 male and 19 female *I. leucospoides* imported, 456 progeny were released from late 1998 to 2001. These parasitoids were released from Cape Town to Riversdale (Fig. 5). The establishment of *I. leucospoides* was not confirmed until 2002, but the parasitiod has now been detected in numerous plantations of the Western Cape. From these emerging wasps, a further nine *I. leucospoides* were released in Knysna in 2002. From the 10 male and 44 female *M. nortoni* imported in 1998, only 79 progeny were released the following year in Van Rhynsdorp (Tribe and Cillié 2004). No further releases were made and *M. nortoni* has since then never been recovered from the field, thus leading to the assumption that this biological control agent has not become established in South Africa.

Ibalia leucospoides appears not to have moved with *S. noctilio* as it spread to the Eastern Cape and KwaZulu-Natal. *Sirex noctilio* infested billets collected from Knysna in 2001, the Eastern Cape and Weza (near Kokstad) in 2002, and from various sites in KwaZulu-Natal from 2003 to 2006 indicated the absence of *I. leucospoides* in these areas (Fig. 5). Plans were thus made to introduce *I. leucospoides* to these areas. In January 2006, 138 *I. leucospoides* collected in the Western Cape were released at sites in KwaZulu-Natal and the Eastern Cape. A further 376 wasps were released from November 2006 to January 2007. *Ibalia leucospoides* were recovered from these release sites in late 2007 and released in the same area (a total of 201 wasps). In the subsequent *S. noctilio* emergence season, 74 *I. leucospoides* were recovered and these were released at sites in KwaZulu-Natal (Verleur and Kanzler 2008b).

Efforts are currently underway to develop a central rearing colony of *I. leucospoides*, from which the parasitoid can be sent to *S. noctilio* infested areas. This approach will provide a more sustainable and higher capacity to release the parasitoid than the capture and release method. A further aim is to increase the genetic diversity of the South African *I. leucospoides* population by introducing *I. leucospoides* from other countries into the rearing colony. The current genetic diversity of the South African population is expected to be very low due to the small number of wasps originally introduced. The influence of genetic diversity on the success of biological control agents is not clear, but could affect its ability to adapt to new environments and host types (Roderick and Navajas 2003).

Plantation Management

Stressed trees are known to be more susceptible to attack by *S. noctilio* (Madden 1968, Talbot 1977, Neumann and Minko 1981), and poor silviculture practices can be a major source of stress in plantations (Madden 1988). In South African pine forests, high stocking of pulpwood stands is likely one of the major reasons for the high levels of infestation of *S. noctilio* in regions where such stands are dominant. These stands are intentionally managed to have high stocking, with no thinning and no pruning or pruning only to allow access into the plantations. The goal here is to maximize revenue by maximizing fibre levels per hectare. The forest industry is currently investigating alternative management options for pulpwood stands, involving different thinning regimes in an effort to decrease stress in the stands while retaining economic feasibility. Saw timber stands are less prone to stress due to thinnings, when these are conducted at the optimal time.

One of the management strategies of the forestry industry in response to *S. noctilio* infestations has been to clear-fell and harvest areas where infestations are above 15 %. The harvested timber is moved to a mill where it was processed and the *S. noctilio* larvae destroyed. This strategy was used in KwaZulu-Natal, and likely contributed to the noticeable decline of *S. noctilio* in those areas in subsequent years.

Monitoring of *Sirex noctilio*

Effective management of *S. noctilio,* including the release of biological control agents, must rest on a clear knowledge of the distribution of the pest. In South Africa, monitoring of *S. noctilio* after its detection in 1994 was mainly by means of field surveys. These monitoring efforts resulted in the detection of *S. noctilio* in the Eastern Cape and KwaZulu-Natal (Fig. 5). Field surveys to detect *S. noctilio* in the northern Eastern Cape and KwaZulu-Natal started in 2002 after *S. noctilio* was unexpectedly detected in Umtata during a routine field excursion. The spread of *S. noctilio* to Umtata, far from the known range of *S. noctilio* the previous year, could have resulted from human-mediated transport of *S. noctilio*, but could also have resulted from the undetected movement of *S. noctilio* before 2002.

From 2004 onwards, various traps and lures based on volatile compounds from pine trees were tested for trapping *S. noctilio*. This work was conducted in collaboration with USDA-APHIS. These tests have resulted in the current black intercept (panel) trap, using a six-component blend lure containing general pine volatiles (Fig. 6E). Using this trap, it has been possible to detect new infestations of *S.*

noctilio and this also led to the detection of *S. noctilio* in northern KwaZulu-Natal during 2007 and 2008 (see Fig. 5) and more recently in Mpumalanga (November 2009). Trials are underway to improve the current trap type and lures used to monitor the spread of *S. noctilio*. These new traps using generic or specific lures will be used to detect the presence of other wood borers.

In 2004, the use of trap trees was tested to monitor the spread of *S. noctilio* for the first time in South Africa. This is an approach described by Madden (1971), where trees are stressed to lure *S. noctilio* females. Trap trees can function as a means of detection as well as an inoculation source for *D. siricidicola*. The trap trees set in 2004 were established using previously described techniques (Anon 2002, Neumann *et al*. 1982), except that glyphosate was used as an alternative to dicamba, which is prohibited for use in South African plantations. Success with these trap trees was very poor. Because there were high numbers of naturally infested trees to inoculate and because of the current development of lure-based traps to detect new *S. noctilio* populations, efforts to use trap-trees were abandoned until 2007. A decision was then made to re-investigate trap trees as a method for monitoring, and to complement the lure-based traps. These trees could then also be used to provide an inoculation source in areas with new *S. noctilio* infestations, and where naturally infested trees were difficult to locate. Trap tree trials in 2007, showed that trap trees could be successfully used when applied a month before adult emergence using Dicamba/24-D/MCPA (Verleur and Kanzler 2009). Plans are underway to use traps and trap trees on a larger scale in areas ahead of the known limits of *S. noctilio* distribution.

Conclusions

It is clear that local adaptation of control strategies for *S. noctilio* is required where this pest has entered new environments. In South Africa, after the detection of *S. noctilio*, control strategies developed in Australia were rapidly adopted, specifically the introduction of biological control agents. Early failures with biological control underscored the importance of developing and modifying control strategies that are effective under local climate, environmental and management conditions, as these factors influence tree vigour and, therefore, susceptibility to *S. noctilio*.

Amongst the major adaptations to the *S. noctilio* control programme in South Africa, those pertaining to the application of the parasitic nematode *D. siricidicola* have been most significant. This nematode was highly successful as a biological control agent in other parts of the world, yet gave poor results in the first two years of inoculation in the summer rainfall area of South Africa. Investigations revealed that low moisture content in the wood at time of inoculation had influenced success. This situation could not be completely avoided, but inoculation techniques were adapted to increase the efficacy of inoculations by targeting the wetter bottom sections of standing trees in pulpwood stands.

Other possible factors influencing inoculation success include the influence of different strains of *A. areolatum* present in South Africa and Australia (Slippers *et al.* 2001, author, unpublished data). Preliminary results have shown that the fungus associated with *S. noctilio* in South Africa may grow slower than the fungus on which *D. siricidicola* has been developed. The influence that this has on nematode survival and reproduction is being investigated. Furthermore, the competition between blue stain fungi commonly present in trees infested with *S. noctilio*, and *A. areolatum*, and the influence that this has on nematode survival is being considered. Both of these factors, namely *A. areolatum* strain and the presence and composition of blue stain fungi in infested trees, can differ between and even within countries. In addition, plans to collect and screen other strains of *D. siricidicola* for their efficacy in South Africa's summer rainfall region are underway.

Insufficient effort has been made to introduce parasitic wasps for biological control of *S. noctilio* in South Africa. These wasps can play an important role in the control of the pest, and could be especially important given the low inoculation success with the nematodes to date. Increased effort is needed to establish a sustainable rearing colony of *I. leucospoides* from which large numbers of wasps can be released annually. Genetic diversity of the population of the parasitic wasps must also be considered. In addition, effort is needed to import and release other parasitic wasps, such as *Megarhyssa nortoni* and *Rhyssa persuasoria*. There is little question that the introduction of these parasitic wasps will contribute to a more robust and sustainable biological control effort.

Plantation management is a major factor determining infestations of *S. noctilio* and requires further attention by the South African forest industry. Clear-felling of highly infested sites provides an effective management approach, but the vast areas of highly stocked, stressed pulpwood stands will always provide an opportunity for *S. noctilio* and other stress-associated pests and diseases to establish. Management strategies are governed by economics, but the financial implications of pest outbreaks need to be considered in this equation. The current thinning trials aimed at finding a 'middle road' are an indication that the industry in South Africa is taking pest threats very seriously.

Effective monitoring tools were developed a decade after *S. noctilio* was first detected in South Africa. Yet the development of monitoring tools should be a priority for any new pest introduction. It is clear that if greater attention had been paid to monitoring after the detection of *S. noctilio* in South Africa, its movement into the Eastern Cape and KwaZulu-Natal would have been recognized earlier, which would have resulted in earlier management interventions and many thousands of trees might possibly have been saved. The monitoring of *S. noctilio* continues to be crucial as it moves northwards.

The extent to which *S. noctilio* will infest plantations in Mpumalanga and the Northern Province provinces is currently unknown. This region has a mixture of saw timber and pulpwood stands and other stress factors such as baboon damage (McNamara 2006) will also need to be taken into account. Past efforts to adapt control strategies for local conditions will certainly contribute to ensuring low populations of *S. noctilio*. *Deladenus siricidicola* is already present at the front of the *S. noctilio* distribution and with the assistance of monitoring tools it can be rapidly introduced, together with *I. leucospoides*, to new infestation sites. Thinning overstocked stands ahead of the front and clear-felling highly infested sites should also be considered. Continued efforts to improve inoculation success, including research on possible barriers to inoculation, the introduction of new nematode strains and the introduction of other parasitic wasps will also be important. Progress in these areas will be fundamental to the future management of *S. noctilio* in South Africa.

References

Anon. 2002. National Sirex Control Strategy Operation Worksheets. National Sirex Co-ordination Committee. Australia

Bedding RA. 1972. Biology of *Deladenus siricidicola* (Neotylenchidae) an entomophagous-mycetophagous nematode parasitic in siricid woodwasps. Nematologica 18: 482-493.

Bedding RA, Iede ET. 2005. Application of *Beddingia siricidicola* for Sirex woodwasp control. *Nematodes as Biocontrol Agents* (ed. by P.S. Grewal, R. Ehlers and D.I. Shapiro-Ilan), pp. 385-400. CAB International, Wallingford, U.K.

Carnegie AJ, Matsuki M, Haugen DA, Hurley BP, Ahumada R, Klasmer P, Sun J, Iede, ET. 2006. Predicting the potential distribution of *Sirex noctilio* (Hymenoptera: Siricidae), a significant exotic pest of *Pinus* plantations. Annals of Forest Science 63: 119-128.

de Groot P, Nystrom K, Scarr T. 2007. Discovery of *Sirex noctilio* (Hymenoptera: Siricidae) in Ontario, Canada. Great Lakes Entomologist 39: 49-53.

Gilbert JM, Miller LW. 1952. An outbreak of *Sirex noctilio* in Tasmania. Australian Journal of Biological Sciences 22: 905-914.

Godsmark R. 2008. The South African forestry and forest products industry 2007. Forestry South Africa. http://www.forestry.co.za/website_industry_data. Accessed 20 February 2010.

Haugen DA. 1990. Control procedures for *Sirex noctilio* in the Green Triangle: Review from detection to severe outbreak (1977-1987). Australian Forestry 53: 24-32.

Hoebeke ER, Haugen DA, Haack RA. 2005. *Sirex noctilio*: discovery of a Palearctic siricid woodwasp in New York. Newsletter of the Michigan Entomological Society 50: 24-25.

Hurley BP, Slippers B, Wingfield MJ. 2007. A comparison of control results for the alien invasive woodwasp, *Sirex noctilio*, in the southern hemisphere. Agricultural and Forest Entomology 9: 159-171.

Hurley BP, Slippers B, Croft PK, Hatting HJ, van der Linde M, Morris AR, Dyer C, Wingfield MJ. 2008. Factors influencing parasitism of *Sirex noctilio* (Hymenoptera: Siricidae) by the nematode *Deladenus siricidcola* (Nematoda: Neotylenchidae) in summer rainfall areas of South Africa. Biological Control 45: 450-459.

Madden JL. 1968. Behavioural responses of parasites to the symbiotic fungus associated with *Sirex noctilio* F. Nature 218: 189-190.

Madden JL. 1971. Some treatments which render Monterey pine (*Pinus radiata*) attractive to the wood wasp *Sirex noctilio* F. Bulletin of Entomological Research 60: 467-472.

Madden JL. 1988. *Sirex in Australasia. Dynamics of Forest Insect Populations. Patterns, Causes, Implications* (ed. by A.A.Berryman), pp. 407-429. Plenum Press, New York.

McNamara LM. 2006. Nutrient concentration of inner bark tissue in pine trees in Mpumalanga in relation to baboon damage. MSc dissertation. Faculty of Science, University of the Witwatersrand, South Africa

Miller D, Clarke AF. 1935. *Sirex noctilio* (Hym.) and its parasites in New Zealand. Bulletin of Entomological Research 26: 149-154.

Neumann FG, Harris JA, Kassaby FY, Minko G. 1982. An improved technique for early detection and control of the Sirex wood wasp in radiata pine plantations. Australian Forestry 45: 117-124.

Neumann FG, Minko G. 1981. The sirex woodwasp in Australian radiata pine plantations. Australian Forestry 44: 46-63.

Neumann FG, Morey JL, McKimm RJ. 1987. *The Sirex woodwasp in Victoria*. Department of Conservation, Forest and Lands, Victoria, Bulletin No. 29.

Owen DL, van der Zel DW. 2000. Trees, forests and plantations in Southern Africa. In: Owen DL (ed). South African Forestry Handbook 2000, South African Institute of Forestry, South Africa

Poynton RJ. 1977. Tree planting in Southern Africa: The pines. Department of Forestry, South Africa.

Rawlings GB. 1955. Epidemics in *Pinus radiata* forests in New Zealand. New Zealand Journal of Forestry 7: 53-58.

Roderick GK, Navajas M. 2003. Genes in new environments: genetics and evolution in biological control. Nature Reviews Genetics 4: 889-899.

Schulze RE. 2007. National Land Cover Database 2000. South African atlas of climatology and agrohydrology, Water Research Commission, WRC Report 1489/1/06, Pretoria.

Slippers B, Wingfield MJ, Coutinho TA, Wingfield BD. 2001. Population structure and possible origin of *Amylostereum areolatum* in South Africa. Plant Pathology 50: 206-210.

Talbot PHB. 1977. The *Sirex-Amylostereum-Pinus* association. Annual Review of Phytopathology 15: 41-54.

Taylor JS. 1962. *Sirex noctilio* F., a recent introduction in South Africa. Entomologist's Record 74: 273-274.

Taylor KL. 1976. The introduction and establishment of insect parasitoids to control *Sirex noctilio* in Australia. Entomophaga 21: 429-440.

Taylor KL. 1978. Evaluation of the insect parasitoids of *Sirex noctilio* (Hymenoptera: Siricidae) in Tasmania. Oecologia 32: 1-10.

Tribe GD. 1995. The woodwasp *Sirex noctilio* Fabricius (Hymenoptera: Siricidae), a pest of *Pinus* species, now established in South Africa. African Entomology 3: 215-217.

Tribe GD, Cillié JJ. 2004. The spread of *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) in South African pine plantations and the introduction and establishment of its biological control agents. African Entomology 12: 9-17.

Verleur PM, Kanzler A. 2006. Some observations on the emergence patterns of *Sirex noctilio* (Fabricius) and parasitism by *Beddingia siricidicola* on Sappi landholdings during 2005. Sappi Research Document 25/2006.

Verleur PM, Kanzler A. 2007. Assessment of the *Sirex noctilio* (Fabricius) infestations in the Western Cape and comparisons between the distribution of *Sirex noctilio* (Fabricius) larvae and levels of parasitism by *Beddingia siricidicola* in the Western Cape and Sappi landholdings in KwaZulu-Natal during 2006. Sappi Research Document 18/2007.

Verleur PM, Kanzler A. 2008a. Comparison of two inoculation methods with *Beddingia siricidicola* against *Sirex noctilio* conducted in Kwazulu-Natal pine plantations during 2006. Sappi Research Document 04/2008.

Verleur PM, Kanzler A. 2008b. Introduction and establishment of *Ibalia leucospoides* as an additional biological control agent against *Sirex noctilio* in KwaZulu-Natal. Sappi Research Document 03/2008.

Verleur PM, Kanzler A. 2009. Testing of six herbicides in order to establish trap tree plots for the control of *Sirex noctilio* in the summer rainfall regions of South Africa. Sappi Research Document 09/2009.

Table 1. Inoculations of *D. siricidicola* in the Eastern Cape and KwaZulu-Natal provinces of South Africa from 2004-2008.

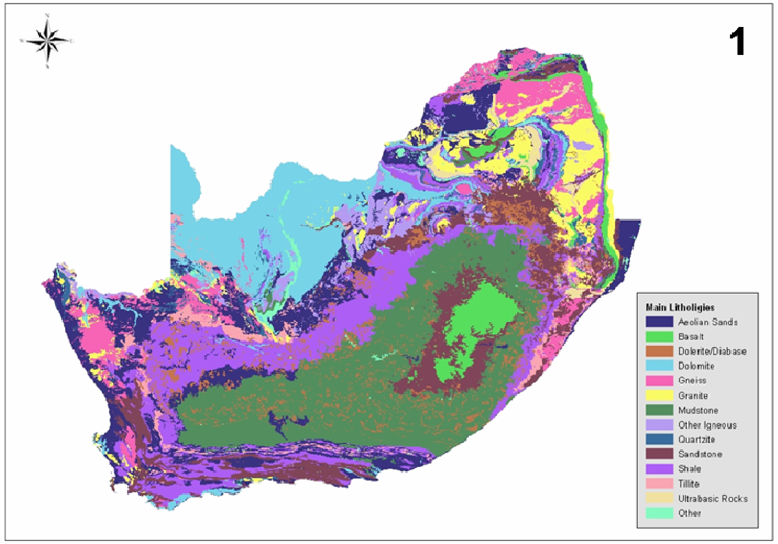
Year*	**Nematodes used (mil.)**	**Trees inoculated**	**% female parasitism of *S. noctilio*****
2004	178	1763	3 (n = 548)
2005	480	4400	7.8 (n = 1836)
2006***	40	396	7.2 (n = 2897)
2007	4641	57522	22 (n = 2132)
2008	3115	38541	35 (n = 1408)

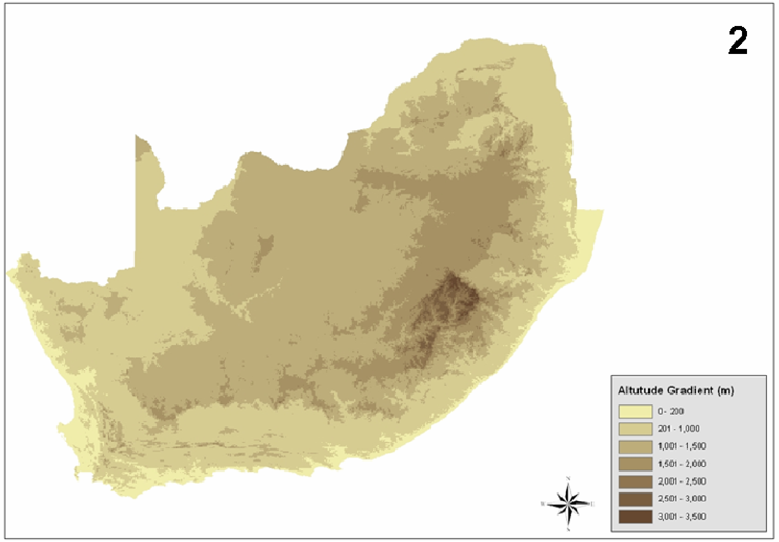
[*] In 2004-2005 felled trees were inoculated, while in 2007-2008 mainly standing trees were inoculated (fewer nematodes are used per tree). Comparison of parasitism results between years requires caution as different sampling strategies were used, where a greater proportion of bottom logs (where parasitism was highest) was sampled in 2007 and 2008.

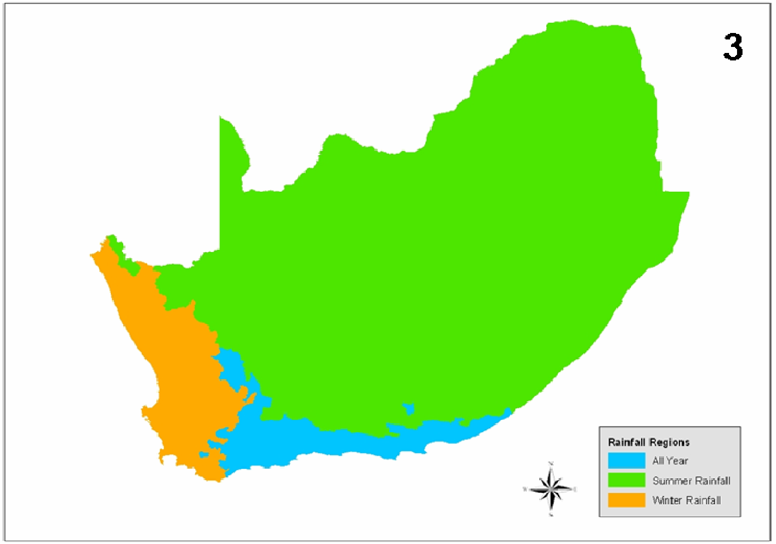
[**] n is the total number of female wasps dissected from sampled logs.

[***] Inoculations in 2006 were part of a trial. All commercial inoculations were stopped in this year pending the result of the trial.

Figures 1-4. Maps of South Africa. 1. Lithology. 2. Altitude. 3. Rainfall. 4. Distribution of pine forestry. (Data sources: Schulze (2007))


1
Main Lithologies
Aeolian Sands
Basalt
Dolerite/Diabase
Dolomite
Gneiss
Granite
Mudstone
Other Igneous
Quartzite
Sandstone
Shale
Tillite
Ultrabasic Rocks
Other


2
Altutude Gradient (m)
0 - 200
201 - 1,000
1,001 - 1,500
1,501 - 2,000
2,001 - 2,500
2,501 - 3,000
3,001 - 3,500


3
Rainfall Regions
All Year
Summer Rainfall
Winter Rainfall

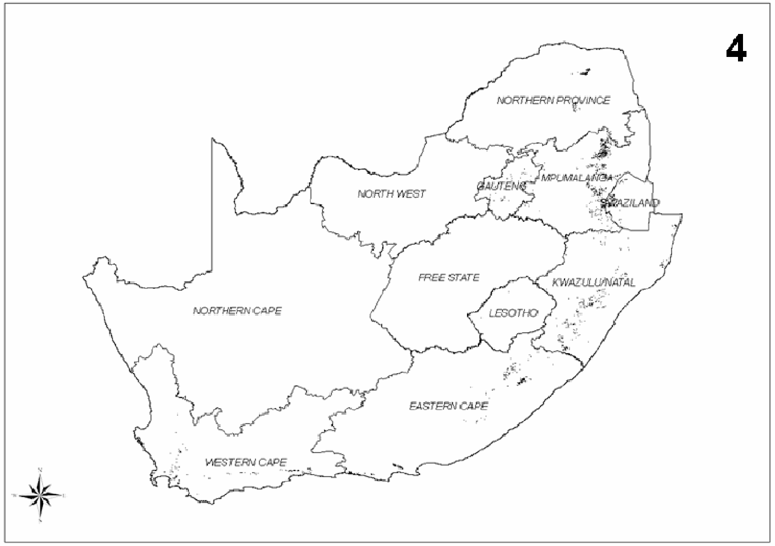

4
NORTHERN PROVINCE
NORTH WEST
GAUTENG
MPUMALANGA
SWAZILAND
FREE STATE
KWAZULU/NATAL
NORTHERN CAPE
LESOTHO
EASTERN CAPE
WESTERN CAPE

Figure 5. Spread of *S. noctilio* in South Africa from 1994-2008

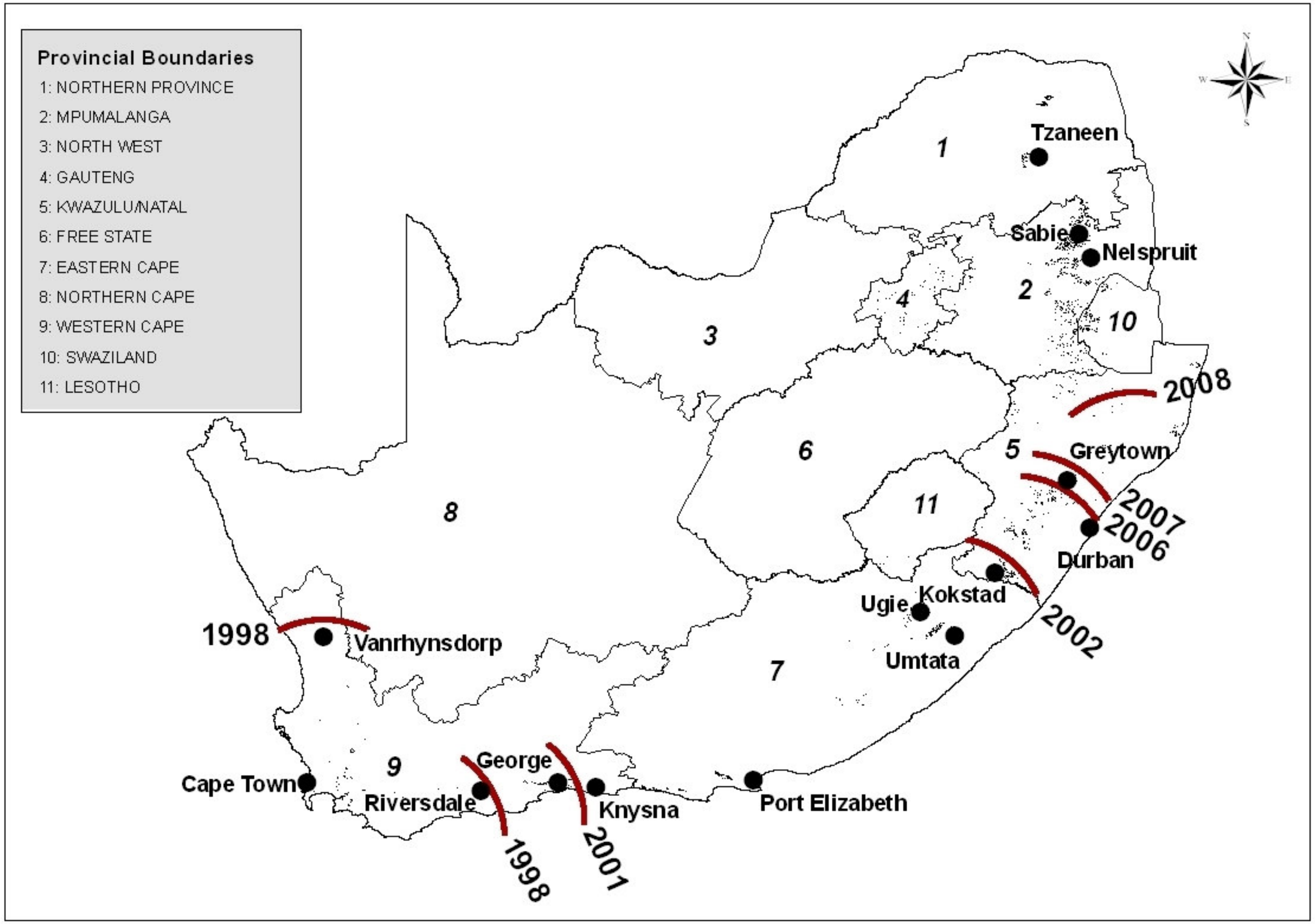

Provincial Boundaries
1: NORTHERN PROVINCE
2: MPUMALANGA
3: NORTH WEST
4: GAUTENG
5: KWAZULU/NATAL
6: FREE STATE
7: EASTERN CAPE
8: NORTHERN CAPE
9: WESTERN CAPE
10: SWAZILAND
11: LESOTHO
N
W
E
S
1
Tzaneen
Sabie
Nelspruit
2
4
3
10
2008
5
Greytown
6
11
2007
2006
Durban
8
Kokstad
Ugie
2002
1998
Vanrhynsdorp
Umtata
7
9
George
Cape Town
Riversdale
Knysna
Port Elizabeth
1998
2001

Figure 6. A. *Sirex noctilio* male emerging from untreated wooden packing material bores through empty cement bags sent to Johannesburg, showing ease at which *S. noctilio* can spread within South Africa. B. *Pinus patula* trees killed by *S. noctilio* in the KwaZulu-Natal province. C. The nematode *D. siricidicola* growing on the fungus *A. areolatum* on Petri-dish cultures in a laboratory environment. D. The parasitoid wasp *I. leucospoides* released as a biological control agent for *S. noctilio*. E. Lure-based black panel traps used to detect new infestations of *S. noctilio*.

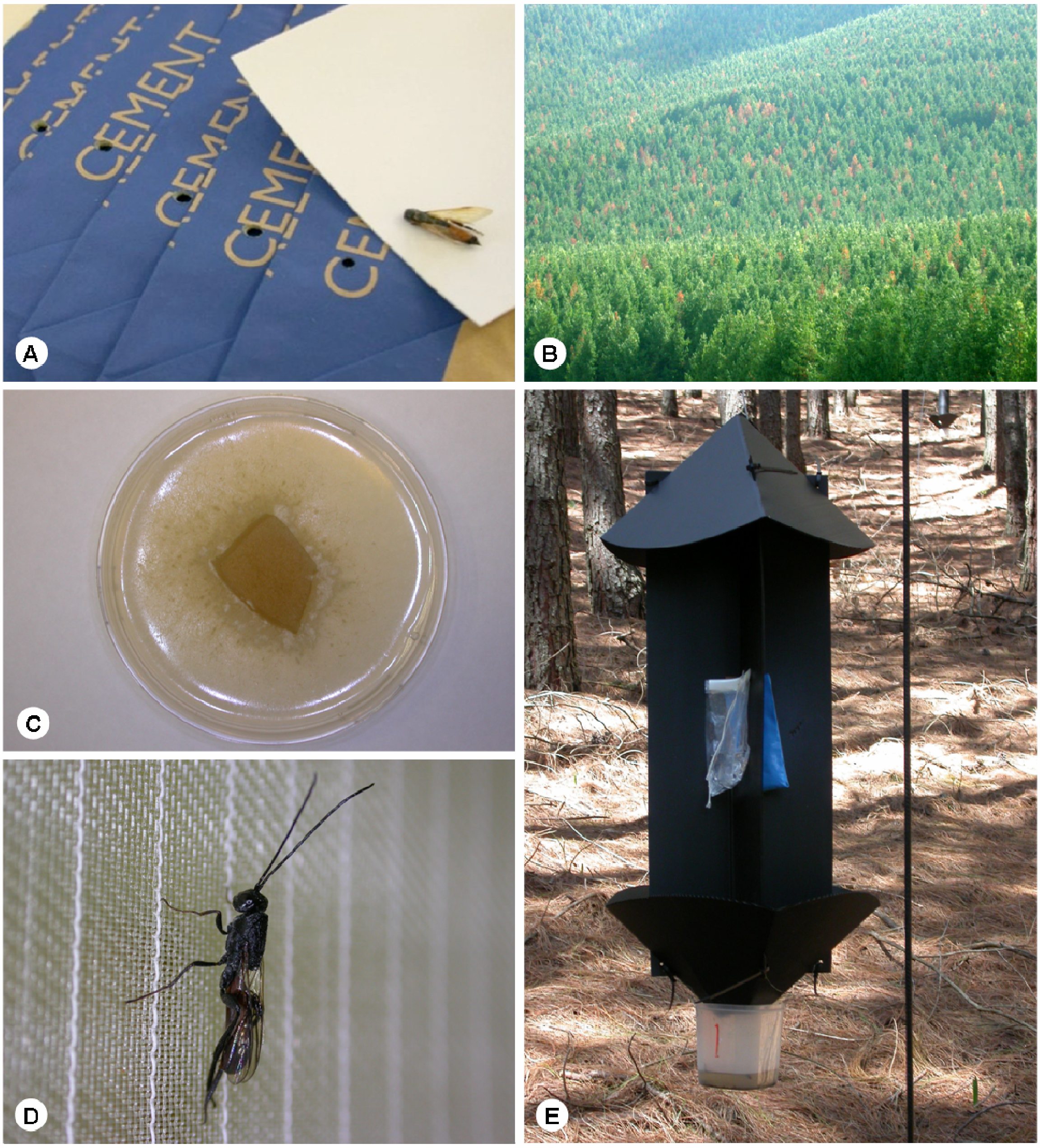

A
B
C
D
E

Figure 7. Techniques used to inoculate *D. siricidicola* into *S. noctilio* infested trees. A, B, C. Standard procedure of felling trees to inoculate. D. Inoculation hammers used. E. Adapted procedure of inoculating standing trees (used in pulpwood stands).


A
B
C
D
E