

ENGINEERING AN INVASION IN TROPICAL ISLANDS: CLASSICAL BIOLOGICAL CONTROL OF THE GLASSY-WINGED SHARPSHOOTER, *HOMALODISCA VITRIPENNIS*, BY THE EGG PARASITOID *GONATOCERUS ASHMEADI* IN FRENCH POLYNESIA

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ABSTRACT.

Tropical islands are paradises for potential invaders. They offer ideal conditions for pest proliferation: mild climate, numerous host-plants, and few competitors and natural enemies. The invasion of the glassy-winged sharpshooter, *Homalodisca vitripennis* Germar (= *H. coagulata* Say) (Hemiptera: Cicadellidae) in French Polynesia is a typical example. *Homalodisca vitripennis* was first recorded in Tahiti in 1999. It reproduced and spread very rapidly and a few years later was found in 10 islands of French Polynesia in three different archipelagos. It became an important pest threatening agriculture and native biodiversity, and created intolerable social and recreational problems. Further, massive uncontrolled populations on Tahiti presented an elevated invasion threat to other South Pacific nations. To minimize these problems, a classical biological control program against *H. vitripennis* was conducted using the host specific egg parasitoid *Gonatocerus ashmeadi* Girault (Hymenoptera: Mymaridae). After risk assessment studies indicated an acceptably low level of risk to non-target species, parasitoids were released in Tahiti in 2005. Within a few months, the parasitoid colonized all Tahiti and all other infested islands in French Polynesia. The impact of *G. ashmeadi* on *H. vitripennis* was extremely rapid and catastrophic in all infested islands. Arrival of *G. ashmeadi* slashed *H. vitripennis* densities by more than 95%. Pest populations were maintained at very low densities until now in spite of seasonal fluctuations. French Polynesia was a paradise for *H. vitripennis* and became a paradise for *G. ashmeadi*.

INTRODUCTION.

Invasive species are exotic species introduced intentionally or by accident, in a new environment where they proliferate in detriment of indigenous species. Invasive species are the second cause in loss of biodiversity after habitat destruction in continents, and the first cause in islands (Wilcove *et al.* 1998). The many, small, isolated islands of French Polynesia are extremely susceptible to invasions, because of the low number of species, the high endemism and because of intensive trade with surrounding countries (Perrings *et al.* 2002). In addition, tropical islands are especially susceptible to invasion because they have climatic conditions favorable to the reproduction and proliferation of numerous species.

French Polynesia has a long history of biological invasions: both intentional (e.g. the giant African land snail, *Achatina fulica* Bowdich (Mollusc)) and accidental (e.g. the little fire ant *Wasmmania auropunctata* Roger (Formicidae, Myrmicinae)). Classical biological control was the answer to several invasions in the past, but the poor track record in biological control safety and program efficacy led to dramatic consequences in several cases. The most egregious example of a “biological control disaster” in French Polynesia was the unintentional extirpation of native *Partula* snails on many islands by the predatory snail, *Euglandina rosea*, that was released in 1977 for the biological control of giant African land snail, *Achatina fulica* (Murray *et al.* 1988). Presently, classical biological control of invasive species in French Polynesia is considered with skepticism and is considered only following: 1) demonstration that there is no other feasible solution, 2) studies assessing the risk of the biocontrol agent for the native fauna, and 3) an impact study of the target species, and if possible, non-target species. A case study was the classical biological control program against the glassy-winged sharpshooter *Homalodisca vitripennis* Germar (= *H. coagulata* Say) (Hemiptera: Cicadellidae).

The glassy-winged sharpshooter is native to the southeastern U.S.A. and northeastern Mexico (Triapitsyn & Phillips 2000). It is a polyphagous sharpshooter that can feed and develop on more than 150 plant species in 34 plant families (Hoddle *et al.* 2003). It is a major pest of agricultural, ornamental and native plants, because of its ability to vector the plant bacteria *Xylella fastidiosa* (Wells *et al.* 1987), which causes a variety of lethal scorch-like diseases in susceptible hosts (Hopkins & Purcell 2002). It invaded California at the end of the 80's and is now spreading to Pacific islands. *Homalodisca vitripennis* was first recorded in Tahiti in 1999. It likely invaded as eggs on ornamental plants imported from California. It reproduced and spread very rapidly in French Polynesia reaching very high densities in Tahiti and nearby Moorea and invaded eight other islands located in three different archipelagos of French Polynesia by 2005 (Fig. 1). The invasion dynamics of *H. vitripennis* in French Polynesia is detailed in Petit *et al.* (2008a), who demonstrated the role of human-mediated transport in the spread of this pest. The bacteria *X. fastidiosa* was not recorded in French Polynesia but the extremely high densities of *H. vitripennis* in Tahiti and Moorea threatened agriculture and native biodiversity and created social nuisance. These problems were mainly due to prolific feeding of *H. vitripennis* which caused impaired growth of plants, created aesthetic problems due to excreta. Recreational activities under trees were impossible due to excreta dripping from trees, and large numbers of insects invaded houses at night due to attraction to light. Further, massive uncontrolled populations on Tahiti presented an elevated invasion threat to other Pacific islands and trading partners (Grandgirard *et al.* 2006). This threat was realized when *H. vitripennis* was discovered on Easter Island in 2005 and the Cook Islands (Rarotonga) in 2007 (Petit *et al.* 2008a). The major factors responsible for successful and rapid invasion of *H. vitripennis* in French Polynesia are: permissive environmental conditions (mild climate and abundant year-round feeding and oviposition substrates) leading to a year-round reproduction of this pest with 7-8 overlapping generations a year; absence of host specific natural enemies; death of generalist predators that attack nymphal and adult stages, and limited competition for resources (Grandgirard *et al.* 2006, Suttle & Hoddle 2005).



Fig. 1. *Pandanus* sp. Infested by *Homalodisca vitripennis* in Tahiti (2005, before the release of the parasitoid *Gonatocerus ashmeadi*) (Photo: J. Petit).

Due to the wide distribution and high abundance of *H. vitripennis* in French Polynesia and the absence of specific natural enemies, classical biological control was considered as the most appropriate solution to combat this pest and minimize its associated problems. A classical biological control program was conducted between 2004 and 2007 using the parasitoid *Gonatocerus ashmeadi* Girault (Hymenoptera: Cicadellidae). This parasitoid, native to southeastern U.S.A. and northeastern Mexico (Triapitsyn *et al.* 1998), was chosen because of its high specificity for eggs of Proconiini sharpshooters and promising control capacities exhibited in California and Hawaii (Triapitsyn *et al.* 1998; Logarzo *et al.* 2003; Bautista *et al.* 2005; Pilkington *et al.* 2005). The present paper gives an overview of this program.

RISK ASSESSMENT TO NATIVE CICADELLID FAUNA. (from Grandgirard *et al.* 2007)

A priori risk assessment studies were performed in the Society Islands before the introduction of the parasitoid in French Polynesia. Initial releases of *G. ashmeadi* were planned for Tahiti (Society Islands) because Tahiti had the highest pest densities. Also, Tahiti is the main island of French Polynesia and is the major hub for domestic and international air and sea transport. It thus represented the most likely source of *H. vitripennis* spreading to new areas (Petit *et al.* 2008a). An inventory of the Cicadellidae of the Society Island archipelago was undertaken and the risk of attack by *G. ashmeadi* was assessed using four criteria: 1) phylogenetic relationships between non-target cicadellids and known hosts for *G. ashmeadi*, 2) morphology, 3) egg laying biology, and 4) ecology. A risk decision tree was used to test criteria 3 and 4. Important knowledge on the host range of *G. ashmeadi*, and the behavior, ecology and taxonomy of native cicadellids from southern California facilitated the

development of this dichotomous risk decision tree. This tree is a useful tool that could be used in other countries (Fig. 2).

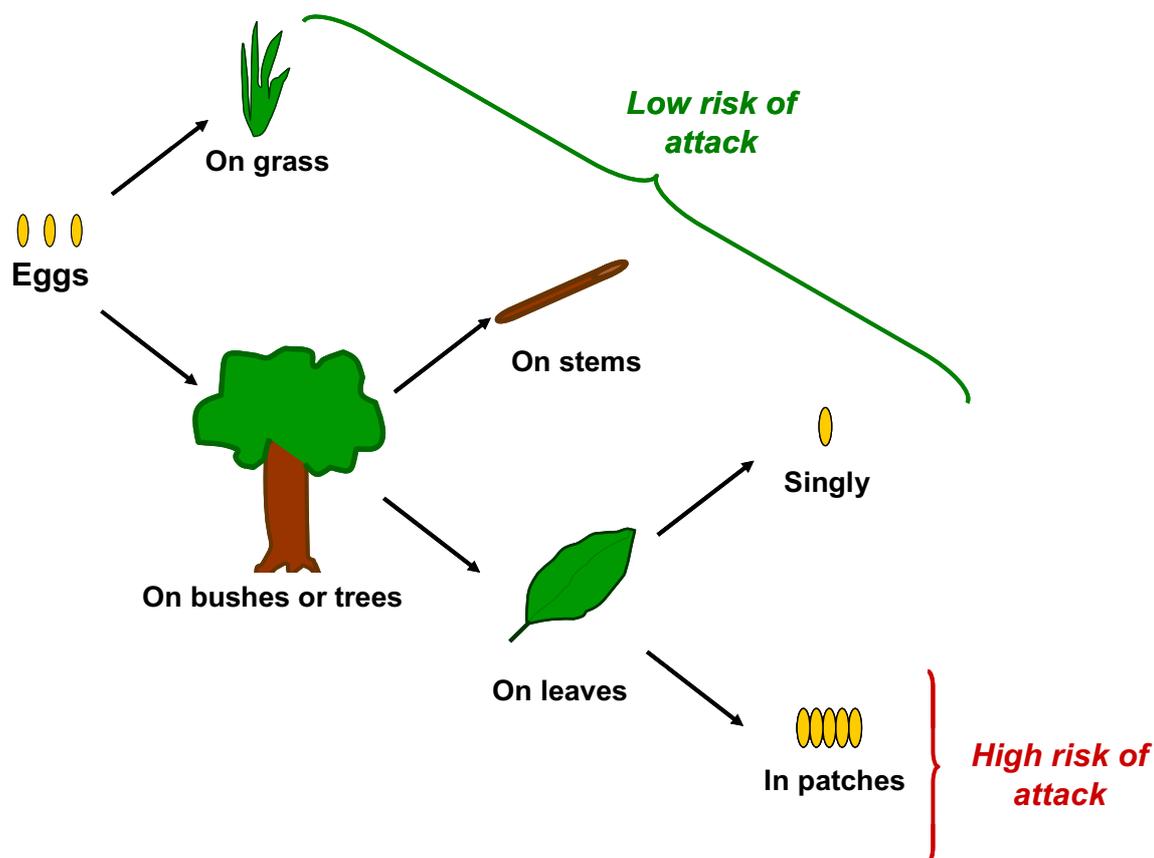


Fig. 2. The dichotomous risk-decision tree used to determine the risk posed by *Gonatocerus ashmeadi* releases on cicadellids native to French Polynesia. This tree enabled rapid assessment of the risk of attack by *G. ashmeadi* on eggs of native cicadellids (from Grandgirard *et al.* 2006).

All native cicadellid species found (14 species at the time of release decision) were considered to be at low risk of attack because they differed greatly from all known hosts for *G. ashmeadi*: (1) none are in the tribe Proconiini, 2) all were very small and, when determined, 3) lay tiny single eggs, which 4) are deposited on the leaves of trees. Hence, the French Polynesian government authorized the release of *G. ashmeadi* in Tahiti in April 2005. The risk assessment study continued *a posteriori* (after release in Tahiti) in Society Islands and was extended to other archipelagos (Marquesas and Australs) before planned releases in these archipelagos (2006). All native cicadellids found (> 25 species) were shown to have a very low risk of attack by *G. ashmeadi*.

RELEASE AND DISPERSAL OF BIOCONTROL AGENT. (from Petit *et al.*, 2008b, 2008c)

Gonatocerus ashmeadi was first released on Tahiti in May 2005. A total of 13,786 parasitoids were released at different 27 sites around Tahiti between May and

October 2005 (Grandgirard *et al.* 2007; Grandgirard *et al.* 2008a). Short and long-distance dispersal of *G. ashmeadi* were studied. This study was an opportunity to identify invasion pathways of its host and to study the invasion process of an invasive species (i.e. the deliberate introduction of *G. ashmeadi*).

Short-distance dispersal.

The parasitoid spread very rapidly in Tahiti and had colonized the entire island by October 2005. Results demonstrated that *G. ashmeadi* exhibits an exponential dispersal capacity. Survey results across different altitudes revealed an effect of vegetative diversity and host density on the mobility and establishment of *G. ashmeadi*, suggesting that many small releases would be needed for establishment when host density is high and larger and fewer releases when host density is low. Results also strongly suggested *G. ashmeadi* should be able to suppress rapidly *H. vitripennis* in every new area that this pest establishes high density populations if the climate is permissive enough to allow year round reproduction by the pest (Hoddle, 2006).

Long-distance dispersal.

All islands of French Polynesia infested by *H. vitripennis* were colonized by *G. ashmeadi* within 10 months and before the deliberate introduction of the parasitoid in the islands. The parasitoid spread quickly from Tahiti to widely separated islands (up to 1400 km from Tahiti); presumably through the transportation of plant material containing parasitized *H. vitripennis* eggs, which prove the existence of failures in inter-island quarantine measures. This result demonstrated the importance of unintentional human-mediated dispersal assisting rapid and widespread distribution of an upper trophic level organism.

EFFICACY OF BIOCONTROL AGENT. (from Grandgirard *et al.* 2008a, 2008b)

In Tahiti and Moorea, the impact of *G. ashmeadi* on *H. vitripennis* populations was determined by comparing parasitism of *H. vitripennis* eggs by *G. ashmeadi* and abundance of *H. vitripennis* before and after parasitoid release at multiple paired-sites: a control (no parasitoid releases) and a release site. In addition, the abundance and distribution of *H. vitripennis* nymphs on each infested island was monitored on *Hibiscus rosa-sinensis* (Malvaceae) hedges located at different sites on the coast of each island.

Results showed that *G. ashmeadi* successfully controlled populations of *H. vitripennis* on 10 infested islands of French Polynesia across four island groups and three archipelagos (Windward and Leeward Islands [Society Islands Archipelago], Marquesas and Austral archipelagos). These islands exhibit different seasonal temperature regimens. Suppression of *H. vitripennis* populations was achieved with the release of relatively few parasitoids (~15,000), and control was widespread, rapid, and effective with > 95% reduction in pest densities on all islands colonized by *G. ashmeadi*. This level of control was achieved within 7-9 months of release of *G. ashmeadi* and is expected to be permanent based on the results of two years of survey data on the Windward Islands (Fig. 3). Possible seasonal variation in parasitism rates and natural enemy and pest densities is expected especially on

island groups (e.g., the Australs) or high elevation sites with relatively cold temperatures (~20-22°C) over the fresh and dry season (May-October).

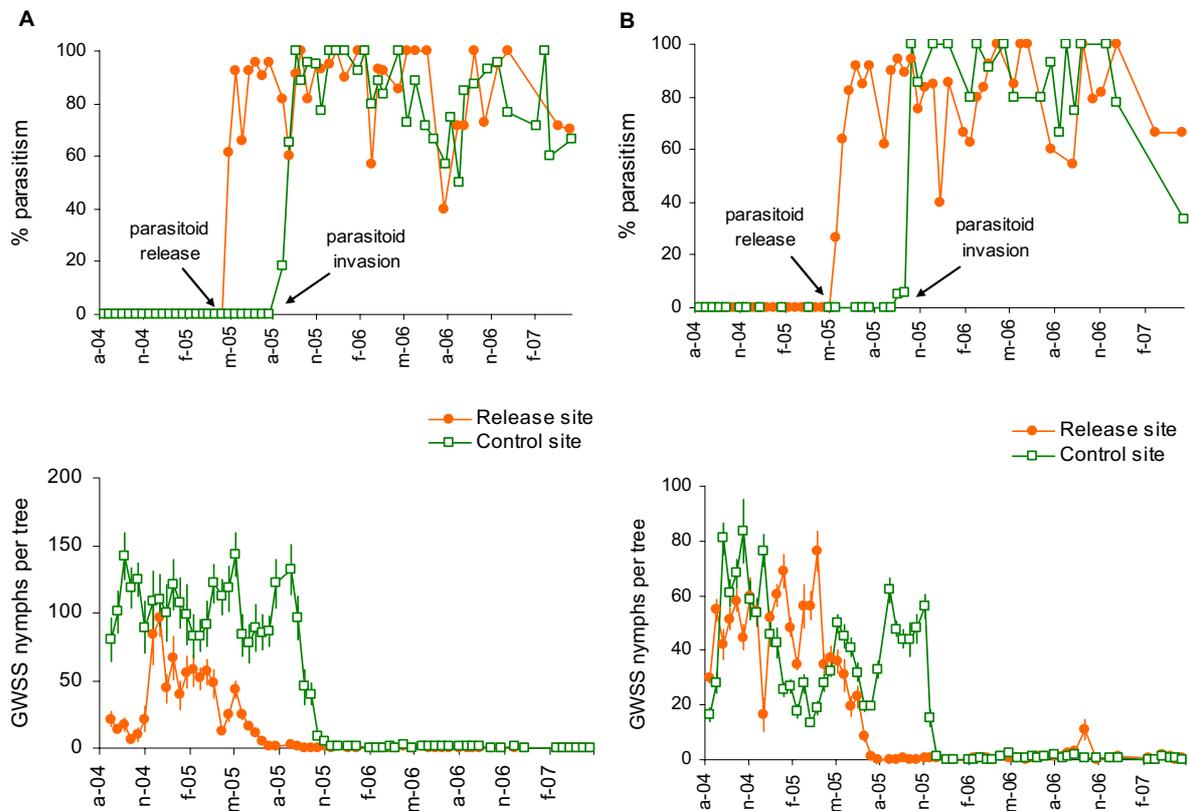


Fig. 3. Impact of *Gonatocerus ashmeadi* on *Homalodisca vitripennis* in release and control paired-sites located at sea level in Tahiti from August 2004 to April 2007. The parasitoid was released on May 2005. Upper figures: Percentage of *H. vitripennis* egg masses parasitized by *G. ashmeadi*: Lower figures: Mean number (\pm s.e.) of *H. vitripennis* nymphs found per tree during 2.5 min of visual counting: **A**: on ornamental *Scaevola* sp. in public gardens, **B**: on *Gardenia tahitiensis* in plantations. The 10 same plants were sampled each time (from Grandgirard *et al.* 2008b).

DISCUSSION.

The classical biological control program developed against the glassy-winged sharpshooter in French Polynesia demonstrated that both *H. vitripennis* and its parasitoid *G. ashmeadi* proliferate and spread extremely rapidly due to highly favourable conditions (mild climate, abundance of hosts, no specific enemies, few competitors), human-mediated transportation, in addition to high dispersal and high capacity for reproduction. French Polynesia was a paradise for *H. vitripennis* and became a paradise for its enemy *G. ashmeadi*. This program showed that classical biological control against invasive species can work and be safe. It appears as a promising method in tropical islands which have permissive environmental conditions

and can be rapidly colonized by the released biocontrol agent due to the small size of the islands.

However, it should be kept in mind that classical biological control is not a perfect solution against invasive species. In fact, there is no perfect solution against once invaders arrived; the best solution remains prevention. Hence, the cost/benefit balance of each possible control option should help deciding the best method for each invasive species. For example, the other control option against *H. vitripennis* was chemical control, however, the wide distribution of the pest (including inaccessible zones) made the chemical control option too dangerous for biodiversity and people and too expensive while classical biological control appeared feasible with low risk to the environment.

The advantages of classical biological control are its low cost, its permanency, and the absence of pollution. The drawbacks are also worth understanding:

1. The invader will never be completely eradicated, consequently, it can continue to spread and can still be a serious pest (for example if it is a disease vector and it requires a low density to infect numerous plants). In the case of *H. vitripennis*, new infested islands were discovered even after the sharpshooter was controlled efficiently by the parasitoid (inside French Polynesia, and in neighbouring countries: Easter Island, Cook Islands). The parasitoid has moved with its host in most cases and found appropriate climate to reproduce, hence *H. vitripennis* remained at low level. But it might not be the case if *H. vitripennis* begin to spread in New Zealand or Australia;

2. The introduced natural enemy may attack the native fauna and threaten the biodiversity and if this occurs, the ecosystem will be indefinitely modified. The selection of the natural enemy to be introduced is a crucial step and it is absolutely necessary to carry out broad safety studies prior to natural enemy introduction, especially in islands that have high endemism. Ideally, non-target impact studies should occur over a suitable geographic range that could climatically accommodate the natural enemy. For *G. ashmeadi*, the appropriate area of concern for potential non-target impact assessment studies could have included the central and eastern Pacific. However, this increased range would have greatly increased the cost and scope of the *H. vitripennis* biological control program to the point of infeasibility. Curtailment of the biological control program would have allowed the pest to continue its spread from highly infested areas into new areas of the South Pacific (Petit *et al.* 2008c). Hence, it is important to consider the cost/benefit balance of accumulating risk assessment data vs. continued damages and spread of the invader.

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