

circumstances favourable to the sustainable management of Galapagos, and is encouraged by the positive attitude on the part of international cooperation organizations. The openness shown provides a grand opportunity to discuss, determine and implement the fundamental changes required to ensure long-term sustainable development of the islands. The WH Committee decision to declare Galapagos as heritage in danger should be understood as Ecuador's opportunity to call on the national and international community to take up new challenges, based on

a shared understanding of the problems, opportunities and possibilities for the future of the islands.

LITERATURE CITED

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THE RESTORATION OF GIANT TORTOISE AND LAND IGUANA POPULATIONS IN GALAPAGOS

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SUMMARY

The giant tortoise *Geochelone* spp. and land iguana *Conolophus subcristatus* programs of the Charles Darwin Foundation and the Galapagos National Park Service are two of the longest running and most successful conservation programs in the archipelago. Both involve a combination of captive breeding and rearing, repatriations, protection of nests in the field and introduced animal control. They have resulted in larger and healthier populations on several of the islands. This success was accomplished through the integration of scientific research and natural resource management.

RESUMEN

La restauración de las poblaciones de tortugas gigantes e iguanas terrestres en Galápagos. El programa para las tortugas gigantes *Geochelone* spp. e iguanas terrestres *Conolophus subcristatus* de la Fundación Charles Darwin y el Parque Nacional Galápagos son dos de los más largos y exitosos programas de conservación en el archipiélago. Ambos involucran una combinación de reproducción y crianza en cautiverio, repatriación, protección de nidos en el campo y control de animales introducidos. Poblaciones más grandes y sanas en varias de las islas han sido el resultado. Este éxito fue logrado por medio de la integración de la investigación científica con el manejo de los recursos naturales.

INTRODUCTION

The rearing and repatriation of giant tortoises *Geochelone* spp. began at the Charles Darwin Research Station (CDRS) in 1965 and is one of the longest running and most successful programs of the Charles Darwin Foundation (CDF) and the Galapagos National Park Service (GNPS). This program, as well as the land iguana *Conolophus subcristatus* program that began in the 1970s, exemplify many of the most important aspects of the missions and strategic lines of action of these two institutions, including:

- conservation and restoration of species and habitat;
- integration of research and management;
- collaboration with other institutions, including with each other;

- involvement of visiting scientists and consultants;
- education and training, via the volunteer and scholarship program;
- community involvement, such as with the tortoise programs in Isabela;
- tourism, with rearing facilities and corrals of adult tortoises attracting many visitors;
- international workshops and resulting plans of action, such as the 1988 Herpetology Workshop;
- threatened species work catalysing invasive species management programs.

A primary threat to the terrestrial fauna of Galapagos is introduced species, including competitors, predators, and disease, which impact the populations directly and also indirectly through habitat destruction. Growth in

tourism and the related rampant growth in the resident human population combine to increase the threat to native and endemic species not only through the increased risk of new introductions, but also through associated problems, such as development, consumption and waste generation.

Of all of the Galapagos species that were over-exploited historically, giant tortoises were the most affected. Once exploitation by humans decreased, they were then under attack by a myriad of introduced species. Land iguanas, on the other hand, were never a major target for exploitation. However, once feral cats *Felis catus* and dogs *Canis familiaris* entered their domain, their survival was at risk.

THE GIANT TORTOISE PROGRAM

Giant tortoises were among the most devastated of all species in the Galapagos Islands. Only the endemic rice rats (Tribe Oryzomyini) were hit harder, with the majority of species now extinct. Humans first exploited giant tortoises as food; a practice that continues today at a much lower rate. In later years, they were harvested for oil. Some introduced species (primarily rats *Rattus*, pigs *Sus scrofa*, dogs and the *Solenopsis* fire ant) prey on tortoises (particularly eggs and young), while others (goats *Capra hircus* and donkeys *Equus asinus*) damage or destroy tortoise habitat.

With the establishment of the Galapagos National Park and the CDF in 1959, a review of the status of the tortoise populations began. Only 11 of the 14 original populations remained and most of these were endangered if not already on the brink of extinction. The breeding and rearing program for giant tortoises began in response to the condition of the population on Pinzón, where fewer than 200 old adults were found. All of the hatchlings had apparently been killed by introduced black rats *Rattus rattus*, for perhaps more than a century. Without help, this population would eventually disappear. The only thing saving it was the longevity of the tortoise. The rearing program began with the first transfer of eggs from Pinzón to the new tortoise center on Santa Cruz in 1965. In 1970, the first 20 tortoises were repatriated to Pinzón after they had reached an age and a size at which they were considered "rat-proof."

Within a few years, several other tortoise populations were included in the program. Other than the Pinta population, where only one tortoise remained (Lonesome George), the Española population, with only two males and 12 females, was the only population on the brink of extinction. The 14 tortoises eventually found on Española were brought into captivity between 1963 and 1974, and the rearing center also became a breeding center. Eggs and hatchlings were brought from natural nests in the wild from Santiago, Santa Cruz, Isabela (Cerro Azul, Sierra Negra, and Wolf volcanoes), and San Cristóbal. Problems in these populations included low population numbers,

nest destruction by pigs, dogs and *Solenopsis*, habitat destruction by goats and poaching by fishermen and residents.

The tortoise program is one of the best examples of the integration of research and management to achieve conservation goals, attained through cooperation between the CDF and the GNPS. In the 1960s, the research was aimed at determining the status of the populations. Fieldwork identified the threatened populations and the level at which they would be included in the program (breeding population in captivity, tortoise eggs and young brought into captivity, or nest protection or pig control in the field). In the 1970s, the field research began to include behavioral study, to determine the requirements for successful breeding, nesting, and rearing. These results were then incorporated into the management practices at the tortoise center. In the 1980s, experiments in the center focused on determining the best incubation and rearing procedures, with the results also immediately incorporated into the program.

In 1988, the CDF and GNPS hosted an international workshop "The Herpetology of the Galapagos Islands", to review the history of herpetological research and management in Galapagos and develop recommendations for the future. Over 70 scientists, administrators, naturalists and resource managers participated. A series of specific conclusions and recommendations resulted, many of them directly applicable to the breeding and rearing programs. They provided a framework for planning, prioritizing, and implementing research and management for the next decade and beyond.

By 1990, the center on Santa Cruz included tortoises from Española, Pinzón, Santiago, and occasionally Santa Cruz. Wolf Volcano tortoises were removed from the program when more extensive fieldwork demonstrated that the population was much larger than originally believed. Transferring eggs and hatchlings from southern Isabela populations was put on hold in the early 1990s while a second breeding and rearing center was built in Puerto Villamil, Isabela. This center was originally planned during the wildfire of 1985 but was not fully operational until the wildfire of 1994, which coincided with an increase in poaching of tortoises in Isabela. GNPS and CDF personnel took advantage of the focus on the fire to inform the world of the threat from poaching. In addition, helicopters used in fire-fighting were also employed to evacuate tortoises from nearby areas on Sierra Negra where they were threatened due to illegal hunting (but not fire). The Isabela tortoise center houses both breeding adults and young tortoises from southern Isabela.

San Cristóbal tortoises were eliminated from the program on Santa Cruz in the early 1980s when the local human population on that island successfully eradicated feral dogs, the primary cause for the population decline. In 2003, a breeding and rearing center was established at Cerro Verde on San Cristóbal to house some tortoises and to help increase the population.

With improvements in methods resulting from the experiments in the 1980s, the tortoise program had even greater success in the 1990s. Routinely, 500–700 young tortoises (hatchlings to three-year-olds) were reared annually in the center; prior to 1991, the average had been 332 (range 53–462). Average mortality of young tortoises in the center was reduced to <3 % per year, whereas in the 1980s it had been 18 % (range 4.2–31.8 %). The almost factory-like production of young tortoises allowed for the expansion of the program. Areas that received more attention during the 1990s included nutrition and general health, genetic analyses, and expansion of the program in southern Isabela. Much of the work was accomplished with the help of consultants and visiting scientists.

The situation of Lonesome George, the last known survivor of the Pinta population, became of primary concern during the 1990s. Unlike the other tortoises in the center, George became severely overweight. At the end of the 1980s it became apparent that George had to go on a diet. Since that time, veterinarians and nutritionists have examined him periodically and personnel of the center have implemented their recommendations. George was put on public view in a new corral with two females that were brought from Wolf Volcano (thought at the time to be the population most closely related to Pinta tortoises). Genetic analyses have now determined that Pinta tortoises are most closely related to Española tortoises and the replacement of the Wolf females with Española females should be considered. However, after 15 years with no results, the two Wolf tortoises nested in July–August 2008. From the three nests produced, 16 eggs have been placed in the incubators (14 are considered fertile) and are expected to hatch before the end of the year.

Overall, the tortoise program is a huge success. In 1990, the first nests of the repatriated tortoises on Española were found, and the first live hatchlings in 1991. The old tortoises in the breeding center of Santa Cruz have grand-tortoises! The 1000th tortoise was repatriated to Española in March 2000. By early 2007, more than 4000 tortoises had been repatriated to their island of origin (Table 1).

Evaluations in the 1990s of the populations on Pinzón and Española indicated 68–77 % survival of repatriated

tortoises on Pinzón and at least 55 % on Española. These are high survival rates for a repatriation program, important factors being that the majority of the natural habitat is still intact, and that the tortoises are reared in semi-natural conditions similar to their native islands.

Genetics have also begun to play an important role in the repatriation program. Research on Española has indicated that the program has resulted in high levels of inbreeding resulting in low levels of genetic variation. Also, a hybrid tortoise, from an Española female and a Pinzón male, has been identified on the island. This suggests that a Pinzón male was inadvertently repatriated to Española in the early years of the program. These results demonstrate the value of rigorous research and of incorporating modern techniques.

Key to the ultimate survival of the giant tortoises is the elimination of introduced mammals, both predators and competitors. On Española, goats, the only introduced mammals, were eradicated in 1978. During the first decades of the program, the other populations were under constant threat from introduced mammals. To support the repatriation program, tortoise protection was carried out in the nesting zones of Santa Cruz, Santiago and southern Isabela. Pigs were regularly hunted during the nesting and hatching seasons. Nests were protected from pigs by constructing temporary rock walls around them.

By the early 1990s, the tortoise population on Alcedo Volcano, one of the largest and healthiest populations in the archipelago, was in trouble. A few goats had crossed the Perry Isthmus, a natural barrier between northern and southern Isabela, more than 15 years previously, and by 1990 their population was exploding and prime tortoise habitat was disappearing at an alarming rate. Worry over the future of the tortoise population spurred a “tortoise summit” held in England in April 1995. This was followed by an international workshop in 1997 to plan the eradication of goats from northern Isabela; Project Isabela was the result. Completed in 2006, Project Isabela achieved the eradication of goats from Pinta, Santiago, and northern Isabela, pigs from Santiago, and donkeys from Santiago and northern Isabela. These successful eradications have had a positive impact on the tortoises and their habitat.

In 2007, an international workshop was held to examine the potential eradication of introduced rodents from the archipelago. The resulting plan is aimed primarily at the eradication of rats from Pinzón. With the eventual success of Project Pinzón, yet another tortoise population will be out of danger and will no longer need the protection of the rearing and repatriation program.

THE LANDIGUANA PROGRAM

In 1959, the status of the extant populations of land iguanas was considered good. Then in 1975, two populations on different islands (Cerro Cartago on Isabela and Conway Bay on Santa Cruz) were decimated in less than six months by feral dog packs. Unlike tortoises, adult iguanas are not

Table 1. Number of giant tortoises repatriated by population and decade, 1970 to 2008.

Population	Decade				Total
	1970s	1980s	1990s	2000–2008	
Española	79	208	696	499	1482
Pinzón	182	86	244	40	552
San Cristóbal	42	13	0	0	55
Santa Cruz	0	67	28	269	364
Santiago	115	90	282	129	616
Cerro Azul (Isabela)	103	102	8	371	584
Sierra Negra (Isabela)	0	51	52	253	356
Wolf Volcano (Isabela)	14	23	3	0	40
Total	535	640	1313	1561	4049

predator-proof. Saving them meant removing them from their natural habitat until dogs were eliminated.

A breeding and rearing center was quickly established, but it was not large enough for all the adults. A management technique used only once before in Galapagos, in the 1930s, was implemented. Thirty-eight Santa Cruz iguanas, about half of the original group brought to the center, were released on the small islets of Venecia off the northwest coast of Santa Cruz. This semi-captive population lived under natural conditions, but the islets had no large areas suitable for nesting. Approximately 100 m³ of soil was moved to Venecia from Santa Cruz and an artificial nesting area built. The population thrived. The iguanas on Venecia breed and juveniles are then repatriated to Santa Cruz. The transfer of iguanas from Venecia to Santa Cruz continues today, approximately every three years.

Knowledge gained in the tortoise center was applied to the iguana center. However, iguanas are much more difficult to maintain and breed in captivity, and field research and experiments in the center were critical to the success of the program. Of primary concern were the physical conditions of the cages and incubation techniques, including temperature and water potential of the substrate. Experiments resulted in the application of the most successful techniques.

However, by the 1990s, the captive land iguanas were in poor condition and not breeding. An animal nutritionist was brought in to review their diet. He developed a diet plan for the iguanas based on previous work with green iguanas, using lentils, quinoa, vitamins, minerals, and other ingredients. Within a short time, the iguanas became healthier and mortality rates declined.

Unlike tortoises, the young land iguanas could not be repatriated to their original habitat unless the introduced predator problem was solved. Dogs eat adult as well as young iguanas, while cats eat only young animals. Once feral dogs had been eliminated on both southern Isabela and northwestern Santa Cruz, iguana repatriations were generally successful (Table 2). Today, both of these populations appear to be healthy. However, cat control trips are carried out periodically to ensure successful recruitment into the populations.

The land iguanas of Baltra have a very different history. Historically, the Baltra iguanas were the largest in the archipelago. However, when the Hancock Expedition visited the island in 1932 and 1933, the iguanas appeared malnourished. Introduced goats had devastated the vegetation. In an attempt to help the iguanas, members of the expedition transferred 70 iguanas to North Seymour, the island to the north of Baltra where there were no land iguanas and no goats. Within 20 years, the iguanas on Baltra disappeared due to a combination of habitat destruction resulting from the construction of the U.S. air base in World War II, predation by dogs and cats, and competition by feral goats. The informal experiment of the Hancock Expedition had saved the Baltra land iguana from extinction.

Table 2. Number of land iguanas repatriated by population and decade, 1982 to 2008.

Population	1980s	1990s	2000–2008	Total
Cerro Cartago (Isabela)	324	70	0	394
Cerro Dragón (Santa Cruz) ¹	184	111	101	396
Baltra	0	94	326	420
Total	508	275	427	1210

¹Includes repatriations to Conway Bay, Cerro Dragón, and Cerro Montura, all in northwest Santa Cruz. Some of the repatriated iguanas in this population came from the semi-captive population on Venecia.

In the 1980s, iguanas from North Seymour (where the population seemed to be in decline) were brought to the breeding and rearing center, with the idea of eventually repatriating the young to Baltra. Given that Baltra has two military bases, air force and navy, iguana repatriations required the collaboration not only of the CDF and GNPS, but also the Ecuadorian Armed Forces. The first 35 young iguanas were released in June 1991. In total, 420 iguanas have been repatriated to Baltra and their survival rate appears high. Recent surveys have shown that both populations, Baltra and North Seymour, are healthy and increasing.

In response to the nutritional problems encountered in the center in the 1990s, a technique similar to that used for tortoise populations was implemented for the Baltra/North Seymour population. Nests were located on North Seymour and eggs and/or hatchlings brought to the center near the end of the incubation season, thus eliminating the need to maintain adults in captivity. The young were reared in captivity during their most vulnerable years and then released on Baltra.

Genetic analyses have highlighted some anomalies in the iguana program. DNA from museum specimens has shed light on potential mixed ancestry among the iguanas of North Seymour. Further studies are examining evolutionary relationships between Santa Cruz and Baltra iguanas and the role they may have played in these findings. Continued application of new methods not only helps to explain the biogeography of the islands but also improve the management programs.

By 2008, the iguana breeding and rearing program was discontinued due to the successful repopulation of the three areas. The last repatriation from the iguana center to Cerro Dragón was in 1991, to Cerro Cartago in 1993, and to Baltra in 2008. Monitoring and transfer of iguanas from Venecia to Cerro Dragón continues every three years and cat control at both Cerro Dragón and Cerro Cartago is carried out about three times per year.

TRAINING

Both volunteers and scholarship students, primarily from Ecuador's many universities, have always participated

in the tortoise and land iguana programs. Several theses have been written based on such studies. Many of the students have gone on to work for the CDF, the GNPS, or other conservation and natural resource management organizations throughout Ecuador and the world.

THE FUTURE

With the eradication of introduced mammals, many of the giant tortoise populations are nearing the point when the breeding and rearing center will no longer be required. Monitoring their populations and restoring their habitat will now be part of larger island restoration programs. On Española, restoration of the *Opuntia* cactus forests that were decimated by goats is beginning. On Santiago, regeneration of the vegetation in the absence of goats, pigs, and donkeys will need to be monitored to ensure that the plant communities return to near-pristine condition, allowing the tortoise population to complete its recovery on its own. When rats are finally eliminated from Pinzón, island restoration and a naturally reproducing tortoise population will become a reality. Work on southern Isabela, where introduced mammals still exist and where poaching of tortoises is more common than elsewhere in the islands, will continue. Current genetic analyses may also highlight small remnant populations that will need intensive management in the future.

On Pinta, where the return of the Pinta tortoise is questionable if not impossible, a plan for restoring the

island, including the return of giant tortoises, has been approved. Since genetic studies determined that the Española tortoise is genetically the closest to the Pinta tortoise, hatchlings from the Española breeding and rearing program will be used to initiate the restoration of that island and re-establish a tortoise population there, on an island now free of introduced mammals.

The land iguana populations are doing well. If we are able to eradicate the cats one day, land iguanas will also be out of danger.

There are now land iguanas back on Baltra and tortoises will soon be back on Pinta. After nearly 50 years of integrated research and management aimed at the conservation of the biodiversity of Galapagos, most land iguana populations are in good shape and all of the tortoise populations are in better condition than when the Galapagos National Park was established in 1959.

ACKNOWLEDGMENTS

A research and management program with more than 40 years of success is only possible with the passion and dedication of many scientists, park wardens, consultants, students and volunteers. I am indebted to all of them, for their work in the field and in the tortoise and iguana centers, for our many discussions, and for their many reports and publications.

BOTANICAL RESEARCH IN THE GALAPAGOS ISLANDS: THE LAST FIFTY YEARS AND THE NEXT FIFTY

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SUMMARY

We review recommendations made since the founding of the Charles Darwin Foundation in 1959, concerning botanical research for the conservation of Galapagos, and present our suggestions for priorities for the immediate future.

RESUMEN

La investigación botánica en las Islas Galápagos: los últimos cincuenta años y los próximos cincuenta. Revisamos las recomendaciones hechas desde el establecimiento de la Fundación Charles Darwin en 1959, acerca de la investigación botánica para la conservación de Galápagos, y presentamos nuestras sugerencias para el futuro inmediato.