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Conservation Problems on Galápagos: the Showcase of Evolution in Danger

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The Galapágos Islands still possess a unique terrestrial and marine flora and fauna. The uniqueness of this ecosystem has evolved because of and depends on isolation from the mainland and among islands. This isolation is increasingly diminished through tourism and, in its wake, the immigration of Ecuadoreans who settle in Galápagos to profit from the economic boom accompanying tourism. The breakdown of isolation threatens the whole ecosystem of the Galapágos, therefore plans for a quarantine system are presently being developed by the Charles Darwin Research Station and the Galápagos National Park Service.

The Galápagos Islands are a group of oceanic islands of volcanic origin [1] belonging to Ecuador, which officially annexed the archipelago in 1832. The islands lie in the Pacific, almost 1000 km off the mainland of South America, straddling the equator. The western volcanoes are the youngest and most active; they erupt regularly and thus give the landscape an often moon-like appearance. While the sea around the Galápagos is very productive due to the cool currents and local upwelling, large areas of the islands are covered by lava. The coastal regions are very arid. This is caused by the cold waters which surround the Galápagos. The Humboldt current from the east carries cool upwelled waters from the South American coast and the Cromwell undercurrent (coming from the west) surfaces at the western islands [2]. The cold water surrounding the archipelago reduces rainfall at the coast as moisture-laden sea winds warm when they meet the land. Precipitation mostly occurs at greater altitude on the flanks of the few high-rising larger islands where a more mesic vegetation is found.

Thus, it is not surprising when early visitors described these islands as "what one might imagine the cultivated parts of the Infernal regions to be" (Darwin, Diary, 16 September 1835). On the other hand, despite this forbidding appearance and the desert climate, particularly marked in the lowlands, the Galápagos are often called a paradise because of the abundance and exceptional tameness of unique animal species. Less recognized, but nevertheless equally unique, are the many endemic plant species [3,4].

All our present knowledge indicates that these islands are truly oceanic in origin, appearing as volcanoes above the water's surface in open ocean, and never having been connected to mainland South America [1]. Thus, whatever organisms reached the Galápagos had to get there over approximately 1000 km of open sea.

In recognition of this ecosystem's uniqueness the Ecuadorean government declared the Galápagos a National Park in 1959 and the surrounding waters a Marine Resources Reserve in 1986.

Excellent reviews are available on the natural history of the archipelago and its flora and fauna [5–9], and on the history of conservation in Galápagos [10]. Rather than developing these themes further, I will instead elaborate three points which seem of paramount importance for understanding the present problems of the "ark" Galápagos.

1. Isolation is an island group's fundamental property, strongly influencing the ecology and evolution of species composing the ecosystem.

2. Most of the present, acute conservation problems have arisen from the introduction of foreign organisms and can in principle be solved by hard work

and the expenditure of much money over long periods of time (years to decades). However, a piecemeal approach to conservation only cures symptoms, but does not get at the root of the problems.

3. The basic Galápagos conservation problem is the ever-accelerating breakdown of the islands' former isolation due to dramatic changes in human population size and mobility. The ever-increasing flow of foreign organisms into the island ecosystem must be reduced by introducing a strict quarantine system. Otherwise, the unique Galápagos flora and fauna may be displaced and the evolutionary processes which depend on isolation will be permanently altered.

Isolation: The Most Decisive Component of Island Ecosystems

Isolation is the key to understanding island biota. This idea was first formalized by MacArthur and Wilson [11] in the theory of island biogeography. They recognized that the probability of arrival of immigrants to an island decreases with the island's distance from the mainland. Moreover, the selection of immigrants is nonrandom: species whose dispersal stages are highly protected against seawater (i.e., mangrove propagules) or very mobile (fern spores) are more likely to occur than less well protected or less mobile species. Thus, colonizing species are a strongly biased sample of the mainland biota. Furthermore, in Galápagos, most potential colonizers arriving by sea have to survive in or cross the harsh and inhospitable coastal lava desert before they can establish.

This coastal desert has kept amphibia and many plant species from establishing in the Galápagos [12, 13]. The resulting low diversity has opened up possibilities for adaptive radiation of successful colonizers. The fact that Galápagos consists of about 16 larger islands and perhaps 40 smaller islands, islets, and rocks, which are isolated from each other to varying degrees, has been conducive to adaptive radiation. The most famous example is provided by Darwin's finches [14 – 17], which evolved a great variety of bill shapes, body sizes, and foraging modes in response to differential selection in different habitats. In this adaptive radiation, isolation again played a major role, this time the isolation among islands within the archipelago. Finches [18] (or *Opuntias* or *Scalesias,* to mention the most famous examples from the Galápagos flora), exposed to slightly different environments on different islands responded to selection by adapting to their respective environments. When the (incipient) species returned to their original island, they had often evolved to the stage where interbreeding with the founder population led to offspring with reduced fitness and it was therefore selected against. This process can lead to the evolution of two species which then coexist on an island where originally only one had lived [16 – 18]. The low probability of arrival of founder individuals at the Galápagos combined with a similarly low probability of migration between islands has led to the evolution of a multitude of endemisms, i.e., species which only occur in Galápagos and even there often only on a single island.

Examples of such evolutionary divergence are the reptiles that differentiated into morphologically distinguishable populations on Galápagos. This applies to the giant tortoises, the "Galápagos" [19, 20], the marine (*Amblyrhynchus cristatus*) and land iguanas (*Conolophus* spp.), lava lizards (*Tropidurus* spp.), geckos (*Phyllodactylus* spp.), and snakes (*Alsophis* spp.). Reptiles flourished even though the islands are not really predator-free. The Galápagos hawk (*Buteo galapagoensis*), the short-eared (*Asio flammeus*) and barn owl (*Tyto alba*) all prey on small reptiles, and on hatchlings of the larger ones. The lack of predatory mammals makes the decisive difference to the mainland situation since none of the indigenous mammalian species preys on reptiles.

Surprinsingly, even among the 19 species of seabirds, highly mobile vertebrates, five species (26 %) are endemic to the Galápagos. Three of them have very small or distributionally limited populations which make them vulnerable to environmental disturbances. These are the flightless cormorant (*Nannopterum harrisi*), with about 1500 individuals, the Galápagos penguin (*Spheniscus mendiculus*), with about 4000 – 5000 individuals, and the lava gull, *Larus fuliginosus,* with only about 750 individuals [21].

Plants show a similarly high incidence of endemism: in a flora of about 642 species 228 are endemic [3, 4].

In conclusion, the Galápagos Islands due to their separation from the mainland and the problems of successful colonization possess a naturally depauperate and vulnerable fauna und flora. Relative isolation, and differences in biotic and abiotic conditions among the islands, permitted extensive adaptive radiation of successful colonizers. These properties of the archipelago ecosystem determine its very nature, mold the evolutionary processes taking place, and gave rise to its many unique species.

Present "Conventional" Conservation Problems and Attempts at Their Solution

Appreciation of isolation as the basic property of island ecosystems leads, by simple logic, to the conclusion that reduction of isolation or introduction of foreign organisms into an island ecosystem will induce major changes that we consider negative from the conservationist point of view. Ever since the buccaneers and whalers began to visit the Galápagos Islands introductions occurred. "Introduction" of the human predator led to the near extinction of the famous tortoises as well as of the fur seals (*Arctocephalus galapagoenis*). Tortoises were used as fresh provisions for ships where they are said to have survived for over 1 year without food or water. Hunting of tortoises for meat and of fur seals for their pelts persisted on a minor scale until about 1965 when it was stopped through the educational efforts of the Charles Darwin Research Station (CDRS).

Early visitors and early settlers brought several species of mammals to the islands. These introduced species competed with or preyed upon the indigenous ones, preventing the tortoise populations from recovering from the early exploitation. Rats, pigs, cats, and dogs were set free and soon developed into serious predators of reptiles and ground-nesting birds, and goats not only destroyed the native vegetation but also deprived reptiles of their food resources in doing so.

These conservation problems began to be tackled in earnest with the inauguration of the CDRS by the international Charles Darwin Foundation in 1964 and the later establishment of the Galápagos National Park Service (GNPS) in 1968. Under its early directors the Station first monitored the status of many of the endemic vertebrates, in particular, the giant tortoises. This monitoring soon led to the conclusion that only a captive breeding program could save several of the populations. Helped by WWF, the Frankfurt, San Diego and New York Zoological Societies a captive rearing program was initiated. Its most spectacular success was the preservation of the Hood (Española) tortoise. Out of a remnant population of 3 males and 12 females, over 200 young were hatched, reared, and successfully returned to their native island. Many of these repatriates have now reached breeding age, and the first successful reproduction of repatriated tortoises was observed in 1990 [22]. Hopefully, a healthy, self-sustaining population will eventually inhabit Española. A similar land iguana breeding project was initiated in the late 1970s when several populations were threatened with local extinction by feral dogs. The breeding projects have increasingly been taken over by the GNPS.

During its first years, the GNPS established and marked the National Park boundaries around the settled areas, an activity which did not make the Park Service particularly popular among the settlers. In addition, eradication programs were begun and succeeded in exterminating goats on the smaller islands of Plazas, Santa Fé, Española, Marchena, Rabida, and Pinta. On the larger islands, Santiago and Isabela, the logistical problems of goat eradication are formidable and thus goats are still numerous on Santiago and are slowly spreading further north on Isabela. On Santiago sections of the coast and quadrants in the highlands were fenced off to protect some of the most endangered plant species until better methods and more financial support allow a major reduction of the goat population. Dogs were successfully eradicated along the coasts of southern Isabela where they threatened to exterminate marine and land iguanas as well as local fur seal populations. Unfortunately, dogs are difficult to eradicate completely on the settled islands since the feral population recruits from the villages (see below).

Eliminating introduced rats is successful only on small islets. However, these small islets are likely to be repopulated by immigrant rats from larger, nearby islands where rat extermination seems presently impossible.

A major success was the rat poisoning campaign on Floreana, which researchers from the CDRS and wardens from the GNPS initiated in 1984. By putting out and maintaining a safety cordon of rat poison for over 6 months, around a colony of Hawaiian or dark-rumped storm petrels (*Pterodroma phaeopygia*) on Floreana (using up to 9 kg of rat bait per day), they were able to improve fledging success from near 10 to 72 %, thus contributing substantially to better prospects for the future of this species [23]. However, this project will have to continue for many years and be extended to more islands before a substantial recovery of the dark-rumped petrel population can be achieved. Long-term maintenance of such a labor-intensive and expensive project may prove difficult since this, like all other projects of the CDRS and the GNPS, has to be financed through grants from conservation agencies.

Unfortunately, the project's success is presently being threatened by yet another introduced organism, *Lantana camara,* which is overgrowing large areas (about 2000 ha) of native vegetation on Floreana. The plant spreads to the petrel breeding colonies and may keep the birds from reaching their breeding burrows. Thus, a further eradication campaign, this time against a plant, is needed to restore the system.

These examples may suffice to demonstrate that conservation action has produced a number of notable successes, but they also show that due to the limits of manpower and financial resources many acute conservation problems cannot be attended to, although immediate action is critical. It becomes evermore evident that more problems crop up as some are treated. Conservation must lose in the long run if it tries to cure problems as they arise and become urgent, instead of preventing the development of new ones.

The Socioeconomic Problems of Conservation

Which factors are responsible for the origin and development of the aforementioned problems? All of them can be traced back to thoughtless introductions of organisms or misguided human action in the past. However, increased tourism (Fig. 1) and, as its indirect effect, the accelerating immigration to the Galápagos Islands (Fig. 2) have recently made the introduction of foreign organisms a permanent feature of the Galápagos system. Movement to and from the Galápagos as well as within the archipelago has increased tremendously. Ships, planes, and the people traveling on them, as well as their cargo, serve as vehicles bringing new organisms to the Galápagos. The isolation of the islands has been greatly reduced over the last 20 years and this is the point where conservation action is needed most.

A few numbers will bring the dimension of the problems into better focus. Nowadays, there are six flights per week by Boeing 727 to both Baltra and San Cristóbal. The flights to Baltra average 160 passengers per day [24]. Sixty-two lincensed tourist boats cruise the archipelago. In 1989, boats and buses for tourism were using 63 % of 1.755 million gallons of imported diesel fuel [24, 25]. In fact, the first oil spill (of 50000 gallons of diesel oil) already occurred when a cargo ship sank in 1988 [26]. Controlling the fleet of tourist boats is impossible for a National Park Service with little resources and dwindling personnel. Nevertheless, hardly any damage to the tourist sites can be documented except for sites near the main villages, which have recently experienced higher visitor pressure through increased day tours organized by small boat owners ([27] and F. Cepeda, pers. comm.). A serious tourist impact is avoided because National Park rules do not allow tourists to stay on land overnight, to bring food onto the islands, or to move off the trails which are generally well staked out. Nevertheless, the large-scale movement of ships between islands must reduce inter-island isolation and thus not only contributes to the spread of foreign species introduced into the archipelago's settlements but also transports native species among the islands, reducing the probability of further adaptive radiation through isolation among islands.

The real impact of the tourist business occurs indirectly via the socioeconomic changes on the four inhabited islands: San Cristóbal, the capital of the province of Galápagos, Santa Cruz (the economic capital), Isabela (Puerto Villamil), and Floreana (total population of all inhabited islands was about 11000 in 1990). All these settlements are rapidly growing due to continued immigration of those who hope to profit from the tourist boom (see Fig. 2 for the example of Santa Cruz). Population growth increases the pressure on resources inside national park boundaries (extraction of wood, sand, lava for construction; land for farming) and has even led to temporary illegal occupation of National Park land, but more importantly it increases the wave of presently uncontrolled introduc-

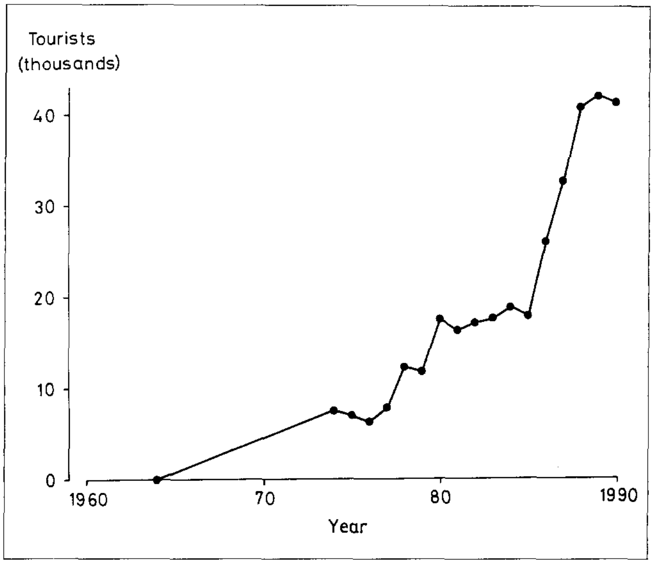

Fig. 1. Number of tourists visiting the Galápagos based on entrance fees collected by the Galápagos National Park Service. Numbers are underestimated by 15 – 20 % because many visitors are exempt from paying the entrance fee (O. Sarango, pers. comm.). The increase in numbers from 1986 to 1987 reflects the opening of the second airport in San Cristóbal

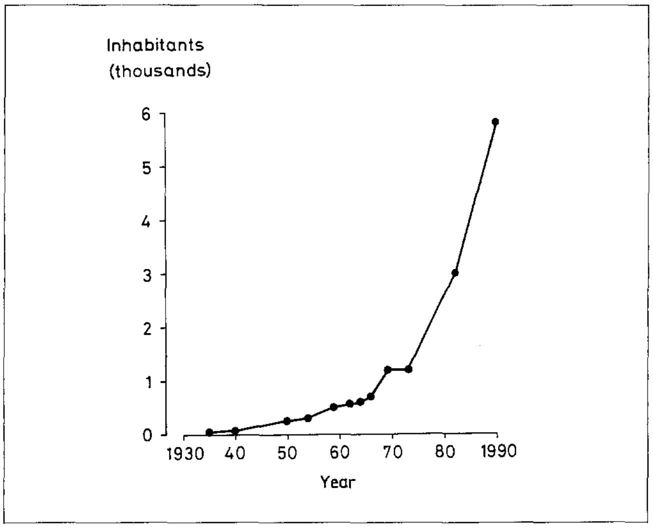

Fig. 2. Number of inhabitants on Santa Cruz Island 1977 – 1989. In 1990, San Cristóbal, the second largest settlement and the capital of the Province Galápagos, had 3585, Pto. Villamil on Isla Isabela about 1500, and Floreana about 70 inhabitants

tions. People bring pets (dogs, cats) and decorative plants and they need mountains of imported goods (food, building materials, etc.), which are brought in from the mainland on large cargo ships [22, 24].

Approximately 100 (!) new plant species arrived over the last 5 years. While these plants are initially introduced to the settled areas, which comprise only about 3 % of the total land area of the Galápagos, they often spread into the National Park where they compete with native and endemic species, often to the detriment of the latter. The potential long-term consequences of such introductions are exemplified by *Cinchona succirubra,* introduced on Santa Cruz in 1946. The plant now covers about 4000 ha on that island, drastically changing the unique vegetation zone where *Miconia robinsoniana* grows and eliminating the species that depended on the original plant community. The effect of this wave of introductions is well documented for the flora. Of 96 endangered endemic species and subspecies, 35 % are endangered by land exploitation, and 21 % by invasive, introduced plants [4]. An analysis of native species and subspecies shows an alarmingly similar situation.

Similarly unfortunate developments occur with animal introductions. A survey by researchers of the CDRS showed that Puerto Ayora, the major settlement on Santa Cruz, has an estimated population of about 300 dogs which are breeding freely. Only 14 % of the dog owners reported that they keep the young, 12 % kill them and the other 74 % give them away, sell them or let them go. The situation is similar for cats. Undoubtedly, the settlements on the inhabited islands provide a constant source of immigrant predators to the National Park land [22] where the Galápagos National Park Service is fighting to keep feral populations of dogs and cats low. It will be difficult to reduce the number of domestic dogs as long as robberies in the villages increase, creating an incentive for settlers to keep dogs.

Lastly, the cargo ships that bring all kinds of produce into the Galápagos are known to carry rodents (rats, mice), cockroaches and, inside the cargo, vertebrates (geckos have become established; frogs and snakes are found occasionally) and a myriad of undertermined nonvertebrate species. For example, an aggressive wasp (*Polistes versicolor*) was recently introduced and has spread throughout the central archipelago, even reaching Fernandina Island, which until now was free of introduced species. The spread of this wasp across the islands occurred within only 2 years from the time it was first reported.

Plant and animal species are thus, often purposefully, brought in by people who are usually unaware of the eventual consequences of such introductions. Large-scale educational campaigns are needed to make immigrants aware of the very special nature of the islands and of their threatened ecology, as well as the idealistic and economic value of the unique Galápagos ecosystems. The CDRS is attempting to build up just such a program. As a major contribution to continuing conservation of the islands, the CDRS is training Ecuadorean students by bringing them out to the islands, establishing contact with visiting scientists, developing and supervising conservation-related thesis work, and helping them to obtain money to complete their studies abroad, in particular, in the USA and Europe.

Although the fruits of this activity will take many years to appear, educational work may be the most important activity of the CDRS, since it is the only way to develop a conservation-oriented appreciation of and knowledge about the Galápagos Islands in the Ecuadorean people. However, if one takes the message of island biogeography [11] serious, it is clear that only a strict quarantine system can reestablish the isolation of the Galápagos biota that is presently being swamped with foreign species. Such a quarantine system should not only reestablish isolation between mainland South America and Galápagos, but also among islands within the archipelago. This will only be successful if the inhabitants of the islands can be convinced through educational programs that the erosion of the islands' biological diversity and specialty through the introduction of foreign organisms will ultimately destroy the basis of their economy, tourism.

Conclusion

Already in 1971, I. Thornton in his book on the Galápagos [5] concluded: "Although settlement and tourism have not reached the scale in the Galápagos that they have in Hawaii, and probably never will, there is still a danger that the sort of thing that has happened in Hawaii ("introduction of exotic organisms") may occur in Galápagos, and this danger increases with the number and frequency of visitors to the islands. The accidental introduction of a single small organism ... could rapidly upset the natural balance of the islands' ecology and wreak untold havoc on the natural attractions of the archipelago. In Hawaii the authorities have learned by bitter experience that prevention is better and cheaper than cure, and the plant and animal quarantine procedures of the State of Hawaii are now among the strictest and most efficient in the world. ... With the expansion of tourism (in Galápagos), however slow, an effective plant and animal quarantine program is also badly needed. There are no quarantine procedures at all for incoming visitors at present."

By now, Thornton's fears have proven well founded. Many species were introduced in recent years, but not so much by visitors as by the local population or accidentally with supplies needed by people living on the Galápagos. The stream of introductions is presently accelerating rather than slowing down. The breakdown of isolation threatens the whole ecosystem of the Galápagos as many of the endemic plant and animal species are eliminated or displaced by introduced species. The dangerous wave of introductions can only be controlled by a strict quarantine system for travelers and goods alike, a reduction of immigration into the Galápagos archipelago, and a much stronger educational program for settlers and tourists. Plans for a quarantine system are presently being developed by the CDRS and GNPS. It is hoped that they will have the full support of the Ecuadorean Government as well as the required financial resources to help establish such a program. The loss of biological diversity on other islands around the world has proven the fragility of isolated island ecosystems sufficiently to predict the disastrous consequences for Galápagos if action is not taken rapidly.

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