18,000 light-years on a side. But by the end, it can resolve details as small as 0.3 light-year—about the size of the cloud of comets thought to surround our solar system. "The higher resolution allows them to follow the process in far greater detail, essentially to the stellar scale," says astrophysicist Jeremiah Ostriker of Princeton University.

In this way, the team can track the growth of a nebulous blob until it forms a tight knot ready to spawn a star. The simulation indicated that most such knots were a few hundred times more massive than our sun. The program can't yet track the gas until it becomes dense enough to ignite nuclear fusion. But Norman says, "The most likely result is a star with 10 to 100 times the sun's mass."

Such stars were giants that lived fast and died young, consuming their fuel within a few million years. Then they blew up and began seeding the cosmos with the heavy elements forged in their cores, such as carbon, oxygen, and iron. Those elements grew more abundant with each stellar cycle of birth and death. That explains why subsequent generations of stars were smaller, says Norman. Heavy molecules such as carbon monoxide radiate heat far more efficiently than the molecular hydrogen that filled the infant universe. That allowed smaller masses of gas to lose energy and collapse.

It's still possible that tiny stars could have formed in the first generation if turbulence—a process the current simulation does not capture—split some of the gas into smaller clouds. "That's a possibility, but we have every indication that most of the initial stars were massive," says Norman.

So far, observations support him. Stars smaller than 80% of the mass of our sun would have survived to this day, rationing their nuclear fuel in long, slow burns. But astronomers have searched without success for these primitive stars within the ancient globular clusters that swarm around the Milky Way. A few dim stars contain just a dash of heavy elements—about 1/10,000th as much as the sun. That makes them old, but not first-generation objects.

Despite the uncertainties, the work by Norman's team impresses Ostriker. "This is the best work that has been done on seeing the conditions that led to the formation of the first stars," he says. —**ROBERT IRION**

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CONSERVATION BIOLOGY

A Species' Fate, By the Numbers

A popular approach for predicting a population's survival is coming under scrutiny now that its use in critical decisions on endangered species is on the rise

SAN DIEGO—When the National Marine Fisheries Service (NMFS) announced on 16 March that it was adding nine populations of Pacific Northwest salmon to the endangered-species list, the agency had barely begun to consider the question of how, exactly, to save this regional icon. The fish face threats from many quarters, including water pollution, dam spillways, and logging practices that harm river ecosystems. Which threats should government officials spend precious dollars trying to address? No single field study can provide the data needed to answer this question. Instead, NMFS scientists must rely, at least in part, on a technique called population viability analysis (PVA).

First developed more than 20 years ago, PVA has become "conservation biology's greatest scientific contribution," according to Steven R. Beissinger, an ecologist at the University of California (UC), Berkeley. The technique focuses on the likely fate of a population and what factors can determine or alter that fate. In its most common form, PVA combines stochastic models of population dynamics with field data on a species and its habitat—everything from birth and death rates to the frequency of natural disasters—to predict how long a given population will persist under given circumstances. PVA has had some notable achievements, such as helping to identify measures for boosting grizzly bear populations in Yellowstone National Park. And as one of the few predictive tools ecologists can call on, PVA has become "practically mandatory in planning for endangered species," says Michael Gilpin of UC San Diego.

But increasingly, PVAs are being attacked as too simplistic, overly demanding of data, error-prone, and hard to verify. "Even good PVAs are almost always fraught with very serious statistical problems," says Mark S. Boyce, an ecologist at the University of Wisconsin, Stevens Point. "The confidence intervals are enormous, the error bars explode into the future, and they're very rarely field-tested." Still, Boyce says, ecologists must make do with this imperfect approach to predicting species survival, because it's the best they've got. "At the moment," he says, "there's no other choice."

Under new management. Researchers have used PVA to protect the desert tortoise in the western U.S.

To assess the state of the art of what PVA pioneer Michael Soulé of the Wildlands Project in Hotchkiss, Colorado, calls conservation biology's "flagship industry," 330 scientists gathered here last month for the first-ever major conference on the technique.* They discussed hurdles facing attempts to extend PVA to cover a wider range of species, and how to factor in the behavior of our own species. And, in an important development, one scientist described how he crash-tested PVA models in the lab, a practice that could help ecologists refine the technique.

Growing pains. For decades empirical studies of wildlife populations resembled stock market analyses, with graphs projecting future trends based solely on historical upturns and downturns. That began to change in 1978 when Mark Shaffer, then a Ph.D. student at Duke University, examined the fate of Yellowstone's grizzly bears, which had been on the endangered list since 1967 and were under increasing stress from tourists. His analysis for the first time incorporated randomly occurring demographic and environmental events, such as unusually low birth rates or sparse food supplies, into a computer model of population growth. From this hybrid, Shaffer, now at the nonprofit Defenders of Wildlife, estimated the likelihood that bear populations of a given size would survive over given periods of time. From this he derived the "minimum viable population," which he defined as the smallest bear population with a 95% probability of surviving 100 years.

Shaffer's analysis, coupled with field data, revealed that the foremost factor determining how long a bear population would survive is the death rate of adult females.

* Population Viability Analysis: Assessing Models for Recovering Endangered Species, 15 to 16 March.

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Spurred by this finding, federal officials adopted new rules in 1983 that, among other things, blocked tourists from areas in Yellowstone frequented by mothers with cubs. Since then, the grizzly population has increased 5% per year, and some experts say the bear could be removed from the endangered list. "By all accounts," says Boyce, "the success has a lot to do with the PVAs."

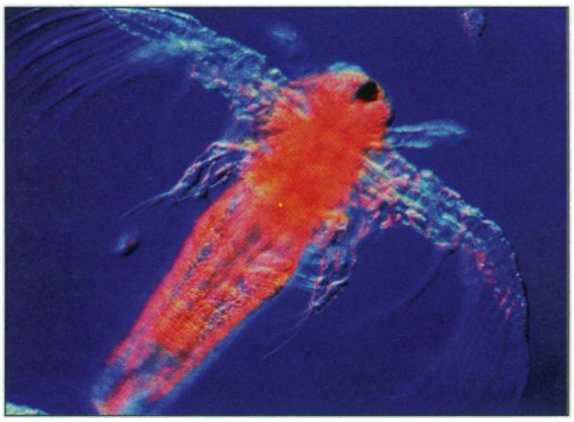
Shaffer's approach appealed to the U.S. Forest Service, which by law must maintain "viable populations" of vertebrates in the national forests (*Science*, 26 March, p. 1996). The agency held PVA workshops in the early 1980s, kindling broader interest in the technique. Subsequently, the appearance of software—freeware, at first, then commercial programs—for running PVAs on a personal computer got everybody doing it. Some ecologists, however, started using the models willy-nilly, even when data were lacking. Barnstorming consultants "would fly in, get together local experts in a species, try to take the information and plug it into the software, and get a result," Beissinger complains. These often slapdash efforts, he says, triggered a backlash from wildlife managers and "did not do PVA any good."

Beissinger and fellow Berkeley ecologist Dale R. McCullough set up last month's conference in part to address these concerns. A main thrust was stretching PVAs to cover a broader range of life-forms—a daunting task, argued Daniel F. Doak of UC Santa Cruz. Endangered plants, he noted, might seem to be obvious subjects for PVA, but their life cycles can defy analysis. For one, legions of individuals can lie dormant for years in natural seed "banks." Impossible to measure and therefore invisible to a routine PVA, these banks can germinate en masse after unpredictable events like floods or fires, confounding PVA predictions. Doak was "not optimistic" that the problem could be solved.

Scientists have also struggled with what some regard as a glaring oversimplification in most PVAs: The models ignore the genetic problems of small populations, such as the accumulation of harmful genes or the loss of beneficial gene variants. Zoos and captive-breeding programs, which work with very small populations, would like to include these factors in PVAs. Russell Lande of Oregon State University in Corvallis argued that ecologists should seek ways to modify PVA equations to reflect the loss of genetic fitness. Indeed, he suggested, negative "genetic factors may be operating at larger population sizes than we thought." But Beissinger and Berkeley colleague M. Ian Westphal argued last year in the *Journal of Wildlife Management* that eroding genetic fitness is unlikely to be the deciding factor in a population's fate—thus modelers should continue to ignore it. The importance of genetics in PVA, says Boyce, is the "hottest debate" in the field.

In perhaps the most ambitious effort to broaden PVA, ecologists are trying to factor humankind into their models. Because hunting, habitat loss from development, and other human acts often are the biggest threats to a species, these researchers believe that neglecting social forces in modeling a species' fate is nothing less than foolish. In one ongoing effort, Philip S. Miller and his colleagues at the World Conservation Union are augmenting PVAs with estimates of human population growth and land use to model how the habitat destroyed in Rwanda's civil war may affect mountain gorilla populations.

Test to extinction. Even as modelers seek ways to make PVAs more complex and realistic, critics decry a lack of empirical verification. A key problem is that no ecologist wants to experiment with natural populations in danger of extinction. If PVAs predict a rapid demise, says Gilpin, "we immediately take steps to make sure those predictions don't come true."



Here today. An innovative experiment has tested PVA by watching how lab populations of brine shrimp go extinct.

One way to sidestep this constraint is to arrange lab extinctions. At the meeting, ecologist Gary E. Belovsky of Utah State University in Logan unveiled results from the first long-term extinction experiment. For 4 years, Belovsky's team monitored more than 600 containers of brine shrimp, keeping track of how long each population would last before going extinct. Inventorying each population every 2 to 3 days, they eliminated the sampling errors that plague ecologists in the field. The experiment hinged on the initial complement of adults in each population, as well as a container's carrying capacity, set by the food supply. Belovsky spiced some containers with environmental stochasticity by randomly varying the food supply, creating more true-to-life conditions.

After the final population winked out last December, the Utah State team compared the results to predictions from five PVA models, including two software packages. Under stochastic conditions, for example, most models underestimated the average time a brine shrimp population lasted—that is, the models predicted that the populations were less resilient than they actually were. In addition, the initial population size, a focus of many PVAs, turned out to be less important than the container's carrying capacity in determining persistence. Belovsky found that simpler models performed better, which some ecologists took as a hint that making PVAs more complicated may backfire.

Despite PVA's spotty showing, Belovsky says he's not ready to abandon the technique. "We might like to think these results would carry over to other species," he says, "but we just don't know." He plans to take his extinction experiments a step further by adding corridors between the containers, creating a set of distinct brine shrimp populations in linked habitat patches—a metapopulation—that will allow migration and will resemble real life more closely.

Scientists agree that they must improve PVAs quickly, as the technique is likely to gain wider use in federal policy-making on the fates of species. In deciding to add the nine salmon populations to the endangered list, says Robin Waples, director of NMFS's Conservation Biology Division in Seattle, the agency used the "smattering" of existing PVAs but relied on other information, including expert opinion. Restoring the populations, an undertaking that could take years and cost billions of dollars, will require examining all the factors that limit recovery. Waples hopes PVAs will play a bigger role as the agency ferrets out the "the baddest factors on the block."

With the future of Pacific salmon and other important species hanging in the balance, Katherine Ralls of the Smithsonian Institution, Beissinger, and two other ecologists issued a plea to the community to help draft guidelines for conducting PVAs and quality standards for evaluating them. Ralls suggests, for instance, that ecologists make it a common practice to ignore all models lacking error bars or discussions of the limits of their data and conclusions. It may take some time to forge a consensus, but Beissinger says he's confident that guidelines and standards will emerge. No doubt, he concedes, it's time to refurbish the 20-year-old technique. But, he adds dryly, "it is also notable that none of us are ready to get rid of PVA."

—CHARLES C. MANN AND MARK L. PLUMMER

Mann and Plummer are the authors of *Noah's Choice*.

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