Invasive Species Impacts:

Avian Malaria (*Plasmodium relictum*)

Several species of the filarial parasite *Plasmodium* are the causal organism for avian malaria. *Plasmodium relictum capistranumae* Russell is the parasite found in infected Hawaiian birds (USDI and USGS 2005) and can infect over 419 avian species (Atkinson 2008). In birds, *P. relictum* reproduces in red blood cells. If the parasite load is sufficiently high, the bird begins losing red blood cells causing anemia (USDI and USGS 2005). Because red blood cells are critical for moving oxygen about the body, loss of these cells can lead to progressive weakness, declines in food consumption and activity levels, loss of up to 30% body weight (Atkinson *et al.* 2000) and eventually, death (USDI and USGS 2005).

Malaria mainly affects birds in the order Passeriformes (perching birds). In Hawaii, this includes most of the native honeycreeper (Drepanidinae) and the Hawaiian crow. Native Hawaiian birds are more susceptible than introduced birds to the disease and exhibit a higher mortality rate (Van Riper *et al.* 1982; Atkinson *et al.* 1995) possibly reflecting their long isolation (ca. 4 million years) from malarial parasites (Fleischer and McIntosh 2001 in Beadell *et al.* 2006). Indeed Hawaiian forest birds suffer mortality rates of 65-90% after being bitten by a single infective mosquito (Atkinson *et al.* 1995; Atkinson *et al.* 2000).

Susceptibility to the disease varies between species. For example, the iiwi is very susceptible to malaria while the apapane less so (USDI and USGS 2005). This has serious implications for native bird faunas (SPREP) with *P. relictum* being blamed for the range restriction and extinctions of a number of bird species in Hawaii, primarily forest birds of low-land forests habitats where the mosquito vector is most common (Warner 1968; Van Riper 1991; USDI and USGS 2005). Many populations of native Hawaiian birds are restricted to mid and high elevations, where malaria is rare due to physiological (thermal) constraints of the primary vector *Culex quinquefasciatus* (Foster *et al.* 2007).

Recent evidence indicates that some native Hawaiian lowland forest birds have developed some tolerance to *P. relictum*. For example, the amakihi are once again breeding in remaining lowland forest habitat although they show incidence of malaria (60-70%) (Trouble in Paradise Undated; Woodworth *et al.* 2005). Although this appears encouraging Freed and colleagues (2005) point out that as more of the common species evolve tolerance they increase reservoirs of the disease, which in turn increases the risk of transmission to rarer species that are vulnerable to avian malaria. Most honeycreeper, especially endangered species, now persist only in forests above 1500m elevation, where cool temperatures prevent effective malaria development in mosquitoes.
The prevalence of malaria in Hawaiian forest birds at 1900m on the island of Hawaii has more than doubled over a decade. This increase is associated with breeding of mosquitoes and warmer summertime air temperatures. Tolerance to malaria in native birds is adding to a reservoir of malaria at upper elevations even while vectors are rare and air temperatures are too low for complete development of the parasite in the vector. Freed and colleagues argue that malaria is becoming an emergent infectious disease at upper elevations and that the spread of avian malaria can be partly attributed to climate change and increasing temperatures.

The parasite does not appear to be pathogenic in birds that have evolved with the parasite, often causing no symptoms. However, it causes varying degrees of pathology and can cause high mortalities in species of birds that have not evolved with the parasite. These susceptible species may come from areas without the vector, such as very cold, dry, or windy environments. This is why avian malaria is so lethal to penguins (in which it is caused by *Plasmodium relictum* and *P. Elongatum*), as illustrated by the 1986 outbreak of the disease in wild-caught Magellanic penguins (see *Spheniscus magellanicus* in IUCN Red List of Threatened Species) at the Blank Park Zoo in Des Moines, Iowa, USA (Fix *et al.* 1988). It is the highest cause of mortality in outdoor penguin exhibits and causes 50% or greater mortality in untreated juvenile and adult penguins when first exposed to the vector (Cranfield *et al.* Undated).

Vanderwerf *et al.* (2006) points out that while the effects of avian malaria in limiting the distribution of Hawaiian birds are well documented, there is little information regarding the long-term threat and the continuing potential effects of the disease on Hawaiian birds. There is little information on annual variation in infection rates or frequencies of disease epizootics, and no information available for some species or areas.

A study by Palinauskas *et al.* (2008) examined the impacts of different lineages of *P. relictum* on a number of bird species. They found that susceptibility of these birds to the infection of *P. relictum* was markedly different, and even that the same lineage of *P. relictum* can cause diseases of different severity in different hosts. The authors conclude that this has evolutionary consequences and should be taken into consideration in conservation projects.

The impact of avian malaria (*Plasmodium relictum*) can also have some unexpected impacts on avian populations. Acute infections could act as a selective agent by removing less fit individuals from a population. A study on amakihi in Hawaii found that “chronic malaria infections in male and female parents did not significantly reduce reproductive success. Indeed pairs with infected males had higher nesting success rate than those with uninfected males, and offspring that had at least one parent that survived the acute phase of malaria infection had a greater chance of being sighted the following year (although this was based on small sample sizes and may be due to lower dispersal of infected birds). Overall the “reproduction and survival of infected birds were
sufficient for a per-capita population growth >1, which suggests that chronically infected Hawaii amakihi could support a growing population” (Kilpatrick et al. 2006)