Assessment of Recovery Strategies for Miami Blue Butterfly

Principal Investigator: Travis Longcore
Agreement No. F12AP00812 (U.S. Fish and Wildlife Service)

July 15, 2013

Travis Longcore

The Urban Wildlands Group, P.O. Box 24020, Los Angeles, CA 90024

Introduction

The Miami blue butterfly was listed as endangered in 2012 following a long period of decline that included presumed extinction, rediscovery, listing by the State of Florida, the start and end of captive breeding an release of captive-bred individuals, loss of the rediscovered population, and discovery of new populations, all before the federal listing. As a preparatory step to convening a recovery team, the Vero Beach office of the U.S. Fish and Wildlife Service commissioned a species review and preliminary recovery strategy as a starting point for federal involvement. This document provides a review of the threats that are hypothesized to hamper species recovery and identifies various approaches that would address those threats, if they indeed were having the suggested impacts.

Our identification of a set of objectives, hypotheses, and alternative management actions frames these issues in a manner that is ready to present to a recovery team to prioritize these actions (Runge et al. 2011).

Miami blue butterfly is a small lycaenid butterfly that was once found on the coast of Florida from Indian River near Cape Canaveral southward on the Atlantic Coast and the Gulf Coast southward through the Florida Keys to the Marquesas Islands and Dry Tortugas. Current populations are limited to Key West National Wildlife Refuge. The causes for decline are likely many and not well discerned from each other, including coastal development, invasion of competitors, decline of foodplant from various causes including herbivory by introduced iguanas, lack of management, indirect impacts from spraying for mosquitos, climatic variation, and other miscellaneous human-induced environmental changes and disturbances.

Lycaena ammon was originally reported as a native of Cuba, but ranged to “Indian River and in Southern Florida” (French 1886). Bethune-Baker first observed that a unique butterfly then classified as *Hemiargus ammon* was found in Florida. He distinguished it from the population in Cuba, about which he noted “this species does not, I believe, occur on the mainland” (Bethune-Baker 1916), thereby acknowledging two taxonomic units. The species was present at Dry Tortugas as *Plebeius ammon* at mid-century (Forbes 1941) and the Florida population was elevated to subspecies status (*Hemiargus ammon bethune-bakeri*) in 1943 (Comstock and Huntington 1943). Nabokov then moved the subspecies to the newly created species *Cyclargus thomasi* (Nabokov 1945).

Ultimately, the large scale decline in Miami blue resulted from coastal development (Calhoun et al. 2002). In 1965, the butterfly was common in Dade and Monroe Counties and not rare between Gainesville and Tampa (Kimball 1965). In the mid-1990s, was still seen as "locally common" in the Florida Keys (Minno and Emmel 1993, 1994), with the last known population occurring at Dagny Johnson Botanical Site on northern Key Largo in 1996 (Calhoun et al. 2002). In 1999 a colony was discovered at Bahia Honda State Park (Ruffin and Glassberg 2000; Olle 2010). By 2002 it was absent from all sites except Bahia Honda (Emmel and Daniels 2002; Minno and Minno 2009). The Bahia Honda State Park population was the subject of prolonged research before its extinction (Daniels 2009a). Pattern of disappearance was first from the mainland, then upper keys, then lower keys (Minno and Minno 2009). Eventually also lost from Bahia Honda, which is attributed to a combination of poor management (impacts to foodplant from trails, sewage facility, and picnic site), climatic variation (drought, tropical storms, and cold), and iguanas competing for the foodplant (Olle 2010). Miami blue was then discovered on Boca Grande and Marquesas Islands in December 2006 (Cannon 2007a, b; Cannon et al. 2010), and genetic information indicate little difference from the Bahia Honda population (Daniels 2009a).

Currently, Miami blue is found only on the Marquesas Islands and Boca Grande, all on National Wildlife Refuge lands. Its population is reported to be highly variable, but at its maximum to number in the thousands of butterflies (Henry et al. 2012). It may undergo facultative diapause during dry conditions (Emmel and Daniels 2003b), explaining the wildly divergent estimates of numbers obtained by those visiting these islands.

Recovery of Miami blue butterfly would certainly require achieving some combination of three different objectives:

1. Increased numbers at existing sites
2. Stabilized numbers at existing sites
3. Introduction and persistence at other sites within the historic range of the species.

Given current information, it is not clear that the first two objectives are wise. The existing sites are not subject to significant disturbance and are protected lands under management for biological resources. To expect them to modified or enhanced in a way that dramatically increases numbers or stability of Miami blue populations is probably not reasonable. The threats to the existing sites are not new (e.g., hurricanes, drought) and the strategies to overcome them for the persistence of the species are much more likely to depend on spreading species risk over additional sites than through manipulation of the existing sites (with the exception of competition for foodplant with introduced iguanas). Spreading risk to additional sites is often a more effective choice than enhancing existing populations in minimizing extinction risk for butterflies (Schultz and Hammond 2003).

This report is organized as follows. The next section reviews the many threats that have been articulated that reduce the probability of recovery of Miami blue butterfly. It is informed by a survey of 11 species experts who were asked to rank these threats in semi-structured interviews on a 10-point scale. The lowest rank (1) was for threats that the interviewee deemed to be least important, while the highest rank (10) was for the gravest threats to species recovery. Standard deviation of these ranks were used to identify which threats respondents agreed most about and those where experts disagreed. The threat assessment is followed by a set of possible recovery actions that have been ranked by the interviewed species experts. Each respondent put the seven possible recovery actions in order of preference to ensure species recovery. Again, standard deviation and mean scores were used to summarize these recommendations and highlight areas of agreement and disagreement. The final section discusses the areas agreement and disagreement that span between threats and recovery actions, and contains recommendations for prioritized action that maximizes the probability of filling in knowledge gaps for the species while reducing the risk of extinction, if not creating a trajectory toward recovery.

Threats to Species Recovery

The threats to species recovery are categorized into four groups: habitat-based threats, ecological threats (from species interactions), demographic threats (factors affecting population growth), and bureaucratic threats (difficulties arising not from species biology, but from the coordination and effectiveness of institutions influencing its condition).

Habitat-based Threats

Changes in habitat have the possibility of dramatically affecting Miami blue populations because their numbers can vary substantially in response to the condition of plant resources (Cannon 2007b). Habitat-based threats in different ways affect the amount and quantity of habitat available, or can result in a catastrophic decline in butterfly abundance (e.g., hurricane, drought). Some of these also might be categorized as demographic threats, since they influence species survival at the individual level.

Hurricane

Expert rank: 7.27 (5th out of 22); S.D. = 3.2 (1st out of 22)

Hurricanes are repeatedly mentioned as threats to survival in the literature (Emmel and Daniels 2003a, 2009; Minno and Minno 2009; Glassberg and Olle 2010; Olle 2010; Halupa 2012), and also as a condition that can be exacerbated by human-induced climate change (Cannon et al. 2010). It is hurricanes, however, that produce the disturbance conditions that promote the various foodplants, including for nickerbean (Daniels et al. 2002) and blackbead (Cannon 2007a). For example, the large stand of blackbead at Bahia Honda State Park in the 2000s was the result of disturbance from Hurricane Georges in 1998 (Daniels et al. 2002) and occupied sites discovered at Boca Grande and the Marquesas Islands had been "transformed" by hurricane Wilma one year prior (Cannon 2007a). But because salt spray and storm surge dramatically affects vegetation, as happened with several storms at Bahia Honda State Park in 2005 (Emmel and Daniels 2006b; Salvato and Salvato 2007; Emmel and Daniels 2009; Olle 2010), it can be a threat in the short term to a particular population. This dual nature of hurricane disturbance is widely recognized by species experts, who recognize that at large scales hurricanes are essential to the mosaic of vegetation necessary to support a viable metapopulation of Miami blue in the long run, while in the short run it could possibly extirpate populations and therefore poses a major threat.

Experts disagree profoundly about the threat posed by hurricanes in the short run. Some see the populations at the Marquesas and Boca Grande as vulnerable to extirpation with each storm season, while others assert that the species must have been present in these locations for some considerable duration and therefore is able to withstand the periodicity and severity of storms that occur there. This disagreement is likely the single most important issue motivating the priorities of different experts and most in need of resolving to develop a consensus path toward species recovery. Widespread discussion of the genetic history of the KWNWR populations, including evidence of recent colonizations, would help to resolve this disagreement. What is clear from the historical record is that the existing populations of Miami blue butterfly are at significant risk of being hit by a tropical storm (Figure 1).

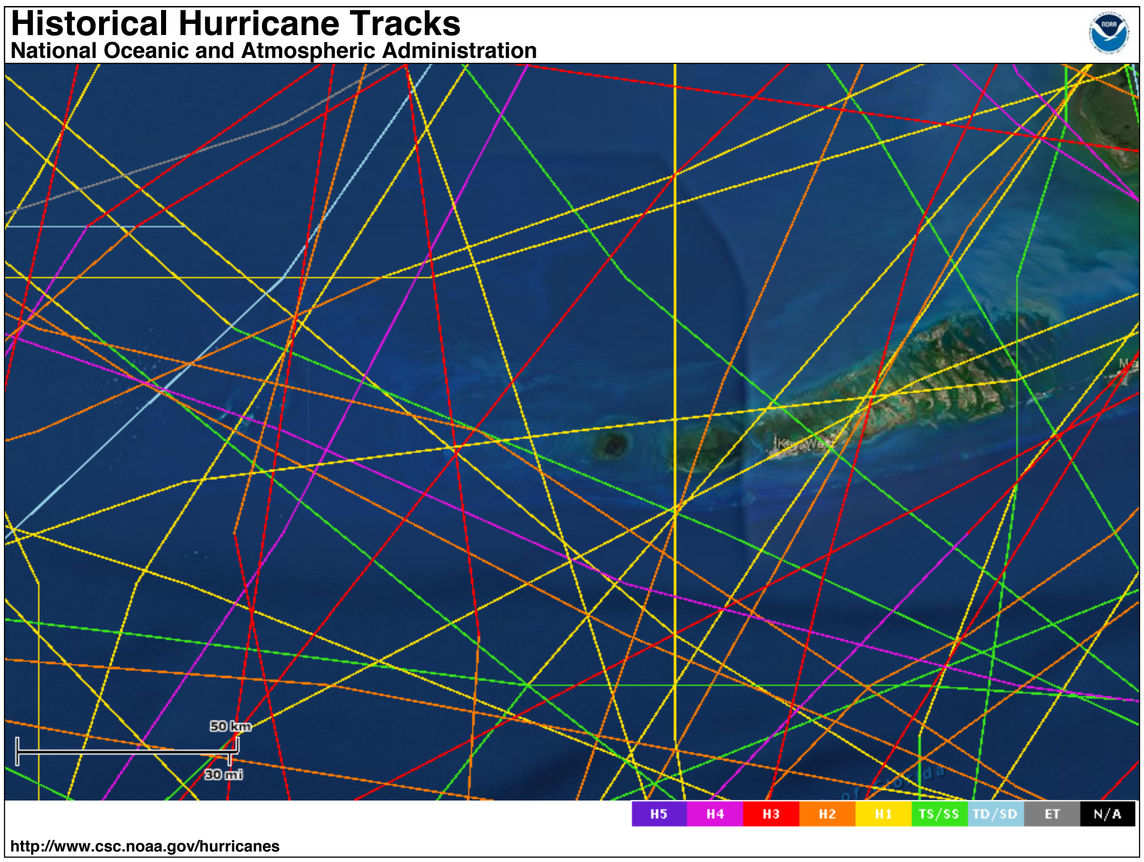

Figure 1. Historical hurricane tracks over the lower Florida Keys, including the Marquesas and Boca Grande (since 1970).

Fire

Expert rank: 2.73 (21st out of 22); S.D. = 2.37 (13th out of 22)

Some authorities have identified wildfire as a threat to Miami blue (Glassberg 2000; Cannon et al. 2010). Fire can be a significant threat to butterflies in some landscapes, although necessary to providing early successional foodplants required by many species (Mattoni et al. 1997). Our panel of experts ranked this threat very low, with some disagreement. Those identifying it as a risk tied it to human activities such as a fire pit constructed by boaters mooring at a beach. Another reason for disagreement could be whether experts viewed the species as historically being present in pinelands away from the coast.

Drought

Expert rank: 6.55 (tied for 10th out of 22); S.D. = 3.05 (3rd out of 22)

Drought, as several observers have noted, dramatically affects foodplant quality (Olle 2010) and may even cause diapause at the larval stage (Emmel and Daniels 2003b). Butterfly numbers are tied closely to foodplant quality which itself is tied to water availability.

Although some experts ranked the threat from drought very low, a good portion of them gave it the highest ranks (9 and 10), resulting high disagreement among the expert group. Susceptibility to drought is likely related to the currently limited distribution on the offshore islands, where conditions are somewhat harsher than the mainland. The role of drought in the demise of the Bahia Honda colony was recognized, but not agreed on its significance. This may be attributable in part to the differences in climatic conditions between current and historic sites for the butterfly with which the experts are familiar.

Sea Level Rise

Expert rank: 4.82 (19th out of 22); S.D. = 2.27 (15th out of 22)

The presence of Miami blue on the islands of the Lower Keys inevitably leads to recognition of sea level rise as a threat to the habitat (Cannon et al. 2010). These locations are not far above sea level and are already subject to overwash and storm surges. In discussions with experts, the long-term threat to the species (50 years) was uniformly agreed to be the highest possible. For purpose of conservation planning, therefore, experts were asked to rate the short term (15-year) threat to recovery from sea level rise. At this time scale, the threat was ranked near the bottom of those explored in the interviews, with less than average disagreement among the experts. This indicates that the long-term survival of the species depends on expanding the occupied range to higher ground, but that rising sea level alone is of a lesser potential threat than either hurricanes or drought.

Habitat Destruction by Humans

Expert rank: 4.91 (18th out of 22); S.D. = 2.74 (6th out of 22)

Destruction of habitat by humans is of course the reason that Miami blue is endangered (Emmel and Daniels 2003a). It remains to be described as a general risk (Glassberg and Olle 2010; Halupa 2012), and trampling of habitat on existing locations at Boca Grande and Marquesas Islands (Cannon et al. 2010) is noted as an ongoing threat. In expert elicitation, this question was focused toward human habitat destruction as an impediment or threat to recovery, setting aside the history leading to the current situation. As such, it was ranked relatively low, probably because all existing sites are on federal land under conservation management and likely reintroduction sites would be as well.

Ecological Threats

The ecological threats to recovery were identified as those that depended on interactions with other species, as opposed to habitat elements such as foodplant or nectar sources.

Iguanas

Expert rank: 6.18 (14th out of 22); S.D. = 2.64 (9th out of 22)

Iguanas have been introduced to Florida and have been implicated in reducing habitat available for Miami blue at Bahia Honda State Park (Daniels 2009b; Olle 2010). Brought up by renewed petition to list (Glassberg and Olle 2010) and planning documents (Minno and Minno 2009; Halupa 2012). They eat fresh leaves of nickerbean, which was in short supply at Bahia Honda following storms and a cold snap. Some experts suggested that their threat was overblown and that the situation at Bahia Honda was a unique confluence of factors rather than a common occurrence. The resulting assessment was one of a moderate threat, with some disagreement, based predominantly on the Bahia Honda extirpation and the described role of iguanas in it.

Exotic Ants as Predators

Expert rank: 6.40 (12th out of 22); S.D. = 2.46 (11th out of 22)

At least two species of exotic ants (fire ant *Solenopsis invicta* and twig ant *Pseudomyrmex gracilis*) have been introduced into Florida within the former range of Miami blue butterfly and may be a threat to immature stages in the same manner as indicated for Schaus' Swallowtail (Forys et al. 2001) and for invertebrates in general (Epperson and Allen 2010). Remarkably little is known about this possibility and some experts ranked the threat as average out of lack of knowledge or refused to provide any ranking at all. Comments during the interviews indicated this was an important area for research.

Loss of Ant Mutualism

Expert rank: 5.09 (tied for 16th out of 22); S.D. = 2.81 (5th out of 22)

Miami blues, like most lycaenids, are tended by ants (Minno and Emmel 1993). These are reported to be primarily *Camponotus floridanus* (Saarinen and Daniels 2006; Saarinen 2009; Trager 2009) and *C. planatus* (Trager and Daniels 2009). Although tending is facultative, and larvae can grow and pupate without it, tending may be an important influence on survival and subsequent adult fecundity (Saarinen and Daniels 2006). Even in the absence of predators, larvae grow faster when tended by *C. floridanus* (Trager 2009), and larger butterflies generally live longer and lay more eggs.

Ants tend both Miami blue and the hairstreak *Strymon martialis*; the hairstreak is larger than the blue and may be more attractive and siphon away tending ants (Daniels et al. 2005). Loss of the ant mutualism from any mechanism (e.g., ant community altered by invading fire ants) is hypothesized to be a general threat to Miami blue (Emmel and Daniels 2003a). It has been suggested that loss of ant mutualism is a mechanism by which negative effects of insecticides are amplified (Glassberg 2000).

Experts ranked the loss of ant mutualisms in the lower half of threats to recovery on average, but disagreed significantly on this point. Some ranked the threat 2, while others ranked it 8 or 10. One respondent noted that no population in the wild has been found that is not also tended by ants.

Competition for Foodplant Resources

Expert rank: 2.45 (22nd out of 22); S.D. = 1.47 (22rd out of 22)

Miami blue numbers are tied closely to the budding and flowering of its foodplants (Cannon 2007b; Cannon et al. 2010). Balloon vine is a native hostplant, but current populations do not have access to it (Carroll and Loye 2006). Competition with other species for this foodplant has been observed; Miami blue and a hairstreak were inversely correlated in individual seed pods of balloon vine, suggesting local competition for foodplant resources (Carroll and Loye 2006). It has been noted that the decline of Miami blue matches the decline of balloon vine and the increase in silver-banded hairstreak (Carroll and Loye 2006). Furthermore, some true bugs share the balloon vine *Cardiospermum corindum* (Carroll 1988). Other lycaenids, including other blues (Daniels et al. 2002) and hairstreaks (Daniels et al. 2005), may also compete with Miami bleu for nickerbean (*Caesalpinia bonduc*). Consequently, competition for foodplant resources with other herbivores (excluding iguanas discussed above) has been proposed a general threat to Miami blue (Emmel and Daniels 2003a).

Experts were nearly unanimous in ranking competition for foodplant resources as the lowest ranking threat in the survey. They noted, for example, that so much larval foodplant exists that it could not be eradicated even if one were to try.

Parasitoids and Native Predators

Expert rank: 5.09 (tied for 16th out of 22); S.D. = 2.07 (17th out of 22)

Native parasitoids (e.g., wasps) and predators may play an important role in population regulation for Miami blue. Very little is known about these rates in the field. *Pseudomyrmex* ants were thought to be larval predators (Saarinen and Daniels 2006), but it seems that all ants tend, just some defend more readily than others (Trager and Daniels 2009). Expert concern about this threat was intermediate, with most attention paid to the role parasitoids and predators might play in the success of reintroduced butterflies. Key factors influencing survival of immature stages (eggs, larvae, pupae) in the wild are simply not known and local ecological conditions may overwhelm an introduced cohort of Miami blue propagules.

Demographic Threats

The demographic threats identified for investigation tease out the different challenges faced by species with small population sizes: inbreeding depression, allee effects, demographic stochasticity, reduced survival from external forces (in this instance illegal collecting and application of insecticides), and constraint of population growth by lack of habitat within dispersal distances.

Inbreeding Depression

Expert rank: 7.00 (7th out of 22); S.D. = 2.72 (8th out of 22)

All small populations are vulnerable to inbreeding depression, leading to a reduction in genetic heterozygocity and a loss of rare alleles. This appears to have happened at Bahia Honda State Park before the extirpation of that population. When compared, the Key West National Wildlife Refuge Miami blue population had higher molecular diversity than the Bahia Honda State Park population (Daniels 2010). The minimal difference between the two populations imply that they were separated recently (Daniels 2010), but the population at Bahia Honda State Park showed evidence of inbreeding (Saarinen 2009; Saarinen et al. 2009) and Key West showed higher genetic diversity than Bahia Honda (Saarinen 2009). Inbreeding depression is therefore identified as a general threat to the species (Emmel and Daniels 2003a; Halupa 2012).

On average, experts ranked the threat posed by the loss of genetic diversity relatively high, but with a fair degree of disagreement. Exploration of this disagreement during interviews revealed that it was based on a difference in the assessment of the size of the populations found at Key West National Wildlife Refuge, with those believing those populations to be larger perceiving the threat of inbreeding depression to be smaller, consistent with the principles of conservation genetics.

Allee Effects

Expert rank: 5.73 (15th out of 22); S.D. = 2.90 (4th out of 22)

Allee effects are the adverse behavioral consequences of small population size. For example, access to mates is a limiting factor for low-density butterfly populations, especially for those species that are protandrous (Calabrese and Fagan 2004). Protandry is a means of competing for females, with males that emerge early being able to mate females as soon as they eclose (Zonneveld 1996). In very small populations, random variation in the timing of male eclosion of males and females can result in almost completely de-synchronized flights and the possibility that later emerging females have no males to fertilize them (Calabrese and Fagan 2004). Miami blue shows no evidence of protandry—the developmental times of male and female pupae are equal (Trager and Daniels 2009)—and thus this concern is reduced.

Experts also saw this threat as lower than inbreeding depression, but with a high level of disagreement. Again, those who saw the Key West populations to be large ranked this threat very low, while others ranked it higher.

Demographic Stochasticity

Expert rank: 7.82 (2nd out of 22); S.D. = 1.66 (21st out of 22)

Large population fluctuations in small populations make species susceptible to random adverse events that can result in extinction or extirpation, and Miami blue is no exception (Cannon 2007b). Although highly variable from season-to-season, population numbers KWNWR populations are preliminarily estimated at thousands per hectare (Henry et al. 2012), while the population at Bahia Honda had been estimated to be far lower, in the hundreds.

Experts agreed that demographic stochasticity posed nearly the highest ranked threat to Miami blue. Those ranking it lowest (5 out of 10) had high confidence that the KWNWR populations numbered in the thousands, while those ranking it higher generally saw the KWNWR populations as being smaller.

Reduced Survival Resulting from Illegal Collecting

Expert rank: 3.00 (20th out of 22); S.D. = 1.90 (19th out of 22)

Rare and endangered butterflies are often subject to collection by enthusiasts, before and sometimes after they receive regulator protection. Such collecting has been hypothesized as contributing to the decline or extirpation of some species (Mattoni 1995; Seidl 1999) and has been identified as a threat for Miami blue (Emmel and Daniels 2003a).

With a high level of agreement, experts ranked the threat from illegal collecting as very low. This resulted from both the remote nature of the existing populations and the likelihood that any subsequent reintroductions would be undertaken at locations that were either remote or under close observation by managers.

Reduced Survival Resulting from Insecticides

Expert rank: 6.55 (tied for 11th out of 22); S.D. = 2.38 (12th out of 22)

South Florida is the site of control operations to reduce mosquito abundance that includes widespread and frequent aerial spraying of insecticides. Larvae of Miami blue are killed by aerially sprayed insecticides with the level of effect influenced by many factors that are difficult to predict (application, weather, topography, barriers to drift, etc) (Daniels 2009b; Zhong 2009;

Zhong et al. 2010). In other studies, Miami blue butterflies were recorded to be more common at sites >50 m from roadway and out of mosquito fog zone (Carroll and Loye 2006). No information is available on the toxicity of the common insecticide (naled) on early instars. For these reasons, mosquito spraying has been viewed as a threat to Miami blue populations. Alternative view has been articulated that mosquito spraying is inconsistent as an explanation for the pattern of decline and that it might actually improve survival of larvae by removing parasitoids that would otherwise kill larvae (Minno and Minno 2009). A first step to supporting this hypothesis would be a study that showed larvae surviving under spraying when parasites and parasitoids of butterflies are killed.

Most of the expert panel assessed the reduced survival from mosquito spraying as representing a moderate threat to recovery. The marked disagreement with one very low rank led to an overall moderate level of disagreement within the panel. Those perceiving the threat to recovery as being moderate tended to attribute this to the likelihood that reintroduction sites for the species would be in locations remote from human populations and not subject to aerial spraying.

Dispersal Limited Populations

Expert rank: 6.91 (8th out of 22); S.D. = 3.05 (2nd out of 22)

Population growth of a small population may be limited if available habitat is occupied but additional habitat is not found within the dispersal distance of the species. Put another way, suitable habitat may exist, but is not occupied because colonists are unable to disperse to it. For Miami blue, mark-recapture research at Bahia Honda recorded only 25 feet movement of individuals (Emmel and Daniels 2003b) and did not detect movement between subpopulations at Bahia Honda (Emmel and Daniels 2003a).

The limitation of population growth by the dispersal ability of Miami blue ranked in the upper half of threats by interviewed experts, but disagreement on this was high. Those ranking this threat low reasoned that butterflies must have long-distance dispersal ability, probably through being carried by winds associated with storms of varying severities. Others note that Miami blue is not a strong flier and although the species might move about within the Marquesas during a storm, it is unlikely to be able to colonize elsewhere from there.

Bureaucratic Threats

The success of a recovery plan for Miami blue butterfly depends not only on an understanding of the species ecology and the available actions available to increase its numbers and distribution, but on the effectiveness of the agencies responsible for making decisions and implementing them. For this section, I concentrated on the public agencies that have a role to play in endangered species conservation in Florida, or that are likely to affect the outcome of recovery actions. These include federal agencies, such as the U.S. Fish and Wildlife Service; a range of state actors, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, University of Florida, and Florida State Parks; and local agencies such as the Monroe County Mosquito Abatement District. The eventual outcome for Miami blue depends in large part on whether and how these agencies work together. To gain insight on the most important elements of such cooperation, I asked experts to assess the threat to recovery posed if certain aspects of bureaucratic coordination did not happen, based on their experience in the past. These categories are lack of coordination between agencies, failure to share data, failure to share decisionmaking (consensus), failure to consult prior to decisionmaking (even if no consensus), general lack of collegiality, and conflicting missions between agencies.

Coordination between agencies

Expert rank: 7.64 (4th out of 22); s.d. = 2.73 (7th out of 22)

This threat represents the perception that agencies have not been, and potentially will not be, coordinating their actions on Miami blue butterfly. Comments arising from asking this question often led to discussion of the captive rearing program that was in place while the Miami blue population at Bahia Honda was still extant. In particular, the end of the program came as a surprise to some, and was perceived as a lack of coordination between the FWS and FWC, and more generally between federal and state officials. This theme was raised many times by many of the expert interviewees, that federal and state officials, despite having mechanisms for communication such as imperiled butterfly working group meetings, do not coordinate their actions. The ranking of this threat was high, but also with reasonably high disagreement, deriving from federal officials seeing coordination as being reasonably good, with all others disagreeing with that assessment.

Shared Data

Expert rank: 7.18 (6th out of 22); s.d. = 2.36 (14th out of 22)

At the heart of good decisionmaking and management is the availability of data about the species and ecosystems in question. For all stakeholders to be informed, data must be shared quickly and clearly, and sharing data is one of the steps in a formal adaptive management process (Haney and Power 1996). Interviewees ranked this has a high threat to recovery were it to continue as has been experienced in the past decade. Some respondents reported that getting data about ongoing research was like "pulling teeth" and that it "needs improvement," leaving the general impression that sharing data, especially preliminary results like monthly survey results, has not been a priority and that state and federal agencies do not go out of their way to share with each other. This is a critically important issue, since the lack of widespread understanding about the results of the current surveys in KWNWR influences the perception of the size of the population there, which in turn affects perceptions of the importance of different threats to those populations, which affects the ranking of different potential recovery actions.

Shared Decisionmaking

Expert rank: 6.82 (9th out of 22); s.d. = 2.56 (10th out of 22)

Shared decisionmaking would represent an arrangement where agencies with an interest in the conservation of Miami blue instituted a formal process by which they would reach consensus about any major decisions affecting the butterfly. This might take the form of a memorandum of understanding (MOU) and a set of rules that govern decisions that affect the species. Such an approach would be used to ensure that all parties were "on board" with various management approaches and funding decisions. The expert panel ranked this reasonably high, and support for an MOU to strengthen the imperiled butterfly working group was expressed, but almost universally the lack of this kind of approach was ranked as a lower threat than the lack of consultation before decisionmaking.

Consultation Before Decisionmaking

Expert rank: 7.91 (1st out of 22); s.d. = 1.97 (18th out of 22)

Consultation before decisionmaking is an approach by which all interested parties are consulted and listened to before any one agency makes a decision affecting the species. Agencies do not cede any authority and can act contrary to the input of the other stakeholders, but all decisions are vetted through the stakeholder group. This appears to have happened to greater and lesser degrees for Miami blue, but broke down around the end of the captive breeding program for the Bahia Honda population. Experts ranked the lack of consultation before decisionmaking as the signal most significant threat to the recovery of Miami blue with a very high level of agreement. The disappearance of the Bahia Honda population may have provided an impetus to improve such consultation. The impression left from the interviews is that consultation among state agencies is far greater and smoother than between state and federal representatives. Given the considerable experience represented by both state and federal employees, a strong consultative process should improve outcomes for the butterfly.

Collegiality

Expert rank: 6.27 (13th out of 22); s.d. = 2.24 (16th out of 22)

Relationships in any professional environment can be marred by a lack of collegiality. This can take the form of being dismissive of others ideas, lack of respect for others by, for example, not being prepared for meetings, or being generally disagreeable. This threat to recovery was rated as moderate by experts, with a moderate level of disagreement. Animosity between individuals in agencies appears to have developed surrounding plans to release captive-bred butterflies, with the Monroe County Mosquito Abatement District suing the State. But the interviewees ranked this lowest of the bureaucratic threats and one non-agency expert noted that it did not matter if people got along, as long as good decisions were made. Some reported that interactions were occasionally antagonistic, but generally friendly, and that the difficulties lay not with individuals but with the level of cooperation between stakeholders.

Conflicting missions of agencies

Expert rank: 7.73 (3rd out of 22); s.d. = 1.85 (20th out of 22)

The many agencies that may influence Miami blue butterfly do not all have the same mission. Even elements within the same agency may have slightly different institutional foci (e.g., between refuges and ecological services in FWS). Florida State Parks has a high emphasis on serving visitors and an emphasis on "ecosystem" management instead of managing for individual species. Mosquito abatement districts may have legal obligations to avoid impacts to endangered species but a mission to reduce human health risk from mosquitos. As a result, experts ranked this threat to recovery very high and with very little disagreement. They singled out the mosquito control district in particular, but also noted the unwise management decisions made by Florida State Parks that ultimately led to the loss of the population at Bahia Honda.

Recovery Strategies

Through a review of the existing literature and planning documents for Miami blue, I extracted a list of seven alternative management actions that could contribute to recovery. In interviews with species experts, I asked them each to rank these general approaches in order of preference to achieve recovery of Miami blue. I described the general approaches but do not specify the details of how each action might be undertaken.

Expert Assessment

Research Species Ecology

Expert rank: 1st out of 7; S.D. = 1.42 (4th out of 7)

Recommendations for research on Miami blue are frequent and varied in existing report and published literature. Some of these include:

- Track the fate of released larvae (Daniels 2011; Halupa 2012);
- Exclude predators from reintroduction sites to investigate survival (Daniels 2011);
- Investigate effectiveness of releasing different life stages (Daniels 2011);
- Track larval survival of larvae on different foodplants (Daniels 2011);
- Measure oviposition preference of adults for different foodplant (Daniels 2011);
- Investigate the effects of iguanas (Halupa 2012);
- Investigate the role of parasitoids (Halupa 2012);
- Track butterflies after release (Minno and Minno 2009; Halupa 2012)

When asked for preferred research projects during interviews, experts mentioned these, plus a number of other questions, ranked by number of times suggested:

- Detailed studies of experimental releases of butterflies or larvae in the field, including behavior after release and demography (5);

- Research on predation and parasitism in the field, for example by putting out plants with and without predator exclosures (4);
- Better establish the risk posted by invasive species, in particular fire ants and iguanas (3);
- Host plant preference studies, and establishment of host breadth in the existing populations (3);
- Investigating the effects of ant mutualisms in the field (2);
- Studies of habitat preference in the field with particular attention to vegetation, precipitation, microclimate (2);
- Evaluate environmental influences on abundance (including weather-host plant interactions, biotic, and abiotic effects);
- Investigation into the possibility of in situ manipulation of abundance (e.g., ranching);
- Establishment of physiological tolerances, especially for low temperatures;
- Observation of larvae under drought conditions to establish if they can facultatively diapause;
- Genetic studies to establish if it is different from the subspecies in Cuba and whether the Marquesas population differs from the former south Florida distribution;
- Surveys in more areas, included repeated surveys in remote locations to find additional populations.

Although research itself does not lead a species to recovery, the topics suggested do narrow in on critical knowledge gaps that must be filled to develop and implement a successful recovery program. Butterflies have been reintroduced to putatively suitable habitats, but despite short-term success, none of these efforts has resulted a colony that has persisted. Research into what specifically happens to adults, eggs, or larvae at a new location is a top priority.

Identification of a need to better understand predators and parasites in the field follows directly from a general uncertainty about the importance of these factors in regulating Miami blue populations. Most experts assume that a significant complement of predators and parasites influence population dynamics, but very little is known with any certainty. This research should focus on exotic species that might be managed in some way; the complement of native predators and parasitoids is undoubtedly a significant, yet natural, influence on survival that will not be managed.

Similarly, the concern about the effects of iguanas and fire ants combined with lack of detailed knowledge about their role in regulating Miami blue populations makes this a research priority. Both of these topics also would help determine if the hypothesis presented by Minno that mosquito spraying would actually benefit Miami blue by suppressing parasite and insect predators could be true.

The host plant preference and breadth of the Marquesas and Boca Grande populations is important to understand before reintroducing stock from these populations to sites with the other host plants used by the species. It is likely that they are plastic in their host plant choice; many lycaenids can shift host plants within a family to exploit the available plant species (e.g., Palos Verdes blue uses two different plants in the Fabaceae in different parts of its range, but can easily switch from one to the other in the laboratory).

Reintroduction to Expand Range

Expert rank: 2st out of 7; S.D. = 1.41 (tied for 5th out of 7)

Reintroduction is an obvious management option for Miami blue (Calhoun et al. 2002). The captive population from Bahia Honda State Park was used to provide individuals for reintroduction starting in 2004 (Daniels 2009a). Early efforts were not successful, presumably because of drought and tropical storms (Daniels 2009a). Introductions in 2004-2005 (Emmel and Daniels 2006a, b), 2007 and 2008 did result in colony establishment (Daniels 2009a), but apparently these have not persisted. Five reintroduction efforts including 2,541 individuals had been completed by 2009 (Daniels 2009b).

Experts agreed with little disagreement that the most important action for recovery of Miami blue butterfly, following research, is the reintroduction of the species within its former range. Interestingly, this opinion emerged despite high disagreement over the level of threat facing the existing populations. That is, even those who did not see an imminent threat to the Boca Grande and Marquesas sites, ranked reintroduction as a preferred management action. Those who saw those populations as being vulnerable to extinction with the next large hurricane, however, ranked captive breeding as a refugium higher.

The question of how and where to undertake reintroductions is open. The need to do reintroductions as part of a research program suggests that reintroduction sites be either locations where staff can live essentially on site (e.g., a remote site with an investigator camping nearby) or close to potential monitors (e.g., a location within easy driving distance from accommodations). A reintroduction project that had been set up for Bill Baggs State Parks but never implemented because of the extinction of the Bahia Honda population seems to fit the second model, as does the Bahia Honda State Park site itself. Remote sites already used for releases from the captive breeding population fit the first.

It is essential that even though reintroduction is itself a recovery action, that it be combined with a well-designed research program that incorporates the major pressing questions about reintroductions: how do adults behave after release, how do larvae behave after release, what are the key factors affecting egg, adult, and larval survival at a reintroduction site, what is the influence of native and exotic predators on reintroduced stock, etc.? An ultimately unsuccessful release would still be a benefit to recovery if it is designed to gain knowledge about the species ecology, so fear of failure should not slow actions to permit and implement a captive release program. Additional considerations for releases are included in the discussion below.

Monitor Existing Populations

Expert rank: 3rd out of 7; S.D. = 1.21 (7th out of 7)

Experts agreed the most on a rank of 3rd for monitoring of the existing populations at Boca Grande and the Marquesas. The results of this monitoring should be shared rapidly and widely because it seems from the results of these surveys, that differences in perception of the size of these populations is influencing experts' assessments of the risks posed to them. The current monitoring protocols being implemented by North Carolina State University (Henry et al. 2012) are the first to pair point counts for butterflies with distance sampling to provide total population estimates. Thorough communication about these techniques and their limitations (e.g., risk of butterfly misidentification) is needed to establish a shared baseline understanding of the existing dynamics of these populations. This shared baseline might normally follow peer-reviewed publication and exchange of final reports, but in this instance a more pro-active discussion is needed to establish a common understanding, given the importance of these numbers to decisions about recovery approaches.

Establish Captive Colony as Refugium

Expert rank: 4rd out of 7; S.D. = 2.37 (1st out of 7)

Captive breeding can be used as a strategy to hedge against extinction of an endangered species. The species is propagated in captivity with no plans of release unless something catastrophic happens to the species in the wild. An "assurance population" such as this has been suggested for Miami blue (Calhoun et al. 2002). Techniques for rearing in captivity were established by University of Florida with stock from the Bahia Honda State Park population before its disappearance, and this effort showed the ability to produce thousands of adults with collection of 6–10 females (Emmel and Daniels 2003c, a). State agencies have applied for grant funding to establish a new captive colony from butterflies in KWNWR (Cook 2011).

Whether or not to establish a captive colony as a refugium was the single most controversial recovery action among the interviewed experts. Those who see the KWNWR populations as in immediate danger of extinction would like to see a captive colony established right away. Those who perceive those populations to be larger and more resilient to existing threats do not. Whether a captive colony can be established and successful is not a question; the problem can be too many butterflies and what to do with them (Emmel and Daniels 2009). Refugia populations without release plans are fraught with difficulties. When overages are produced, it is expected that they will be released to the wild. If no sites are ready and permitted for releases, the rearing laboratory must allow the butterflies to die in captivity, which can be difficult from a public relations perspective. Miami blue presents a considerable challenge from this perspective because it breeds year-round and a captive population is therefore expensive to maintain (in addition to producing many individuals).

The threat of hurricanes to Miami blue in its current range and the high stakes of improperly assessing that threat being lower than it is lead me to suggest that a seasonal assurance population might be advised. Peak hurricane season for KWNWR is August through October. It would be advisable to establish a short-term captive colony during this season. This population could be used to produce stock for reintroduction efforts, or terminated at the end of the season. This would hedge against the risk of species extinction during the period of highest risk from this threat, while concentrating resources on research and reintroduction efforts that could be paired with the captive rearing effort.

Improve Agency Coordination

Expert rank: 5rd out of 7; S.D. = 4.36 (2nd out of 7)

On average, experts ranked improvement of agency coordination as a low priority recovery action, but disagreement was high. Combined with the threats assessment, it seems that consultation between agencies before decisionmaking would be preferable, as would be rapid and extensive sharing of data. Data sharing is particularly important, and should include at least monthly updates of any survey activities. This is important to increase trust between agencies and develop a common framework through which to assess the vulnerability of existing populations. Because the populations are now all on federal land, and the species is now federally listed, it would be beneficial to engage state officials through a research/reintroduction project on state land. By re-engaging state regulators and land managers through a recovery action targeted at state property additional resources are likely to become available for recovery efforts and the degree of coordination between agencies could be enhanced.

Enhance Habitat

Expert rank: 6th out of 7; S.D. = 1.67 (3rd out of 7)

Some authors have suggested the need for habitat restoration to support recovery of Miami blue butterfly (Calhoun et al. 2002). Except as part of efforts to prepare sites for reintroduction/research projects, however, species experts did not rank habitat enhancement as a priority recovery action. In specific instances some habitat-based work should probably accompany reintroduction efforts (e.g., removal/control of iguanas or reestablishment of food plant) but the consensus is that Miami blue is not limited by habitat quality.

The primary reason for failure of butterfly reintroduction (or one can presume augmentation) efforts is low quality habitat at the recipient site (Schultz et al. 2008). Indeed this has been the experience in Great Britain (Oates 1992; Pullin 1996). Restored sites are frequently of lower habitat quality than donor sites for reintroductions (Chan and Packer 2006), so attention to habitat quality is of concern to reintroduction success.

Habitat conditions should be assessed and compared against known requirements for a species before a reintroduction is implemented (Chan and Packer 2006; Armstrong and Seddon 2008), and ideally, the conditions that have caused extirpation or species decline should have been identified and corrected (IUCN 1998). This would be difficult for Miami blue, since these key conditions and explanations are as-yet elusive. Habitat considerations therefore become part of the research agenda articulated as the top recovery priority, and experimental reintroduction to better determine habitat needs is required, rather than habitat enhancement to match needs before reintroduction.

Secure More Land Under Conservation Management

Expert rank: 7th out of 7; S.D. = 1.41 (tied for 5th out of 7)

Species experts do not believe that additional land is needed to recover Miami blue butterfly. This is extraordinarily good news in one respect; land acquisition is often the most expensive element of species recovery, especially for species that are reasonably tolerant of urban conditions (see e.g., California gnatcatcher). The challenge for Miami blue recovery will not be finding sufficient land, but figuring out what conditions are necessary to support butterflies in those places that are already available.

Discussion

Federal recovery planning for Miami blue has some unique challenges. The species already has a long history of conservation attention by the State of Florida. Ideas have developed about the state of current and past populations that influence perceptions held by experts about current threats and preferred management approaches. Because implementing recovery actions depends in some part at least on cooperation between agencies, any recovery plan must address these different perspectives head-on and illustrate how they can be resolved, either with existing data or through an adaptive management approach that increases knowledge while pursuing management projects that will benefit the species.

Research Species Ecology (Adaptive Management)

The prioritized list of recovery actions lends itself to an adaptive management approach (Haney and Power 1996; Armstrong et al. 2007). As discussed in more detail in this section, the top two recovery priorities are additional research about species ecology and reintroduction into additional sites. Many of the goals for research into species ecology could be addressed through carefully designed and monitored release programs. These will at least temporarily reduce the risk of extinction (even if they fail after some period of time) and can provide insight into the limiting factors that must be addressed to increase persistence times.

I would recommend pursuing research projects similar to those raised by the experts consulted in this study: track survival of released larvae, track survival of released larvae in exclosures that protect them from predators and parasites, and track behavior and persistence of released adults.

Such experiments could take place at any of the suggested reintroduction sites, and location should be prioritized based on logistical concerns. Sites that have been suggested include Fort Zachary Taylor State Park, Key West Little Hamaca Park, and Key West Tropical Forest and Botanical Garden (Minno and Minno 2009), Bill Baggs State Park on Key Biscayne (Olle 2010), other sites were used by Daniels and colleagues for releases from the captive colony, and the obvious choice of Bahia Honda State Park itself.

Miami blue has a metapopulation structure even in relatively small areas (Emmel and Daniels 2003a), with very little movement between patches. This behavior means that multiple experiments might be set up reasonably close to one another with minimal interference between them.

Reintroduction Concerns

Managers have contemplated reintroduction of Miami blue from both captive-bred and translocated individuals (Calhoun et al. 2002). The benefit of a captive-bred source is that many individuals can be produced with a minimum impact on the donor population. Using translocated individuals avoids the risks of captivity (e.g., disease, contamination) and breeding (inadvertent genetic selection and drift). By adopting an approach that minimizes time in captivity (two generations at most) and adoption of best practices to address disease and genetic diversity, a short-term captive propagation program seems most appropriate to produce stock for research-oriented release projects. From a genetic perspective, establishing additional populations is far preferable to augmenting existing sites (Saarinen et al. 2010). Some of the concerns involved with captive propagation and release are reviewed here.

Life Stage

Experts expressed concern about the appropriate life stage to be released to maximize success of any releases. A review of British butterfly reintroductions concludes that a release of a moderate number of adult butterflies (25–50) can successfully establish a population (Oates and Warren 1990). They suggest that best results will be obtained from releasing "freshly emerged and mated females" (emphasis added; Oates and Warren 1990). In a recent review of British and American butterfly propagation and release programs, Shultz et al. (2008) report that British reintroductions and augmentations predominantly use adult butterflies, while American efforts have used several life stages. Use of adult females a few days old for introductions is documented to be a successful technique in lycaenids (Marttila et al. 1997). The baton blue butterfly (*Pseudoeuphilotes baton schiffermuelleri*) was translocated several hundred miles by capturing gravid females in the field, confining them in darkened boxes for travel, and releasing at a recipient site (Marttila et al. 1997). Holdren and Ehrlich (1981) introduced *Euphydryas gillettii* to a site south of its existing range by taping 83 egg masses with 10,000 eggs on leaves of foodplants and releasing cups full of newly hatched larvae at one site and releasing 17 gravid females at a second site. Both approaches were successful, at least in the short term. The Palos Verdes blue butterfly has been released to new locations with at least short-term success by releasing eggs, larvae, and adults (Johnson et al. 2010; Johnson et al. 2011).

It is definitely possible to establish butterfly populations by setting out larvae, pupae, or adults (Oates and Warren 1990, Schultz et al. 2008). From a monitoring perspective, use of pupae or adults has advantages for release to a site presumed to be unoccupied because subsequent observation of larvae could be taken as confirmation of reproduction. For certain research questions, however, release of larvae (or confinement of females on plants and subsequent tracking of eggs and larvae) is most appropriate.

Establishing new (experimental) populations with 40–80 adults or a substantially larger number of larvae would be advisable to that the colonizing population has far more genetic variation than occurs in natural colonization, where half of new populations are founded by a single female (Austin et al. 2010).

Disease

Lepidoptera are susceptible to a range of diseases caused by bacteria, viruses, fungi, microsporidia, and nematodes (Tanada and Kaya 1993; Boucias and Pendland 2001). Mattoni et al. (2003) documented Bt and microsporidian infection in a captive population of Palos Verdes blue butterfly. The endo-symbiont *Wolbachia* is also known to have subtle but important demographic effects on butterfly populations (Nice et al. 2009). Release of diseased individuals into wild populations is of concern if these individuals will reduce fitness of wild individuals (Crone et al. 2007). Consequently, Crone et al. (2007) report that butterfly propagation programs avoid release if disease is found in captivity (e.g., for Oregon silverspot) (see also Pearce-Kelly et al. 1998).

Introduction of disease (bacteria, viruses, and other pathogens) and parasites can be minimized by practicing good hygiene with captive stock, maintaining multiple layers of containment, minimizing time in captivity, and segregating butterflies from different regions (Cunningham 1996; Crone et al. 2007). Good hygiene includes basic protocols to minimize transport of bacteria and viruses, including:

- Hand washing before and after handling stock;
- Removal of shoes or cleaning shoes with 10% bleach when entering rearing areas;
- Immediate segregation of butterflies or larvae that appear to be infected or ill;
- Quarantine of larvae that were co-housed with larvae that exhibit signs of infection (see e.g., Mattoni et al. 2003);
- Seasonal sterilization of equipment and rearing chambers;

- Monitoring humidity to avoid production of mold.

Risk of transfer of disease to new locations (e.g., a recipient site of a reintroduction) can be minimized by the measures described above, and by selecting stock for release that have no outward signs of infection in captivity.

Genetic Management

The possibility for genetic drift and/or selection while in captivity is an issue for any captive breeding program (Snyder et al. 1996; Lewis and Thomas 2001; Ford 2002; Schultz et al. 2008). The captive population from Bahia Honda State Park maintained heterozygocity but declined in allelic richness over time (Saarinen 2009). It is possible, for example, that selective pressure results in genetic changes favoring compliant butterflies that respond to mating in captive environments at the expense of necessary behaviors for obtaining mates in the wild. This risk can be minimized by reducing the number of generations that any geneline is kept in captivity. For Miami blue, a short-term captive breeding program associated with the period of hurricane risk in KWNWR and targeted toward producing stock suitable for release in experimental reintroduction efforts would reduce that risk. Such release/research should be clearly defined and permitted before the captive breeding program starts so that the program is not faced with a growing population of butterflies and no place to release them.

Managing genetic diversity requires that captive breeding programs maintain meticulous records of the lineages of individuals in the population. A studbook may take the form of a computer database, which details critical life cycle dates, sex, parentage, source location, and identification numbers for each individual in the program. These data can provide important information for genetic management, and represent a standard component of a captive breeding program across all animal taxa.

Monitor Existing Populations

The existing program to document populations of Miami blue butterfly in KWNWR has concentrated on deriving total population sizes that can be extrapolated to all available and occupied habitat. The techniques are innovative for use on butterflies — point counts combined with distance sampling — and results need to be shared carefully and widely within the community of experts working on Miami blue to build confidence in their accuracy. This research is developing an understanding of the annual fluctuations of the populations and density estimates that can be extrapolated to areas of occupied habitat. Consensus on the relative importance of risks to the species and consequent recovery priorities depends on agreement over the results of this research, which makes it incredibly important.

Most releases of butterflies to new habitats should be taking place as part of planned experiments designed to increase knowledge about key aspects of species ecology. For example, it might involve tracking individual larvae through the developmental period and collecting last-instar larvae to pupae and eclose in the laboratory so that parasitoids can be recorded. For this reason, post-release monitoring at the early phases of recovery will be dictated by concerns beyond documenting success of a reintroduction.

Once reintroduction sites are no longer being used explicitly to address research questions, ongoing monitoring will still be needed. For this purpose, raw transect counts and peak counts have been shown to provide reliable information (Collier et al. 2008, Haddad et al. 2008, Isaac et al. 2011), but their use can be problematic (Harker and Shreeve 2008). Occupancy modeling might be appropriate, since populations are relatively small and probably not all habitat patches are occupied (Bried and Pellet 2011). Therefore, occupancy alone could be used to track population status as the distribution is extended to many sites. This is an appropriate approach where distribution is patchy and dynamic (Wahlberg et al. 2002, WallisDeVries 2004).

I have used occupancy approaches for the status of Palos Verdes blue butterfly — the total number of butterflies did not have a significant trend, but the proportion of occupied to unoccupied areas was undergoing decline and has triggered management actions (Longcore and Osborne 2011). Similarly trends in occupancy clearly highlighted areas of concern for endangered butterflies near San Francisco (Longcore et al. 2010; MacDonald et al. 2012). Repeat visits that are appropriately timed would be necessary to address detectability issues (Zonneveld et al. 2003), but such a spatial sampling scheme might ultimately be less labor-intensive than approaches to monitor population size with greater resolution than spatial distribution.

As recovery efforts progress, a combined survey approach could be used, which combines "sentinel" sites that are monitored for abundance (using techniques to account for detectibility) and panel sites that are monitored only to establish presence (and also account for detecibility). Such an approach would allow resources to be split between higher intensity efforts to track population size and lower intensity efforts to determine occupancy. The population monitoring that is ongoing and concurrent can be used to focus survey efforts for occupancy surveys to periods when numbers are maximum and probably of detection is greatest (Zonneveld et al. 2003).

Recovery Criteria

This report has largely addressed the means by which recovery of Miami blue might be achieved, and the conditions that might jeopardize such efforts. A recovery plan for the species will require development of numerical targets to measure recovery and inform any decision to downlist the species. Developing such targets is outside the scope of this report, but it may be advisable to incorporate occupancy as opposed to abundance metrics, given the high variability of numbers during the year being reported from the KWNWR surveys. The key priority for conservation has to be establishing as many more additional populations as feasible, even if some of them periodically wink out. The species historically existed within a dynamic landscape that involved patterns of colonization and extinction on multiple time scales (annual, decadal) and the landscape to support those patterns is gone and not going to be restored. Recovery planning for the species should therefore recognize that extinction of local colonies (especially those established through reintroduction) is a natural process and that ongoing assisted colonization/reintroduction will characterize the long-term management for the species. This is sometimes a difficult perspective to communicate with species managers who work on large, long-lived species and are used to reintroductions resulting stable, long-term populations. For butterflies, however, recovery might include a network of reintroduced populations that occasionally require re-establishment. At long time scales, some of these habitats might also require disturbance to produce the open conditions needed for the relatively weedy host plants.

Literature Cited

Armstrong, D. P., I. Castro, and R. Griffiths. 2007. Using adaptive management to determine requirements of re-introduced populations: the case of the New Zealand hihi. Journal of Applied Ecology 44:953–962.

Armstrong, D. P., and P. J. Seddon. 2008. Directions in reintroduction biology. Trends in Ecology and Evolution 23:20–25.

Austin, A., O. Ovaskainen, and I. Hanksi. 2010. Size and genetic composition of the colonizing propagules in a butterfly metapopulation. Oikos early view.

Bethune-Baker, G. T. 1916. Notes on the genus *Hemiargus* Hübner in Dyar's list (Lep.). Entomological News 27:449–457.

Boucias, D., and J. Pendland. 2001. Principles of insect pathology. Kluwer, Boston.

Calabrese, J. M., and W. F. Fagan. 2004. Lost in time, lonely, and single: reproductive asynchrony and the Allee effect. American Naturalist 164:25–37.

Calhoun, J. V., J. R. Slotten, and M. H. Salvato. 2002. The rise and fall of tropical blues in Florida: *Cyclargus ammon* and *Cyclargus thomasi bethunebakeri*. Holarctic Lepidoptera 7:13–20.

Cannon, P. 2007a. Miami blue: rarest of the rare. Pages 16–18 in Keys Sunday.

Cannon, P. 2007b. A survey of the Miami blue butterfly (*Cyclargus thomasi bethunebakeri*) in the Florida Keys National Wildlife Refuges, 26 November 2006–30 July 2007.

Cannon, P., T. WIlmers, and K. Lyons. 2010. Discovery of the imperiled Miami blue butterfly (*Cyclargus thomasi bethunebakeri*) on islands in the Florida Keys National Wildlife Refuges, Monroe County. Southeastern Naturalist 9:847–853.

Carroll, S. P. 1988. Contrasts in reproductive ecology between temperate and tropical populations of *Jadera haematoloma*, a mate-guarding hemipteran (Hropalidae). Annals of the Entomological Society of America 81:54–63.

Carroll, S. P., and J. Loye. 2006. Invasion, colonization, and disturbance: historical ecology of the endangered Miami blue butterfly. Journal of Insect Conservation 10:13–27.

Chan, P. K., and L. Packer. 2006. Assessment of potential Karner blue butterfly (*Lycaeides melissa samuelis*) (family: Lycaenidae) reintroduction sites in Ontario, Canada. Restoration Ecology 14:645–652.

Comstock, W. P., and E. I. Huntington. 1943. Lycaenidae of the Antilles (Lepidoptera, Rhopalocera). Annals of the New York Academy of Sciences 45:49–130.

Cook, D. 2011. Preventing extinction of the Miami blue butterfly through reintroduction research and captive breeding.

Crone, E. E., D. Pickering, and C. B. Schultz. 2007. Can captive rearing promote recovery of endangered butterflies? An assessment in the face of uncertainty. Biological Conservation 139:103–112.

Cunningham, A. A. 1996. Disease risks of wildlife translocations. Conservation Biology 10:349–353.

Daniels, J. C. 2009a. Cooperative conservation efforts to help recover an endangered south Florida butterfly. Insect Conservation and Diversity 2:62–64.

Daniels, J. C. 2009b. Miami blue butterfly conservation.

Daniels, J. C. 2010. Conservation and field sureys of the endangered Miami blue butterfly (*Cyclargus thomasi bethunebakeri*) (Lepidoptera: Lycaenidae).
Daniels, J. C. 2011. Toward a better understanding of organism reintroduction: implications for the recovery of imperiled butterflies in southern Florida using the Miami blue as a model [grant proposal].
Daniels, J. C., J. A. Pence, and T. C. Emmel. 2002. Additional records of *Cyclargus ammon* (Lycaenidae: Lycaeninae) in the Florida Keys. Journal of the Lepidopterists' Society 60:97–99.
Daniels, J. C., J. A. Pence, and T. C. Emmel. 2005. A new hostplant record for *Strymon martialis* (Lycaenidae: Theclinae) in the Florida Keys. Journal of the Lepidopterists' Society 59:174–175.
Emmel, T. C., and J. C. Daniels. 2002. Status survey and monitoring of the rare Miami blue butterfly (*Hemiargus thomasi bethunebakeri*) in south Florida 2002–2003.
Emmel, T. C., and J. C. Daniels. 2003a. Captive propagation of the rare Miami blue butterfly (*Hemiargus thomasi bethunebakeri*) in south Florida.
Emmel, T. C., and J. C. Daniels. 2003b. Status survey and monitoring of the rare Miami blue butterfly (*Hemiargus thomasi bethunebakeri*) in south Florida: third preliminary report.
Emmel, T. C., and J. C. Daniels. 2003c. USFWS Agreement No. 40181361 Preliminary Report No. 1: Captive propagation of the Miami blue butterfly (*Cyclargus thomasi bethunebakeri*).
Emmel, T. C., and J. C. Daniels. 2006a. Miami blue butterfly conservation USFWS Grant Agreement No. 401713G179 Interim Annual Report Period Covered: 2004.
Emmel, T. C., and J. C. Daniels. 2006b. Miami blue butterfly conservation USFWS Grant Agreement No. 401813G179 Interim Annual Report Period Covered: 2005.
Emmel, T. C., and J. C. Daniels. 2009. Miami blue butterfly conservation final project report.
Epperson, D. M., and C. R. Allen. 2010. Red imported fire ant impacts on upland arthropods in southern Mississippi. American Midland Naturalist 163:54–63.
Forbes, W. T. M. 1941. Lepidoptera of the Dry Tortugas. Psyche 48:147–148.
Ford, M. J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16:815–825.
Forys, E. A., A. Quistorff, and C. R. Allen. 2001. Potential fire ant (Hymenoptera: Formicidae) impact on the endangered Schaus Swallowtail (Lepidoptra: Papilionidae). Florida Entomologist 84:254–258.
French, G. H. 1886. The Butterflies of the Eastern United States. J. B. Lippincott Company, Philadelphia.
Glassberg, J. 2000. Petition for emergency endangered listing for the Miami blue butterfly (*Hemiargus thomasi bethunebakeri*).
Glassberg, J., and D. J. Olle. 2010. Renewed petition for emergency endangered listing for Miami blue (*Hemiargus thomasi bethunebakeri*).
Halupa, P. 2012. Recovery outline for Miami blue butterfly (*Cyclargus thomasi bethunebakeri*).
Haney, A., and R. L. Power. 1996. Adaptive management for sound ecosystem management. Environmental Management 20:879–886.
Henry, E., N. Haddad, and J. Wilson. 2012. Miami blue butterfly monitoring interim report covering September 2010 – May 2012. Grant Agreement 40181AG136.
IUCN. 1998. Guidelines for reintroductions. IUCN/SSC Re-introduction Specialist Group, IUCN, Gland, Switzerland and Cambridge.

Johnson, J., A. Lansing, M. Azemon, D. Renner, J. VanKempen, D. Amoroso, S. Foster, A. Romero, B. MacQuiddy, M. J. Handley, and T. Longcore. 2010. Final Report for Palos Verdes Blue Butterfly Year 2009 Captive Rearing on Defense Fuel Support Point, San Pedro, California and The Butterfly Project, Moorpark, California. Pages 1–24. Los Angeles: The Urban Wildlands Group (Defense Logistics Agency Agreement # N62473-08-LT-R0011), Los Angeles.

Johnson, J., A. Stangeland, D. Amoroso, A. Romero, J. VanKempen, T. Wilson, S. Foster, T. Hampton, J. Eccles, K. Virun, R. Minzer, B. Coomes, J. Mauck, D. Flanner, B. MacQuiddy, M. McNeil, M. Wagner, and T. Longcore. 2011. Final Report for Palos Verdes Blue Butterfly Year 2010 Captive Rearing on Defense Fuel Support Point, San Pedro, California and The Butterfly Project, Moorpark, California. Pages 1–21. Los Angeles: The Urban Wildlands Group (Defense Logistics Agency Agreement # N62473-08-LT-R0011), Los Angeles.

Kimball, C. P. 1965. The lepidoptera of Florida: an annotated checklist. Division of Plant Industry, State of Florida Department of Agriculture, Gainesville.

Lewis, O. T., and C. D. Thomas. 2001. Adaptations to captivity in the butterfly *Pieris brassicae* (L.) and the implications for ex situ conservation. Journal of Insect Conservation 5:55-63.

Longcore, T., C. S. Lam, P. Kobernus, E. Polk, and J. P. Wilson. 2010. Extracting useful data from imperfect monitoring schemes: endangered butterflies at San Bruno Mountain, San Mateo County, California (1982–2000) and implications for habitat management. Journal of Insect Conservation 14:335–346.

Longcore, T., and K. H. Osborne. 2011. Final report for 2011 Palos Verdes blue butterfly adult surveys on Defense Fuel Support Point, San Pedro, California. (NAVFAC SW Agreement # N62473-11-2-2304). Pages 1–18. The Urban Wildlands Group, Los Angeles.

MacDonald, B., T. Longcore, and S. B. Weiss. 2012. Status and variability of mission blue butterfly populations at Milagra Ridge, Marin Headlands, and Oakwood Valley. Pages 1–69. The Urban Wildlands Group, Los Angeles.

Marttila, O., K. Saarinen, and J. Jantunen. 1997. Habitat restoration and a successful reintroduction of the endangered Baton blue butterfly (*Pseudophilotes baton schiffermuelleri*) in SE Finland. Annales Zoologici Fennici 34:177–185.

Mattoni, R., T. Longcore, Z. Krenova, and A. Lipman. 2003. Mass rearing of the endangered Palos Verdes blue butterfly (*Glaucopsyche lygdamus palosverdesensis*: Lycaenidae). Journal of Research on the Lepidoptera 37:55–67.

Mattoni, R. H. T. 1995. Rediscovery of the endangered Palos Verdes blue butterfly, *Glaucopsyche lygdamus palosverdesensis* Perkins and Emmel (Lycaenidae). Journal of Research on the Lepidoptera 31:180–194.

Mattoni, R. H. T., G. F. Pratt, T. R. Longcore, J. F. Emmel, and J. N. George. 1997. The endangered Quino checkerspot butterfly, *Euphydryas editha quino* (Lepidoptera: Nymphalidae). Journal of Research on the Lepidoptera 34:99–118.

Minno, M. C., and T. C. Emmel. 1993. Butterflies of the Florida Keys. Scientific Publishers, Gainesville.

Minno, M. C., and T. C. Emmel. 1994. Miami blue *Hemiargus thomasi bethunebakeri*. Pages 646–649 in Rare and endangered biota of Florida. Volume IV. Invertebrates (M. Deyrup, and R. Franz, Eds.). University of Florida Press, Gainesville.

Minno, M. C., and M. Minno. 2009. A plan to conserve rare butterflies in the Florida Keys.

Nabokov, V. 1945. Notes on Neotropical Plebejinae (Lycaenidae, Lepidoptera). Psyche 52:104–138.

Nice, C. C., Z. Gompert, M. L. Forister, and J. A. Fordyce. 2009. An unseen foe in arthropod conservation efforts: the case of *Wolbachia* infections in the Karner blue butterfly. Biological Conservation 142:3137–3146.

Oates, M. R. 1992. The role of butterfly releases in Great Britain & Europe. Pages 204–212 in Future of butterflies in Europe; proceedings of an international congress. Department of Nature Conservation, Agricultural University, Wageningen, Wageningen.

Oates, M. R., and M. S. Warren. 1990. A review of butterfly introductions in Britain and Ireland. Joint Committee for the Conservation of British insects funded by the World Wildlife Fund for Nature, London.

Olle, D. 2010. Who killed all the Miami blues? American Butterflies 18:4–14.

Pearce-Kelly, P., R. Jones, D. Clarke, C. Walker, P. Atkin, and A. A. Cunningham. 1998. The captive rearing of threatened Orthoptera: A comparison of the conservation potential and practical considerations of two species' breeding programmes at the Zoological Society of London. Journal of Insect Conservation 2:201-210.

Pullin, A. S. 1996. Restoration of butterfly populations in Britain. Restoration Ecology 4:71–80.

Ruffin, J., and J. Glassberg. 2000. Miami blues still fly. American Butterflies 8:28–29.

Runge, M. C., S. J. Converse, and J. E. Lyons. 2011. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biological Conservation 144:1214–1223.

Saarinen, E. V. 2009. Population genetics of the endangered Miami blue butterfly *Cyclargus thomasi bethunebakeri*: implications for conservation. Ph.D. Dissertation, University of Florida, Gainesville.

Saarinen, E. V., J. D. Austin, and J. C. Daniels. 2010. Genetic estimates of contemporary effective population size in an endangered butterfly indicate a possible role for genetic compensation. Evolutionary Applications 3:28–39.

Saarinen, E. V., and J. C. Daniels. 2006. Miami blue butterfly larvae (Lepidoptera: Lycaenidae) and ants (Hymenoptera: Formicidae): new information on the symbionts of an endangered taxon. Florida Entomologist 89:69–74.

Saarinen, E. V., J. C. Daniels, and J. E. Maruniak. 2009. Development and characterization of polymorphic microsatellite loci in the endangered Miami blue butterfly (*Cyclargus thomasi bethunebakeri*). Molecular Ecology Resources 9:242–244.

Salvato, M. H., and H. L. Salvato. 2007. The influence of hurricane and tropical storm activity on resident butterflies in the lower Florida Keys. Journal of the Lepidopterists' Society 61:154–164.

Schultz, C. B., and P. W. Hammond. 2003. Using population viability analysis to develop recovery criteria for endangered insects: case study of the Fender's blue butterfly. Conservation Biology 17:1372–1385.

Schultz, C. B., C. Russell, and L. Wynn. 2008. Restoration, reintroduction and captive propagation efforts for at-risk butterflies: a review of British and American conservation efforts. Israel Journal of Ecology and Evolution 54:41–61.

Seidl, A. L. 1999. Population demographics and the conservation status of the Uncompahgre Fritillary Boloria acrocnema (Nymphalidae). Journal of the Lepidopterists' Society 53:32–36.

Snyder, N. F. R., S. R. Derrickson, S. R. Beissinger, J. W. Wiley, T. B. Smith, W. D. Toone, and B. Miller. 1996. Limitations of captive breeding in endangered species recovery. Conservation Biology 10:338–348.

Tanada, Y., and H. K. Kaya. 1993. Insect pathology. Academic Press, San Diego.

Trager, M. D. 2009. Patterns, mechanisms and consrequnces of ant association in the Miami blue butterfly (*Cyclargus thomasi bethunebakeri*). Ph. Dissertation, University of Florida, Gainesville.

Trager, M. D., and J. C. Daniels. 2009. Ant tending of Miami blue butterfly flarvae (Lepidoptera: Lycaenidae): partner diversity and effects on larval performance. Florida Entomologist 92:424–482.

Zhong, H. 2009. Impact of aerial ULV application of naled on Miami blue butterfly larvae. Final report to Imperiled Species Subcommittee, FCCMC. Florida A&M University, Panama City, Florida.

Zhong, H., L. J. Hribar, J. C. Daniels, M. Feken, C. Brock, and M. D. Trager. 2010. Aerial ultra-low-volume application of naled: impact on nontargetimperiled butterfly larvae (*Cyclargus thomasi bethunebakeri*) and efficacy against adult mosquitoes (*Aedes taeniorhynchus*). Environmental Entomology 39:1961–1972.

Zonneveld, C. 1996. Being big or emerging early? Polyandry and the trade-off between size and emergence in male butterflies. American Naturalist 147:946–965.

Zonneveld, C., T. Longcore, and C. Mulder. 2003. Optimal schemes to detect presence of insect species. Conservation Biology 17:476–487.