

Loss of Diversity as a Consequence of Habitat Destruction in California Vernal Pools

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ABSTRACT. Habitat destruction often results in the loss of biodiversity in natural communities. Vernal pools are a feature of California's native landscape which have been heavily impacted over the past century by agricultural and urban development. Current estimates of vernal pool losses in the Central Valley range from 50-85% of pre-settlement acreages. In this paper I apply data from recent field surveys of vernal pool crustacean assemblages to a model developed by Koopowitz et al. (1994) in order to investigate the potential magnitude of species extinctions and loss of biodiversity resulting from the conversion of vernal pool habitats by human activities in the Central Valley. Based on observed species distribution profiles and habitat loss estimates of 50-85%, the model predicts that 15% to 33% of the original biodiversity of Central Valley vernal pool crustaceans has been lost since the 1800's. The high rate of extinction expected to result from loss of vernal pools is due to the large proportion of species which are sporadic in distribution and relatively rare in occurrence. These results suggest that, although a handful of vernal pool crustaceans are currently federally listed as Threatened or Endangered, it is likely that many other less conspicuous species are also in danger of extinction. It is critical that the nature of species distribution patterns be used to develop policies aimed at adequate levels of vernal pool habitat preservation, and that mitigation efforts such as the creation of artificial pools ensure the maintenance of species which are rare endemics.

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INTRODUCTION

Destruction of natural habitats is the primary reason for the existing worldwide trend of decreasing biodiversity (Ehrlich, 1988). As human populations grow at ever-accelerating rates, an increasing proportion of the land which supports ecological communities is converted for agriculture, urban development, or other human activities. The degree to which habitat loss translates into biodiversity loss (i.e., loss of species due to extinctions) often depends largely upon two factors: the relative amount of habitat converted over time and the nature of species distributions among patches of the habitat. For example, species which are widespread, common, and occur in a large fraction of habitat patches are less likely to be threatened with extinction due to habitat loss than are species which are endemic, rare, and occur in only a small fraction of patches.

Vernal pools are one feature of California's natural heritage that has suffered extensive habitat destruction over the past century. Until recently, however, the kinds of data necessary to assess the implications of this habitat loss in terms of invertebrate species extinctions and threats to vernal pool faunal diversity were lacking. Recent field surveys and detailed taxonomic work on vernal pool crustaceans in California have revealed extraordinarily diverse and highly endemic species assemblages

(Simovich, 1998; King et al., 1996). An important finding of these studies is that many vernal pool crustacean species are sporadic and rare in occurrence. In a survey of 58 pools distributed among 14 sites in one region of California's Central Valley, over a quarter of the species (18 out of 67 species) had only a single pool occurrence, and 40% of the species (27 out of 67) had only a single site occurrence (King et al., 1996). This same study found that the average species was present in only 12% of the pools surveyed. The species distribution profile drawn from these data is heavily skewed toward species which are relatively rare in occurrence (Figure 1). Therefore, we might expect vernal pool assemblages to be particularly susceptible to species extinctions as a result of habitat loss.

In this paper I employ a stochastic model developed by Koopowitz et al. (1994) to investigate the potential impact of habitat destruction on the diversity of crustacean assemblages in Central Valley vernal pools. The model uses observed species distribution profiles and estimated rates of habitat loss to predict the number of species extinctions expected as random patches of habitat are lost over time. Results of the model simulation can be used to estimate the magnitude of past extinctions, as well as to predict future extinction rates, as a function of the fraction of habitat converted.

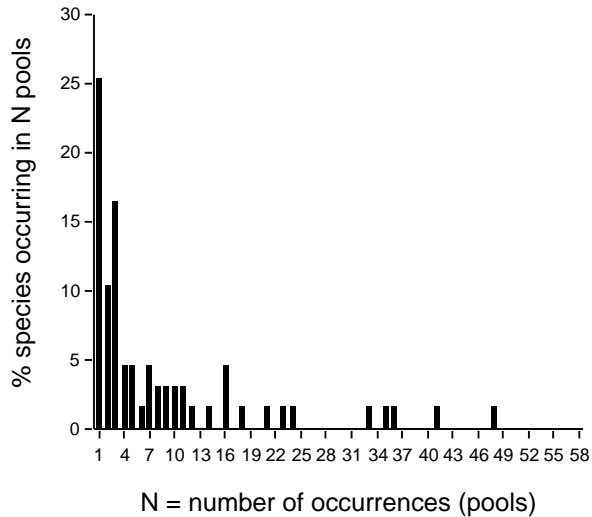


FIGURE 1: Species distribution profile for crustaceans in 58 vernal pools in California's Central Valley (redrawn from King et al., 1996).

METHODS

The Model

The Koopowitz et al. (1994) model operates by randomly assigning hypothetical species to squares within a grid according to a specified species distribution profile. Each square within the grid represents a patch of habitat, or a single pool in the case of the vernal pool system. Species distribution profiles are represented in the model by a series of bin values, where the value of a given bin is the proportion of species occurring in a certain number of habitat patches. The beginning bin values are obtained from field survey data, but bin values change as the model runs due to the changing distribution of species as patches of habitat (and their occupants) are eliminated. The model simulates successive bouts of stochastic habitat destruction using any prescribed rate of habitat loss, keeping track of changing bin values and extinctions that result from each round of habitat destruction.

Assumptions and Data

The model relies upon a number of assumptions which are detailed in Koopowitz et al. (1994). In general, the discrete nature of vernal pool habitats makes them ideally suited for the application of this model (Koopowitz, pers. comm.), and most of the model's assumptions seem reasonable for the purposes of this analysis and do not warrant elaboration here. Violation of certain of these assumptions, such as the assumption that all habitat types are converted equally, could mean that extinction rates in some regions or certain habitat types are actually higher or lower than predicted by the model. However, such violations

would not invalidate the model's general result which is meant to be a rough estimate of species losses averaged across Central Valley vernal pools.

The most critical assumption is that the species distribution estimates are representative of reality. The data I used to run the model are from a survey of crustacean species in vernal pools along a 200 km north-south transect through the upper to middle Central Valley (King et al., 1996). Strengths of this dataset are that it includes pools of several different vernal pool habitat types (i.e., northern volcanic mudflow, northern claypan, and northern hardpan), it contains information from whole assemblages of crustaceans, and it was compiled with reliable species identifications provided by taxonomic specialists. The high quality of this database, in conjunction with the fact that it is the only published dataset which contains species distribution data across different habitat types and reasonably large spatial scales, makes this database our best source for species distribution profiles of vernal pool crustaceans at the present time.

From this database I calculated beginning values for 25 bins (see Table 1). I then ran the model until all squares in the habitat grid were gone to obtain a predicted species extinction curve across all levels of habitat loss from 0 to 100%. To see how the extinction curve predicted by the model would change if vernal pool crustacean assemblages contained a high proportion of common species (as opposed to the actual case of many rare species), I also ran the model using the reverse of the actual series of bin values (i.e., values for bins 1-25 were reassigned to bins 25-1).

RESULTS

The percentage of crustacean species predicted by the model to be extinct at various levels of vernal pool habitat loss are shown in Table 2 and Figure 2. Results for the hypothetical scenario, where the species distribution profile is the reverse of reality, are shown in Figure 3.

DISCUSSION

There has been much debate about the amount of vernal pool habitat that existed in pre-settlement times and how much has been lost up to the present-day. Many sources use the early to mid-1800's as a starting point in the calculation of vernal pool losses, since this is when widespread conversion of seasonal wetlands began in the Central Valley (Frayer et al., 1989; Kreissman, 1991). Estimates of vernal pool habitat loss since pristine times include 66% (Kreissman, 1991) and 60-85% (Holland, 1978 with minor calculation corrections given in Federal Register, 1994). More conservative estimates around 50% have also been made, although not in the published literature. According to the predictions of this model, habitat losses from 50-85% mean that between 15% and 33% of the original crus-

LOSS OF DIVERSITY AS A CONSEQUENCE OF HABITAT DESTRUCTION

TABLE 1. Bin values used to run the model, taken from the distribution profile of crustacean species in northern California vernal pools (from King et al., 1996). Values are calculated as the proportion of species having the number of pool occurrences indicated by the bin number, except for Bin #25 which includes all species occurring in ≥ 25 pools. For example, 17 out of a total of 67 species occurred in only 1 of the surveyed pools, therefore, the value for Bin #1 is 0.2537.

Bin #	Value
1	0.2537
2	0.1045
3	0.1642
4	0.0448
5	0.0448
6	0.0149
7	0.0448
8	0.0299
9	0.0299
10	0.0299
11	0.0299
12	0.0149
13	0.0000
14	0.0149
15	0.0000
16	0.0448
17	0.0000
18	0.0149
19	0.0000
20	0.0000
21	0.0149
22	0.0000
23	0.0149
24	0.0149
25	0.0745

tacean species in Central Valley vernal pools may have already gone extinct due to habitat destruction (Figure 2, Table 2). Additionally, the model shows that extinction accelerates as habitat destruction proceeds. If the true amount of habitat lost to date is at the upper end of the estimated range, vernal pool habitats are now at the most rapidly rising portion of the extinction curve.

Approximately half of the crustacean species found in Central Valley vernal pools appear to be vernal pool endemics, while the others have also been reported from other freshwater habitats such as permanent ponds, lakes, rivers or streams (King et al., 1996). Because the species which are limited to vernal pools also tend to be rare in occurrence and sporadic in distribution, these endemics are more likely to go extinct than are more widely-occurring species. Therefore, the components of diversity unique to vernal pools could be almost completely gone once the extinction curve in Figure 2 reaches 50% on the vertical axis.

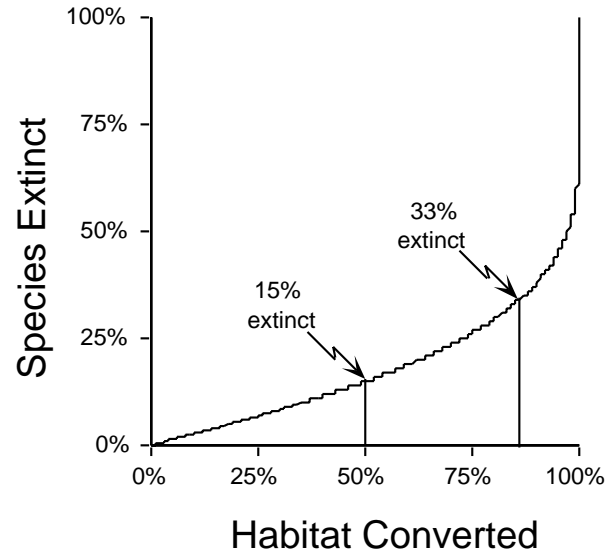


FIGURE 2. Fraction of species extinct versus fraction of habitat converted, based on model predictions using the data in Table 1.

The shape of the species extinction curve is dependent only upon the assumptions of the model and the species distribution profile. What would the extinction curve look like if the species distribution profile were exactly the opposite, in other words, if most species occurred in many, rather than few, pools? Given a species distribution profile which is the reverse of reality, the model predicts that relatively few extinctions would occur until a large amount of habitat is converted (Figure 3). For example, under this hypothetical scenario conversion of 85% of the habitat would result in only 8% of species going extinct, whereas 33% of species would be extinct at the same amount of habitat loss under the actual profile (Figures 2 and 3).

The observation that a large proportion of vernal pool crustacean species seem to be narrow endemics which occur sporadically and relatively rarely leads to the conclusion that a number of vernal pool species may already be extinct as a result of conversion of vernal pool habitats in the Central Valley. In southern California where habitat losses are estimated to be as high as 97% (Bauder and Wier, 1990), the loss of diversity due to the extinction of locally endemic species is probably even more extreme. Furthermore, although only a handful of vernal pool crustacean species are now federally listed as Threatened or Endangered, it is likely that many other less conspicuous species are also in danger of extinction. The characteristics of high diversity, high endemism, and limited species distributions which typify vernal pool crustaceans are the same qualities which are correlated with high extinction rates in tropical rainforest species as a result of deforestation (Wilson, 1988). In these types of systems where taxonomically rigorous surveys are lacking and diversity is so high that many species remain

TABLE 2. Output from model run using bin values in Table 1. The model predicts the fraction of species that will go extinct as habitat is destroyed over time.

Fraction of Habitat Converted	Fraction of Species Extinct	Fraction of Habitat Converted	Fraction of Species Extinct
0.01	0.00	0.51	0.15
0.03	0.01	0.53	0.16
0.04	0.01	0.54	0.16
0.05	0.01	0.55	0.17
0.06	0.02	0.57	0.17
0.08	0.02	0.58	0.18
0.09	0.02	0.59	0.19
0.10	0.03	0.60	0.19
0.12	0.03	0.62	0.20
0.13	0.03	0.63	0.20
0.14	0.04	0.64	0.21
0.15	0.04	0.66	0.21
0.17	0.04	0.67	0.22
0.18	0.05	0.68	0.23
0.19	0.05	0.69	0.23
0.21	0.06	0.71	0.24
0.22	0.06	0.72	0.25
0.23	0.06	0.73	0.25
0.24	0.07	0.75	0.26
0.26	0.07	0.76	0.27
0.27	0.07	0.77	0.28
0.28	0.08	0.78	0.29
0.30	0.08	0.80	0.29
0.31	0.09	0.81	0.30
0.32	0.09	0.82	0.31
0.33	0.09	0.84	0.32
0.35	0.10	0.85	0.33
0.36	0.10	0.86	0.34
0.37	0.11	0.87	0.36
0.39	0.11	0.89	0.37
0.40	0.11	0.90	0.38
0.41	0.12	0.91	0.40
0.42	0.12	0.93	0.42
0.44	0.13	0.94	0.43
0.45	0.13	0.95	0.46
0.46	0.14	0.96	0.48
0.48	0.14	0.98	0.52
0.49	0.15	0.99	0.58
0.50	0.15	1.00	1.00

unknown to science, it is clearly impossible at the present time to design management plans that consider every species individually. Additionally, as the model simulation makes clear, certain species distribution profiles will result in the loss of substantial amounts of biodiversity even with intermediate levels of habitat destruction. Therefore, it is critical that the nature of

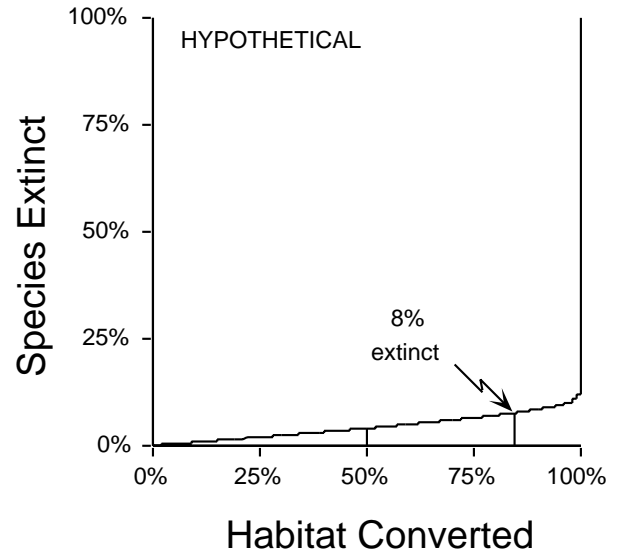


FIGURE 3. Hypothetical scenario. Fraction of species extinct versus fraction of habitat converted, based on model predictions using a species distribution profile which is the reverse of actual data.

species distribution patterns, and the potential for extinction based on those patterns, be addressed in policies aimed at adequate levels of habitat preservation.

Current wetlands policies in the U.S. call for no net loss of vernal pool habitats into the future. A major strategy for achieving no net loss is the construction of artificial vernal pools which are intended to mitigate for the destruction of natural pools (Federal Register, 1995). If created pools maintain the diversity and species distribution profiles of natural pools – particularly if they provide habitat for rare endemics – then the ultimate goal of no net loss (i.e., the preservation of species diversity) will be achieved. However, if constructed vernal pools are not successful in these terms (or if success criteria do not address such key factors as the maintenance of rare endemics), then no net loss will be a fallacy; for some species, habitat loss will continue to occur even though the specified acreages hold water for the prescribed period of time each year. Taxonomically thorough surveys of both natural and artificial pools, and policies which explicitly consider the properties of species distribution profiles, will be necessary to prevent further erosion of the unique and rich biodiversity of California’s vernal pool communities.

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LOSS OF DIVERSITY AS A CONSEQUENCE OF HABITAT DESTRUCTION

LITERATURE CITED

- Bauder, E. and H. Wier. 1990. Vernal pool management plan Naval Air Station Miramar. Prepared by Michael Brandman Associates, San Diego, for Miramar Engineering Field Division.
- Ehrlich, P.R. 1988. The loss of diversity: Causes and consequences. Pages 21-27 *in*: E.O. Wilson (Editor). Biodiversity. National Academy Press. Washington, DC.
- Federal Register. 1994. Endangered and threatened wildlife and plants: Determination of endangered status for the Conservancy fairy shrimp, longhorn fairy shrimp, and the vernal pool tadpole shrimp, and threatened status for the vernal pool fairy shrimp. Federal Register 59(180):48144.
- Federal Register. 1995. Federal guidance for the establishment, use, and operation of mitigation banks. Federal Register 60(228):58605-58614.
- Frayer, W.E., D.D. Peters, H.R. Pywell. 1989. Wetlands of the California Central Valley: Status and Trends. U.S. Fish and Wildlife Service. Portland, OR. 28 pp.
- Holland, R.F. 1978. The geographic and edaphic distribution of vernal pools in the Great Central Valley, California. California Native Plant Society special publication.
- King, J.L., M.A. Simovich, and R.C. Brusca. 1996. Species richness, endemism, and ecology of crustacean assemblages in northern California vernal pools. *Hydrobiologia* 328:85-116
- Koopowitz, H., A.D. Thornhill, and M. Andersen. 1994. A general stochastic model for the prediction of biodiversity losses based on habitat conversion. *Conservation Biology* 8 (2):425-438.
- Kreissman, B. 1991. California: An Environmental Atlas and Guide. Bear Klaw Press: Davis, CA. p 81.
- Simovich, M.A. 1998. Crustacean biodiversity and endemism in California's ephemeral wetlands. Pages 107-118 *in*: C.W. Witham, E.T. Bauder, D. Belk, W.R. Ferren Jr., and R. Ornduff (Editors). Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.
- Wilson, E.O. 1988. The current state of biological diversity. Pages 3-18 *in*: E.O. Wilson (Editor). Biodiversity. National Academy Press. Washington, DC.