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MANAGEMENT OF THE AVIAN PARASITE PHILORNIS DOWNSI IN THE GALAPAGOS ISLANDS: A COLLABORATIVE AND STRATEGIC ACTION PLAN

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*The **Galapagos National Park Service** has its headquarters in Puerto Ayora, Santa Cruz Island, Galapagos and is the Ecuadorian governmental institution responsible for the administration and management of the protected areas of Galapagos.*

*The **Governing Council of Galapagos** has its headquarters in Puerto Baquerizo Moreno, San Cristóbal Island, and is the Ecuadorian governmental institution responsible for planning and the administration of the province.*

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***Galapagos Conservancy**, based in Fairfax, Virginia USA, is the only US non-profit organization focused exclusively on the long-term protection of the Galapagos Archipelago.*

Adult *Philornis* in a McPhail trap, which contains papaya juice.

Photograph: © Charlotte Causton

Management of the avian parasite *Philornis downsi* in the Galapagos Islands: A collaborative and strategic action plan

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Background

No bird extinction has ever taken place in the Galapagos Islands since the arrival of humans in 1535. However, some endemic land bird populations are now declining in number, in part due to an introduced parasitic fly, *Philornis downsi*. This fly was first recorded in the Galapagos Islands in the 1960s, but its negative impact on birds was only discovered in the 1990s (Causton *et al.*, 2006). Adult flies lay eggs in bird nests and then the fly larvae feed on the blood and tissue of hatchlings affecting growth and causing anemia, bill deformation and ultimately death (Figure 1). Nestling mortality due to these parasites can be up to 100% (references cited in O'Connor *et al.*, 2010). So far flies have been recorded on 13 islands with the highest numbers on the inhabited islands; of the 15 islands surveyed only Genovesa and Española have been found free of these parasites (Figure 2). At least 16 endemic bird species, one native, and one introduced species are attacked by *P. downsi* (Table 1). The fly's impact on birds is a serious threat especially to vulnerable and declining species. *P. downsi* parasitism has already been implicated in the decline of endemic, critically endangered species such as the Mangrove Finch (*Camarhynchus heliobates*) and the Medium Tree Finch (*C. pauper*) (Fessl *et al.*, 2010; O'Connor *et al.*, 2010).

There are currently no known techniques to effectively mitigate the threat of *P. downsi*. In spite of considerable efforts by the Charles Darwin Foundation (CDF) and collaborators there are still substantial gaps in the understanding of the life history and ecology of *P. downsi*, which has prevented the development of methods to control the fly. Furthermore, little is known about the fly in its native range (Trinidad and Brazil). Because of this, an international workshop was held by the Galapagos National Park Service (GNPS) and CDF in February 2012 to bring together local and international experts to find a solution for the management of *P. downsi*.

Workshop participants concluded that the development of effective management tools will depend on a collaborative and coordinated effort between experts in different parts of the world (Argentina, Austria, Ecuador, Trinidad, and USA) working in different areas of insect biology, control and management, and ornithology. These research activities are outlined in a strategic research plan that was developed by the specialists during the workshop (https://sites.google.com/site/philornisworkinggroup/action-plan). The key research questions and actions are listed below and highlight the complexity of developing a management program for an invasive insect.

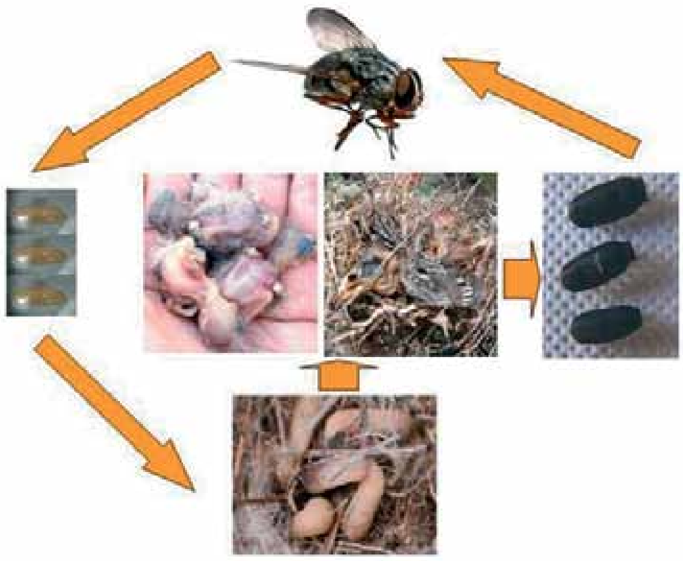

Figure 1. Life cycle of *P. downsi*. Adults feed on decaying plants and fruits. The female flies lay eggs in the nests of birds. After 1-2 days the larvae hatch and move inside the nostril cavity of the baby birds. Mature larvae migrate outside the chick, spending the day in the nest base and feeding on blood as ectoparasites during the night. Larvae pupate in the nest base after about 7 days, and emerge as flies approximately 14 days later.

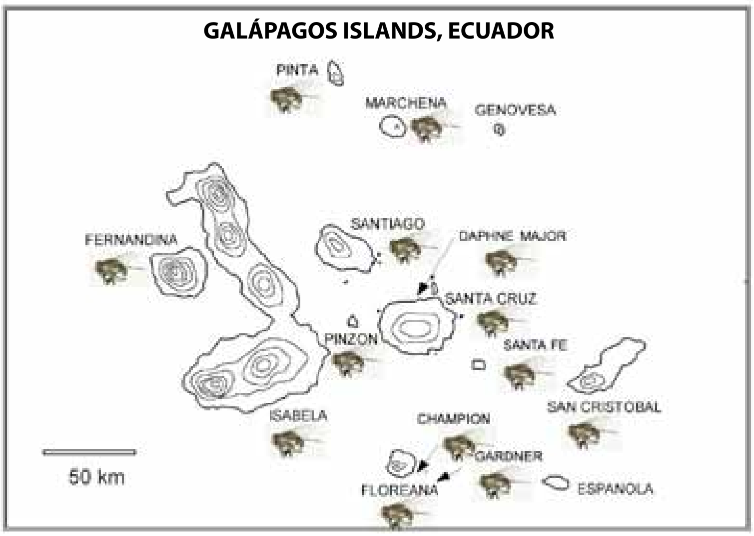

Figure 2. Distribution of *P. downsi* in the Galapagos Islands. Of 15 islands surveyed, only Genovesa and Española have not been invaded by the fly (Wiedenfeld *et al.*, 2007; B. Fessl and P. Lincango, pers. comm.).

Goal 1: Understand the biology and ecology of *Philornis downsi*

Why/how does *P. downsi* emerge in such large numbers at the beginning of the bird breeding season? Where are the flies in the dry season?

Studies suggest that the humid vegetation zones of the Galapagos Islands act as a reservoir for flies during the dry season. Some birds may reproduce all year in this zone thus maintaining a permanent fly population. Monitoring will be conducted to determine whether flies move from the humid zone to the arid zone when conditions are favorable.

Is fly behavior guided by chemical attractants?

The investigation of chemical attractants is important because attractants can be used to trap flies, which in turn can be used to monitor pest populations or to suppress fly numbers (see below). Preliminary studies suggest that *P. downsi* may produce a pheromone to attract mates and that flies are attracted to fermentation products and odors produced by protein decomposition (Muth, 2007; Lincango & Causton, 2008a; Collignon & Teale, 2010). Additional experiments are required to determine what attracts flies to nests, how flies locate their mates, and what foods they are attracted to.

Table 1. Bird hosts of *P. downsi* in Galapagos.

Scientific name (origin) (Origin: E = endemic, N = native)	English common name
Camarhynchus heliobates (E)	Mangrove Finch
Camarhynchus pallidus (E)	Woodpecker Finch
Camarhynchus parvulus (E)	Small Tree Finch
Camarhynchus pauper (E)	Medium Tree Finch
Camarhynchus psittacula (E)	Large Tree Finch
Certhidea olivacea (E)	Warbler Finch
Coccyzus melacoryphus (N)	Dark-billed Cuckoo
Crotophaga ani (I)	Smooth-billed Ani
Dendroica petechia (N)	Yellow Warbler
Geospiza fortis (E)	Medium Ground Finch
Geospiza fuliginosa (E)	Small Ground Finch
Geospiza magnirostris (E)	Large Ground Finch
Geospiza scandens (E)	Cactus Finch
Mimus melanotis (E)	San Cristóbal Mockingbird
Mimus parvulus (E)	Galapagos Mockingbird
Mimus trifasciatus (E)	Floreana Mockingbird
Myiarchus magnirostris (E)	Galapagos Flycatcher
Pyrocephalus rubinus (E)	Vermilion Flycatcher

Where do flies mate and what is the reproductive biology of the fly?

Understanding the fly's mating system is critical to the development of the management program. If we are able to determine where mating occurs (e.g., on food or in nests), we might be able to find attractant odors that are associated with the mating location and then develop a trapping method. On the other hand, an understanding of the cues for initiating copulation and egg depositing behavior is important when evaluating the feasibility of using Sterile Insect Technique (see below).

What are the dispersal capabilities of *P. downsi*?

P. downsi was probably first introduced to Galapagos with imported fruit, pigeons/chickens, or nest material, or in the holds of planes. It is possible that there has been more than one introduction event. Understanding the dispersal capability of *P. downsi* is crucial to determining which control methods could be effective. For example, if re-invasion is highly likely, management should focus on long-term suppression/management rather than eradication. The colonization pathway of *P. downsi* within the archipelago may have been natural (by wind) and/or assisted (on fruits, attracted to lights on boats, etc.). Studies suggest that *P. downsi* can disperse over large distances and can colonize new areas on its own (Dudaniec *et al.*, 2008). Monitoring of airplanes and boats, and an analysis of the genetic population structure will help confirm how *P. downsi* disperses.

How can we breed *P. downsi* in captivity?

Being able to breed *P. downsi* in captivity is crucial for developing control techniques such as biological control and Sterile Insect Technique. From 2007-2008 CDF placed considerable effort on trying to rear *P. downsi* in captivity, with only partial success. Researchers were unable to find a suitable medium for attracting female flies to lay eggs or for rearing newly hatched larvae. To enable mass rearing it is necessary to develop easy-to-manufacture diets for all life stages of the fly and to define what stimulates egg-laying in the laboratory.

How do *P. downsi* and related species behave in their native and introduced ranges, and how does this relate to the environment?

Parallel investigations of *P. downsi* and closely related species in their native and introduced ranges may help us to understand its biology. The genus *Philornis* comprises c. 50 species and the main distribution of *Philornis* is in Central and South America, extending to the southern United States. *P. downsi* has been reported from Trinidad and Brazil, where it is thought to be native (Dudaniec & Kleindorfer, 2006). Recently, it was found in Argentina where it is likely to have dispersed naturally (Silvestri *et al.,* 2011). It is not known whether it is found in mainland Ecuador.

Figure 2. Larvae feeding on a Galapagos finch nestling. Photo: J. O'Connor, Flinders University

Is *P. downsi* a vector of disease?

A study by Aitken *et al.* (1958) showed that larvae of some *Philornis* species can transmit arbo viruses to birds. It is unknown whether *P. downsi* plays a role in the transfer of viruses between birds and it is important that this be investigated.

Goal 2: Develop methods for the effective management of *P. downsi*

There are currently no methods that effectively control *P. downsi*. Given the urgency of protecting endangered bird species, workshop participants concluded that while long-term control methods are being developed, it is imperative that an immediate management plan to protect birds be developed and implemented, even if the initial methods only result in a partial reduction in bird mortality.

What methods can we implement in the short-term to reduce *P. downsi* numbers in nesting areas of highly threatened bird species?

To date the application of 1% permethrin to the base of the nest is the only method that has been shown to be effective in reducing fly numbers and increasing fledgling survival (Koop *et al.*, 2011). Additional research is needed to determine the safety of using permethrin with a threatened species and to design methods for delivering the insecticide to nests in tall (25 m) trees. This method in combination with the placement of traps with attractants, such as papaya and sugar, at key times during the nesting season, may increase nestling survival. Removal of abandoned nests may also help.

What long-term options can we use for the management of *P. downsi*?

Several potential management options for *P. downsi* exist and could be investigated concurrently (Table 2). Techniques such as mating disruption or Sterile Insect Technique (SIT) could be used to eradicate *Philornis* from the archipelago. However, because of its extensive distribution, eradication would only be possible if new introductions of *P. downsi* do not occur on a regular basis and long-term funding is guaranteed. A combination of the management strategies may be the best option for reducing *P. downsi* damage to an acceptable level. Regular monitoring and evaluation will indicate success or failure.

Mass trapping with attractants (high priority). Mass trapping using attractants is a useful technique for suppressing populations in areas of high conservation value, but not for archipelago-wide control. Chemical attractants are also useful for measuring populations over time or measuring the efficacy of other control programs such as Sterile Insect Technique and biological control. If it is found that the flies use attractants it might be possible to synthesize the attractant for use in a trapping program.

Mating disruption with pheromones (high priority). The general effect of mating disruption is to confuse the male by masking the natural pheromone plumes produced by the female by releasing a synthetic pheromone in the pest's habitat. This causes the males to follow "false pheromone trails" and thus reduces the probability of successfully locating and mating with females, leading to the eventual cessation of breeding and collapse of the insect infestation. If it is found that the flies use pheromones it might be possible to synthesize these pheromones for release over large areas of the archipelago.

Table 2. Summary of management options for *P. downsi*.

Management options	Advantages	Disadvantages
Trapping with pheromones or other attractants	• Effective method for protecting threatened species with restricted populations • Important tool for monitoring populations	• Can only be used over small areas • Need to apply on a regular basis • Not all methods are species specific
Mating disruption with pheromones	• Species specific and ecologically safe • Should be used in combination with other techniques • Most effective when controlling low to moderate pest population densities (inversely density dependent) • Works best if large areas are treated • Can treat inaccessible areas • Can result in eradication	• Expensive
Classical biological control (importation of natural enemies)	• Can be genus or species specific • Ecologically safe • Used over large areas • Can be applied over difficult topography • Permanent and self-sustaining • Good cost-benefit ratio	• Takes longer to develop • Hard to know level of control until it is released
Augmentative biological control (using natural enemies already found in Galapagos)	• Can be genus or species specific • Ecologically safe • Used over large areas • Lower development costs	• May not be self-sustaining and may require periodic releases of the natural enemy
Chemical control (IGRs, insecticides, chitinase inhibitors, etc.) and biopesticides	• Some like IGRs are safer and more group specific • May be useful for protecting threatened species with restricted populations	• Some are broad spectrum and safety would depend on what technique is used to deliver insecticide • Only effective in small areas • Requires repeated applications • Resistance can be developed over time
Sterile Insect Technique	• Species specific control method • Can be applied over difficult topography • Inversely density dependent • Integrates well with other methods • Can result in eradication • May also be used for long-term suppression and exclusion if reinvasion is likely (e.g., California preventive release program)	• Expensive

Biological control (medium/high priority). Biological control, if used safely, can be highly effective in keeping pests at non-damaging levels over large areas. Until recently, biological control was principally used in agricultural settings, but more recently it has been used in natural ecosystems to conserve threatened species, including in the Galapagos where the Australian ladybird (*Rodolia cardinalis*), was used to reduce the impact of the cottony cushion scale (*Icerya purchase*), on endemic plants (Calderón *et al.*, 2012). Natural enemies of *P. downsi,* in particular those species that are specialist feeders, could be highly effective in reducing *P. downsi* to non-damaging levels. There are two types of biological control that could be used: 1) augmentative biological control where natural enemies already found in Galapagos are mass reared and released, or 2) classical biological control through importation of natural enemies from the fly's native range. So far, four species of parasitic wasps have been reared from *Philornis* pupae in Galapagos. All are generalist feeders that could affect native species and, because of this, are unlikely to be suitable for use in a biological control program (Lincango & Causton, 2008*b*). There are no records of parasitoids of *P. downsi* in its native range; however, at least three species of wasps are known to parasitize *Philornis* species (Couri *et al.*,. 2006; Di Iorio & Turienzo, 2011).

Chemical control (high priority). Insect growth regulators (IGRs), chitinase inhibitors or biopesticides such as *Bacillus thuringiensis* toxins and Spinosad, could be useful for controlling *Philornis* in areas of high conservation value such as Los Gemelos, or in the nesting areas of threatened species. The scale for use of these methods depends on the delivery technique and could include splat technique on trees and/or injection/spraying on nests. These compounds are safer and more eco-friendly than traditional insecticides that are widely used for fly-control, and are low risk for non-target organisms.

Sterile Insect Technique (medium/high priority). The Sterile Insect Technique (SIT) is a method of pest control in which large numbers of sterile males are released. When wild fertile females mate with these males, their reproduction is reduced such that over a number of generations, the population shrinks to an unsustainable density and dies out. This method has been used against a number of pest species (Hendrichs *et al.*, 2005). It is highly species specific (it will not cause damage to other species) and it is environmentally benign. Requirements for assessing the feasibility of SIT include knowledge about the reproductive biology of the pest (mating and egg-laying behavior, diet, environmental conditions, how to rear pest in captivity), and availability of methods for monitoring and suppressing populations. SIT works best following an initial population suppression; SIT programs depend on population density and are often used in combination with other techniques.

Conclusions

Iconic bird species are declining in Galapagos, in large part due to *P. downsi*. Because of this, major and urgent action is required. A strategic research plan has been designed to develop effective tools for managing this invasive species. Research will be conducted in parallel by researchers in different parts of the world to find a solution as quickly as possible. The success of this plan will depend on a collaborative approach between specialists with regular cross communication about the progress of each activity, the timely sharing of newly published and relevant reports or articles, and cooperation in seeking funding opportunities.

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