PREDICTABLE RISK TO NATIVE PLANTS IN BIOLOGICAL CONTROL OF WEEDS IN HAWAI'I.

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ABSTRACT. The analysis examines the use of non-target native plants in Hawai'i resulting from biological control projects on target weeds with close relatives compared with projects on target weeds that lack close relatives. Target weeds with close relatives are riskier targets for biological control than are weeds without close relatives in Hawai'i. The two projects conducted against weeds with close relatives resulted in non-target use of native species; four of the five insect species established in these projects now use native plant species as hosts. Only one of 18 (5.6%) projects against Hawaiian weeds that lack close relatives has produced native plant use. Overall, 53 of 54 agents established for weed control exhibit predictable and highly stable host ranges. This pattern of non-target plant use indicates that the risk to the native flora can be judged reliably before introduction. The degree of risk is directly related to the relative relatedness of the targeted weeds and the native flora and the specificity of the natural enemies employed.

Keywords: biological control of weeds, non-target use, insect/plant interactions

INTRODUCTION

Biological control is a valuable method of controlling introduced pests in agriculture and in natural areas. Biological control is currently being employed against invasive weeds at a number of United Nations World Heritage Sites including South African Cape Fynbos, Kakadu National Park in northern Australia, and Everglades National Park in Florida (Center 1995). It has been an important tool in the fight against introduced weeds in Hawai'i for almost 100 years (Funasaki *et al.* 1988).

Like other pest control technologies it carries some risk. The associated risks relate primarily to organisms targeted for biological control and host specificities of the biological control agents employed. The safety of introduced biological control organisms to non-target native organisms is an important issue in biological control (Follet & Duan 2000, Wajnberg 2001). In the 1980's some practitioners of biological control of weeds reported the use of native plants by introduced biological control agents (Andres 1985, Pemberton 1985, Turner 1985, Turner *et al.* 1987). Howarth (1983, 1991) challenged the safety of biological control in general and specifically in Hawai'i, claiming harm to native insects by introduced biological control parasitoids. Hawkins and Marino (1997) examined the use of North American native insects by introduced parasitoids and found that 16% of these parasitoids adopted native insects as hosts. Louda *et al.* (1997) reported population level damage to a native *Cirsium* thistle in Nebraska by the biological control weevil *Rhinocyllus conicus* (Froelich) (Coleoptera, Curculionidae). Because of the concerns for and documented cases of non-target impacts, reform of biological control practice and regulation to ensure greater attention to environmental safety is needed (McEvoy and Coombs 2000, Strong and Pemberton 2000).

An important part of the biological control safety debate concerns the predictability and stability of the host ranges of introduced biological control agents. Understanding the predictability and stability of the host ranges of introduced agents is hampered by the lack of general assessments of non-target host usage. This paper draws upon my recent analysis of the use of non-target native plants by introduced biological control agents of weeds in the United States, the Caribbean, and Hawai'i (Pemberton 2000). Presented here is the information for Hawai'i.

MATERIALS AND METHODS

The analysis examines the use of non-target native plants in Hawai'i resulting from biological control projects on target weeds with close relatives compared with projects on target weeds that lack close relatives. By "use" I mean a completed life cycle of the introduced agent on the non-target plant species. "Use" does not imply impact that is unstudied. Close relatives are defined as congeneric species in the native flora. The data set includes the establishment of 54 agents on 20 target weeds in Hawai'i. The first releases were against *Lantana camara* L. (Lamiales, Verbenaceae) in 1902. The last introductions resulting in establishment included in the analysis were in 1994; later releases were excluded because I judged that insufficient time had passed for agent population growth and dispersal to non-target species. Overall agents established on weeds with close relatives and on weeds without close relatives have been released for similar mean lengths of time (47 vs. 50 years, respectively).

The source of information on biological control of weeds projects in Hawai'i is Julien and Griffiths' 1998 *Biological Control of Weeds: A World Catalogue of Agents and Their Target Weeds*. The principal source of information on the use of non-target native plants is the entomological literature supplemented with personal communications with researchers familiar with the projects.

RESULTS AND DISCUSSION

Target weeds with close relatives are riskier targets for biological control than are weeds without close relatives in Hawai'i. The two projects conducted against weeds with close relatives resulted in non-target use of native species; four of the five insect species established as biological control agents in these projects now use native plant species as hosts (Tables 1, 2). The project to control an introduced blackberry, *Rubus argutus* Link - Rosales, Rosaceae) led to the establishment of three insect species in the 1960's; all three use the two native Hawaiian species, *Rubus hawaiensis* A. Gray *and R. macraei* A. Gray, (Funasaki *et al.* 1988, George Markin, personal communication). The other project in this category, control purple nutsedge, *Cyperus rotundus* L. - Juncales, Cyperaceae, established two insect species, one of these, a weevil (*Athesapeuta cyperi* Marshall, Coleoptera, Curculionidae) introduced in 1925, uses a native sedge *Cyperus polystachyos* Rottb. (Poinar 1964).

By comparison, only 1 of the 18 (5.6%) projects against Hawaiian weeds that lack close relatives has produced native plant use (Tables 1, 2). In these projects, only 1 of 49 (1.6%) established biological control agents now uses a native Hawaiian host. The lacebug *Teleonemia scrupulosa* Stal (Hemiptera,Tingidae), introduced for control of *Lantana camara L.* (Lamiales, Verbenaceae), was reported to use *naio, Myoporum sandwicense* (DC) Gray (Lamiales, Myoporaceae), an endemic shrub (Maehler and Ford 1955, Bianchi 1961). All five biological control insects that have adopted native non-target plants as hosts were released prior to 1970, before risk to native plants was seriously considered by Hawaiian biological control researchers (Ken Terramoto, personal communication). In Hawaiian biological control projects, 53 of 54 established agents exhibit predictable and highly stable host ranges.

Teleonemia scrupulosa was collected in Mexico and released in Hawai'i in 1902, without host specificity testing. The insect has been thought to be a *Lantana* specialist (Winder and Harley 1983). The Myoporaceae and Verbenaceae are now considered to be in the same order- the Lamiales (Angiosperm Working Group 1998), but lantana and *naio* are not closely related. Changes in our understanding of plant phylogenetic relationships brought about by molecular research (e.g., DNA sequence data: Angiosperm Working Group 1998) suggest that it will be important to evaluate the weed and its relatedness to the Hawaiian flora in this light. The true host range of *T. scrupulosa* is unclear. When introduced to Uganda for lantana control, it fed on and damaged sesame, *Sesamum indicum* L. - Lamiales, Pedaliaceae), and reproduced on the plant to a limited extent (Davies & Greathead 1967). This report, as well as other unverified records on target hosts (a *Lippia* sp. - Verbenaceae) in the Antilles, ebony, *Diospyros* sp. - Ebenales, Ebenaceae) in the U.S. (Drake and Ruhoff 1965), and *Xanthium* sp. (Asterales, Asteraceae) in Hawai'i (Funasaki *et al.* 1988), suggest that the insect may not be the specialist that it was presumed to be. Recent searches on the island of Hawai'i, where both *naio* and lantana grow closely together, found much *T. scrupulosa* damage to lantana but none to *naio* (S. Hight and P. Conant, personal communication).

This pattern of non-target plant use by introduced biological control agents indicates that the risk to the native flora can be judged reliably before introduction. The degree of risk is directly related to the relative relatedness of the targeted weed and the species in the native flora. Species in the native flora can be protected by selecting target weeds that are related only distantly to species in the flora and by employing agents with diets narrow enough to avoid damaging native plants in the flora.

Hawai'i's flora is taxonomically circumscribed, with many common plant families absent or with limited distribution (Wagner *et al.* 1999). Most invasive weeds are distantly related to native species, which suggests that biological control programs against these weeds would unlikely harm native species. Of the 20 targeted weeds for which biological control agents were released prior to 1994, only two have close relatives. These weeds were targeted because of the problems they caused, independent of the presence of native relatives. The Hawai'i Department of Agriculture's Priority lists of weeds for FY 2000 (Nakahara 1999) lists 30 plant species for which chemical/mechanical or biological control activities will be directed. Seven of these plants belong to non-native families, while 17 others belong to non-native genera (Wagner *et al.* 1999). Only six of these plants have congeneric native relatives that could be put at risk by biological control. These are species of *Acacia*, *Caesalpinia*, *Cenchrus, Rubus*, *Solanum*, and possibly *Digitaria* (one species may be native) (Wagner *et al.* 1999).

Most of the seriously disruptive weeds in Hawai'i lack close relatives in the native flora. For instance, Hawai'i has many invasive weeds in the Melastomataceae, including the dangerous *Miconia calvescens* DC (Myrtales, Melastomataceae) (Medeiros *et al.* 1997), but no native members of this family. Similarly, Hawai'i has no native gingers (Zingiberales, Zingiberaceae) so biological control of Kahili ginger (*Hedychium gardnerianum* Sheppard ex Ker-Gawl.), which can dominate the understory of rain forests at mid-elevations, should be of low risk to the native flora. However, cultivated gingers in Hawai'i are closely related and must be considered. Although this paper deals with the risk to native plants, risk to other valued plants (agricultural, horticultural, and cultural) related to the target weed also should be considered, as they traditionally have been. Likewise, the lack of native species of *Psidium*, *Senecio*, and *Paederia* suggest that weeds in these genera are appropriate targets. Since all three genera belong to families containing native plants, it is important to evaluate the degree of relatedness of the weeds to their confamilial Hawaiian relatives. Invasive weeds with close relatives, such as Himalayan blackberry (*Rubus ellipitcus* Sm.), would be much riskier targets for biological control. Specialist insects typically use host plants limited to a circumscribed taxonomic range (Strong *et al.* 1984), e.g., within a plant family, within a tribe within a family, a genus, subgenus, section or even a species. However, single species specificity is less common than genus or subgenus host specificity). Plant pathogens may have narrower host plant ranges than insects, with some forms limited to subspecific taxa of plants, as with the rust *Puccinia chondrillina* Bubak & Snow (Uredinales, Pucciniaceae) used to control rush skeletonweed, *Chondrilla juncea* L.in California (Piper and Andres 1995). Careful determination of field host range of the candidate biological control organism in its native area coupled with rigorous host plant specificity testing will predict the agent's potential host range in the area of introduction. The specificity required depends directly on the degree of relatedness of the target weed and species in the local native flora (Pemberton 2000). Biological control agents employed against melastomaceous weeds in Hawai'i need be tested against native species only at the family level to assess their likely use of native species. By contrast, agents employed against *Rubus* weeds should be tested against individual species of *Rubus* to avoid introducing species that might feed on Hawai'i's two native *Rubus* species. The natural enemy pool from which to select biological control agents will be larger for potential agents that require testing only at the family level. Species level specialists, which may be needed for weeds with congeneric native relatives, may not exist or may be difficult to find. Moreover, projects on weeds with close relatives will be more expensive because more exploration and host specificity testing will be needed to identify narrower specialists.

Given enough resources and time to identify specialist enemies and to confirm their specificities, projects on weeds with close relatives can still be viable. The biological control effort against leafy spurge (*Euphorbia esula* L.) in North America is an example of a successful program on a weed with many native relatives in North America (Nowerski and Pemberton, in press). This program was successful despite the many native *Euphorbia* species in North America for a number of reasons. First, most of the native species were actually not very closely related the target weed; most belong to subgenera other than the subgenus *Esula* to which the target weed belongs. Second, funding for the primary research programs continued for more than 25 years, which enabled the examination of large numbers of candidate agents. This enabled the narrow specialists to be identified and employed and the candidates with broader host ranges to be discarded. Third, large numbers of narrow specialists that are also very damaging to target weed, the *Aphthona* flea beetles (Chrysomelidae), had evolved with subgenus *Esula* plants.

Given the constraints on funding for biological control, the limited quarantine space and low number of qualified biological control researchers, only a small portion of invasive weeds can be subject to full biological control programs. Potential targets are then necessarily prioritized by the seriousness of the problems they cause (kinds of impacts, rates of spread, etc.), the control potential and cost of biological control, and risk associated with such projects. Weeds with close relatives reasonably should be of lower priority. Because biological control can be so effective against invasive weeds that are frequently difficult to manage by other methods, there is a tendency to view all such weeds as appropriate targets. But biological control may not be the most appropriate control method for weeds with close native relatives. The risk to native plants associated with biological control projects on weeds with close relatives should be considered in relation to the risks associated with other control methods or with the continued spread of the weed. In the fight against aggressive invasive weeds, absence of control is not without risk as well. Fortunately, most Hawaiian weeds appear to be safe targets for biological control.

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TABLE 1. Known non-target native host plants of introduced biological control agents of weeds in Hawai'i.

Target Weed	Non-target plant host	Biological control agent	Reference
Cyperus rotundus (purple nut sedge- Cyperaceae)	*Cyperus polystachyos* (manyspike flatsedge-Cyperaceae)	*Athesapeuta cyperi* (Coleoptera: Curculionidae)	Poinar, 1964
Lantana camara (lantana- Verbenaceae)	*Myoporuum sandwicense* (naio- Myoporaceae)	*Teleonemia scrupulosa* (Hemiptera: Tingidae)	Maehler & Ford, 1955; Bianchi, 1961
Rubus argutus (prickly Florida blackberry-Rosaceae)	*Rubus hawaiensis* (Hawaii blackberry- Rosaceae)	*Croesia zimmermani* (Lepidoptera: Tortricidae)	Funasaki et al., 1988 Markin pers. com.
		Priophorus morio (Hymenoptera:Tenthredindae)	G. Markin pers. com.
		Schreckensteinia festaliella (Lepidoptera: Heliodinidae)	G. Markin pers. com.
	Rubus macraei ('akala)	*Croesia zimmermani* (Lepidoptera: Tortricidae)	G. Markin pers. com.
		Priophorus morio (Hymenoptera:Tenthredindae)	G. Markin pers. com.
		Schreckensteinia festaliella (Lepidoptera: Heliodinidae)	G. Markin pers. com.

TABLE 2. Comparison of non-target use of native plants by introduced agents in biological control projects on target weeds with close relatives against projects on target weeds that lack close relatives. Close relatives are plant species that belong to the same genus as the weed.

	Target Weeds	
	With native relatives	Without native relatives
Percent of projects with non-target use	100	5.6
	(2 of 2)	(1 of 18)
Percent of agents adopting native hosts	80.0	2.0
	(4 of 5)	(1 of 49)
Number non-target plants used	3	1

Total agents	54
Percent using non-target native plants	9.3
Percent of unpredicted use	1.6