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Insight

Galápagos Birds and Diseases: Invasive Pathogens as Threats for Island Species

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ABSTRACT. Exotic diseases and parasites have caused extinctions on islands and continents, particularly when they spread through assemblages of immunologically naïve species. Hawaii has lost a substantial part of its endemic bird fauna since the introduction of avian malaria at the beginning of the 20th century. In contrast, the Galápagos archipelago still possesses its entire endemic avifauna. Several of these Galápagos bird populations are in decline, however, and wildlife managers seek guidance to counteract a potential man-made ecological disaster. We recommend that endemic birds be tested for susceptibility to disease outside the Galápagos so that protection efforts can be better designed to deal with actual threats. At present, the best and perhaps only management option is to protect the isolation of these island communities because treating or vaccinating wild bird populations against diseases is almost impossible. If the isolation of the Galápagos Islands is successful, we will preserve the complete avifauna of an archipelago for the first time in the history of human colonization in the Pacific eco-region.

INTRODUCTION

One of the most important factors contributing to extinctions on islands is the introduction of exotic organisms (Diamond 1984, Groombridge 1992, Dobson and Foufopoulus 2001). Among exotic organisms, pathogens have been largely ignored by conservation biologists until recently (Altizer et al. 2001). This can be attributed in part to the cryptic and frequently transient nature of parasite infection and in part to the difficulty of collecting disease data in the field. A careful review of the literature indicates that pathogenic organisms have been involved in numerous declines and extinctions of endemic species on oceanic and land-bridge islands (Diamond 1994; Table 1).

DISEASE SUSCEPTIBILITY AND EXTINCTION IN ISLAND POPULATIONS

The Galápagos Islands have not experienced recent extirpations of bird species, although one exception may be the demise of the Floreana Mockingbird (*Nesomimus trifasciatus*) which is now found only on Floreana's satellite island, Champion (D. J. Anderson, *personal communication*). This situation is remarkable given that island populations are highly susceptible to extinction (Groombridge 1992). In other oceanic archipelagos, many bird species were extirpated soon after prehistoric humans reached them. For example, more than 200 species of extinct island birds are only recorded as only subfossils on islands in the Pacific Ocean. These probably vanished following settlement of the islands by Polynesians during the Austronesian expansion (Milberg and Tyrberg 1993). In addition, several species now considered endemic to single islands or island groups had a much wider distribution in the past (Smith et al. 1995, Steadman 1995). The anthropogenic mechanisms resulting in the demise of island taxa are complex and include habitat destruction, predation by humans, and the introduction of exotic predators, competitors, and pathogens (Diamond and Veitch 1981, Holmes 1996). Although most, if not all, of these factors also affect mainland species, the small size and naïve nature of most island populations render them particularly prone to extinction (Atkinson et al. 1995, Cole et al. 1995).

A well-documented example of indigenous island hosts adversely affected by exotic pathogens is the introduction of avian poxvirus and avian malaria, *Plasmodium relictum*, into the avifauna of the Hawaiian Islands (Warner 1968, Van Riper et al. 1986, Jenkins et al. 1989, Atkinson et al. 1995, Atkinson et

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al. 2000, Work et al. 2000). Similar but less well-documented examples exist from Christmas Island in the Indian Ocean where the extinction of two endemic species of rodent appear to be linked to the introduction of a trypanosome pathogen (Day 1981, Pickering and Norris 1996, see also Fancy and Snetsinger 2001). Epidemics that have devastated island taxa have also been reported for lacertid lizards in the Tyrrhenian Sea and for birds along the eastern seaboard of the United States (Day 1981).

Endemic island species held in captivity appear similarly sensitive to infection by exotic pathogens. A captive breeding program for the Pink Pigeon (*Nesoenas mayeri*), an endangered species from Mauritius, encountered serious problems after the hatchlings were infected with a pigeon herpesvirus from asymptomatic Rock Doves (*Columba livia*) used as foster parents (Snyder et al. 1985). Another Mascarene endemic, the Mauritius Kestrel (*Falco punctatus*) was shown to be sensitive to herpesvirus hepatitis (Cooper et al. 1981). Penguins, which are not island endemics per se but have evolved mainly in the absence of diverse pathogen communities, have been shown to be very susceptible to infectious pathogens, most notably various *Plasmodium* species (Graczyk et al. 1995).

Table 1. Examples of disease outbreaks with conservation implications on islands.

Disease/Parasite	Host	Geographic Area (or host origin if captive)	Comments	Reference
A. Free-ranging host populations				
Histomoniasis (Blackhead) (*Histomonas meleagridis*)	Heath Hen (*Tympanuchus c. cupido*)	Martha's Vineyard, USA	Likely introduced by turkeys; contributed to the extinction of the subspecies	(Day 1981)
Avian Pox (*Poxvirus avium*)	Various spp. of Drepanidae, Hawaiian Crow (*Corvus hawaiiensis*)	Hawaii	High host susceptibility documented for native birds	(Day 1981), (Van Riper et al. 1986), (Jenkins et al. 1989), (Ralph and Van Riper 1985)
Avian malaria (*Plasmodium relictum capistranoae*)	Various spp. of Drepanidae, Hawaiian Crow	Hawaii	Pathogen implicated in the extinctions of several endemic honeycreeper species.	(Warner 1968), (Van Riper et al. 1986), (Jenkins et al. 1989), (Ralph and Van Riper 1985)
Exotic ticks	Huia (*Heteralocha acutirostris*)	New Zealand	Ticks on museum skins likely introduced by exotic mynahs.	(Day 1981)
Unknown pathogen	Reunion Starling (*Fregilupus varius*)	Reunion, Mascarene Islands	Suggestion that disease did contribute to species decline, no supporting evidence.	(Cooper 1993), (Brasil 1910)
Trichomonas gallinae	Galápagos Dove, (*Zenaida galapagoensis*), Rock Dove (*Columba livia*)	Galápagos Islands	Parasite outbreaks in endemic doves. Pathogen likely introduced by domestic pigeons	(Harmon et al. 1987)

Unknown pathogen	San Stephano lizard (*Podarcis sicula sanctistephani*)	San Stephano Island, Tyrrhenian Sea	Epidemic wiped out majority of the population and contributed to subspecies extinction	(Day 1981)
Trypanosoma sp.	Captain MacLear's rat (*Rattus macleari*)	Christmas Island, Indian Ocean	Individuals of this and the following species were observed dying in large numbers following the introduction of black rats (*Rattus rattus*) and their pathogens	(Day 1981), (Pickering and Norris 1996)
Trypanosoma sp.	Bulldog Rat (*Rattus nativitatus*)	Christmas Island, Indian Ocean	...	...
Unknown pathogen (*Morbillivirus*?)	Thylacine (*Thylacinus cynocephalus*)	Tasmania	Circumstantial evidence suggests that the species extinction was hastened by an introduced epidemic	(McCallum. and Dobson 1995)
B. Captive settings				
Avian malaria	Various penguin spp. *Plasmodium* spp. (*Megadyptes antipodes, Eudyptes chrysocome, Eudyptula minor*)	New Zealand, Antipode Islands, Campbell Island	High susceptibility to avian malaria in captive birds	(Graczyk et al. 1995)
Mycobacterium avium	Hawaiian Goose (*Branta sandvicensis*)	Hawaii	High incidence of infection in captive bred birds in the UK	(Cooper 1993)
Cyathostoma bronchialis	Hawaiian Goose	Hawaii	Outbreak of introduced parasite in captive Hawaiian birds	(Gassmann-Duvall 1987)
Pigeon Herpesvirus	Mauritius Pink Pigeon (*Nesoenas mayeri*)	Mauritius, Mascarene Islands	Virus lethal to captive hosts held in the USA	(Snyder et al. 1985)
Herpesvirus hepatitis	Mauritius Kestrel (*Falco punctatus*)	Mauritius, Mascarene Islands	Virus lethal to captive hosts held in the UK species may be susceptible to disease	(Veterinary Record 1992), (Cooper et al. 1981)

Several mechanisms are blamed for the predisposition of island populations to exotic pathogens. Both theoretical and empirical evidence suggests that small host populations on isolated islands support only impoverished parasite communities (Dobson et al. 1992, Dobson and McCallum 1997). This is because resident parasites are subject to the same constraints that limit host diversity. They are also subject to additional demographic and genetic constraints dictated by the small population sizes of their hosts. As a result, island endemics have been exposed to few parasites and other pathogens during their recent evolutionary history. Long-term release from parasitism could result in a partial loss of energetically expensive immune systems in isolated island populations (K. Lindström, *personal communication*). Host immune responses could be particularly compromised by the loss of genetic diversity in small, isolated populations (Lyles and Dobson 1993). Within inbred island populations, loss of heterozygosity has been shown to result in reduced major histocompatibility complex diversity and also in subsequent selection against inbred individuals (Keller et al. 1994).

In summary, the evolution of island taxa in a parasite-scarce environment, alone or in combination with a long-term loss of genetic diversity, often results in a compromised ability to respond to new pathogens.

Fig. 1. A Darwin's finch affected by avian pox (St. Cruz Island, Galápagos, 2000).

CURRENT AVIAN DISEASE PROBLEMS ON THE GALAPAGOS

Despite isolation and the short duration of human settlement on the Galápagos Islands, several exotic pathogens have been introduced to the archipelago and appear to be affecting wildlife populations. However, no hard evidence has been gathered to support this statement unambiguously.

The introduction of some of these parasites may be related to the importation and maintenance of domestic chickens which share the habitat of endemic birds on islands inhabited by humans. Evidence for or against disease transmission via chickens is so far missing; it is currently being studied (P. Parker, *personal communication*). During periods of abundant food, supply chickens may become feral and invade National Park areas, a circumstance documented during the El Niño year of 1988 (Vargas 1999). This increases the risk of disease transmission to indigenous birds.

Fig. 2. A domestic chicken with avian pox (St. Cruz Island, Galápagos, 2000).

Infectious diseases, such as Newcastle disease, Marek's disease, avian mycoplasmosis and avian pox (Fig. 1), have been recorded in domestic chickens farmed on the islands (Vargas and Snell 1997). Avian pox now regularly occurs in several species of Darwin's finches (Fig. 2); Galápagos Mockingbirds, *Nesomimus parvulus* (Vargas 1987); and Yellow Warblers, *Dendroica petechia* (Duffy and Harcourt 1981). This disease may have been brought to the island during the first human visits. As early as 1905, the journal of the California Academy of Sciences expedition mentions lesions that could be interpreted as avian pox (E.W. Gifford, *unpublished manuscript*; B. West, *personal communication*). Several known vectors of diseases have been more recently introduced, further increasing the risk of disease transmission. For example, the mosquito *Culex quinquefasciatus*, a vector of avian malaria (*Plasmodium* spp.), was recently introduced to the Galápagos (H. Vargas, *personal observation*). It is unclear whether avian malaria already exists on the islands; it has not been detected. Bird surveys conducted in the past four years indicate that several of the island's bird species have declined in population and range. Diseases are suspected among the reasons for these declines (H. Vargas, *personal observation*). Most of the declines have taken place on inhabited islands where introduced bird species are most abundant. One of the most endangered birds now appears to be the San Cristóbal Vermilion Flycatcher (*Pyrocephalus rubinus dubius*). Not a single individual of this species was observed during a six-month survey in 1998 (Vargas and Bensted-Smith 2000). A long-term, steady decline in population size is clearly distinct from the frequent, normal population fluctuations of native bird fauna on the Galápagos Islands (cf. Grant and Grant 1980, 1993). On the other hand, some potentially sensitive species have avoided some of these pathogens. For example, Galápagos Penguins (*Spheniscus mendiculus*) appear free of avian malaria and Marek's disease (Miller et al. 2001). However, penguins may simply be less susceptible to mosquito-transmitted diseases because they inhabit coastal habitats far from mosquitoes.

Rock Doves introduced to the Galápagos have carried with them *Trichomonas gallinae*. This parasite has now been recorded in the endemic Galápagos Dove, *Zenaida galapagoensis* (Harmon et al. 1987). The impact of this pathogen on the endemic dove species is not known. Nevertheless, populations of Galápagos Dove appear to be rapidly declining on inhabited islands. A new botfly species (*Philornis downsi*), a parasite known to significantly lower fledgling success, was recently detected on nestlings of several species of Darwin's finches, Galápagos Mockingbirds, Yellow Warblers and the Dark-billed Cuckoo, *Coccyzus melacoryphus* (Fessl and Tebbich 2002). Parasitic nematodes (*Dispharynx spiralis*) were found in the endemic Dark-billed Cuckoos and may have been partially responsible for the high cuckoo mortality observed in 1998 (Vargas and Bensted-Smith 2000). It is not known whether these parasites are endemic to the Galápagos or were introduced from feral animals.

POTENTIAL AVIAN DISEASE THREATS TO THE GALÁPAGOS

Table 2 provides a comprehensive list of the most important potential disease threats to Galápagos birds identified by an interdisciplinary group of biologists (International Workshop on Avian Diseases 2000). Although most of the pathogens listed have caused conservation problems in other regions of the world, it is difficult to predict the extent to which they could affect Galápagos bird populations; the effect of an introduced pathogen is dependent upon the intricate interplay between host, parasite and prevailing environmental conditions (Aron and Patz 2000). For example, although avian malaria is a serious conservation problem on the Hawaiian Islands, this disease may not spread through certain populations of Galápagos birds because the requisite mosquito vectors are not well suited for the relatively arid environment. However, environmental conditions could provide opportunities for the successful spread of malaria and other diseases if these pathogens reach the humid Galápagos highlands or if coastal parts of the islands become wetter because of climate change, e.g., increased frequency and intensity of El Niño.

Another potential threat is West Nile encephalitis, a serious avian disease that spread rapidly across North America after its introduction to New York City in 1999 (Lanciotti et al. 1999). Cases of this viral disease have now been documented on the western coast of the United States (Causey et al. 2003, Rappole and Hubalek 2003). The virus is expected to be transported to Central and South America, and from there to the Galápagos by migrating shore and sea birds (cf. Rappole et al. 2000, Malakoff 2002, Malkinson et al. 2001, 2002, Zeller and Murgue 2001, Causey et al. 2003). So far, it is unknown how island birds will react to this virus, and whether the virus will remain as destructive as it is currently.

Most of the other pathogens listed in Table 2 are widespread, opportunistic, bacterial, or viral microparasites. In general, they infect a wide range of hosts. If these pathogens become established in Galápagos bird populations, they have the potential to cause widespread die-offs. Although these diseases have not yet been implicated in any global species extinctions, their introduction to a small isolated ecosystem like that of the Galápagos archipelago could have catastrophic results for the local bird taxa.

WHAT CAN WE DO TO PREVENT AN ECOLOGICAL DISASTER?

Past experience from continental North America indicates that, once an exotic pathogen becomes established in a wildlife population, few, if any, effective mechanisms exist to control its transmission. Although the spread and/or persistence of a disease on an island may be somewhat different from its spread and/or persistence on the mainland, the principles of disease establishment are likely to prove similar in both scenarios. The culling of infected individuals from natural populations may help in disease control when host densities are high (Ferguson et al. 2001), such as at breeding farms or densely visited stopover habitats (Rocke and Brand 1994). Vector control is often the method of choice to stop the transmission of mosquito-borne diseases (Hougard et al. 2002). Bird behavior can be influenced as well so that pathogen transmission becomes less likely. For example, influence can result in the exclusion of infected birds from conspecific flocks. However, exclusion of birds may work only in very small and specific locations, such as garbage dumps, and may not be effective in natural areas. The transmission of specific diseases like botulism (Rocke and Brand 1994) can be achieved by wildlife managers who simply pick up infectious carcasses, change the environment, e.g., burn habitat, or eliminate pathogen reservoir species. However, in all cases considered by wildlife experts so far, the possibilities for reducing disease transmission are very limited. This will be particularly true in the Galápagos Islands. The main reason for these management limits in the Galápagos are that many areas of the archipelago are difficult and expensive to reach. Conservation managers also have to keep in mind the political realities of an economy based on eco-tourism. Extreme measures, such as the culling of birds, are hard to prescribe when eco-tourists want to see those same birds, even if rare.

Table 2. Diseases that cause major mortality in wild birds, methods of transmission, and methods of control.

	Control	Transmission	Avian group affected
Salmonella	No intervention, behavioral, elimination of reservoir	Contact-host	Forest birds, waterfowl
Mycoplasma	No intervention, behavioral, elimination of reservoir	Contact-host	Forest birds
Cholera	No intervention, carcass pick-up	Contact-host	Waterfowl
Malaria	No intervention, vector control	Insects	Forest birds, pelagic birds
Trichomoniasis	No intervention, Behavioral, elimination of reservoir	Contact-host	Forest birds, raptors
Duck plague	No intervention, depopulation	Contact-host	Waterfowl
Pox	No intervention, vector control	Contact-host, insects, fomites	Forest birds, raptors
West Nile	No intervention, vector control	Contact-host, insects	Forest birds
Newcastle disease	No intervention, depopulation	Contact-host	Pelagic birds, waterfowl
Botulism	No intervention, behavioral, carcass pick-up, environmental modification	Contact-transvector	Waterfowl
Marine toxins	No intervention, behavioral	Contact-t	…

In light of the inability to control a disease epidemic once it has been established on the Galápagos Islands, emphasis needs to be placed on preventing the introduction of pathogens to the archipelago. Unfortunately, options to protect Galápagos birds against the introduction of diseases are limited. First, authorities should protect and guard the ecological isolation of the islands via activities supplemental to the existing Galápagos quarantine program (Trillmich 1992). The current quarantine program attempts to prevent the introduction of foreign organisms by surveying shipments at Ecuadorian ports before organisms can reach the Galápagos archipelago. Additional activities should emphasize control for alien vectors of avian diseases and parasites. For example, the number of chickens on the islands should be reduced to the extent possible, even if there have not been any obvious disease transmissions documented between domestic chickens and wild birds.

The second necessary activity to help prevent the further spread of disease is a realistic baseline monitoring program to allow early detection of novel avian diseases or parasites in the Galápagos. This means a modest veterinary pathology laboratory should be established and operated. A list of opportunistic activities should also be set out to ensure that collaborating scientists and managers work to increase monitoring efficacy. Fortunately, both programs have already been started (H. Snell, *personal communication*).

Third, conservation ecologists and managers need detailed contingency plans in place to respond to cases of abnormal morbidity or mortality. These plans could include provisions for the rapid export of samples from infected animals to international centers for disease control and detection. A contingency plan should also include an evaluation of the intervention options available for those pathogens most likely to threaten native species. It is imperative to test, outside of the Galápagos, whether and to what degree land birds, such as Darwin's finches, are susceptible to several major avian diseases like malaria or the West Nile virus. If Darwin's finches are indeed susceptible to these diseases, a long-term captive breeding program at a disease-free location should be considered to prevent and anticipate problems of captive propagation before populations decline too far (cf. Jenkins et al. 1989). Information on disease susceptibility would also help to strengthen quarantine procedures and allow for more political leeway in conservation efforts.

Of the limited options for disease control currently available to the Galápagos Islands, vector control through education and eradication programs around human settlements may be the most promising. Such practices, although seemingly limited, can go a long way toward preventing the introduction of pathogens exotic to the Galápagos Islands or reducing their spread. Resources should be committed to building diagnostic laboratories, collecting baseline data, and training personnel.

THE FUTURE

The Galápagos Islands provide a rare chance to preserve the intact endemic avian communities of an archipelago because no species of Galápagos birds has yet gone extinct. A powerful legal framework exists to support the activities necessary to reduce the arrival of new diseases, and global concern over the loss of biological diversity in the area is increasing. The islands therefore represent a unique opportunity to successfully apply the lessons in wildlife disease control and prevention that have been learned in other areas of the world (Friend et al. 2001). Because some populations of Galápagos birds are in decline, local management agencies are seeking guidance for the formulation of effective regulations. The opportunity to conserve a natural laboratory of evolution as a showcase for humanity could be lost quickly unless global concern is translated into effective and appropriate management (Loope et al. 2001).

Responses to this article can be read online at:
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