Scientists are waging a two-pronged assault on the goats, rats, weeds, and other exotic species that threaten the fabled archipelago's flora and fauna

Galápagos Takes Aim at Alien Invaders

Venturing across a lava isthmus, the first goats reached northern Isabela Island, an uninhabited section of the largest island in the Galápagos, in the early 1980s. Since then, that handful of invaders has exploded into a marauding troop of 100,000 that has devoured the lush vegetation carpeting the flanks of Alcedo Volcano. Their food source converted to arid grassland, the local population of 3000 giant tortoises is facing an uncertain future.

Trouble spots. Some of the exotic species plaguing biodiversity in the islands that inspired Darwin's theory of natural selection.

But the goats' days are numbered. Early next year, a SWAT team of up to 100 sharpshooters plans to descend on the volcano and kill every last goat—even if it means dangling from helicopters to get a clear shot.

Although animal rightists may wince, to biologists, the planned Isabela goat removal is no less than a battle to save the Galápagos' largest remaining population of giant tortoises, an icon of the famous archipelago 965 kilometers off Ecuador's coast. Indeed, a war is raging in the Galápagos, and feral goats are not the only species targeted. Also in the cross hairs are imported cats, pigs, fire ants, weeds, and many other invasives that are considered the number one threat to the extraordinary diversity of birds and reptiles that inspired Darwin's theory of natural selection.

The brainchild of scientists and managers at the Galápagos' Charles Darwin Research Station and the Galápagos National Park Service, this project developed over the past 5 years is one of the most ambitious ever to combat invasive species. With $18 million over 6 years from the United Nations and World Bank–run Global Environment Facility (GEF) and an expected $19 million from other sources, biologists and park staff will use a combination of brute force, high-tech gadgetry, and cutting-edge science to wipe out some alien species, make a dent in other populations, and bolster controls to keep other exotics out.

The scientists believe that eradicating the most troublesome species all at once—different species are a problem on different islands—is the only way to stop the destruction of the Galápagos. And they're attacking the problem from all angles, from supporting a clampdown on imported goods that could carry in new species to enlisting the help of the islands' villagers. They know some steps will be controversial but hope this holistic approach will set an example for other places battling invasives, especially developing countries, where poverty poses an especially big challenge to conservation. "There's a tremendous chance to see how all the elements of this package can work together," says Robert Bensted-Smith, director of the Charles Darwin Research Station. It also offers ecologists a chance to see what happens when major players are suddenly plucked out of an ecosystem.

Prominent biologists are cheering them on. "It certainly appears to be an important project … in view of the biological uniqueness of the Galápagos and what is at stake," says ecologist Hal Mooney of Stanford University. But some experts question Ecuador's odds of success. "It's not a simple problem, and they need a very long-term commitment by the government. But I don't know if they can necessarily afford it," says Clifford Smith, a botanist who recently retired from the University of Hawaii.

Space invaders

The first invasives arrived with sailors and whalers in the early 1600s—goats, rats, dogs, and cats that came along onboard. Settlers in the 1800s added more animals to the mix. As they escaped into the wild, feral populations grew, sometimes popping up on several islands, as the goats did. The damage they inflict is enormous and varied. When pigs and goats destroy native vegetation, for example, they wipe out not only food sources but also foliage that shades temporary rain pools and regulates temperatures crucial to reptile egg development. Pigs, dogs, rats, and cats also feast on lizards and the eggs and hatchlings of imperiled endemic species such as dark-rumped and Galápagos petrels, mangrove finches, tortoises, and snakes. Even more insidious in the long run are such insects as fire ants and weedy plants that can quickly blanket a patch of land and "change the whole basis of the ecosystem," says Bensted-Smith.

MAP: ALEX TAIT/EQUATOR GRAPHICS INC.

The archipelago is lucky in one sense: Unlike Hawaii and other islands that have also been inundated with exotic species, it was invaded relatively recently. So although several tortoise species were nearly extinct by the time of Darwin's 1835 visit, 95% of all original species remain. Also working in its favor is that the Galápagos has a relatively small population—16,000 people on just four of the 19 islands—and 97% of the land is park, protected from human activity.

The park service and research station have been battling invasives since they were set up in the 1960s, occasionally ridding small islands of goats or dogs. Erratic funding meant they weren't always able to finish the job, however. In the last 15 years, moreover, the exotic species problem has worsened as immigrants, attracted by the booming tourist trade and fisheries, flood in from mainland Ecuador. The traffic in tourists and immigrants brings more cargo and fresh produce that can carry stowaway species. The latest newcomers include the cottony cushion scale insect, a notorious pest that's now attacking at least 50 species of endemic plants. Frogs, aided by an unusually wet El Niño year that helped them survive in cargo, showed up in 1997 "for the first time since the islands arose out of the sea millions of years ago," says Marc Patry of the station. Over the last decade, the number of problem invasives has climbed to at least 60 plants, 15 vertebrates, and six insects.

Battle lines drawn

The new war plan has been gathering steam for the last few years, and researchers began testing it in February 2000 with several pilot projects funded with $4 million from Ted Turner's U.N. Foundation. Now, with $18 million on its way from GEF through the U.N. Development Foundation, scientists and park managers are concentrating on the most destructive species. Topping the most-wanted list are Isabela Island's goats. Park staff plan a $6 million eradication "on a larger scale than has been attempted anywhere else," says Bensted-Smith. They're borrowing techniques from New Zealand and Hawaii, which also have a long history of coping with island invaders. Over several weeks, riflemen will shoot the easiest targets and use the Global Positioning System to map goat positions. Sharpshooters in helicopters will then scour the rocky volcanic terrain, and trained dogs and radio-collared "Judas" goats will track down missed animals.

Also under fire are feral cats on Baltra Island and black rats on several islands. Some cats will be radio collared so scientists can find where their brethren are hiding. The invasives team hopes to rid four islands of two alien birds, rock doves—which live in towns—and smooth-billed anis. These intruders are competing with native birds for food and are suspected of spreading diseases. All will be put down in "as humane a way as possible," says station vertebrate biologist Howard Snell, using high-powered air guns, traps, and nonpersistent poisons. Team members will come back every few months to check for surviving aliens. Poisons, together with brush clearing, will also be used to eradicate some of the worst invertebrates, such as the little fire ants that swarm over 18 hectares on Marchena Island, pushing out other insects and threatening the nests of masked boobies.

Stemming an invasion. Park scientists and staff hope to wipe out destructive nonnative species such as black rats (*lower left*), iguana-eating cats, and vegetation-destroying goats and pigs (*inset*, trees protected by a goat fence).

The project has a heavy research component as well. In beach areas where wild pigs prey on the nests of green sea turtles and giant tortoises, scientists are comparing several approaches to boosting reptile numbers: killing pigs, incubating eggs in cages, and simply protecting nests with netting. And to kill black rats without harming the native rice rats, the researchers have designed an elevated bait station that only black rats seem to climb.

The invasives team faces an uphill battle in trying to wipe out quinine, a tree native to the Ecuador mainland that has covered the highlands of Santa Cruz with a dense canopy. Eradicating a well-established plant invader would be a first in the annals of exotic plant species, says station botanist Alan Tye: "We are trying to find out whether it's feasible." His team is studying the reproductive rate of quinine and how long its seeds remain viable in soils; depending on the answer, regular weeding and spraying with an experimental brew of herbicides might eventually eliminate all seedlings once the adult plants are gone. "It may take 5 years, it may take 15 years," Tye says. Far easier, hopes Tye, will be tackling 30 smaller plant invasions of such species as kudzu and water hyacinth.

The second prong of the government's attack is to put teeth into a 1998 law that limits immigration to the islands and sets up a quarantine and inspection system to keep invasives out (*Science*, 20 March 1998, p. 1857). But with 36 inspectors still learning the job—the first was hired in 1999—the fortress is far from impregnable. Inspection of travelers' bags on the mainland and island is "turning up an awful lot of stuff" such as stashed fruit and a few guinea pigs, says Snell, "but there's still some getting through."

The plan won't work, Smith and others agree, without the participation of the local populace. The scientists of Galápagos know that all too well: Their station has been attacked three times over the past 6 years, most recently last December, by fishers protesting fishing quotas for sea cucumbers and spiny lobsters (*Science*, 15 December 2000, p. 2059).

So far, the reaction to the invasives program has been decidedly more positive. There has been some grumbling about the inspection system, but mostly because inspection officers need more "public relations" training, says Michael Bliemsrieder, coordinator for the station's UN Foundation project. The team has also launched a pilot educational effort to

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encourage Galápagos farmers to grow more produce, which should both cut down on imports of produce that can bring in aliens and also keep invasive weeds from spreading beyond little-used fields. One sign of success, Snell says, is that last month villagers cooperated when the invasives team eliminated every rock dove they found in one town on Santa Cruz, except for a few owned by one holdout family.

Victory?

Even with local support, the challenges are enormous. Poverty is a constant pressure. And perhaps no country has attempted anything this comprehensive before, says Bensted-Smith, with a program that not only seeks to wipe out major invasive species populations but halt human immigration as well. But then, no developing country, anyway, has had so much money before either. "The added funding should make a huge difference in what Galápagos can manage to do," says Lloyd Loope, an invasive-plant expert with the U.S. Geological Survey in Hawaii. And to make sure these actions don't die out in a few years for lack of funds, the plan calls for setting up a $15 million endowment for the station's conservation efforts from the GEF grant and other sources.

And what will happen to the Galápagos ecosystems if the project succeeds? Some should spring back, says Bensted-Smith. Once the cats are gone on Baltra, for instance, snakes, land iguanas, and native doves should flourish. And vegetation on northern Isabela should come back right after the goats are gone. However, on other islands that have both goats and invasive plants, the weeds could take over after goats are removed if land managers don't intervene, perhaps by planting native species. And on Pinta Island, the "solution" has created a new problem. After the goats were removed, vegetation returned—with a vengeance. The island historically was grazed by giant tortoises—but only one is left, Lonesome George. So the biologists are debating whether to put captive-bred tortoises of a different subspecies on the island so it will have enough herbivores.

Even if the plan is a resounding success, Charles Darwin Station scientists say they don't expect to claim victory. For one, their plan targets only "a small percentage of the invasive species that occur on the Galápagos," says station biologist Brand Phillips, albeit the most destructive ones. And unlike an oil spill, he says, keeping invasive species in check "is a permanent situation."

–JOCELYN KAISER

MEETING NORTH AMERICAN PALEONTOLOGICAL CONVENTION

Fossils With Lessons for Conservation Biology

BERKELEY, CALIFORNIA—This quadrennial meeting regularly runs the gamut of life history, but this year's convention, from 26 June to 1 July, featured an emphasis on research with relevance to problems of today, such as invasive species and the decline of coral reefs.

Big Clams Make Good Invaders

When exotic species invade new territory, trouble may ensue—or it may not. In the sea, some creatures that humans intentionally or unwittingly moved to new homes have turned conqueror, wreaking ecological devastation on marine habitats. Others, however, fail to thrive. Why the difference? Studies haven't found a hallmark of modern marine invaders that can predict their success. At the meeting, however, a trio of paleontologists showed that—for ancient clams, at least—a warning sign of a potentially successful invader may be its size.

By analyzing millions of years' worth of invasions recorded in the marine fossil record, David Jablonski of the University of Chicago and his colleagues—Kaustuv Roy of the University of California (UC), San Diego, and Jim Valentine of UC Berkeley—found that bulkier clams were more likely than small clams to have expanded their geographic range. That held true both during the ice ages of the Pleistocene and after the Cretaceous-Tertiary mass extinction 65 million years ago. "This suggests we're picking up a general pattern, and that range dynamics of fossil species can provide insights and perhaps predictions for human-mediated biotic interchanges as well," Jablonski says.

Jablonski, Roy, and Valentine started by compiling a database of sites where 216 species of marine clams along the California coast were known to have lived during the middle and late Pleistocene. Since then, 26% of the species have changed their range by at least 1 degree of latitude, as the team will describe in an upcoming issue of *Ecology Letters*. Then the paleontologists looked for ways in which successful invaders differed from other species in their native habitat that didn't spread out.

Muscling in. Large bivalves, such as *Mytilus edulis*, appear to have an edge in invading new habitat.

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What made the invaders unique, it turned out, was not life habits—for example, whether they lived on the sea floor or embedded in the sediment—or even reproductive traits such as spawning free-floating larvae. But on average, the invasive taxa were larger than species that didn't expand their turf. "It seems that size really does matter when it comes to geographic range shifts in the Pleistocene," Jablonski says.

The same pattern held when the group examined biological invasions that took place in the Gulf Coast after the Cretaceous-Tertiary mass extinction, 65 million years ago. It was also true when they compared the median size of 25 successful recent marine bivalve invaders, compiled by Jim Carlton of Williams College in Williamstown, Massachusetts, to 914 marine bivalve species native to the northeast Pacific shelf. All together, Jablonski says, the three data sets imply that large bivalves are better than small ones at exploiting good habitat as it opens up. A possible reason for their success is that larger bivalves tend to produce more eggs and gametes—and consequently more larvae that can colonize new habitat.

"This is really a first for the marine realm," says Ted Grosholz, a marine and invasion biologist at UC Davis. Most studies of modern marine invaders, Grosholz says, have compared the size of invaders to that of other taxa in their new habitats—not the ones they left. That's misleading, because exotic marine species of all sorts tend to get bigger after invading a new ecosystem. And that, in turn, makes it hard to say whether size gave them an advantage to start with.