Readings for Environmental Literacy

Edited by

Michael L. McKinney

Parri Shariff

Readings for Environmental Literacy

Edited by

Michael L. McKinney and Parri Shariff
University of Tennessee, Knoxville

West Publishing Company

Minneapolis/St. Paul New York Los Angeles San Francisco

Cover Image: Wind turbines, Mojave, California. ©1996 Dean DeChambeau.

WEST'S COMMITMENT TO THE ENVIRONMENT

In 1906, West Publishing Company began recycling materials left over from the production of books. This began a tradition of efficient and responsible use of resources. Today, 100% of our legal bound volumes are printed on acid-free, recycled paper consisting of 50% new paper pulp and 50% paper that has undergone a de-inking process. We also use vegetable-based inks to print all of our books. West recycles nearly 27,700,000 pounds of scrap paper annually—the equivalent of 229,300 trees. Since the 1960s, West has devised ways to capture and recycle waste inks, solvents, oils, and vapors created in the printing process. We also recycle plastics of all kinds, wood, glass, corrugated cardboard, and batteries, and have eliminated the use of polystyrene book packaging. We at West are proud of the longevity and the scope of our commitment to the environment.

West pocket parts and advance sheets are printed on recyclable paper and can be collected and recycled with newspapers. Staples do not have to be removed. Bound volumes can be recycled after removing the cover.

Production, Prepress, Printing and Binding by West Publishing Company.

TEXT IS PRINTED ON 10% POST CONSUMER RECYCLED PAPER

Printed in the United States of America
03 02 01 00 99 98 97 96   8 7 6 5 4 3 2 1

ISBN 0–314–07569–0

Preface

Our concern for the environment shouldn't change, but our focus constantly shifts with each dramatic report of a new problem. Our solutions change as we understand our responsibilities and we develop new, or give up old, technology. Government administrations change and so do their policies. *Reading for Environmental Literacy* is designed to keep students and instructors abreast on what is happening to our environment today, and who is involved.

This collection of fifty recent articles from popular magazines and science journals presents new success stories, new concerns, and new approaches for sustainable use of our resources. The editors have carefully selected articles that present the different, and sometimes unpopular, viewpoints of what is often a controversial field. Each article begins with a summary of the ideas presented in the selection and ends with a set of questions to help identify the key points of the discussion.

Readings for Environmental Literacy is intended to supplement material a student might encounter when taking a course in environmental science. There is no guarantee that the authors of these articles are always right: science, and opinion, don't work that way. What is important is to understand that the problems—and sustainable solutions—are out there, and that you use the information to make your own decisions.

Acknowledgment

The editors and West Publishing wish to express their sincere thanks to the many magazines and journals that allowed us to reprint their articles.

Contents

Preface / vii

Section One: Overview / 1

1. **Back to Nature**
   by Peter Radetsky
   You can put a zoo-bred animal back into the wild. But that doesn't mean you're putting back anything like a wild animal.
   (*Discover*, July 1993) / **3**

2. **Chaos in the Solar System**
   by Neil de Grasse Tyson
   (*Natural History*, July 1995) / **8**

3. **The Andes' Deep Origins**
   by Raymond M. Russo and Paul G. Silver
   Peering into the mantle, geophysicists are now able to detect the currents of rock that shape the Andes' and other major features of our planet.
   (*Natural History*, February 1995) / **11**

4. **The Real Message from Biosphere 2**
   by John C. Avise
   (*Conservation Biology*, June 1994) / **15**

5. **Mankind Must Conserve Sustainable Materials**
   by John E. Young and Aaron Sachs
   As the supply of natural resources dwindles, the world must focus on meeting human needs with a minimum of materials and energy usage.
   (*USA Today*, July 1995) / **18**

6. **Taking Back the Nest**
   by Daniel Dunaief
   As cowbirds push some songbirds toward extinction, conservationists are debating an uncomfortable solution: killing the pests.
   (*Discover*, May 1995) / **23**

7. **The Environmental Challenges of Sub-Saharan Africa**
   by Akin L. Mabogunje
   (*Environment*, May 1995) / **25**

8. **Women, Politics, and Global Management**
   by Lincoln C. Chen, Winifred M. Fitzgerald, and Lisa Bates
   (*Environment*, January/February 1995) / **37**

9. **Haiti on the Brink of Ecocide**
   by Dwight Worker
   Haitian boat people are environmental refugees, fleeing an island being devastated down to its very roots. Poverty and politics created this crisis, but the environment has paid the price.
   (*E Magazine*, July/August 1994) / **46**

10. **Earth Is Running Out of Room**
    by Lester R. Brown
    Food scarcity, not military aggression, is the principal threat to the planet's future.
    (*USA Today*, January 1995) / **52**

11. **Easter's End**
by Jared Diamond
In just a few centuries, the people of Easter Island wiped out their forest, drove their plants and animals to extinction, and saw their complex society spiral into chaos and cannibalism. Are we about to follow their lead?
(*Discover*, August 1995) / **57**

Section Two: Problems of Resource Scarcity /65

12. **USGS Oil & Gas CD Hits the Charts**
by R.C. Burruss
(*Geotimes*, July 1995) / **67**

13. **The Unexpected Rise of Natural Gas**
by Christopher Flavin and Nicholas Lenssen
With growing advantages to its use, natural gas may usurp oil as the world's energy source of choice.
(*The Futurist*, May/June 1995) / **70**

14. **The Forecast for Wind Power**
by Dawn Stover
(*Popular Science*, July 1995) / **74**

15. **Sea Power**
by Mariette DiChristina
(*Popular Science*, May 1995) / **80**

16. **The Truly Wild Life Around Chernobyl**
Many animals are in evolutionary overdrive.
by Karen F. Schmidt
(*U.S. News & World Report*, July 17, 1995) / **84**

17. **Bringing Back the Everglades**
by Elizabeth Culotta
Amid great scientific and political uncertainty, ecosystem managers in Florida are pushing ahead with the boldest—and most expensive—restoration plan in history.
(*Science*, June 23, 1995) / **87**

18. **Will Expectedly the Top Blow Off?: *Environmental Trends and the Need for Critical Decision Making***
by Thomas E. Lovejoy
The real challenge is how we as biologists can create a sense of urgency about biological diversity, climate change, and human population growth.
(*BioScience Supplement*, 1995) / **92**

19. **The World's Forests: *Need for a Policy Appraisal***
by Norman Myers
(*Science*, May 12, 1995) / **98**

20. **Is He Worth Saving?**
by Betsy Carpenter
The potent new campaign to overturn the Endangered Species Act.
(*U.S. News & World Report*, July 10, 1995) / **103**

21 **Nature, Nurture and Property Rights**
(*The Economist*, July 8, 1995) / **106**

22. **Is Marine Biodiversity at Risk?**
by Elizabeth Culotta
(*Science*, February 18, 1994) / **108**

23. **Building a Scientifically Sound Policy for Protecting Endangered Species**
by Thomas Eisner, Jane Lubchenco, Edward O. Wilson, David S. Wilcove, and Michael J. Bean
(*Science*, September 1, 1995) / **112**

24. **Back to Stay**
by Jon R. Luoma
Once nearly wiped out by trapping, beavers are booming across the country—and land managers must cope with the only creatures that can alter an ecosystem nearly as efficiently as humans themselves.
(*Audubon*, January-February 1996) / **117**

25. **Common Ground**
by Barbara Ruben
Farmers, environmentalists, and anti-hunger activists join forces to redefine the way food is grown and distributed.
(*Environmental Action*, Summer 1995) / **122**

26. **Will the World Starve?**
(*The Economist*, June 10, 1995) / **126**

27. **Who Owns Rice and Beans?**
by Fred Powledge
The Patent Office's seeming shift on broad biotechnology patents still leaves unanswered questions about plant germplasm.
(*BioScience*, July/August 1995) / **128**

Section Three: Problems of Environmental Degradation / 135

28. **The Alarming Language of Pollution**
by Daniel Glick
(*National Wildlife*, April/May 1995) / **137**

29. **What Is Polluting Our Beaches?**
by Joe Brancatelli
Everything from cigarette butts to raw sewage. But it's what you don't see that really hurts.
(*Popular Science, 1995*) / **142**

30. **Drinking Recycled Wastewater**
by Ginger Pinholster
Can groundwater recharge safely address the drinking-water needs of rapidly growing urban areas?
(*Environmental Science & Technology*, April 1995) / **144**

31. **Particulate Control: *The Next Air Pollution Control Growth Segment***
by Robert W. McIlvaine
Where should environmental firms direct their research, money, and workforce? Where will the next growth spurt in the industry occur? How should firms prepare for the next decade? In what direction should environmental professionals take their careers as they search for the field's next market boom?
(*Environmental Manager*, April 1995) / **151**

32. **The Sound of Global Warming**
by Stuart F. Brown
Cold war spy technology could become the world's largest ocean thermometer to measure global warming. But will the residents object?
(*Popular Science*, July 1995) / **156**

33. **Dusting the Climate for Fingerprints**
by Richard Monastersky
Has greenhouse warming arrived? Will we ever know?
(*Science News*, June 10, 1995) / **159**

34. **Complexities of Ozone Loss Continue to Challenge Scientists**
by Pamela S. Zurer
Severe Arctic depletion verified, but intricacies of polar stratospheric clouds, midlatitude loss still puzzle researchers.
(*Chemical & Engineering News*, June 12, 1995) / **162**

35. **Ozone-Destroying Chlorine Tops Out**
by Richard A. Kerr
(*Science*, January 1996) / **168**

36. **Superfund Renewal Expected to Be Rocky**
by Lois Ember
(*Chemical & Engineering News*, June 26, 1995) / **170**

37. **Fowling the Waters**
by Jim Mason
Animal factories are the biggest contributors to polluted rivers and streams—bigger than storm sewers, bigger than all industrial sources combined.
(*E / The Environmental Magazine*, September/October 1995) / **172**

38. **Green Revolution in the Making**
by Curtis Moore
Nations like Germany that mandate clean technologies are poised to profit. It's an economic lesson the U.S. has yet to grasp.
(*Sierra*, January/February 1995) / **174**

Section Four: Social Solutions / 181

39. China Strives to Make the Polluter Pay
by H. Keith Floring, Walter O. Spofford, Jr., Xiaoying Ma, and Zhong Ma
Are China's market-based incentives for environmental compliance working?
(*Environmental Science & Technology*, June 1995) / **183**

40. Comparative Risk Assessment and the Naturalistic Fallacy
by Kristin S. Shrader-Frechett
(*Trends in Ecology and Evolution*, January 1995) / **190**

41. Debt and the Environment
by David Pearce, Neil Adger, David Maddison and Dominic Moran
Loans cause great human hardship, but their connection to ecological troubles is hard to prove.
(*Scientific American*, June 1995) / **193**

42. Growing Crops, and Wildlife Too
by Greg Breining
Though far from perfect, the Farm Bill has made the nation's farmers into some of its most important conservationists. Is Congress about to change all that?
(*National Wildlife*, December/January 1995) / **198**

43. Selling Blue Skies, Clean Water
by Jeff Johnson
Will deregulation, pollution prevention, and international competition hold promise or problems for a stagnant environmental compliance industry?
(*Environmental Science & Technology*, June 1995) / **202**

44. How to Make Lots of Money, and Save the Planet Too
(*The Economist*, June 3, 1995) / **209**

45. Forging a New Global Partnership to Save the Earth
by Hilary F. French
An international effort must be made to stabilize the planet before environmental deterioration reaches a point that it becomes irreversible.
(*USA Today*, May 1995) / **212**

46. Ecologists and Economists Can Find Common Ground
by Carl Folke
(*BioScience*, April 1995) / **220**

47. The Man with the Spear
by James Murtaugh
(*Nature Conservancy*, January/February 1995) / **223**

48. The Real Conservatives
by Jim Motavalli
Whatever became of fixing things? A noble tradition is dying, but reuse is still alive and well.
(*E / The Environmental Magazine*, July/August 1995) / **227**

49. New Defenders of Wildlife
by Jeffrey P. Cohn
Practicing conservation and protecting habitat are not usually considered parts of the military's job description.
(*Bioscience*, January 1996) / **232**

50. Three Theories from Economics About the Environment
by J.E. de Steiguer
(*BioScience*, September 1995) / **238**

Answers / 246

Section One

Overview

1

Putting zoo-bred animals back into the wild is a very slow process. Animals such as the golden lion tamarin, the red wolf and the black-footed ferrets find it difficult to survive in the harsh environment of a natural habitat after being in safe captivity. Programs are facing problems such as the animals' reduced reactions to predators and their riendliness with humans. But because of these efforts, these animals are breeding in the wild, and their population is slowly increasing. This second generation now has a greater potential for survival because they are less vulnerable to predators, more territorial, and much more wary of humans.

BACK TO NATURE

Peter Radetsky

You can put a zoo-bred animal back into the wild. But that doesn't mean you're putting back anything like a wild animal.

A small face pokes from between the branches of an oak tree. It has a thick golden mane and looks oddly familiar, like the cowardly lion in *The Wizard of Oz*. Soon it's joined by another maned head, then two, three, four others. The animals are about the size of squirrels, with silky fur and dangling 12-inch tails. They scurry nimbly from branch to branch, 30 feet above the ground. "Look at the monkeys," shouts a grade-schooler in a Washington Redskins cap, dribbling ice cream onto his T-shirt. Seemingly oblivious of the human crowd, the little creatures dart about the treetops, calling to one another with whistles and trills.

These golden lion tamarins are a long way from their ancestral rain forests in Brazil. But they are going back. They were bred here at the National Zoo in Washington, D.C., as part of a plan to rescue the endangered species and return it to its tropical habitat. In the meantime, to help them make the transition from the zoo cages where they were born to the wild that awaits them, they are living on a couple of wooded acres just down the path from the bison exhibit.

This tamarin equivalent of a halfway house was conceived by Ben Beck, a primatologist, and Devra Kleiman, the zoo's assistant director of research, to address a vexing question in conservation biology: Once you've succeeded in breeding an endangered animal in captivity, how do you ensure that the animal will be fit to live in the wild? How much of its natural behavior will survive? The same worry underlies plans to return red wolves to Tennessee's Great Smoky Mountains and to restore black-footed ferrets to Wyoming's plains. For these efforts, the case of the golden lion tamarin is a prelude and an object lesson.

By the 1970s golden lion tamarins had almost vanished from Brazil, victims of their own appeal (the handsome animals were exported as pets) and of rampant deforestation. Hoping to reverse the trend, the Brazilian government set aside a 12,500-acre reserve in the rain forests north of Rio de Janeiro for some 100 wild survivors. In the United States, meanwhile, the National Zoo had become involved in breeding the animals in captivity. At the time, there were fewer than 80 golden lion tamarins in zoos around the world, and they were not doing well—deaths were exceeding births. Kleiman determined that one of their problems was diet. Zoos were feeding their tamarins traditional monkey fare: fruits and vegetables. But in the wild these animals also ate insects and birds' eggs. When, on Kleiman's recommendation, they were fed protein in the form of insect grubs, their health improved. Another problem, Kleiman found, was that because monkeys are usually social animals, zoos invariably caged tamarins in large groups. But if a group contained more than one adult female, Kleiman determined, only the dominant female gave birth. When tamarins were separated into breeding pairs, their birthrate shot up. By 1983 the worldwide zoo population of golden lion tamarins had risen to 370.

The following year, to bolster the wild population, Kleiman and Beck sent 13 tamarins back to the Brazilian reserve. They were in for a nasty surprise: the animals were almost helpless. "We thought that their primary problem would be finding natural foods," says Beck. In fact it was more a case of not knowing what to do with food when they found it. "Imagine a monkey that doesn't know how to peel a banana," Beck says with a sigh.

But the tamarins' main problem—"which we failed totally to anticipate," says Beck—was their disorientation. They were lost in the rain forest. Raised in cages, they simply didn't know how to plot a route through uncharted territory. Furthermore, they were used to climbing on sturdy lumber frames. Natural vegetation, which bent and swayed under their weight, literally floored them—they frequently fell. They preferred to crawl along the ground, a dangerous proposition for a small monkey. One fell prey to a snake, another to a feral dog. Seven others died or disappeared the first year—killed, perhaps, by such other predators as lizards and ocelots, or overcome by starvation, disease, and mishaps. "We had to go back, regroup, and revise our techniques," says Beck.

A first experiment in tamarin jungle-training met with mixed results. At the National Zoo several cages were stuffed with natural, springy vegetation, forcing monkeys to negotiate their way over the plants to find their food. In 1985 Beck's team released 11 tamarins in Brazil, 7 trained and 4 not. "For the first couple of weeks the trained group clearly had an advantage," says Beck. They moved more easily in the trees and found more food. "But the untrained group rapidly caught up," he adds. "In fact, the survival rate was the same for both groups—very low." Only two of the animals survived beyond a year.

Still, it was apparent that the tamarins could learn, and might learn better given more appropriate conditions. "That's how the outdoor exhibit here at the zoo originated," Beck says. Since 1986 tamarin families have lived in the trees in the warm-weather months from May through October. (Insects and fruits, including bananas in their skins, are provided for them in the trees, not on the ground.) Those that take to arboreal living are then transported to the rain forest to tackle the real world. Not only do these animals do better, Beck has found, but their offspring, who receive the benefits of their elders' experience, fare better still. As of this past January, Beck and his team had released 134 tamarins to the forest. Of those, 43 have survived. These 43 pioneers have given birth to 97 babies, of which 70 are still alive, for a grand total of 113 tamarins added to the existing wild population. Some 400 golden lion tamarins now roam the coastal forest of Brazil.

Curiously, says Beck, one thing that tamarins don't forget in captivity is how to recognize their most common predators. "Recognition of aerial predators is inborn," he says. "Anything that flies over, any dark shadow, and they give an alarm call. Then they either drop to the ground or run right to the center of a tree to avoid them. This behavior is genetically hardwired—they don't have to learn a thing about it." Tamarins are somewhat less wary of earthbound predators, perhaps because they can usually count on making a quick escape through the trees. Typically, when a tamarin encounters a threat such as a large snake, it approaches the animal nois-ily, as though alerting its family group to flee. (That first batch of disoriented, ground-hugging tamarins may have come to grief not because they failed to recognize their predators but because they failed to even detect them in time to make their clumsy getaway.)

Red wolves born in captivity don't have to learn to recognize wild predators, either, but for quite different reasons. Nothing in the wild preys on a wolf. Nor do they need to learn how to find food.

They'll readily hunt wild rodents, raccoons, rabbits, deer, even wild pigs. The problem with wolves is that they'll also readily hunt livestock, chickens, and turkeys. If their reintroduction is to be successful, red wolves must adapt to the wilderness, not to the all-too-inviting civilization surrounding it. The key is instilling in the animals a sense of territory and fear of humans.

Red wolves have ample reason to fear humans. By the late 1970s these lanky canids (which once ranged halfway across the country, from Texas to North Carolina) had been driven from their ranges and slaughtered to near extinction. In 1987, however, a federal program to restore the species got underway with the release of some captive-born animals in North Carolina, at Alligator River National Wildlife Refuge. Then in November 1991 a family of four red wolves was introduced as an experiment to Tennessee's Great Smoky Mountains National Park; for the first time in almost a century the howls of wolves were once more heard in the southern Appalachian mountains.

It was not a completely successful debut. Some of the animals weren't sufficiently savvy or cautious—in short, they were not wild enough. A large male took three turkeys from a farm just outside the park, says Chris Lucash, the U.S. Fish and Wildlife biologist who runs the Smokey Mountain project. "It wasn't that big a deal. It's not uncommon for a wild predator to take something like a domestic turkey. The problem was that the farmer came out and chased the wolf, but the wolf didn't leave. He sat down in the woods just outside the garden and ate the bird. When the guy went to work, the wolf came back and took another turkey. By the time we got there he had taken still another one, despite the presence of people and a barking dog—that's not a good wild animal. He had spent too much of his life in captivity. He was too comfortable with people. We recaptured him that day, and I didn't turn him loose again. He was a liability."

As planned, Lucash ended his experiment after ten months and recaptured the rest of the family. He also rethought his strategy, having decided it was necessary to instill in the wolves a sense of territory and a wariness of humans. Now before red wolves taste freedom, they're given an acclimation period in their own lupine halfway house. It consists of a pen 50 feet by 50 feet, with an 11-foot-high fence, set among the maple, oak, and pine trees of the Smoky Mountains. The wolves pass their first year there, amid the scents and seasonal shifts of the forest, mating and giving birth to pups.

Human contact is kept to a minimum. A caretaker who provides food and cleans the pen lives discreetly in a tent some 200 yards away. No visitors are allowed. Hikers or fisherman blundering into the area encounter a sign threatening a $20,000 fine for harassment of an endangered species. During most of 1992 two such pens on the western side of the park, separated by eight miles, provided transitional homes for two families of wolves, each consisting of an adult pair and their four pups.

The idea is to condition the animals to consider this plot their own. Food is plentiful in the Great Smokies, as is space—over 500,000 acres of it. If each group of wolves establishes a defined territory and sticks to it, not venturing into the ranches and farms bordering the park, one of the great hurdles facing the reintroduction will have been surmounted. Lucash envisions as many as eight family groups, possibly 50 animals, roaming the park, coexisting with one another, with farmers, and with the numerous visitors to the area.

Last October he took a step toward that goal by pulling open the gate to one of the pens. "I put a pig carcass outside the pen so they wouldn't just bolt out of the gate and run all over the place," says Lucash. "A week and a half later I gave them another carcass, and three weeks later another one. That gave them time to hone their hunting skills and not starve."

Just as Lucash and his colleagues hoped, the wolves began to consider the pen the heart of their territory. "They just hung out for the first week at the release area," says Lucash. "Then they started going out into the meadow and regrouping at the pen. They left a lot of scent marks there, defining their territory." And they began to hunt. "We saw them standing in a creek with a freshly killed 70-pound wild pig. We were pleasantly surprised by that."

In December Lucash opened the gate of the second pen. That meant 12 red wolves were now loose in country where just two years before there had been none. The strain began to show. "Some of them have been acting a little stupid," says Lucash. "We've seen them on the road. They're not afraid enough of vehicles to satisfy me. I'll probably have to do some negative reinforcement by shooting at them with exploding blank shells."

In January one of the pups released in December strayed out of the park into farm country; he was soon followed by his three siblings. Lucash and his crew returned the animals to the park, only to watch them stray again. The first pup wandered away three times. "They weren't necessarily misbehaving," says Lucash. "It's just that legally we can't let them out of the park. They cross this imaginary line and they're outlaws." Rather than perpetually retrieving them, Lucash decided to return the wandering pups to the pen.

That left eight wolves on the loose, and one of those has apparently made forays outside the park as well, judging from complaints Lucash has received about wolves taking chickens. "I didn't even argue with the farmer who reported them missing—a bus driver claims he saw a wolf with a chicken," says Lucash. "I just paid the farmer for the birds."

Such behavior wouldn't be too surprising in a not-quite-wild wolf. "We knew that the problem we were going to have with these transitional animals was that they were still too accustomed to people," says Lucash. "We can't get around that until we get pups born and raised in the open forest. We're just going to have to work real hard to get the animals through this transition until they start reproducing as real wild animals."

Wyoming Game and Fish Department veterinarian Tom Thorne agrees that keeping animals in a delineated area is the key to releasing them. Thorne is part of a joint venture between federal and state agencies to return black-footed ferrets to America's plains. "If they disperse to the four winds, they might as well be dead," he says. "Even if they escape getting killed, their chances of finding a mate and contributing to a stable population are zero. We want to keep them at the release site for as soon as possible, long enough so that they'll consider it their territory and stick around." A tall order, as Thorne and his colleagues have found out, when you're dealing with creatures as skittery, secretive, and nocturnal as ferrets.

These narrow, skinny two-pound animals are preyed on by coyotes, badgers, and owls, so it's a matter of survival for them not to show themselves. They spend much of their time underground in prairie dog burrows, and prairie dogs constitute virtually their entire diet. Earlier this century you were likely to find black-footed ferrets wherever there were prairie dogs. But farmers destroyed vast networks of burrows by plowing, and the U.S. government (responding to ranchers, who regarded prairie dogs as pests) systematically exterminated them. Ferrets died from eating strychnine-poisoned prairie dogs, and as prairie dog towns dwindled, ferret populations became increasingly isolated and fragmented. In fact, black-footed ferrets were believed extinct until a group turned up in Wyoming in the early 1980s. Beginning in 1985, the last 18 of these animals were rounded up to start a captive-breeding program.

The current plan is to reintroduce the animals to Wyoming, then to Montana and South Dakota, and eventually to the entire West. But bringing them back isn't proving easy. Just keeping track of the nocturnal animals is a challenge. Some are fitted with radio collars, but the collars are a burden to these small animals, and they are designed to disintegrate in about two or three weeks. After that biologists resort to "spotlighting"—sweeping lights across the prairie in the hope of glimpsing flashes of the ferrets' emerald green eyes—and searching the wintry, snow-covered plains for small footprints before the wind erases them.

In addition, the animals' vulnerability to predators has had biologists worried from the start. Had captivity blunted the ferrets' wariness? Could you train them to avoid predators they had never seen? "A ferret has one chance to learn about a predator: its first encounter," explains Thorne. "It either lives or dies. And the difference between living and dying is getting into a burrow fast." In the late 1980s, with captive breeding of black-footed ferrets barely begun, biologists with the U.S. Fish and Wildlife Service in Front Royal, Virginia, were already thinking about ways to improve the animals' chances. Using an unendangered ferret, the Siberian polecat, as a stand-in, they tried some rather fanciful experiments to gauge how well the animals would fare. A badger run over by a pickup truck in Wyoming was frozen and mailed to Virginia, explains Dean Biggins, who designed the experiment with fellow biologist Brian Miller (now at the National University of Mexico). The animal was stuffed by a taxidermist at the Smithsonian and mounted on a remote-control Radio Shack truck chassis.

Robo-badger, as he was called, was used to pursue captive-bred Siberian ferrets living in a pen riddled with burrows to provide escape hatches. To drive home the danger of the situation, the researchers fired rubber bands at the animals with a toy-store gun. For good measure they occasionally dive-bombed the animals with a stuffed owl slung from an ingenious network of pulleys. Even Miller's Labrador, Rosa, was pressed into service, retrieving ferrets in her soft mouth before releasing them unharmed.

Still, when these animals were tracked into the wilderness of Colorado and Wyoming, they fared only somewhat better than those raised in cages. Though trained ferrets were more venturesome than untrained ones, they didn't live any longer—the record was 34 days. It was sobering news, because wild ferrets live for two to three years.

Thorne's team in Wyoming, meanwhile, has decided on a different tack. At the group's ferret breeding facility north of Cheyenne, they've added a series of 22-by-20-foot outdoor pens, each enclosed by a chain link fence sunk 8 feet into the ground. When prairie dogs were released inside them, they quickly established miniature prairie dog towns. These training pens allow families of black-footed ferrets to live, hunt prairie dogs, and raise their young in wildernesslike conditions.

When it comes time to release the animals, they're transported, barking and chattering, inside nest boxes to a windswept prairie called Shirley Basin, some 80 miles north of Laramie. There the team bolts the boxes to protective wire cages. Four-inch plastic tubing, big enough to accommodate a ferret but not a predator, provides safe passage from each cage to a nearby prairie dog burrow. After a ten-day acclimation period, a trapdoor springs open and the ferrets can wriggle along the tube to explore the surrounding plains and the labyrinthine tunnels beneath them. But they always have the security of the cage. If an owl swoops over them when they're on the open plain, they can duck into the tube and back to safety. It's an offer they seem to refuse. Ferrets have been observed returning to the cages for no more than a few days after the trapdoor was opened. Just in case, the team keeps food and water inside them for five days past the last sighting, but by then the animals are long gone, fending for themselves in the prairie dog town and beyond—far beyond.

Last fall 90 captive-bred ferrets were set loose in Shirley Basin. To the biologists' consternation, over half of them lit out for destinations unknown, for all intents and purposes lost forever. ("They suffer from some sort of wanderlust," shrugs Biggins.) Of the 37 ferrets that were radio-collared, at least 10 are known to have been killed, mostly by coyotes. "A hawk or eagle got one," says Biggins. "We found wing prints and tracks in the snow." But at least 16 ferrets are still known to be alive on the site.

The figures may look meager. But they're better than those for 1991, the first year of the release program, when only 4 of 49 ferrets made it through the winter. In fact, the reintroduction team is quite encouraged. Those four original survivors gave birth to six kits, more than doubling their number. If the latest batch does as well, the black-footed ferret has a fighting chance of making a comeback. Thorne, for one, is looking on the bright side. "Several days after the last release," he recalls with gratification, "one of our guys saw ferrets near their cage in Shirley Basin. One was barking at him from a burrow right next door. He was sticking close to his territory, warning the human to get away—just as he was supposed to do." ■

Questions

1. When the tamarinds were taken back to the rain forest what was the main problem they faced?

2. What are two characteristics the red wolf needs in order to adapt to the wilderness?

3. Why are the black–footed ferrets difficult to keep track of?

Answers are at the back of the book.

2

Predicting future events with accuracy helps to set science apart from most other human disciplines. But science can also predict which factors cannot be predicted. This understanding of unpredictability is the basis of chaos. Chaos, we find, characterizes the future of the solar system. Distance, energy, orbit size, orbit shape, and orbit inclination are just a few variables one must include in order to begin understanding chaos as it relates to the solar system. Four hundred years ago we did not know the motions of the planets. Now we have progressed to knowing not only the history of the solar system, but to the knowledge that we cannot predict how the solar system will evolve in the distant future.

Chaos in the Solar System

Neil de Grasse Tyson

The ability to predict future events with precision is what distinguishes science from almost all other human endeavors. Daily newspapers often give dates for upcoming phases of the moon or the time of tomorrow's sunrise. But they do not report news items of the future such as next Monday's plane crash or next Tuesday's closing prices on the New York Stock Exchange. The general public knows intuitively, in not explicitly, that science makes predictions, but it may surprise people to learn that science can also predict that something cannot be predicted. Unpredictability is the basis of chaos. And unpredictability characterizes the future evolution of the solar system.

A chaotic solar system would no doubt have upset the German astronomer Johannes Kepler, who is generally credited with the first predictive laws of physics, published in 1609 and 1619. Using a formula that he derived from planetary positions in the sky, he predicted the average distance between any planet and the sun by knowing the duration of the planet's year. In 1687, Isaac Newton published the *Principia*, which contains the law of universal gravitation from which Kepler's laws can be mathematically derived.

In spite of the immediate success of his new laws of gravity, Isaac Newton remained concerned that the solar system might one day fall into disarray. With characteristic prescience, Newton noted: "The Planets move one and the same way in Orbs concentric, some inconsiderable Irregularities excepted, which may have arisen from the mutual actions of...Planets upon one another, and which will be apt to increase, till the system wants a Reformation." Newton implied that God might occasionally be needed to step in and fix things. The celebrated French mathematician and dynamicist Pierre-Simon Laplace had the opposite view of the world. In his 1799 four-volume treatise *Mécanique céleste*, he declared that the universe was stable and fully predictable. Laplace later wrote, "[with] all the forces by which nature is animated...nothing [is] uncertain, and the future as the past would be present to [one's] eyes." When queried by Napoleon Bonaparte on the absence of any reference to God in his treatise, Laplace replied, "Sire, I have no need of that hypothesis."

The solar system does, indeed, look stable if all you have at your disposal is a pencil and paper—with or without God. But in the age of super-computers, where millions of computations per second are routine, solar system models can be followed for hundreds of millions of years. What thanks do we get for our deeper understanding of the universe?

Chaos—which reveals itself through the application of our well-tested physical laws in computer models of the solar system's future evolution. Today's leading solar system modelers include Scott Tremaine and his colleagues at the Canadian Institute of Theoretical Astrophysics and Jack Wisdom and his colleagues at the Massachusetts Institute of Technology.

Chaos has also reared its head in other disciplines, such as meteorology, predator-prey ecology, and in most other places where there are complex interacting systems. To understand chaos as it applies to the solar system, one must first recognize that the difference in location between two objects—their distance—is just one of many differences that can be calculated. Two objects can also differ in energy, orbit, size, orbit shape, and orbit inclination. It is therefore useful to broaden the concept of distance to include the separation of objects in these other variables as well. For example, two objects that are (at the moment) near each other in space may have very different orbit shapes. Our modified measure of distance would tell us that the two objects are widely separated.

A common test for solar system chaos begins with two computer models that are identical except for a small detail. For example, in one of the models, Earth much recoil slightly in its orbit as a result of being hit by a small meteor. We are now armed to ask a simple question: Over time, what happens to the "distance" between these two nearly identical models? It may remain constant, fluctuate, or increase. If the distance between the two models increases exponentially, then small changes to the system are extremely magnified over time, and the ability to predict future behavior based on well-known initial conditions is compromised. This is the hallmark of chaos. We owe much of our early understanding of the onset of chaos to Aleksander Mikhailovich Lyapunov (1857-1918), a Russian mathematician and mechanical engineer whose 1892 doctoral thesis, "The Stability of Motion," remains a classic to this day. (By the way, Lyapunov committed suicide during the political chaos that followed the Russian Revolution.)

It has been known since the work of Newton that the paths of two isolated objects in mutual orbit, such as a binary star system, can be solved exactly for all of time. No instabilities there. But as more objects are added to the dance card, orbits not only become more complex but also more sensitive to their initial conditions. In the solar system we have the sun, its nine planets, and sixty-plus satellites, along with innumerable asteroids and comets. While this may sound complicated, the story is not yet complete. Orbits in the solar system are further influenced by the sun's loss of 4 million tons of matter every second from the thermonuclear fusion in its core. (The matter is converted to energy that is subsequently released as light from the sun's surface.) The sun also loses mass from the continuously ejected stream of charged particles known as the solar wind. And the solar system is further subject to perturbing gravity from stars that occasionally pass by in their normal orbit around the galactic center.

To appreciate the task of the solar system dynamicist, consider that the equations of motion allow you to calculate, at any given instant, the net force of gravity exerted on an object by all other known objects in the solar system and beyond. Once you know the force on each object, you nudge them all (on the computer) in the direction they ought to go. But the force on each object in the solar system is now slightly different because everything has moved. You must therefore recompute all forces and nudge them again. This continues for the duration of the simulation, which in some cases involves billions of nudges. When you do these calculations or similar ones, you reveal that the solar system's behavior is chaotic: over time intervals of about 5 million years for the inner planets (Mercury, Venus, Earth, and Mars) and about 20 million years for the outer, "Jovian" planets (Jupiter, Saturn, Uranus and Neptune), arbitrarily small "distances" between initial conditions noticeably diverge. By 100 to 200 million years into the model, we have lost all ability to predict planet trajectories.

Yes, this is bad. Consider the following example: The recoil of Earth from the launch of a single space probe can influence our future in such a way that in about 200 million years, the position of Earth in its orbit around the sun will be shifted by nearly 60 degrees. Combine the effects of all past and future launches, and we simply do not know