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Preliminary analysis of fisher population viability in the southern Sierra Nevada

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INTRODUCTION

Fisher Conservation Status in the Sierra Nevada

During the early 20th century, the fisher (*Martes pennanti*) occurred throughout forested regions of the Sierra Nevada, Klamath Mountains and North Coast Ranges of California (Grinnell *et al.* 1937). Since this time the species has experienced a substantial reduction in geographic range and currently occurs as 2 populations, one occupying the Klamath Mountains and Coast Ranges of Humboldt and Del Norte counties, and one occurring from Yosemite National Park south to the southern extent of the Sierra Nevada in Kern County (Zielinski *et al.* 1995). This range reduction is probably due to a combination of factors including: legal trapping in the first half of the 20th century and occasional incidental trapping since 1954, timber harvest and associated road building, growth of communities within the forest matrix, development of trans-Sierran highways, increased recreational use of the Sierra Nevada and porcupine poisoning campaigns conducted during the 1950s and 1960s. Fishers use large diameter trees and snags as rest structures (Zielinski *et al.* in prep.); features which are best represented in old forest ecosystems.

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Consequently, the decrease during the last century in the average size of trees in the Sierra (McKelvey and Johnston 1992) and the reduction in area of old forest conditions (Franklin and Fites-Kaufmann 1996) are assumed to have negatively affected fisher habitat suitability. Accordingly, vegetation management and habitat planning are two tools available to address the conservation of fishers in the Sierra Nevada.

Several factors currently put the Sierra Nevada fisher population at risk of extinction:

1. **population size.** Although no population size estimates have been published, the population is likely to be no less than 100 and probably no more than 500 individuals.
2. **population isolation.** Fishers in the southern Sierra Nevada appear to be isolated from those in northern California by >350 linear km (Zielinski et al. 1995 and W.J. Zielinski, unpublished data). This distance exceeds the maximum observed dispersal distance for fishers, ~100 km (Arthur *et al.* 1993, York 1996).
3. **habitat / landscape specificity.** Recent surveys have detected fishers from Yosemite National Park south through the Greenhorn Mountains in a variety of habitats ranging from low elevation mixed chaparral habitats on the fringe of the forest matrix into red fir forests. However, most detections have occurred in mid-elevation habitats including montane hardwood, montane hardwood-conifer, mixed conifer and ponderosa pine forests. Radio-telemetry research conducted on Sequoia National Forest has suggested these mid-elevation forests have large trees and logs needed for denning and resting (Zielinski et al., in prep) as well as a diverse prey base (Zielinski *et al.* 1998). The combination of timber harvest and fire suppression during the 20th century has resulted in

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a greater prevalence of small diameter trees throughout the Sierra Nevada (McKelvey and Johnston 1992).

Although higher elevation habitats (i.e., red fir forests) may provide ample structures for denning and resting, deep snow during the winter months likely impedes fisher mobility (Krohn *et al.* 1995); as a result, these forests are of less value to fisher than mid-elevation habitats where snow cover is sporadic and rarely deep for extended periods. Lower elevation habitats in the southern Sierra Nevada (chaparral and woodlands) lack resting and denning structures, and may not provide thermal regulation during hot summer months.

4. **physiological limitations.** The fisher has a relatively low annual reproductive capacity. Fishers are capable of reproducing annually beginning at 2 years old, producing 1-4 young per year ($\bar{x} = 2.5$, Heinemeyer and Jones 1994).
5. **risk of habitat loss / alteration due to fire and land management.** In the southern Sierra Nevada habitat loss due to catastrophic fire is of concern. Fire suppression policies have apparently altered the disturbance regime from one of frequent, low intensity fires of small areal extent to rare, high intensity fires of potentially large extent. While the former played a crucial role in maintaining a landscape where forests with large trees and heterogeneous canopies were more common, the latter can result in large-scale crown fires that result in habitat of little or no value to fishers.
6. **stochastic phenomena.** As with any small, isolated population, risks of extinction are enhanced by stochastic factors. Demographic stochasticity, the chance events associated with annual survival and reproduction, and environmental stochasticity, temporal

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fluctuations in environmental conditions, tend to reduce population persistence (Shaffer 1981, see Boyce 1992 and Beissinger and Westphal 1998 for reviews).

7. **the interaction of these factors.** The interaction of these factors may move the population from a relatively stable, though numerically small condition, into an irreversible extinction vortex. For example, if demographic stochasticity results in lower than average recruitment of female kits into the population in 3 consecutive years, and this is followed by 2 heavy-snow winters and one large fire, the population may quickly become in jeopardy of local extinction.

Given the numerous factors contributing to the risk of fisher extinction in the Sierra Nevada and legal obligations to maintain habitat and conditions to ensure viable populations of native vertebrates on National Forests (as established in the National Forest Management Act of 1976), we conducted an exploratory population viability analysis (PVA) to better understand threats to population persistence.

Population Viability Analysis

During the past decade PVA has become a cornerstone of conservation biology and provided a powerful tool to examine threats to population persistence. During this time numerous PVA modeling approaches have been developed and applied, each with somewhat different mathematical structure and different model outputs. Unfortunately, the numerous PVA model types, the availability of PVA software and the need to better understand extinction processes in light of potential management actions have increased the potential for misuse of PVA.

Beissinger and Westphal (1998) provided a thorough review of PVA modeling and potential problems associated with PVA. The authors outline 4 main types of applied PVA models, each

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requiring different model inputs and producing different outputs: deterministic single population, stochastic single population, meta-population, and spatially explicit models. Deterministic single population models are the simplest in mathematical form and require the fewest input parameters while spatially explicit models are the most complex. Selecting an appropriate model form when conducting PVA is critical and should be dictated by knowledge of the system to be modeled and modeling objectives (Beissinger and Westphal 1998).

Fisher PVA Model Development

Although our current understanding of fisher ecology in the Sierra Nevada has grown immensely during the past decade, research has focused on understanding fine scale habitat needs and large-scale patterns of distribution. We have gained insight into certain demographic parameters for fisher in the southern Sierra Nevada; however, we still lack precise and accurate estimates of many population parameters. Likewise, we are limited in our understanding of disturbance patterns and the impacts of disturbance on fisher demographic rates. Because of the limited data and the uncertainty of parameter values, we present here only the results of deterministic models. Preliminary analyses that introduce stochasticity (environmental and demographic) have been conducted (R. Lamberson, pers. obs.) but this work will require additional development.

Our efforts to address fisher population viability have the following objectives:

1. to explore trends in population size using a deterministic model and a set of parameters likely to encompass true population parameters

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2. depending on results of the deterministic model, to further explore trends by incorporating demographic stochasticity, environmental stochasticity and catastrophic events into the matrix model
3. to describe future research needed to better understand fisher population persistence in the Sierra Nevada.

The present report summarizes the results of objective 1, and to a lesser degree objective 3.

Objective 2 will be the subject of future efforts.

METHODS

To develop the preliminary PVA model, we enumerated specific factors we believed were likely to influence population persistence based on fisher biology, population biology, and physical and biotic aspects of the Sierra Nevada. We then developed a set of biologically realistic parameter values from published research and reviews (available upon request) as well as unpublished data from telemetry research conducted on Sequoia National Forest (W.J. Zielinski, unpublished data) (Table 1). A simplified life history diagram based on fisher ecology and our observations of fishers in the southern Sierra Nevada was developed to form the structure of the Leslie stage-matrix model for females only; we assume males will not be a limiting factor during the short term. Parameters for each stage class included: (1) proportion of females that reproduce (f_i), (2) litter size (l_i), and (3) survival rate (s_i).

The basic model used for population projections was a stage model with 4 stage classes. Using a stage-based model allowed us to simplify the model by aggregating age classes we assumed to

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have similar demographic rates that are indistinguishable in the field. The four stages are defined as follows:

Stage 1: kits (age 0-1 year, 0-12 months)

Stage 2: subadult 1 (age 1-2 years, 13-24 months)

Stage 3: subadult 2 (age 2-3 years, 25-36 months)

Stage 4: adults (age >3 years, >37 months)

These stages are represented by the following relative parameter values:

Stage 1: low survival and no reproduction.

Stage 2: higher survival than Stage 1, low reproductive capability. Assumes that a small proportion of females will breed early in their second year and give birth just prior to 24 months of age.

Stage 3: same survival as Stage 2, but slightly higher reproductive capability. Although survival rates are the same as Stage 2, proportion of reproducing females increases due to physiological maturation.

Stage 4: highest survival and reproductive capability.

For all deterministic models, we assume an equal female: male sex ratio at birth. Parameter values were used to calculate survival and fecundity for each stage and the population vector at time $t+1$ results from multiplying the vital rate matrix by the population vector at time t :

$$\begin{bmatrix} j_{(t+1)} \\ sa1_{(t+1)} \\ sa2_{(t+1)} \\ a_{(t+1)} \end{bmatrix} = \begin{bmatrix} 0 & \beta_1 & \beta_2 & \beta_3 \\ s_j & 0 & 0 & 0 \\ 0 & s_{sa1} & 0 & 0 \\ 0 & 0 & s_{sa2} & s_a \end{bmatrix} \begin{bmatrix} j_{(t)} \\ sa1_{(t)} \\ sa2_{(t)} \\ a_{(t)} \end{bmatrix}$$

where the vital rate matrix elements are defined as follows:

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β_1 = subadult 1 fecundity rate

β_2 = subadult 2 fecundity rate

β_3 = adult fecundity rate

s_j = juvenile survival rate

s_{sa1} = subadult 1 survival rate

s_{sa2} = subadult 2 survival rate

s_a = adult survival rate

and the population vector elements correspond to the total number of females in each stage at each time step.

Using the biologically realistic range of parameters, we projected the population for 50 years using an initial population size of 50, 100 and 200 females with all parameters set at high, medium, and low values. Additional parameter sets were projected to assess the relative influence of demographic parameters on population trajectories. Starting population sizes were chosen to represent our best guesses as to the range of number of females that currently exist in the southern Sierra population. Because this was a deterministic model, the choice of initial population size is not crucial; finite growth rate will be identical for any initial population size. We have no evidence to suggest that the southern Sierra population receives immigrants from elsewhere so the population was assumed to be closed. Microsoft Excel was used to execute the model.

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RESULTS

Using this deterministic population scenario with all parameters (i.e., proportion of reproducing females, litter size and survival) at their highest values results in exponential growth (Figure 1), while the low parameter set quickly results in extinction (Figure 2). The medium parameter set also results in extinction, though the process is somewhat slower (Figure 3). Larger initial female population sizes extend only slightly the time to extinction or the time to exponential growth. Varying individual parameter values within the bounds of the high and medium values reveals that the population trajectory is most sensitive to parameters associated with the adult life stage, particularly survival and proportion of females reproducing (Table 2).

DISCUSSION

Despite the fact that the model treats all parameters as invariant and relies on several other assumptions, it does provide insight to the combination of parameters needed to maintain a stable population in the absence of immigration. Although we conducted no formal sensitivity or elasticity analyses, estimates of λ (growth rate) indicate that the model is most sensitive to changes in adult survival and the adult litter size (Table 2). Maintaining nearly stable population size under the deterministic conditions can be achieved through various parameter permutations, including medium values for all adult parameters along with high values for all other parameters. Decreases in other parameters can be offset by maintaining high adult female survival and average litter size. For example, when all parameters assume medium values except adult female survival and litter size which are set at high values, the population grows slowly and nearly doubles in size over 50 years.

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It is crucial to recognize the assumptions of this heuristic model:

1. it assumes no density dependence
2. it assumes no demographic stochasticity
3. it reflects a stable environment (no environmental stochasticity or catastrophes)
4. it does not consider the potential implications of loss of genetic variation

The inclusion of density dependence or demographic stochasticity would appear to do little to make the conclusions more optimistic. Density dependence retards growth rate as the population approaches carrying capacity; a phenomenon that did not occur under scenarios we modeled. However, density dependence can play a role at low population size because as population size decreases the likelihood of males and females finding each other also decreases. The inclusion of this effect (the 'Allee effect' [Allee 1931]) would result in more pessimistic outcomes than those presented here. Similarly, the chance production of skewed sex ratios that can occur when population size is small (demographic stochasticity) would further increase the likelihood of extinction.

In our model population growth only occurs when parameter combinations are extremely optimistic and likely unrealistic: if female survival and fecundity are high, other parameters can be relaxed to medium or low values. If female survival and fecundity are medium and all other parameters high, a steady decline toward extinction occurs. Theoretical implications of the effects of stochastic phenomenon on small populations suggest that unless fishers in the southern Sierra Nevada can maintain high vital rates (reproduction and survival), the population may face imminent extinction. Preliminary research that introduces stochasticity into the models leads to even more dire predicted consequences for the population (R. Lamberson, pers. obs.).

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Furthermore, the southern Sierra population has very low genetic diversity (only one mitochondrial haplotype; Drew et al. submitted) and this impoverishment may put it at additional risk. Without a source of immigrants from the north, the population in the southern Sierra cannot be ‘rescued’ or genetically enriched by new animals from other populations.

The results suggest that two courses of action may be necessary to protect the southern Sierra fisher population from extinction: (1) management that focuses on the maintenance and connectivity of high-quality habitat, and (2) the augmentation of fisher populations via artificial means. Management to restore mature forest landscapes in the Sierra Nevada—landscapes where stands with large trees, snags and logs and moderate to dense canopy conditions are abundant—will assist the fisher population in its currently occupied area as well as the dispersal of fishers into the unoccupied portion of its historic range. Augmentation via reintroduction, if it is considered, should only be applied at this time to the unoccupied region of the fisher’s range.

It must be recognized, however, that these projections are based largely on parameter estimates derived from literature review, limited field data and expert opinion. More accurate depictions of fisher population viability and potential for recolonizing the species’ former range in the Sierra Nevada will require extensive future effort. Ongoing research modeling fisher habitat suitability in the Sierra Nevada will guide assessment of areas most likely to be recolonized or most suitable for reintroduction. Likewise, ongoing surveys will help refine our understanding of fisher distribution in the southern Sierra Nevada and may identify population ‘hot spots’, areas which may warrant special management considerations. However, considerable fieldwork will be required to better understand the current population status and demographic trends. More

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precise and accurate estimates of total population size, sex and age distribution will also need to be developed. Additionally, assessment of reproductive success and habitat characteristics associated with successful reproduction will be crucial advancements toward increasing our understanding of fisher ecology and how management activities will influence population persistence. Toward this end, methods for estimating the vital rates of fisher populations (e.g., Zielinski et al. 1999) will need additional research and thought.

Fishers use habitat elements that occur primarily in old forests. Thus, attention to the distribution and abundance of old forest conditions, especially the large woody structures and continuous forest canopies, is the primary means that land management agencies can affect the recovery and persistence of fishers in the Sierra Nevada. Ultimately, long-term planning to restore the connectivity, extent and quality of old forest conditions should be the foundation for fisher recovery in the Sierra Nevada. Short-term population augmentation may also need to be considered to safeguard this population from extinction.

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Table 1. Range of parameter values used for deterministic population model for female fisher in the southern Sierra Nevada. Parameter ranges developed based on literature review (available upon request) and telemetry research conducted on Sequoia National Forest, 1994-1997 (Truex et al. 1998). Stages are defined as follows: Stage 1, kits age 0-12 months; Stage 2, subadult 1 age 13-24 months; Stage 3, subadult 2 age 25-36 months; Stage 4, adults age >37 months.

Parameter	Stage	Symbol	Parameter Value		
			Low	Med	High
Proportion of females that reproduce	1	$f_{(0)}$	0	0	0
	2	$f_{(1)}$	0.4	0.5	0.6
	3	$f_{(2)}$	0.5	0.6	0.7
	4	$f_{(3)}$	0.6	0.75	0.9
Litter size	1	$l_{(0)}$	0	0	0
	2	$l_{(1)}$	0.5	1	1.5
	3	$l_{(2)}$	1	1.5	2
	4	$l_{(3)}$	1	2.5	4
Survival	1	$s_{(0)}$	0.3	0.4	0.5
	2	$s_{(1)}$	0.4	0.5	0.7
	3	$s_{(2)}$	0.4	0.5	0.7
	4	$s_{(3)}$	0.6	0.75	0.9

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Table 2. Results of deterministic population projections for female fisher in the southern Sierra Nevada. Parameters are defined as follows: $f(1,2,3)$ = proportion of subadult1, subadult2 and adult females reproducing (respectively); $l(1,2,3)$ = litter size for subadult 1, subadult 2, and adults (respectively); $s(0, 1, 2, 3)$ = survival rates for juveniles, subadult 1, subadult2 and adults (respectively). For all parameter combinations, the initial starting population size is 100 females.

Model description	Parameter Values											
	f(1)	f(2)	f(3)	l(1)	l(2)	l(3)	s(0)	s(1)	s(2)	s(3)	lambda	N(end)
All high	0.6	0.70	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.193	810341
All medium	0.5	0.60	0.75	1.00	1.50	2.50	0.40	0.50	0.50	0.75	0.875	0
All low	0.4	0.50	0.60	0.50	1.00	1.00	0.30	0.40	0.40	0.60	0.642	0
All parameters set to high except:												
s(3) med	0.6	0.70	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.75	1.091	9602
s(3) low	0.6	0.70	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.60	0.994	93
s(2,1) med	0.6	0.70	0.90	1.50	2.00	4.00	0.50	0.50	0.50	0.90	1.138	79857
s(2,1) low	0.6	0.70	0.90	1.50	2.00	4.00	0.50	0.40	0.40	0.90	1.106	19736
s(0) med	0.6	0.70	0.90	1.50	2.00	4.00	0.40	0.70	0.70	0.90	1.133	62069
s(0) low	0.6	0.70	0.90	1.50	2.00	4.00	0.30	0.70	0.70	0.90	1.153	140824
l(3) med	0.6	0.70	0.90	1.50	2.00	2.50	0.50	0.70	0.70	0.90	1.108	18424
l(3) low	0.6	0.70	0.90	1.50	2.00	1.50	0.50	0.70	0.70	0.90	1.129	41656
l(2) med	0.6	0.70	0.90	1.50	1.50	4.00	0.50	0.70	0.70	0.90	1.074	2578

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l(2) low	0.6	0.70	0.90	1.50	1.00	4.00	0.50	0.70	0.70	0.90	1.188	655797
l(1) med	0.6	0.70	0.90	1.00	2.00	4.00	0.50	0.70	0.70	0.90	1.182	484405
l(1) low	0.6	0.70	0.90	0.50	2.00	4.00	0.50	0.70	0.70	0.90	1.175	360547
f(3) med	0.6	0.70	0.75	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.167	244854
f(3) low	0.6	0.70	0.60	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.137	61201
f(2) med	0.6	0.60	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.190	717892
f(2) low	0.6	0.50	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.188	636363
f(1) med	0.5	0.70	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.189	694415
f(1) low	0.4	0.70	0.90	1.50	2.00	4.00	0.50	0.70	0.70	0.90	1.186	596199
s(3), f(3), l(3) med	0.6	0.70	0.75	1.50	2.00	2.50	0.50	0.70	0.70	0.75	1.004	115
s(3) and l(3) high, f(3) low, all others med	0.5	0.60	0.60	1.00	1.50	4.00	0.40	0.50	0.50	0.90	1.016	196

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Population Trajectory: All parameters high

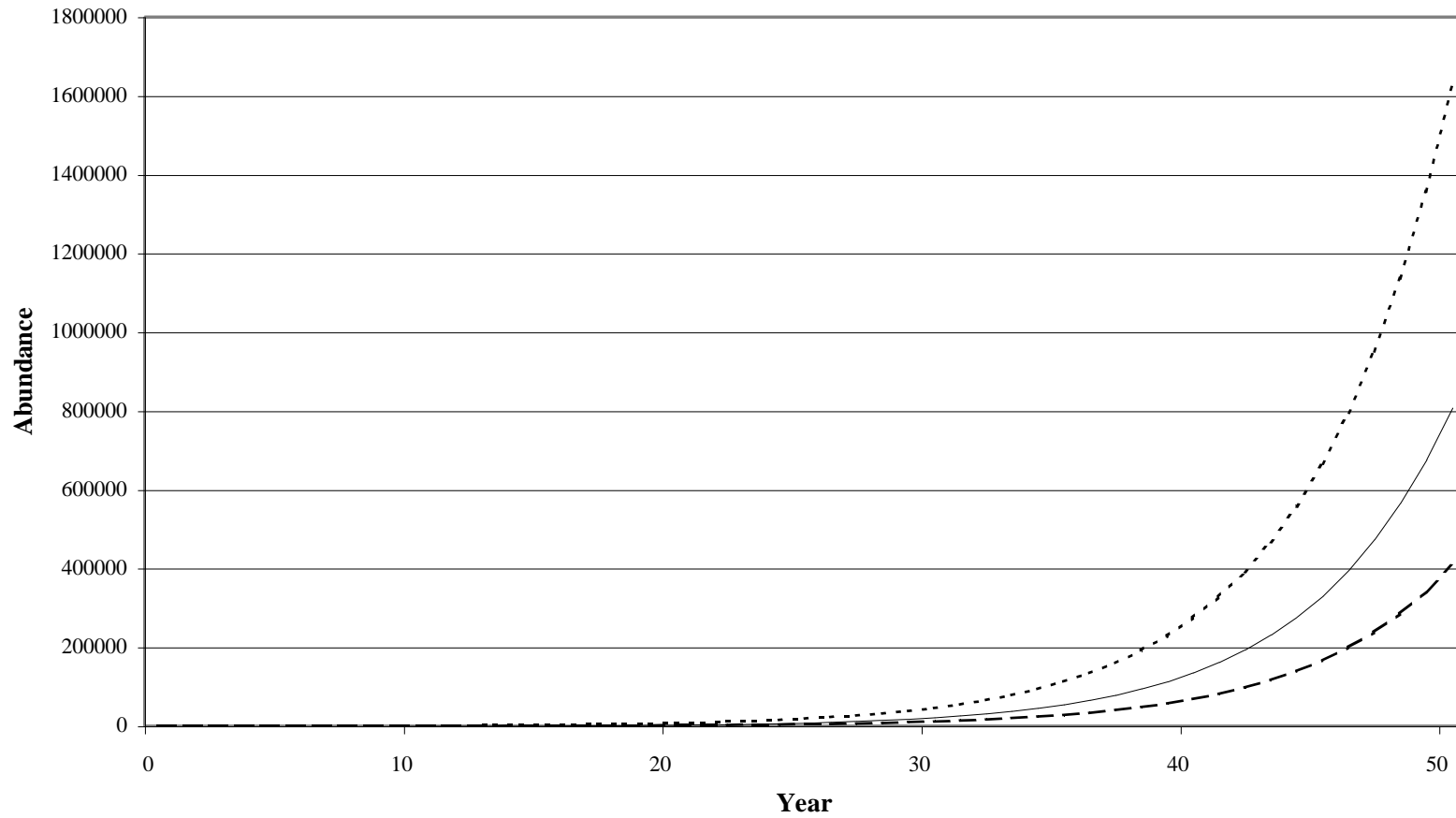


Figure 1. Female fisher population trajectory calculated using highest parameter values and initial population size of 50, 100, and 200 females.

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**Population Trajectory:
All parameters low**

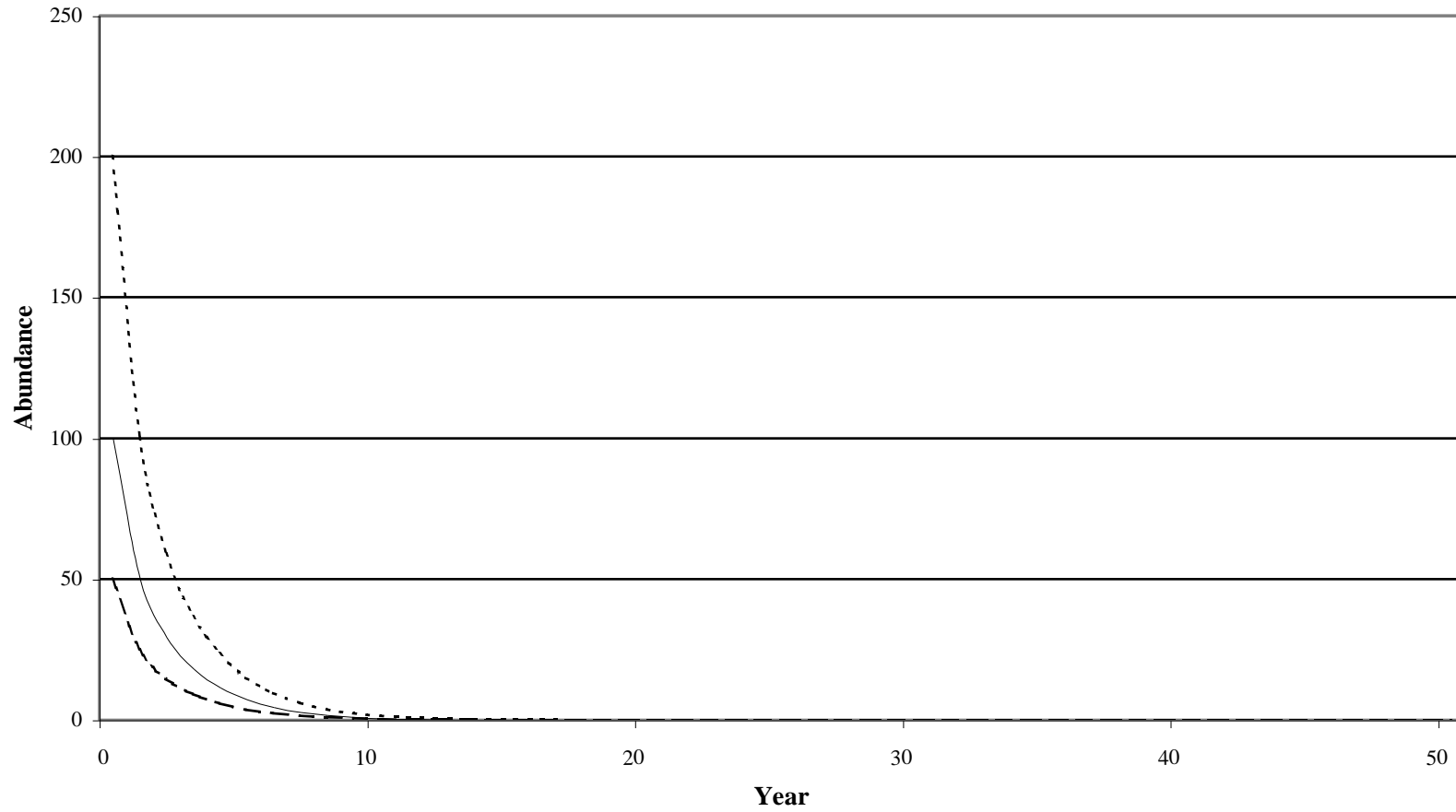


Figure 2. Female fisher population trajectory calculated using lowest parameter values and initial population sizes of 50, 100 and 200 females.

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**Population Trajectory:
All parameters medium**

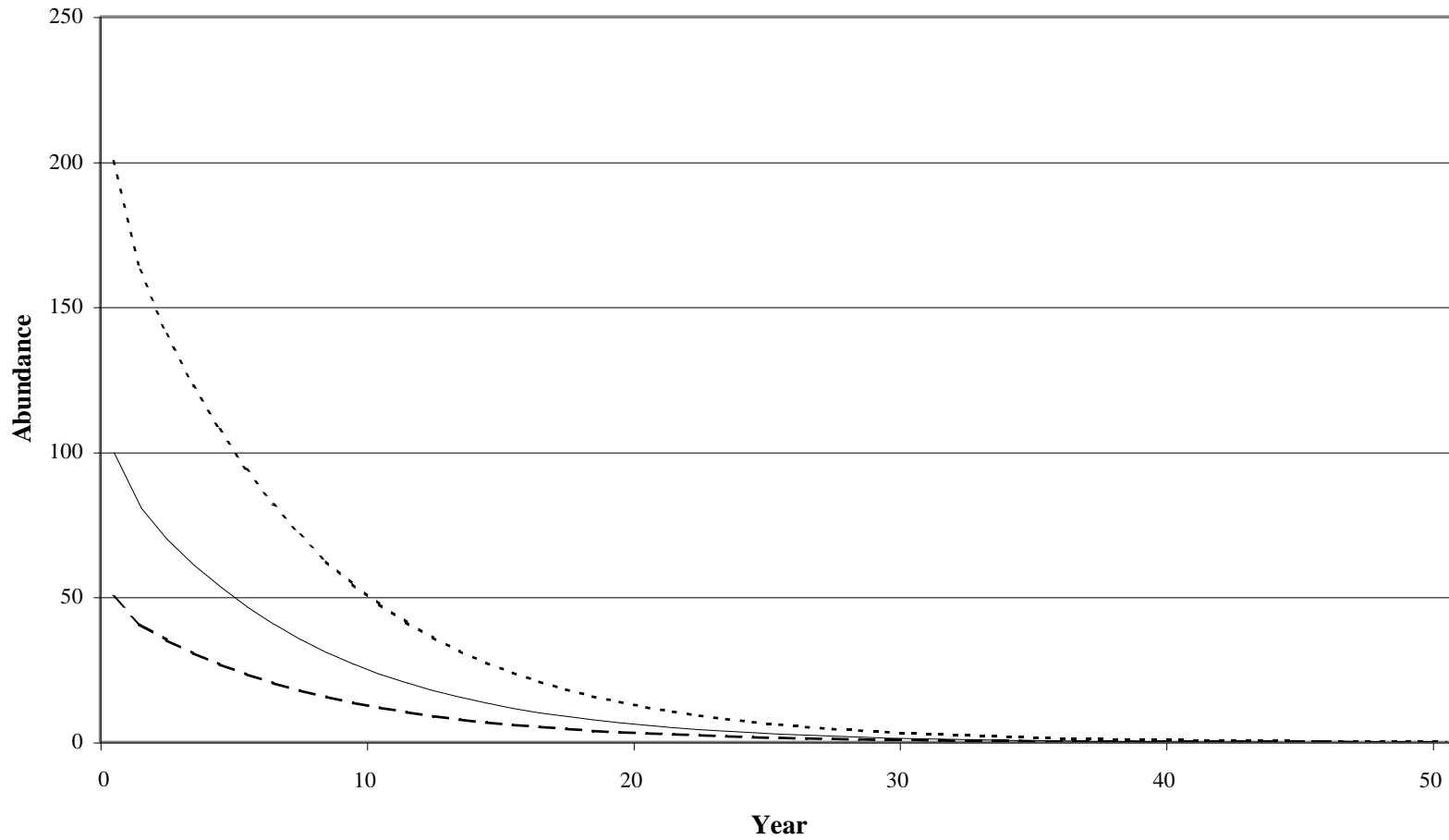


Figure 3. Female fisher population trajectory calculated using medium parameter values and initial population sizes of 50, 100 and 200 females.