RESTORATION OF PINTA ISLAND THROUGH THE REPATRIATION OF GIANT TORTOISES

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Introduction

The ultimate aim of the project is to restore the ecosystem of the island of Pinta by reintroducing the Galapagos giant tortoise.

A subspecies of the Galapagos giant tortoise (*Chelonoidis abingdoni*) was once prevalent on Pinta island. The population was decimated to the point where just one Pinta tortoise – Lonesome George – remained. Invasive feral goats soon became widespread in the landscape, and with their clearance the island's vegetation made an impressive recovery. In order to rebalance the ecosystem a dominant herbivore needed to be present – giant tortoises needed to return. With only one of the Pinta subspecies remaining, the decision of which subspecies of tortoise should be introduced to Pinta needed to be made.

It was originally thought that Espanola tortoises were the most suitable species to introduce to Pinta. With the success of the Galapagos National Park (GNP)'s captive breeding programme, including a long-term repatriation programme, an excess of juvenile tortoises could be used.

During the same period, two major developments took place. Firstly, new genetic research discovered a hybrid tortoise on a volcano on Isabela island containing some Pinta genes (Russelo *et al.,* 2007), which suggested that there might be more; and secondly, females sharing Lonesome George's corral laid eggs, which turned out to be infertile, but gave new hope that one day tortoises containing his genes might be reintroduced. These new breakthroughs highlighted the importance of making the right decision about which tortoises to settle onto Pinta island.

While this difficult decision was being made the Charles Darwin Foundation began to carry out more preparation work, by investigating the vegetation of Pinta in order to advise the GNP on its suitability as a habitat for giant tortoises.

Tortoises now live on Pinta island for the first time since 1972. The decision to repatriate Espanola tortoises to Pinta was ruled out and eventually it was decided to release 39 adults of mixed ancestry that had been living at the Charles Darwin Research Station onto Pinta island. Both major phenotypes of tortoises (saddlebacked and domed) were introduced to Pinta. Being adults, they would have a greater impact in the shorter term and a greater chance of survival. They were also large enough to be fitted with the GPS

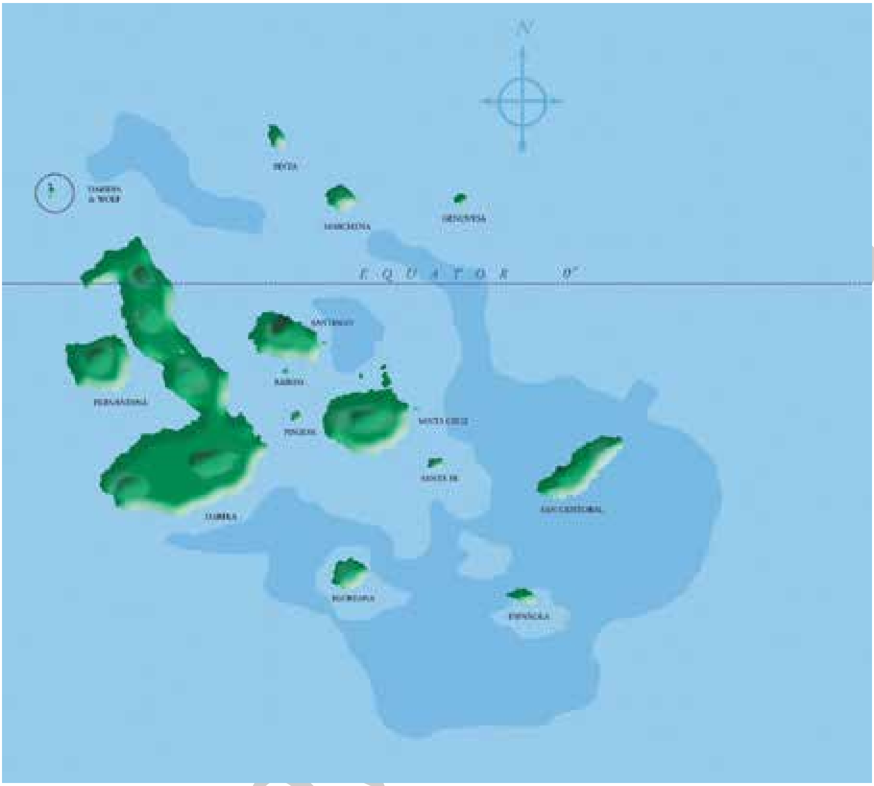

Fig. 1. Map of the Galapagos islands, located off the coast of Ecuador.

equipment required to track them. Prior to their release they were sterilised (Knafo & Divers, 2010a & 2010b), due to new hopes for the long term future of Pinta tortoises, so that genes from the introduced tortoises should not contaminate the gene pool of any other tortoises which might be introduced in the future.

PHASE I
Investigation of the vegetation of Pinta

In 1974, botanist Henning Andsersen had established thirteen 100 square metre monitoring plots on Pinta at altitudes of between just above sea level to 580 metres. In April 2009 scientists from the Charles Darwin Foundation participated in a reconnaissance expedition to Pinta, and surveys of the same plots were carried out in order to gain a necessary understanding of the island conditions relative to the 1974 baseline, and to identify a probable tortoise release site.

Goat eradication had been completed in 2002 and they expected to find a closed habitat, with a high density of woody vegetation, which could endanger some endemic plants. The first two days of the mission were dedicated to monitoring the vegetation plots. When comparing the vegetation composition of each plot from 1974 to 2009, it seemed that species richness had remained stable over time. However, the cover of woody plants increased substantially, particularly in the zones between 50-200 metres and 400-580 metres. Interestingly, woody species cover remained constant in the middle grassland zone. Based on these findings, it was concluded that 40 years of goats had not irreversibly affected the vegetation of Pinta and natural functions, such as long-lived seed banks, still persist (Fig. 2).

The island was searched for a suitable site to release tortoises. On the west side of the island an area of two square kilometres of grassland was found. This site was perfect for reintroduced tortoises: in terms of available food, productivity of 9.32 tonnes per hectare of the coarse-leaved grass *Paspalum galapageium* was measured and a high abundance of *Opuntia* cactus was found. In terms of future reproduction, two areas suitable for nesting (warm and with deep soil) were located near the grassland.

In conclusion, this trip showed (a) goats did not irreversibly damage the ecosystem, (b) the habitat was becoming more dense and close due to the renewal of woody population but had not yet negatively impacted on endemic species, (c) a very suitable area that could support a large population of tortoises was found and (d) it was a perfect time for a successful reintroduction of tortoises in Pinta because of ideal conditions for feeding and breeding.

PHASE II
Repatriation of giant tortoises to Pinta island

The ecological restoration of Pinta island through the reintroduction of giant tortoises is a high conservation priority for Galapagos. This project focussed on the introduction of 39 non-reproductive adult tortoises in May 2010 as ‘Project Pinta’ to catalyse a more balanced restoration of the Pinta ecosystem (Fig. 3).

Masters student Elizabeth Hunter and three field assistants spent two months on Pinta immediately after the tortoise release monitoring their movements, food habits and impact on the ecosystem (Figs 4 & 5). They studied tortoise movements by carapace type and sex, habitat preferences in the mid-elevation area surrounding the release site and foraging preferences and areas of high forage availability. Preliminary conclusions were:

Fig. 2. The landscape of Pinta island. (Photos by Francisco Laso).

Fig. 3. Tortoise #64 being carried up to the introduction point by two park guards.

- ❏ saddlebacked and domed tortoises prefer different elevation zones
- ❏ in mid-elevation areas saddlebacked and domed tortoises select the same habitat features
- ❏ tortoises prefer areas with higher cactus density and areas with less slope
- ❏ tortoises show little preference for particular plant community types.

The continuation of the project involved a revisit to Pinta in May 2011 that allowed the monitoring of changes in tortoise behaviour and ecosystem impacts since introduction. Together the phases I and II research would permit the development of recommendations for the long term management of Pinta in relation to: firstly, the likely carrying capacity of tortoises on Pinta and best strategies for future introductions (e.g., preferred habitats, numbers, and seasons for release); and secondly, how tortoises were likely to alter habitats on Pinta and, particularly, whether an introduced tortoise population could reverse woody plant succession and over what time frame. As such, the information gathered from the monitoring programme will support development of a recovery plan for the island's ecosystem through the eventual release of a reproductive tortoise population genetically related to the Pinta tortoise species, now extinct in the wild. However, as a consequence of the death of Lonesome George in June 2012, this aspect of the plan will have to be reappraised.

The research team returned to Pinta island in May 2011 with two primary research objectives:

1. To determine how tortoises interact with the plant community, to enable prediction of how tortoise habitat preferences may impact on the plant community over time.
2. To suggest guidelines for future introductions of reproductive tortoises, including introduction sites and best release strategies.

Toward achieving these goals, they continued to monitor the introduced tortoises' movements, observed tortoise behaviour extensively, revisited vegetation plots, quantified habitat features important to tortoises across the island and checked on the released tortoises' health status.

Activities and primary results

1. Environmental drivers of tortoise movement

Activity:

When the team left Pinta in July 2010, 19 of the 39 tortoises had functioning GPS loggers attached to them, recording hourly movements. When they returned in May 2011, these units were no longer functioning (most likely due to battery failure), and thus they could not locate the tortoises using

Fig. 4. Searching for tortoises.

Fig. 5. Elizabeth Hunter downloading data from tortoise #68's GPS data-logger.

radio signals. Through diligent searching, they located 14 of the tortoises and removed their GPS loggers, which they were able to send to the manufacturer who downloaded the data (the longest that any of the units lasted was until November 2010). Despite this problem, they were able to gather a total of 2,412 days of detailed movement data or an average of 121 days per unit during a critical phase of the release programme. They supplemented the movement data with behavioural observations for tortoises that they were able to track (eight individuals). Through these methods, they were able to independently measure habitat preferences that they had observed from the GPS logger data during the first months after introduction.

Results:

Tortoises strongly selected areas with high arboreal *Opuntia* cactus density just as they had immediately after the introduction. Selection for other habitat features, such as topographic slope and vegetation density, varied across time, indicating that adult cactus density is probably the most important driver of where tortoises moved (Fig. 6). The proportion of time spent foraging on cactus by saddlebacked tortoises also remained steady from 50% of foraging time in 2010 to 60% in 2011. An increase in cactus use is evident in tortoise faecal samples. Thirty-seven percent of faecal samples in 2011 had cactus seeds present, compared to only 8% in 2010. The differences in selection for slope and vegetation density between years (Fig. 6) may be due to a switch in overall tortoise behaviour. In 2010, tortoises may have been in an exploratory mode, thus they avoided barriers to their movements (like high slopes and dense vegetation), whereas tortoise movements in 2011 may have been directed more by food resources (cactus) and thermoregulation (dense vegetation).

Domed tortoises disproportionately occurred at higher elevations (where the climate is moister and the vegetation denser) and the saddlebacks at lower elevations (where cactus is more prevalent). This pattern continued in 2011 (Figs 7 & 8).

2. Tortoise health

Activity:

Through the course of the second field season, 31 tortoises were located, which were weighed and had blood and faecal samples taken to determine overall health.

Result:

Tortoises gained on average 10kg, or 22% of their mass prior to introduction. This weight gain would be compared with average mass change from tortoises on other islands to determine whether it was above average, but,

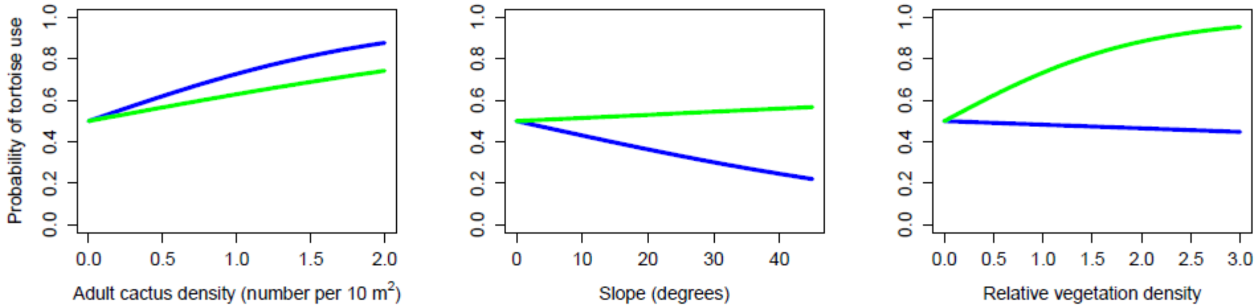

Fig. 6. Differences in tortoise selection on Pinta Island for important habitat features (from left to right: adult cactus density, topographic slope, and relative vegetation density) between 2010 (blue) and 2011 (green). Note selection for cactus density is high in both years (increasing use with increasing density), while selection for slope and vegetation density differs between the two years.

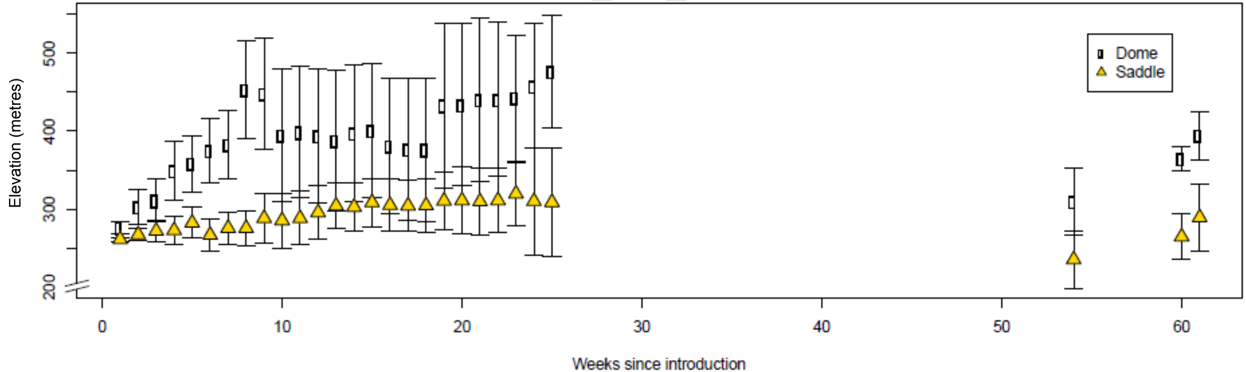

Fig. 7. Differences in elevation preferences between domed (purple circles) and saddlebacked (yellow triangle) tortoises on Pinta Island from May 2010 (week 0) to July 2011. Domed tortoises prefer higher elevations more than saddlebacks do, although this preference is not significant in weeks 10-25 due to a reduction in the sample size of tortoises.

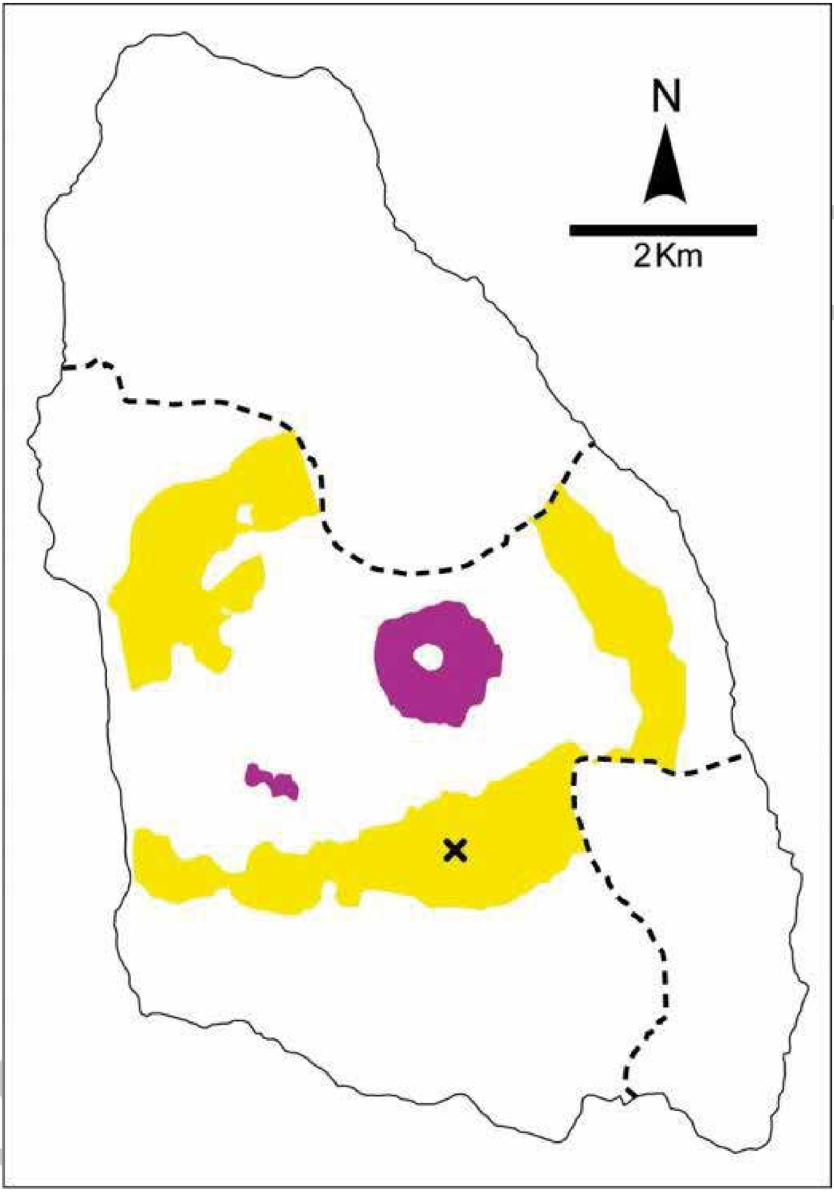

Fig.8. Estimated niches for saddlebacked (yellow) and domed (purple) tortoises introduced to Pinta island. Domed tortoises are almost entirely restricted to the high elevation zone of the island, whereas saddlebacks can occupy a much larger area in the mid-elevations. The 'x' indicates the original tortoise introduction location and the dashed lines delineate the lava fields to the north and south east of the island.

preliminarily, seemed to represent extraordinary weight gain. Blood samples from the tortoises showed normal levels of plasma protein and packed cell volume.

3. Tortoise effects on plant community

Activity:

Vegetation plots that were established in 2010 were revisited to determine whether changes in the plant community were due to tortoise activities.

Result:

The revisit to vegetation plots demonstrated no detectable difference between 2010 and 2011 in vegetation density or species composition due to tortoise activities. This could be due to insufficient sampling; however, the very wet year of 2010-2011 may have overwhelmed measurement of any tortoise impacts on plant growth. An overall increase in woody plant abundance in the plots was detected, and this may have been due to climate effects. It is also possible that the tortoises simply did not have enough time to make substantial changes in the plant community. Whatever the case, these plots will prove valuable to detect any future tortoise-induced changes in the plant community.

Tortoises making substantial impacts when they created trails were observed. With information from the tortoise movements, the team could estimate how the trail making phenomenon would impact vegetation at differing levels of tortoise density.

4. Cactus population size and density

Activity:

From 2010 results, the arboreal *Opuntia* cactus was identified to be a strong driver of tortoise habitat selection, so adult cactus density was sampled in transects across the island to determine the overall cactus population size and areas of highest adult cactus density that may be good locations for future introductions of tortoises.

Result:

The highest cactus densities were found in the area called ‘the saddle’ or ‘*las pampas*’ in the western portion of the island (Fig. 9). Here, adult cactus reached densities of 200 adults/hectare, which is much higher than the 25 adults/hectare found near the original introduction point. Introducing new tortoises to the saddle would serve the dual purpose of providing plenty of food resources to young tortoises and restoring seed dispersal to the area. Although the saddle has very high adult cactus densities, there are very few young cacti and most reproduction is asexual. Tortoise seed dispersal

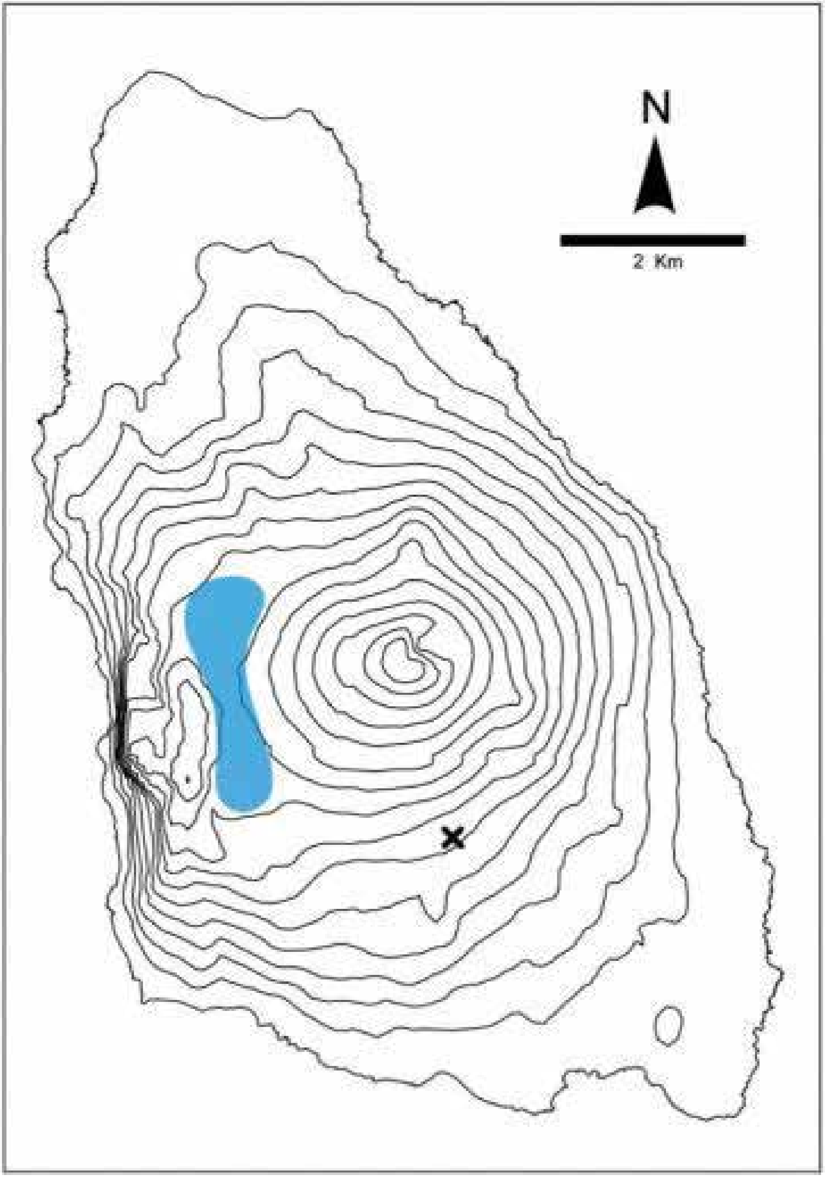

Fig. 9. The highest density cactus areas (blue) are in the saddle region where adult cactus densities reach 200 adults/hectare.

in this area may help to reinvigorate the large cactus population. It has flat topography and ample vegetation for shade and browsing.

The total number of adult cacti on the island was estimated to be 93,000 ± 3,500 adults. This is a substantial number of cacti and many more tortoises could be supported on these cactus resources. If tortoises use resources similarly to the way tortoises use resources on Espanola island (another arid island of similar size to Pinta island where cactus may be a limiting resource), the cactus population on Pinta could support in the order of tens of thousands of tortoises. It is not clear exactly how many tortoises could be supported, but Pinta's ecosystems could clearly sustain a very large tortoise population.

5. Vegetation history

Activity:

To determine vegetation history through carbon isotope analysis of soil samples, three soil pits were dug up to 80cm deep.

Result:

Preliminary results from carbon isotope analysis of the soil cores indicate that the current vegetation structure on Pinta has a higher proportion of woody plants than at any other time in the recent past. This pattern is repeated on Espanola and Santa Fe, islands that have also had severe disruptions due to invasive goat populations.

Discussion

Once the necessary fieldwork for Project Pinta phases I and II was finished, analyses were completed to address the primary objectives:

Tortoise carrying capacity

A carrying capacity was estimated for a genetically similar, arid-zone tortoise (Espanola tortoises) on Pinta island based on suitable habitat (for both foraging and nesting) and habitat quality differences between the two islands (mainly due to the much higher cactus density on Pinta).

Tortoise impact on vegetation density

Using information on how tortoises create and use trails, the researchers simulated their impacts on vegetation density at different levels of tortoise abundance. Through this analysis, they were able to determine what tortoise population size would be likely to reduce vegetation density and whether this is within the probable carrying capacity of tortoise populations on Pinta island.

Fig. 10. Tortoise #21 resting after eating *Opuntia* cactus pads.

Fig. 11. Tortoise #12 eating Tournefortia fruits.

Tortoise introduction scenarios

All the relevant results were combined into actionable management recommendations, simulating different introduction scenarios of Espanola tortoises on Pinta island to determine which scenarios produce (i) the most rapid production of a self-sustaining population near carrying capacity, and (ii) the greatest (if any) impact on the plant community.

The *Opuntia* cactus played an important role in the behaviour of the saddlebacked tortoises. They overwhelmingly selected areas with high densities of adult cactus over areas with low densities of cactus, and selection for cactus-rich areas increased over time. They spent a majority (57%) of their foraging time on fallen and low-hanging cactus pads (Fig. 10). Because cactus is such a large part of tortoise diets, a year after introduction almost 40% of tortoise droppings contained cactus seeds, indicating that analog tortoises are likely reinstating seed dispersal services for cactus. After foraging for a year on Pinta Island, the introduced tortoises gained on average 22% of their mass prior to introduction. This mass gain is significantly higher than the average 5% yearly mass gain of tortoises on Alcedo Volcano, which indicates that the analog tortoises are more than adequately meeting their resource needs (Fig.11).

Predictions were made as to whether tortoises would be able to reduce woody plant encroachment by aggregating our observations through an individual-based model of tortoise movement and tortoise impact on vegetation. Tortoises were observed creating openings and reducing vegetation density at small scales and these individual impacts were 'scaled up' to see what would happen with greater numbers of tortoises on the island. An important mechanism of vegetation reduction was the creation and repeated use of tortoise trails, which the tortoises used to move more easily between cacti and also to find other tortoises. (Tortoises were repeatedly revisiting the introduction site, which has a high density of trails surrounding it. It is not clear why tortoises would revisit the heavily trampled introduction zone, where food resources have been depleted, except that we saw most mounting attempts in this area, so tortoises may be following trails to find potential 'mates'.)

The model showed that even at low tortoise densities (0.5 tortoises/hectare or ~2000 tortoises) and low individual impacts on vegetation density, tortoises would be able to reduce overall vegetation density on the island within a period of a few decades, thus largely halting woody plant encroachment (Fig. 12). However, there are many uncertainties associated with this model, and if the estimates are conservative, it may take much longer (in the order of 50-100 years) for changes to occur even if tortoises are introduced immediately. Therefore, reproductive tortoises should be introduced as soon as possible to start the process of building an ecologically effective tortoise population that could restore the plant community.

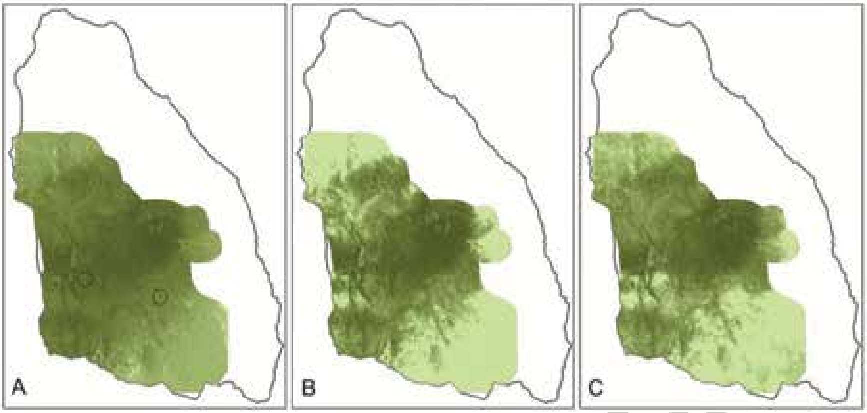

Fig. 12. Current vegetation density (A) on Pinta island, where white areas are unvegetated lava fields and darker green shades have a higher vegetation density. Two black circles indicate the introduction points for ecological analog giant tortoises in the individual-based model. Tortoises reduced vegetation density (lighter green shades in B and C) both when they were introduced randomly across vegetated parts of the island (B) and at the introduction sites (C).

Management recommendations

1. Because domed tortoises preferentially use higher, moister zones of Pinta island which are extremely restricted on the island, domed tortoises do not seem appropriate for further release on Pinta. Of the saddlebacked individuals, there was little variation in behaviour and habitat preferences, despite different genetic origins among saddlebacked individuals. This argues that saddlebacked tortoises from Espanola could serve as well as any other analog saddlebacked tortoises for introduction to Pinta.

2. The best introduction zone for cactus resources is in the *pampas*, but the current introduction point has a much higher density of trails due to high tortoise use. Trails could be important for juvenile tortoises' mobility in the dense vegetation on Pinta, and it is also likely that many of these adult tortoises will stay in this zone creating trails. Depending on expert knowledge about the relative importance of food resources versus functional trails to young tortoises, GNP could put groups of tortoises in either or both locations. The key issue is to establish multiple sites of released animals in cactus-rich areas so that tortoises will be able to find other tortoises upon reaching sexual maturity but not compete heavily for food resources during their early years of development. The team will examine the Espanola mark-recapture data further to understand the approximate spatial scale of tortoise 'neighbourhoods' (distances tortoises have moved from release sites over the 30-year release period).

Within these neighbourhoods a release site could be located to establish tortoises in an area while also enabling interactions with tortoises from other sites upon sexual maturity a decade or more later. This will probably involve approximately 5-10 release sites.

3. The high weight gain of the tortoises indicates that food resources are now abundant on Pinta for tortoises and further introductions can probably be supported by the environment.

4. Based on the analysis of the mark-recapture data from Espanola, introduction of 5-year old juvenile tortoises (and not younger) is best in terms of survival. Introduction of reproductive adults does not increase initial population growth substantially more than juvenile-only introductions, and so is not recommended. Recommendations on how many individuals to release and on what schedules will also be provided when they have estimates of the carrying capacity and impacts on the plant community.

5. To fully understand the impact that tortoises have on the plant community, we recommend erection of tortoise exclosures before future releases that would prohibit tortoise disturbance, herbivory, and seed dispersal in areas of high tortoise impact near release sites. This will allow a direct comparison of tortoise areas and non-tortoise areas to greatly clarify our understanding of tortoise impacts on ecosystems. Clarifying these impacts is important for articulating the role tortoises play as ecosystem engineers in Galapagos and hence, as appropriate, building support for archipelago-wide restoration efforts.

Conclusion

We conclude that further introductions of ecological analog giant tortoises to Pinta Island are possible and prudent. The use of such tortoises is not only an important conservation measure for Pinta island, but may be a valuable tool for the restoration of other islands in the Galapagos where ecosystems are degraded due to loss of giant tortoises. Moreover, at this point in time tortoises introduced to Pinta island thrive as indicated by substantial net gains in body mass. We end with a few salient recommendations for management strategies and future studies on introductions of tortoises to Pinta island:

❑ Saddlebacked tortoises should be introduced to Pinta island. It is likely that any saddlebacked tortoise will be able to adequately provide the needed ecosystem services.

- Tortoises should be introduced as soon as possible and in substantial numbers to ensure that benefits to the ecosystem from tortoise presence accrue on a reasonable time frame.
- Tortoises should be introduced to locations with high adult cactus densities, preferably the saddle region, to maximize food availability for young tortoises. If logistical constraints allow for multiple introduction sites, it may be desirable to also introduce juvenile tortoises to areas with lower cactus densities and higher trail densities (i.e. the original introduction site) and study juvenile survival rates to determine the importance of cactus density for young tortoises.
- Although our modelling effort has shown that tortoises can reduce vegetation density over time, it would be of great interest (both scientifically and for conservation purposes) to determine tortoise effects on vegetation experimentally through the use of tortoise exclosures in tortoise introduction areas.

Acknowledgements

Since the British Chelonia Group gave their donation towards this project, much work has been carried out and Pinta island is well on its way to recovery. We are very grateful for the BCG's on-going support. This report includes information from the Executive Summary of the Project Pinta Final Report produced for the Galapagos Conservation Trust by Elizabeth Hunter and her colleagues.

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