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Can captive rearing promote recovery of endangered butterflies? An assessment in the face of uncertainty

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Captive rearing is increasingly used as an interim strategy to maintain at-risk butterfly populations while long-term recovery techniques are developed. However, it is seldom feasible to measure effects of captive rearing on small, fragile, and highly mobile organisms, such as butterflies, in wild populations. We use a series of general population viability models to assess the demographic effects of a number of captive rearing strategies, defined by the source of butterflies brought into captivity (the at-risk “small” population vs. a different, stable “large” population) and the number brought into captivity. In general, captive rearing increases population viability, although the benefits are small for rapidly declining or highly stochastic populations. Taking butterflies from the large population is consistently better than taking butterflies from the small population, as long as the large population is not also at imminent risk of extinction. We then modify these models to include two possible risks of captive rearing: captive-reared individuals might not perform as well as wild individuals, and captive-reared individuals might decrease the population growth rate of the wild population, e.g., by introducing deleterious alleles or diseases. Reductions in individual performance do not change optimal captive rearing strategies. Short-term extinction risk is also robust to small ($\lesssim$5%) reductions in population growth rate. Although studying performance of captive-reared individuals in the wild is often not feasible, it is often possible to monitor performance while in captivity. Captive rearing is a robust way to maintain severely at-risk populations in the short-term, though it cannot replace long-term solutions.

1. Introduction

For numerous at-risk species, causes of endangerment are clear, but methods to recover at-risk populations are unknown. For butterflies, primary causes of endangerment include habitat loss, habitat fragmentation, and habitat degradation due to cessation of historic disturbance regimes and encroachment by invasive species (Schultz and Chang, 1998). Methods to augment and restore degraded habitat limit the success of attempts to recover numerous butterfly species (e.g., Thomas, 1984; Schultz, 2001). In addition, once methods are developed to augment and restore habitats, it may take a decade or more for restored areas to function as habitat. As a result, captive propagation has been suggested as a short-term measure to maintain numerous severely at-risk populations until long-term measures can be developed

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and implemented. For example, the American Zoo and Aquarium Association recently launched the Butterfly Conservation Initiative, which reflects the mandate of 53 zoos and associated organizations to engage in local (North American) conservation efforts by supporting the recovery of 22 butterfly species, largely with captive propagation programs (http://www.butterflyrecovery.org/recovery/). Similarly, for 10 of 25 at-risk British butterfly species with a Species Action Plan, reintroduction, often implemented with captively propagated stock, is a priority (http://www.butterfly-conservation.org/).

Nonetheless, little is known about how these programs contribute to population viability. In this paper, we evaluate the potential demographic consequences of captive rearing, using models based on population dynamics of the Oregon silverspot butterfly. To put our analyses in context, we first review the effects of captive rearing in general, then summarize the ecology and management of the Oregon silverspot in particular.

2. Effects of captive propagation on invertebrate species

Several zoos and other facilities are currently engaged in captive rearing programs for protected butterfly species. The basic protocol is to collect eggs from wild-mated females, rear larvae to adult butterflies in captive propagation facilities, and release adults and/or pupae back into wild populations. The effects of the current protocols on wild butterfly populations are unknown. Captive propagation programs have the potential to significantly aid declining populations, but scientists have raised several significant concerns about potential limitations of these programs. These include concerns about behavioral, demographic and genetic changes as a result of domestication, problems with reintroduction and disease, and limitations of financial and physical resources (Bryant and Reed, 1999; Ford, 2002; Heath et al., 2003; Lynch and O'Hely, 2001; Snyder et al., 1996; van Oosterhout et al., 2000). In butterflies, few studies have been conducted to evaluate the potential effects of these programs. Studies of the large white butterfly (*Pieris brassicae*) suggest that captive breeding leads to individuals that are heavier, have smaller wings and have heavier egg masses (Lewis and Thomas, 2001). Such changes are likely to influence butterfly dispersal behavior and demography once the butterflies are returned to the wild. Morphological changes are linked to changes in insect dispersal behavior and demography (e.g. Fairborn and Roff, 1990; Palmer and Dingle, 1989). Strikingly, Nicholls and Pullin (2000) observed that larval survivorship for the large copper (*Lycaena dispar batavus*) was lower for captive bred individuals than for wild individuals. In other insects, captive breeding has led to decline in life expectancy, changes in fecundity, lower larval viability, severe inbreeding, and overall reduced fitness (Bryant and Reed, 1999; Linnen et al., 2001; van Oosterhout et al., 2000). Of note, these studies were conducted on insects for which captive breeding programs were continued for tens to hundreds of generations, not the relatively short duration proposed by captive rearing programs. In one single generation study, Dzurisin (2005) observed that captively reared Puget blue butterflies (*Icaricia icarioides blackmoreii*) were significantly smaller than wild individuals.

Diseases have been observed in several programs rearing at-risk invertebrates. For example, Mattoni et al. (2003) found that Palos Verdes blue butterflies reared in captivity experienced significant losses due to microsporidian infection. Eugregarine protozoan parasite infections have been common in a program to rear the field cricket *Gryllus campestris* and a pathogenic fungus was observed to cause high mortality in a rearing program for wart-biter bush cricket *Decticus verrucivorus* (Pearce-Kelly et al., 1998). In addition, captive populations of the Olimpia ground beetle (*Chrysocarabus olympiae*) have been infected by entomopathogenic fungi (Cunningham and Frank, 1993). In one noteworthy case, the last individuals of an endangered tree snail, *Partula turgida*, died due to a microsporidian infection that spread through the captive population (Cunningham and Daszak, 1998). In general, lepidoptera are infected by a wide range of agents; fungi, viruses, bacteria, microsporadian, and nematodes have all affected lepidoptera (Tanada and Kaya, 1993).

2.1. *Ecology and management of the Oregon silverspot*

The Oregon silverspot is a federally-listed threatened butterfly species that persists at only five sites in Oregon and California USA, and appears to be in decline throughout its range (Fig. 1). Oregon silverspot caterpillars feed on *Viola* spp., and adults nectar on a variety of native and nonnative forbs in coastal dune habitat. Habitat alteration and invasion by exotic grasses are considered the major factors limiting Oregon silverspot recovery (US Fish and Wildlife Service, 2001), but methods for habitat restoration are still being developed. Since 1999, female butterflies have been taken from wild populations on the Oregon Coast into the Oregon Zoo (Portland, OR, USA) and/or Woodland Park Zoo (Seattle, WA, USA), and their offspring have been released into natural populations. For every female taken into a zoo, ∼4 female offspring have been reared through pupation and released in the field, leading to a much higher recruitment per capita than in natural populations. Typically, butterflies have been taken from one Oregon Coast population, Cascade Head, and their offspring released at Cascade Head. However, butterflies have occasionally been taken from the larger populations at Mt. Hebo and Rock Creek and released at the smaller populations, Cascade Head and Bray Point. Large releases of captive-reared butterflies were made at Cascade Head in 2000 and 2003 (107 and 161 individuals, respectively). These releases did not detectably change population trends, although such effects would be difficult to detect relative to high year-to-year variance in population trends (Fig. 1, E. Crone, unpublished analysis). Similarly, measurements of the performance and fitness of captive-reared butterflies in wild populations, such as extensive capture–recapture or genetic analyses, could directly harm individual butterflies. They would also be difficult to interpret in the most at-risk populations, where statistical power is limited by very small numbers of butterflies. In spite of well designed monitoring, the consequences of this captive rearing program remain unknown.