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Biocontrol of *Chromolaena odorata* in Papua New Guinea

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Chromolaena odorata (L.) King and Robinson (Asteraceae) is a significant agricultural weed in Papua New Guinea (PNG), affecting plantations, food gardens and grazing lands. It was the focus of a collaborative biocontrol program funded by the Australian Government between 1998 and 2007. Chromolaena was recorded at 680 sites in 13 provinces of PNG through surveys, field releases of biocontrol agents and feedback from public awareness programs. Three biocontrol agents, the moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae), the stem-galling fly *Cecidochares connexa* (Macquart) (Diptera: Tephritidae) and the leaf mining fly *Calycomyza eupatorivora* Spencer (Diptera: Agromyzidae), were introduced to control chromolaena. *Cecidochares connexa* was found to be the most effective of the agents introduced as it quickly established at over 300 sites where it was released and spread up to 100km in five years from some sites. Experimental field plots established to determine the impact of the agents on chromolaena, showed that the size of chromolaena infestations decreased with the presence of *C. connexa*. A survey was conducted to quantify the social and economic benefits of biocontrol of chromolaena to landholders. Chromolaena is considered to be under substantial/significant control in nine provinces in PNG, with about 50% of respondents stating that there is less than 50% of chromolaena remaining following the release of the gall fly. This has resulted in landholders spending less time clearing chromolaena and the re-establishment of small-scale subsistence farms and the regeneration of natural vegetation. Crop yield and income generated from the sale of agricultural produce have increased by at least 50% since chromolaena was brought under biocontrol. It is anticipated that the gall fly will continue to spread and control chromolaena in areas where it has not yet reached, thereby further reducing the impact of the weed in PNG.

KEYWORDS: *Calycomyza eupatorivora*; *Cecidochares connexa*; economic benefits; field monitoring; *Pareuchaetes pseudoinsulata*

INTRODUCTION

Chromolaena odorata (L.) King and Robinson (Asteraceae) or chromolaena, is native to the Caribbean and was first reported in Papua New Guinea (PNG) in East New Britain Province in the 1960s (Henty and Pritchard 1973). It subsequently spread to another 11 provinces through the movement of people and machinery, particularly logging equipment (Day and Bofeng 2007). Chromolaena impacts on agricultural production and natural ecosystems. In plantations, it can form a dense understorey, preventing landholders from collecting coconuts, cocoa pods and oil palm nuts, and reducing vanilla production. Chromolaena can invade small-scale subsistence farms, reducing the yield of crops such as *Colocasia esculenta* (L.) Schott (Araceae) (taro), *Dioscorea alata* L. (Dioscoreaceae) (yam), *Carica papaya* L. (Caricaceae) (papaya) and *Musa acuminata* Colla (Musaceae) (bananas). It also increases

the time required to weed such gardens (Orapa 1998; Day and Bofeng 2007). As a result, income generated from the sale of crops is reduced, while clearing of new areas for crop production becomes increasingly difficult. Chromolaena has also infested grazing lands in PNG, displacing preferred pasture species and increasing the cost of maintaining paddocks. Regeneration of plant species in logged areas, as well as natural succession and biodiversity in fallow lands has also been affected negatively by chromolaena (Orapa et al. 2002).

In 1998, a biological control program against chromolaena, coordinated by the Queensland Government, was initiated, with funding from the Australian Centre for International Agricultural Research (ACIAR). Three biological control agents, the leaf-feeding moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) obtained from Guam in 1998, the stem-galling fly *Cecidochares connexa* (Macquart) (Diptera: Tephritidae) obtained from the Philippines in 2001, and the leaf-mining fly *Calycomyza eupatorivora* Spencer (Diptera: Agromyzidae) first obtained from South Africa in 2004 (Bofeng et al. 2004) were introduced after evaluation showed them suitable for release. This paper updates Day and Bofeng (2007), and reports on activities since the completion of the project in 2007, including an assessment of the impacts of the biocontrol agents and the benefits to landholders in PNG.

MATERIALS AND METHODS

Distribution of chromolaena

The distribution of chromolaena in PNG was determined through direct observations by project staff while releasing biocontrol agents and through reports arising from the distribution of brochures and other public awareness programs. Locations of infestations were obtained using a Global Positioning System (GPS) unit or from approximate co-ordinates obtained from web-based sites such as Google Earth or EarthTools or through government census reports.

Field status of biocontrol agents on chromolaena

Pareuchaetes pseudoinsulata

Field surveys to determine the presence and extent of the moth *P. pseudoinsulata* were conducted throughout Morobe and Eastern Highlands provinces where it had established. Surveys were conducted in August and September 2008 when numbers of larvae are the greatest. At each site, plants were searched for eggs, larvae and/or signs of larval feeding damage. Plants were searched mainly in the early morning or late afternoon when larvae are more active. During the day, larvae move down into the leaf litter where they are more difficult to find. Opportunistic surveys were also conducted in other provinces while performing other project duties.

Cecidochares connexa: field release and distribution

Field trips were conducted in all provinces where the presence of chromolaena had been confirmed, during which the presence/absence of *C. connexa* was determined. Bunches of stems containing about 100 galls, collected in Morobe Province, were released in areas with chromolaena where the gall fly was not yet present. The presence of the gall fly was recorded using a hand-held GPS unit or from approximate co-ordinates obtained from web-based sites such as Google Earth or EarthTools or through government census reports.

Impact of *Cecidochares connexa*

The effect of *C. connexa* on chromolaena was measured quantitatively and qualitatively. For many sites in most provinces, the number of galls present on chromolaena was counted and the degree of damage was described. Detailed monitoring was conducted in Morobe (five study sites) from early 2004 and East New Britain (one study site) from early 2007. At each site, five fixed $1m^2$ quadrats were laid out and the number of stems per quadrat, stem height and the number of galls per stem recorded every eight weeks. In addition, at each site in Morobe province, a 100m transect line was set out and the percentage of the line

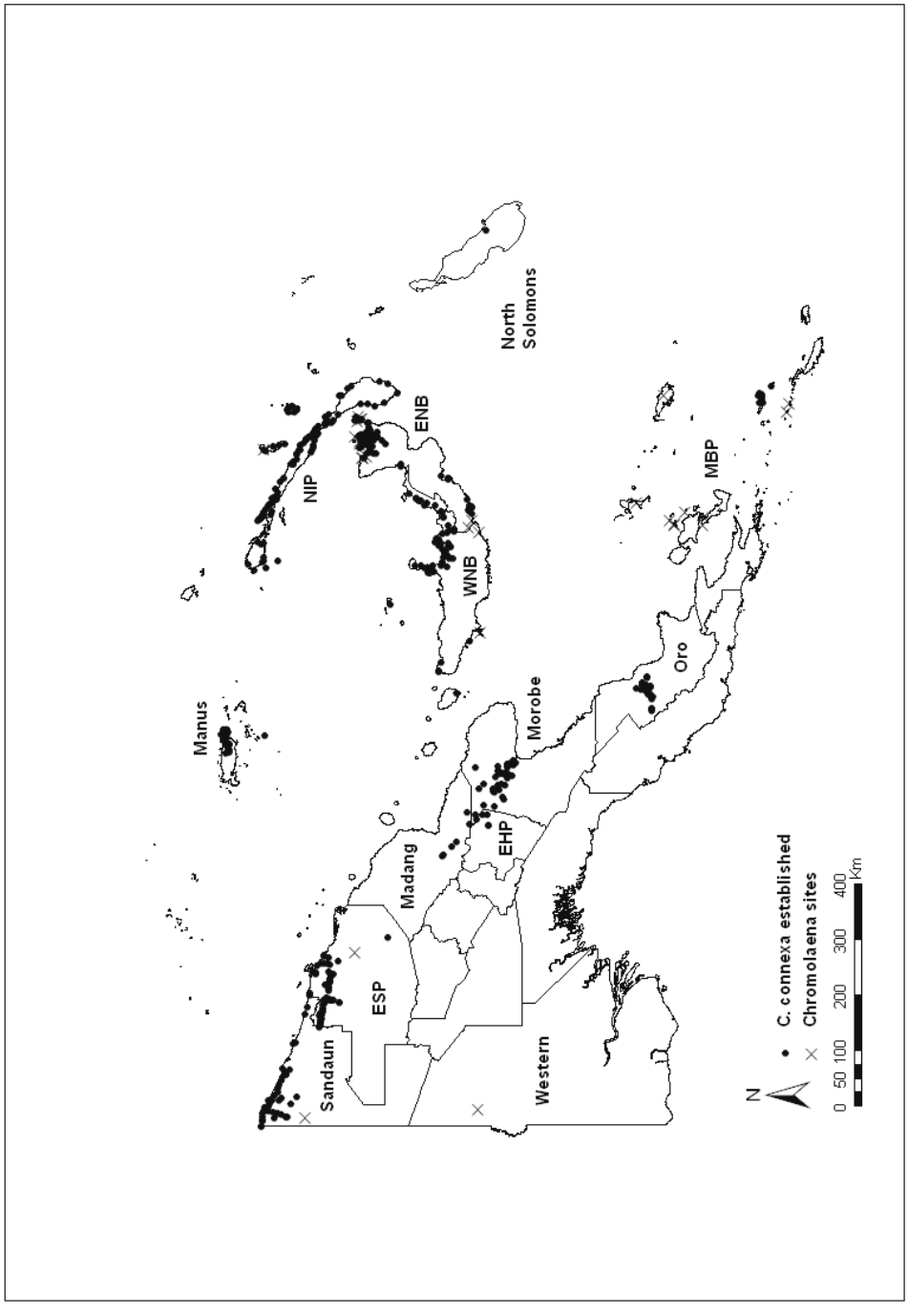

Figure 1. The known distribution of *Chromolaena odorata* in Papua New Guinea (all symbols) and where *Cecidochares connexa* has established. EHP = Eastern Highlands Province; ESP = East Sepik Province; ENB = East New Britain; MBP = Milne Bay Province; NIP = New Ireland Province; WNB = West New Britain.

covered by chromolaena was determined every eight weeks in order to calculate percent cover over time. Monitoring ceased at all sites in September 2009.

Calycomyza eupatorivora

Seven shipments of this leaf-mining fly were imported into PNG from 2004-6, following host -specificity testing conducted by the ARC-Plant Protection Research Institute in South Africa (Day and Bofeng 2007). As the *C. eupatorivora* could not be reared in quarantine and the insectary, direct field releases of newly emerged adults from the last two shipments were conducted (Day and Bofeng 2007). Over 1,000 flies were released at five sites all in the Markham Valley, Morobe Province between February and March 2006. At two sites, Labu (riverbank) (near 6°40′27.6″S 146°54′33.4″E) and Wara Pumpkin (6°40′34.9″S 146°53′ 58.2″E), less than 100 flies were released at each site. Over 100 adults were released at Kasuka (6°27′36.6″S 146°43′13.0″E) over three occasions, nearly 500 flies were released at Labu (piggery) (6°40′27.6″S 146°54′33.4″E) over 12 occasions and approximately 300 adults were released at Limbun (no GPS reading) over seven occasions. Sites were checked weekly for developing mines for two months after the final release.

Economic benefits arising from the biocontrol of chromolaena

Surveys to ascertain the benefits of biocontrol of chromolaena using *C. connexa* were conducted throughout PNG where the gall fly had been released. The survey consisted of 22 questions covering land use, whether or not the gall fly was present, the change in the size of the chromolaena infestations, and whether there were changes in time spent weeding, cost of control, yield of crops and income, following the release of the gall fly. Landholders were selected from roadside markets to avoid bias towards particular land uses or visible changes to chromolaena density.

RESULTS

Distribution of chromolaena

From 2006 until 2010, chromolaena was reported in only one province (Western), at one site at Kiunga (Fig. 1), additional to the other 12 provinces where chromolaena was already

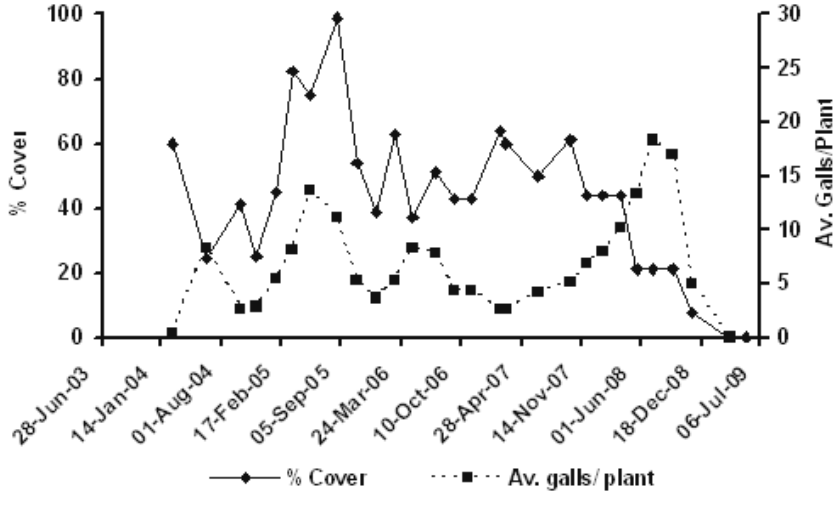

Figure 2. Percent chromolaena cover and the average number of *Cecidochares connexa* galls/plant at Kasuka site 1, Morobe Province.

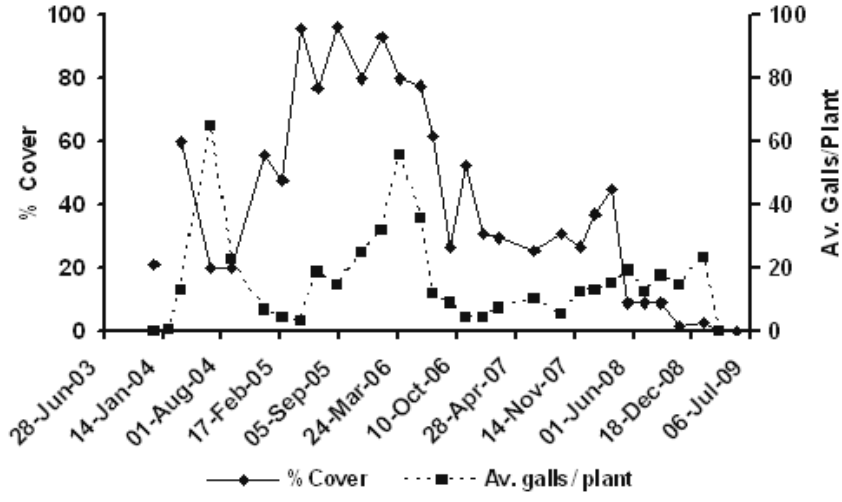

Figure 3. Percent chromolaena cover and the average number of *Cecidochares connexa* galls/plant at Trukai Farm, Morobe.

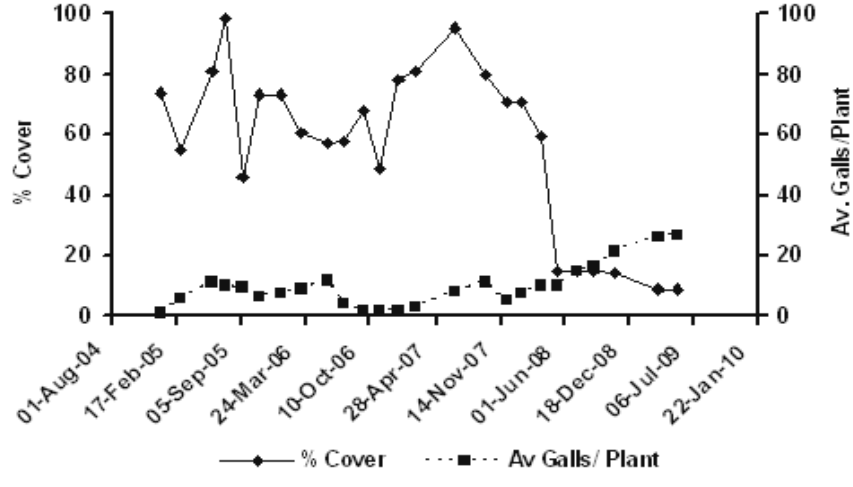

Figure 4. Percent chromolaena cover and the average number of *Cecidochares connexa* galls/plant at Wantoat Road, Morobe Province.

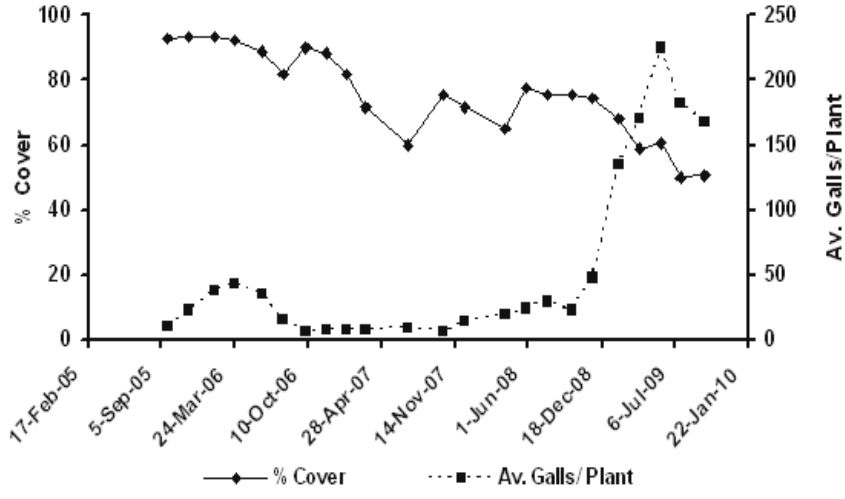

Figure 5. Percent chromolaena cover and the average number of *Cecidochares connexa* galls/plant at Kasuka site 2, Morobe Province.

known. There were unconfirmed reports of chromolaena being present in Central Province (Day and Bofeng 2007). However, several surveys conducted in 2009 and 2010 failed to confirm these reports.

There was a slight increase in the extent of spread of chromolaena in most provinces from where chromolaena was reported in Day and Bofeng (2007). Chromolaena was recorded on several more islands in Milne Bay Province since 2006. It was also found further west along the Sepik Highway in East Sepik Province and is more widespread in East New Britain, West New Britain and Madang Provinces (Fig. 1). These infestations may have existed for several years but were discovered due to wider search efforts during field releases and assessment of the biocontrol agents.

Field status of biocontrol agents on chromolaena

Pareuchaetes pseudoinsulata

Surveys conducted in August-September 2008 found *P. pseudoinsulata* at Kassam Pass in Eastern Highlands Province where it was released in 2004 and at nine other sites in the province where it had not been released. It was found at only two sites in Morobe Province and no sites in any other province.

Cecidochares connexa: field release and distribution

Since September 2006, over 23,000 galls were released at over 90 sites, covering 11 provinces. Provincial staff and the public also assisted in the spread of the agent by collecting galls from established sites and moving them to areas where the fly was not present. However, these releases were opportunistic and independent of any releases made by project staff. Hence, there are no official records of numbers released or where.

The establishment rate was over 98%, with only four sites where the gall fly failed to establish. These sites were either slashed or burnt soon after the gall fly was released. Since releases commenced in 2001, *C. connexa* has been confirmed at nearly 300 release sites, covering all provinces except Western Province where the release site was destroyed. Following

establishment, the gall fly spread quickly, moving up to 7km from release sites within the first two years of release, 40km within four years and dispersing over 100km in five years. It was found at nearly 300 additional sites, suggesting that the gall fly is now present at almost 90% of the known chromolaena-infested sites in PNG (Fig. 1).

Impact of *Cecidochares connexa*

In most areas where there were more than 20 galls per plant, dieback of branches and stems was noticeable. Plant death often occurred when gall numbers exceeded 100 per plant. Chromolaena is now reported under substantial/ significant control at over 200 sites in nine provinces, namely Bougainville, East New Britain, Eastern Highlands, Madang, Manus, Morobe, New Ireland, Oro and Sandaun, with subsistence farms and natural vegetation subsequently being re-established.

Monitoring of four of the study sites demonstrated that chromolaena cover decreased over time with the presence of the gall fly (Fig. 2-5). At Kasuka site 1 (6°27′36.6″S 146°43′ 13.0″E) (Fig. 2) and Trukai Farm (6°30′54.3″S 146°42′54.4″E) (Fig. 3) both in Morobe Province, chromolaena cover at each site was about 60% when the gall fly was released in March 2002 and April 2001 respectively. By March 2009, all plants in the study sites had died due to the impact of galling by *C. connexa*. The average number of galls per plant at each site fluctuated between 5 and 20 during this period. At Kasuka site 1 and Trukai Farm, recruitment of trees, herbaceous plants and grasses were observed to increase as chromolaena cover decreased.

At the Wantoat Road study site (6°21′49.5″S 146°25′46.6″E), which is further west than Kasuka and Trukai Farm, chromolaena cover decreased from nearly 80% in 2004 to less than 10% in 2009, while the average number of *C. connexa* galls per plant fluctuated between 1 and 15 during this period (Fig. 4). At a fourth site in Morobe Province, also at Kasuka, percent cover decreased from 93% in September 2005 to 50% in September 2009, while the number of galls per plant fluctuated over the same time between 5 and 40 before increasing to over 200 per plant in mid 2009 (Fig. 5).

Monitoring of the two remaining sites was disrupted. At Bomginan, Morobe Province (data not presented), chromolaena cover decreased until late 2006 when a fire destroyed much of the study area. Following the fire, chromolaena cover began to steadily increase in 2007. Gall fly numbers subsequently began to increase and by January 2009, stem die back was observed and by September 2009, percent cover had decreased to around 69%.

At a sixth study site, at Vulcan, East New Britain Province, chromolaena cover decreased from 65% in early 2007 to 15% in late 2008. The site was burnt, after which the plants began to recover without the presence of the gall fly. Monitoring ceased when the site was burnt again in 2009.

Calycomyza eupatorivora

First generation mines appeared on some plants around Labu (piggery) following release but no flies emerged. Mines were not seen at any other site. Consequently, the fly has not established at any site in PNG.

Economic benefits arising from the biocontrol of chromolaena

Over 130 landholders, representing nearly 80 villages and covering six provinces, namely Madang, Manus, Morobe, New Ireland, East New Britain and West New Britain were interviewed. Most of these landholders (81%) were mixed-cropping subsistence farmers or were engaged in semi-commercial cropping. About 85% of respondents reported a reduction in chromolaena following the release of *C. connexa*. Over 50% of respondents stated that the average area invaded by chromolaena was half of the area previously invaded prior to release of the gall fly. There was a corresponding decrease in the time spent controlling chromolaena, with 40% of respondents stating that they spend less than half the time controlling the weed than before the gall fly was released, and 37% of

respondents reported that control costs in terms of labour and herbicides were also less than 50% of those prior to the release of the gall fly.

About 70% of respondents reported an increase in crop yield and subsequent increase in income from the sale of crops. Overall, about 40% of the landholders reported moderate to substantial benefits of the reduced chromolaena while another 34% reported minor benefits. While crop yield and associated income generally increased as a result of control by the gall fly, many landholders also reported that chromolaena generally improved soil quality.

DISCUSSION

Since 1998, three biocontrol agents have been released in PNG in an attempt to control chromolaena. *Pareuchaetes pseudoinsulata* established in only Morobe and Eastern Highlands provinces and is damaging on only a seasonal basis. *Pareuchaetes pseudoinsulata* was difficult to establish in PNG as well as in other countries where it has been introduced, as large numbers of larvae are required to be released simultaneously (Muniappan et al. 2007). Similarly, where the moth has established elsewhere, damage to chromolaena has also been seasonal (Zachariades et al. 2009). When larval numbers were high after the wet season, plants became defoliated and larvae then fed on the young stems. Following the defoliation of plants in PNG, moth populations declined significantly and there was a considerable lag time before populations built up again to damaging numbers. For much of the year, especially during the dry season, larval numbers were generally low and there was minimal damage to the plants (Day and Bofeng 2007).

It is possible that in some instances in PNG, especially in provinces other than Morobe, insufficient numbers of moths were released or that the releases were not coordinated so as to ensure a critical mass of larvae was present at the same time to overcome Allée effects. Due to the difficulty in achieving successful establishment, it is unlikely that further releases or redistribution of the moth will be conducted.

Despite being imported seven times from 2004-6, a colony of *C. eupatorivora* could not be established and the insect does not appear to have established at any of the five sites at which it was released in PNG. It is not known why the agent failed to establish. Incompatible host is unlikely to be a reason as *C. eupatorivora* has been found on several forms of chromolaena in South America (C. Zachariades pers. comm. 2006). Other leaf-mining Agromyzidae utilised for weed biocontrol were easy to rear and have readily established on their target weeds (Day et al. 2003). It is hypothesised that the areas in the Markham Valley in Morobe Province are much warmer than those in South Africa where the fly readily established and may therefore be unsuitable for the fly's establishment.

The most successful agent on chromolaena in PNG is *C. connexa*. It was easy to mass-rear, field-release and establish and spread quickly from release points, moving up to 100km in five years. *Cecidochares connexa* is now present at 90% of chromolaena sites throughout PNG and is expected to continue to disperse as the weed spreads. It is also a particularly damaging agent. Stem or branch dieback of chromolaena is observed when *C. connexa* gall numbers reach 20 galls per plant, while larger plants can die if gall numbers reach above 100.

Day and Bofeng (2007) reported substantial control of chromolaena in Sandaun and New Ireland provinces. Since then, chromolaena is reported to have been brought under control by the gall fly in most areas of nine provinces. Patches of chromolaena still exist but the sizes of infestations are much smaller than prior to the release of the gall fly. Reports from around Aropa airport on Bougainville Island indicate that very little of the original chromolaena infestation remained a few years after the gall fly's introduction in 2005 (J. Konam pers. comm. 2008). Similar trends have been observed in East New Britain, where very little chromolaena remains in the province in comparison to a few years ago (J. Bokosou pers. comm. 2009). Control was generally reached more quickly in the wetter lowland provinces of PNG, particularly East New Britain, New Ireland and Bougainville, than in the drier

provinces such as Morobe and Madang.

In Morobe province, control of chromolaena using *C. connexa* has not been as marked or as rapid as in the other provinces. However, a high level of control as measured by decreased plant cover, height and density, occurred at three sites (Kasuka, Trukai Farm and Wantoat Road), while at other sites in the same province there has been a general decrease in the size of chromolaena infestations.

While control of chromolaena has been achieved with the establishment of *C. connexa* in most provinces, control has not been observed in many parts of West New Britain. The reasons for this are not clear. West New Britain is generally a wet province and the cooler daytime temperatures experienced may affect the behaviour and reduce mating opportunities of the female gall flies. Female *C. connexa* adults typically require daytime temperatures of at least 30°C to mate (R. McFadyen pers. comm. 2010).

The release and re-distribution program of *C. connexa* was highly successful, with as little as 100 mature galls needed to achieve establishment. There were only four occasions where *C. connexa* did not establish and these were usually because sites had been cleared and/or burnt soon after the gall fly was released.

The gall fly is expected to continue to spread either through natural means or by re-distribution by villagers and landholders. However, in remote areas which are far from sites where *C. connexa* has established, such as parts of West New Britain, Milne Bay and Western Province, galls will still need to be released.

Field monitoring data and general observations showing that there is an overall reduction in the amount of chromolaena in PNG, have been supported by the socio-economic surveys conducted. Landholders also reported a substantial decrease in chromolaena following the introduction of the gall fly, as well as reductions in weeding times and control costs, coupled with increases in crop yield and associated income. Chromolaena still needs to be cleared at times, especially when new crops are established, but infestations are not as severe, nor are the plants as tall as they were prior to the establishment of the gall fly.

Cecidochares connexa has been released in numerous other countries where it is also reported to have a significant impact on chromolaena (Zachariades et al. 2009). In Indonesia, the gall fly is widespread and has reduced chromolaena density, particularly in northern Sumatra, in combination with *P. pseudoinsulata* and the butterflies *Actinote anteas* (Doubleday and Hewitson) and *A. thalia pyrrha* Fabr. (Lepidoptera: Nymphalidae) (Tjitrosemito 2002; Wilson and Widayanto 2004; R. Desmier de Chenon pers. comm. 2010). *Cecidochares connexa* is also well established and contributing to the control of chromolaena in the Federated States of Micronesia, Palau, Guam and Timor Leste (Zachariades et al. 2009; Day et al. this proceedings; M. Day pers. obs. 2009).

Cecidochares connexa is expected to continue to spread from current locations in PNG as chromolaena spreads. With time, it is hoped that the gall fly will reduce the rate of spread of chromolaena and that it will continue to control chromolaena in PNG, providing relief for farmers in controlling the weed.

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REFERENCES

Bofeng I, Donnelly G, Orapa W, Day MD (2004) Biological Control of *Chromolaena odorata* in Papua New Guinea. In: Day MD,

McFadyen RE (eds) Chromolaena in the Asia-Pacific region: proceedings of the sixth international workshop on the biological control and management of chromolaena, Cairns, Australia, May 2003. ACIAR Technical Reports No. 55, Canberra, Australia, pp 14-16

Day MD, Bofeng I (2007) Biocontrol of *Chromolaena odorata* in Papua New Guinea. In: Lai P-Y, Reddy GVP, Muniappan R (eds) Proceedings of the seventh international workshop on biological control and management of *Chromolaena odorata* and *Mikania micrantha*, Pingtung, Taiwan, September 2006. National Pingtung University of Science and Technology, Taiwan, pp 53-67

Day MD, Wiley C, Playford J, Zalucki MP (2003) Lantana: current management status and future prospects. ACIAR, Canberra, Australia

Henty EE, Pritchard PH (1973) Weeds of New Guinea and their control. Botany Bulletin No. 7, Department of Forests, Lae, Papua New Guinea

Muniappan R, Englberger K, Reddy GVP (2007) Biological control of *Chromolaena odorata* in the American Pacific Micronesian Islands. In: Lai P-Y, Reddy GVP, Muniappan R (eds) Proceedings of the seventh international workshop on biological control and management of *Chromolaena odorata* and *Mikania micrantha*, Pingtung, Taiwan, September 2006. National Pingtung University of Science and Technology, Taiwan, pp 49-52

Orapa W (1998) The status of *Chromolaena odorata* in Papua New Guinea. In: Ferrar P, Muniappan R, Jayanath KP (eds) Proceedings of the fourth international workshop on biological control and management of *Chromolaena odorata*, Bangalore, India, October 1996. Agricultural Experiment Station, Mangilao, Guam, USA, pp 82-85

Orapa W, Donnelly GP, Bofeng I (2002) The distribution of Siam weed, *Chromolaena odorata,* in Papua New Guinea. In: Zachariades C, Muniappan R, Strathie LW (eds) Proceedings of the fifth international workshop on biological control and management of *Chromolaena odorata*, Durban, South Africa, October 2000. ARC-PPRI, Pretoria, South Africa, pp 19-25

Tjitrosemito S (2002) Introduction and establishment of the gall fly *Cecidochares connexa* for control of Siam weed, *Chromolaena odorata*, in Java, Indonesia. In: Zachariades C, Muniappan R, Strathie LW (eds) Proceedings of the fifth international workshop on biological control and management of *Chromolaena odorata*, Durban, South Africa, October 2000. ARC-PPRI, Pretoria, South Africa, pp 140-147

Wilson CG, Widayanto EB (2004) Establishment and spread of *Cecidochares connexa* in Eastern Indonesia. In: Day MD, McFadyen RE (eds) Chromolaena in the Asia-Pacific region: proceedings of the sixth international workshop on the biological control and management of *Chromolaena odorata*, Cairns, Australia, May 2003. ACIAR Technical Reports No. 55, Canberra, Australia, pp 39-44

Zachariades C, Day M, Muniappan R, Reddy GVP (2009) *Chromolaena odorata* (L.) King and Robinson (Asteraceae). In: Muniappan R, Reddy GVP, Raman A (eds) Biological control of tropical weeds using arthropods. Cambridge University Press, Cambridge, UK, pp. 130-162