# GEF Project 9282

# Safeguarding biodiversity in the Galapagos Islands by enhancing biosecurity and creating the enabling environment for the restoration of Galapagos Island ecosystems

## Environmental Management Plan for Translocation and Captive Rearing of Giant Tortoises

| PROJECT INFORMATION | | | |
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| **PROJECT TITLE:** | Safeguarding biodiversity in the Galapagos Islands by enhancing biosecurity and creating the enabling environment for the restoration of Galapagos Island ecosystems. | | |
| **PROJECT OBJECTIVE:** | To safeguard biodiversity in the Galapagos Islands by enhancing biosecurity and creating the enabling environment for the restoration of Galapagos Island ecosystems. | | |
| **PROJECT OUTCOMES:** | **Outcome 1.1.:** The number of invasive alien species entering the Galapagos archipelago is substantially reduced<br>**Outcome 2.1.:** The social license is established for the protection and recovery of Floreana Island ecosystems<br>**Outcome 3.1.:** Ecosystem processes, particularly seed dispersal, re-initiated across Santa Fe island (2,413 ha) as the result of the translocation of giant tortoises<br>**Outcome 3.2.:** Production in captivity of giant tortoises for future reintroductions throughout the archipelago is significantly increased | | |
| **COUNTRY(*IES*):** | Ecuador | **GEF ID:** | 9282 |
| **GEF AGENCY(*IES*):** | Conservation International | **CI CONTRACT ID:** | |
| **OTHER EXECUTING PARTNERS:** | **Island Conservation (IC),** Galapagos National Park, Ministry of Environment of Ecuador | **DURATION IN MONTHS:** | 30 |
| **GEF FOCAL AREA(*S*):** | Biodiversity | **START DATE** (*mm/yyyy*): | February 2019 |
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| **RE-SUBMISSION DATE(*S*):** | | | |

**Environmental Management Plan for Translocation and Captive Rearing of Giant Tortoises**

## 1. Executive Summary

Reintroduction of tortoise populations is increasingly proposed as a tool for ecosystem restoration. Giant tortoises, once widespread on all continents except Antarctica, are ecosystem engineers that manipulate the distribution and abundance of other organisms through direct effects of herbivory, disturbance and seed dispersal on plant communities and subsequent indirect impacts on animal communities.

As part of the Giant Tortoise Restoration Initiative, Española tortoises, as the closest genetic relative and of the same saddleback morphology, will be used as ecological analogs for the extinct Santa Fe tortoise to re-initiate ecosystem processes on Santa Fe Island. Since 2015, a total of 396 Española (*Chelonoidis hoodensis*) tortoises have been released on Santa Fe. Additional efforts will be required in coming years to build capacity and restore the island with approximately 4,000 tortoises, the abundance predicted by habitat suitability models to have been present originally.

Component 3 of the present project aims at restoration of a critical natural habitat, namely Santa Fe Island. Captive raising and translocation of giant tortoises, ultimately to Santa Fe Island, are the means by which such transformation is being sought. Work will proceed in accordance with guidelines developed by IUCN to direct conservation-oriented translocations in an ecologically sound manner.

The reintroduction of Espanola giant tortoises to Santa Fe Island, like any ecological restoration action, is a long-term process. Its purpose is to achieve the establishment of a population of tortoises large enough for tortoises to fulfill their role as ecosystem engineers and thus actively contribute to the restoration of the ecological integrity of the island.

In order to achieve Target 3.1.1.a., juvenile giant tortoises, approximately five years in age, will be translocated from the Santa Cruz Island tortoise breeding center, where they were hatched and raised, to Santa Fe Island. Prior to being translocated, they will be subject to a quarantine process and equipped with subdermal microchips (transponders) to enable individual identification where re-encountered. These tortoises will be transported via the DPNG 'Sierra Negra' research vessel and will be carried by DPNG rangers from the ship to selected sites on Santa Fe Island for release. At least 40 juvenile giant tortoises will be translocated annually during the course of the project, i.e. at least 80 juvenile giant tortoises in total.

This Environmental Management Plan provides essential physical, scientific and programmatic context which underpins the project efforts. It describes the project's proposed activities and targets. It clearly identifies issues and associated safeguards. It analyzes impacts, risks and mitigation mechanisms. Finally, it presents the project's monitoring system.

*Context*

Santa Fe (0049'0"S, 9003'30"W) is a rectangular-shaped island 2,413 hectares in area located 16.6 km from the main island of Santa Cruz at the archipelago's center. There is no infrastructure at present on the island to support human activity including field researchers, by intent. Noteworthy endemic fauna include the Santa Fe land iguana (*Conolophus pallidus*), the Santa Fe rice rat (*Oryzomys bauri*), and the Santa Fe leaf-toed gecko (*Phyllodactylus barringtonensis*). Santa Fe Island apparently originally had its own lineage of giant tortoise. Santa Fe's terrestrial ecosystems are in a transitional state due to the extermination of tortoises over a century ago which was soon followed by invasion by an introduced population of feral goats.

Tortoise breeding centers run by the Galapagos National Park Directorate, hereafter DPNG (according to its Spanish-language acronym), have played a critical role in saving several species from extinction and augmenting the population restoration process for others. Improvement and expansion of the physical infrastructure of the rearing centers remains a primary outstanding need of this programme.

The recovery of Floreana Island tortoises is a primary focus now for tortoise restoration in Galapagos. The potential restoration of the Floreana tortoise lineage has been made possible by the recent discovery of inter-species hybrids between an extant and secure lineage and the extinct Floreana tortoise lineage. Recent scientific evaluations elucidate how best to move forward with capturing what remains of the Floreana tortoise lineage and genome, providing clear guidance for proceeding with science-based captive rearing and translocation efforts to resurrect the Floreana giant tortoise lineage.

*Description*

The project includes three components, which are briefly described below.

Component 1 will build on past and ongoing efforts by the Galapagos Biosecurity Agency, hereafter ABG (according to its Spanish-language acronym) to implement and strengthen biosecurity through interception and control of invasive alien species and diseases. The benefits to biodiversity of adding new pest detection equipment, training inspectors to use the new equipment effectively, and implementing new inter-island biosecurity protocols will be substantial over the long-term and will accrue to the whole of the archipelago, as well as to continental Ecuador and Ecuador's trading partners. Invasive alien species intercepted as a result of enhanced detection capacities will be eliminated from the pathway by which they were being mobilized, and their establishment in natural ecosystems will be prevented.

Under Component 2, a conflict transformation process, led by Island Conservation, that has been underway on Floreana Island for the last six years, will be brought to a conclusion. Additional rounds of consultation and feedback solicitation will help to deepen the community and partnership's understanding of the proposed actions and responsibilities, and to refine details of risk management plans. All plans will be included within an Environmental and Social Impact Assessment (ESIA), the development of which will include additional stakeholder engagement and considerations for gender mainstreaming.

Under Component 3, Española tortoises (*Chelonoidis hoodensis*), as the closest genetic relative and of the same saddleback morphology, will be used as ecological analogs for the extinct Santa Fe tortoise to re-initiate ecosystem processes on Santa Fe Island. Since 2015, a total of 396 Española tortoises have been released on Santa Fe. Additional efforts will be required in coming years to build capacity and restore the island with approximately 4,000 tortoises, the abundance predicted by habitat suitability models to have been present originally.

*Issues and safeguards*

The Espanola Island population of *C. hoodensis* has been chosen as the target species for translocation to Santa Fe Island in order to reinstate the ecological services the original lineage of giant tortoises once provided as well as to help in fully restoring the island's plant communities and the wide variety of fauna that depend on it. The **rationale** for the choice of this taxon as the "ecological analog" species integrates phylogenetic, ecological and operational considerations.

Aside from a few informal and illegal short-term campsites used by fishermen, there are **no known physical cultural resources or sites** on Santa Fe Island.

Having never been occupied by humans for an extended period, Santa Fe Island **lacks any known cultural resources or sites**. It receives the highest level of protection within the DPNG park zonation system.

The project has been designed to comply with major elements of **national and international legislation, regulations and policies**, all of which are being taken into account in the design, implementation and monitoring of the project's translocation and captive rearing elements. These include: the Galapagos Islands Protected Areas Management Plan; National Park protocols for handling of giant tortoises (including repatriation and captive rearing), and IUCN Guidelines for reintroductions and other conservation translocations.

*Impacts, risks and mitigation mechanisms*

The **expected impact** of the tortoise reintroduction programme is the establishment of a self-sustaining breeding population of giant tortoises on Santa Fe Island, using individuals from the population of Española. The island tortoise population is expected to reach a level of about 12.5% of its original abundance *within the life of the project*, and 65% occupancy after 30 years. The following risks have been identified, together with corresponding mitigation measures:

- risks to source population
- vectoring plant seeds among islands
- disease risk
- invasion risk
- biological risk
- ecological engineering impacts
- Risk to other endemic species
- Financial risks

*Monitoring*

Each of the above identified risks will be carefully monitored, with clear responsibilities identified along with dissemination pathways. In biological terms, key populations subject to monitoring will include: tortoises, pallid iguanas, rice rats and cactus, along with broader changes in island plant communities.

## 2. Overview of the GEF project

The objective of the project is to safeguard biodiversity in the Galapagos Islands by enhancing biosecurity and creating an enabling environment for the restoration of Galapagos Island ecosystems. The project includes three technical components, with four outcomes and multiple outputs. The three components have been carefully identified to cover the major pieces in a change process aimed at reversing a downward spiral of degradation and species loss associated with invasive species introductions.

Outcomes and outputs will be delivered through a combination of GEF support and cofinancing. The activities identified for GEF financial support have been selected based on:

- Priority needs to prevent and mitigate the impacts of invasive alien species on globally significant biodiversity in the Galapagos Islands;
- Their ability to prevent the extinction of IUCN Critically Endangered species and facilitate ecosystem recovery region wide;
- The likelihood that they can serve as catalysts for the next phase of work in the Galapagos, as well as similar initiatives in other island systems worldwide;
- The inability of other donor institutions and organizations to access sufficient resources (i.e. GEF funding is allowing incremental activities to occur); and
- National priorities for public finances and international non-reimbursable cooperation[1,2].

The present Environmental Management Plan (EMP) is focused on Component 3 of the project, the context and contents of which are described in detail in sections 3 and 4 respectively.

## 3. Context for Component 3 activities

### *i. Physical context*

Santa Fe (0049'0"S, 9003'30"W) is a rectangular-shaped island 2,413 hectares in area located 16.6 km from the main island of Santa Cruz at the archipelago's center. Santa Fe terrestrial ecosystems present particularly favorable conditions for young tortoises to grow and survive upon release to the wild: highly abundant cactus of all stage classes, extended flat plains that support production of grasses in the wet season (an important tortoise forage), patches of woody vegetation, cliff areas and abundant land iguana burrows for tortoises to find refuge during hot, dry periods and at night, and a flooded area in the island's central zone with surface water that persists for many months of the year as an accessible source of drinking water for tortoises.

There is no infrastructure at present on the island to support human activity including field researchers, by intent. As an island designated for strictest protection by the DPNG, all researchers arrive and leave in self-supported expeditions according to a "leave-no-trace" approach. However, there is a significant monitoring infrastructure present, consisting of 20 experimental plots for measuring vegetation change (10 with fences to exclude tortoises and/or iguanas), a series of 25 permanently marked plots for measuring change in population structure, growth and survival of the cactus population along a gradient of tortoise density, a large cactus "macroplot" with almost 600 individuals permanently tagged and measured to enable monitoring cactus population dynamics, and an island-wide series of permanently marked transects (~60 km in length, total) and plots for measuring iguana and cactus populations.

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[1] DGNP 'Reducing vulnerability of endemic species by eradicating priority invasive species' project, approved by National Planning Authority (2012)

[2] ABG 'Consolidating the system of preventing, controlling and eradicating invasive species in the Galapagos Islands' approved by National Planning Authority (2013)

*ii.* *Biodiversity context*

Santa Fe Island has a low profile (< 260 meters above sea level throughout) and is formed by flat uplifted fault blocks of basaltic lavas, which generally are orientated east-west alternating with ridges and cliffs formed by conspicuous fault scarps. At 2.8-4.6 million years of age, Santa Fe is one of the oldest islands in the archipelago. Lacking significant elevation to precipitate moisture from passing air currents, Santa Fe's vegetation is of predominantly arid types (Wiggins and Porter, 1971) comparable to those found at low altitude elsewhere in the archipelago (Hamann 1981). The vegetation types that characterize Santa Fe Island range from open, desert-like scrub to denser dry season deciduous steppe forest (the most prevalent type) or forest (Hamann 1981). Some 95 plant taxa have been recorded from Santa Fe, of which 44 are endemic, 47 indigenous and not endemic and four introduced (Hamman 2004).

Among the flora are two prominent island endemics. The first is *Opuntia echios* var. *barringtonensis,* which is significant not only as an endemic but also due to its extraordinary abundance. An evaluation carried out by the GNPS in 2011 of the entire island estimated a cactus population of approximately 250,000 individuals, with a population structure dominated by adults. The second notable island endemic is *Scalesia helleri* ssp. *helleri,* still largely restricted to the coastal cliffs to which it was marginalized through decades of herbivory by invasive goats, but increasingly repopulating the island's interior since goat eradication. Other dominant and common species are *Bursera graveolens*, *Cordia lutea*, *Lantana peduncularis*, *Encelia hispida*, *Castela galapageia* and *Croton scouleri*, while such species as *Maytenus octogona*, *Prosopis juliflora*, *Scutia pauciflora* and *Alternanthera filifolia* are regular in occurrence and locally dominant. The characteristic and visually impressive Santa Fe landscape is not found elsewhere in the archipelago, with the conspicuous presence and dominance of Opuntia "forest" a highly distinct feature of the island (Hamman 2004).

Noteworthy endemic fauna include the Santa Fe land iguana (*Conolophus pallidus*), the Santa Fe rice rat (*Oryzomys bauri*), and the Santa Fe leaf-toed gecko (*Phyllodactylus barringtonensis*). The land iguanas are particularly important for the ecology of the island, because they are the only large herbivores currently present there in substantial numbers. A DPNG survey in 2011 estimated a population of 6,500 pallid iguanas, with a density of 2.7 individuals per hectare. They are solitary and territorial animals that occur over most of the island, but most abundantly in the many areas with loose, gravel-like soil where they can dig their burrows. Free-ranging land iguanas on Santa Fe mostly eat leaves of *Lantana* in the hot season and leaves of *Cordia* in the garua (cool) season due to the high digestibility and protein content of these shrubs' leaves. *Opuntia* pads are an additional focus for pallid iguana foraging given their high water and calcium content (Carpenter 1969, Christian et al. 1984).

The Santa Fe rice rat is at present a thriving species found throughout the island, with an estimated population of > 10,000 individuals and one of the most stable populations ever recorded for a rodent species (Clark 1980). The Santa Fe rice rat is also one of the few remaining native rat lineages in the archipelago, a once widespread group now mostly exterminated due to introductions of black and Norway rats and remaining only on Santa Fe Island, Fernandina Island, and at one site on Santiago Island.

No formal investigation of the Santa Fe leaf-toed gecko has ever been made, yet the species is considered secure ("Least Concern") at present given that it faces no obvious threats (Márquez and Yánez-Muñoz 2016).

Notably, Santa Fe Island apparently originally had its own lineage of giant tortoise. As happened throughout the archipelago, this population of giant tortoises was subject to overexploitation by pirates, whalers and colonists as a source of fresh meat (Van Denburgh, 1914; Townsend, 1925). According to Townsend (1925), 22 tortoises were removed from Santa Fe Island by the ship *George and Susana* in 1839 and one tortoise was removed by the *Henry Crapo* in 1853. According to Van Denburgh (1914), the expedition of the California Academy of Sciences (1905-1906) found compelling evidence that tortoises were once abundant on the island, with Rollo Beck collecting remains of 14 individuals as well as discovering the remains of eggs and very old feces. Van Denburgh (1914) also presented the testimonies of captains from local boats, who reported that they had captured several dozen tortoises on Santa Fe Island between 15 and 30 years before the visit of the California Academy of Sciences (i.e., around 1875 and 1890) and that during that earlier period there had been tortoises and tortoise feces throughout the island. A recent analysis of habitat suitability for tortoises throughout the archipelago—done with the help of a species distribution model that linked habitat conditions at 16,000 known points of occurrence of giant tortoises throughout the archipelago that had been recorded in the database of the DPNG—revealed that the entire island of Santa Fe represents suitable habitat for tortoises, especially those of the saddle carapace type (Gibbs et al., unpublished data).

Phylogenetics data also supports the contention that Santa Fe tortoise, though not yet formally described, constitutes a distinct lineage. A group of geneticists from Yale University, led by Gisella Caccone, has extracted DNA from sub-fossilized material from tortoises from Santa Fe, including four bone samples obtained from the collections of the California Academy of Sciences (CAS 8143, 8145, 8146, and 8148). Mitochondrial DNA from three samples was sequenced using the control region (CR) (715 bp), 16s rDNA (16S, 361bp) and cytochrome b (cyt b; 415bp). Analyses indicated that the Santa Fe tortoise is a monophyletic lineage, that is, genetically distinct from all the other species described in Galapagos (Poulakakis et al 2008) but not yet formally described taxonomically since it became extinct more than 150 years ago. The Yale group is currently working on a formal species description along with a formal taxonomic revision of the entire Galapagos giant tortoise species complex based on an integration of the corpus of phylogenetic and morphological data that has accumulated on these animals during the last decade.

Santa Fe's terrestrial ecosystems are in a transitional state due to the loss of an important native herbivore and subsequent invasion by an exotic one. More specifically, the extermination of tortoises over a century ago roughly was soon followed by invasion by an introduced population of feral goats (Hamman, 1979). Specifically, goats on Santa Fe were first recorded in 1905 (although they were likely there well before that date) and removed 67 years later, in 1972. The eradication program removed some 3,008 goats (Carrion et al. 2011). The goats appear to have caused severe changes in the structure but not the composition of the island's vegetation (Hamman, 1979, 2004). Hamman (2004) has summarized 30 years (1972-2003) of change on Santa Fe Island following goat eradication based in tracking vegetation on a series of permanent plots he established on the island. After the eradication of feral goats, the previously threatened small tree *Scalesia helleri ssp. helleri* recovered and some recruitment of the dominant trees *Opuntia echios var. barringtonensis* and *Bursera graveolens* took place. Recovery of the *Bursera* has been greatly aided by animal dispersal, in some combination of animal dispersal resulting from birds (likely mockingbirds), reptiles (land iguanas) and mammals (rice rats) (Clark and Clark 1979). The disproportionate recruit of *Bursera* beneath *Opuntia* suggests seed dispersal by mockingbirds. The dominant shrub species *Cordia lutea, Encelia hispida* and *Lantana peduncularis* increased in number, whereby the shrub layer became denser and the structure of the predominant dry season deciduous steppe forest vegetation also became more dense. The strong impact of El Niño on the survival and recruitment of cactus indicates that recovery of cactus should be viewed on a time-scale of perhaps 150 years or more, in correspondence with the long life-expectancy of adult cacti. Recruitment and survival of cacti may be hindered if future El Niño events are to occur with increased strength. Recent research corroborates a spread of woody vegetation since tortoise extinction and goat appearance and eradication as indicated by shifts in characteristic forms of carbon isotopes of woody versus herbaceous plants in the upper, more recent soil strata (J. P. Gibbs, unpublished data). Moreover, this same soil isotope study suggest that Santa Fe Island had a more extensive presence of herbaceous plants (like grasses and annual dicots) 1,000 - 10,000 years before present, perhaps reflecting what was once a more heavily browsed system, with populations of both an endemic tortoise and iguana present.

### *iii. Previous tortoise captive breeding and rearing: experience and lessons*

The DPNG tortoise breeding centers have played a critical role in saving several species from extinction and augmenting the population restoration process for others. In 1965, the Charles Darwin Research Station (CDRS) established the Tortoise Rearing Center on Santa Cruz Island with the specific aim of preventing the extinction of the race of tortoises from Pinzón. Within a few years, the rearing program was expanded to include other threatened populations. Since the establishment of the Galapagos National Park Service (GNPS) in 1968, the program began to be managed jointly by the CDRS and the GNPS and is now managed solely by the GNPS.

The Tortoise Rearing Centers include corrals for adults, clinic corrals for adults, corrals for juveniles (hatchlings to 1.5 to 2 years old), adaptation corrals (1.5 to 2 year olds until repatriation), and incubator houses. The centers focus on an annual cycle of activities needed to sustain each captive population and the offspring produced: maintenance of nesting areas, inspection of nesting areas, inspection and collection of eggs and hatchlings, maintenance of juvenile corrals, maintenance of incubation temperatures and conditions, measuring and health inspection of adults and juveniles, and introduced animal control (mainly rat trapping/poisoning).

During the 1990s and into the new century, work at the Tortoise Center of Santa Cruz focused on four populations—*C. hoodensis*, *C. ephippium*, *C. porteri*, and *C. darwini*. A second Tortoise Rearing Center, established in 1990 at Puerto Villamil, Isabela, contains tortoises from southern Isabela Island (*C. vicina* and *C. guntheri*). Both centers focus on completing an annual cycle of maintaining breeding stock for highly endangered forms while head-starting their offspring as well as those from wild populations via eggs collected in the field.

An international workshop, *Giant Tortoise Recovery through Integrated Research and Management*, was convened by the Galapagos National Park Service (GNPS) in Puerto Ayora in July 2012 to review the status of Galapagos giant tortoises and develop priority research and management plans for the next 5-10 years. The workshop resulted in the launch of the Giant Tortoise Restoration Initiative (GTRI) in 2014, a collaborative effort led by Galapagos Conservancy and the Galapagos National Park Directorate (DPNG). The long-term goal of the GTRI is to restore tortoise populations to their historical distribution and numbers across Galapagos, including on islands where tortoises went extinct. This historic effort is composed of four main components: 1) Research and conservation on tortoises, vegetation, etc., on targeted islands, 2) Breeding and rearing tortoises of threatened species, 3) Repopulation of islands where tortoises went extinct, and 4) Research and management of tortoise-human interactions and conflicts. All of these efforts are now well underway, with Galapagos-based staff and outside collaborators advancing tortoise restoration efforts across the islands. This ambitious initiative builds on a half century of tortoise research and conservation carried out by the Charles Darwin Research Station, the DPNG, and numerous visiting scientists and volunteers, with extensive support from the Galapagos Conservancy.

Among the workshop's many foci was the captive rearing programs for tortoises. The workshop concluded that the Galapagos National Park's highly successful tortoise breeding and rearing program, which had been running for over 45 years, had ensured that many tortoise populations had avoided extinction and that they have begun to increase in numbers. The program had expanded substantially in the past decade with, until recently, three tortoise centers (Santa Cruz, San Cristóbal and Isabela), as well as a corral of captive adult tortoises on Floreana.

Significant deficiencies were identified as well, the identification of which catalyzed the formation of an expert group that toured the rearing centers and discussed the current status of each center with emphasis on health, nutrition, reproduction and repatriation issues. The team of assessors included DPNG senior staff, Galapagos Conservancy-based tortoise experts, and an international veterinary expert. This external assessment was conducted under an existing Memorandum of Understanding between Galapagos Conservancy and DPNG to provide technical assistance as requested and also under a permit granted by the DPNG to the Galapagos Conservancy to operate to Galapagos Tortoise Restoration Initiative. As a result of the assessment, there was agreement that there were many improvements that needed to be made to tortoise center operations including genetic perspectives needing to be incorporated in decision-making regarding breeding pairs and groups, greater consistency in practices among the different tortoise centers, and improved supervision. In the context of captive-rearing to advance tortoise restoration, the workshop emphasized the clear need across all centers to:

- Compile all available tortoise reproduction and survival data from captive tortoise program as well as all available tortoise health status information
- Improve and expand the physical and infrastructure of the rearing centers

Importantly, on the first point -- compile all available tortoise reproduction, survival and health data – this massive effort is now underway by Galapagos Conservancy, which has recovered and is assembling data archives and has scanned countless pages of paper records in anticipation of digitizing those data on a unified platform that will be compatible with DPNG data systems. This recovery, digitization and integration process is well underway, leaving improvement and expansion of the physical infrastructure of the rearing centers as the primary outstanding need.

### *iv. Previous restoration work: experience and lessons learned*

The process that has unfolded with the restoration of the Espanola tortoise species on its home island of Espanola Island over the last 50 years is perhaps one of the most successful species recovery programs ever undertaken, while also one of the least heralded. The outcomes of the program provide a clear guide to what can be expected to happen on Santa Fe given the similarities of the islands' ecosystems combined with the use of the very same core breeding group of tortoises and captive breeding and repatriation protocols and facilities.

About half of tortoises released on Espanola Island since 1975 were still alive in 2007 and reproducing *in situ* and considerably so. Population viability analyses built around vital estimates derived from 40 years of mark-recapture population monitoring indicate future extinction risk is low with or without continued repatriation. There was, however, some evidence for declining survival rates, growth rates, and body condition over the last decade, suggesting that resources for continued population growth are becoming limiting. This is likely due to the well-known paucity of cactus on Espanola Island (Marquez et al. 2003), the cause of which is not known but suspected to be due to a lack of tortoises that hindered cactus dispersal over the last 300 years, combined with a feral goat infestation during the last 100 years that caused extensive mortality of adult cacti. Monitoring of the impact of tortoises on the island's vegetation via measurement of vegetation in a set of 25, 6 m x 6 m plots of which 12 have tortoises excluded and 13 serving as controls suggests that tortoises do significantly reduce woody plant recruitment and expand herbaceous plant cover (Tapia and Gibbs, unpublished data).

It has also become clear that deterministic changes in woody plant communities in these arid zones is slow, despite strong inter-annual changes in herbaceous plant communities associated with the highly variable patterns of rainfall that characterize Galapagos. In other words, tortoise impacts will likely manifest slowly and will unfold fully over the course of several decades. In terms of impacts on cactus, the keystone resource for many vertebrate animals during the dry season, tortoises seem to remove virtually all fallen pads and fruits from below adult cacti, thereby eliminating any vegetation reproduction that might otherwise have occurred. But by dispersing seeds away from adult plants where seed predators (mainly cactus finches) focus their efforts and also by depositing scarified seeds in moist nursery packages (tortoise droppings) far from adult cactus, tortoises have been effecting a remarkable recovery of cactus in areas across the central zone of Espanola Island where they have been reintroduced. There are now two primary classes of cacti on the island – very old, "pre-goat" adults and a new cohort of small juveniles aged via growth rate calculations to coincide with the restoration of tortoises. Notably, there are very few subadults or young adults of intermediate age.

*v. Optimizing tortoise recovery on Floreana Island*

The recovery of Floreana Island tortoises (*C. niger,* previously referred as *C. elephantopus*) is a primary focus now for tortoise restoration in Galapagos, for the same reasons provided earlier regarding the restoration of tortoises to Santa Fe Island. However, the Floreana tortoise presents its own peculiarities as a globally unique (at this time) opportunity for species restoration, while also presenting its own significant challenges. The potential restoration of the Floreana tortoise lineage has been made possible by the recent discovery of inter-species hybrids between an extant and secure lineage and the extinct Floreana tortoise lineage. The latter, *C. niger*, went extinct during the $19^{th}$ century with no records of animals alive beyond the 1840s. However, genetic data (Poulakakis et al., 2008) identified tortoises with genomic representation from this extinct species living on Wolf Volcano on northern Isabela island, where they co-occur with tortoises of the endemic species *C. becki*. This is likely the outcome of human-mediated translocation (many tortoises were recorded to have been moved around the archipelago by whalers). This discovery provides a novel opportunity for partially restoring *C. niger* species using inter-species hybrids. This is globally unique in that no species has yet been rescued from hybrids (although other opportunities may present themselves in the future).

In 2015, an expedition conducted in the region of Wolf Volcano, where admixed individuals occur, revealed that 127 of the 144 individuals sampled with saddle-backed morphology characteristic of *C.*

*niger* had some *C. niger* genetic ancestry (Miller et al 2017). Twenty-two of these tortoises were brought to the Galapagos National Park Directorate (DPNG) breeding center on Santa Cruz Island and integrated with four other individuals already in captivity with high genetic assignment to *C. niger* in order to initiate a breeding program. The program poses major challenges, some conventional—such as how best to maximize the amount of genetic diversity in the resulting offspring— and others unique, such as to maximize the retention of *C. niger* ancestry present in the founders. Moreover, these genetic-driven considerations need to be balanced against the need to introduce tortoises on Floreana island to help restore its terrestrial ecosystem, especially given the species' sluggish demography (age of first breeding of ~ 20 years; Marquez et al 1991) and limited resources available for captive-rearing of tortoises.

To these ends, two related evaluations have been made to generate science-based guidance on how to build the most effective captive breeding programs to recover the Floreana tortoise lineage. In the Quinzin et al evaluation (manuscript in review) that focused on genetic management issues in captivity, genetic estimates developed from screens of microsatellite loci derived from DNA extracted from blood samples of known, living hybrids were used together with a forward-in-time simulation-based framework to identify optimal groups of breeders. The Quinzin et al. study first focused on how to maximize genetic diversity of the offspring of the *C. niger* "hybrids" both in terms of the numbers of individuals in each group and the number of groups and mating strategies. With regard to group combinations, it was determined that the 22 breeders already in captivity would best be divided into 4 groups of 5 individuals, with an alternative option of 5 corrals with 7 breeders per corral. With regard to changing group compositions, doing so periodically would also increase the offspring genetic diversity. For the 50-year long-term scenarios, changing group composition improved genetic diversity, regardless of the combinations used. This improvement was higher when changing the groups every 5 years rather than once after 25 years. Frequently changing group composition may also have the added value of breaking up group hierarchies, which can lead to skewed reproductive success among breeders. Such reproductive skewedness has been shown to occur within the 35-year captive breeding program for *C. hoodensis* from Española Island. Skewed breeder contribution is known to reduce population persistence in the wild by reducing effective population sizes (Frankham et al 2002).

The major insight from the Quinzin et al. (in prep) evaluation was that the best strategy for genetic management of the founding population of *C. niger* in captivity is to augment the captive breeding population with unrelated individuals with high *C. niger* ancestry, many of which still occur on Wolf Volcano. Increasing number of breeders by adding a new corral and including more tortoises per corral would catalyze a significant increase in genetic diversity of the offspring and hence improve capture of the *C. niger* genome. Doing so is important to ensure that as many of the original *C. niger* alleles are present in the tortoises released to Floreana Island, which will facilitate the process of re-adaptation of the tortoise lineage to the Floreana ecosystem. If the remaining *C. niger* polymorphisms captured through this captive-rearing program are still adaptive in the current Floreana island conditions, then the genomic representation of *C. niger* will increase over time. In contrast, if these variants are no longer adaptive, new genetic combinations suited to local environmental conditions will likely emerge. To facilitate this process, Quinzin et al. recommended that because population growth is important for assuring population establishment, all offspring should be released on Floreana Island as soon as they reach an age that maximizes their survival chance, i.e. 4-7 years (Gibbs et al 2014).

As second evaluation of how to optimize tortoise recovery on Floreana Island was conducted by Hunter et al. (in review) who examined the complex trade-offs that exist among recovering the *C. niger* tortoise lineage and regenerating the ecosystem services it provided in a timely fashion under time and cost constraints. To do so, Hunter et al. (in prep) built an individual-based model that integrated giant tortoise demography and the genetics data from the Quinzin et al. study to investigate the effects of management actions on four potentially conflicting program objectives for a wild tortoise population: 1) producing an ecologically relevant population size, 2) capturing the *C. niger* genome, 3) creating a genetically diverse population, all while 4) minimizing costs. Optimal solutions for each program objective differed with respect to most simulated management actions, including program duration, translocation age of juveniles, sex ratios of captive-bred juveniles, and direct translocation of adults with low *C. niger* genome representation to Floreana Island.

One important outcome was that manipulation of juvenile sex ratios (via temperatures at which eggs are incubated) to produce more females favored population growth but had a negative effect on overall genetic diversity ($H_o$), producing a conflict. The advantage of highly biased sex ratios for the population growth objective is clear – with each male tortoise mating with multiple females, the number of females is expected to limit population growth. However, wild giant tortoise populations have approximately 1:1 sex ratios for both adults and hatchlings, suggesting that female-skewed populations may have disadvantages from an evolutionary perspective. Furthermore, it is unclear how female-skewed a population can be without negatively affecting breeding opportunities. Thus, a compromise 2:1 sex ratio is likely the best option; fortunately, the DPNG Tortoise Center has successfully used 2:1 female:male juvenile sex ratios in its captive breeding programs for decades. These results indicated that there may be genetic diversity consequences for biasing sex ratios towards females, so the benefit for population growth should be weighed against long-term population sustainability.

The Hunter et al. (in prep) evaluation corroborated the Quinzin et al. (in prep) assessment on a critical point: direct translocation of 20 adults with lower *C. niger* representation than the original breeders improved overall genetic diversity by infusing the population with new alleles albeit reducing, as expected, overall *C. niger* genome representation in the population. Outcomes of this option are largely dependent on which individuals can be found and recovered from the mixed ancestry population on Wolf Volcano, where individuals of both high (e.g., backcrosses to *C. niger*) and low levels of *C. niger* ancestry still occur. If more individuals with high levels of *C. niger* ancestry are recovered, adding them to the captive breeders would support all program objectives. If adults with lower *C. niger* genome representation than the breeders currently in captivity are recovered on Wolf Volcano, translocating them directly to Floreana Island would have minimally negative effects on the *C. niger* genome representation objective.

In summary, the evaluations of Quinzin et al. and Hunter et al. elucidate how best to move forward with capturing what remains of the Floreana tortoise lineage and genome via the recent discovery in the wild of individuals with mixed ancestry between an extant and extinct species of Galapagos giant tortoises. The primary outcomes of both of these evaluations provide clear guidance for proceeding with science-based captive rearing effort to resurrect the Floreana giant tortoise lineage:

- Change group compositions regularly;
- Release all offspring to the wild as soon as they reach 5 years;
- Generate offspring at a 2:1 female: male sex ratio via manipulation of incubation temperatures;
- Augment the captive breeding population with unrelated individuals with high *C. niger* ancestry, many of which still occur on Wolf Volcano

**4. Description of Component 3: Advancing the recovery of island ecosystems following invasive species eradication through the establishment of keystone species (i.e. giant tortoises)**

Although invasive rodents and feral cats have not yet been removed from Floreana Island, invasive vertebrates have been removed from Santa Fe (goats) and other Galapagos islands. These islands are now candidates for the recovery of endangered species and associated ecological processes. Giant tortoises are a case in point because these icons of Galapagos act as “engineers” of Galapagos ecosystems, yet have been lost from several of the main islands of Galapagos. Although it is not feasible to resurrect extinct species, saddleback tortoise species characteristic of the arid zones that comprise most of Galapagos are similar enough in ecological role to enable the recovery of ecological processes through the translocation of closely related species—so-called ‘ecological replacements’. The DPNG’s Tortoise Breeding Centers have been conducting giant tortoise breeding, head-starting, and translocation activities as part of island-specific recovery efforts for over five decades, resulting in remarkable conservation success stories like the Española Island tortoise.

As part of the Giant Tortoise Restoration Initiative[3], Española tortoises, as the closest genetic relative and of the same saddleback morphology, will be used as ecological analogs for the extinct Santa Fe tortoise to re-initiate ecosystem processes on Santa Fe Island. Since 2015, a total of 396 Española (*Chelonoidis hoodensis*) tortoises have been released on Santa Fe. Additional efforts will be required in coming years to build capacity and restore the island with approximately 4,000 tortoises, the abundance predicted by habitat suitability models to have been present originally[4]. Work will proceed in accordance with guidelines developed by IUCN to direct conservation-oriented translocations in an ecologically sound manner.[5]

Outcome 3.1.: Ecosystem processes, particularly seed dispersal, re-initiated across Santa Fe island (2,413 ha) as the result of the translocation of giant tortoises.

Outcome target 3.1: At least 506 giant tortoises of the species *Chelonoidis hoodensis* are dispersing seeds on approximately 50% (1,206 ha) of the area of Santa Fe Island

| **Output** | **Output targets** |
|---|---|
| *3.1.1:* Giant tortoises (*C. hoodensis*) translocated to Santa Fe Island | 3.1.1.a. On average, at least 40 juvenile giant tortoises (*C. hoodensis*) are translocated annually<br>3.1.1.b. At least 30 sub-adult giant tortoises (*C. hoodensis)* are translocated |
| ***3.1.2:*** Monitoring and evaluation protocols for assessing the role of giant tortoises as ecosystem engineers, including seed dispersal, are tested and optimized | 3.1.2. One monitoring and evaluation protocol |

[3] A collaborative 15-year project (2014-2028) implemented by the DPNG and Galapagos Conservancy, with support from visiting scientists from around the world. https://www.galapagos.org/conservation/our-work/tortoise-restoration/

[4] Tapia et al. 2015. Plan para la Reintroducción de las Tortugas Gigantes a la isla Santa Fe como Estrategia para su Restauración Ecológica.

[5] http://www.iucn-whsg.org/node/1471

As of December 2017, those surviving among the 396 giant tortoises of the species *C. hoodensis* released were dispersing seeds near their release site in the central part of Santa Fe Island, on approximately 10% of the island's area, or 240 ha. Following translocation activities, these figures will be increased as per the above target.

Output 3.1.1.: Giant tortoises (*Chelonoidis hoodensis*) translocated to Santa Fe Island

**Output target a. On average, at least 40 juvenile giant tortoises (*C. hoodensis*) are translocated annually**

**Output target b. At least 30 sub-adult giant tortoises (*C. hoodensis)* are translocated**

This output seeks to enhance the process of populating Santa Fe Island with Española tortoises (*C. hoodensis*) by:

- translocating juvenile tortoises from the Santa Cruz breeding center to Santa Fe (target 3.1.1.a), and
- translocating sub-adult tortoises from Española to Santa Fe (3.1.1.b).

In order to achieve Target 3.1.1.a., juvenile giant tortoises, approximately five years in age, will be translocated from the Santa Cruz Island tortoise breeding center, where they were hatched and raised, to Santa Fe Island. Prior to being translocated, they will be subject to a quarantine process and equipped with subdermal microchips (transponders) to enable individual identification where re-encountered. These tortoises will be transported via the DPNG 'Sierra Negra' research vessel and will be carried by DPNG rangers from the ship to selected sites on Santa Fe Island for release. At least 40 juvenile giant tortoises will be translocated annually during the course of the project, i.e. at least 80 juvenile giant tortoises in total.

To achieve Target 3.1.1.b., the project will bring older, sub-adult giant tortoises, which will soon begin breeding (at 18 – 20 years of age), from Española Island to Santa Fe Island to accelerate the natural breeding process, an intervention demonstrated via population viability modeling to not affect likelihood of population persistence. The sub-adult tortoises targeted for translocation from Española were originally incubated in the breeding center on Santa Cruz Island and then released on Española at around age five. Over the years, as they were maturing, Santa Fe Island has been with "goat-free"; as a result, the island is now a suitable destination for these sub-adults, which will likely commence breeding shortly after being translocated. The advantage of bringing sub-adult tortoises to Santa Fe—as opposed to only bringing juveniles—is jumpstart the population restoration process by some 15 years (as compared with waiting until the 5-year old juveniles turn 20 and are able to reproduce).

The translocation process will begin with a trip by scientists and park rangers to Española Island to locate sub-adult tortoises suitable for translocation. Before traveling to Española Island, people, equipment and provisions will undergo a thorough quarantine process, as per protocols being developed in component 1. Search groups will be divided into 10 camps throughout Española Island. Once the search groups locate suitable sub-adult Española tortoises, they will be marked with telemetry equipment until they are ready to be airlifted. At that point, helicopters will transfer the tortoises from remote locations on Española Island to the Sierra Negra vessel[6], which will bring them to the breeding center on Santa Cruz Island for at least a three month quarantine.

[6] Without a helicopter, it may require up to two to three days to transport these very heavy animals overland over very difficult terrain, with associated risks for both tortoises and people.

Following the quarantine process, the tortoises will be airlifted back to the Sierra Negra ship, which will move with the tortoises to Santa Fe Island, where they will be transported via helicopter to carefully selected locations throughout the island. A portion of the costs of the expedition will be covered by GEF and the remainder through co-financing from GC and DPNG.

**Output 3.1.2.:** Monitoring and evaluation protocols for assessing the role of giant tortoises as ecosystem engineers, including seed dispersal, are tested and optimized

**Output target: One monitoring and evaluation protocol**

Tortoises released under Output 3.1.1 will be equipped with microchips (subdermal transponders) to aid monitoring. A standard protocol will be developed and tested in the field to evaluate the health and status of individual tortoises repatriated, tortoise population growth and dispersal, and interactions of tortoises with other species, particular the plant community. The protocol will be updated as additional knowledge is generated. This is among the first experiences in the world of repopulating an island with "ecological analog" giant tortoises, thus the importance of carefully developing a protocol based on ongoing experience gained and lessons learned. The protocol will be made available for use by, *inter alia*, the DPNG and its partners to start and manage the repopulation of adult tortoises on other islands, such as Floreana.

Monitoring will be undertaken in accordance with the above protocol. In biannual monitoring, survival rates, body condition, growth rates, habitat use and dispersal will be measured through mark-recapture methods. Interactions with other species, including seed dispersal and habitat change attributable to tortoises, will be measured via studies of diet (inferred from fecal samples) and foraging ecology of tortoises (observational studies) as well as vegetation response and habitat use by other animals inside and outside of areas from which tortoises are excluded. *Opuntia* cactus represents a keystone species for the entire vertebrate community on Santa Fe Island, and a major focus of both tortoise and terrestrial iguana foraging: demographic studies of *Opuntia* across a gradient of tortoise density will enable tracking *Opuntia* response to tortoise re-establishment.

Outcome 3.2.: Production in captivity of giant tortoises for future translocation throughout the archipelago is significantly increased along with associated capacities.

Outcome target 3.2: In the breeding centers, an enhanced and expanded breeding stock and associated husbandry capacities contribute to the following numbers of giant tortoises reaching the age of one year:

In the Santa Cruz Island breeding center in Puerto Ayora, at least 180 tortoises annually from the populations of Española, Santiago, Floreana, Pinzón and Eastern Santa Cruz;

In Isabela Island breeding center in Puerto Villamil, an average of 140 tortoises annually from the populations of the Sierra Negra and Cerro Azul volcanoes.

| Output | Output targets |
|---|---|
| *3.2.1:* Giant tortoise breeding centers on Santa Cruz and Isabela Islands are modernized and expanded | 3.2.1. Two centers modernized and expanded |

| | |
|---|---|
| ***3.2.2:*** Giant tortoise breeding stock with partial ancestry of *C. niger* are selected, located and transferred to the Santa Cruz breeding center | 3.2.2.: At least 5 breeders with partial ancestry of Floreana (*C. niger*) selected, located and transferred to the breeding centers. |
| ***3.2.3*** Scientific and technical findings reported in the professional and popular literature. | 3.2.3: 1 peer reviewed article and 2 popular articles produced |

Taking full advantage of the ongoing expansion of suitable habitat for giant tortoise reintroduction—itself a function of previously planned and carefully executed invasive species eradications—will require a significant increase in the capacity of giant tortoise breeding facilities from baseline levels. Increases in the number of tortoises reaching one year of age at the captive breeding centers of Santa Cruz and Isabela will be the indicator used to measure this outcome, which will be enabled by expansion of breeding centers (Output 3.2.1). In addition, the genetic quality of the juvenile population will be improved through the acquisition of enhanced breeding stock with partial ancestry of *C. niger* for the repopulation of Floreana Island (Output 3.2.2). Finally, the findings will be shared with both scientific and popular audiences (Output 3.2.3)

**Output 3.2.1.:** Giant tortoise breeding centers on Santa Cruz and Isabela Islands are modified and expanded

**Output target: 3.2.1. Two centers modified and expanded**

1. The process of producing 320 tortoises from the Española, Santiago, Floreana, Pinzon, Eastern Santa Cruz, Sierra Negra and Cerro Azul lineages begins with collection of eggs. For some species, breeders are kept in captivity at the breeding center and their eggs harvest from nesting areas at the Breeding Center. For other species, eggs are collected in the wild. In both cases, eggs are incubated in the Breeding Center under controlled conditions to improve the hatching percentage. Young tortoises are kept in the Centers until they reach five years of age, which generates a huge increase in survival rates (typically 90% of eggs reach juvenile stage) versus in the wild (estimated at just 5%), with major ramifications for tortoise population growth rates.

To strengthen the role of captive breeding in restoration of wild populations, GEF funding will be used to renovate and expand the giant tortoise breeding centers on Santa Cruz and Isabela Islands. Improvements will include construction[7] of at least two new breeding pens, a quarantine pen, a pre-adaptation pen, and ten pens for hatchling tortoises.[8] These augment the recent installation of 8 state-

[7] Tortoise pens are open air enclosures of natural terrain, delineated by rock walls. They are not buildings. The current footprint of these facilities is 3.6 ha, a figure which will increase to approximately 5 ha due to the project activities. Most construction by volume will be of lava block for corral walls sourced adjacent to the corrals – lava block is very abundant locally and corral construction will in no measureable manner reduce local supply. Remaining construction will be cement block based from cement imported from the mainland and brought in via freighter system with quarantine stage such that impacts on local environment are minimal. The footprint of the rearing center both currently and when expanded will be just 0.01% of the island.

[8] These will augment the current facilities which consist of 8 breeding pens, 1 quarantine pen, 4 pre-adaptation pens and 20 hatching pens

of-the-art tortoise egg incubators. A competitive bidding process will be used to select and hire a general contractor for construction of the pens.

Within the improved breeding centers, breeders will be kept in captivity and eggs will be incubated[9]. Newly hatched tortoises will be cared for in secure, covered pens until they are a year old, including daily feeding and provisioning of water, ensuring adequate barriers to prevent predation by rats, and health monitoring. Beyond the life of this project, the tortoises will be transferred to pre-adaptation pens where they will remain until they are five years old. Here, they will adapt to the terrain and temperature extremes that they will face in the wild. Finally, the tortoises will be subject to a quarantine period, which aims to ensure that they are healthy and also have been purged of seeds in their digestive tracts, before being released in the wild in their respective species' ranges[10].

**Output 3.2.2**: Giant tortoise breeding stock with partial ancestry of *C. niger* are selected, located and transferred to the Santa Cruz breeding center to enable eventual repopulation of Floreana Island

**Output target: At least five giant tortoises located and transferred (20% increase in captive population of Floreana breeders)**

Beginning in the late 1990s and continuing through 2014, a series of systematic scientific expeditions took place to Wolf Volcano, located at the northern end of Isabela Island, to inventory the tortoise population there. In 2008, scientists tagged and collected blood samples from some 1,600 tortoises, 89 of which turned out to be partly related to the extinct Floreana Giant Tortoise (*C. niger*). Another 17 were found to be related to Pinta Island tortoises. Their presence on Wolf, as much as 100 miles from their place of origin, was explained by the fact that, over a century ago, sailors left many saddlebacked tortoises, initially collected from other islands in the Galapagos, at neighboring Banks Bay (a major stopping over place for whalers and other sailors to repair their ships). Some of these tortoises interbred with the local domed tortoises (*C. becki*), enabling the *C. niger* genome to persist in the resulting hybrid offspring. To date, over 200 tortoises have been identified as having partial Floreana ancestry. In November 2015, an expedition to Wolf Volcano selected 17 individuals from this group, which were transported to the Santa Cruz Breeding Center to begin the current *C. niger* breeding program.

As elaborated in Section 3*v* above, it was concluded that the Floreana repopulation program would be significantly enhanced by expanding the pool of breeders with additional, carefully selected giant tortoises with Floreana ancestry from Wolf Volcano. The project will therefore support a ten-day expedition to Wolf Volcano to search for and remove at least five tortoises and no more than 20 tortoises with partial *C. niger* ancestry—from a population of 5,000 – 6,000 individuals—which will be added to the breeders' stock. Doing so will provide a critically needed increase in genetic diversity and Floreana tortoise genome capture, with the added benefit of removing them from the endemic *C. becki*, thus improving that species' genetic status.

Before the field trip, a laboratory analysis of the genetic identity of previously identified collected blood samples will be performed, using molecular techniques to identify the set priority individuals[11] to be re-located on Wolf Volcano. All previously sampled tortoises with Floreana tortoise–

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[9] In the wild, 10% of the eggs hatch and make it to 5 years of age. In breeding centers, >90% of eggs hatch and reach 5 years of age.

[10] This captive breeding program uses the data and learning that DPNG and its partners have learned in the last 50 years, each time improving the hatching and survival rates.

[11] Priority individuals for selection will be those with the highest % of *C niger* genes, greatest heterozygosity and most "outbred" relative to the current breeders.

like morphology whose blood will be analyzed had subdermal transponders (PIT tags) added, enable us to identify them with very high confidence when re-encountered on Wolf Volcano. To find the selected tortoises, ten groups of four people each will be deployed across the very rugged terrain in Wolf Volcano. A helicopter will provide logistical support—including ferrying water and food—to the teams and remove the priority tortoises once they have been located. The DPNG's Sierra Negra vessel will remain on the coast at Banks Bay as a base of operations for the helicopter and the search groups. Importantly, the helicopter is critical to move by cargo net priority tortoises re-located in the field back to the ship (tortoises are generally too heavy to be moved by people over long distances and rough terrain). Veterinarians will be on board to receive the tortoises and to take samples to ensure the health of selected individuals. The GEF funding will support helicopter time, genetic analysis to support identification of the best individuals, field equipment (tents, sleeping bags, GPS, etc.) and protection (clothing, boots, helmets, etc.) for park rangers and scientists, as well as planning of the field work.
The selected tortoises will be brought by the Sierra Negra vessel to the breeding facility at Santa Cruz Island. These tortoises will be integrated into the existing breeding stock and provide expanded genetic variation to the program and greater capture of the Floreana tortoise genome, thereby improving the fitness of the offspring and helping to ensure the future success of the tortoise population restoration on Floreana Island. The addition of these five breeders represents a 20% increase in the size of what is at present a small core breeding population to restore tortoises to Floreana Island. Given that lifetime female production of offspring reaching breeding age is likely 2-3 in the wild over the ca. 100-year life span of a female giant tortoise, captive rearing intervention can increase her production to some 250-300 offspring reaching breeding age (a factor of 100x). Therefore, the gains of adding this seemingly modest number of 5 individuals to the core breeding stock plus head-starting in the long-term represents a substantial contribution to population recovery on Floreana Island. Keeping the number of additional breeders to this modest level also recognizes the very significant financial burden that hosting these additional new breeders for the rest of their lifespan (many decades) in captivity plus the costs rearing all their offspring and releasing them to the wild.

**Output 3.2.3:** Scientific and technical findings reported in the professional and popular literature

**Output target:** 1 peer reviewed article and 2 popular articles produced.

This output seeks to share the project's scientific findings regarding tortoise relocation and habitat restoration with global audiences and especially with the population of Galapagos. First, a scientific article will be produced which will be submitted for publication to a respected, peer-reviewed science periodical.[12]

Second, at the local level, it is also important to share knowledge with decision makers and the general public. A popular diffusion article will be produced and submitted for publication in the Galapagos Report, a report published every year with articles about key policies, conservation programmes and summaries of key science reports. This annual publication aims to provide decision makers with key information in terms of key development in conservation and social policy. It is also a very useful resource for students and investigators, by compiling in one place this kind of information. Printed copies are distributed to key decision makers, while PDF copies can be downloaded for free.

[12] Depending on the editorial process of the different journals to which it will be submitted, the article might not be published by the time of project closing.

The third product will be a poster to be presented at the Galapagos National Park Symposium, which is organized every year and is open to the public. Attendance at the Symposium includes other investigators (both visiting and resident scientists), guides, students and members of the general public.

## 5. Issues and safeguards

### *i. Rationale for selection of species being translocated*

The Espanola Island population of *C. hoodensis* has been chosen as the target species for translocation to Santa Fe Island in order to reinstate the ecological services the original lineage of giant tortoises once provided as well as to help in fully restoring the island's plant communities and the wide variety of fauna that depend on it. The rationale for the choice of this taxon as the "ecological analog" species integrates phylogenetic, ecological and operational considerations.

In phylogenetic terms, the Santa Fe Island tortoise forms part of a larger Pinta-Española-San Cristóbal-Cerro Fatal genetic complex, since it is closely related to *C. chatamensis*, *C. hoodensis*, *C. abingdoni* and the newly described species of Cerro Fatal / Santa Cruz (Poulakakis et al., 2008). Therefore, all members of this complex could be considered as potential "ecological analog" species for restoring tortoises on Santa Fe Island, with the exception of the Pinta Island form that is now extinct as far as is known.

Ecological niche is an important factor in choosing a species for translocation because species occupying similar niches on different islands are pre-adapted to occupying one another's habitats. The habitat suitability analysis discussed above (Gibbs et al., unpublished data) revealed that the islands of Santa Fe, Española and the northeast section of San Cristóbal (where that island's endemic tortoises persist today) share very similar ecological and habitat conditions. In the case of the closely affiliated (genetically) Cerro Fatal tortoise, the ecosystems occupied are quite different, as it migrates between arid and moist ecosystems that do not occur on Santa Fe. Therefore, Cerro Fatal is not a good option for a pre-adapted analog occupying a similar niche. Moreover, the Cerro Fatal population is very small (reduced by overhunting) and therefore not currently suitable for supplying individuals for translocation. The habitats currently occupied by tortoises on Española and the northeast of San Cristóbal are the most similar ecologically (all arid ecosystem types as occur throughout Santa Fe); therefore, these tortoises are likely the best preadapted forms to the ecological conditions currently found on Santa Fe Island.

Operational and logistical factors are further important considerations in selecting an analog species. While analysis of phylogenetic and pre-adaptation aspects have led to the identification of two extant species as suitable candidates (Española and San Cristóbal), in operational and cost terms for the DPNG, the existing breeding program in captivity for Española tortoises provides a more readily accessible and cost effective source of ecologically and genetically appropriate tortoises for translocation to Santa Fe Island. Moreover, the repatriation program for the Española Island population itself has been successful. Starting from just 15 remaining founder individuals (14 recovered from the island and one from a zoo), there are now some 1,000 surviving repatriates on Espanola Island, the product of a ~50% post-release survival rate among the > 2,000 repatriated individuals, all of which were offspring of the 15 surviving founders. Currently, there is a growing tortoise population on Espanola Island with reproduction in the wild and recruitment of juveniles produced by repatriates on the island.

Population viability analyses indicate that population management interventions that include continuing repatriations, terminating repatriations, or extracting 50 subadults while terminating repatriations would not negatively impact the population trajectory or probability of extinction. The only predicted difference is that terminating repatriations or removing 50 subadults and terminating repatriations delays full recovery marginally (Gibbs et al., 2014). In contrast, *C. chatamensis* on San

Cristóbal Island has recently (2016) been systematically inventoried and revealed to support a large and rapidly growing tortoise population (Tapia et al. unpublished data) and likely could easily support translocation of some individuals to Santa Fe Island. However, there is no captive rearing program now in operation to generate repatriates, nor any easy means to secure juveniles from northern San Cristobal to repatriate to Santa Fe Island. For this reason, the Espanola Island giant tortoise is the clear choice from an operations / management perspective.

Based on this integration of genetic, ecological, demographic and logistical considerations, the project design team has concluded that the most suitable species for use as an "ecological analog" to restore tortoises to Santa Fe Island is *C. hoodensis* from Espanola Island. Moreover, there is further value in using Espanola tortoises for Santa Fe insofar as Espanola tortoises can serve as an insurance population for the IUCN-designated "critically endangered" original Espanola tortoise population on Espanola Island itself. In contrast, there is less value in having an insurance population for the IUCN-designated "endangered" form from San Cristobal.

*ii. Description of existing physical cultural resources or sites (if any)*

Aside from a few informal and illegal short-term campsites used by fishermen, there are no known physical cultural resources or sites on Santa Fe Island. The island has likely never been the site of any prolonged human occupation, due to difficulty of access and lack of any reliable and drinkable freshwater supply.

*iii. Description of relevant socio-economic/cultural (including gender), institutional, historical, legal and political context of project area*

Having never been occupied by humans for an extended period, Santa Fe Island lacks any known cultural resources or sites. It receives the highest level of protection within the DPNG park zonation system.

*iv. Compliance with national and international legislation, regulations and policies on protected area/habitat restoration, release/translocation of tortoises and animal welfare/handling*

The following are the major elements of national and international legislation, regulations and policies that are being taken into account in the design, implementation and monitoring of the project's translocation and captive rearing elements (i.e. Component 3):

(a). <u>Galapagos Islands Protected Areas Management Plan</u>

Release of "ecological analog" tortoises to Santa Fe Island is underpinned by "The Management Plan for Protected Areas of Galapagos for Good Living" which guides decision-making for biodiversity conservation in the Galapagos Islands. The ecological restoration of Santa Fe Island represents a key action for implementation of the Management Plan.

The plan embraces restoration of "ecosystem engineers" and keystone species, including giant tortoises in the case of Santa Fe Island, noting that:

> …the conservation of functional biodiversity creates a buffer against anomalous disturbances and a natural insurance for the long-term maintenance of the services that ecosystems supply to

> human systems, and based on this concept not all species of an ecosystem play the same role in determining its functioning but there are ecologically essential species that take center stage in biodiversity conservation programs. (DPNG, 2014)

The plan also states that "any restoration project, before being carried out, must comply in a sequential and hierarchical manner with the following requirements: (a) scientific feasibility, (b) territorial viability, (c) technical viability, (d) economic feasibility, (e) legal feasibility, (f) social viability, and (g) political feasibility" within the Province of Galapagos (DPNG, 2014). Additionally, the plan establishes that the entire Conservation and Restoration of Ecosystems and its Biodiversity Program is considered an experiment to learn from and build upon (DPNG, 2014). Project activities have been designed in full compliance with all requirements of the Management Plan.

Careful monitoring of the project's ecological impacts will support adaptive management of the process and learning for applying lessons learned to new restoration efforts using ecological analogs in Galapagos and elsewhere.

(b). National park protocols for handling of giant tortoises (repatriation and captive rearing)

In all phases, the care in captivity, transfer, release and monitoring of the tortoises will be carried out according to protocols established by the Directorate of the Galapagos National Park for the transfer of live vertebrates, and more specifically for the repatriation of giant tortoises (DPNG, 2008a, DPNG, 2008b). All activities associated with rearing giant tortoises in captivity will align with the DPNG protocols as outlined in: "*The Captive Rearing of Galapagos Tortoises: An Operative Manual*." The manual provides guidance in the following areas: (i) *Routine activities* (periodic activities, seasonal activities, measuring and marking), (ii) *Thermal and habitat requirements* (adult corrals, juvenile corrals, hatchling corrals, adaptation corrals), (iii) *Feeding* (type, amount, sourcing and precautions), (iv) *reproduction* (reproductive behavior, nesting areas, inspection of females, inspection and opening of nests), (v) *incubation* (incubation methodologies, inspection of incubators), (vi) *Hatching* (hatching problems, hatchling development, care of newly hatched tortoises, hatchlings or eggs brought from the wild), (vii) *Diseases, treatments, and necropsies*, *problems with introduced animals* (rats, ants), (viii) *Materials needed at the Rearing Center*, and (ix) *Data collection forms and methods*.

(c) IUCN Guidelines for reintroductions and other conservation translocations

The project will abide by Guidelines outlined by the IUCN for conservation translocations with an emphasis is guidance that pertains to conservation translocations. In this case the focus is on ecological replacements, i.e., intentional movement and release of an organism outside its indigenous range to perform a specific ecological function. Given that project is being augmented and expanded but already implemented. More germane will be a focus on guidelines pertaining to Risk assessment, Monitoring and continuing Management, Dissemination of information.

## 6. Impacts, risks and mitigation

### *i. Additional details regarding the process and expected impacts / benefits*

The reintroduction of Espanola giant tortoises to Santa Fe Island, like any ecological restoration action, is a long-term process. Its purpose is to achieve the establishment of a population of tortoises large enough for tortoises to fulfill their role as ecosystem engineers and thus actively contribute to the restoration of the ecological integrity of the island. Reintroduction of tortoise populations is increasingly proposed as a tool for ecosystem restoration. Giant tortoises, once widespread on all continents except Antarctica, are ecosystem engineers that manipulate the distribution and abundance of other organisms through direct effects of herbivory, disturbance and seed dispersal on plant communities and subsequent indirect impacts on animal communities. The effects of giant tortoises on terrestrial ecosystems of oceanic islands (to which giant tortoises are currently restricted) are potentially on par with those of continental mega-herbivores as drivers of savanna structure and function.

The overall reintroduction / restoration process, which began in 2015, is broken down into two main phases:

**First phase***: Introduction in July 2015 of a first group of 205 juvenile tortoises, a second introduction in June 2016 of 191 juveniles, and subsequent annual introductions of between 70 and 100 juvenile tortoises from 2018 to 2026 release site conditions permitting.*[13]

The first component of this phase, consisting of the introduction of juvenile tortoises of the species *C. hoodensis*, was executed in 2015 using a group of juvenile tortoises (n = 205) from the Fausto Llerena Breeding Center on Santa Cruz Island. A second release of 191 juveniles was implemented in 2016. Further releases were contemplated for 2018; however, severe drought curtailed any releases and tortoises remain in quarantine.  Juveniles reared in captivity to 4-5 years have been chosen, and will be used, because they have much higher rates of survival upon release to the wild than do younger "head-started" tortoises but comparable rates to older head-started tortoises (Gibbs et al. PLoS); therefore, 4-5 years represents a cost-effective compromise for the investment in head-starting to increase survival in the wild but terminating the process when further gains become marginal.

The reintroduction process takes place as follows. On the day of the release, tortoises are placed in wooden boxes and moved by ship with enough capacity to transport all the tortoises at the same time as well as the personnel required to release them all at once. Tortoises are then moved from the ship to a protected embayment of Santa Fe Island by boat and then transferred to land. Once there, groups of 8 to 10 tortoises are placed in backpacks and carried by park rangers to the release sites (these have been mainly in the central area of the island to date).

For the first week after their release, daily monitoring of the release zone is carried out to monitor the adaptation process. This release process is being iterated annually, environmental conditions permitting (no tortoises will be released unless there is sufficient recent rainfall to generate a supply of herbaceous vegetation and grasses at the release site sufficient to sustain released tortoises for at least 2 months). The number of juvenile tortoises released annually is provided as a range because it cannot be a fixed quota as the number available for release is determined by offspring production "pipeline" in captivity, itself a function of number of females ovipositing, hatching success, and juvenile growth and survival rates in the years preceding release which in turn is affected by vagaries of climate, food supply and husbandry practices. This said, the captive-rearing process does afford a highly predictable *range* of cohort sizes available for release each year.

**Second phase:** *Introduction of a group of 50-100 subadult tortoises collected on Española Island in 2019.*

For the second phase of the project, 50 subadult tortoises between 15 and 20 years old (at the point of

[13] No ESIA or EMP was done for this, although the report submitted by GC to the Park proposing the action was very similar in scope.

sexual maturity) will be located on Espanola Island for eventual translocation to Santa Fe Island. Locating suitable individuals for translocation requires extensive fieldwork by multiple park ranger teams searching through the difficult terrain of Espanola Island over the course of 10 days. Communication and coordination is accomplished through radio. Once suitable tortoises have been identified, a helicopter will be used to transfer tortoises from capture site to the DPNG ship *Sierra Negra* which will then transfer the selected tortoises from Española Island to the Fausto Llerena Breeding Center on Santa Cruz Island. At the breeding center, tortoises will be subjected to health status evaluation and a strict quarantine process for at least two months, during which they will remain isolated and receive food without seeds (to prevent them from vectoring seeds among islands). After this quarantine period, tortoises will be transferred again via helicopter first from the Centro de Crianza to the DPNG ship *Sierra Negra*, transported by the DPNG ship to a protected embayment on Santa Fe Island, and then moved again by helicopter to release sites around the island where the tortoises will be received by waiting park guards. Following the tortoises' release on Santa Fe Island, a field crew will remain for a week monitoring their activities and movements. Each tortoise will also be outfitted with a satellite tracker to monitor movements, survival and settlement behavior over the next year.

The **expected impact** of these two project phases are reintroduction and establishment of a self-sustaining breeding population of giant tortoises on Santa Fe Island, using individuals from the population of Española. More specifically, a similar outcome is expected to unfold on Santa Fe as has been demonstrated on Espanola, with the exception being that the tortoise population, along with the ecological impacts, will likely increase considerably more quickly on Santa Fe because cactus – a critical resource for tortoises – is far more limited on Espanola Island (an estimated 1,000 adult cacti remained after goat depredations) than on Santa Fe Island (where an estimated 200,000 adult cacti remain). Indeed, survival of the tortoises initially translocated to Santa Fe is already much higher than what has been observed on Espanola.

Based on the estimates of the survival and reproduction of the tortoises repatriated to Española (Gibbs et al., 2014) and the parameters mentioned above (for each of the two project phases) applied to the Santa Fe introduction scenario, a "Lefkovitch" population projection matrix was used to predict 30 years into the future the population of tortoises in Santa Fe based on the two phases of the project. We generated predictions for population growth assuming a relatively low survival of juveniles (= 0.90 per year or 9 of 10 juveniles that survive each year). The model estimated that, within 30 years, there will be about 300 adult tortoises and 1,000 juvenile tortoises distributed throughout Santa Fe, for a total population of some 1,300 individuals. To date, we have estimated 99% survival among tortoises released so far; therefore, these estimates are conservative. Given an approximate historical population of Santa Fe of 2,000 adults (estimated at 1 adult tortoise/hectare of suitable habitat, which is typical for robust populations of giant tortoises in Galapagos) this activity is predicted to repopulate the island tortoise population to a level of about 12.5% the original abundance *within the life of the project*, eventually leading to 65% occupancy after 30 years, enabling *in situ* reproduction and subsequent recruitment to lead to full population recovery and reinstatement of ecosystem services.

*ii. Risks and mitigation*

Santa Fe Island has never supported a human population; therefore, project impacts, threats and risks are primarily biological as well as operational / financial. These risks, and related mitigation measures, are described below and summarized in **Table 1**.

In terms of biological impacts, **risks to source population** are, in theory, a concern given that individuals of the tortoise species to be deployed on Santa Fe Island will be derived from both captive and wild stocks elsewhere (Espanola tortoises at Santa Cruz breeding center and on Espanola Island). However, a detailed analysis of this issue by Gibbs et al. (Gibbs et. al 2014) revealed that continued repatriation of tortoises from the Santa Cruz breeding center to Espanola Island for 25 more years, termination of repatriation, and termination of repatriation coupled with one-time removal of 50 adults (for translocation to Santa Fe) all yielded nearly equal and, importantly, negligible extinction risk estimates over a 100-year time frame (likely about 5 tortoise generations). Therefore, the approach proposed here—termination of repatriation during the life of the project coupled with one-time removal of 50 adults—is predicted to pose no risk to the source population. Importantly, ongoing monitoring of the Espanola population as part of the Giant Tortoise Restoration Initiative, following completion of the GEF project, will reveal patterns of tortoise population growth on that island during the coming decade.

**Vectoring plant seeds among islands** in the digestive tracts of translocated tortoises is a genuine risk. A nearly completed thesis on this topic by Jennifer Vasconez (unpubl. data) measured the seed retention rates of tortoises captured on Volcan Wolf and relocated to the Breeding Center in Santa Cruz. Tortoises were confined to a study pen, placed on a diet consisting of only plant leaves, and their droppings collected for a year and seeds extracted from those droppings. Results indicate that two months of quarantine are needed to fully purge accumulated plant seeds from tortoise digestive tracts. Large plant seeds are passed quickly but small seeds more slowly. Therefore, quarantine period for translocated tortoises (both headstarts from the Breeding Center and subadults moved from Espanola) will be extended beyond two months to reduce this risk to near zero. As headstarts are reared on a diet of only leaves of three species, risks are near zero to begin with. However, for subadult translocates from Espanola the risk is considerable, with the caveat that the flora of Espanola is nearly identical to that of Santa Fe, both being low dry islands located in the same region of the archipelago.

We do not anticipate any **disease risk** insofar as there are no other tortoises on Santa Fe island to transmit diseases to, and the remaining reptiles (marine and terrestrial iguanas, lava lizards, racers [snakes], and geckos) are so distantly related that inter-taxon disease transmission is unlikely. Moreover, the DPNG breeding center has well-established protocols for disease monitoring and treatment via collaborating veterinarians should disease issues arise in captivity that might lead to vectoring disease via tortoise translocations to the Santa Fe population.

Similarly **invasion risk** is very low. Unlike many vertebrate animals, giant tortoises are unable to make themselves cryptic in refuges, burrows, cavities etc. due to their very large size hence remain readily detectable for removal if such were deemed necessary. Should tortoises be deemed "overabundant" at any point in the future they can simply be removed from the island, in subsets or entirely. For this reason, invasion risk is minimal.

A known **biological risk** is an unusual one: Santa Fe Island currently hosts one massive, male giant tortoise determined by geneticists to have been translocated to the island from the western side of Santa Cruz Island (*C. porteri*). The animal has a domed morphology not adapted to this arid island. The circumstances of its translocation are not well known. The tortoise could pose a risk to young Espanola tortoises translocated to Santa Fe, which will reach sexual maturity at the age of 10 years. Attempted matings between the large alien male and small, sexually maturing headstarts could be problematic both in terms of physical trauma as well as potential gene transfer / hybridization. For this reason, the male will be removed by helicopter during the first phase of this project (the male is too large to be carried out). The male will be removed to the Santa Cruz breeding center, placed in quarantine for six months and then moved by truck for release back in its original range on the western side of Santa Cruz Island.

The most significant risks relate to **ecological engineering impacts** of translocated tortoises and whether they might ultimately have deleterious impacts to populations of native species present on Santa Fe Island. Ecological changes associated with tortoise restoration will not be immediate and will require significant numbers of adult tortoises to manifest, on the order of at least one per hectare (Hunter and Gibbs 2014). Most primary risks will be associated with vegetation change induced by the re-established tortoise population to the habitats of endemic species / subspecies on the island: the *Opuntia* cactus, pallid iguana, Santa Fe leaf-toed gecko, and Santa Fe rice rat. The key question is not whether these changes will occur but whether they could be deleterious. It is clear that the tortoises will alter the ecosystem–indeed, this is the primary rationale for this tortoise translocation—and, by extension, its constituent biota. The issue is whether such changes affect long-term population viability in affected species. Therefore, the focus on risk management, and ecological monitoring conducted to inform it, will be on tracking any dramatic changes in population status of endemic species / subspecies mediated by habitat change induced by tortoises.

Based on their well-documented interactions with the Espanola ecosystem, which is quite similar to that of Santa Fe, tortoises are expected to generate the following primary ecological trajectories: reduce woody plant extent, expand the extent of herbaceous vegetation, and facilitate cactus regeneration through seed dispersal away from parent plants. Given these likely trends, the following changes in habitats components of endemic fauna will be the focus for monitoring to inform risk management. For the pallid iguana, a recently completed MSc thesis by Cano (2018) revealed that diets of iguanas and newly released Espanola tortoises broadly overlapped on Santa Fe Island with 39 species in total consumed from 27 genera and 16 families: 13 species were consumed only by tortoises, 10 only by iguanas and 16 by both. Cactus was a particularly important component of the diet of both. Given dietary preferences, cactus is likely to be the main linkage mediating relationships between these species, along with the shrub / tree *Cordia lutea* (or "muyuyo") and persistent forb *Lantana peduncularis* ("supirosa endemica"), the leaves of which are also preferred sources of food for iguanas and likely tortoises, as these have high energetic and nitrogen levels (Christian et al. ), as well as seasonal grasses, which are important forage for tortoises. These plants will be the key focus for plant monitoring to understand trends in these key forage species. Cactus impacts of tortoises are likely to be positive for cactus (Gibbs et al. 2008) as well as iguanas and tortoises themselves, negative for muyuyo and supirosa and hence iguanas, and positive for grasses and hence tortoises.

**Risk assessment and monitoring for other endemic species** is more problematic because so little is known about them or the relevant ecological inter-relationships. Given that there has been only a single, limited and now dated study of rice rat ecology (in the 1970's, Clark 1980) there is sparse information to predict likely consequences, especially given that current population status is unknown.

This said, abundance of the endemic rice rat indicated a weak, positive relation to the "volume" of vegetation and structural complexity of the vegetation (Clark 1980). Ecological factors that simplify vegetation structure, as tortoises likely would, could reduce abundance of the rice rat. As almost nothing is known of the ecology of the Santa Fe gecko it is difficult to frame potential impacts of a tortoise translocation on this taxon; that said, being mostly fossorial during the day and surface active at night, it appears unlikely that the vegetation shifts projected for Santa Fe will affect gecko populations. Inferences about likely risks to these species will be derived from analyses of monitoring data of changes in the island's vegetation.

**Financial risks** for this undertaking are quite low. The tortoise reintroduction program is built around a captive rearing and repatriation program of the DPNG that has been operating successfully for 50 years. All program components are currently operational in some form with existing personnel and knowledge of processes still engaged. Moreover, all monitoring efforts are underway in some form and have completed several cycles successfully and hence are stable and have low risk of failure. This is to say the program is robust not only in terms of probability of execution but also in terms of capacity to change adaptively as needed based on past successes executing all components proposed.

*iii. Description of stakeholders and their involvement and support for project activities before and during project implementation including mechanism for resolving conflicts/grievances*

The stakeholder "landscape" for this program is simplified. There is essentially only the DPNG and, by extension, the Government of Ecuador as primary stakeholders given that DPNG is the sole decision-maker about management and restoration efforts for strictly protected islands such as Santa Fe. Other than the GEF, the only other entity that will be contributing significantly to this activity is the Galapagos Conservancy, which collaborates with the DPNG strictly in an advisory capacity. Galapagos Conservancy focuses its advising on scientific issues that pertain to decision-making by DPNG, in this case, on matters of giant tortoise conservation and restoration, both for captive-bred and wild populations. Galapagos Conservancy has a long-established relationship with the DPNG with well-honed communication channels and means of resolving any conflicts that might arise. These primarily revolve around reports of monitoring outcomes, relevant scientific work conducted outside Galapagos, and expert knowledge communicated to DPNG decision-makers via annual reports, technical publications (often authored collaboratively), and frequent "sit down" and "in person" meetings.

Ultimately as tortoise numbers build and the population distributes itself fully across the island, tortoises will begin to appear at the sole tourist site on Santa Fe Island, to the northeast of the central tortoise release zone. At that point, tortoises will become a significant part of tourist and guide experience on Santa Fe Island, thereby involving these groups as indirect stakeholders. However, that is not likely to transpire for at least a decade, that is, until such time as the population has increased sufficiently to expand to the site. More generally, the conservation science community will be interested in learning about the outcomes of this innovative restoration program using an ecological replacement species, especially given that reintroduction of tortoise populations is increasingly proposed as a tool for ecosystem restoration in island systems where tortoises once occurred and for other taxa of large herbivores in terrestrial environments.

*iv. Exit strategy if undesired and unacceptable consequences have occurred*

In terms of an exit strategy should project outcomes be determined to be adverse (reducing habitat components and population levels of key endemic species unacceptably), tortoises can be removed from Santa Fe in subsets or entirely. After period of extended quarantine, tortoises removed could be relocated to Espanola Island where they would significantly enhance the population recovery process there (the population is currently at 20% of original size). Moreover, the Espanola tortoise has been frequently identified as a possible surrogate species to use to repopulate Pinta Island where tortoises are now extinct.  There is ample habitat capacity on Espanola Island and Pinta Island (should DPNG deem Pinta an appropriate destination to receive Espanola tortoises) in the upcoming decades to accommodate all tortoises that might be produced on Santa Fe should they be subject to removal and translocation if a determination based on monitoring data collected and synthesized be made that undesired and unacceptable consequences to endemic species have occurred. There is certainty all tortoises can be found and removed within a year should they be deemed undesirable.

**Table 1: Details of risk management for Component 3**

| Risk | Rating | Risk mitigation measures | | Responsibilities (who in the project will be directly responsible) |
|---|---|---|---|---|
| | | incorporated into project design | Managed via ongoing monitoring | |
| Risks to source populations | Low | Risk assessment already complete (Gibbs et al. 2014) and revealed zero risk | Source population subject to regular monitoring which would reveal and population decline due to conservation translation should it occur | DPNG advised by GC / GTRI |
| Vectoring plant seeds among islands | High | Translocating tortoises among islands presents a known, high risk for seed transport and plant establishment – scientific dimensions of problem well understood (Vasonez thesis) quarantine procedures well established and proven | | DPNG advised by GC / GTRI |
| Disease risk | Low | Disease management protocols well established and proven in Breeding Centers and very low risk of inter-taxon disease where ecological replacement tortoises present (no other tortoises on Santa Fe Island except for those released). | Health assessments of released tortoises part of tortoise monitoring protocols | DPNG advised by GC / GTRI |
| Invasion risk | Low | Tortoises can be removed at any time should they be deemed invasive. Highly unlikely to be so deemed given their former presence on Santa Fe Island and evolutionary adaptation of flora and fauna to this herbivore. | Measurement of plant community health and population status of endemic and keystone species part of monitoring protocols | DPNG advised by GC / GTRI |

| Risk | Rating | Risk mitigation measures | | Responsibilities (who in the project will be directly responsible) |
|---|---|---|---|---|
| | | incorporated into project design | Managed via ongoing monitoring | |
| Biological risk | High | Alien massive tortoise present on island targeted for removal as part of project design. | | DPNG advised by GC / GTRI |
| Risks from ecological engineering | Low | Evolutionary adaptation of flora and fauna to this herbivore implies risks of deleterious impacts low (intention of project is to effect such changes to a beneficial degree) | Vegetation and fauna monitoring to measure such impacts of ecological engineering part of monitoring protocols, be such impacts beneficial or deleterious | DPNG advised by GC / GTRI |
| Risk assessment and monitoring for other endemic species | Medium | | Tortoises could potentially impact endemic iguanas, rice rats and cacti to a deleterious degree – monitoring programs design to detect such impacts should they occur in all relevant taxa | DPNG advised by GC / GTRI |
| Financial risks | Low | There are no novel approaches employed in this project – all are well-proven with known costs and hence likely highly successful with low risk of failure or cost overrun | | DPNG advised by GC / GTRI |

## 7. Monitoring

This section presents details of key issues to be monitored under Component 3, along with information on responsible parties and dissemination of information. **Table 2** below provides a summary of these issues.

### *i. Description of system for monitoring the ecological, social, and physical-cultural impacts, including key indicators, baseline data, location and frequency of monitoring activities*

The emphasis of monitoring will be on ecological issues because, as indicated earlier, there is no human population present on Santa Fe Island and hence social and physical-cultural impacts are irrelevant in the context of this project. Key indicators will involve the agent of ecological change being introduced to the system – the Espanola tortoises—including their ecological impact on plant communities and habitat components for endemic species, and the population status and trends among those endemic species, with a focus on the species of primary concern in terms of likelihood to be impacted: *Opuntia* cactus, pallid iguanas, and rice rats.

For **monitoring the tortoise population**, since 2015 annual week-long systematic mark-recapture survey of tortoises have been conducted over the release zone and its surrounding regions (2015-2018). For each tortoise encountered, geographic location (accurate to 2 m), multiple measures of size, mass (as a measure of condition relative to size), and unique ID (all tortoises are uniquely identified with subdermal transponders) are recorded. Following four such surveys to date, a database of almost 1,000 captures and recaptures has been assembled. These data enable monitoring of many critical aspects of the tortoise population, including growth rates, body condition, movement, distribution and dispersal, habitat use, survival, detectability per survey and population size.

The above monitoring effort will continue to be undertaken annually during the life of the project in order to inform decision-making as it pertains to the size and well-being of the tortoise population. Tracking devices will also be placed on representative groups of both juveniles and sub-adult tortoises. These devices will report the position of each tortoise tagged several times per day via satellite, such that hardware costs, initial deployment and data fees are the only costs. We will use the newly available tags from the Icarus system – a novel animal tracking program associated with the European Space Station. Tracking tortoise movements will enable a better understanding of dispersal, habitat use, inter-species interactions and hence ecological impact.

For **monitoring the pallid iguana population**, established a remarkable baseline of abundance and distribution of iguanas was established in 2011 via an island-wide, distance sampling program conducted by DPNG rangers who counted iguanas (and the distances they were located away from the transect line) along 307, 100-m-transects. At transect intersections, 185 permanently marked plots were established, where iguanas were counted. This combined approach generated two independent estimates of population size (and structure) that corroborated one another (yielded essentially the same estimate) and that were both highly precise (SE/mean = 10%). Transects in the core of the island associated with the initial tortoise introduction were resampled in 2017, further extending the baseline. This large-scale survey will be repeated once at the end of the project to measure change in pallid iguana numbers and distribution, with special emphasis on changes in iguana numbers at locations with elevated densities of translocated tortoises.

For **monitoring the rice rat population**, the sampling conducted by Clark (1980), who established a baseline on density and distribution during trapping from 1973-1976 (the first and last time this species was systematically surveyed), will be repeated. Following Clark's (1980) methods, rats will be trapped with collapsible Sherman aluminum live traps baited with peanut butter and opened in late afternoon 16.00-18.00 hours and checked at sunrise (about 6.00 hours). Each trapline will consist of twenty-five stations, two traps per station, with 10 m between stations, distributed at six sites across the island. For each rat, weight, sexual condition, and tail, total, and perineum lengths will be recorded. will trap rats once annually in May/June in conjunction with the tortoise monitoring. By matching sampling to Clark's (1985) sampling sites, much needed data can be generated on rat population change while an updated baseline can be established and follow-up change may be measured. Notably, some of Clark's (1985) trap lines are proximal to the tortoise release site and others distant, thus enabling contrasts to be made regarding population change in the native rats and tortoise occurrence.

For **monitoring the cactus population**, our focus is on general abundance and population structure across the island, detailed studies of population structure across a gradient or tortoise density, and demographic processes at the site of tortoise releases. These will be monitored as follows:

- For monitoring general changes across the island, recorded counts of cactus of three life stages (juveniles, subadults and adults) have previously been made on 183 plots systematically arranged across the entire island. These will be resurveyed in in conjunction with the iguana resurvey to examine change associated with time and tortoise impacts, using distance from the tortoise release area and density of tortoise droppings as the proxy variables.
- For monitoring change in cactus populations along a gradient of tortoise density, have established 26 25-m radius circular plots have been established, with every cactus geolocated, its height measured and its life stage recorded. These plots range from the epicenter of the tortoise release zone to well beyond areas where tortoises have dispersed to (or will during this project). These plots have been re-measured annually for three years. Contrasts in densities of different stage classes of cactus on these plots in relation to distance to the epicenter of the tortoise release site will inform about near-term changes in cactus populations associated with tortoise occurrence.
- Demographic processes in cactus at the epicenter of the tortoise release site are being measured starting in 2018 (with one year of baseline data already collected) on a large "macro-plot" where (~2 hectares) where every cactus have been geolocated and its life stage, height, number of pads and fruits (~600 in total) have been recorded, and each one permanently tagged with copper wire and aluminium plant tags. Tracking these individual cacti into the future will enable to track cactus growth rates, recruitment, mortality, and transitions among stage classes as the tortoise population grows. Cacti in this macroplot will be measured annually during the life of the project.

For **monitoring broader changes in the plant community**, baseline data include relevé measures of plant cover, substrate characteristics, overhead canopy and frequency of stems of woody plants in 20, 6x6 m square plots, 5 of which are fenced to exclude tortoises, 5 fenced to exclude tortoises and iguanas, and the remaining 10 unfenced to serve as "controls." Detailed measures on plots have been made annually since 2014, which includes prior to the initial release of tortoises as well as prior to construction of the fences (thereby a "before-after / control-treatment" or BACI design, a classic, statistically powerful design for measure treatment effects in ecology). Data are analyzed not only to estimate extent of cover of key habitat components (herbaceous plants, grasses, woody plants) and species but also the interaction with presence of tortoises and iguanas. The plots are located at the heart of the tortoise release zone where they are optimized to measure tortoise impacts. These plots will continue to be monitored annually during the life of this project.

*ii. Description of responsible party for implementing and monitoring the mitigation measures, including their capacity and experience*

All of the required monitoring activities and mitigation measures will be undertaken by, and be the responsibility of, the Giant Tortoise Restoration Initiative of the Galapagos Conservancy, in close coordination and cooperation with the DPNG. This institutional arrangement has conducted successfully all population and ecosystem monitoring efforts described herein to date, demonstrating ample capacity to conduct the work described.

*iii. Dissemination of information including means and frequency:*

The reintroduction of tortoises to Santa Fe constitutes an important milestone in the process of ecological restoration of the island; therefore, the DPNG will invite the local, national and international press whose representatives will be able to document the transfer process from the Fausto Llerena Breeding Center to the beach in Santa Fe Bay, where the tortoises will then be conveyed to the interior of the island by park rangers. If there are any press and television reporters specializing in nature documentaries, their participation in the entire process will be authorized, including time at the release site in the island's interior. The DPNG Communication and Education Department will be in charge of coordinating this part of the process.

Status and trend data for all key indicators will be synthesized with each iteration of the indicator's monitoring cycle (not all indicators are monitored every year). Outcomes will be shared in written form annually by Galapagos Conservancy to DPNG, with a follow up in-person meeting to discuss findings and implications.

Monitoring outputs will also include a scientific article submitted for publication to a respected science periodical on the near-term ecological outcomes of the tortoise translocation in order to share the scientific findings with the population of Galapagos and with the world. Depending on the editorial process of the different journals to which it will be submitted, the article might not be published by the time of project closing.

Outcomes will also be summarized in a poster to be presented at the Galapagos National Park Symposium, which is organized every year and is open to the public. Attendance at the Symposium includes other investigators (both visiting and resident scientists), guides, students and members of the general public.

**Table 2: Monitoring of Component 3**

| Component 3: Advancing the recovery of island ecosystems following invasive species eradication through the re-establishment of keystone species (i.e. giant tortoises). | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Indicators** | **Metrics** | **Methodology** | **Baseline** | **Location** | **Frequency** | **Responsible Parties** | **Indicative Resources** |
| Indicator 3.1.:<br><br>Percentage of Santa Fe Island land area where giant tortoises are dispersing seeds | Hectares within 100 m of a known tortoise occurrence since repatriations began in 2015 to project end | Mark-recapture surveys of tortoises and tortoise movement studies | 2014 when no tortoises were present = 0 hectares within 100 m of a known tortoise occurrence | Santa Fe Island (entire island) | Annual prior to project initiation and bi-annual thereafter to project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |
| Indicator 3.1.1.a.:<br># of giant tortoises (*Chelonoidis hoodensis*) translocated to Santa Fe Island | Number of tortoises | Visual counts by Breeding Center staff according to Breeding Center protocols as tortoises are processed into the travel boxes for transfer to Santa Fe Island on day of transfer | As of December 2017, 396 giant tortoises of the species *Chelonoidis hoodensis* had been released to Santa Fe Island. | Santa Fe Island | Likely annual but dependent any given year on environmental conditions conducive to tortoise release | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |
| Target 3.1.1.b:<br>At least 30 sub-adult giant tortoises (*Chelonoidis hoodensis*) are translocated | Number of tortoises | Visual counts by DPNG rangers as subadult tortoises are released onto Santa Fe Island | As of December 2017, there were no subadult tortoises on Santa Fe Island. | Santa Fe Island | Single event when transfer transpires | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |
| Indicator 3.1.2.:<br>Tested and optimized monitoring and evaluation protocol (and sub-protocols) accepted | Existence of protocol | Outside verification of tested and optimized monitoring protocol | As of December 2017, there was no tested and optimized monitoring protocol | Not applicable | Single event at project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of |

| Component 3: Advancing the recovery of island ecosystems following invasive species eradication through the re-establishment of keystone species (i.e. giant tortoises). | | | | | | | |
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| **Indicators** | **Metrics** | **Methodology** | **Baseline** | **Location** | **Frequency** | **Responsible Parties** | **Indicative Resources** |
| by the Project Steering Committee | | | | | | | indicators. No additional dedicated budget is allocated |
| Indicator 3.2.: Number of giant tortoises raised in captivity annually: Santa Cruz | Number of tortoises | Counts of tortoises according to record keeping programs outlined in "The Captive Rearing of Galapagos Tortoises: An Operative Manual" | In Santa Cruz, an average of 250 tortoises annually is produced for the populations of Española, Santiago, Floreana, Pinzón and Eastern Santa Cruz | Santa Cruz Island Breeding Center | Single event at project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |
| Indicator 3.2.: Number of giant tortoises raised in captivity annually: Isabela | Number of tortoises | Counts of tortoises according to record keeping programs outlined in "The Captive Rearing of Galapagos Tortoises: An Operative Manual" | In Isabela, an average of 200 tortoises annually from the populations of the Sierra Negra and Cerro Azul volcanoes | Isabela Island Breeding Center | Single event at project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |
| Indicator 3.2.1: Number of centers modified and expanded | Number of new breeding pens<br>Number of quarantine pens<br>Number of pre-adaptation pens<br>Number of pens for hatchling tortoises | Facility inspection at project end | Design blueprint of Breeding centers in 2017 | Breeding Centers on Santa Cruz Island and on Isabela Island | Single event at project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |
| Indicator 3.2.2: # of breeders selected, located, and transferred to breeding center | Number of tortoises | Counts of tortoises according to record keeping programs outlined in "The Captive Rearing of Galapagos | Breeding stock as of Dec. 2017 | Breeding Centers on Santa Cruz Island and on Isabela Island | Single event at project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No |

| Component 3: Advancing the recovery of island ecosystems following invasive species eradication through the re-establishment of keystone species (i.e. giant tortoises). | | | | | | | |
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| **Indicators** | **Metrics** | **Methodology** | **Baseline** | **Location** | **Frequency** | **Responsible Parties** | **Indicative Resources** |
| | | Tortoises: An Operative Manual" | | | | | additional dedicated budget is allocated |
| Indicator 3.2.3:<br># of scientific, technical and popular articles and reports. | Number of technical articles in peer-reviewed literature<br>Number of informal articles in publicly available Galapagos<br>Number of scientific posters presented DPNG conference | Provision of final copies of documents | Dec. 2017 | Not applicable | Single events at project end | DPNG advised by GC/GTRI staff | Approximately 5-10% of the project team's time will be allocated to monitoring of indicators. No additional dedicated budget is allocated |

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