

Review

# The *Erythrina* Gall Wasp *Quadrastichus erythrinae* (Insecta: Hymenoptera: Eulophidae): Invasion History, Ecology, Infestation and Management

Sheng-Feng Lin <sup>1</sup>, Gene-Sheng Tung <sup>2,\*</sup> and Man-Miao Yang <sup>1,\*</sup><sup>1</sup> Department of Entomology, National Chung Hsing University, Taichung 40227, Taiwan; sflin654@gmail.com<sup>2</sup> Division of Botanical Garden, Taiwan Forestry Research Institute, Taipei 100051, Taiwan

\* Correspondence: gall@tfri.gov.tw (G.-S.T.); mmy.letsfall@gmail.com (M.-M.Y.)

**Abstract:** The *Erythrina* gall wasp *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae) is an invasive insect that induces galls on coral trees (species of *Erythrina*, Fabaceae) in urban and suburban landscapes. Weakening and death of the tree were both observed after the infestation by this insect, wherein feeding and consequent draining of nutrients by a large population of *Q. erythrinae* could be playing a key role. In this article, we consolidate and summarize the information on the distribution, invasion route, ecology, infestation level, and management of *Q. erythrinae* populations in the last two decades and analyze the challenges in their management.

**Keywords:** invasive insect; gall-inducing wasp; coral tree; urban tree



**Citation:** Lin, S.-F.; Tung, G.-S.; Yang, M.-M. The *Erythrina* Gall Wasp *Quadrastichus erythrinae* (Insecta: Hymenoptera: Eulophidae): Invasion History, Ecology, Infestation and Management. *Forests* **2021**, *12*, 948. <https://doi.org/10.3390/f12070948>

Academic Editors: Rostislav Zemek and Katarína Pastirčáková

Received: 11 June 2021

Accepted: 14 July 2021

Published: 18 July 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

*Quadrastichus erythrinae* Kim is a gall-inducing wasp (Hymenoptera: Eulophidae) which was not known until year 2000, when it became a serious invasive pest [1]. This tiny wasp (1–3 mm in body length) exhibits sexual dimorphism in body size and color (Figure 1A): males being smaller, white and brown; the females larger, orange and brown [1]. *Quadrastichus erythrinae* induces galls (Figure 1B) on new flushes of leaves, young stems and petioles of species of *Erythrina* that the infested trees wither and die. Many species of *Erythrina* were reported being attacked; for example, five species and a subspecies of coral trees are found affected in Taiwan, which are *E. variegata* L., *E. variegata* var. *orientalis* (L.) Merr., *E. corallo dendron* L., *E. cristagalli* L., *E. abyssinica* Lam., and *E. berteriana* [2]. *Erythrina* includes about 130 species [3], which are generally confined to warmer parts of the world. Many of them are planted as avenue trees due to its bright red and showy flowers and bright green thick foliage. *Erythrina* means ‘red’ in Greek, implying the color of their flowers. The bright-red flowers (Figure 1C) bloom before new flushes of leaves appear, rendering the tree canopy appear red and hence popular as the ‘flame tree’ (Figure 1D). *Erythrina sandwicensis* exceptionally bears orange, yellow, salmon, green and white flowers [4,5]. Species of *Erythrina* are widely utilized by humans as ornamentals and some of them have high ethnobotanical relevance [6–8]. Therefore, *Q. erythrinae*'s effect on various species of *Erythrina* gain in significance because *Q. erythrinae* populations alter the general appearance of *Erythrina* species with highly deformed foliage. The geographical spread of *Q. erythrinae* was discovered starting in the southern tropical hemisphere near Africa, later towards the subtropical and tropical areas of both southern and northern hemispheres in Asia and Oceania, and further extended to the New World, which reveals an obvious pattern of invasive dispersion in terms of time and geography. Two decades have passed since the discovery of *Q. erythrinae*, and it is time that we looked at what we have known and learnt from the outbreak of this gall-inducing, invasive insect. In this article, we review the invasion history, biology, ecology and current management of *Q. erythrinae* to know how this insect could be better managed in future. We also analyze and discuss the challenges in the management of *Q. erythrinae* and provide possible management options.



**Figure 1.** *Quadrastichus erythrinae* Kim induced galls and *Erythrina variegata* L. (A) adult male (left) and female (right) wasps, (B) malformations (=galls), (C) red showy flowers of *Erythrina variegata*, (D) a blooming *E. variegata*.

## 2. Invasion History

### 2.1. Distribution

*Quadrastichus erythrinae* has been reported in many tropical and subtropical nations (Table 1). The species was described based on specimens reared from the malformations (hereafter, galls) on *E. fusca* Lour. in Singapore [1]. Furthermore, the insects extracted from the leaf galls on *E. variegata* in Mauritius in 2003 and on another unidentified species of *Erythrina* in Réunion in 2000 and 2003 were also examined in the same article. Later, the insect was reported invading other Asian countries and Pacific islands in neighborhoods such as Taiwan, Vietnam, Thailand, the Philippines, China, India, Japan, and Hawaii. It has also spread to the New World, including USA and Latin-American countries, such as Brazil, Mexico, and Panama. We synthesize a list of earliest recorded occurrence of *Q. erythrinae* in different localities, which consolidates information on its spread from the Old World to New World (Table 1).

Table 1. Records of *Quadrastichus erythrinae*.

Locality (Year of the Earliest Discovery)	Hosts	References
Réunion (2000)	<i>Erythrina</i> sp.	Kim et al., 2004 [1]
Seychelles (2002)	<i>E. variegata</i> L.	Gerlach and Madl, 2007 [9]
Mauritius (2003)	<i>E. variegata</i> L. (= <i>E. indica</i> )	Kim et al., 2004 [1]
Singapore (2003)	<i>E. fusca</i> Lour. (= <i>E. glauca</i> )	Kim et al., 2004 [1]
Taiwan (2003)	<i>E. variegata</i> L., <i>E. variegata</i> var. <i>orientalis</i> (L.) Merr., <i>E. corallo dendron</i> L., <i>E. cristagalli</i> L., <i>E. abyssinica</i> Lam., and <i>E. berteroana</i> Urban	Yang et al., 2004 [2]
Thailand (2004)	<i>E. variegata</i> L.	EPPO 2021 [10]
India (2005)	<i>Erythrina</i> spp.	Faizal et al., 2006 [11]; Jacob and Devasahayam, 2010 [12]; Das and Takukdar, 2011 [13]; Narayana and Dhanya, 2014 [14]
China (2005)	<i>E. variegata</i> L.	Huang et al., 2005 [15]; Wu et al., 2008 [16]; Yao and Yin, 2009 [17]
Japan (2005)	<i>E. variegata</i> L.	Uechi et al., 2007 [18]; Kanai et al., 2008 [19]
Malaysia (2005)	<i>E. variegata</i> L.	Chung, 2006 [20]
Hawaii, USA (2005)	<i>E. variegata</i> L., <i>E. crista-galli</i> , <i>E. sandwicensis</i>	Heu et al., 2008 [21]
Florida, USA (2006)	<i>E. herbacea</i> L.	Howard et al., 2008 [22]
Guam, USA (2006)	<i>Erythrina</i> sp.	Rubinoff et al., 2010 [23]
Samoa (2006)	<i>E. variegata</i> var. <i>orientalis</i>	Rubinoff et al., 2010 [23]
Sri Lanka (2006)	<i>Erythrina</i> spp.	Prathapan, 2006 [24]
Vietnam (2007)	<i>E. variegata</i> L.	EPPO 2021 [10]
Philippines (2010)	<i>E. variegata</i> L.	Lit et al., 2010 [25]
French Polynesia (2010)	<i>E. variegata</i> L.	IPPC website, 2021 [26]
Martinique (2012)	<i>E. variegata</i> var. <i>fastigiata</i> , <i>E. variegata</i> var. <i>orientalis</i> , <i>E. variegata</i> var. <i>variegata</i>	Etienne and Dumbardon-Martial, 2013 [27]
Guadalupe (2012)	<i>E. variegata</i> var. <i>fastigiata</i> , <i>E. variegata</i> var. <i>orientalis</i> , <i>E. variegata</i> var. <i>variegata</i>	Etienne and Dumbardon-Martial, 2013 [27]
Puerto Rico (2012)	<i>E. variegata</i> L.	Jenkins et al., 2014 [28]
Brazil (2013)	<i>E. variegata</i> L.	Culik et al., 2014 [29]
Mexico (2017)	<i>E. variegata</i> L.	Palacios-Torres et al., 2017 [30]
Panama (2018)	<i>E. variegata</i> L.	Medianero and Zachrisson, 2019 [31]

During early phases of this insect's occurrences, Li et al. [32] predicted the potential invasion area of *Q. erythrinae* by the Genetic Algorithm for Rule Set Prediction based on insect incidence records and environmental data. The potential invasion area was determined as 30° N and 35° S, and along coastal areas. Vegetation forms and humidity were predicted as critical factors for the spread of *Q. erythrinae*. They also suggested that Africa could be the site of origin. In their study, the potential area covered most of *Q. erythrinae*'s incidence from the world, and the Indian subcontinent was not included, which is where the insect was actually occurring before the paper was published. Later, more records were reported from not only the predicted invasion sites, but outside areas as well. For example, Medianero and Zachrisson [31] reported the occurrence of *Q. erythrinae* in Central

America, which was not predicted in Li et al. [32]. Therefore, the potential distribution of *Q. erythrinae* needs to be updated according to new information on distribution.

## 2.2. Tracing the Geographical Origin

Identifying the exact origin of *Q. erythrinae* is not an easy task simply by the time of its occurrence because the early outbreak of *Q. erythrinae* seemed to happen in a short period of time in several southeastern Africa, Asian and Pacific countries (Table 1) [1,9,10]. In 2000~2003, specimens from Réunion, Mauritius, Singapore and Taiwan were sent to the late John LaSalle (CSIRO, Canberra, Australia) to determine this gall-inducing insect. In 2004, it was described as a new species based on materials from Réunion, Mauritius, and Singapore [1] and later as a new record in Taiwan [2]. This gall-inducing wasp is apparently an invasive in Taiwan because it was not found before [2,33]. The spread of *Q. erythrinae* seems rapid not only in Taiwan, but also other warm parts of the world. In a few years, many countries had been invaded by *Q. erythrinae*, such as the Seychelles, Thailand, India, China, Japan (Okinawa), Malaysia, Sri Lanka, Vietnam, and the Philippines [10–20,24,25]. Severe infestations of *Erythrina* species by *Q. erythrinae* were reported from the Pacific islands also, such as Hawaii, Guam, Samoa, and French Polynesia [21,23,26]. Currently, the species is found in Florida (USA), some of the islands in the Caribbean and Latin-American countries such as Puerto Rico, Martinique, Guadalupe, Mexico, Panama, and Brazil [22,27–31]. The time of reports from different countries hint at the spread pattern. Messing et al. [34] first assessed its origin by host–plant relationship of *Q. erythrinae* populations and *Erythrina* species. In their study, the infestation rate of *Q. erythrinae* on 71 species of *Erythrina* was examined utilizing trees brought from different bioregions of the world that were growing in the botanic garden of Hawaii. They use a four-scale infestation level (0~3 from none to severe) as an indication which was based on gall-infested leaf area of the entire tree (detailed explanation in Section 3.2). The infestation of African *Erythrina* species (infestation index < 0.5) was significantly lower than those species of *Erythrina* from regions such as Asia, Australia, Caribbean, Central, North, South Americas, Indo-West Pacific (infestation index > 1.0). In addition, those species of *Erythrina* from Benin, Burundi, Congo, Gambia, Lesotho, Rwanda, and Somalia were free of *Q. erythrinae* infestation and galls indicating that these countries could not be the site of origin of *Q. erythrinae*. The species of *Erythrina* from Mozambique, Swaziland, and Zimbabwe were also free of *Q. erythrinae* infestation and galls, indicating these countries were the unlikely source of *Q. erythrinae*. These findings serve as indirect references on this issue because the infestation performance of a gall inducing species may change in a different environment. Lin et al. [35] also argued that the pest infestation level could be affected by both abiotic and biotic factors, such as ecological performance and physiological responses of hosts, natural enemies and the environment [36–39]. Population genetics and phylogeography using DNA sequencing is one method to interpret the spread of an invasive insect [40–43]. For *Q. erythrinae*, the spread was unclear due to its monomorphic genotype from many regions. Homogeneity of sequences (COI, 12S, ITS2) in the samples obtained from Taiwan, Singapore and Mauritius has been demonstrated [44]. Rubinoff et al. [23] later included taxa from Hawaii, Guam, American Samoa, Japan, Singapore, Taiwan, and China, and used mitochondrial (COI) and nuclear DNA (Ef-1a) to explore the dispersal pathways of *Q. erythrinae* in the Pacific Basin. The result showed genetic monomorphy of the tested populations. Lacking genetic variation of *Q. erythrinae* suggests that the insect spread widely to other areas may come from a monomorphic genotypic founder population which went through genetic bottleneck. Recently, Lin et al. [35] analyzed the genetic variation of *Q. erythrinae* based on the genes of both mitochondrial COI and nuclear ITS2 in samples from not only Pacific-Asia taxa (Singapore, Taiwan, Thailand, India, Indonesia, Philippine, China, Japan, Guam, and Hawaii) but also from the Afro-Malagasy bioregion (Tanzania and Mauritius) to infer the origin area of *Q. erythrinae*. This study revealed that there are only one ITS2 haplotype and three COI haplotypes. Generally, most of sampling areas outside Africa presented one kind of COI haplotype. This agrees with the results of two

previous studies of Tung et al. [44] and Rubinoff et al. [23]. The other two haplotypes were respectively detected from Indonesia and Tanzania. The COI haplotype network showed that the Tanzanian haplotype is a primitive one compared with the other two. In addition, the reconstructed molecular phylogeny based on the combined COI and ITS2 regions demonstrated the monophyly of *Q. erythrinae* taxa and samples from Tanzania located in the basal lineages, next to other outgroup *Quadrastichus* species. The ‘Out of Africa’ hypothesis thus gains support. Africa was confirmed as the area of origin of *Q. erythrinae* and central Africa (Tanzania) could be a putative source to date. A revision of *Quadrastichus* using more samples from Africa would possibly clarify further.

### 3. Ecology and Infestation

#### 3.1. Ecology

Basic biological and ecological traits of *Q. erythrinae* are indispensable to develop an IPM plan. Female adults deposit eggs into young tissues (leaf, stem and petiole) using their ovipositors. The plant tissue swells where the neonate *Q. erythrinae* larva feeds. The gall is monothalamous, harboring one larva in one chamber. When in high density, galls coalesce, resulting in a swollen plant organ [1]. An adult *Q. erythrinae* will exit the gall by cutting an emergence hole on the gall wall, which may lead to decay of the infested plant part and the overall weakening the tree’s vigor [1,2,18]. Additionally, the *Q. erythrinae* presents an overlapping generation and different development stages occur concurrently [1], which makes it difficult to manage the insect population. Short lifespan and high fecundity also enhance the difficulty of *Q. erythrinae* management. It takes 20 days for one generation of *Q. erythrinae* to develop, and adult stage is 4–8 days [45]. Yang et al. [2] showed that the female adult laid  $322 \pm 98$  eggs ( $n = 10$ ). The sex ratio is a critical element in the selection of management strategies. Heu et al. [21] showed strong male bias (7:1) on lab-infested *E. variegata* in Hawaii. The sex ratio of *Q. erythrinae* may also be affected by biotic factors such as host features (nutrition supplied in the gall and the chemistry of the host plant taxon), intraspecific interactions (e.g., density of galls) and parasitism of natural enemy. More studies on the abiotic factors, such as temperature and humidity, and possible biotic factors are necessary to understand the mechanism of the gender determination in this species. Huang et al. [46] tested the preference of female oviposition on different developmental stages of *E. variegata* and location such as the mid part of the leaflet, lateral part of the leaflet and petiole. The findings indicated that female wasps preferentially lay eggs on new shoot flushes and do not show any location preference. Therefore, rigorous protection efforts are needed, particularly when new shoots emerge to avoid insect outbreak.

#### 3.2. Infestation Assessment

Invasive gall-inducing insects are not apparent due to their tiny body sizes and embedded habit within galls. Nevertheless, the availability of galls on plant organs is a reliable feature to monitor. The degrees of infestation of *Q. erythrinae* on *Erythrina* species could be categorized based on symptoms. Lan et al. [47] proposed four infestation stages and Wang et al. [48] modified Lan et al.’s proposal further: stage 1, the gall number per leaflet less than 15 and the leaf and stem appear healthy and with no obvious changes; stage 2, the gall number per leaflet is 16–30 and aggregated galls make the foliage curl; stage 3, the gall number per leaflet is 31–50 with closely aggregated galls on leaves and stems, and leaves are deformed and together with the shoots are distorted into a ball; stage 4, the gall number per leaflet is more than 50, the trees defoliate and appear withered. Sap may ooze from trunk which makes the tree smell stinky. Similar categories were also proposed by Messing et al. [34] and Bell et al. [49] Both studies use four infestation levels (0–3): 0 = no galls on the plant; 1 = light infestation: gall-infested leaf area of the entire tree less than 33%; 2 = moderate gall induction: gall-infested leaf area of the entire tree is 33–66%; 3 = heavy gall induction: gall-infested leaf area of the entire tree over 66%.

## 4. Management

### 4.1. Application of Insecticides

Chemical management is usually selected as the first tactic to regulate a severe outbreak of an invasive organism because it is dramatically effective and often rapidly suppresses the pest populations. Xu et al. [50] tested control efficacy of three systemic insecticides (abamectin, dinotefuran and imidacloprid) together with two applications (trunk injections and soil drenches). The emerged insect numbers from soil-drench treatments of imidacloprid and dinotefuran and trunk injection of abamectin showed no significant difference from the untreated contexts during the next four months after insecticide treatment, whereas trunk injection of the imidacloprid showed significant lower numbers of *Q. erythrinae* emergence. The actual concentration of imidacloprid absorbed into the plant is critical to effectively regulate *Q. erythrinae* population and the optimal concentration is 4 µg imidacloprid/g of plant biomass, which will decline the emergence numbers of *Q. erythrinae* less than five individuals per gram of gall tissue. Applying the dosage above the optimal concentration (galled tissues with imidacloprid concentration > 4 µg) showed no significant difference on pest regulation while applying lower concentration (<4 µg) failed to regulate the pest population. As understanding of the transportation dynamics of imidacloprid within the tree may provide a useful indication to help understand the efficacy of the insecticide, further exploration was done by the same authors [45]. Imidacloprid concentration in different part of *Erythrina* trees was measured three months after injecting. Leaves in the lower canopy had the highest concentration of imidacloprid compared to that of leaves on middle and upper canopies. The longevity data of imidacloprid in *Erythrina* trees indicated that it was strongly related to the control efficacy of the *Q. erythrinae* population. In general, the untreated tree died in about 20 weeks after it was infested. In contrast, with imidacloprid application treatment, the concentration of imidacloprid gradually increased in the first 15 weeks, followed by a gradual decrease and was not detected until 50 weeks. However, the study showed that control efficacy is variable due to variation in injection methods and modifications may apply to different situations. For instance, the infested trees of *E. variegata* in Hawaii Island bear vertical trunks of 12–30 cm in diameter at breast height (DBH) and 6.0–7.5 m in height. In Taiwan, the chemical injection was applied to treat the native heritage trees [48] and the cumulative diameter was often more than 1 m and with multiple branches for these elder trees. Thus, the dosage of imidacloprid to regulate the pest population in Taiwan should be higher than in Hawaii. Wang et al. [48] gave dosages of the imidacloprid dependent on the DBH of each branching trunk, giving one dose per 5 cm of DBH. In addition, to prevent evapotranspiration of pesticides, the injection point on the tree surface was covered by silicone gel [48].

### 4.2. Biological Control

To regulate populations of cryptic organisms such as gall-inducing insects, hymenopteran parasitoids with long, slender, pointed ovipositors are the best biological control agents. To *Q. erythrinae*, parasitoid species, such as *Eurytoma erythrinae* Gates and Delvare in Tanzania, Ghana, and South Africa [51], *Aprostocetus exertus* La Salle in Tanzania and South Africa [52], *A. nitens* Prinsloo and Kelly in South Africa [53], and *A. felix* La Salle, Yang and Lin in Taiwan [54] are known. Among them, several have been assessed for their biocontrol effectiveness and only *E. erythrinae*, a larval parasitoid of *Q. erythrinae*, was further explored as a biological control agent [39]. In Hawaii, four of the six main Islands (Hawaii, Oahu, Maui and Kauai) including 16 localities and two environment types (botanical gardens and natural primary forests) were selected for the biocontrol experiment from 2008 to 2018. Before the experiments, *Q. erythrinae* infestation reached level 2 (galled leaf is 30–66% of the tree) or 3 (galled leaf is more than 66% of tree), and >70% of young shoot were infested before release of *E. erythrinae* [39]. After three-year release of *E. erythrinae*, the number of trees with severe infestation (level 3) dropped from 80% to 40% and the proportion of trees with level 0 increased to 20% among the surveyed trees. In addition, the seed-set increased from <3% to 30% and >60% of trees started blooming.

The mortality of *Q. erythrinae* was low (0 to <30%) during the stage of *E. erythrinae* release and it increased to 60–90% during the later months of the first year of *E. erythrinae* release. In some localities, the mortality of *Q. erythrinae* remained >95% after second year of *E. erythrinae* release. In both natural areas and botanical gardens, the infestation decreased yearly in 2008–2011 and finally maintained approximately between 0 and 1. Infestation of botanical garden stands was much higher than the natural stand in 2010. In 2013–2018, trees in some locations with high levels of infestation previously dropped to  $\leq$  level 1 in 2017. Environmental factors such as humidity may affect the regulation efficacy of natural enemies because the infestation level of *Q. erythrinae* in drier locations is higher than in other localities [39]. Presently, establishment of *E. erythrinae* has successfully controlled *Q. erythrinae* population in the Hawaiian Islands. Future monitoring of the dynamics of *Q. erythrinae* and *E. erythrinae* is necessary to confirm its efficacy in *E. erythrinae*'s biological management. Many successful biocontrol instances of gall-inducing invasive insects are available, see, e.g., Protasov et al. [55], who showed that *Closterocerus chamaeleon* (Girault) (Hymenoptera: Eulophidae) can regulate populations of *Ophelimus maskelli* on *Eucalyptus* species in the Mediterranean. Kim et al. [56] discovered two natural enemies, *Q. mendeli* Kim and La Salle and *Selitrichodes kryceri* Kim and La Salle (Hymenoptera: Eulophidae) parasitizing *Leptocybe invasa* Fisher and La Salle (Hymenoptera: Eulophidae), another invasive gall inducer on *Eucalyptus* species in the Mediterranean, in its native bioregion. Nevertheless, concerns on exotic natural enemies for classical biological control should be noticed. In the biocontrol case of chestnut gallwasp *Dryocosmus kuriphilus* Yasumatsu, its specific natural enemy *Torymus sinensis* Kamijo was introduced to Japan from China to regulate populations of *D. kuriphilus* [57,58]. However, the hybridization of *T. sinensis* and Japanese native species *T. beneficus* Yasumatsu was detected [59–61]. In Italy, *T. sinensis* also was introduced for biological management, which was found to attack non-target gall inducing species impacting negatively the local ecosystem. Fifteen out of 23 native cynipid species were detected being attacked by *T. sinensis*. Parasitism rates were generally low (between 0.6% and 1.6%) to most native cynipid hosts; however, two of the species had relative higher parasitism, i.e., *Andricus curator* Hartig (3.5%) and *A. inflator* Hartig (5.7%) [62]. Therefore, exotic natural enemies should be used cautiously and the impact on local ecological system needs to be considered [63].

#### 4.3. Public Policy and IPM

Because *Erythrina* species impress as desirable ornamental trees, many countries plant them as ornamental trees along their coasts. Invasion by *Q. erythrinae* has affected species of *Erythrina* cultivated in many countries after its incidence was discovered in 2000 [1]. Most of the published papers on the biology and population dynamics, and management of *Q. erythrinae* highlighted local contexts. The population dynamic and potential management practices vary in different countries due to varying government regulations. Here, we provide information from government-sponsored projects, local reports, and personal communications from Taiwan, and other countries to look at a firsthand information on the management of populations of *Q. erythrinae*, providing an insight for an effective action plan. In Singapore, the National Parks Board (NParks) is in charge of maintaining and managing the road verge trees. Infestation by *Q. erythrinae* severely altered the physical appearance of *E. variegata* and *E. variegata* var. *picta* grown as road verge ornamental in Singapore. Imidacloprid application was unsatisfactory. Replacement of *Erythrina* with other tree species was agreed upon and *Erythrina* trees were gradually replaced [64]. In southern coastal regions of India, farmers planted *Erythrina variegata* and *E. subumbrans* as shade trees for other crops, such as *Piper nigrum* (Piperaceae). After the outbreak of the *Q. erythrinae*, the Department of Agriculture, Cooperation and Farmers Welfare replaced species of *Erythrina* with *Millettia pinnata* (Fabaceae) and other native trees [65]. *Erythrina sandwicensis* is an endemic species, commonly known as 'wiliwili', growing in the volcanic lava sites in Hawaii. Its flowers are red similar to other *Erythrina* species, but Williwili also presents orange, yellow, salmon, green and white flowers. There is a

cultivated variety from *E. variegata*, known as ‘tall wili’, commonly used as windbreaks in Hawaii. Both *E. sandwicensis* and *E. variegata* (tall wili) are susceptible to infestation by *Q. erythrinae*. The slender and tall traits of *E. variegata* (tall wili) made it hard to spray pesticides to regulate *Q. erythrinae*. The Hawaii Department of Agriculture (HDOA) is the major unit in charge of controlling *Q. erythrinae* and other institutes are also involved in the work, such as the University of Hawaii and the US Navy. The tree injection technique was used to apply systematic pesticide to reach the high tips of *E. variegata* (tall wili). However, the damage of *Q. erythrinae* was too rigorous to rescue these trees in time. The other action was taken to send scientists to find parasitoids in Africa. Candidate parasitoids were sent back to Hawaii to evaluate its possibility as a biocontrol agent. Among several parasitoids examined, *E. erythrinae* was the one cultured and released in Hawaii. Positive results were reported after a few years regulating populations of *Q. erythrinae* on *E. sandwicensis* [39,49,66]. Unfortunately, most of the *E. variegata* (tall wili) were unable to survive before the establishment of the parasitic *Eurytoma* wasp and therefore it is now hard to find tall wili in the urban area. The successful biocontrol in Hawaii provides a good management chance for other countries and Okinawa, Japan, has introduced *Eurytoma erythrinae* from Hawaii. Early records on the occurrence of *Q. erythrinae* in Japan stated in Isigaci island and Irimuti island, which quickly spread to all the islands of Okinawa. The flower of *E. variegata* is the symbol of Okinawa Prefecture. The Okinawa Prefectural Forest Resources Research Center concentrated on the infestation by *Q. erythrinae*, including the total sampling weight of adult emergence [18,19]. Chemical control was first tested indoors and the imidacloprid was applied to trees [67–69]. Volunteers were recruited to participate in the maintenance of saved trees for many years. However, the cost was high and several injections in one tree altered the structure of the trunk which succumbed to typhoons. Further evaluation has resulted in the introduction of the successful African parasitoid *E. erythrinae*. After the official quarantine application and host tests, *E. erythrinae* was released in Sumuzu island [70,71] and the monitoring continues presently [72]. In Taiwan, *E. variegata* was widely planted in urban area, along the pedestrian walkways and parks, in the main island and the surrounded islands. Early detection of *Q. erythrinae* infestation was in 2003 and a wide dispersal was noticed in other islands [2]. After confirming the identity as *Q. erythrinae*, the Forest Bureau, Council of Agricultural of the central government implemented several tactics to control it. These included conducting an emergent efficacy test to use an appropriate insecticide [2], testing various colored sticky traps and further applying yellow sticky trap for management and monitoring, developing quick and easy ways to identify the levels of infestation, running training workshops to the employees of local government and related persons, establishing a website in central government to report the updated local status of infestation and to further decide on the control strategies. The government also prepared different versions of leaflets through time to guide people in recognizing *Q. erythrinae* and its management [73–76]. As most of the urban coral trees are big and tall, trunk injection with imidacloprid solution was suggested as the possibility [2] and a video named ‘savecoralree’ was uploaded onto YouTube to provide proper guidance of implementation (<https://www.youtube.com/watch?v=4hVcPrA9-Po&t=41s>; accessed on 6 July 2021). Because the diversity in flora and fauna is high in Taiwan and several native parasitoids were observed attacking *Q. erythrinae*, the introduction of *E. erythrinae* was not considered. An IPM strategy according to plant phenology was laid out. Although *Q. erythrinae* infestation was alleviated, the result is not as successful as expected due to the wide distribution of the host tree in urban and natural areas.

## 5. Challenges and Dilemma

### 5.1. Potential Crisis of Pesticide Control

At present, chemical control by injection of imidacloprid into the tree is a convenient and quick-acting way to inhibit *Q. erythrinae* infestation under level 1 infestation *sensu* Messing et al. [34] (galled leaves of the tree less than 30%). It also shows as an effective control of *Q. erythrinae* infestation in stage 1 (gall number per leaflet less than 15) and 2 (gall

number per leaflet 16~30) infestation *sensu* Wang et al. [48]. Even in the more serious stage 3 infestation (gall number per leaflet is 31~50 and leaf and stem make gall clusters), this control application may rescue the declining tree and the status of level of infestation may be reversible to stage 2 and 1. However, pesticide resistance of *Q. erythrinae* is an important concern in the near future. Considering the case of another notorious invasive pest in Japan, the chestnut gall wasp *Dryocosmus kuriphilus* Yasumatsu developed pesticide resistance soon after chemical control was employed, and it also overcame the resistant host strain after 10 years of treatment. Finally, classical biological control was selected to suppress the pest population by introducing *Torymus sinensis* Kamijo from the pest native range (China), and successfully lowered its infestation rate to less than 3% from 43% [57]. We need to keep this example in view that development of other control tactics of *Q. erythrinae* are needed in case should resistance to pesticide treatments eventuate.

### 5.2. Dilemma of Biological Control

Biological control is an environmentally friendly and sustainable control tactic. Nevertheless, negative effect of any exotic natural enemy on local ecosystem should be considered seriously before it is released because food chain and species diversity of local ecosystem could be disturbed and interfered [66,77]. In Hawaii, many studies reveal that exotic natural enemy causing change in native ecosystem [78,79]. For *Q. erythrinae*, the introduced agent *E. erythrinae* has already established and well controlled the pest damage [39]. Further research on allied species of *Q. erythrinae* is needed to confirm possible impact on native ecosystems in preventing *E. erythrinae*'s attack on non-target species. Alternatively, biological control using native natural enemies is named fortuitous/adventive biocontrol [80]. It provided an environmentally friendly way to the native ecosystem with two benefits. First, it reduces the impact of introduced species on native ecosystems, which avoid chances to disturb the local trophic chain and to attack non-target species. Second, native natural enemies have an advantage in pre-adapting to native habitat compared to introduced agents, thus being easier in maintaining a stable trophic chain in its community. However, the process may take a much longer time in contrast to the classical (introduced) biocontrol, because recruiting native natural enemies may undergo complex interactions among the related taxa in the local community.

## 6. Conclusions

The *Erythrina* gall wasp *Q. erythrinae* is an invasive alien species that threatens *Erythrina* species worldwide. Its distribution and invasion route may provide us useful information to predict the outbreak pattern of the potential invasive organisms from similar ecological niches. In addition, low genetic variation of *Q. erythrinae* in different bioregions indicates it has rapidly invaded these areas. A specific genotype may be responsible for its successful invasion. Studying biological and ecological characteristics of different genotypes of *Q. erythrinae* may help us to understand its patterns in their invasion capability. Facing such a fierce insect, application of pesticides is perhaps the immediate strategy to restrict its population and maintain tree vigor. Tree trunk injection is the best chemical application, but to reach an optimal effect, injection frequency and tools differ according to environmental factors and landscapes. Both biotic and abiotic factors may affect the efficacy of *Q. erythrinae* management. Biocontrol by natural enemies is a notable method to lower *Q. erythrinae* populations. However, it is necessary to assess the risk before the introduction of exotic natural enemy, such as its impact on native organisms and ecosystems. Studies on the biocontrol of invasion gall inducing insect in urban areas is so far poorly known. However, for a long-term consideration, this method appears sustainable and with lower contamination. It is predictable that more restrictions and difficulties will be faced by the candidate agent because the relatively less complex urban environment may provide limited resources and shelters to maintain the population. More ecological studies and experiments of *Q. erythrinae* and/or their associated organisms are needed to develop its IPM, as well an appropriate way to control it in different ecosystem and environment.

**Author Contributions:** Conceptualization—equal contribution by M.-M.Y., S.-F.L. and G.-S.T.; First draft, S.-F.L.; writing—review and editing, M.-M.Y.; visualization, M.-M.Y. and G.-S.T.; supervision, M.-M.Y.; project administration and funding acquisition, M.-M.Y. and G.-S.T. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Taiwan Forest Bureau (grant number: tfb-970502, tfbr-980501, tfb-99-00-5-16, tfbc-1040506) and Ministry of Science and Technology, Taiwan (grant number: MOST 109-2313-B-005-030, MOST 108-2313-B-005-029).

**Acknowledgments:** We thank the Taiwan Forest Bureau (project number: tfb-970502, tfbr-980501, tfb-99-00-5-16, tfbc-1040506) and the Taiwan Forestry Research Institute for the partial financial support. We are most indebted to Raman Anantanarayanan for his invaluable comments and the review of our manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

- Kim, I.K.; Delvare, G.; La Salle, J. A new species of *Quadrastichus* (Hymenoptera: Eulophidae): A gall-inducing pest on *Erythrina* (Fabaceae). *J. Hymenopt. Res.* **2004**, *13*, 243–249.
- Yang, M.M.; Tung, G.S.; La Salle, J.; Wu, M.L. Outbreak of erythrina gall wasp on *Erythrina* spp. (Fabaceae) in Taiwan. *Plant Prot. Bull.* **2004**, *46*, 391–396. [[CrossRef](#)]
- Nesom, G.L. Key to native and cultivated species of *Erythrina* (Fabaceae) in the USA and comments on naturalization of *E. crista-galli*. *Phytoneuron* **2015**, *29*, 1–8.
- Little, E.L.; Skolmen, R.G. *Common forest trees of Hawaii (Native and Introduced)*; Agricultural Handbook No. 679; U.S. Department of Agriculture: Washington, DC, USA, 1989; 321p.
- Gramling, C. Conservation biology. Hawaii’s coral trees feel the sting of foreign wasps. *Science* **2005**, *310*, 1759–1760. [[CrossRef](#)] [[PubMed](#)]
- De Araújo-Júnior, J.X.; de Oliveira, M.S.G.; Aquino, P.G.V.; Alexandre-Moreira, M.S.; Sant’Ana, A.E.G. A phytochemical and ethnopharmacological: Review of the genus *Erythrina*. In *Phytochemicals—A Global Perspective of Their Role in Nutrition and Health*; Rao, V., Ed.; InTechOpen: Rijeka, Croatia, 2012; pp. 327–352.
- Kaushal, A.; Sharma, M.; Navneet, M.S. Ethnomedicinal, phytochemical, therapeutic and pharmacological review of the genus *Erythrina*. *Int. J. Bot. Stud.* **2020**, *5*, 642–648.
- Pan, L.Y.; Hung, T.Y.; Liang, J.Y.; Tung, G.S. Ethnological uses of *Erythrina variegata* in Taiwan. *Taiwan J. For. Sci.* **2020**, *22*, 1105–1119. (In Chinese)
- Gerlach, J.; Madl, M. Notes on *Erythrina variegata* (Linnaeus 1754) (Rosopsida: Fabaceae) and *Quadrastichus erythrinae* Kim 2004 (Hymenoptera: Chalcidoidea: Eulophidae) in Seychelles. *Lin. Biol. Beitr.* **2007**, *39*, 79–82.
- EPPO. *Quadrastichus erythrinae*: Distribution. Available online: <https://gd.eppo.int/taxon/QUSTER/distribution> (accessed on 6 July 2021).
- Faizal, M.H.; Prathapan, K.D.; Anith, K.N.; Mary, C.A.; Lekha, M.; Rini, C.R. *Erythrina* gall wasp, *Quadrastichus erythrinae*, yet another invasive pest new to India. *Curr. Sci.* **2006**, *90*, 1061–1062.
- Jacob, T.K.; Devasahayam, S. Incidence of *Erythrina* gall wasp (*Quadrastichus erythrinae* Kim), an invasive insect pest on *Erythrina* spp., in major black pepper (*Piper nigrum* L.) areas of Kerala and Karnataka, India. *J. Plant. Crop.* **2010**, *38*, 161–164.
- Das, B.K.; Talukdar, B. Record of invasive *Quadrastichus erythrinae* Kim, gall wasp on *Erythrina variegata* L. from Eastern India with notes on gall morphologies. *Insect Environ.* **2011**, *17*, 9–11.
- Narayana, R.; Dhanya, M.K. Infestation of *Quadrastichus erythrinae* Kim (Eulophidae: Hymenoptera) an invasive pest on *Erythrina* spp, a popular standard for black pepper (*Piper nigrum*) in Idukki district in Kerala, India. *Entomon* **2014**, *39*, 143–150.
- Huang, P.Y.; Fang, Y.W.; Huang, J.; Lin, S.M.; Wang, H.Y. A new invasive alien species, *Quadrastichus erythrinae*, in mainland of China. *Entomol. Knowl.* **2005**, *42*, 371–374.
- Wu, M.K.; Chen, C.N.; Li, H.; Han, F.C.; Yu, F.S.; Wu, K.H. Incidence and control of *Quadrastichus erythrinae* in Hainan. *Trop. For.* **2008**, *36*, 39–41.
- Yao, P.Y.; Yin, F.P. The damage situation of the *Erythrina* gall wasp in Nanning and control countermeasures. *J. Guangxi Agric.* **2009**, *24*, 44–45.
- Uechi, N.; Uesato, T.; Yukawa, J. Detection of an invasive gall-inducing pest, *Quadrastichus erythrinae* (Hymenoptera: Eulophidae), causing damage to *Erythrina variegata* L. (Fabaceae) in Okinawa Prefecture, Japan. *Entomol. Sci.* **2007**, *10*, 209–212. [[CrossRef](#)]
- Kanai, K.; Matsuhira, K.; Uechi, N.; Yukawa, J. Invasion of the Amami Islands, Kagoshima, Japan by *Quadrastichus erythrinae* (Hymenoptera: Eulophidae). *Jpn. J. Appl. Entomol. Zool.* **2008**, *52*, 151–154. [[CrossRef](#)]
- Chung, A.Y.C. *Attack of the Erythrina Gall Wasp on the Coral Tree Erythrina variegata in Sandakan, Sabah, Malaysia*; Forest Research Centre, Sabah Forestry Dept.: Sandakan, Malaysia, 2006.

21. Heu, R.A.; Tsuda, D.M.; Nagamine, W.T.; Yalamar, J.A.; Suh, T.H. Erythrina gall wasp *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae), New Pest Advisory. No. 05-03, Dept. of Agriculture, Hawaii. 2008. Available online: <https://dlnr.hawaii.gov/ecosystems/files/2013/07/Erythrina-Gall-Wasp-Advisory-HDOA.pdf> (accessed on 6 July 2021).
22. Howard, F.W.; Pemberton, R.; Liu, H. *Erythrina* gall wasp, *Quadrastichus erythrinae* (Hymenoptera: Eulophidae) in Florida, and susceptibility of *Erythrina herbacea* (Fabaceae). *Proc. Fla. State Hortic. Soc.* **2008**, *121*, 363–369.
23. Rubinoff, D.; Holland, B.S.; Shibata, A.; Messing, R.H.; Wright, M.G. Rapid invasion despite lack of genetic variation in the erythrina gall wasp (*Quadrastichus erythrinae* Kim). *Pac. Sci.* **2010**, *64*, 23–31. [[CrossRef](#)]
24. Prathapan, K.D. The invasive pest *Erythrina* gall wasp, *Quadrastichus erythrinae* Kim enters Sri Lanka. *Insect Environ.* **2006**, *12*, 28–29.
25. Lit, I.L.; Ca Asilit, M.T.; Balatibat, J.B.; Palijon, A.M.; Larona, A.R.; Borja, A. Postscript to an invasion: The erythrina gall wasp, *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae), in the Philippines. *Philipp. Entomol.* **2010**, *6*, 100–121.
26. IPPC website. Official Pest Reports—French Polynesia *Quadrastichus erythrinae* on *Erythrina variegata*. Available online: <https://www.ippc.int/en/countries/french-polynesia/pestreports/2010/05/quadrastichus-erythrinae-on-erythrina-variegata/#> (accessed on 6 July 2021).
27. Etienne, J.; Dumbardon-Martial, E. *Quadrastichus erythrinae* Kim: Un redoutable ravageur pour les érythrinées de Guadeloupe et de Martinique (Hymenoptera, Eulophidae, Tetrastichinae). *Bull. Société Entomol. Fr.* **2013**, *118*, 155–158.
28. Jenkins, D.A.; Mizel, R.F.; Bloem, S.V.; Whitmire, S.; Wiscovitch, L.; Zaleski, C.; Goenaga, R. An analysis of arthropod interceptions by APHIS-PPQ and customs and border protection in Puerto Rico. *Am. Entomol.* **2014**, *60*, 44–55. [[CrossRef](#)]
29. Culik, M.P.; Martins, D.S.; Ventura, J.A.; Costa, V.A. The invasive gall wasp *Quadrastichus erythrinae* (Hymenoptera: Eulophidae) in South America: Is classical biological control needed? *Biocontrol Sci. Technol.* **2014**, *24*, 971–975. [[CrossRef](#)]
30. Palacios-Torres, R.E.; Malpica-Pita, J.; Bustamante-Ortiz, A.G.; Valdez-Carrasco, J.; Santos-Chávez, A.; Vega-Muñoz, R.; Vibrans-Lindemann, H. The invasive gall wasp *Quadrastichus erythrinae* Kim in Mexico. *Southwest. Entomol.* **2017**, *42*, 1099–1102. [[CrossRef](#)]
31. Medianero, E.; Zachrisson, B. *Erythrina* gall wasp, *Quadrastichus erythrinae* Kim, 2004 (Hymenoptera: Eulophidae: Tetrastichinae): A new pest in Central America. *BioInvasions Rec.* **2019**, *8*, 452–456. [[CrossRef](#)]
32. Li, H.; Xiao, H.; Peng, H.; Han, H.; Xue, D. Potential global range expansion of a new invasive species, the erythrina gall wasp, *Quadrastichus erythrinae* Kim (Insecta: Hymenoptera: Eulophidae). *Raffles Bull. Zool.* **2006**, *54*, 229–234.
33. Yang, M.M.; Tung, G.S. The diversity of insect-induced galls on vascular plants in Taiwan: A preliminary report. In *The Biology of Gall-Inducing Arthropods*; General Technical Report; Csoka, G., Mattson, W.J., Stone, G.N., Price, P.W., Eds.; USDA Forest Service North Central Research Station: Matrafured, Hungary, 1998; pp. 44–53.
34. Messing, R.H.; Noser, S.; Hunkeler, J. Using host plant relationships to help determine origins of the invasive *Erythrina* gall wasp, *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae). *Biol. Invasions* **2009**, *11*, 2233–2241. [[CrossRef](#)]
35. Lin, S.F.; Tung, G.S.; Yang, M.M. Out of Africa: Origin of the *Erythrina* gall wasp *Quadrastichus erythrinae* (Hymenoptera: Chalcidoidea: Eulophidae). *Formos. Entomol.* **2021**, *41*, 26–36. [[CrossRef](#)]
36. Kolesik, P. Distribution of infestation by lentil gall midge *Contarinia lentis* (Dipt., Cecidomyiidae) in lentil fields: Statistical model. *J. Appl. Entomol.* **2000**, *124*, 7–10. [[CrossRef](#)]
37. Vidart, M.V.; Mujica, M.V.; Bao, L.; Duarte, F.; Bentancourt, C.M.; Franco, J.; Scatoni, I.B. Life history and assessment of grapevine phylloxera leaf galling incidence on *Vitis* species in Uruguay. *Springerplus* **2013**, *2*, 181. [[CrossRef](#)] [[PubMed](#)]
38. Veenstra, A.A.; West, J.M.; Milne, J. Infestation levels of the gall midge *Asphondylia floriformis* (Diptera: Cecidomyiidae) on its host plant *Sarcocornia quinqueflora* (Chenopodiaceae). *Plant. Prot. Q.* **2014**, *29*, 37–44. [[CrossRef](#)]
39. Kaufman, L.V.; Yalamar, J.; Wright, M.G. Classical biological control of the erythrina gall wasp, *Quadrastichus erythrinae*, in Hawaii: Conserving an endangered habitat. *Biol. Control.* **2020**, *142*, 104161. [[CrossRef](#)]
40. Zepeda-Paulo, F.A.; Simon, J.-C.; Ramirez, C.C.; Fuentes-Contreras, E.; Margaritopoulos, J.T.; Wilson, A.C.C.; Sorenson, C.E.; Briones, L.M.; Azevedo, R.; Ohashi, D.V.; et al. The invasion route for an insect pest species: The tobacco aphid in the New World. *Mol. Ecol.* **2010**, *19*, 4738–4752. [[CrossRef](#)] [[PubMed](#)]
41. Ascunce, M.S.; Yang, C.-C.; Oakey, J.; Calcaterra, L.; Wu, W.-J.; Shih, C.-J.; Goudet, J.; Ross, K.G.; Shoemaker, D. Global Invasion History of the Fire Ant *Solenopsis invicta*. *Science* **2011**, *331*, 1066–1068. [[CrossRef](#)]
42. Perdereau, E.; Bagnères, A.G.; Bankhead-Dronnet, S.; Dupont, S.; Zimmermann, M.; Vargo, E.L.; Dedeine, F. Global genetic analysis reveals the putative native source of the invasive termite, *Reticulitermes flavipes*, in France. *Mol. Ecol.* **2013**, *22*, 1105–1119. [[CrossRef](#)]
43. Ryan, S.F.; Lombaert, E.; Espeset, A.; Vila, R.; Talavera, G.; Dincă, V.; Doellman, M.M.; Renshaw, M.A.; Eng, M.W.; Hornett, E.A.; et al. Global invasion history of the agricultural pest butterfly *Pieris rapae* revealed with genomics and citizen science. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 20015–20024. [[CrossRef](#)]
44. Tung, G.S.; Wu, L.W.; Yang, Y.S.; Hsu, C.C.; Yang, M.M. Genetic differentiation of the eulophid wasp *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae) from various *Erythrinae* hosts based on mitochondrial and nuclear genes. *Formos. Entomol.* **2008**, *28*, 305–313. [[CrossRef](#)]
45. Reimar, N.J. Field release of *Eurytoma* sp. (Hymenoptera: Eurytomidae), for biological control of the *Erythrina* gall wasp, *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae), in Hawaii. In *Draft Environmental Assessment*; Department of Agriculture: Honolulu, HI, USA, 2007; p. 8.

46. Huang, H.Y.; Wu, Y.S.; Tung, G.S. Oviposition and galling preference of erythrina eulophid wasp (*Quadrastichus erythrinae* Kim) on Coral Tree. *Formos. Entomol.* **2011**, *31*, 67–73. [[CrossRef](#)]
47. Lan, Y.C.; Chang, C.H.; Hsu, Y.L.; Hsieh, Y.H.; Tung, G.S.; Hsu, C.C. Using branch sampling to estimate the erythrina gall wasp *Quadrastichus erythrinae* (Hymenoptera: Eulophidae) infection level of the coral tree (*Erythrina variegata*). *Formos. Entomol.* **2006**, *26*, 454.
48. Wang, T.S.; Tung, G.S.; Yang, E.C.; Yang, M.M. A preliminary study of controlling *Quadrastichus erythrinae* Kim on heritage coral trees with trunk injection. *Formos. Entomol.* **2011**, *31*, 281–286. [[CrossRef](#)]
49. Bell, R.C.; Belmaker, A.; Couch, C.S.; Marchetto, K.M.; Simonis, J.L.; Thomas, R.Q.; Sparks, J.P. Effectiveness of *Erythrina* gall wasp biocontrol and implications for the recovery of threatened Wiliwili trees (Fabaceae: *Erythrina sandwicensis*). *J. Torrey Bot. Soc.* **2013**, *140*, 215–224. [[CrossRef](#)]
50. Xu, T.; Jacobsen, C.M.; Hara, A.H.; Li, J.; Li, Q.X. Efficacy of systemic insecticides on the gall wasp *Quadrastichus erythrinae* in wiliwili trees (*Erythrina* spp.). *Pest Manag. Sci.* **2009**, *65*, 163–169. [[CrossRef](#)]
51. Gates, M.; Delvare, G. A new species of *Eurytoma* (Hymenoptera: Eurytomidae) attacking *Quadrastichus* spp. (Hymenoptera: Eulophidae) galling *Erythrina* spp. (Fabaceae), with a summary of African *Eurytoma* biology and species checklist. *Zootaxa* **2008**, *1751*, 1–24. [[CrossRef](#)]
52. La Salle, J.; Ramadan, M.; Kumashiro, B.R. New parasitoid of The *Erythrina* gall wasp, *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae). *Zootaxa* **2009**, *2083*, 19–26. [[CrossRef](#)]
53. Prinsloo, G.L.; Kelly, J.A. The tetrastichine wasps (Hymenoptera: Chalcidoidea: Eulophidae) associated with galls on *Erythrina* species (Fabaceae) in South Africa, with the description of five new species. *Zootaxa* **2009**, *2083*, 27–45. [[CrossRef](#)]
54. Yang, M.M.; Lin, Y.C.; Wu, Y.; Fisher, N.; Saimanee, T.; Sangtongpraow, B.; Zhu, C.; Chiu, W.C.; La Salle, J. Two new *Aprostocetus* species (Hymenoptera: Eulophidae: Tetrastichinae), fortuitous parasitoids of invasive eulophid gall inducers (Tetrastichinae) on *Eucalyptus* and *Erythrina*. *Zootaxa* **2014**, *3846*, 261–272. [[CrossRef](#)]
55. Protasov, A.; La Salle, J.; Blumberg, D.; Brand, D.; Saphir, N.; Assael, F.; Fisher, N.; Mendel, Z. Biology, revised taxonomy and impact on host plants of *Ophelimus maskelli*, an invasive gall inducer on *Eucalyptus* spp. in the Mediterranean Area. *Phytoparasitica* **2007**, *35*, 50–76. [[CrossRef](#)]
56. Kim, I.K.; Mendel, Z.; Protasov, A.; Blumberg, D.; La Salle, J. Taxonomy, biology, and efficacy of two Australian parasitoids of the eucalyptus gall wasp, *Leptocybe invasa* Fisher & La Salle (Hymenoptera: Eulophidae: Tetrastichinae). *Zootaxa* **2008**, *1910*, 1–20. [[CrossRef](#)]
57. Moriya, S.; Shiga, M.; Adachi, I. Classical biological control of the chestnut gall wasp in Japan. In Proceedings of the 1st International Symposium on Biological Control of Arthropods, Honolulu, HI, USA, 14–18 June 2002; pp. 407–415.
58. Aebi, A.; Schönrogge, K.; Melika, G.; Alma, A.; Bosio, G.; Quacchia, A.; Picciau, L.; Abe, Y.; Moriya, S.; Yara, K.; et al. Parasitoid recruitment to the globally invasive chestnut gall wasp *Dryocosmus kuriphilus*. In *Galling Arthropods and Their Associates: Ecology and Evolution*; Ozaki, K., Yukawa, J., Ohgushi, T., Price, P., Eds.; Springer: Tokyo, Japan, 2006; pp. 103–121.
59. Yara, K.; Yano, E.; Sasawaki, T.; Shiga, M. Detection of hybrids between introduced *Torymus sinensis* and native *T. beneficus* (Hymenoptera: Torymidae) in central Japan, using malic enzyme. *Appl. Entomol. Zool.* **2000**, *35*, 201–206. [[CrossRef](#)]
60. Yara, K.; Sasawaki, T.; Kunimi, Y. Displacement of *Torymus beneficus* (Hymenoptera: Torymidae) by *T. sinensis*, an indigenous and introduced parasitoid of the chestnut gall wasp, *Dryocosmus kuriphilus* (Hymenoptera: Cynipidae), in Japanese chestnut fields: Possible involvement in hybridization. *Biol. Control.* **2007**, *42*, 148–154. [[CrossRef](#)]
61. Yara, K.; Sasawaki, T.; Kunimi, Y. Hybridization between introduced *Torymus sinensis* (Hymenoptera: Torymidae) and indigenous *T. beneficus* (late-spring strain), parasitoids of the Asian chestnut gall wasp *Dryocosmus kuriphilus* (Hymenoptera: Cynipidae). *Biol. Control.* **2010**, *54*, 14–18. [[CrossRef](#)]
62. Ferracini, C.; Ferrari, E.; Pontini, M.; Nova, L.K.H.; Saladini, M.A.; Alma, A. Post-release evaluation of non-target effects of *Torymus sinensis*, the biological control agent of *Dryocosmus kuriphilus* in Italy. *Biol. Control.* **2017**, *62*, 445–456. [[CrossRef](#)]
63. De Clercq, P.; Mason, P.G.; Babendreier, D. Benefits and risks of exotic biological control agents. *Biol. Control.* **2011**, *56*, 681–698. [[CrossRef](#)]
64. Wong, W.; NParks Singapore, Singapore. Personal communication, 2021.
65. Devasahayam, S.; IISR, Kerala, India. Personal communication, 2006.
66. Kaufman, L.V.; Wright, M.G. Parasitism of a Hawaiian endemic moth by invasive and purposely introduced Hymenoptera species. *Environ. Entomol.* **2010**, *39*, 430–439. [[CrossRef](#)] [[PubMed](#)]
67. Kiyuna, C. Evaluation of the effectiveness of insecticides on *Quadrastichus erythrinae* by tree injection- Insecticidal effect on seedlings. *Anneal Rev. Okinawa Prefect. For. Resour. Res. Cent.* **2006**, *1*, 14–17. (In Japanese)
68. Kiyuna, C. Insecticidal effect test on *Quadrastichus erythrinae*. *Anneal Rev. Okinawa Prefect.* **2007**, *2*, 6–9. *For. Resour. Res. Cent.* **2007**, *2*, 6–9. (In Japanese)
69. Kiyuna, C. Control effect of *Quadrastichus erythrinae* by tree injecting. *Anneal Rev. Okinawa Prefect. For. Resour. Res. Cent.* **2007**, *2*, 10–14. (In Japanese)
70. Yasuda, K.; Daisuke, K.; Shimizu, Y.; Kiyuna, C. Examination of biological control on *Quadrastichus erythrinae*. *Kyushu J. For. Res.* **2018**, *71*, 23–25. (In Japanese)
71. Yasuda, K. Coral trees damage by *Quadrastichus erythrinae* and background to the introduction of the natural enemy *Eurytoma erythrinae*. *Kyushu J. For. Res.* **2019**, *72*, 145–149. (In Japanese)

72. Oishi, T.; Agarie, K.; Atsushi, H. Effectiveness of controlling *Quadrastichus erythrinae* by releasing natural enemies *Eurytoma erythrinae*. Estimating the control effect by Convergent cross mapping. *Okinawa Prefect. For. Resour. Res. Cent. Rep.* **2019**, *31*. (In Japanese)
73. Tung, G.S. *Saving Coral Trees*; Extension Pamphlet No. 39; Forest Bureau and Taiwan Forestry Research Institute, Council of Agriculture, Executive Yuan: Taipei, Taiwan, 2006.
74. Tung, G.S.; Yang, M.M.; Yang, E.C.; Lan, Y.C. *Saving Coral Trees II: Infestation Level and Pest Control of Erythrina Eulophid Wasp Quadrastichus Erythrinae*; Forest Bureau, Council of Agriculture, Executive Yuan: Taipei, Taiwan, 2008.
75. Tung, G.S.; Yang, M.M.; Yang, E.C.; Lan, Y.C.; Wu, Y.S. *Saving Coral Trees III: Infection Assessment and Chemical Control of the Erythrina Eulophid Wasp*; Forest Bureau, Council of Agriculture, Executive Yuan: Taipei, Taiwan, 2011.
76. Tung, G.S.; Pang, L.Y.; Liu, C.; Hung, T.Y. *The IPM for Pest Control of Quadrastichus Erythrinae*; Extension Pamphlet No. 153; Forest Bureau and Taiwan Forestry Research Institute, Council of Agriculture, Executive Yuan: Taipei, Taiwan, 2019.
77. Johnson, M.T.; Follett, P.A.; Taylor, A.D.; Jones, V.P. Impacts of biological control and invasive species on a non-target native Hawaiian insect. *Oecologia* **2005**, *142*, 529–540. [[CrossRef](#)] [[PubMed](#)]
78. Henneman, M.L.; Memmott, J. Infiltration of a Hawaiian community by introduced biological control agents. *Science* **2001**, *293*, 1314–1316. [[CrossRef](#)] [[PubMed](#)]
79. Howarth, F.G. Environmental impacts of classical biological control. *Annu. Rev. Entomol.* **1991**, *36*, 485–509. [[CrossRef](#)]
80. De Bach, P. *Biological Control by Natural Enemies*; Cambridge University Press: Cambridge, UK, 1974; pp. 1–323.