Dispersal of insect species attracted to ship lights: Conservation implications for Galapagos

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Over the past century, the Galapagos Islands have suffered numerous transformations in the composition of their flora and fauna as a result of human colonization and the introduction and establishment of exotic species. The opening of more routes to Galapagos, the increase in the frequency of arrival of ships and planes, and the increase in imported products has compromised the natural isolation of the archipelago and resulted in the islands becoming filled with various introduced plants and animals.

Insects comprise the group of organisms with the highest capacity for arrival and eventual movement among the islands of the archipelago, due to the small size of most species and their dispersal strategies. Causton *et al.* (2006) reported that there are 463 species of introduced insects in Galapagos. Following their initial arrival, 73% of these species have dispersed to other islands within the archipelago and some have caused serious negative impacts (e.g., fire ants and wasps).

Silberglied (1978) was the first to discuss the introduction and dispersal of insect species in Galapagos through their attraction to the lights of ships that arrive from the continent and travel among the islands. This preliminary study, which collected data from only two tourist boats, reported 16 different species of insects attracted by ship lights. It highlighted two key considerations: (i) the introduction and dispersal of exotic species via boats traveling among the islands and (ii) the consequences that such dispersal could have on the biogeography and evolution of Galapagos species. During the more than 25 years since Silberglied's study, the tourist industry has undergone notable growth and development. The number of visitors has increased from 11 765 in 1979 to 161 859 in 2007 (GNPS archives). This increase in the number of visitors has brought with it an increase in the number and size of tourist boats that operate in Galapagos and in the number of visits to the various islands.

The Galapagos Islands are also visited occasionally by international cruise ships such as the M/N Discovery as well as smaller yachts. These vessels, some of which are very large and have many external lights, put in at various international ports prior to their arrival in Galapagos, posing a serious risk of introducing species to the archipelago.

The analysis of different means by which insects and other invertebrates are able to disperse within the archipelago that are dependent upon human activity is very important because it enables us to recommend mitigation measures. In this context, the Charles Darwin Foundation (CDF) has carried out research since 2001 to analyze this phenomenon and recommend mitigation measures. This article discusses the results of studies based on the collection of insects from tourist ships in 2001, 2002, 2007, and 2008, as well as the collection carried out aboard the M/N Discovery in 2007.

Results

The research demonstrates that the transport of insects attracted by onboard lights is a common phenomenon that has received little attention during the development of tourism management plans. The quantity of insects attracted to ship lights of tourist vessels depends upon: (i) environmental factors such as season, wind direction and velocity, the presence or absence of a full moon, etc.; (ii) physical factors such as the distance of the vessel from shore, the type and quantity of lights, etc.; and (iii) biological factors such as species diversity on the island, biological characteristics of each species, etc.

Calculations of the number of insects that can be transported by this medium vary greatly. For example, results of the research in Puerto Ayora in 2001 and 2002 showed that a medium-sized boat with 18 external lights could attract an average of 150 insects in three hours during the dry or garúa season (8.3 insects per light) and 466 insects in the rainy season (25.8 insects per light). When extrapolated to a full year, this results in 102 150 insects per year that could be attracted to the lights of a single boat and dispersed to other islands. If these results are then extrapolated to one of the larger tourist vessels with an average of 65 external lights, the number of insects that could potentially be dispersed by a single boat in a year is 367 543 (Roque-Albelo *et al.*, 2006). These figures can also be extrapolated to the entire fleet. Similar results were obtained in the collections in 2007 (Table 1), when a large number of specimens were collected from ship lights (Lomas, 2008).

Table1. Number of insects attracted to the lights of tourist vessels examined in 2007 in Puerto Ayora.

Name of vessel	Size (m)	Number of lights	Number of insects attracted to the lights
Eclipse	64	46	217
Isabela II	54	60	140
Polaris	72	75	123
Santa Cruz	72	63	153
Xpedition	89	75	139

Of even greater concern is the number of species that could be introduced to the islands through frequent visits by international vessels. One study onboard the M/N Discovery in 2006 detected 653 specimens of terrestrial invertebrates that could have been introduced to the islands if the insect monitoring system of the vessel or the intensive collections by researchers of the CDF, the Galapagos National Park (GNP), and the Ecuadorian Quarantine Inspection Service for Galapagos (SICGAL) had not occurred (Roque-Albelo *et al.*, 2007).

Are the color and type of light important in attracting insects?

Nocturnal insects are extremely sensitive to lights because they have developed special adaptations to them. The majority of insects are attracted to lights with low wave-lengths in the ultraviolet region of the electromagnetic spectrum, which includes both white and black lights. This

attraction is due to the sensitivity of the eyes of the insects to a wave-length of 254-600 nm. This same principal is used in the design of electronic insect collectors that use an ultraviolet light and an electric field that kills the insects that are attracted to the light.

The majority of boats in Galapagos use yellow or white incandescent or fluorescent lights. These lights have a wave-length of 300-700 nm and insects are attracted to some of them. For this reason the use of these types of lights is not recommended for vessels in Galapagos. Alternatives that have not been commonly used are orange-red lights and low-pressure sodium lights. These lights are not visible to insects because they have a wave-length greater than the detection ability of these organisms.

Implications for conservation

The dispersal of species between islands by vessels can have serious impacts on the biodiversity and evolutionary processes of Galapagos, especially considering that many endemic insects of Galapagos are restricted to a single island in the archipelago (Peck, 2001; 2006). Another potential consequence resulting from the unnatural dispersal of insects by boats includes the probable genetic contact between co-specific populations that are geographically isolated, potentially decreasing the separation between species. It is important to conduct additional research on this issue in order to establish the actual impact of this dispersal on the unique organisms of Galapagos.

The dispersal of introduced species deserves special attention. These studies indicate that there are various introduced species that can use the boats to disperse among the islands. Some of these species are highly aggressive and can cause serious losses in agricultural production, and can affect human health and the natural biota of the islands. Some possess biological properties that are typical of rapid invaders of new islands or habitats. The majority of these species were first accidentally introduced to the inhabited islands of the archipelago (Peck *et al.*, 1998; Causton *et al.*, 2006). The risk of their dispersal to and colonization on pristine islands increases if boats visit an altered island the night before. An improved design of itineraries for visiting tourist sites should focus on minimizing the risk of dispersal of species to pristine islands such as Fernandina.

Recommendations

The following measures are recommended to decrease the risk of dispersal of insects by boats:

1. Design itineraries for tourist boats taking into account the number of introduced species that are found on each island. For example, a tourist boat should not visit Fernandina (an island with few introduced species) if on the previous night it was anchored at Santa Cruz or San Cristóbal, where there are many introduced species.

2. Replace the ultraviolet and white lights currently used on many of the boats with yellow or orange-red lights or low pressure sodium lights that are less attractive to insects.

3. Turn off the onboard external lights at least two hours before departure from a port and immediately deploy insect traps. These traps are equipped with ultraviolet light and an electric field to attract and then kill the insects.

4. Carry out research to determine the diversity and abundance of insects that are dispersed during the year and the effectiveness of trapping and improved light systems in order to improve the design of itineraries to the various islands and mitigation measures to ensure a decrease in the dispersal of insects in the islands.