Minimum viable population size for the Bay checkerspot butterfly

Amy Campbell
(Bethany Eckroth)

Wildlife 448
Fall 2002
December 6, 2002
Dr. E. O. Garton

Abstract: The populations of threatened Bay checkerspot butterfly (*Euphydryas editha bayensis*) at the Jasper Ridge Biological Preserve (JRBP), Stanford University, California, have gone extinct. Research has been conducted on the butterfly's population dynamics since 1960, and in this paper, we analyzed the theoretical probabilities of persistence in the C and H populations given the λ, σ^2, and μ values calculated by STOCHMVP from 1960 until 1980. Also, minimum viable population (MVP) size was modeled to determine if the butterflies could avoid extinction at 1980 population levels. Based on estimated MVP from the STOCHMVP analyses, it was determined that the populations were prone to go extinct. This is due to the small habitat size available at the JRBP and various stochastic factors. The C population went extinct in 1989 and the H population went extinct in 1997. Population G was not analyzed due to the lack of adequate data. The opportunity to augment populations through methods such as grazing are discussed in this paper, as well as the viability of captive breeding techniques.

JUSTIFICATION AND INTRODUCTION

Background Information

The Bay checkerspot butterfly (*Euphydryas editha bayensis*) forms new populations through a metapopulation dynamic. The butterflies only occur on serpentine-based grasslands in the Bay Area of California (See Figure 1). The populations in the Jasper Ridge Biological Preserve have been studied since 1960; Paul Ehrlich at the Center for Conservation Biology at Stanford University began these studies (Ehrlich and Murphy 1987).

Selection pressures work to limit gene flow between butterfly populations. These pressures are a result of the limited flight season, from about March 18th to April 22nd, and the reproductive tactic used by the butterfly. The limited dispersal of the butterfly due to these factors contributes to their current low numbers. It is very important for species to disperse to new unoccupied habitats for the advent of new populations (Federal Register 2001). The Bay checkerspot butterfly occasionally disperses up to 5.6 miles (Harrison 1989).

The butterflies are a "univoltine host-specialist on annual plantain, *Plantago erecta*, and owl's clover, *Orthocarpus* spp. which grow in serpentine grasslands" (Harrison 1989). Serpentine soils are high in magnesium and low in calcium, and are good indicators of butterfly habitat (Federal Register 2001). They usually support only native plant species, but recently, introduced grasses and forbs have been able to invade native plant communities (Murphy and Ehrlich 1988). Nitrogen is usually the limiting factor in serpentine soils, and high amounts of nitrogen deposition from the surrounding urban areas contribute to the exotic plant increases (Weiss 1999).

The butterflies lay eggs at the base of native host plants, and the young hatch after 13 to 15 days. They feed for about three weeks, and then enter summer diapause that is broken in late December or January (Singer 1972). According to Murphy *et al*. (1990), the timing of emergence is dependent on the angle of incident solar radiation. Ehrlich and Murphy (1987) stated that north-facing slopes are productive for larval development in most years, and south-facing slopes are the most productive in wet years. During wet years, the fecundity from the south-facing slope breeders helps the populations survive through the dry years.

Justification for Study

The bay checkerspot species is at risk of extinction, and the populations at Jasper Ridge Biological Preserve have been considered extinct as of 1997 (Weiss 1999). This species is currently on the United States Fish and Wildlife Service's threatened list and was listed in 2001. There are currently 9,673 hectares of critical habitat designated for the butterfly in San Mateo and Santa Clara Counties, California (Federal Register 2001). Only remnant individuals of the original populations remain, and it is important to know the minimum viable population (MVP) size for management considerations to allow for the butterfly's persistence through time. This study will determine the MVP needed by populations such as the Jasper Ridge colonies to successfully persist through time. This information is crucial for management; it will help managers determine what if any, habitat modifications, breeding programs, and the like should be undertaken to augment remaining or newly formed populations.

According to Ehrlich and Murphy (1987) all sites except the Edgewood Park population in the San Mateo-Woodside grasslands system are too small for long term population persistence through extended drought. The only sustainable source population known to date is the Morgan Hill population in Santa Clara County, which is too far away for migration and re-colonization from Jasper Ridge.

Objectives

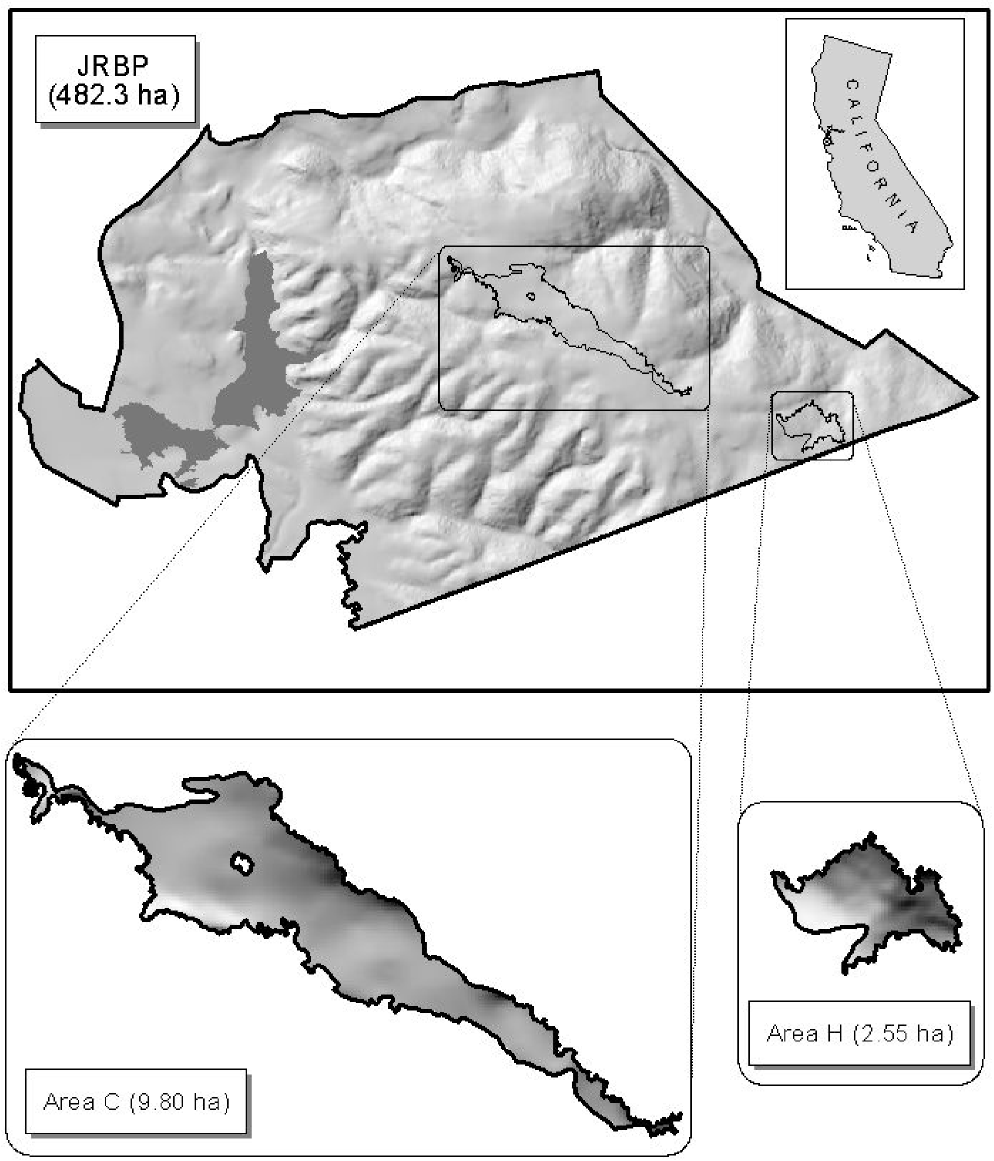
The objectives of our study are to (1) utilize annual count data to calculate trends and variations in the population of *E. e. bayensis*, (2) enter this information into STOCHMVP to determine the minimum viable population size for the *E. e. bayensis* species to persist for various amounts of time, and (3) determine necessary habitat changes to encourage butterfly persistence.

DESCRIPTION OF STUDY AREA

The study area for which performed analyses is at Stanford University's Jasper Ridge Biological Preserve in San Mateo County, California (Figure 1). The checkerspot butterflies occupied approximately 11 hectares of habitat patches that consisted of native serpentine-based grasslands and serpentine rock outcroppings. These serpentine soils consist primarily of native species including the host plant species *Plantago erecta*, *Castilleja densiflorus*, and *Castilleja excreta*, and exclude the majority of non-native species to richer soils. The habitat is continuous, with no barriers to butterfly flight, and is surrounded by chaparral and sandstone-based grasslands (Weiss 1999). The climate is Mediterranean, with a cool rainy season (October-April) and a warm summer drought (May-September). Both seasons play an integral role in the ecology of the butterflies (Murphy *et al.* 1990).

The colony of *E. editha bayensis* at Jasper Ridge was comprised of three populations, G, C, and H, which were sufficiently isolated to have independent dynamics, but not independent genetics (Ehrlich and Murphy 1987). These populations fluctuated in size independently of each other. Each had a distribution of adult insects that was variable from year to year, and none of the butterflies present in these populations occupied the entire available habitat (Singer 1972).

Figure 1: Jasper Ridge Biological Preserve and Bay checkerspot butterfly population locations at Stanford University (Hellman *et al.* in press).



METHODOLOGY

Statistical Analyses

This project analyzed Bay checkerspot butterfly population data for Areas C and H at the Jasper Ridge Biological Preserve in the San Francisco Bay Area. Due to the current state of decline in this species, we wished to determine what MVP would have been necessary for the Jasper Ridge populations to have persisted. This study used annual count data from previous studies to calculate trends and variations in the population numbers of the butterfly (Hellmann *et al*. in press). The data was analyzed in STOCHMVP to determine the minimum viable population based on a stochastic model of the population growth. By determining the MVP, we were able to determine numbers of individuals necessary for a new or current populations and the probability of persistence of such populations. We were also able to make comparisons of what actually occurred in the population to what is predicted by the program.

The STOCHMVP modeling program was developed by E. O. Garton at the University of Idaho in 1995. It gives estimates of persistence based on the following parameters: infinitesimal mean growth rate (μ), infinitesimal variance (σ^2), years population must persist, lower threshold for N to avoid extinction (N_e), desired probability of persistence, and initial population size (N_o). STOCHMVP accepts either raw data or data that has already been compiled. In this analysis, we used compiled data provided by Stanford University's Center for Conservation Biology, and calculated mean growth rate and variance, as well as a minimum viable population estimate.

We used several levels of persistence for varying amounts of time in STOCHMVP. We calculated the MVP at 95% persistence for 100 years, which is the currently accepted standard of persistence (Garton *pers. comm.*). We also calculated the MVP at 90% persistence for 50 years and 99% persistence for 1000 years.

We planned on using the program INMAT2AC to further analyze our data. The program INMAT2AC would have allowed us to project population growth and extinction under the effects of stochastic variation and inbreeding depression. The program INMAT2AC was written by Dr. Scott Mills of the University of Montana. By inputting the initial population size, rate of growth (λ), level of environmental stochasticity (CV), inbreeding costs, lethal equivalents for survivorship and fecundity, theta, and whether you want the projection based on stochastic or deterministic variation you can project population growth. However, due to the fact that the Bay checkerspot butterfly lives only for one year, the critical INMAT2AC assumption of overlapping generations was violated, and we were unable to use this modeling program.

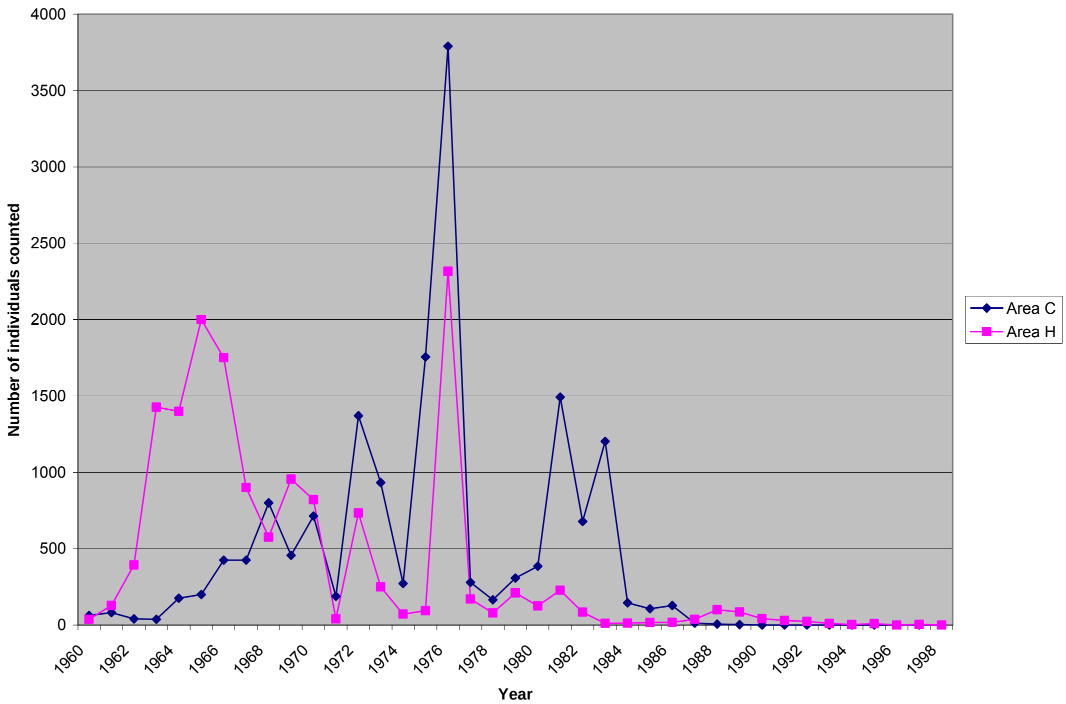
Through our research, we also hoped to make recommendations on habitat improvements that could increase the probability of persistence of a newly introduced population of Bay checkerspot butterflies into the area. In addition we hoped to make some educated guesses on whether the creation of additional metapopulations within Areas C and H would increase the persistence of the colony. Other areas studied were the required habitat size for a viable population and the viability of supplemental captive rearing.

The assumptions of our study were that (1) the population at Jasper Ridge can be re-colonized and the minimum viable population is attainable, (2) stochastic events or inbreeding depression will not cause the population to go extinct, (3) the STOCHMVP program provides an accurate assessment of the MVP using the given parameters, (4) the data from previous studies is accurate and indicative of future population trends, (5) there is no density dependence in the population, and (6) the trends in the population are long term.

RESULTS

The annual counts of females from 1960 until 1998 in Areas C and H are graphed in the following figure (Figure 2).

Figure 2: Female population counts in Areas C and H at the Jasper Ridge Biological Preserve



The values used for this chart and for the STOCHMVP analyses are cleaned, or updated, for variations in sampling methods and accuracy. While the figure shows the population data from 1960 until each population went extinct, the data analyzed in this project was from 1960 until 1980. This cutoff point was chosen because it occurred before the population sizes dropped to low levels. In the final years of each population's persistence, the values were very low, and would have skewed our MVP and probability of persistence results. See Appendix 1 for the data inputted into STOCHMVP.

A text file was used to organize the female population data for Areas C and H into the correct format for STOCHMVP, which then calculated the μ, λ, and σ^2 for each of the populations. These values were analyzed by the program using various desired probabilities of persistence, number of years the population will persist, lower threshold for extinction (N_e), and initial N values (N_o). The following table (Table 1) shows the predicted probability of persistence and minimum viable population size for each scenario and also with two and three metapopulations. The predicted probability of persistence and MVP for each population using the N_o from 1960 was also calculated.

Table 1: Probability of persistence and minimum viable population sizes for Areas C and H.

Population C

λ = 1.0947, μ =0.0905, σ^2 = 1.22728

Predicted probability of persistence with one population

# of Populations	# of Years Population Should Persist	Desired Probability of Persistence	N_e	N_o	MVP	Probability of Persistence with 1980 N_o
1	50	90%	50	385	697,252	0.337
1	50	90%	100	385	1,394,102	0.234
1	100	95%	50	385	129,415,830	0.297
1	100	95%	100	385	258,762,427	0.206
1	1000	99%	50	385	>1 trillion trillion	0.26
1	1000	99%	100	385	>1 trillion trillion	0.18

Predicted probability of persistence with two and three metapopulations

# of Metapops.	# of Years Population Should Persist	Desired Probability of Persistence	N_e	N_o	MVP For Each Subpopulation	Total Metapopulation Size	Probability of Persistence for each subpop. with 1980 N_o
2	50	90%	50	385	9,937	19,874	0.684
2	100	95%	50	385	160,630	321,260	0.776
2	1000	99%	50	385	291,365,755	582,731,511	0.9
3	50	90%	50	385	1,960	5,880	0.536
3	100	95%	50	385	12,952	38,857	0.632
3	1000	99%	50	385	1,630,588	4,891,763	0.784

Predicted probability of persistence with at least one individual remaining using the initial population size in 1960

# of Metapops.	# of Years Population Should Persist	Desired Probability of Persistence	N_e	N_o	MVP	Probability of Persistence
1	30	99%	1	63	390,443	0.65

Population H

λ= 1.0628, μ =0.0609, σ^2 = 2.35289

Predicted probability of persistence with one population

# of Populations	# of Years Population Should Persist	Desired Probability of Persistence	N_e	N_o	MVP	Probability of Persistence with 1980 N_o
1	50	90%	50	125	256,247,348	0.091
1	50	90%	100	125	512,355,291	0.023
1	100	95%	50	125	>1 trillion trillion	0.073
1	100	95%	100	125	>1 trillion trillion	0.018
1	1000	99%	50	125	>1 trillion trillion	0.048
1	1000	99%	100	125	>1 trillion trillion	0.012

Predicted probability of persistence with two and three metapopulations

# of Metapops.	# of Years Population Should Persist	Desired Probability of Persistence	N_e	N_o	MVP For Each Subpopulation	Total Metapopulation Size	Probability of Persistence for each subpopulation
2	50	90%	50	125	405,328	810,657	0.684
2	100	95%	50	125	113,531,925	227,063,850	0.776
2	1000	99%	50	125	>1 trillion trillion	Not viable	0
3	50	90%	50	125	29,870	89,610	0.536
3	100	95%	50	125	1,644,396	4,933,188	0.632
3	1000	99%	50	125	4.56232E+13	1.36869E+14	0.784

Predicted probability of persistence with at least one individual remaining using the initial population size in 1960

# of Metapops.	# of Years Population Should Persist	Desired Probability of Persistence	N_e	N_o	MVP	Probability of Persistence
1	37	99%	1	37	409,586,655	0.368

We discovered that using the program INMAT2AC would not work with our data due to the butterfly's life history. The Bay checkerspot butterfly only lives one year, and therefore, there are no overlapping generations, a key assumption of the INMAT2AC program. Due to this fact, we only analyzed the data using STOCHMVP.

DISCUSSION AND CONCLUSIONS

The lambda values calculated for each area are both slightly greater than one, meaning that the populations are slightly increasing. However the low infinitesimal mean growth rate (μ) values of 0.0905 for Area C and 0.0609 for Area H predispose the populations to low or negative growth rates, as does the high values of variance (σ^2) around that μ. The σ^2 values were 1.22728 for Area C and 2.35289 for Area H.

Our results from the STOCHMVP model show that the minimum viable population estimates for these populations are unrealistic given the habitat constraints and stochastic events. For Area C to have a 95% probability of persistence for 100 years, the minimum viable population size is between 129,415,830 and 258,762,427 individuals, based on 50 and 100 individual lower thresholds for extinction, respectively. For it to have a 99% probability of persistence for 1000 years, the minimum viable population size is over one trillion trillion individuals for both lower threshold values. With the initial population size of 385 individuals which occurred in 1980, our final year of analysis, the probability of persistence ranged from only 0.18 and 0.337. This is not viable for a continued population. The same general scenario occurred in Area H, with MVPs ranging from 256,247,348 to over one trillion trillion individuals. The probabilities of persistence from the 1980 data range between 0.012 and 0.091. These are even lower than the values estimated for Area C. This is probably due to the smaller size of Area H.

We also considered whether the addition of metapopulations to each population would increase the probability of persistence and decrease the MVP. The data showed that adding metapopulations did do this; however, it is not probable that more than one metapopulation exists in each area due to their small size (9.8 and 2.55 ha). In Area C, the probability of persistence with metapopulations increased to the range of 0.536 to 0.9. In Area H, it ranged from 0 to 0.784 probability of persistence. While these values are higher, the habitat is probably not sufficient to support over one population (Harrison 1989). These populations are instead better suited to be sink populations with periodic re-colonizations. This is more in line with the true dynamics of the population.

The persistence of a population has been linked to its proximity to a large reservoir population, such as that at Edgewood Park, a reserve approximately 50 miles south of the JRBP. These reservoir populations act as source populations that periodically supplement the populations in the sink populations. The Edgewood Park reservoir population consists of approximately 100 ha, an order of magnitude larger than Areas C and H (Murphy *et al*. 1990). Therefore, it is concluded that Areas C and H are not large enough to support viable long-term populations. However, they are important as they can be used as stepping stones to colonize populations further from the reservoir population. A problem with this scenario is that it has been discovered that the butterflies are poor colonizers and dispersers (Harrison 1989). If populations did reestablish at the JRBP, they would contribute to increased genetic diversity in the subspecies. But, the likelihood of long-term population persistence there is low.

When conducting our literature search, it was discovered that recent research has advocated using managed grazing to improve butterfly habitat. The cattle forage more on the grasses than the forbs, and therefore tend to eat the non-native vegetation and leave the native vegetation. The large amounts of nitrogen deposition due to increased air pollution on the typically nitrogen-deficient soil allow non-native species to invade the serpentine soils (Weiss 1999). This causes increased hardship on butterfly survival.

The transplanting of butterflies has previously been undertaken with limited success. Only 25% of butterflies persisted after one year (Harrison 1989). This low rate of success leads to the conclusion that translocation of butterflies is not very feasible, nor is captive breeding.

Even if the species could be bred successfully, there is such a low rate of success in transplanting that the endeavor would not be worthwhile. The most success occurs through natural dispersal, and therefore, large reservoir populations must survive to supplement the sink populations, such as those at the JRBP. Also, large populations allow for major fluctuations in population levels. As it can be seen in Figure 2, butterfly populations fluctuated as much as 2000 individuals in one year. This is probably due to the fact that their lifespan is only one year long, and the population size the next year is dependent on many stochastic factors affecting the various larval stages.

Most of our assumptions for the population were violated by the data that resulted. The minimum viable population sizes estimated are not viable given the habitat size available at the JRBP. They would not be viable unless extremely large habitat areas were available, and with the dispersed distribution of the serpentine soils, this is not probable. Therefore, it is important to preserve habitat patches throughout their range to assist with the long-term viability of the species. Also, another assumption is that stochastic events do not cause populations to go extinct. In the case of the butterfly, their life history is extremely dependent on the weather for emergence, plant availability, and ease of dispersal. Therefore, this assumption is also not true. There is variation in the accuracy in the population counts throughout the various years. However, these discrepancies have been eliminated as much as possible by data cleaning (Hellmann *et al.* in press). We can assume that there is no density dependence in the population as there are always such small numbers of butterflies in Areas C and H. The downward trends in the population do appear to be long term. The Bay checkerspot butterfly is on the path to extinction.

LITERATURE CITED

Ehrlich, Paul R., and Dennis D. Murphy. 1987. Conservation Lessons from Long-Term Studies of Checkerspot Butterflies. Conservation Biology 1: 122-131.

Federal Register. Endangered and Threatened Wildlife and Plants; Final Determination of Critical Habitat for the Bay Checkerspot Butterfly (*Euphydryas editha bayensis*), 66 (83). 30 April 2001.

Harrison, Susan. 1989. Long-Distance Dispersal and Colonization in the Bay Checkerspot Butterfly, *Euphydryas editha bayensis*. Ecology 70: 1236-1243

Hellmann, Jessica J., Stuart B. Weiss, John F. Mclaughlin, Carol L. Boggs, Paul R. Ehrlich, Alan E. Launer, and Dennis D. Murphy. Do hypotheses from short-term studies hold in the long-term? An empirical test. In press.

Murphy, Dennis D., Kathy E. Freas, and Stuart B. Weiss. 1990. An Environment-metapopulation Approach to Population Viability Analysis. Conservation Biology 4: 41-50.

Singer, Michael C. 1972. Complex Components of Habitat Suitability within a Butterfly Colony. Science 7: 75-77.

Weiss, Stuart B. 1999. Cars, Cows, and Checkerspot butterflies: Nitrogen Deposition and Management of Nutrient Poor Grassland for a Threatened Species. Conservation Biology 13: 1476-1486.

APPENDIX 1

Female Population Counts in Areas C and H

Year	Area C	Area H
1960	63	37
1961	82	128
1962	40	394
1963	37	1427
1964	175	1400
1965	200	2000
1966	425	1750
1967	425	900
1968	800	576
1969	457	955
1970	713	820
1971	188	40
1972	1371	733
1973	933	250
1974	272	72
1975	1756	94
1976	3789	2316
1977	279	171
1978	165	79
1979	307	211
1980	385	125
1981	1492	228
1982	678	84
1983	1203	11
1984	145	12
1985	107	16
1986	128	17
1987	13	37
1988	6	100
1989	3	85
1990	0	41
1991	0	30
1992	0	24
1993	0	10
1994	0	3
1995	0	9
1996	0	0
1997	0	4
1998	0	0

Grey highlighting indicates when the population was considered extinct.