Endangered Species UPDATE

Including a Reprint of the latest USFWS Endangered Species Technical Bulletin

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School of Natural Resources and Environment
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In this Issue

Optimization Techniques for the Genetic Management of Endangered Species

by

David W. Tonkyn

The survival of an increasing number of species worldwide rests entirely, if temporarily, on captive propagation. Examples include the California condor, black-footed ferret, Asiatic wild horse, Guam rail and Micronesian kingfisher. An additional, much larger set of species persist in the wild in small, remnant populations with uncertain prospects. For these species as well, captive propagation can play a critical role in survival, providing migrants to buffer wild populations against demographic and genetic fluctuations and, if necessary, a final refuge.

For many captive endangered species, scientists routinely play God, deciding each year which individuals will breed and with whom, which will be returned to or collected from the wild, and which will be culled. Often the overriding objective in these decisions is to prevent any further loss to the severely depleted gene pools, since such losses may threaten the survival of the species. After all, the world population of Guam rails, a flightless, ground-nesting bird, is descended from only 16 founders; the Asiatic wild horses, from 13; red wolves, from 13; Arabian oryx (North American captive population), from 12; and black-footed ferrets, from 9; and genetic diversity in many species has declined further in captivity.

Unfortunately, it has often proven impossible to identify which animals should be selected for breeding or reintroduction to best preserve genetic diversity, or even to know whether one's choice is near the optimum. The problem lies not in the lack of data—often complete pedigree or other information is available—but rather in the lack of systematic methods to sort through the astronomical number of choices to find the best. Mathematician Michael Kostreva and I, together with our students at Clemson University, have shown that these genetic optimization problems can be translated naturally into mathematical optimization problems and in some cases solved for the global optimum. In this paper, I shall review the causes for the loss in genetic variability in captive populations, the strategies proposed to minimize this loss, and our research on how best to implement these strategies.

The Loss of Genetic Diversity in Captive Populations

Species that are endangered may already have lost significant amounts of genetic variation in the wild, but further losses are likely during the establishment and maintenance of captive breeding populations, and their eventual reintroduction to the wild. Certainly, the initial step of collecting animals from the wild creates a bottleneck of at least one generation, at which many alleles (the alternative forms of each gene) are lost. These initial losses can be reduced by collecting many founders from each of multiple sites, but there are often practical, legal, economic, and other reasons why this might not be possible.

Subsequent generations of captive animals may experience further declines in genetic variation through genetic drift and selection. Genetic drift refers to the change in allele frequencies due to chance variation in how many copies of each allele are transmitted to the next generation. It is most pronounced in small, closed populations, typical of many endangered species, and can lead to the rapid loss of rare alleles. Selection can further reduce genetic variation, whether through the intentional favoring of animals with desired traits or from differential success at life in captivity. Such genetic changes can be minimized by allowing the population to grow rapidly from the start, but this is often not an option for captive populations.

Finally, past management practices have sometimes accelerated the loss of genetic variation in captive endangered populations. Mundane but real constraints of space and money have kept many populations small, and restricted matings to pairs, often related, in close proximity. Even informed decisions, for example to increase numbers rapidly or to create a few, more-natural, extended family groups, can reduce genetic diversity by favoring some breeders at the expense of others. It is important to note that many captive populations were established before the animals were endangered, when genetic diversity could be restored whenever necessary by adding founders. For many species, this situation no longer applies, and one must weigh carefully non-genetic management goals that carry a high genetic cost.

Genetic Optimization Goals

There are, in fact, two decisions to make in the management of captive breeding programs: which animals will breed, and with whom. The first determines which genes or founder lines will be present in the next generation, and in what proportions; the second determines their distribution among individuals. These two decisions determine the genetic composition of the next generation, within the limits of Mendelian inheritance, and can be made so as to best achieve or maintain some "optimal" genetic outcome. Not surprisingly, there is discussion among geneticists over what the optimal goal should be, for each of these two decisions. There appears to be agreement on two general points. First, with rare exceptions, captive populations of endangered species should not be selected in any way, for example, for life in captivity, since this might reduce their potential to survive in the wild on reintroduction. The second general point of agreement is that genetic variation should be preserved at every step from capture through captive breeding and eventual reintroduction to the wild. Differences remain, however, on which measures of genetic variation are most important to preserve. At the population level, one might wish to select animals to equalize the representation of founder lines, or minimize the loss of rare alleles. At the individual level, one might wish to minimize inbreeding or equalize relatedness.

It is not our intent to enter this debate over the ideal genetic composition of a population and its members. We are concerned instead with the practical implementation of specific goals. Once one chooses, say, to equalize founder contributions in the next generation or the released population, there remains the nontrivial problem of identifying which subset of the population should be bred or released to best achieve that goal. After all, there are over 10^{50} different ways one can select 50 animals out of a population of 250; finding the best by trial and error or even exhaustive computer search is impossible. In addition, in many captive populations the animals are all descended in complex ways from the same few founders, sharing genes in slightly varying proportions and mixtures, so that some selections will do far better than others at preserving rare alleles, minimizing inbreeding, etc. This makes it both more difficult and more critical to select the best animals for breeding or reintroduction.

The Problem

The problem that managers face can be illustrated with the contrived pedigree of 9 animals descended from 4 founders shown in Figure 1. This is small, for convenience, but it contains many of the complexities common to real pedigrees: parent-offspring and sib-sib matings, variable levels of inbreeding, and uneven founder representation. It is also complex enough that optimal selections may be difficult to obtain by eye. This pedigree can be converted into a matrix of founder contributions to each of the living animals (Table 1). The problem of selecting, say, 4 out of these 9 animals with some optimal composition of founder genes is then equivalent to selecting 4 rows from this matrix whose column sums—the expected number of copies of each founder genome—have some optimal values. Since there are exactly 126 different ways of choosing 4

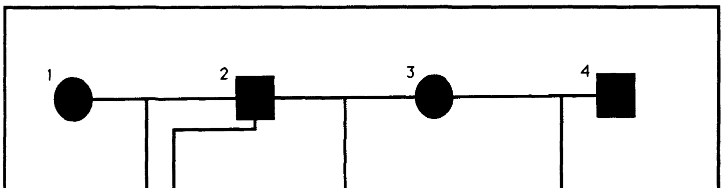

Figure 1. Contrived pedigree for illustration of the genetic optimization approach.

Endangered Species UPDATE

A forum for information exchange on endangered species issues
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Readers include a broad range of professionals in both scientific and policy fields. Articles should be written in an easily understandable style for a knowledgeable audience. For further information, contact the editor.

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Cover: Red wolf (*Canis rufus*). Photo by Mel Woods, Point Defiance Zoo and Aquarium.

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Table 1. Matrix of founder contributions to each of the living animals from the contrived pedigree in Figure 1.

Founder representation to each living animal in Figure 1				
Animals	Founders			
	1	2	3	4
12	0	0.5	0.5	0
22	0.25	0.75	0	0
23	0	0.25	0.5	0.25
24	0	0	0.5	0.5
31	0.375	0.625	0	0
32	0.125	0.625	0.25	0
33	0.125	0.5	0.25	0.125
34	0	0.125	0.5	0.375
35	0.125	0.375	0.25	0.25
Founder contribution	1	3.75	2.75	1.5

animals out of 9 (based on probability theory), we can solve *any* genetic optimization problem for this population by simply calculating the value of every possible selection of four, and taking the one that best meets our goals.

In choosing animals for breeding or release, one may seek the genetic optimization solution in which all founder lines are present, and the minimum founder contribution is greatest. (The minimum founder contribution is that portion of the genome in the selected group attributed to the founder having the smallest genetic representation.) Figure 2 shows the minimum founder contribution to each of the 126 possible sets of 4 animals. Three points can be made from this example.

First, it matters greatly which animals are selected: some selections do poorly by this measure while others do well, and a random selection may not be close to the optimum. There are even two selections that would lead to the total loss of a founder line, yielding 0% minimum founder contribution (see Fig. 2). One of these selections—12f, 23f, 24m, 34m—carries no genes from founder 1, while the other—12f, 22m, 31f, 32m—carries none from founder 4 (see Table 1).

Second, in this simple pedigree there is a unique optimal solution. The minimum founder contribution is greatest, 0.75, in the single selection of 22m, 24m, 31f, 35f. Indeed, three founder lines (founders 1, 3, and 4) are represented at this value, while the fourth founder (founder 2) is responsible for the remaining 1.75 of the gene pool (see Table 1).

A third point is that, in general, different animals will be selected to best achieve different objectives. The selection above is far from having equal founder representations, and the optimal solution for the latter goal, determined as having the smallest sum of squared deviations from equality, would substitute 34m for 22m to yield founder representations of 0.5, 1.125, 1.25, and 1.125 (for founders 1,2,3, and 4, respectively).

The examples above were solved by exhaustive computation of all possible solutions. However, this will not be an option with even slightly larger problems. Figure 3 shows a more realistic example, the pedigree for the world red wolf population on December 31, 1988, when there were 84 living descendants of 14 founders, with one founder still alive. This is the native wolf of the southeastern United States, that was extirpated from the wild but is now being reintroduced. As with many endangered species, the red wolf pedigree is enormously complex, with intricate mixing of founder lines, disproportionate representation of some lines at the expense of others, and variable but sometimes high levels of inbreeding.

Consider the ostensibly straightforward problem of selecting 21 of the 84 animals with some optimal genetic composition. Using probability theory, there are over a trillion trillion different possible selections of 21. Without some computer search strategy, one would have to try them all to be sure of finding the best, and that may be impossible for even this small pedigree let alone for the 1993 population of over 200 animals.

The current, pragmatic solution to such large problems is to find a single number to characterize the genetic value of each animal, and then simply rank the animals by this score. The first such measure that was widely adopted is the Founder Importance Coefficient, or FIC, equal to the sum of weighted founder contributions to each animal, where the weights equal the relative abundance of each founder's genes in the overall population. Animals with a high proportion of genes from underrepresented founders had low FIC scores and were selected first in breeding. One problem with this is that common founder alleles, with high weights, will only be included in the selection if they are linked with rare alleles. More recently, Jonathan Ballou of the National Zoological Park and Robert Lacy of the Chicago Zoological

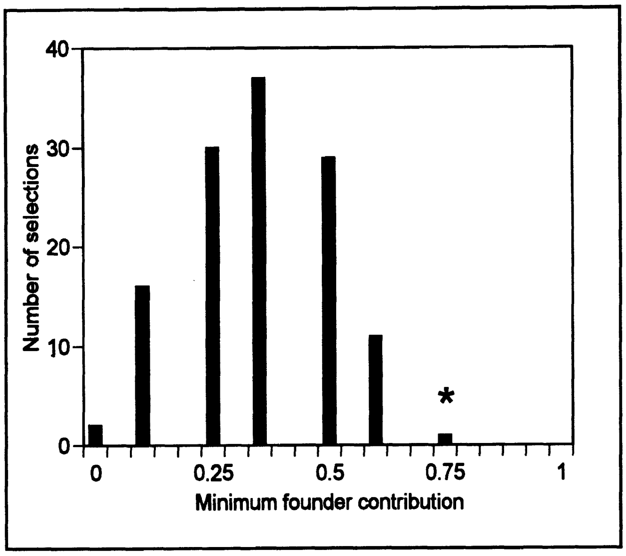

Figure 2. Minimum founder contributions to each of 126 possible selections of 4 out of the 9 animals of the contrived pedigree. The asterisk marks the single optimum selection.

Park proposed ranking individuals by their mean kinship with the entire population. Individuals with the lowest mean kinship values are in some sense the most unique genetically, and are preferentially selected. This measure is widely adopted in Species Survival Plans© (coordinated management plans of the American Association of Zoological Parks and Aquariums), and works extremely well despite its reduction of the enormous amount of information present in complex pedigrees into a single score for each individual.

Reformulation of Genetic Objectives

We have taken a different approach and attempted to solve genetic optimization problems by translating them into their corresponding mathematical forms as integer programs, so-named because individuals are either selected in their entirety (1), or not at all (0). Different genetic goals require different mathematical formulations: the problem of maximizing the minimum founder contribution is structurally different than that of equalizing founder contributions. Nevertheless, these various formulations share common elements—data, variables and constraints—and differ primarily in their objectives. For the first management decision, of which animals to use for breeding or reintroduction, we use as data the founder contributions to each animal, as in Table 1. We then define a large number of variables indicating, for example, the number (0 or 1) of each individual and its genes that are selected. We also specify numerous constraint equations on these variables, to assure that no animal is ignored, that every individual is either selected or not, that the desired number are selected, and that genes cannot be selected without their owners. This vast structure of variables and constraint equations appear to confound the problem, though in fact allows for its ready solution. The final step, then, is to state the objective as a function of the data, subject to the constraints, and solve with the machinery of operations research.

With this approach, we can solve some problems for any size pedigree that could previously only be solved by brute force on relatively small pedigrees. For example, of all the different sets of 21 red wolves that can be chosen from 84, we can obtain the selection that maximizes the minimum founder contribution. This is not a unique optimum, since by this measure siblings can be substituted for one another. Figure 4 shows the actual founder contributions to this set of 21 animals, (and to the sets of 42 and 63 animals), with greatest minimum founder contributions.

Obviously, the population can be partitioned into classes of any size, and used to select the genetically most valuable animals, perhaps for retention and breeding in captivity, and least valuable

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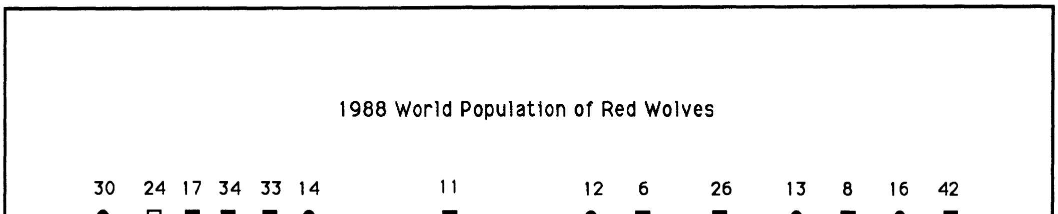

Figure 3. Pedigree of the world red wolf population on December 31, 1988, with founder IDs given.

State Expenditures on Federally Listed Threatened and Endangered Species

by

Kristen Conway

In January of 1993 the International Association of Fish and Wildlife Agencies (IAFWA) conducted its third annual Threatened and Endangered Species (T/E) State Expenditure Report. The report, required as a result of a 100th Congressional amendment to the Endangered Species Act in 1988, calls for the collation of "...reasonably identifiable expenditures made primarily for the conservation of endangered and threatened species pursuant to this Act by States receiving grants under Section 6." The IAFWA has been retained by Congress for the past three years to collect and collate the state expenditure information and write a report based on information received. This article presents some of the information in that report, along with some additional figures and tables.

Currently, thre are 775 federally listed threatened and endangered (T/E) species within the U.S. In the most recently completed fiscal year (1991 or 1992, depending on the state reporting) the total amount spent on the then 633 T/E species was $131 million non-federal monies. This amount is more than double the amount reported for the previous year, $66.6 million. The large difference between the two amounts is due in part to anticipation of budget requests and more thorough reporting of information. Several states mentioned that relevant sources not communicated with last year were contacted this year, such as departments of transportation.

Most states reported the information on a per species basis. When gross estimates were given, the total was divided evenly among all listed species in that state. States with portions or entire budgets divided evenly include: Hawaii, Louisiana, Texas, and Wisconsin.

In 1990 and 1991, birds as a group received a considerable portion of the total state funds spent. The $70 million spent on birds per the 1993 report (FY 1991 or FY 1992) greatly surpassed the amount spent on mammals, the second highest funded group ($40 million).

Figure 1 contains the breakdown of funds spent by groups. All groups except birds received ten percent or less of total non-federal funds in the last fiscal year (amphibians 0.02%; fish 0.9%; invertebrates 1.7%; and reptiles 10%). Of the estimated $70 million spent on birds this fiscal year, 89% is attributed to a single species, the red-cockaded woodpecker (*Picoides borealis*). The majority of the sum spent on birds is a result of land acquisition purchases in Florida, for the benefit of the red-cockaded wood-

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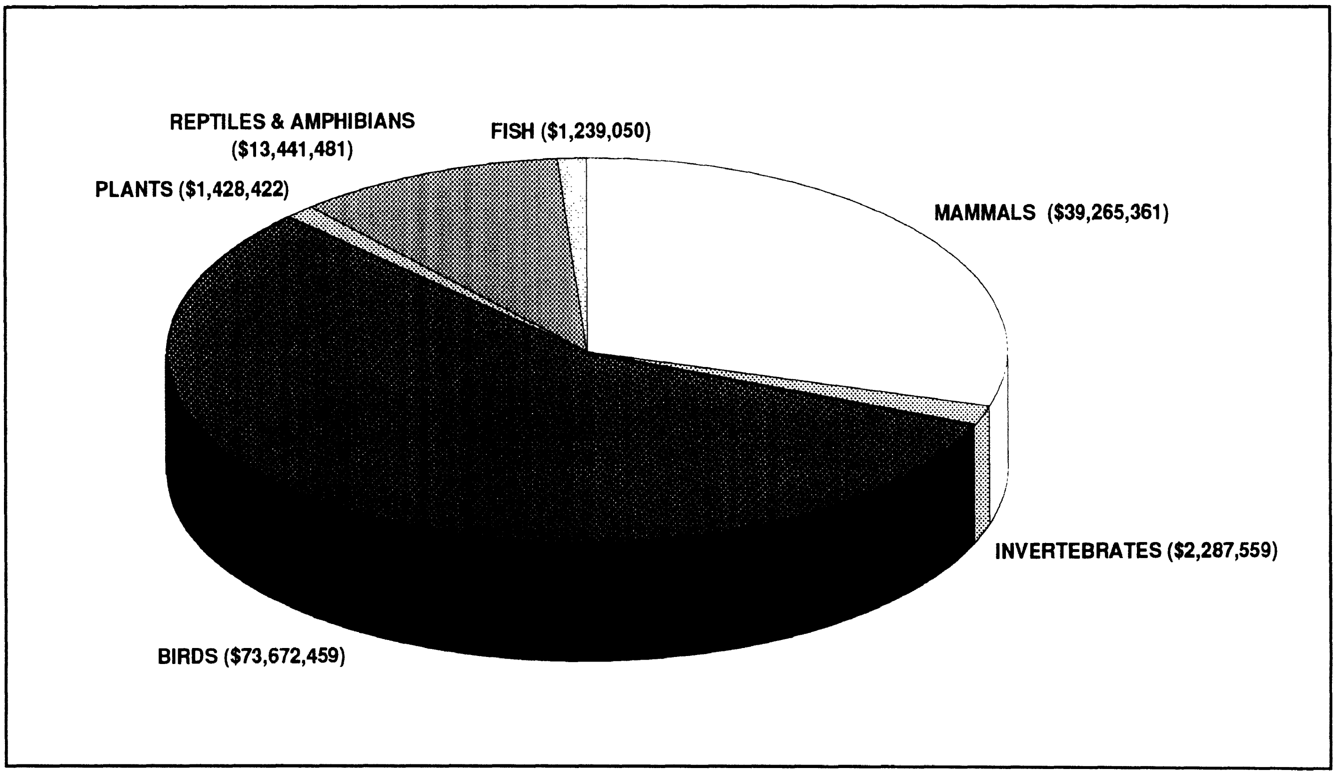

Figure 1. Breakdown, by groups, of the total state expenditures on federally listed threatened and endangered species for FY 1991 or FY 1992. Note that 89% of the money spent on birds is attributed to one species, the red-cockaded woodpecker.

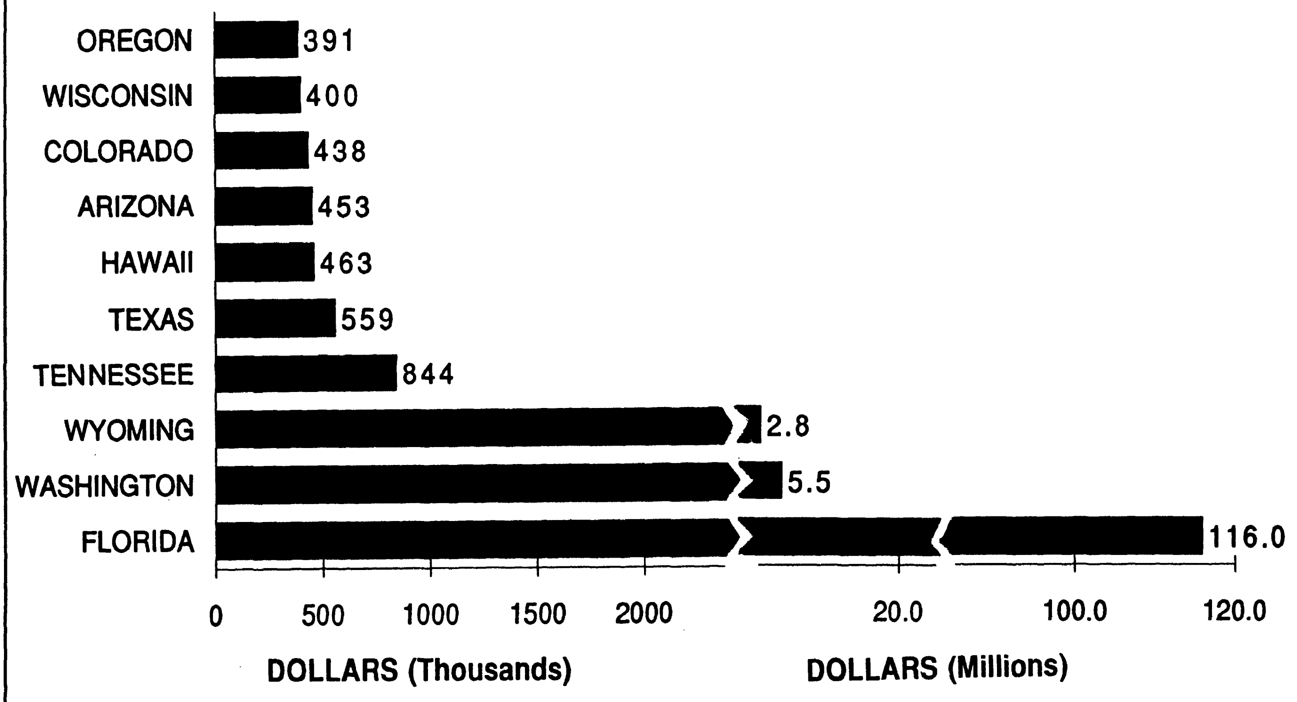

Figure 2. The top 10 spending states for federally listed threatened and endangered species during FY 1991 or FY 1992.

pecker and other species (see Figure 2 for the top 10 spending states). In the previous survey (FY 1991), Florida spent a large sum, $19.5 million, on land acquisition for the Florida scrub jay (*Aphelocoma coerulescens coerulescens*).

Florida's reported expenditures are much higher than the other states and requires special mention. A large portion of Florida's expenditures ($115.9 million) is spent on land acquisition for fisheries, wildlife, and recreation. Florida's land acquisition programs are supported financially by aggressive programs within the state. Programs administered by the Florida Department of Natural Resources that contribute mainly to land acquisition include: Conservation and Recreation Lands (CARL); Florida Natural Areas Inventory (a state heritage program); Land Acquisition Trust Fund (LATF); Preservation 2000 (P2000); Save Our Coast (SOC); and Save Our Rivers (SOR). Funding programs administered by the Florida Game and Fresh Water Fish Commission (FGFC) include: the Nongame Wildlife Trust Fund for management and research; license plates for manatees and panthers; and, a trust fund for private donations made specifically for panthers.

When ranked in descending order of spending, the 15 highest species consist of six mammals, five birds, one reptile, two invertebrates, and one plant (see Table 1, page 7). Table 2 (page 8) gives the total state expenditures for the top 100 species. Species receiving upwards of one million dollars both this year and last year include: Key Largo woodrat (*Neotoma floridana smalli*); loggerhead sea turtle (*Caretta caretta*); Schaus swallowtail butterfly (*Heraclides aristodemus ponceanus*); Florida panther (*Felis concolor coryi*); and, the bald eagle (*Haliaeetus leucocephalus*). Of the 633 federally listed T/E species, 261 received no funding this reporting, (306 received none last reporting).

In the three years the IAFWA has reported T/E expenditure information, states and territories have demonstrated considerable effort to rehabilitate and maintain T/E species in their respective states. Despite widespread financial constraints, state efforts continue to provide vital support to T/E species programs nationwide. As is evident by the figures, states continue to spend a great deal of non-federal funds on T/E species. These efforts play a vital role in the conservation of species and biodiversity.

Copies of the FY 1991 and FY 1992 state expenditure reports are available from the IAFWA, 444 North Capitol St., NW, Suite 544, Washington, D.C. 20001.

Tables follow on UPDATE pages 7 and 8.

Kristen Conway worked as research assistant to the International Association of Fish and Wildlife Agencies for the past year during which the information for this report was collected. She is currently in Carara Biological Reserve, Costa Rica, researching the ecology of scarlet macaws for a management plan.

Table 1. Total and state-by-state expenditures for the fifteen federally listed threatened and endangered species on which most money was spent.

SPECIES	STATE EXPENDITURES FOR FEDERALLY LISTED THREATENED & ENDANGERED SPECIES				
Woodpecker, red-cockaded	FL $64,783,626	GA $1,100	KY $3,000	LA $17,105	
$64,911,733	MS $1,500	NC $40,000	OK $4,242	SC $26,060	
	TN $16,145	TX $12,455	VA $6,500		
Mouse, Choctawahatchee beach	FL $16,067,495				
$16,067,495					
Manatee, West Indian (Florida)	FL $12,828,812	GA $3,000	LA $17,105	PR $1,000	
$12,849,917					
Turtle, Loggerhead Sea	FL $12,698,083	GA $15,000	HI $833	LA $17,105	MS $500
$12,849,438	NJ $500	NY $4,000	NC $30,000	PR $875	SC $82,542
Falcon, American peregrine	AK $9,282	AZ $42,000	CA $350	CO $161,500	FL $275
$4,932,355	GA $14,000	ID $16,000	IL $4,000	IN $70,000	IA $32,500
	KS $1,500	KY $28,000	LA $17,105	ME $3,000	MD $3,000
	MA $1,600	MI $8,000	MN $9,722	MS $100	MO $33,000
	MT $7,000	NE $3,000	NV $10,200	NH $1,500	NJ $10,000
	NC $30,000	OH $95,000	OR $25,000	PA $5,969	SC $6,214
	TN $18,645	UT $17,500	VT $5,600	VA $7,675	WA $4,116,250
	WV $6,140	WI $36,364	WY $75,634		
Panther, Florida	FL $4,387,370				
$4,387,370					
Bear, Grizzly or Brown	ID $42,000	MT $190,000	WA $63,000	WY $2,485,607	
$2,780,607					
Eagle, bald	AL $3,000	AZ $90,000	AR $1,000	CA $350	CO $16,000
$1,233,744	CT $2,200	DE $833	FL $22,745	GA $15,700	ID $21,000
	IL $1,500	IN $25,000	IA $9,000	KS $9,000	KY $3,000
	LA $17,105	ME $54,000	MD $10,000	MA $10,000	MI $15,700
	MN $40,314	MS $3,500	MO $4,000	MT $10,000	NE $4,000
	NV $4,100	NH $1,500	NJ $25,000	NY $8,333	NC $15,000
	ND $500	OH $39,000	OR $27,000	PA $5,969	RI $300
	SC $41,463	TN $79,645	TX $9,455	UT $14,500	VA $6,750
	WA $484,200	WV $755	WI $36,364	WY $44,963	
Woodrat, Key Largo	FL $1,200,052				
$1,200,052					
Butterfly, Schaus swallowtail	FL $1,200,052				
$1,200,052					
Mouse, Key Largo cotton	FL $1,200,052				
$1,200,052					
Jay, Florida scrub	FL $772,226				
$772,226					
Owl, Northern spotted	CA $29,500	OR $290,500	WA $325,000		
$645,000					
Spurge, deltoid	FL $556,725				
$556,725					
Butterfly, Oregon silverspot	WA $432,100				
$432,100					

Table 2. Total state expenditures for the top 100 federally listed threatened and endangered species on which most money was spent.

SPECIES	TOTAL SPENT
Woodpecker, red-cockaded	$64,911,733
Mouse, Choctawahatchee beach	$16,067,495
Manatee, West Indian (Florida)	$12,849,917
Turtle, loggerhead sea	$12,849,438
Falcon, American peregrine	$4,932,355
Panther, Florida	$4,387,370
Bear, grizzly or brown	$2,780,607
Eagle, bald	$1,233,744
Woodrat, Key Largo	$1,200,052
Butterfly, Schaus swallowtail	$1,200,052
Mouse, Key Largo cotton	$1,200,052
Jay, Florida scrub	$772,226
Owl, northern spotted	$645,000
Spurge, deltoid	$556,725
Butterfly, Oregon silverspot	$432,100
Tortoise, desert	$247,810
Ferret, black-footed	$199,594
Plover, piping	$194,859
Sturgeon, pallid	$163,750
Squawfish, Colorado	$145,438
Salmon, chinook	$143,000
Wolf, gray	$134,191
Chub, humpback	$121,500
Crow, Hawaiian ('alala)	$121,434
Turtle, Kemp's (Atlantic) ridley sea	$104,726
Goose, Hawaiian (nene)	$102,434
Warbler (wood), golden-cheeked	$99,857
Tern, least	$72,710
Vireo, black-capped	$70,216
Trout, Lahontan cutthroat	$69,000
Warbler (wood), Kirtland's	$65,364
Squirrel, Carolina northern flying	$59,645
Pigeon, Puerto Rican plain	$54,500
Bat, Indiana	$52,617
Turtle, green sea	$51,231
Chub, bonytail	$51,100
Heelsplitter, inflated	$48,105
Trout, greenback cutthroat	$48,000
Falcon, Arctic peregrine	$47,311
Bush-clover, prairie	$43,354
Monkshood, northern wild	$39,364
Thistle, Pitcher's	$37,996
Pearly mussel, Higgins' eye	$37,864
Bat, gray	$37,403
Iris, dwarf lake	$37,364
Pelican, brown	$37,212
Locoweed, Fassett's	$36,364
Whitlow-wort, papery	$35,000
Tree, pygmy fringe	$35,000
Plum, scrub	$35,000
Hypericum, highlands scrub	$35,000
Squirrel, Mount Graham red	$34,000
Tortoise, gopher	$32,605
Turtle, leatherback sea	$32,146
Pronghorn, Sonoran	$30,000
Trout, Little Kern golden	$30,000
Crane, whooping	$27,375
Sparrow, Florida grasshopper	$27,000
Mussel, dwarf wedge	$25,050
Turtle, hawksbill sea (=carey)	$25,013
Darter, Niangua	$24,000
Topminnow, Gila (incl. Yaqui)	$24,000
Caribou, woodland	$23,700
Tern, roseate	$23,100
Lipochaeta venosa (=Sci. Name)	$21,934
Logperch, Roanoke	$21,500
Pondberry	$20,305
Pearly mussel, little-wing	$20,245
Palila (honeycreeper)	$20,234
Chub, spotfin	$20,045
Parrot, Puerto Rican	$20,000
Bat, Hawaiian hoary	$19,684
Coot, Hawaiian (=alae keo keo)	$19,634
Shearwater, Newell's Townsend's	$19,534
Vetch, Hawaiian	$19,534
Prairie dog, Utah	$19,500
Turtle, ringed sawback	$19,305
Duck, Hawaiian (Koloa)	$19,234
Stilt, Hawaiian (=Ae'o)	$19,034
Kauai hau kuahiwi	$19,034
Moorhen (gallinule), Hawaiian common	$19,034
Gardenia, Hawaiian (na'u)	$18,734
Kokio, Cooke's	$18,734
Pigtoe, shiny	$18,145
Pearly mussel, pink mucket	$17,990
Madtom, yellowfin	$17,945
Prairie-chicken, Attwater's	$17,455
Pigtoe, fine-rayed	$17,145
Pearlshell, Louisiana	$17,105
Fanshell	$16,995
Darter, slackwater	$16,945
Mussel, ring pink (=golf stick pearly)	$16,795
Pearly mussel, cracking	$16,745
Pigtoe, rough	$16,645
Pearly mussel, purple cat's paw	$16,645
Falcon, northern aplomado	$16,455
Trout, Apache	$16,000
Spiraea, Virginia	$15,989
Darter, fountain	$15,955
Logperch, Conasauga	$15,645

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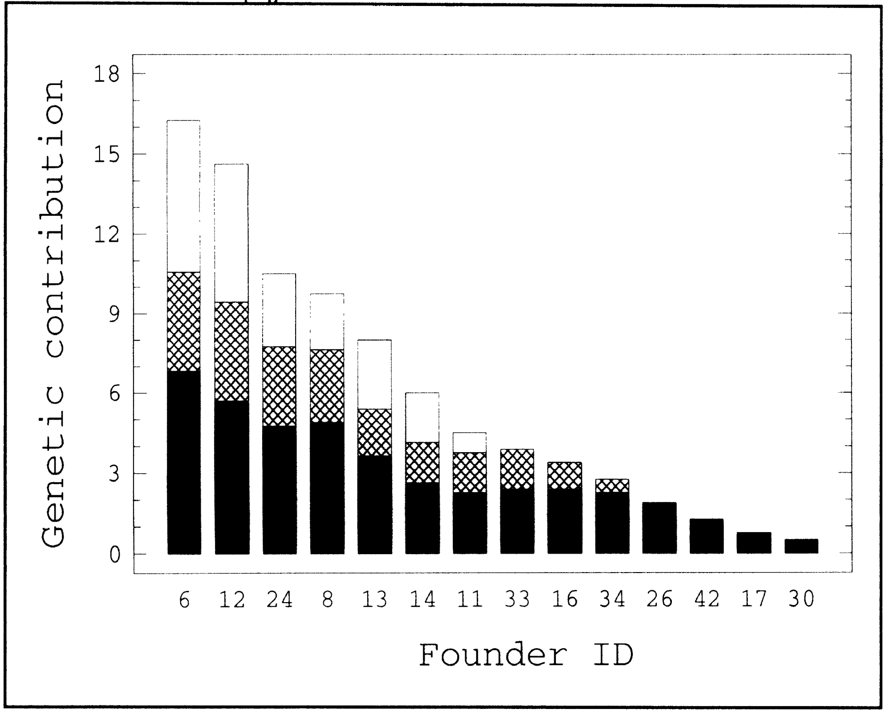

Figure 4. Founder contributions to the selections of 21 (black), 42 (plus shaded) and 63 (plus hatched) red wolves out of 84, that each maximize the minimum founder contribution.

animals, for a trial reintroduction. Other goals such as to equalize founder contributions can be solved in analogous ways, and yield slightly different solutions. However, founder contributions, like mean kinship values, do not completely specify the structure of the pedigree and may be misleading in some cases. This is an area of active research for us.

We have also begun to address the second major question of how best to pair off the selected animals to minimize inbreeding. Again, this is only a problem when there are many potential choices. In the selection of 2 males and 2 females that maximizes minimum founder contributions in Figure 1, there are only two possible choices, and the pairing of 22m–35f and 24m–31f yields average inbreeding coefficients 1/3 that of the alternative. Suppose however, that we wished to pair the 11 male and 14 female red wolves in the prime breeding ages between 3 and 7 in 1988. There are 14 possible mates for the first male, and for each choice, 13 for the second (=182), and so on, for a total of over 14 billion choices for all 11 pairings. One might evaluate all of these by computer and select the one that produced the lowest average level of inbreeding, but that approach would quickly fail with larger pedigrees. However, we have found that integer programming techniques can readily solve such problems for the global optimum (in prep.).

This treatment of genetic optimization problems with mathematical optimization techniques allows for immediate generalization in important, practical ways. First, it allows for individuals and/or founders to be weighted differently, all else being equal. There are numerous reasons why this might be desired. For example, one could weight individuals by their expected future lifetime reproduction, thereby implicitly optimizing genetic representation in the next generation. Alternatively, one could weight more heavily those individuals that had greater prior reproductive success, are less inbred, are preferred on subjective judgements of vigor, compatibility, etc., or even on non-biological measures of cost or distance. Some founder lines might be valued differently than others because they prove more fecund, more tolerant of inbreeding, rarer, underwent bottlenecks in captivity or, in extreme cases, represent genetic contamination from different species or subspecies. In addition, the approach can be extended to other sorts of multivariate genetic data on individuals, from the analysis of allozymes or DNA. This allows for the improved genetic management of populations for which pedigrees are not available, including most wild populations but also captive populations of animals maintained in herds or flocks. Finally, this approach generalizes naturally to the joint management for multiple genetic objectives, and of multiple populations, such as captive and released portions of the same species.

These and other genetic optimization techniques, such as those based on mean kinship, cannot replace the scientific judgement of individuals responsible for breeding endangered species, who must weigh other non-genetic factors. Nevertheless, these may prove valuable tools in the selection process, and can reveal the genetic costs of alternative selections. In addition to the obvious, direct benefits of this research, I would like to point out the following. Physical limits to the number of animals that can be held in captivity have forced managers to consider abandoning some endangered subspecies (e.g., of tigers and lions) or higher taxa (e.g., rhinos) to better preserve genetic variation in the others. Any method that aids in the preservation of genetic variation in captive populations will free space for these additional threatened taxa. Finally, even species that are not currently threatened in the wild are often managed for genetic variation, so that captive populations used for research, education, and display in zoos can be self-sustaining, avoiding financial, legal, ethical and other costs of continued dependence on wild populations for such uses. In many cases, these decisions are made with imperfect tools, and could benefit from the continued development of optimization techniques such as outlined here.

Acknowledgments

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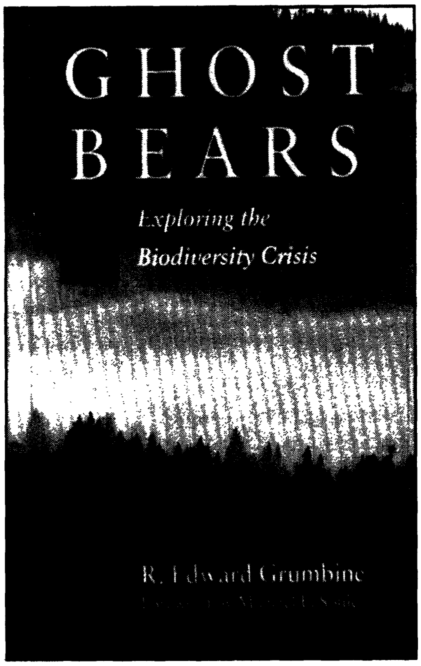
Book Review

Ghost Bears: Exploring the Biodiversity Crisis

By R. Edward Grumbine. 1992.
Island Press. Washington, D.C. $25.00. xx+290 pp.

Reviewed by Diana L. Randlett



While environmentalists often seem to be at odds, this book unites naturalists, academicians, foresters, land managers, and deep ecologists toward a common goal: tackling the biodiversity crisis. The author is an excellent teacher, illustrating his points with examples that are easily understood by the layperson but which also provide a fresh perspective for the trained biologist. Grumbine offers a rational, detailed analysis of the biodiversity crisis, with concrete solutions and directions for the future.

Too often, the biodiversity crisis is focused on the tropics, allowing those of us in the Northern hemisphere to shirk responsibility here at home, and point instead at problems in far-away places. Grumbine avoids this trap, using the North Cascades greater ecosystem as home base. The reader accompanies the author on his personal walk as an environmentalist. This style might be conducive to self-congratulation, but Grumbine pulls it off in a humble, casual manner. You will feel his hopes and his disappointments as you journey with him to Capitol Hill, national and international meetings, backpacking trips, and even to deep ecology ceremonies in the middle of the woods. As you walk with him, you will smell the air of the lush northwest forest, following him through logging towns, up and down mountains, and beyond.

Grumbine's analysis of the biodiversity crisis takes place in the context of the grizzly bear, caught in the complex web of government agencies, environmental legislation, and land management practices. The "classic umbrella species of conservation biology," the bear cares little for artificial boundaries and is "simply at home." The image of ghost bears is a symbol of the urgency of the call: "The largest, most powerful animal living in the Greater North Cascades ecosystem is a modern apparition that, some day, may well be nothing more than a dweller in the shadowlands of memory." The author recounts the "Bear Mother myth," the story of a woman who married a bear. The tale is at once chilling, profound, and illustrative of many aspects of the human/bear relationship, which through time has disintegrated, as has the human/earth relationship. The environmental ills we suffer are symptoms of a serious disease, which Grumbine correctly diagnoses: our separation from our home in nature.

The author's insight into the origins of our current thinking gives the book yet another dimension. *Ghost Bears* explores the circumstances surrounding the first official land management policy in the U.S., and other historical events and trends. Many land management practices are traced to an anthropocentric utilitarian view of conservation. The end result of this paradigm is ugly indeed, and we are urged to break our evil habits. The author unabashedly questions the whole concept of multiple-use management (stating that its basis lies in economics, not ecology), and he tells us in no uncertain terms why our biodiversity laws are not working. Restoration is essential, says Grumbine, and it is essential *now*.

Grumbine's initiatives are soundly based in conservation biology principles. Interconnectedness, gap analysis, multiple use models, and new forestry are all discussed in simple but complete terms. Still, the author's ideas do not necessarily represent a typical academic approach, which often tends toward a species view of conservation. Many argue that ecosystems cannot be adequately defined and therefore do not represent the level at which conservation efforts should be focused. Grumbine, however, not only espouses management at the ecosystem level, but he also urges management at the greater ecosystem level, and he shows us why the species approach is inadequate.

I could not agree more. Too often, we focus on saving one species to the exclusion of the larger goal. After all, species could be preserved indefinitely in zoos, but is this the point? To me, Grumbine is right on target when he says that "The sort of ecosystem management that plans to radio collar every grizzly and track every wolf dooms our vertebrate kin to a piecemeal existence."

This book points to a better kind of ecosystem management, with clear paths to clear goals. Grumbine's envisioned wilderness recovery strategy is realistic and takes place over the long term. My hope is that many will hear the call. I want to believe Grumbine when he says that "In some future time there won't be any national forests, national parks, or even a Greater North Cascades Ecosystem. There will simply be home."

Diana L. Randlett is a research associate at the School of Natural Resources and Environment, University of Michigan. She is currently studying the effects of global climate change on forest ecosystem processes.

Bulletin Board

Red Wolf Pups Born

Lowry Park Zoo in Tampa, Florida, recorded its first litter of red wolves. Red wolves are SSP© (Species Survival Plan©) animals, whose propagation is cooperatively coordinated by North American zoos through the American Association of Zoological Parks and Aquariums. The two pups (one male, one female) were the first offspring of a five-year-old female and a four-year-old male. The pups were born in a den dug under an upright cypress stump. Soon after their eyes opened, at ten days, the mother parked them in various sheltered locations in the exhibit.

Zoo and Aquarium Conference

The American Association of Zoological Parks and Aquariums will hold its annual conference in Omaha, Nebraska from September 12-16, 1993. Among the many sessions held will be those on: The Endangered Species Act, Contributions of Animal Behavior Studies to Zoo Propagation Programs, Conserving Freshwater Fishes, In Situ Conservation, Tackling the Species Dilemma, Conserving Aquatic Biodiversity, and Primate Topics. For further information, contact Randy Wisthoff, Omaha's Henry Doorly Zoo, 3701 South 10th Street, Omaha, NE 68107; (402) 733-8401.

Symposium on Bats

The 23rd Annual North American Symposium on Bat Research will be held in Gainesville, FL, from October 13-16, 1993, and hosted by the Lubee Foundation, Inc., and the University of Florida. Postmark deadline for abstracts is September 1. For further information, contact G. Roy Horst, Department of Biology, Potsdam College of SUNY, Potsdam, NY 13676; (315) 267-2259; FAX (315) 267-3001.

Call For Papers

People interested in presenting a paper or poster at the Fifth International Symposium on Society and Resource Management should submit an abstract by November 1, 1993. The symposium will be June 7-10, 1994 at Colorado State University. The main focus of the symposium is on improving the utility of social science for natural resource managers and policy makers. Abstracts should be no longer than 2 double-spaced typed pages, and sent to Michael J. Manfredo, Program Chair, Human Dimensions in Natural Resources Unit, Colorado State University, Fort Collins, CO 80523.

Northern Forest Ecology Workshop

The Ecology of the Northern Forest: A Scientific Workshop will be held at Lyndon State College from August 17-20, 1993. For further information, contact National Wildlife Federation, Northeast Natural Resource Center, 18 Baldwin Street, Montpelier, VT 05602; (802) 229-0650.

USFWS Endangered Species Technical Bulletin

The latest Technical Bulletin is included in this issue of the *Endangered Species UPDATE*. The *UPDATE* features the Technical Bulletin as soon as it is produced by USFWS and received by us.

Announcements for the Bulletin Board are welcomed. Some items from the Bulletin Board have been provided by the American Association of Zoological Parks and Aquariums bulletin, Communique.

Endangered Species UPDATE

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