Flowering, fruiting, germination and seed dispersal of the newly emerging weed *Solanum mauritianum* Scop. (Solanaceae) in the wet tropics of north Queensland

S.K. Florentine[A,B], **M. Craig**[A] and **M.E. Westbrooke**[B]
[A] School for Field Studies, Centre for Rainforest Studies, Yungaburra, Queensland 4872, Australia.
[B] School of Science and Engineering, University of Ballarat, PO Box 663, Victoria 3350, Australia. Email: s.florentine@ballarat.edu.au

Summary

Solanum mauritianum **(wild tobacco) has recently become a weed of major concern in some agricultural production areas, and tropical rainforest restoration sites, of the Atherton Tablelands, north Queensland. Until recently, little was known about the ecology of this species. A study was conducted to examine: (i) the flowering, fruiting pattern, (ii) seed germination pattern, (iii) density of soil stored seed bank, and (iv) potential avian seed dispersers of *S. mauritianum*. Flowering and fruiting patterns were studied on randomly selected plants within the study site over a period of 35 days. A germination study was performed on green (unripe) and yellow (ripe) fruits with seeds from green fruits germinating faster than seeds collected from yellow fruits. The density of germinable seeds in the soil seed bank was determined from 94 samples collected beneath the canopy of 24 randomly selected *S. mauritianum* plants. Of seedlings that germinated, 73% were *S. mauritianum* and seedling density of *S. mauritianum* averaged 16 000 seedlings per hectare.**

To determine the role of birds in the dispersal of *S. mauritianum* seeds, observations were made of all birds visiting eleven fruit-bearing plants. To examine the bird's excrement, birds were captured in mist-nets, their excrement collected and any seeds present identified. A total of 340 seeds from 15 plant species were obtained. Four tropical rainforest birds (Australian king parrots (*Alisterus scapularis*), brown cuckoo doves (*Macropygia amboinensis*), spotted catbirds (*Ailuroedus melanotis*) and silvereyes (*Zosterops lateralis*)) consumed seeds of *S. mauritianum* and were potential seed dispersers.

Results suggest that *S. mauritianum* possessed ideal weed traits such as copious seed production, and high seedling recruitment from soil stored seed. Its use in rainforest restoration plantings should be discouraged as it may aid the spread of the species on the Atherton Tablelands.

Key words: avifauna, seed germination, *Solanum mauritianum*, soil seed bank, weed.

Introduction

Weeds are characterized by the ability to spread rapidly beyond their natural distribution, having high growth rates, rapid seedling recruitment, and high seed production (Kleinschmidt *et al*. 1987, Ashton and Monaco 1991, Zimdahl 1993). Weeds are often able to proliferate at the expense of native species, because they possess ecological characteristics that enable them to reproduce quickly. The invasion of non-native plants is considered one of the major threats to native ecosystems because they modify their function and biodiversity (Williams and West 2000). Williams and West (2000) reported that approximately 50% of naturalized exotics are considered invasive or environmental weeds. In Queensland, 57 (13%) of the 441 species of plants classified as endangered in 1992 are considered threatened by weed competition (Groves and Willis 1999). It is estimated that there are 950 introduced plant species in Queensland alone, making up 13% of the plant species (Humphries *et al.* 1991).

One such introduced species of concern is *Solanum mauritianum*, a perennial tree/shrub that originated in Argentina, Brazil, Uruguay, and Paraguay (Olckers 1999). Olckers (1999) found that in South Africa, *S. mauritianum* grows in high rainfall areas causing significant negative ecological and economic impacts on productive and conservation lands. In north Queensland, *S. mauritianum* was introduced in restoration programs because of its potential to attract birds that would naturally disperse the seeds of rainforest plants increasing the diversity of rainforest restorations (Adam 1994). It is currently present in low numbers in scattered parts of the Tablelands. There is however the potential for the species to spread and become a major agricultural and environmental pest across the Tablelands. If it became widespread any control regime would be very costly and probably futile.

In Australia, *S. mauritianum* is classified as a potential weed (Kleinschmidt *et al*. 1987). However, in the wet tropics of Australia, specifically the Atherton Tablelands, this species is widespread on roadsides, disturbed rainforest areas, along fence lines and in pasture lands (Kleinschmidt *et al.* 1987) and has the potential to become a significant weed.

Ecological data can be valuable in determining whether a weed is likely to become a serious pest and what control strategies should be implemented if it does (Panetta and McKee 1997). Little information is available on *S. mauritianum*, particularly its ecological characteristics in northeast Australia. This study was conducted to provide ecological information about the species. The objective of this study was to describe the ecology of *S. mauritianum* in the wet tropics by examining: (i) the flowering, fruiting pattern, (ii) seed germination pattern, (iii) density of soil stored seed bank, and (iv) potential avian seed dispersers of *S. mauritianum*. From this information we hoped to recommend whether the species should continue to be used in rainforest restoration plantings.

Methods

Study site

This study was conducted at the Centre for Rainforest Studies (17° 15′ 19″S, 145° 30′ 59″E) on the Atherton Tablelands of north Queensland, Australia. The study site is 62 ha in area and encompasses cleared land, *Acacia* regrowth rainforest (Type 12a of Tracey 1982) and mature rainforest (Types 5a and 8 of Tracey 1982). It is situated approximately 780 m above sea level and has an average rainfall of 1700 mm year^{-1}, most of it falling between December and May. *S. mauritianum* and other invasive species, such as lantana (*Lantana camara*), Singapore daisy (*Wedelia tricornuta*), blue top (*Ageratum conzyoides*), Guinea grass (*Panicum maximum*), and snake-weed (*Stachytarpheta jamaicensis*), are widespread on the forest edges, roads and tracks.

Flowering and fruiting

The flowering phenology of *S. mauritianum* was determined from six randomly selected mature plants that were flowering on the study site on 1 March 2001. Four flower bunches, one from each of the cardinal directions (north, south, east and west) were selected and covered with bird proof netting. Flowers were tagged, counted and monitored for seven weeks. Flowers that developed into fruits were selected and re-tagged upon fruiting.

The production of the total number of fruits per branch and total number of fruit bunches per *S. mauritianum* was estimated from 25 randomly selected plants within the study site. On each plant, four bunches, one from each of the cardinal directions, were selected and all fruits counted.

Seed germination
Fresh seed for germination studies was collected on 2 March 2001, from both green (unripe) and yellow (ripe) fruits of mature *S. mauritianum* located within the study site. Preliminary observations showed that green (unripe) fruits were consumed by birds, which is why we included them in the study. Seeds were extracted by soaking fruits in distilled water for 15 minutes. The extracted seeds were placed on a paper towel in a Petri dish and air-dried at room temperature for 24 hours. These air-dried seeds were placed in a labelled plastic bottle and kept at room temperature until used in the experiment. On the 20 March, seeds were separated into 24 lots of 50 seeds from green fruit and 24 lots of 50 seeds from yellow fruit and one lot from each of the green and yellow fruits was placed on a 5 cm Petri dish lined with two sheets of moistened filter paper. The 24 Petri dishes containing seeds were then placed in six compartments of a thermogradient incubator (LMMT, Lindner and May, Qld) set at six constant temperatures: 17.0, 22.0, 25.0, 29.5, 33.0, and 34.5°C. Each Petri dish received 12 h white fluorescent light and 12 h darkness and the number of seeds that germinated was recorded daily for 50 days.

Germinable seedbank
An estimate of the density of germinable seeds in the soil was determined from soil core samples. A total of 94 samples were collected from beneath 24 randomly selected plants using a soil corer (cores were 8.50 cm in diameter and 10.0 cm deep, with a volume of 567 cm^3). Samples were taken 1 m from the base of each plant in each of the four cardinal directions. Soil samples from each plant were bulked and placed in a plastic Ziploc bag and returned to the Centre. The soil samples were then placed in seedling trays (35 × 30 × 7 cm), lined with paper towels to maintain moisture and prevent soil from falling through the base. Each tray was labelled with a metal tag, placed in a shadehouse and watered at the start and daily thereafter if needed. Trays were checked weekly and any seedlings that germinated from the soil sample were identified to species.

Seed dispersal
To understand the possible role of avian frugivores in dispersing the seeds of *S. mauritianum*, a total of twenty-five hours was spent observing the behaviour of birds that visited *S. mauritianum* plants around the study site. Eleven fruit-bearing *S. mauritianum* were observed at four locations around the study site. Hour long observations took place between 06:30 and 7:30 and 15:30 and 17:30. To determine what proportion of seeds were consumed by frugivores, partially eaten fruit were collected on 25 and 26 February and the numbers of seeds left in the fruits were counted.

To determine whether seeds were being dispersed in the excrement of frugivores birds were captured in mist-nets from 0500 to 0730 hrs on 28 February, 1, 2, 16, and 17 March. Captured birds were transported to the Centre in cloth bags and placed in a dark holding pens (30 × 30 × 45 cm) where the floor was lined with paper. The birds were released after 30 minutes and any excrement was collected. The excrement was then washed with distilled water to separate the seeds from waste matter. Seeds were placed in glass vials and stored in a refrigerator until identified.

Results

Flowering and fruiting
The flower, fruit and seed production of *S. mauritianum* is given in Table 1. Just over 70 flowers per plant were observed at the first measurement but this fell to 59.33 ± 5.10 (Mean ± SE, n = 6 plants) and 8.00 ± 2.49 (mean ± SE, n = 6 plants), by the second and third day of measurements respectively. However, between the first and last measurements, 33.41% (n = 141) of flowers had fallen. Within seven days 12% (n = 51) of the flowers had turned to young fruit and by 21 days this number reached 73% (n = 332). The average number of bunches per plant and average number of fruits per bunch was 18.85 ± 1.28 (mean ± SE, n = 24 plants) and 6.75 ± 0.72 (mean ± SE, n = 24 plants) respectively. Mature *S. mauritianum* produce an average of 241.5 ± 14.22 fruits (n = 6 plants) and each mature fruit contains 161.57 ± 7.87 seeds (n = 28 fruits).

Seed germination
After 50 days, none of the seeds collected from the yellow fruits had germinated while seed from the green fruit had germinated at all temperatures. Germination percentage generally decreased with increasing temperature except at 29°C where seeds showed similar number of germination as in seeds placed in 17 and 22°C (Figure 1).

Soil seed bank
During the observation period 7 October 2000 – 31 May 2001, 824 seedlings germinated in the soil seed bank study of which 73% were *S. mauritianum*.

Seed dispersal

Table 1. Flowering and fruiting characteristics of *S. mauritianum*.

Parameter	N	Mean ± SE
Average number of flowers per plant	6	70.30 ± 4.22
Average number of fruits per bunch	24	18.85 ± 1.28
Average number of bunches per plant	24	6.75 ± 0.72
Average number of seed per fruit	28	161.57 ± 7.87
Average number of fruits per plant	6	241.5 ± 14.22

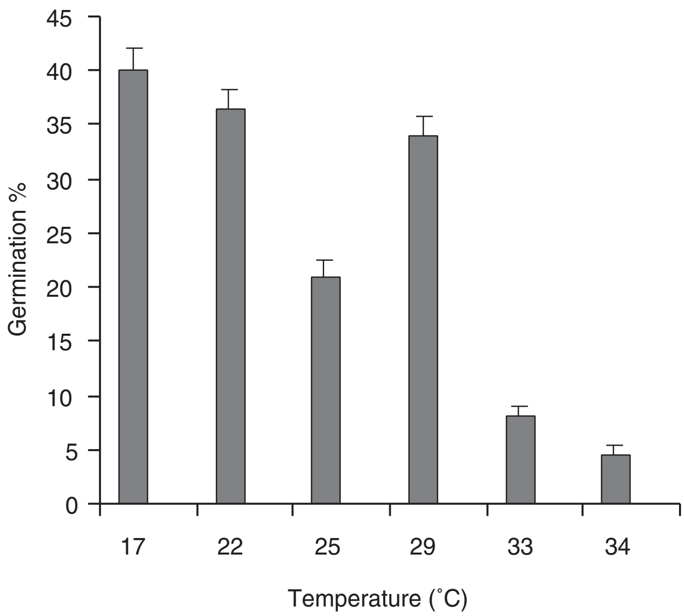

Figure 1. The effect of temperature on the germination percentage after 50 days of *S. mauritianum* seeds collected from green fruits, incubated in the light and dark. None of the yellow seeds had germinated.

Seventeen bird species were observed on *S. mauritianum* plants. A total of 100 individuals were observed during morning observations and 33 during afternoon observations. Only one of the 17 species observed, the brown cuckoo dove (*Macropygia ambionensis*), was an obligate frugivore. A further three species, spotted catbird (*Ailuroedus melanotis*), Victoria's riflebird (*Ptiloris victoriae*), and silvereye (*Zosterops lateralis*), were facultative frugivores. Spotted catbirds and brown cuckoo doves were observed to consume whole fruits. Undamaged fruits contain a mean of 161.57 (SE ± 4.03, n = 28), and it was found that minimum of 42.41 seeds were consumed by birds. Two seed predators, Australian king parrot (*Alisterus scapularis*) and red browed finch (*Neochmia temporalis*), were observed. Australian king parrots, which were often observed feeding on *S. mauritianum*, removed large numbers of fruits but dropped the partially eaten fruits on the ground. Partial damaged fruits contained a mean of 119.16 (SE ± 7.87, n = 25) seeds. They were also often observed with seeds stuck to their feathers while eating. Ten of the 17 species observed do not feed on seeds, nectar or fruit and so were probably visiting *S. mauritianum* to feed on insects, invertebrates, or small vertebrates or just for a perch since many birds observed were noted as just sitting on a branch. None of the birds observed were seen utilizing flowers for nectar.

Scat analysis

Fourteen individual birds belonging to five different species were captured and a total of 340 seeds belonging to 15 different plant species were collected from their excrement (Table 2). Of the seeds, six could be identified to species namely *Alphitonia petriei*, *Omalanthus novo-guineensis*, *Acacia* sp., *Ficus pleurocarpa*, *Ficus* sp., and *S. mauritianum*. *S. mauritianum* was found in the excrement of one silvereye (6%) and one Victoria's riflebird (1.5%).

Discussion

Solanum mauritianum produces an abundance of fruits and seeds, which is similar to other woody weeds in Australian ecosystems (Smith and Harlen 1991, Grice 1996, Gentle and Duggin 1997, Buist *et al*. 2000). This high seed production can often lead to successful invasion in disturbed areas (Olckers 1999, Buist *et al*. 2000).

Seeds from green (unripe) fruits germinated faster and had a higher germination rate than seeds collected from yellow (ripe) fruits. This is probably because fully mature seeds of *S. mauritianum* are embryo dormant and remain dormant for a short period after entering the soil profile (Campbell and van Staden 1983). This feature is similar to other species from the Solanaceae (Porter and Gilmore 1976, Roberts and Lockett 1977)

The present study documented that at least five different bird species consumed either partial or whole fruits of *S. mauritianum*. One of these, the brown cuckoo dove is a seed dispersal agent for a wide range of plant species in northeast Queensland and is capable of dispersing seeds long distances (Crome 1975). Another, the Australian king parrot was frequently observed dropping partially eaten fruits and was observed with seeds stuck to their feathers and faces while eating. These seeds may also be dispersed away from the parent plant. Amor and Piggin (1977) demonstrated that use of fruits or seed by generalist dispersal agents facilitated a weed to expand its range and this pattern had been found for a number of woody weed species in

Table 2. Bird species and total number of seeds collected from caught during the mist-netting.

Scientific name	Common names	Number of seeds excreted	Plant species	Family
Xanthotis macleayana	Macleay's honeyeater	2	*Alphitonia petriei*	Rhamnaceae
Zosterops lateralis	Silvereye	2	*Omalanthus novo-guineensis*	Euphorbiaceae
		5	*Omalanthus novo-guineensis*	Euphorbiaceae
		20	*Solanum mauritianum*	Solanaceae
		33	*Alphitonia petriei*	Rhamnaceae
Meliphaga lewinii	Lewin's honeyeater	3	*Omalanthus novo-guineensis*	Euphorbiaceae
		1	Unidentified	–
		4	Unidentified	–
		6	*Alphitonia petriei*	Rhamnaceae
Ptiloris victoriae	Victoria's riflebird	29	*Omalanthus novo-guineensis*	Euphorbiaceae
		3	Unidentified	–
		5	*Solanum mauritianum*	Solanaceae
		42	*Omalanthus novo-guineensis*	Euphorbiaceae
		57	*Acacia* sp.	Mimosaceae
		10	Unidentified	–
		2	*Alphitonia petriei*	Rhamnaceae
Ailuroedus melanotis	Spotted catbird	27	*Alphitonia petriei*	Rhamnaceae
		1	Unidentified	–
		1	Unidentified	–
		4	*Ficus pleurocarpa*	Moraceae
		7	*Ficus pleurocarpa*	Moraceae
		2	Unidentified	–
		35	*Ficus* sp.	Moraceae
		26	*Alphitonia petriei*	Rhamnaceae
		8	Unidentified	–
		5	Unidentified	–
Total	5	340	15	5

Australian ecosystems (Gleadow 1982, Bass 1991, Grice 1996, Panetta and McKee 1997, Rose 1997). Similarly, Olckers (1999) found that the invasion success of *S. mauritianum* in disturbed areas, forest edges and plantation in South Africa was due to prolific seed production and long-range seed dispersal by frugivorous birds. Because *S. mauritianum* is a food resource for birds in both rainforest and regrowth areas, and it attracts a considerable number of tropical rainforest bird species, it was often selected for restoration programs in northeast Queensland (Adam 1994). The results from mist netting and scat collection indicated that bird species utilizing *S. mauritianum* brought in 340 seeds from 15 different rainforest pioneer species. This is significant because mature *S. mauritianum* plants may provide a soil seed bank of pioneer species in disturbed areas which is one of the primary goals of restoration (Goosem and Tucker 1995, Tucker and Murphy 1997). However, the risk of long distance seed dispersal aiding the spread of *S. mauritianum* in new areas probably outweighs any benefits. Weed invasions are also associated with fragmentation or disturbance. Furthermore, edges of natural vegetation habitats are more sensitive to weed invasion than the core of a habitat (Hester and Hobbs 1991). These features have been clearly observed in the present study. In particular, both our seedling monitoring study plots and plants marked for phenology and bird observations were found in disturbed areas, which are often adjacent to tropical rainforest remnant vegetation. Also, a long-range seed dispersal agent such as brown cuckoo dove may play a vital role in distributing the seeds in to a new area

In conclusion, although *S. mauritianum* has been used as a 'bait crop' in restoration programs in Australia in the past, its copious seed production, high seedling recruitment from soil stored seeds and, allelopathic characteristics (Florentine and Westbrooke 2003) are all attributes that are typical features of an ideal weed (Rejmánek 2000). In South Africa this species has invaded forest edges, plantations and riparian edges aided by long range seed dispersal by frugivorous birds and a similar pattern has been observed in some Australian ecosystems. If *S. mauritianum* is left alone in open paddocks and cleared rainforest margins it becomes the dominant plant species and may hinder the recruitment of tropical rainforest pioneer and climax species. Although, this species attracts a number of birds that bring with them a significant number of seeds of pioneer species, we did not observe any seedling recruitment beneath the canopy of mature plants. Therefore, we do not recommend the use of *S. mauritianum* in rainforest restoration plantings. In fact, the removal of seedlings and mature plants from the infestation areas may reduce the soil seed bank and create suitable conditions for native pioneer species to grow successfully.

Acknowledgments

We would like to thank the following students from USA, Casie Stockdale, Jessica Knoll, Megan Bockenkamp, Tristan Wohlford, Julia Gustine, Noah Levine and Allison Eller, for their assistance during data collection. We thank Stephen Setter and Melissa Setter (Department of Natural Resources and Mines, Queensland) for permission to use the thermogradient incubator and for help with seed germination data collection. We are grateful to Dr. Per Milberg (Linkoping University, Sweden), Dr. Faiz Bebawi (Department of Natural Resources and Mines, Queensland) and two anonymous reviewers for providing valuable comments and suggestions on early versions of the manuscript. We would also like to thank Bruce Williams, Tracy Farrell, and Paul Houlihan for providing support and encouragement of this project. Birds were captured and banded with the approval of the Queensland Parks and Wildlife Service (Permit No. F1/000364/00/SAC), the Australian Bird and Bat Banding Scheme (Authority No. 2002, Project 2) and the Department of Primary Industries Animal Ethics Committee Approval No. FNQ 00/010. This research was funded by School for Field Studies, Beverly, USA.

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Survey of *Polymeria longifolia* (Lindley) in the Australian cotton industry

Stephen B. Johnson[A,B], **Brian M. Sindel**[B] and **Christine E. Jones**[C]

[A] Australian Cotton Research Institute, Narrabri, New South Wales 2390, Australia.

[B] Agronomy and Soil Science, School of Rural Science and Agriculture, University of New England, Armidale, New South Wales 2351, Australia.

[C] Formerly of Botany, School of Environmental Sciences and Natural Resources Management, University of New England, Armidale, New South Wales 2351, Australia.

Summary

The present status and control of polymeria take-all (*Polymeria longifolia* Lindley) in the Australian cotton industry was assessed in a survey involving the 96 cotton consultants and farm agronomists in New South Wales (NSW) and southern and central Queensland (Qld) at the start of the 1996/97 growing season. The survey aimed to draw together much of the anecdotal information that existed about the weed and to use this information to direct future research needs. A response rate of 62.5% was achieved indicating that the survey technique was successful and that there was real concern about the impact of this weed.

The areas of greatest concern for polymeria take-all were the Gwydir, Namoi and Macintyre Valleys and the St. George area. Overall, even though infestations occurred in only 1% of the area surveyed, it was believed to be the fourth worst weed in cotton crops, being difficult to control and causing large yield reductions by removing moisture from the soil. The additional cost of treatment of polymeria take-all ranged from \$12 to \$100 ha^{-1} y^{-1}. Herbicide application was regarded as the most successful means of control but it resulted in a decrease in the occurrence of the weed in only 37% of cases and all herbicides registered for in-crop use in non-herbicide resistant cotton were ineffective.

Introduction

Polymeria take-all (*Polymeria longifolia* Lindley) is a native Convolvulaceae species and a weed of both irrigated and dryland cropping in Australia (Johnson 2000). In a survey of NSW cotton growers conducted during the 1988/89 growing season, polymeria take-all was found to affect 23% of cotton properties and appeared to be increasing in abundance (Charles 1991). The difficulty in controlling polymeria take-all in existing cotton areas and the rapid development of large infestations in areas of expanding production, for example, Walgett (north western NSW) and St. George/Dirranbandi (south western Qld), has highlighted the need for ecologically based research in an effort to develop more successful management strategies.

While there has been extensive research into the distribution, biology and control of many weeds in Australia, for example, Groves *et al*. (1995) and Panetta *et al*. (1998), there is a notable lack of published data on the 34 genera indicated as cotton weed problems, including polymeria take-all (Charles 1991). The survey reported in this paper aimed to draw together observations made by cotton consultants and agronomists regarding the weed to direct future research. In particular, information was sought on the relative importance of polymeria take-all among other weeds of cotton, where polymeria take-all occurred, the factors believed to favour its growth and what problems it caused, the cost of control and effective management methods.

Materials and methods

The mail survey was undertaken at the start of the 1996/97 cotton growing season. The survey was given advance publicity by way of a poster presentation at the Eighth Australian Cotton Conference (August 1996) where the form was piloted to elucidate any ambiguities or other problems intrinsic in the questions.

Professional consultants and large-farm agronomists (referred to from here on as consultants) were targeted in the survey rather than individual growers for two important reasons. Firstly consultants are responsible for a wide range of agronomic advice to growers including weed identification and control. Secondly, a broader and more comprehensive picture could be obtained which would show less variability than responses from individual growers.

A short presentation about polymeria take-all was delivered at a meeting attended by NSW consultants during September 1996. The one page, double-sided survey was then handed out for