POPULATION VIABILITY ANALYSIS FOR THE LEOPARD DARTER (PERCIDAE: *PERCINA PANTHERINA*)

By

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PANTHERINA)

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PREFACE

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CHAPTER II

POPULATION VIABILITY ANALYSIS FOR THE LEOPARD DARTER (PERCIDAE: *PERCINA PANTHERINA*)

ABSTRACT: I used the computer program RAMAS to perform a Population Viability Analysis for the leopard darter, *Percina pantherina*. This percid fish is a federally threatened species confined to five isolated rivers in the Ouachita mountains of Oklahoma and Arkansas. A base model from life-history data indicated a 6% probability that the leopard darter would go extinct in 50 years. After development of this initial model, I performed sensitivity analyses to determine effects of population abundance, variance in age-structure, variance in severity and probability of catastrophes, and migration on viability of the leopard darter. Catastrophes (modeled as the probability and severity of drought) and migration had the greatest effect on persistence. The results of these simulations can be used to guide management decisions for this species.

INTRODUCTION

In this study I used a computer program, RAMAS/GIS (Akcakaya 1994), to perform a population viability analysis (PVA) for the leopard darter, *Percina pantherina*, a federally threatened percid fish endemic to the Little River system of southeastern Oklahoma and southwestern Arkansas (Miller and Robison 1973; U.S. Fish and Wildlife Service 1978). Population viability analysis is considered a keystone paradigm in conservation biology (Boyce 1993). More than 50 PVAs have been performed on various species, ranging from plants to vertebrates (Norton 1995). Population viability analysis uses computer simulation modeling to assess vulnerability to extinction of small populations (Lindenmayer et al. 1993). It is also a useful tool for organizing life-history information for a species and for identifying deficiencies in knowledge (Boyce 1993; Lindenmayer et al. 1993).

Sensitivity analyses can be performed on PVAs to isolate which factors have the greatest effect on persistence (Boyce 1992; Akcakaya and Burgman 1995; Norton 1995). Sensitivity analyses can aid in prioritizing needs for missing information and in evaluating effects of various management options (Seal 1991; Boyce 1992; Norton 1995; Bustamante 1996). The latter is important considering cost and possible consequences of management decisions for

endangered species.

Previous PVAs have incorporated a variety of elements, including basic life-history characteristics such as abundance, fecundity, and survivorship. Also, most PVAs model stochastic variation, usually in terms of variation in demography, environmental parameters, or population genetic considerations (Shaffer 1981; Boyce 1992; Akcakaya et al. 1995). Some PVA models are custom-designed to address specific threats for a particular species (Murphy et al. 1990; Emlen et al. 1993; Emlen 1995). Others are developed from packaged computer programs (Haig et al. 1993; Lacy and Clark 1993; Lindenmayer et al. 1993; Akcakaya et al. 1995; Bustamante 1996; Mills et al. 1996).

The leopard darter is threatened by water quality degradation caused by forest clear-cutting, road construction, environmental contaminants, gravel dredging/mining, and the poultry and swine industries (Eley et al. 1975; Rutherford et al. 1992; James and Collins 1993). In addition, drought seems to have a marked effect on abundance of leopard darters (Toepfer et al. *in prep*), and survival of the species may be affected by global warming trends (Matthews and Zimmerman 1990). The primary factor limiting leopard darter populations appears to be availability of suitable habitat for growth and spawning (James and Collins 1993). Four of the five rivers containing leopard darters are impounded, and a reservoir has been proposed for the remaining unimpounded river in the range of the species (U.S. Army Corps of Engineers 1975).

Interpretations of PVA models have received intense scrutiny (Caughley 1994; Hamilton and Moller 1995; Taylor 1995). Taylor (1995) argues that results of PVA models should not be used to classify status of a species (i.e., endangered, etc.). Akcakaya et al. (1995) argue that PVA is more useful as a tool to organize ecological data and to explore management options than as a tool to make predictions about persistence. Preliminary PVA models are a useful way to formalize our understanding of the status of a species; however, these models are no substitute for field data, some of which may take decades to collect (Boyce 1993; Ruggiero et al. 1994; Akcakaya and Burgman 1995; Hamilton and Moller 1995). Despite these criticisms, the interpretation of results from PVA can be useful if the limitations of the models are fully understood.

METHODS

Study Area

The Little River system is in the Ouachita uplift of Oklahoma and Arkansas. This mountain range consists of east-west oriented valleys and ridges with an average elevation of 150 to 790 m above sea-level. Gradient varies from 4.6 to 7.6 m/km in upper reaches of the rivers. These mountains are composed of Paleozoic sedimentary rock ranging from Cambrian to Pennsylvanian periods. The dominant rock types are sandstone, shale, and novaculite. Rivers in the uplifted area are crooked with irregularly cut hills, producing cliffs and gorges along stream valleys (Fenneman 1938; Robison 1986).

The leopard darter presently occurs as five populations isolated from each other by reservoirs near the tailwaters of their respective streams (Zale et al. 1994; Figure 1). The species occurs primarily in streams with pools of moderate depth (25-108 cm) with cobble/boulder substrata, current velocity near zero, and associated gravel riffles for spawning (James and Maughan 1989).

Data Collection

I used RAMAS/GIS (Akcakaya 1994) to develop a model of population viability for the leopard darter. RAMAS uses a Monte Carlo simulation of age- or lifestage-structured population growth based on Leslie matrices (Leslie 1945; Ferson et al. 1989). RAMAS has been used to model bald eagle population dynamics (Wood and Callopy 1993), Hudson River striped bass populations (Ginzberg et al. 1990), and population viability of the helmeted honeyeater (Akcakaya et al. 1995).

Table 1 shows the variables used in the PVA model, their estimated values, and, where appropriate, standard deviations or 95% confidence intervals. Sex ratios approximate 1:1 for the species (Robison 1978; James 1989). Average fecundity for adults (males and females) was computed as one-half the average ovum count (Robison 1978; James 1989) for adult females. Length-frequency data for leopard darters reveal two age-classes, juveniles (age 0) and adults less than two years old (James 1989). From five years of length-frequency data (James 1989; C. Toepfer and L. Williams *unpubl. data*), I estimated a survivorship (Johnson 1994) from age 0 to age 1 of 0.38 (SD = 0.22) and an age-structure of 86% juveniles and 14% adults (95% CI = 83% juveniles, 17% adults and 89% juveniles, 11% adults).

To estimate population size (N) in Robinson Fork River, I estimated population density at three localities within the river (T4S R32W S21, T4S R32W S32, T5S R32W S4). For estimates of N at each locality, I collected darters with small, hand-held aquarium nets while snorkeling, a method of capture that is more effective for benthic darters when visibility is good than seining or electroshocking (James 1989; Greenberg 1991). Within one hour of capture, I marked individuals dorsolaterally with an injection of colored latex (Hill and Grossman 1987; Northwest Marine, Shaw Island, WA) and released them at the site of capture. This collection effort was repeated on the following two days, during which newly captured individuals were marked and released. Mark-recapture data were pooled across sites. Using area of suitable habitat in each of the three localities and a pooled Schnabel estimate (Lancia et al. 1994), I obtained an estimate of density, with confidence intervals, for the area sampled.

To estimate total area usable by leopard darters in Robinson Fork River, I first mapped meso-habitats (i.e., pools, riffles, runs, etc.) for a 12-km stretch of stream encompassing the range of the species in the river (Zale et al. 1994; pers. observ.). I compiled these data into a Geographic Information System, and, using microhabitat preferences of the species (James and Maughan 1989; Zale et al. 1994), derived an estimate of 70,369 m^2 for area of usable habitat. To represent population size and 95% confidence interval estimates for the entire river, I multiplied the measure of overall density by an estimate of amount of suitable habitat in Robinson Fork River, producing a population size estimate of 4848 (95% CI = 3370-6326).

Mark-recapture studies of population size were also done on leopard darters in tributaries of Glover River and Mountain Fork River (Toepfer et al. *in prep*). I used density esimates for these tributaries, together with the amount of leopard darter habitat in Glover and Mountain Fork Rivers (C. Toepfer *unpubl. data*) to extrapolate density estimates for the entire rivers. For both rivers, density of leopard darters per river-kilometer was multiplied by length of stream occupied by the species, producing estimates of 443,969 for Mountain Fork River (95% CI = 56,849-1,067,544) and 148,547 for Glover River (95% CI = 42,887-254,463).

No estimates of density or habitat availability have been made for populations in the Little and Cossatot rivers. Based on proximity and relative size of drainages occupied, I used density of leopard darters per stream-kilometer in Robinson Fork and Glover rivers to estimate population sizes in, respectively, Cossatot and Little rivers. Multiplying density per kilometer by length of stream occupied produced estimated population sizes of 2284 (95% CI = 1587-2980) for Cossatot River and 178,328 (95% CI = 51,464-305,356) for Little River.

To model effect of catastrophe, I used frequency of drought and the observed effect of a severe drought that extended from fall 1995 to summer 1996. Using hydrograph data from 1962 to 1996 for Glover River, we estimated the probability of a drought as severe as the 1995-96 drought to be six percent in a given year (Toepfer et al. *in prep*). Apparently in response to the drought, abundance of leopard darters decreased by 96% in Robinson Fork River and 33% in Glover River between 1995 and 1996 (Toepfer et al. *in prep*). The effect was not observed for the other three rivers occupied by leopard darters. In summer 1996, flow in Robinson Fork River almost ceased in some areas supporting leopard darters, whereas the other rivers seemed less affected (pers. observ.). On this basis, I used the effect of drought on the Glover River population (33%) for the effect on populations in Little, Cossatot, and Mountain Fork rivers.

The Model

Using estimates for the life-history variables in Table 1, I first derived a base PVA model for the leopard darter (Table 2). Viability was projected over 50 years, and all simulations were performed with 1000 replications.

I then examined robustness of the base model by modeling effects of variation in one or two of the following characteristics at a time: population size, age-structure, probability and severity of catastrophe, and migration. For some variables, I compared effects on the metapopulation with those for the individual populations in Robinson Fork and Glover rivers, the two populations with the most comprehensive data sets.

To examine effect of population size, I performed one PVA using the lower 95% confidence value for abundance of each population and another using the upper 95% confidence value (Table 1). Effect of variance in age-structure was explored using lower and upper confidence values of the estimated age-structure to produce separate PVA models.

To illustrate effect of severity of catastrophe, I constructed one model without catastrophe and one model with total loss (100% reduction) in Robinson Fork River and twice the estimated effect (66% reduction) in the other four populations. I also modeled the effect of increasing probability of catastrophe. For this analysis, the base model with 6% probability of catastrophe was compared to a model with no catastrophe and one with double the probability, 12%.

At present, reservoirs preclude migration among the five leopard darter populations in separate drainages of the Little River system. Therefore, I constructed two additional models to explore how "migration" through human transport would affect metapopulation viability. I modeled effect of an "island-model" migration rate (MacArthur and Wilson 1967, Akcakaya 1994) of one migrant per 10,000 and one per 100,000 individuals in the recipient population. I also examined effect of migration on Robinson Fork River and Glover River separately and compared the results with population viability under the base model for the metapopulation.

I used Komolgorov-Smirnov D-tests (Akcakaya 1994; Sokal and Rohlf 1994) to compare results from each of the derived models with results from the base PVA. Alpha-levels for metapopulation models (Table 2) and individual river models (Table 3) were separately adjusted using the Bonferroni technique to reduce the probability of type-I error (Sokal and Rohlf 1994). This adjustment resulted in alpha-levels of 0.005 and 0.004, respectively, for the metapopulation models and for individual river comparisons.

RESULTS

Trajectories for probability of extinction over 50 years under base conditions with varying severity of catastrophe are shown in Figure 2. The estimated probability of leopard darter extinction in 50 years was 6% (95% CI = 4%-8%) under conditions represented by the base model (Table 2). When severity of catastrophe was doubled, chance of extinction increased to 18% (95% CI = 16%-20%). The chance was 2%(95% CI = 0%-4%) when viability was modeled without any catastrophe. Both of these alternative models differed significantly from the base model ($P < 0.005$; Table 2). Doubling probability of catastrophe from 6% to 12% had no significant effect on viability of the species.

I modeled effect of variance in age-structure by using the 95% confidence interval around the estimated values. This had no detectable effect on population viability.

Models containing either the lower or the upper 95% confidence values for population size did not differ significantly from the base model (Table 2). Extinction trajectories based on upper and lower confidence values for population size under varying levels of catastrophe are shown in Figures 3 and 4. The likelihood of extinction under all models without catastrophe and those with twice the estimated catastrophe differed significantly from the base model. However, there was little difference in probability of extinction between models with the same level of catastrophe, regardless of whether I used the mean or the upper or lower 95% confidence values for population size (Table 2).

Extinction trajectories over 50 years for the base model (no migration) versus models incorporating migration are illustrated by Figure 5. Probability of extinction under the model with a low migration rate (one migrant per 100,000 individuals in the recipient population) did not differ from the probability under the base model (no migration; Table 2). However, with a higher migration rate (1 in 10,000), probability of extinction (5%) was significantly lower than that (6%) predicted by the base model ($p < 0.005$).

Population viabilities for leopard darters in Glover and Robinson Fork rivers are compared with results for the metapopulation in Table 3. For these analyses, I modeled base conditions and effects of severity of catastrophe and migration. Under base model conditions, results for populations in the individual rivers varied little from results for the metapopulation. There was little difference between results for different levels of catastrophe and migration on viability of individual populations as compared with the metapopulation; thus, probability of extinction held constant regardless of whether I modeled the metapopulation or a population from a small (Robinson Fork) or large (Glover) river.

DISCUSSION

Gaston and Lawton (1990) emphasized that adding effects of catastrophe to population models will reduce time of persistence for individual species. Catastrophes will act to make local extinction more common than will local environmental variability (Mangel and Tier 1994). This is especially true for species like the leopard darter, in which individuals live only 18 months or less and have only one reproductive opportunity. Correspondingly, severity of catastrophe had a significant effect on chance of extinction for the leopard darter. Chance of extinction within 50 years tripled from 6% to 18% when the effect of catastrophe was doubled. However, doubling the probability of catastrophe from 6% to 12% did not significantly alter the results. Global warming trends may intensify severity of droughts, reducing habitat availability and increasing physiological stress for individual species (Matthews and Zimmerman 1990). My results indicate that increased severity of drought, through global warming or other means, would significantly affect viability of the leopard darter.

Within the limits I examined, population size seemed to have little effect on probability of extinction for the leopard darter. This insensitivity to population size was little affected by varying severity of catastrophe. In addition, there was no difference in viability between the metapopulation and viability of a small (Robinson Fork River) or a large (Glover River) individual population. These results probably reflect the relatively large population sizes and high fecundity of leopard darters compared with most other species subjected to Population Viability Analysis.

The estimates of population sizes are probably the most questionable data used in my analyses because they depend on the untested assumption that observed local densities can be extrapolated to the entire reach of river occupied by the species. However, the lack of significant difference in viability between the small Robinson Fork population (N = 4848, 95% CI = 3370-6326) and the metapopulation (minimum value for 95% CI = 156,157) indicate that, even if population size estimates are an order of magnitude smaller than estimated, there still would be little effect on viability of the species.

My estimates of fecundity may also be questionable. They were based on egg counts from a single clutch per female. Like many other darter species, leopard darter females may have multiple clutches during the breeding season (Page 1983, James 1989). Thus, my estimates of fecundity may be somewhat low, resulting in an overestimate of probability of extinction. However, this may not be a problem considering that not all of the eggs released by a female will be fertilized and given the large range of fecundities incorporated into the model (Table 1).

Migration had a significant effect on viability of leopard darters. The migration rate of one individual per 100,000 members of the recipient population did not significantly affect viability, whereas one migrant individual per 10,000 significantly reduced probability of extinction (Table 2). Although this model only reduced the likelihood of extinction by 1% (5% versus 6%), it was a significant departure from the base model. Presence of reservoirs precludes migration of individuals from population to population; however, artificial transport of individuals among populations may be a viable management option, both to reduce the risk of extinction and (Meffe and Vrijenhoek 1988) to conserve genetic diversity of the species.

In summary, levels of catastrophe and migration significantly affect leopard darter viability. There was no significant effect of variance in abundance estimates, and I detected little difference between viability of populations in individual rivers and metapopulation viability. Since variance in abundance estimates had little effect on viability, I recommend that monitoring relative abundance at several sites over time would be a more cost-effective management strategy than trying to determine exact densities for the leopard darter in each river. Seasonal monitoring of the species at several stations would yield more detailed information about how the leopard darter responds to fluctuations in water levels. Such monitoring should include at least one site for each of the five river populations. Of particular interest is the Little River population. There have been no studies of density in this population. Thus, while its range is the second-largest of the five species, its abundance is poorly understood.

Overall, it seems that the leopard darter is relatively secure at present. However, like any other localized endemic, the species is vulnerable to adverse effects of a number of land-use practices that could eventually affect viability. In the Ouachita mountains, these primarily include the timber and poultry/swine industries. Future changes in land-use might also affect viability of the species. For example, since 1975, Lukfata Reservoir has been proposed for construction on Glover River. This project would eliminate 25% of the critical habitat designated for the species under the Endangered Species Act (James and Collins 1993). In addition, predictions of extinction probabilities from Population Viability Analyses may represent underestimates because of the potential for unknown effects (Lindenmayer et al. 1993).

LITERATURE CITED

Akcakaya, H.R. 1994. RAMAS/GIS: linking landscape data with population viability analysis. Applied Mathematics, New York.

Akcakaya, H.R., and M. Burgman. 1995. PVA in theory and practice. Conservation Biology **9**:704-710.

Akcakaya, H.R., M.A. McCarthy, and J.L. Pearce. 1995. Linking landscape data with population viability analysis: management options for the helmeted honeyeater *Lichenostomus melanops cassidix*. Biological Conservation **73**:169-176.

Boyce, M.S. 1992. Population viability analysis. Annual Review of Ecology and Systematics **23**:481-506.

Boyce, M.S. 1993. Population viability analysis: adaptive management for threatened and endangered species. Transactions of the 58th North American Wildlife and Natural Resources Conference **58**:520-527.

Bustamante, J. 1996. Population viability analysis of captive and released bearded vulture populations. Conservation Biology **10**:822-831.

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology **63**:215-244.

Eley, R.L., J.C. Randolph, and R.J. Miller. 1975. Current status of the leopard darter, *Percina pantherina*. Southwestern Naturalist **20**:343-354.

Emlen, J.M. 1995. Population viability of the Snake River chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Science **52**:1442-1448.

Emlen, J.M., T.A. Strekal, and C.C. Buchanan. 1993. Probabilistic projections for recovery of the endangered Cui-ui. North American Journal of Fisheries Management **13**:467-474.

Fenneman, N.M. 1938. Physiography of Eastern United States. McGraw Hill Book Co., Inc., New York and London.

Ferson, S., L. Ginzburg, and A. Silvers. 1989. Extreme event risk analysis for age-structured populations. Ecological Modeling **47**:175-187.

Gaston, K.J., and J.H. Lawton. 1990. The population ecology of rare species. Journal of Fish Biology **37A**:97-104.

Ginzberg, L.R., S. Ferson, and H.R. Akcakaya. 1990. Reconstructability of density dependence and the assessment of extinction risks. Conservation Biology **4**:63-70.

Greenberg, L.A. 1991. Habitat use and feeding behavior of thirteen benthic stream fishes. Environmental Biology of Fishes **31**:389-401.

Haig, S.M., J.R. Belthoff, and D.H. Allen. 1993. Population viability analysis for a small population of red-cockaded woodpeckers and an evaluation of enhancement strategies. Conservation Biology **7**:289-301.

Hamilton, S., and H. Moller. 1995. Can PVA models using computer packages offer useful conservation advice? Sooty shearwaters *Puffinus griseus* in New Zealand as a case study. Biological Conservation **73**:107-117.

Hill, J., and G.D. Grossman. 1987. Effects of subcutaneous marking on stream fishes. Copeia **1987**:492-495.

James, P.W. 1989. Reproductive Ecology and Habitat Preference of the Leopard Darter, *Percina pantherina*. Unpubl. Ph.D. dissertation, Oklahoma State University, Stillwater, OK.

James, P.W. and O.E. Maughan. 1989. Spawning behavior and habitat of the threatened leopard darter, *Percina pantherina*. Southwestern Naturalist **34**:298-301.

James, P.W., and K.D. Collins. 1993. Leopard Darter *Percina pantherina* (Moore and Reeves) Revised Recovery Plan. U.S. Fish and Wildlife Service, Albequerque, New Mexico.

Johnson, D.H. 1994. Population analysis. Pages 419-444 in T.A. Bookhout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland.

Lacy, R.C., and T.W. Clark. 1993. Simulation modeling of american marten (*Martes americana*) populations: vulnerability to extinction. Great Basin Naturalist **53**:282-292.

Lancia, R.A., J.D. Nichols, and K.H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 in T.A. Bookhout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland.

Leslie, P.H. 1945. On the use of matrices in certain population mathematics. Biometricka **33**:183-212.

Lindemayer, D.B., T.W. Clark, R.C. Lacy, and V.C. Thomas. 1993. Population viability analysis as a tool in wildlife conservation policy: with reference to Australia. Environmental Management **17**:745-758.

MacArthur, R.H. and E.O. Wilson. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

Mangel, M., and C. Tier. 1994. Four facts every conservation biologist should know about persistence. Ecology **75**:607-614.

Matthews, W.J., and E.G. Zimmerman. 1990. Potential effects of global warming on native fishes of the southern Great Plains and the southwest. Fisheries **15**:26-32.

Meffe, G.K., and R.C. Vrijenhoek. 1988. Conservation genetics in the management of desert fishes. Conservation Biology **2**:157-169.

Miller, R.J. and H.W. Robison. 1973. The Fishes of Oklahoma. Oklahoma State University Press, Stillwater, OK.

Mills, L.S., S.G. Hayes, C. Baldwin, M.J. Wisdom, J. Citta, D.J. Mattson, and K. Murphy. 1996. Factors leading to different viability predictions for a grizzly bear data set. Conservation Biology **10**:863-873.

Murphy, D.D., K.E. Freas, and S.B. Weiss. 1990. An environmental-metapopulation approach to population viability analysis for a threatened invertebrate. Conservation Biology **4**:41-51.

Norton, T.W. 1995. Introduction. Biological Conservation **73**:91.

Page, L.M. 1983. Handbook of Darters. T.F.H. Publications, Inc., Neptune City, New Jersey.

Robison, H.W. 1978. The Leopard Darter (A Status Report). Endangered Species Report No. 3. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Robison, H.W. 1986. Zoogeographic implications of the Mississippi River basin. Pages 267-286 in C.H. Hocutt and E.O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York.

Ruggiero, L.F., G.D. Hayward, and J.R. Squires. 1994. Viability analysis in biological evaluations: concept of population viability analysis, biological population, and ecological scale. Conservation Biology **8**:364-372.

Rutherford, D.A., A.A. Echelle, and O.E. Maughan. 1992. Drainage-wide effects of timber harvesting on the structure of stream fish assemblages in southeastern Oklahoma. Transactions of the American Fisheries Society **121**:716-728.

Seal, U.S. 1991. Life after extinction. Symposium of the Zoological Society of London **62**:39-55.

Shaffer, M.L. 1981. Minimum population sizes for species conservation. Bioscience **31**:131-134.

Sokal, R.R., and F.J. Rohlf. 1994. Biometry. W.H. Freeman and Company, New York.

Taylor, B.L. 1995. The reliability of using population viability analysis for risk classification of species. Conservation Biology **9**:551-558.

Toepfer, C.S., L.R. Williams, W.L. Fisher, and A.A. Echelle. *In prep.* Factors influencing abundance of the threatened leopard darter. *To be submitted to* Copeia.

U.S. Army Corps of Engineers. 1975. Environmental Statement, Lukfata Lake, Glover Creek, Oklahoma. U.S. Army Corps of Engineers, Tulsa District, Tulsa, OK.

U.S. Fish and Wildlife Service. 1978. Final threatened status and critical habitat for the leopard darter. Federal Register **43**:3711-3716.

Wood, P.B., and M.W. Callopy. 1993. Effects of egg removal on bald eagle productivity in northern Florida. Journal of Wildlife Management **57**:1-9.

Zale, A.V., S.C. Leon, M. Lechner, O.E. Maughan, M.T. Ferguson, S. O'Donnell, B. James, and P.W. James. 1994. Distribution of the threatened leopard darter, *Percina pantherina* (Osteichthyes: Percidae). Southwestern Naturalist **39**:11-20.

Table 1. Life-history variables and data used in PVA models.

Variable	Value
Migration	0
Number of life-stages	2
Fecundity	
Age 0	0
Age 1[a]	233 ± 90
Survivorship	
Age 0	0.38 ± 0.22
Age 1	0
Age structure proportions (95% CI)	
Age 0	0.86 (0.83-0.89)
Age 1	0.14 (0.11-0.17)
Mean initial population size (95% CI)	
Robinson Fork River	4848(3370-6326)
Cossatot River	2284(1587-2980)
Mountain Fork River	443,969(56,849-1,067,544)
Glover River	148,547(42,887-254,463)
Little River	178,328(51,464-305,356)
Catastrophe effect[b]	
Robinson Fork	P = 0.06, Reduction = 96%
Other Rivers	P = 0.06, Reduction = 33%

[a] one-half the average for females = fecundity of the the population (males + females).

[b] p = probability of catastrophe in a given year; reduction is effect on population size (see text).

Table 2. Probability of extinction of leopard darter in 50 years under varying severity of catastrophe[a], migration rate[b], and population abundance[c]. Asterisks signify significant deviation from the base model, with estimated abundance and level of catastrophe.

	Catastrophe Effect		
Model	Estimated	Twice estimated	None
Base	0.06 ± 0.02	0.18 ± 0.02*	0.02 ± 0.02*
Low Migration	0.06 ± 0.02		
High Migration	0.05 ± 0.02*		
Lower Abundance	0.06 ± 0.02	0.16 ± 0.02*	0.03 ± 0.02*
Upper Abundance	0.05 ± 0.02	0.18 ± 0.02*	0.04 ± 0.02*

[a] Estimated catastrophe effect = 96% reduction for Robinson Fork River and 33% reduction for other rivers. Twice estimated = 100% reduction for Robinson Fork and 66% for other rivers.

[b] Low migration = 1 in 100,000 migrant per individuals in recipient population. High migration = 1 in 10,000.

[c] Abundance estimates for base model are mean estimates. Lower abundance = lower 95% CI value. Upper abundance = upper 95% CI value.

Table 3. Probability of extinction of leopard darter in 50 years under varying levels of catastrophe (i.e. drought). This table includes metapopulation results along with results from Glover and Robinson Fork Rivers. See Table 2 for explanation of migration rates and effects of catastrophe. Asterisks signify significant deviation from the base model, with estimated abundance and level of catastrophe.

	Catastrophe Effect		
Model	Estimated	Twice estimated	None
Base (Metapopulation)	0.06	0.18*	0.02*
Robinson Fork	0.06	0.17*	0.03*
Glover	0.05	0.16*	0.02*
Low Migration			
Metapopulation	0.06		
Robinson Fork	0.06		
Glover	0.06		
High Migration			
Metapopulation	0.05*		
Robinson Fork	0.05*		
Glover	0.05*		

Figure 1. The Little River system in Oklahoma and Arkansas. The numbers denote specific rivers (1 = Little River, 2 = Glover River, 3 = Mountain Fork River, 4 = Robinson Fork River, 5 = Cossatot River). Shaded areas correspond to current distribution of the leopard darter within the Little River system. Within the shaded areas, the species occurs in the illustrated streams, and not in smaller tributaries.

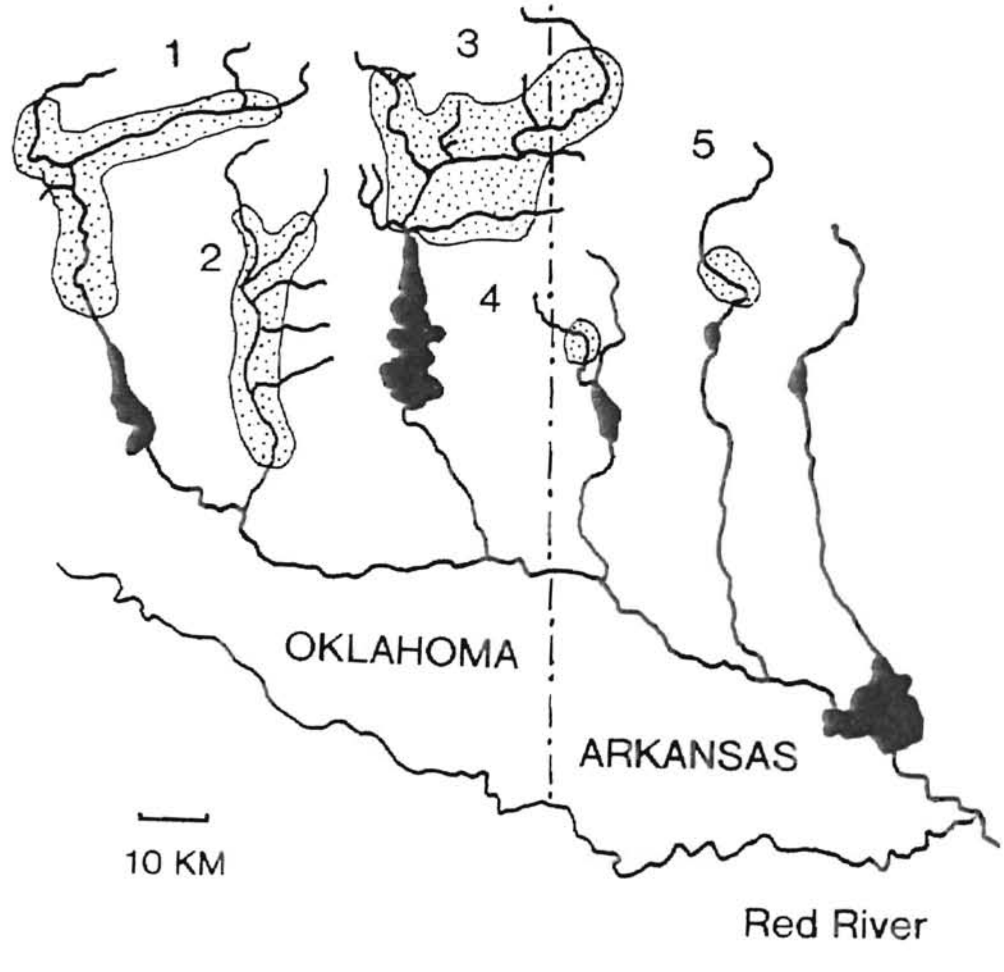
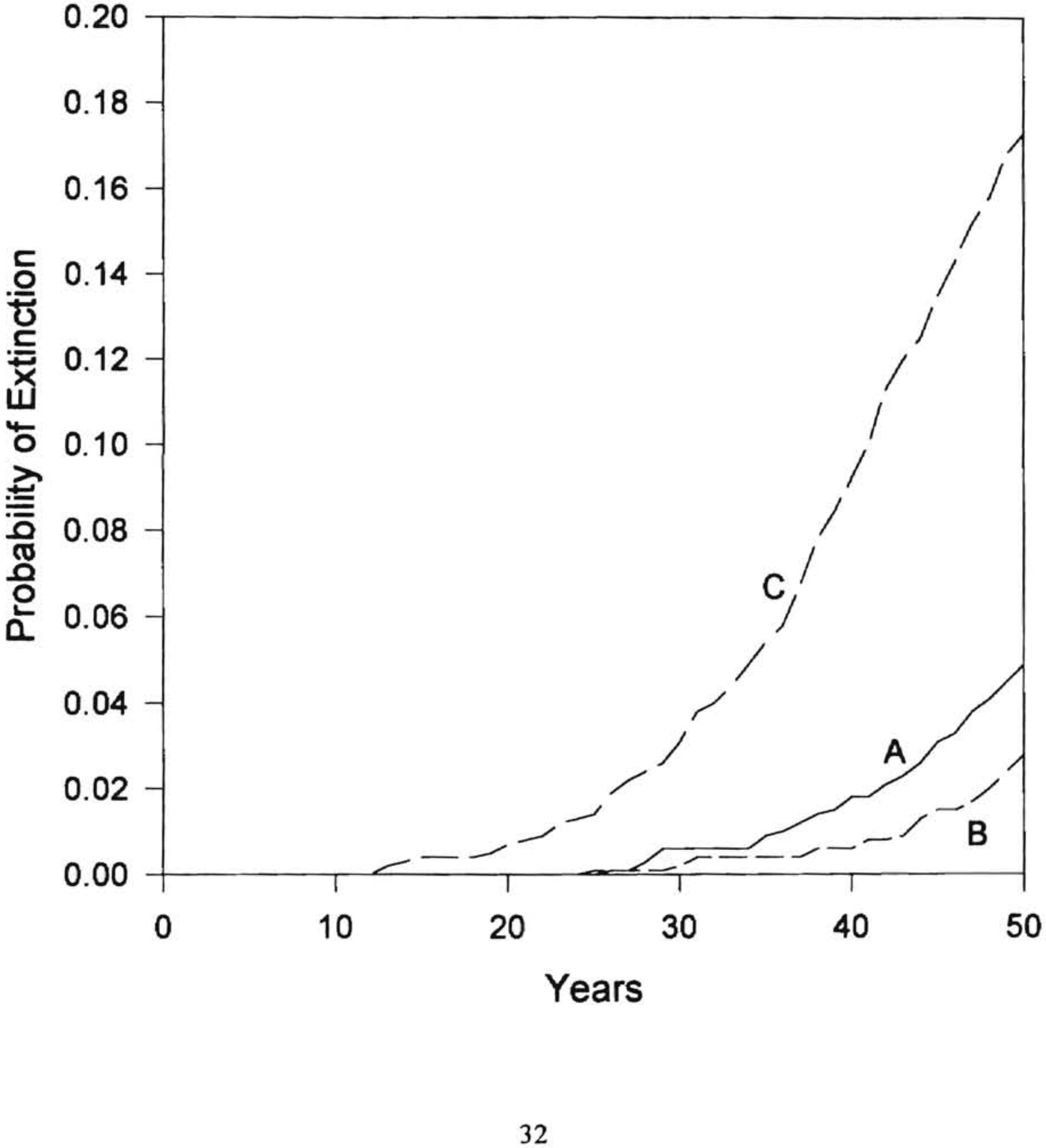
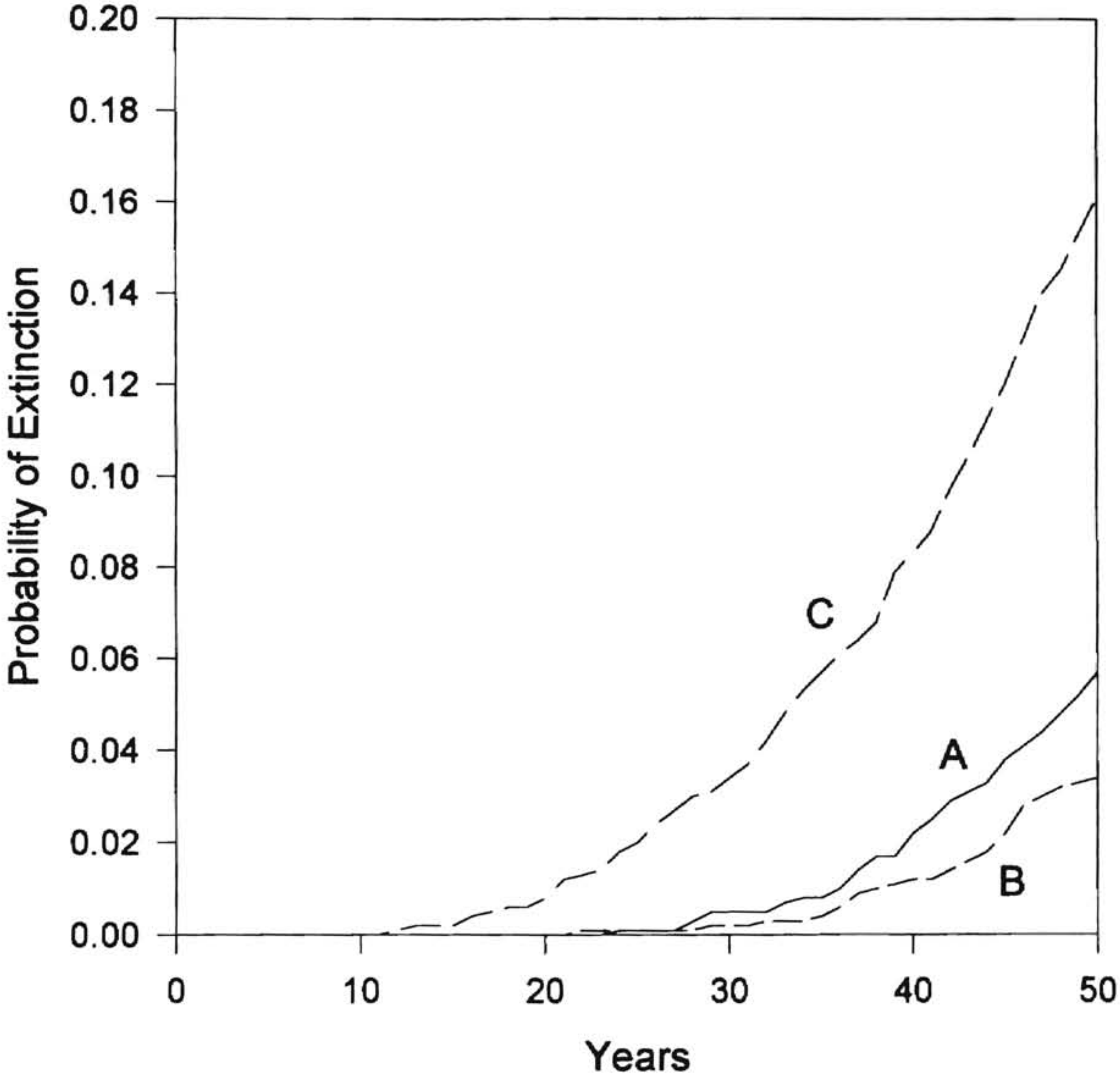

1
3
5
2
4
OKLAHOMA
ARKANSAS
10 KM
Red River

Figure 2. Effect of varying levels of catastrophe on probability of extinction of leopard darters over 50 years in PVA models incorporating mean population sizes. A = estimated effect of catastrophe (Table 1), B = no catastrophe, C = twice the estimated effect.



Probability of Extinction
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40
50
Years
C
A
B

Figure 3. Effect of varying levels of catastrophe on probability of extinction of leopard darters over 50 years in PVA models incorporating lower 95% confidence values for population size. A = estimated effect of catastrophe (Table 1), B = no catastrophe, C = twice the estimated effect.



Probability of Extinction
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40
50
Years
C
A
B

Figure 4. Effect of varying levels of catastrophe on probability of extinction of leopard darters over 50 years in PVA models incorporating upper 95% confidence values for population size. A = estimated effect of catastrophe (Table 1), B = no catastrophe, C = twice the estimated effect.

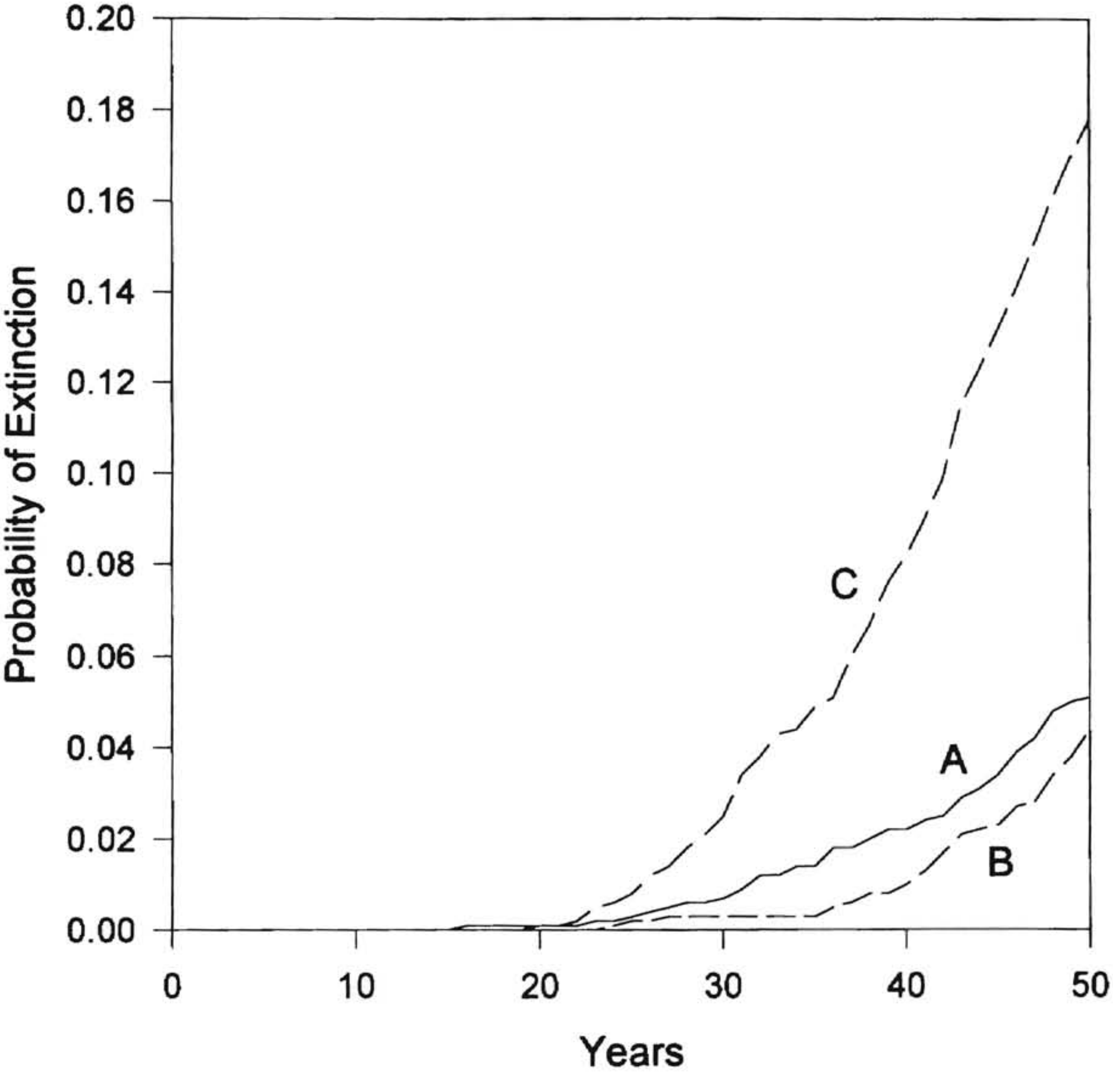
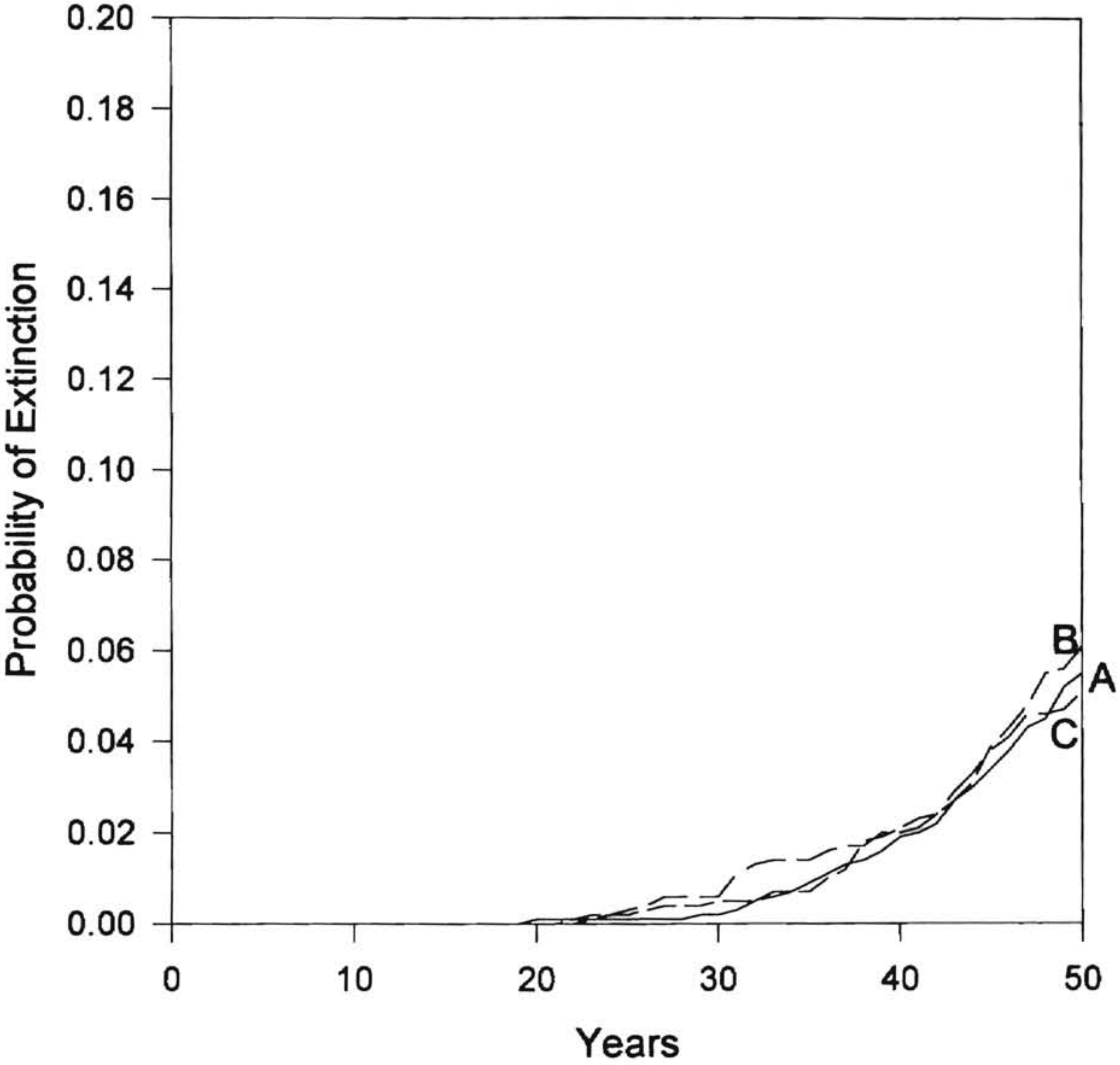

0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Probability of Extinction
C
A
B
0
10
20
30
40
50
Years

Figure 5. Effect of varying levels of migration on probability of extinction of leopard darters over 50 years. A = no migration, B = migration of 1 in 100,000 individuals, C = migration of 1 in 10,000.


0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Probability of Extinction
0
10
20
30
40
50
Years
B
A
C

VITA

Lance R. Williams

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Master of Science

Thesis: POPULATION VIABILITY ANALYSIS FOR THE LEOPARD DARTER (PERCIDAE: *PERCINA PANTHERINA*)

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