CHAPTER 30

Erythrina Gall Wasp Successfully Controlled by the Introduction of a Parasitoid Wasp in Hawaii

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NON-TECHNICAL SUMMARY

The erythrina gall wasp (*Quadrastichus erythrinae*) (Hymenoptera: Eulophidae) invaded Hawaii in 2005. High infestation levels and tree mortality rates were observed on the endemic wiliwili (*Erythrina sandwicensis*) tree and other exotic erythrina species soon after the gall wasp's arrival. A classical biological control program was initiated a few months after detection. A promising biocontrol agent, *Eurytoma erythrinae* (Hymenoptera: Eulophidae) was collected during foreign exploration in Africa and approved for release in 2008. The parasitoid quickly established in Hawaii and significantly reduced leaf infestation levels and tree mortality. Flowering and seed production resumed, but flower-infestation levels are still high at some sites. A second biocontrol agent is currently being considered for release to provide an improved level of control.

HISTORY OF INVASION AND NATURE OF PROBLEM

Quadrastichus erythrinae (Hymenoptera: Eulophidae), also known as the erythrina gall wasp (EGW) (**Fig. 1**), is an invasive species in Hawaii that was recorded for the first time in the Mascarene Islands and Singapore in 2003 (Yang et al., 2004). The gall wasp quickly spread through the islands in the Indian Ocean, in South-East Asia, and islands in the Pacific Ocean (Day et al., 2021). It was first detected on the island of Oahu in Hawaii in 2005, and within a few months it spread through all the main Hawaiian Islands (Heu et al., 2008).

Female gall wasps lay eggs inside young leaves, stems, petioles, flowers, and seedpods of trees in the genus *Erythrina* (Kim et al., 2004; Heu et al., 2008).

Figure 1. Adult female *Quadrastichus erytrhinae* on a galled leaf. (M. Tremblay, University of Hawaii)

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Larval feeding induces swelling (galling) of the infested tissues. Heavy infestations (**Fig. 2**) cause defoliation and can lead to tree mortality (Kim et al., 2004).

In Hawaii, the EGW was first found infesting the exotic tree *Erythrina variegata* in urban and agricultural settings (Heu et al., 2008), and shortly afterwards infestations were detected in forests on the endemic tree *E. sandwicensis*, locally known as wiliwili. *Erythrina variegata* was commonly used in Hawaii as a windbreak in agricultural fields, while the ornamental form of the same species was a common tree in urban areas. The endemic wiliwili is one of the few dominant endemic trees of lowland dry forests in Hawaii, and it has important ecological functions in that ecosystem (Little and Skolmen, 1989; Wagner et al., 1990). Lowland dry forests are considered one the most endangered habitats in the Hawaiian Archipelago (Cabin et al., 2000). The endemic wiliwili also has strong cultural significance for native Hawaiians.

Figure 2. Galled erythrina leaves, showing severe infestation and malformation. (L. Kaufman, University of Hawaii)

WHY CONTROL THIS INVASIVE SPECIES?

High levels of EGW infestation were observed on exotic and endemic erythrina trees soon after the detection of the invasive wasp in Hawaii, and these quickly caused tree mortality in both urban and natural areas (Kaufman and Yalemar, 2017; Kaufman et al., 2020). The Department of Parks and Recreation of the City and County of Honolulu removed over 1,000 dead *E. variegata* trees within a year of the invasion (Vorsino, 2006). Early methods of control included pruning and removal of infested material, tree removal, and chemical control (Kaufman et al., 2020). None of these methods were found to be sustainable for controlling the gall wasp, especially in remote natural areas. Without effective and self-sustaining control tools, the endemic wiliwili was at risk of extinction, with trees dying and surviving trees not flowering or producing seeds.

THE ECOLOGY OF THE PROBLEM

The windbreak and ornamental forms of the exotic *E. variegata* proved to be highly susceptible to the gall wasp, and most of those trees quickly died. Similarly high mortality rates were observed for the endemic wiliwili, which caused great concern to the conservation community. A seed-banking program was started in 2007 to ensure there would be germplasm available for future restoration efforts (Hollier, 2007).

The EGW was also reported infesting several exotic species of *Erythrina* growing in botanical gardens around the islands, with various degrees of severity. A susceptibility study that examined 71 *Erythrina* species present in Hawaiian botanical gardens determined that *Erythrina* species of African origin were more tolerant or resistant to the gall wasp than species from other regions, suggesting a possible African origin for the invasive wasp (Messing et al., 2009).

Given that no other control method was sustainable or practical as a means to save the endemic wiliwili, a classical biological control of the EGW was started only a few months after the detection of EGW in Hawaii, with the goal of reuniting the invasive pest with natural enemies from its area of origin and restoring balance to the EGW/*Erythrina* tree system in the invaded area.

PROJECT HISTORY THROUGH AGENT ESTABLISHMENT

In 2005, shortly after the severity of EGW infestations in Hawaii was realized, exploration for natural enemies of EGW began in Africa. Africa was considered the most likely origin of the pest, as many species of *Erythrina* had previously been observed hosting gall insects in South Africa. The spread of EGW also appeared to have started on islands close to the east coast of Africa (Mauritius and Réunion), followed by rapid invasion of other islands in the Indian Ocean, then Pacific Ocean islands, Southeast Asia, and Taiwan. In 2006 and 2007, explorations were carried out in South Africa, Mozambique, Kenya, Tanzania, Benin, and Ghana by entomologists from the Hawaii Department of Agriculture and the University of Hawaii at Manoa. Collections returned to the Hawaii quarantine facility yielded at least 13 species of parasitoids. Of these, two species (*Eurytoma erythrinae* [**Fig. 3**] and *Aprostocitus nitens*) (both Hymenoptera: Eulophidae) were selected for further study because they appeared to be dominant parasitoids and could be reared in the quarantine facility. *Eurytoma erythrinae* was collected from a wide geographic range (Tanzania to South Africa) and from various species of gall wasps attacking *Erythrina* species in Africa. Also, this parasitoid had promising impacts on the target gall wasp under quarantine conditions. Non-target host screening was conducted in quarantine on seven non-target species in 2008. These studies found that *E. erythrinae* was host specific to EGW versus gall-makers found in the Hawaii fauna. The non-target gall-making species used in these host specificity tests included one Hawaiian endemic psyllid, four beneficial galling insects used for weed biological control (three tephritids and one eriococcid), and two immigrant galling wasps (one agaonid and one eulophid). Permission was obtained in December 2008 to release *E. erythrinae* in Hawaii. Batches of 30–60 wasps were released into populations of EGW-infested *Erythrina* trees. The parasitoid established readily after release, and recoveries were made within three to six months at most release sites. Pre-release monitoring had started previously, in early 2008, while post-release monitoring spanned a period of 10 years. Monitoring sites were established in several locations on the four main islands (Kauai, Oahu, Maui and Hawaii Island). High levels of gall wasp mortality were observed within a year of releasing the biological control agent (**Fig. 4**).

Figure 3. Female *Eurytoma erythrinae.* (Hawaii Department of Agriculture)

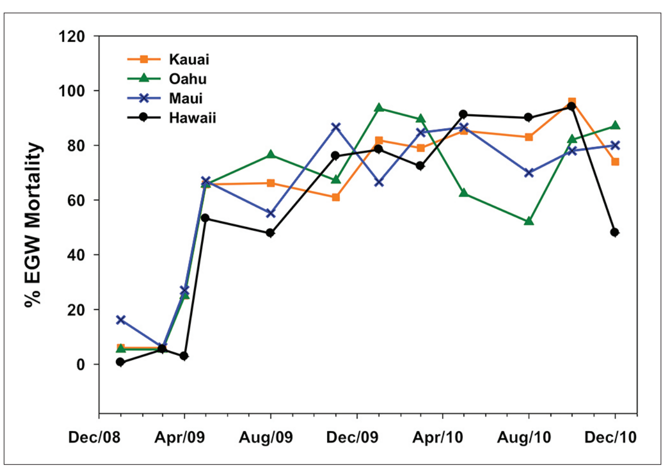

Figure 4. *Quadrastichus erythrinae* mortality attributed to Eurytoma erythrinae in galled Eythrina leaves on four Hawaiian islands over a two-year period following release of the biocontrol agent. (from Kaufman et al., 2020, reprinted with permission from Elsevier)

HOW WELL DID BIOLOGICAL CONTROL WORK

Pre- and post-release monitoring data measuring gall wasp damage levels and *E. erythrinae* persistence over a period of ten years showed that the biocontrol agent *E. erythrinae* was very effective at reducing infestation levels, as well as tree mortality rates (Van Driesche et al., 2016; Kaufman and Yalemar, 2017; Kaufman et al., 2020). Monitoring consisted of rating infestation levels separately in leaves and flowers and using a 4-point scale (scale from 0 to 3). During flowering season, young inflorescences were tagged and inspected monthly until seeds reached maturity. During the pre-release monitoring period, over 70% of young shoots inspected were rated as severely infested (infestation levels 2 or 3) (**Fig. 5**). At the end of the third post-release year, over 80% of the young foliage was free from gall wasp damage (Kaufman et al., 2020). Before the release of the biocontrol agent, about 15% of monitored trees were able to flower, and <3% were able to mature seeds, due to high gall wasp infestations in flowers and seedpods. By the third-year post-release, over 60% of monitoring trees were able to flower and over 20% of the trees were able to mature seeds (Kaufman et al., 2020). Even though flowering and seed production resumed after release of the first biological control agent, infestation levels in inflorescences and seedpods remained high at some sites (Van Driesche et al., 2016). With the goal of further suppressing galling of inflorescences, a second biocontrol agent, *Aprostocitus nitens* (Hymenoptera: Eulophidae), is currently being considered for release. An Environmental Assessment and Cultural Impact Assessment have been completed, and the filing for release permits by the Hawaii

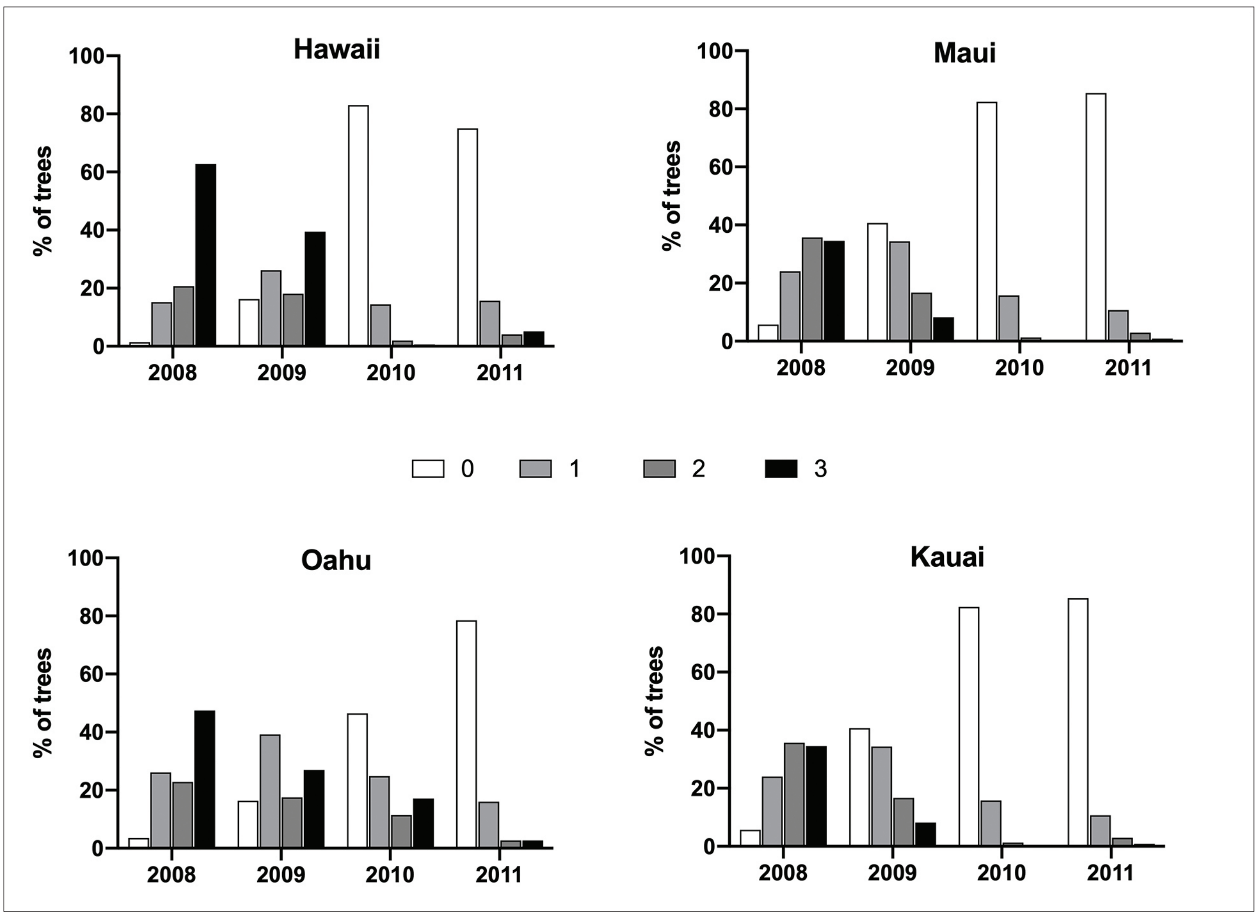

Figure 5. Changes in *Quadrastichus erythrinae* damage levels on a 0–3 scale (0 = zero infestation; 3 = 66–100% infestation) over a three-year period following release of *Eurytoma erythrinae* in 2008, on four Hawaiian islands. (from Kaufman et al., 2020, reprinted with permission from Elsevier)

Department of Agriculture is pending. Pre-release monitoring is currently documenting the status of flower and foliage infestations at several sites. This second biocontrol agent is expected to have different feeding preference and therefore reduce overall infestation levels (Kaufman et al., 2020).

A census of wild wiliwili stands conducted in 2012 found that 30–35% of trees had died due to EGW infestations (Van Driesche et al., 2016). Mortality rates would have been higher if the biocontrol agent was not released in a timely manner.

BENEFITS OF BIOLOGICAL CONTROL OF ERYTHRINA GALL WASP

Classical biological control of EGW in Hawaii is clear proof that the approach can be successfully used for the conservation of native species and ecosystems (Kaufman et al., 2020). EGW posed an imminent threat of extinction to the endemic wiliwili. The timely release of *E. erythrinae* significantly reduced infestation levels and mortality rates of the endemic wiliwili, eliminating that threat to conservation of a critical native tree. Before the parasitoid's release, the only effective method of EGW control was the injection of infested trees with systemic insecticides. Even though chemical control was effective at reducing infestation levels in urban settings, it was not cost-effective or feasible for remote wild tree populations. Data collected after the release of the biological control agent also showed that tree recovery was delayed in sites that received pesticide treatments, suggesting that pesticide residues interfered with the successful establishment of *E. erythrinae*. In non-treated areas, the biological control agent established readily after release and self-dispersed to remote natural areas. The biocontrol agent is also safeguarding many species of exotic erythrina grown as ornamental trees in Hawaii.

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