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Plant Research for Conservation in Galapagos

BY THE BOTANY DEPARTMENT, CHARLES DARWIN RESEARCH STATION

REPORT FOR THE YEARS
1998-2003
AND CHALLENGES FOR THE FUTURE

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If you would like to contribute towards the continuation and expansion of the work described, please contact the Head of the Botany Department, Dr Alan Tye, at: botanica@fcdarwin.org.ec

International volunteers

We owe a great debt to the many individuals who have offered their expertise, often completely free, to help us in our work. During the period covered by this report we have benefited from the expert assistance of a succession of international volunteers, including:
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If you would like to contribute to our projects by becoming an International Volunteer, please see our web page: www.darwinfoundation.org

Galapagos National Park Service

Our partner in Galapagos conservation is the Galapagos National Park Service, the park management agency. All of our projects are carried out with their permission and often with their help, especially on projects that include management as part of a research goal. The work described in this report could not have been achieved without their collaboration.

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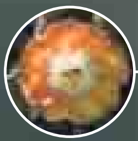
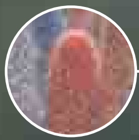
Cover photograph: *Scalesia stewartii,* one member of the largest radiation of endemic plants in Galapagos, the genus *Scalesia* (Asteraceae). Photo: Alan Tye.

The Galapagos Islands are unique in being probably the most pristine large tropical archipelago in the world. Their flora is similarly exceptional, including spectacular examples of adaptive radiation, rivalling the well-known Darwin's finches, and strange endemic plants, such as trees that have evolved from daisy-like ancestors. But these treasures are facing serious pressures, and many plant species found nowhere else in the world are in decline. They are threatened by destruction of their habitat and especially by the host of introduced animal and plant species that humans have brought to the islands since their discovery in 1535. This report describes our efforts to deal with these threats and conserve the wonderful and irreplaceable Galapagos flora.

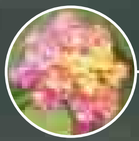


Galapagos and its Flora 4

The CDRS Botany Department 6
- history, achivements and strategies



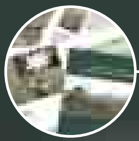
Ecology and Conservation of Native Plants 14



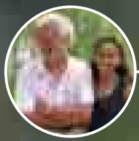
Ecology And Control Of Introduced Plants 30

Herbarium, Resources, Training and Development 40

Challenges for the Future 44



Publications 48

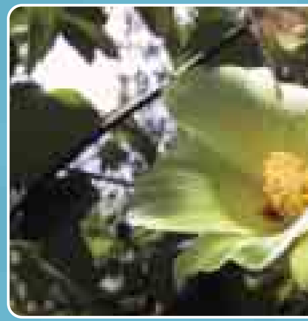


Staff 50

Galapagos and its Flora

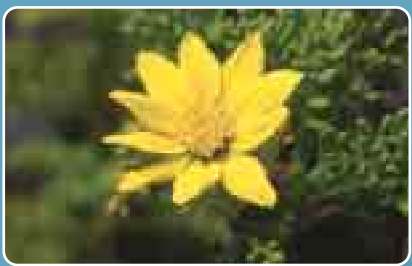
The candelabra cactus *Jasminocereus thouarsii*, a genus endemic to Galapagos.

Passiflora foetida



One of our two endemic cotton sp

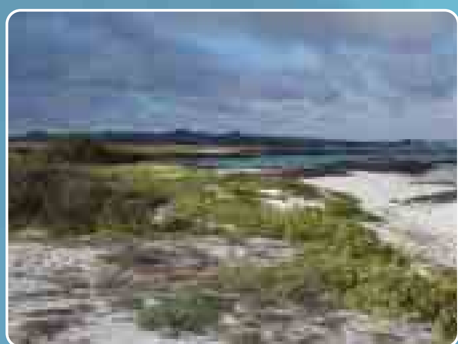
Opuntia megasperma

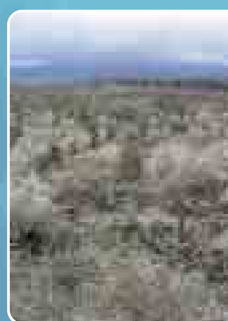


Lecocarpus pinnatifidus, a member of another Galapagos endemic genus, this species occurs only on the island of Floreana.

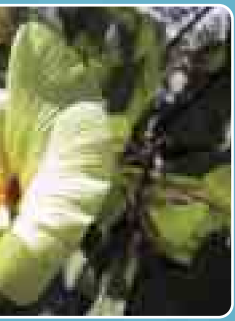
Scalesia pedunculata, in yet another endemic genus and dominant tree in the highlands of four islands, this species and the forests that depend on it have been drastically reduced in the last 50 years.

Epidendrum spicatum and *Ponthieva maculata*, two of the few orchids found in Galapagos (both endemic).





Galapagos vegetation is markedly zoned according to altitude, the major
the highest parts of the seven largest islands.



pecies, *Gossypium darwinii*

Alternanthera filifolia, member of one of our largest radiations of endemic plants.

Brachycereus nesioticus, endemic genus of cactus, with only one species.

The Galapagos archipelago comprises 14 major islands and over 120 smaller islets and rocks that can be regarded biogeographically as part of their neighbouring major island. Four of the major islands are inhabited (Floreana, Isabela, San Cristóbal and Santa Cruz), and Baltra islet is a military base and civil airport.

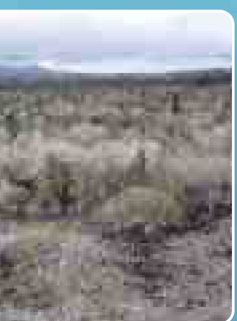
The Galapagos flora comprises some 500 native species, of which about 180 (about 240 taxa including subspecies) are endemic, that is, found naturally only in Galapagos and nowhere else in the world. Another 60 species are questionably native but were possibly introduced accidentally by man, and a further 550 species were introduced by man since the islands' discovery in 1535, either deliberately (the majority) or accidentally.

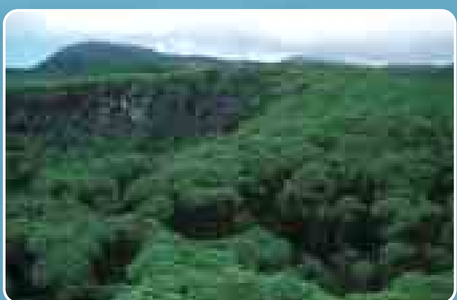
Since their arrival, humans have caused dramatic changes in Galapagos, including habitat destruction for the creation of towns and agricultural areas, direct exploitation of certain native species and, now the worst problem of all, the introduction of a huge number of new species of animal, plant, pest and disease. The size of this last problem is illustrated by the fact that only 500 or so plant species have managed to establish and survive naturally during the more than 3 million years of the existence of the islands, while another 550 have been introduced by man in less than 500 years.

Jasminocereus thouarsii

Lantana camara, or "Curse of India", one of our worst invasive introduced shrubs, brought as a garden ornamental.

Guava *Psidium guajava* - a beautiful flower but one of our worst invasive trees.





zones being coastal, arid and humid. The humid zone is only found on

Our job therefore comprises two main objectives:

research for the conservation of the native flora, and research for the control of introduced invasive plants.

The Botany Department

The CDRS Botany Department came into existence gradually, from the beginnings of the Charles Darwin Research Station in the early 1960s. Starting with one botanist, we have since built up to a staff, student and volunteer complement of 20-30 people, with our own building and an internationally important herbarium collection. We have developed a strategic, planned approach to botanical research for conservation in Galapagos, and begun projects in priority areas of concern, working on the most threatened endemic species and the worst invasive weeds.

A Brief History

Galapagos botany has benefited from a long history of study by visiting scientists since the early 19th century, as outlined by Ira Wiggins & Duncan Porter in their "Flora of the Galapagos Islands" (1971, Stanford University Press). This scientific interest, combined with alarm at the rapid destruction of the natural treasures of the islands, led to international moves to establish a scientific research station here. The story of the establishment and early years of the Charles Darwin Research Station (CDRS) is outlined by G.T. Corley-Smith in his "A Brief History of the Charles Darwin Foundation for the Galapagos Islands, 1959–1988" (1990, Noticias de Galápagos 49).

The Galapagos International Scientific Project (GISP) expedition in 1964, which was associated with the original establishment of CDRS on Santa Cruz Island, saw the start of botanical research by scientists actually based in Galapagos. In the early years following the expedition, there was only one scientist at CDRS, apart from the Station Director. The first botanical work by staff scientists was carried out by Tjitte de Vries, who initially held the post of "UNESCO Associate Expert in Ecology" (1965–68), and continued until 1970 under a Dutch grant. He returned in 1973–5 for another period of residence. De Vries set up the first permanent vegetation monitoring plots, on Santa Cruz, Santiago and Sierra Negra volcano, and supervised the building of goat-proof fences to protect fragments of natural vegetation against the estimated 100,000 goats on the island. He was assisted by Jacinto Gordillo and the late Arnaldo Tupiza, who continued to monitor permanent plots, supervise construction of goat exclosures and help botanists on the islands for many years, and by student Luís Calvopiña. Other botanical work during this period was done by Daniel Weber (1969–71), a Swiss architect, who assisted the then Station Director Roger Perry to organise the herbarium, made the first good hand-drawn maps of the islands (which we still use in the field today) and discovered several endemic orchid species.

As CDRS slowly expanded its personnel, there came a period when a trained botanist was usually on staff — still usually the only staff scientist apart from the Director. Among the early botanists who held the UNESCO post, now "Associate Expert in Plant Ecology", were Ole Hamann (1971–2), who expanded the plot series to examine changes after goat eradication projects, Henning Adsersen (1974) and Stig Jeppeson (1975–6). In those days, scientific staff often came to the islands for relatively short periods of 1–3 years, but managed to achieve remarkable results. Their productivity was aided by the secure funding from UNESCO, a relative lack of administrative duties, and dedication to a specific research task. For example, Adsersen's main initial remit was to document plant distributions, resulting in him amassing what is still the single largest contribution to the station's Herbarium collections.

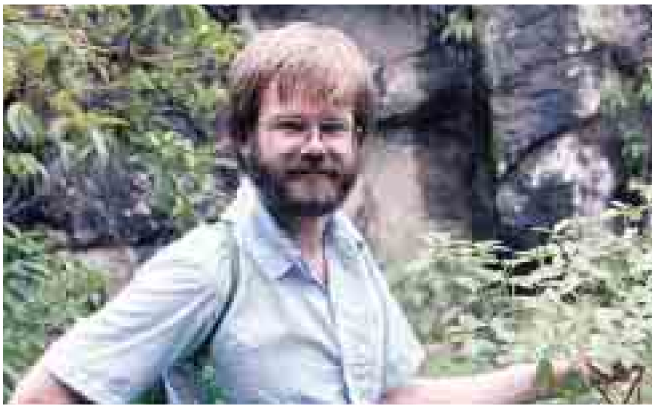
Arnaldo Tupiza and Jacinto Gordillo in 1987.

Tjitte de Vries, first staff botanist, arriving for the 1987 Botany Workshop.

David Snow, third station director and initiator of the present herbarium collection, in January 1964 at the CDRS inauguration ceremony.

In addition to the staff botanists, the first and third Directors of CDRS, the ornithologists Raymond Lévêque (1960–1) and David Snow (1963–4), established an herbarium at the Station, which, since 1975, has been internationally recognised in the Index Herbariorum under the initials CDS. The Lévêque collections seem to have been lost; the first of the existing collections were made in 1963 by Peter Kramer and David Snow. CDS has since grown into probably the largest and certainly the most taxonomically complete single collection of Galapagos plants in the world, with almost 15,000 catalogued specimens representing some 1500 plant species native or introduced to Galapagos.

After 1976 there were periods in which no botanist was employed at the Station. Henning Adsersen returned in 1977 for six months as a Visiting Scientist, but also took care of the herbarium. The staff position changed title to Resident Botanist, and among the holders was Luís Calvopiña (1979–80), who aside from his main work on goat ecology, continued monitoring permanent plots and building exclosures on Santiago. In 1980 Ulrike Eberhardt undertook reorganisation of the Herbarium. Luong Tan-Tuoc, Resident Botanist 1982–4, worked mainly on the invasive introduced species Quinine and Guava, and the effects of the 1982–3 major El Niño event. He and his assistant Basilio Toro also established nurseries at CDRS and at Bellavista in the agricultural zone of Santa Cruz, to examine possibilities of producing native species with economic value, such as timber trees. Luong was replaced by Henning Adsersen again (1984–5), who this time combined field exploration with management planning, and started planning for what eventually became the 1987 International Workshop on Botanical Research and Management in Galapagos. Adsersen also restored the herbarium after a period of relative neglect, with the aid of volunteer Phyllis Bentley (1982–6).



Jonas Lawesson in 1986.

Jonas Lawesson (1985–7) arrived as Resident Botanist and left as Head of the Botany Department. He was one of three newly appointed scientists at a time when CDRS was suffering from several unfortunate events. The main building had burnt, the station boat had sunk, and Jonas had a small desk in a wooden hut. The office moved to a proper building in 1986, where Lawesson built a drier for plant specimens, which is still in use, some distance from the present Department building. The herbarium collections were at that time kept in another building nearby.

The establishment of a Botany Department increased the emphasis on plants within CDRS, but the new position of department head involved more administrative duties, including developing annual plans and budgets, and building contacts with universities in mainland Ecuador. In this period, students began to play a larger role in Department projects. Despite the administrative burden, Lawesson wrote, with Adsersen, a revision of the endemic genus *Darwiniothamnus*, including a new species from Isabela, made expeditions to remote areas such as Pinta, and evaluated the status of endangered species. He also expanded work in two main areas: on invasive species (including drawing up the first checklist of introduced plants) and with the farming community (with a demonstration project promoting teak as a non-invasive tree from the Bellavista nursery). An associate researcher, Bosco Nowak, carried out studies of the effects of the 1985 fire on the vegetation of Sierra Negra Volcano on Isabela and established new permanent plots in the burnt area.

Bosco Nowak (left) with members of the 1987 international Botany Workshop, including Dieter Müller-Dombois and Raymond Fosberg, at Los Gemelos.

Lawesson began the database of the Galapagos flora (on the first computer at CDRS), which was used to produce "An Updated and Annotated Check List of the Vascular Plants of the Galapagos Islands" (Lawesson, J.E., Adsersen, H. & Bentley, P. 1987, Rep. Bot. Inst. Univ. Aarhus 16), which remains a key reference today. Phyllis Bentley also made major collections of introduced plant species during this period.

Lawesson found funding for an important event for the Department, the International Workshop on Botanical Research and Management in Galapagos, which was held in 1987 and to which came botanists and conservationists from Hawaii, New Zealand and elsewhere. The proceedings of this workshop (Lawesson, J.E., Hamann, O., Rogers, G., Reck, G. & Ochoa, H. 1990. "Botanical Research and Management in Galapagos". Monographs in Systematic Botany from the Missouri Botanical Garden 32) are another milestone in Galapagos botany, marking

Henning Adsersen (in yellow shirt) and Ole Hamann (facing rt.) at the 1987 international Botany Workshop.

the change from an emphasis on botanical exploration, and placing plant conservation firmly on the agenda of CDRS and the Galapagos National Park Service (GNPS). The workshop laid the foundation for many activities and programmes that are still going on today.

Ole Hamann during a plot monitoring trip to Santa Fe in 2003.

In addition to the resident botanists, Galapagos botanical research has benefited over the years from a strong programme of visiting scientists, including many of those who initially came as staff members but have continued their research since. Ole Hamann and Henning Adsersen both still regularly visit Galapagos to continue their studies of long-term vegetation monitoring plots. Hamann's work has included the population dynamics of *Bursera* trees, *Scalesia* species and *Opuntia* cacti, while Adsersen supervises a thriving programme of Danish visiting research students, working mainly on the evolution of the endemic Asteraceae. Other visiting scientists who have made major contributions include Paul Colinvaux and Eileen Schofield (vegetation history), Uno Eliasson (systematic studies, especially of *Scalesia*, 1966–7), Charles Huttel (plants of small islets, and colonisation of lava flows 1984–92), Syuzo Itow (also spelt Ito — a member of the 1964 GISP expedition who still regularly visits Galapagos: vegetation dynamics), Conley McMullen (author of the field guide Flowering Plants of the Galapagos, 1999, Cornell University Press), James Mears (1977, Amaranthaceae), Duncan Porter and Ira Wiggins (authors of the Flora of the Galapagos Islands, 1971, Stanford University Press), and Henk van der Werff (floristics, 1974–7), among many others. In addition, significant contributions to collections or surveys have been made by members of other CDRS departments and GNPS, among whom Juan Black wrote the first Spanish language book on Galapagos conservation (Galápagos: Archipiélago del Ecuador), including plant issues.

Syuzo Itow working in humid-zone vegetation in the highlands of San Cristóbal island, 1999.

Uno Eliasson on Santa Cruz in 1987.

From the late 1980s, the botanical staff at CDRS remained for some years at up to eight people, including scientists, students and support staff (nurserymen). During this period, the department came to focus less on the endemic and native plants of the uninhabited islands, and more on the immediate problems facing the flora. Major projects included expansion of control trials to develop effective and safe means of killing invasive weeds, a large farm forestry project to encourage the use of non-invasive timber and forage trees, and the establishment of more exclosures and permanent plots to monitor the effects of feral goats on the native vegetation. US Peace Corps Volunteer Andy Schmidt (1987–8) took over from Lawesson as Department Head, but there then followed a period with no-one in the position, when Coordinator of Sciences Pádraig Whelan (1988–1991) acted as combined head of botany, entomology and marine biology. During this period, Charles Huttel, of the French research organisation ORSTOM, played an important

The late Ira Wiggins, author of the Flora of the Galapagos Islands, during the 1964 GISP expedition.

Hugo Valdebenito in the former herbarium room.

role in orienting the work of the Department and training students and staff, and other Peace Corps volunteers, including Tom Larson, John Kolbe and Marc Otto, contributed especially to the farm forestry and herbicide trials projects. Huttel also ensured continuity by providing the next Head, Hugo Valdebenito (1991–3), with a good induction and orientation. André Mauchamp (1993–6) continued the programmes, with work on rare endemics and cactus biology, and a continuing focus on invasive plant control trials and farm forestry, the latter managed by staff scientist and former student Lenín Prado.

In 1994, the Department moved into a new building, which considerably improved working conditions and provided proper, air-conditioned housing for the Herbarium for the first time. At the end of 1996, the Department took on two important new tasks: beginning the implementation of a quarantine system for Galapagos, and a new programme of entomological research. In consequence, our name changed to the Department of Plant and Invertebrate Sciences. When Alan Tye took over in July 1996, the Department still comprised only eight people, as it had 10 years previously: three staff scientists (including the head of dept), a nurseryman, three Ecuadorian students and one US Peace Corps volunteer. Between 1996 and 2000, the staff and student complement increased dramatically, to 35, and by June 2000 the quarantine and invertebrates programmes were considered strong enough to become independent as the new CDRS Department of Terrestrial Invertebrates. The important achievements of the combined department in the areas of entomology and quarantine are beyond the scope this report. Botanical research carried on, and our name changed back again, to the Department of Botany. Since 2000, the botanical staff and student complement has remained at 20–30 people, of whom around 10 are scientific staff, 5–10 field operations staff, up to 8 research students, up to 6 Ecuadorian work-experience students, and up to 3 international volunteers at any one time.

The Department's offices.

The Botany Department's present building, constructed in 1993.

Major Achievements of the Past Five Years

Building on the background developed over 30 years by our predecessors in the Department, our greatest achievement of recent years has been to put botanical research for conservation in Galapagos onto a strategic footing. Until recently, research and management priorities have changed according to perceived needs, personal interests, and short-term demands and emergencies, as well as according to the availability of funding and donor preferences.

In the past five years, we have developed what we intend to be long-term strategies in two major areas: threatened plant conservation and invasive plant control. These strategies, outlined on pages 12-13 and described in the succeeding sections, permit us to assess conservation needs according to well-defined, explicit criteria, and therefore assign our limited funds to conservation priorities based on sound science, which should make a real difference in the long term. A strategic approach also permits us to seek funding for specific priorities based on rational assessment of overall conservation needs, rather than simply applying for or accepting funding for ad hoc projects, just because it seems to be readily available for a certain area of research.

Some major achievements since 1998

- **A strategic, planned approach to research for plant conservation in Galapagos**
- **Prioritising work on the most threatened endemics and the worst invasive weeds**
- **Investigating areas never before visited by botanists**
- **Rediscovering "extinct" plants**
- **Mapping and red-listing the entire endemic flora**
- **Creation of the IUCN Galapagos Plant Specialist Group**
- **Building up a strong programme of research on invasive introduced plants**
- **Designing weed prioritisation systems for strategic planning**
- **Developing effective control techniques for the worst invasive plants in Galapagos**
- **Eradicating invasive plants completely from the archipelago**
- **Consolidating the most complete reference collection of Galapagos plants in the world**
- **Management recommendations based on sound science**

Plants believed extinct rediscovered: Isolated plants of *Scalesia a. atractyloides* among hostile lava in a previously unstudied area of Santiago.

Current Programmes & Strategies for Botanical Research & Conservation

Since1996, the Department's activities have been grouped into three thematic programmes:

Ecology and Conservation of Native Plants

This programme's main focus is on the most endangered plant species and vegetation community types that are found only in Galapagos. Our strategy of research for the conservation of these plants and their habitats is built from five elements.

1. An important part of this programme is building up a BASELINE of information on the status and distribution of the native flora. It is often thought that Galapagos has been so well studied that we already have this baseline. In fact, there are large gaps in our knowledge of the distribution and population sizes of the Galapagos native plants, and much more basic SURVEY is required.

2. Once a baseline is established, we require MONITORING to detect the changes caused by natural or human influences. Monitoring critical plant communities and individual species is thus an important part of our work. With the data from the monitoring programme, we can attempt to distinguish natural fluctuations and trends from those resulting from human activities, and plan action to mitigate or reverse the damaging changes caused by our presence in the islands.

3. Results from the baseline surveys and monitoring are also used for PRIORITISATION. We need to determine which are the most endangered species and habitats, so as to direct our scarce financial resources to the most urgent and serious problems.

4. Prioritisation tells us which are the most endangered species and habitats but, in order to understand fully the factors that are bringing about the declines and changes that they are experiencing, we need BIOLOGICAL STUDIES. We need to understand what threat factors are affecting them and at which stages of their life cycle the key factors act, whether it be grazing by goats, damage to flowers by an introduced insect or disease, seed predation by a beetle, lack of fertility due to inbreeding in small populations, or some other factor. If we do not know what the problem is, we cannot treat it, but with this information, we can find out where we need to intervene to reverse the declines.

5. Finally, with the results of these studies, we can make MANAGEMENT recommendations and take remedial action. Our recommendations for conservation management are passed to the Galapagos National Park Service, with whom we discuss the options for conservation action. Our aim is to reverse species declines and degradation of habitats and, as far as possible, bring about RESTORATION of the species or habitat to its original status.

Ecology & Control of Introduced Plants

This programme focuses on the worst invasive weeds, among the many introduced plants of the archipelago. As for native plants, our strategy for introduced species consists of five elements.

1. The need for a BASELINE of information on introduced plant species is even more evident than for native plants. Almost every week we add new species to the list of introduced plants known in Galapagos, and basic INVENTORIES are fundamental to this process. There have never been exhaustive surveys of the inhabited zones, the towns and agricultural areas on the five inhabited islands, so we do not yet know how many introduced plant species are already present in the archipelago. The inhabited areas are crucial, in that they are where most species are first introduced. We need to detect them there, before they begin to spread more widely into the Galapagos National Park.

2. MONITORING of inhabited zones has not yet been implemented, because the first surveys still need to be completed, but ideally each inhabited zone should be continually monitored to detect new introductions. Monitoring is also critical for detecting the spread of species already known to be present, and for recording decreases in target species and (hopefully) the recovery of native vegetation where an invader is being controlled.

3. Once we have a list of introduced plant species, we must prioritise them. We know that there are already approaching 600 introduced plant species in Galapagos, and we need to focus our inadequate resources on taking action against the worst actual and potential invaders. In order to do this we need PRIORITISATION systems to assess the known characteristics of each species, help us predict its behaviour, and determine the feasibility of different types of control action.

4. Once we have selected the species that we consider priority targets, we need individual SPECIES STUDIES to determine their key biological characteristics, which affect our ability to control them. Such factors include age at first reproduction, seed production, dispersal and viability, and seed longevity in the soil. We may also need control trials to determine a suitable method for controlling the species, since many of the worst weeds in Galapagos have not been well studied elsewhere in the world. The results of these studies feed back into the prioritisation system.

5. Finally, with the results of these studies, we can make MANAGEMENT recommendations and take action to CONTROL the species. Our recommendations for conservation management are passed to the relevant institution such as the Galapagos National Park Service or Quarantine Service, with whom we discuss the options for control. Generally, the best option for controlling an introduced plant is complete eradication from Galapagos, if feasible, because even though it may be expensive at the start, the cost reduces to zero once the species has been eradicated. If eradication is considered impossible with the resources available, we may consider containment, control at key sites, or biological control.

Herbarium, Resources, Training and Development

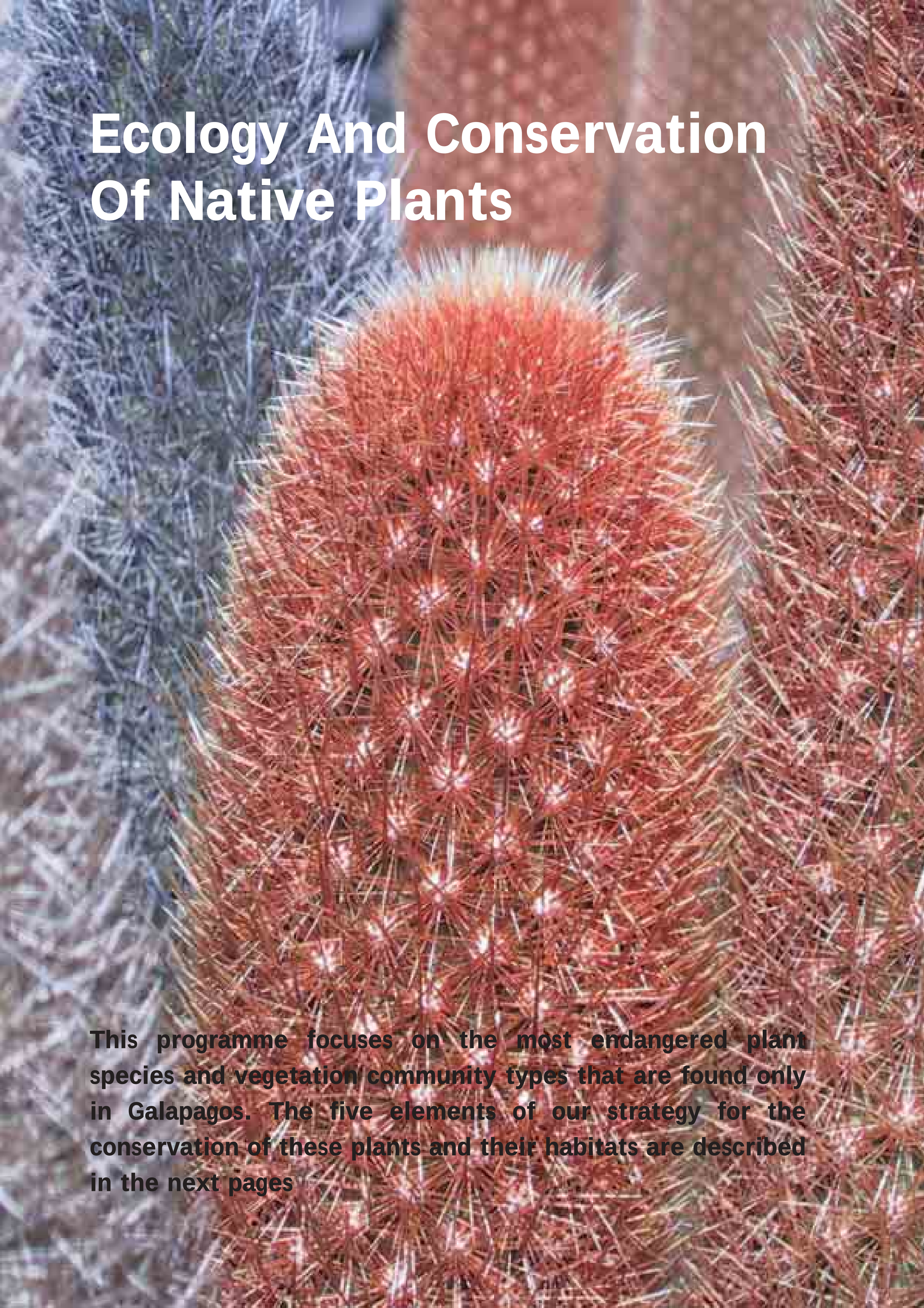
This programme comprises all of the support functions of the Department, including institutional reporting, contributions to planning processes, personnel management, and maintenance of key resources including buildings and equipment, and the reference collections.

1. The HERBARIUM CDS contains the plant reference collections and is the key basic resource used by virtually all of our projects. Data on the collections and other records are maintained in the DATABASE OF THE GALAPAGOS FLORA and the Department's research files.

2. An important part of our work is TRAINING Ecuadorian nationals in conservation biology, to enable them to take charge of managing Ecuador's conservation areas in the future, and to contribute to an increased awareness of the value of conservation in the country.

3. Production of PUBLICITY MATERIALS AND PRESENTATION of results are important for increasing awareness in the local community, helping relationships with supporters and visitors, and reporting the results of our research to the scientific community.

Ecology And Conservation Of Native Plants

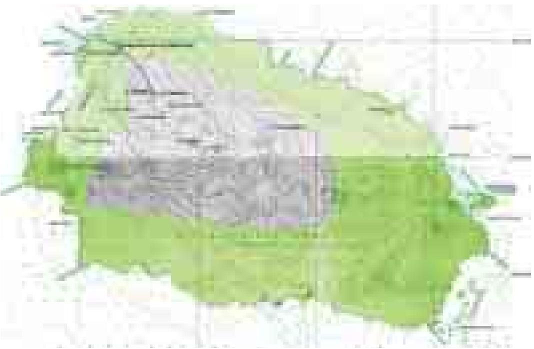


This programme focuses on the most endangered plant species and vegetation community types that are found only in Galapagos. The five elements of our strategy for the conservation of these plants and their habitats are described in the next pages

Baseline surveys

In 1998, we began a long-term project to survey the plants of the entire archipelago, to document the distribution of the native flora with an emphasis on the endemic species and subspecies, especially those known or suspected to be threatened. There is no secure funding for this work, but we do parts of it as money becomes available. Up to 2003, we have completely surveyed Española Island and most of Santiago and San Cristóbal. We have also surveyed the islets associated with each of these islands.

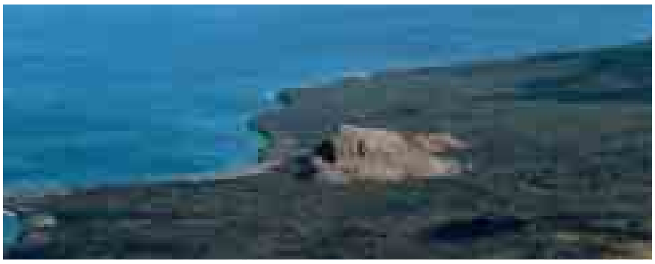
Santiago



Santiago showing areas surveyed to date (green).

Santiago is one of the islands worst affected by introduced species in Galapagos. Its native vegetation has been devastated in recent decades by introduced goats, donkeys and pigs. Santiago has the dubious honour of being one of the only two Galapagos islands from which an endemic plant species (one found only on that island) has become extinct, and many more of its plants have severely declined.

Scalesia atractyloides subspecies *darwinii*: one of the five adult trees that were discovered in 1995, just before its death in 1997.



The last known site for the subspecies *Scalesia a. atractyloides* was this old red hill standing in a sea of new black lava

Exciting findings for the new project. The Santiago endemic tree *Scalesia atractyloides* was a target for the first surveys of the new project. It had been removed from the list of extinct Galapagos plants in 1995, when a tiny group of five trees of the subspecies *S. a. darwinii* was found in the east of the island. This was protected by a fence in 1997, by which time the adult trees had died and been replaced by just two seedlings.

Two red hills of old lava, forming "islands" in a new black lava flow on the west coast, were the site where the other subspecies *S. a. atractyloides* was last recorded in 1987. This site had been visited several times since by botanists, who found no trace of the plant and suggested that it must be extinct. Surprisingly, during our first survey in 1988 we spotted two adult trees of this species growing on an inaccessible cliff on one of the hills. The cliffs also carried a population of the Critically Endangered Galapagos Shrub Snapdragon *Galvezia leucantha*. The vegetation on the hills was badly damaged by goats and feral donkeys, and we considered protection of the hill to be of the highest priority. A fence was built around it the next month (see p. 27).

The newly described Galapagos Shrub Snapdragon, growing high on a cliff out of the reach of goats.

Rediscovery of our second "extinct" plant (see p. 26) **and a new subspecies for science.** The principal findings of this first new survey were thus the rediscovery of a presumed extinct plant, *Scalesia a. atractyloides,* and the discovery of populations of other rare, threatened and endemic plants — encouraging signs for the new project. Further, on examining the specimens of *Galvezia* that the team collected, it became clear that they were different from existing descriptions. We subsequently described them as a new subspecies, *Galvezia leucantha porphyrantha* (see Tye & Jäger 2000 in the list of recent publications p 48).

More Scalesia. A further survey of an additional section of Santiago, in June 1999, covered the entire south coast and part of the east coast. A completely unexpected discovery, in a field of broken black lava very difficult of access (see photo on page 11), in the SW corner of the island, was a previously unknown population of *S. a. atractyloides*. We found several small groups of 2–6 trees each, on small patches of old red lava scattered over about 15 km^2 in the more recent black lava flow. Some of the plants were damaged, although it was unclear whether goats or grasshoppers were the culprits. We initially proposed to fence some of the populations, but eventually shelved the idea when it became clear that goat eradication was a distinct possibility for the near future.

Many trees of *Scalesia a. darwinii* discovered in a crater far from the coast of Santiago.

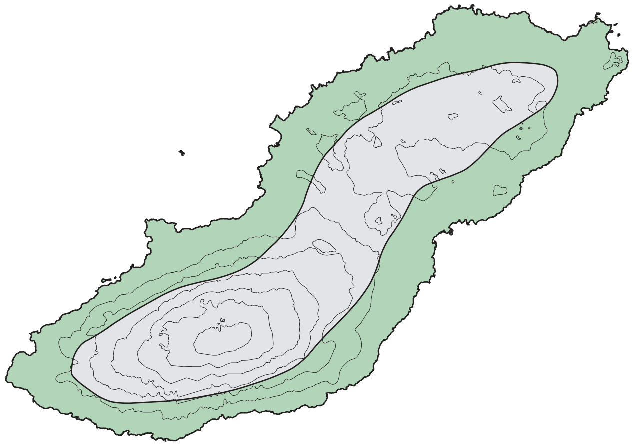
Scalesia atractyloides darwinii **increases from two to more than 2000 plants.** Three more surveys of the remaining coastal and arid-zone sections of Santiago were carried out between April and June 2000, covering the NE and NW coasts and the islets of Gran Felipe, Logie, Mao, Albany and Beagle. Not a single survey seemed to be without its surprise. This time, a new site for *Scalesia atractyloides darwinii* was found near Sullivan Bay, in an area not visited by botanists for more than 30 years. This is the subspecies that was known at the time from a single site with two seedlings, but the new site, a crater several km from the coast, was found to contain about 450 adults and 2500 seedlings! In April 2001, we visited another big crater about 1 km away, and found another 90 adult trees there, showing once more the importance of complete baseline surveys. Unfortunately, we also found that goats had eaten almost all of the 2500 seedlings that we had discovered in the other crater the previous year, but hopefully this threat will soon become a thing of the past, now that goat eradication has begun on the island.

Blutaparon rigidum, one of the only three Galapagos endemic plant species currently classed as extinct.

Still looking for more "extinct" plants. The June 2000 survey was specifically to search for *Blutaparon rigidum*, a plant endemic to Santiago, not seen since 1906, and another of the very few plants of Galapagos generally regarded as extinct. During a visit to the California Academy of Sciences in San Francisco, we found specimens of this plant with locality information, which enabled us to pin down and revisit the collection area. We have not found *Blutaparon* yet, but we will look again when goat grazing pressure has been significantly reduced.

Sicyos villosa, another of our extinct plants, described as abundant by Darwin when he collected this specimen, but not seen since.

San Cristóbal



San Cristóbal showing areas surveyed to date (green).

New populations of threatened and endemic species. The first survey on San Cristóbal took place in August 1998, covering the NE part of the island and the SW extremity. Before this survey, the distribution of two of the San Cristobal endemic daisy-trees, *Scalesia incisa* and *S. divisa*, was incompletely known, with no recent information on the size of the populations or threats to them. We located the limits of the two species on the north coast, where they seem restricted to cliffs and lava outcrops and are separated from each other by a gap of c. 10 km. Two major populations of the rock-loving Vulnerable* *Lithophila radicata* were found, both severely damaged, probably by goats. Given the dispersed nature of the populations of many of the threatened plant species on this island, the management priority is reduction in the populations of feral ungulates, rather than fencing.

Scalesia incisa, endemic to NE San Cristóbal.

Lithophila radicata, like the extinct *Blutaparon*, is a member of the amaranth family, one of the favourite foods of feral goats.

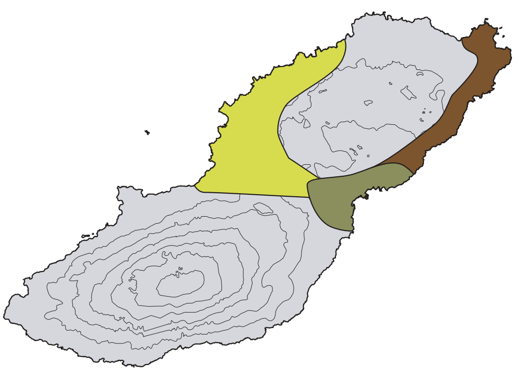
***A description of these IUCN red-list categories is on p. 23**

Further surveys covered the south coast, where we hoped to encounter the beautiful Critically Endangered* Galapagos Rock Purslane *Calandrinia galapagosa* (probably San Cristóbal's rarest plant) and the Endangered* *Lecocarpus darwinii*. We discovered new populations of both, including thousands of plants of *Lecocarpus*. Many were under pressure from goats, and the population of *Calandrinia* will be fenced in 2003.

The Critically Endangered Galapagos Rock Purslane *Calandrinia galapagosa.*

Lecocarpus darwinii (Endangered), another of San Cristóbal's single-island endemic plants.

We also found unexpectedly large populations of *S. incisa* and *S. divisa* along the south coast of the island, in an area that had apparently never been visited by botanists before. In one area, the plants appear to be hybrids between these two. This seems to be an example of an incipient "ring species", where at the extremes of their distribution they seem to be separate species, but the extremes are linked by an intermediate population. The genetics of this situation are being investigated by Henning Adsersen's group at the University of Copenhagen. More *Calandrinia* were found on the north coast in June 2002. As in the case of Santiago, these findings reveal the relatively poor state of knowledge of the Galapagos flora, and the urgent need for more baseline survey work.



Scalesia incisa (brown) and *S. divisa* (yellow) and their zone of intermediates.

Española

Española showing the main *Opuntia* populations.

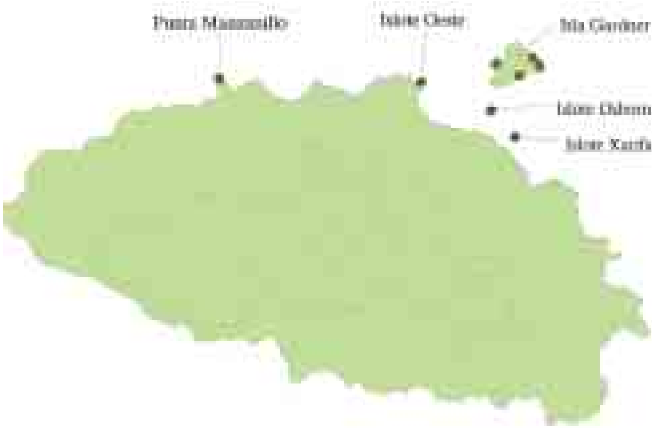
One island completed. In 2001, Española became the first major island to be completely surveyed by the project. It is smaller than Santiago and San Cristóbal, and was completed, including its associated islets, with a total of just three weeks' work between May 1999 and August 2001.

The skyline of this island was formerly dominated by the tree cactus *Opuntia megasperma orientalis*, which became much reduced during the century up to 1978, when goats were present on the island. Since the eradication of goats, there has been little recovery of the *Opuntia*, which is now extinct over parts of the island where it was formerly abundant. In the central part of the island, where most of the *Opuntia* survive, we estimated population size and age structure, to evaluate the regeneration and current status of the species and plan for its restoration (see p. 28).

Photographs of Punta Cevallos, Española, from 1906 and 2001. The circles mark *Opuntia* cacti that have disappeared in the interim.

Lecocarpus lecocarpoides. When this photograph was taken this was the only plant left alive on the main island of Española. It has since died, but more seedlings have grown.

Lecocarpus lecocarpoides is another plant that is almost extinct on the main island, with its remaining stronghold being on the islets, where it is common. There is a single known population at one site on the main island, which we have monitored in recent years and whose numbers have fluctuated between zero and 40 plants. This population is obviously extremely vulnerable to chance extinction and we have been planning how to save it. Our surveys found no other populations of this species.



Distribution of *Lecocarpus lecocarpoides* on the four islets of Gardner Bay, and at one site on the main island of Española.

Monitoring

Monitoring threatened species — a gap in our programmes

This is one of the greatest gaps in our existing programmes. As a result of having assessed the threat status of the endemic flora, we now know which are the most threatened species, as well as the "lost" species for which we have no recent information. For the lost species we need more survey. For species known to be endangered, all of which have suffered declines, we need biological studies to identify the causes of the declines and plan the interventions that we need to make to promote recovery. But for all these, as well as the less endangered but still vulnerable species, we need a monitoring programme, able to detect population declines and hopefully to measure recovery following conservation action.

Monitoring, a chronic long term gap in funding.

Unfortunately, it is expensive to monitor regularly plants that are scattered over such a large area and so many separate islands, and we have not been able to raise the funds to enable us to implement a monitoring programme for threatened plants. The little monitoring of species that we have been able to do has been short-term, associated with individual research projects, as described on pp. 25-6. We urgently need to put this right (see p. 45-6).

Monitoring plant communities threatened by goats: Santiago and Alcedo

Isabela Island is the largest island in Galapagos, representing more than 50% of the land area of the archipelago. **Alcedo Volcano**, one of the six shield volcanoes that make up Isabela, carries one of the largest surviving populations of giant tortoise and, until recently, the largest expanse of the endemic *Scalesia microcephala* forest. However, since the 1980s, Alcedo has suffered drastic habitat changes due to the arrival of feral goats in about 1978. The goat population rapidly expanded to perhaps 100,000 (no complete census has been possible), and the animals have destroyed most of the natural highland vegetation, severely reducing the former forests. The Galapagos National Park Service has carried out intermittent hunting, but this has not reduced the goat population significantly. However, a complete eradication attempt is expected to begin during 2003.

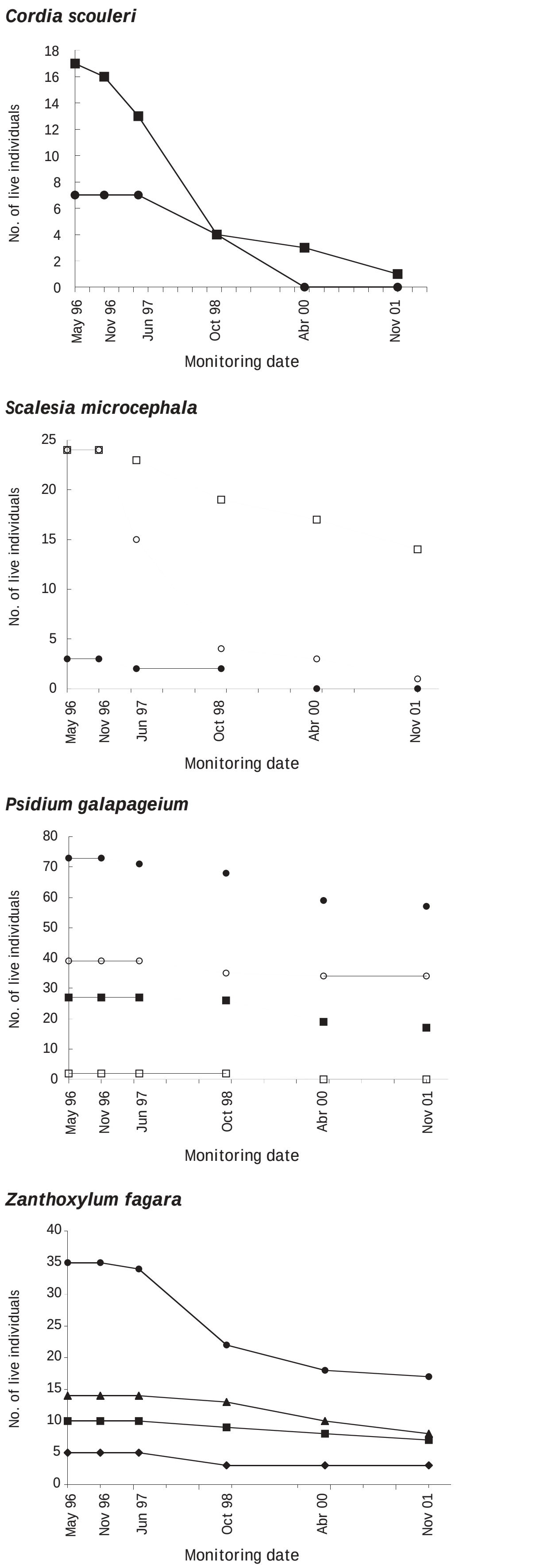
Goats and Giant Tortoises on the rim of Alcedo Volcano.

Despite the widely reported impact of introduced goats on oceanic islands, there have been few studies of their detailed effects on the vegetation. The late arrival of goats on Alcedo and their rapid population growth have provided an opportunity to document these effects. The intention to eradicate the goats in the near future gives an additional opportunity to study regeneration of the vegetation and identify long-term, and perhaps permanent, changes to the vegetation caused by a high density of goats over a relatively short period.

Intact *Scalesia microcephala* woodland, and former forest destroyed by goats, on Alcedo Volcano, Isabela Island.

For these reasons, in 1995 we began a vegetation monitoring programme on Alcedo, based on permanent plots established in areas representative of the remnant native vegetation communities. The original objective was to monitor vegetation change before and during the proposed eradication campaign. However, delays in this campaign have enabled us to track changes during seven years of high goat density, over a period that included a major El Niño event in 1997–8. This also allowed us to make quantitative descriptions of the effects of the El Niño on Galapagos vegetation.

The plots were initially monitored every 6 months, then every 18 months (alternate wet and dry seasons), and more recently, as the time for goat eradication draws near, every 6 months again. We monitor two aspects: the growth, mortality and recruitment of nine woody species (the dominant trees and shrubs of the various native communities), and the species composition and per-



Graphs showing the decline in four tree and shrub species in permanent plots on Alcedo. The longer-lived *Psidium* and *Zanthoxylum* are declining more slowly than the shorter-lived species.

centage cover of all plant species found in the plots. Our results so far show that all of the woody species monitored have declined since 1996, mostly because adult trees and shrubs die and are not replaced. The higher rainfall during the El Niño did not interrupt this trend and possibly even made it worse, with many trees falling at that time, perhaps due to increased erosion combined with high winds and storms. We suspect that other, more insidious effects will emerge when we complete the data analysis, including expansion of species such as Bracken *Pteridium arachnoideum* that are avoided as food by goats, a change that may in effect be irreversible.

A remnant *Zanthoxylum fagara* tree on the rim of Alcedo, showing the importance of cloud condensation in the trees to the understorey vegetation — see the green patch under the tree. This effect is lost when the forest is destroyed, causing general drying of the habitat.

On Santiago we have had a similar monitoring programme since 1995, with one key difference. Santiago has had goats for far longer than Alcedo, and exclosures have been built to protect the key vegetation communities that have been almost completely destroyed by the animals (see p. 27). These may serve as sources for plant recovery when the goats can finally be controlled.

Our monitoring programme compares permanent quadrats

Monitoring vegetation outside one of the exclosures on Santiago.

inside and outside the exclosures and tracks changes in both over time. The vegetation is clearly different inside and out, proving the value of the fences, but we also want to be sure that key species do not disappear from the exclosures, and assess which species are most severely affected by the goats outside them. Expansion of some exclosures in 1998 allowed us to compare the old protected areas, the unprotected vegetation outside, and the newly protected areas, to assess the recovery of different species when goat pressure is removed. Goat eradication began in 2002,

The vegetation inside the exclosures is clearly much more lush than the overgrazed near-desert and grassland outside.

so we hope to see similar changes outside the exclosures soon. Continued monitoring during and after goat eradication should tell us if certain species are failing to regenerate adequately, in which case we may need to intervene to help their recovery.
The monitoring visits of 2002 revealed notable regeneration of the vegetation already, possibly due to the goat control. We expect to see more dramatic recovery during the wet season of 2004.

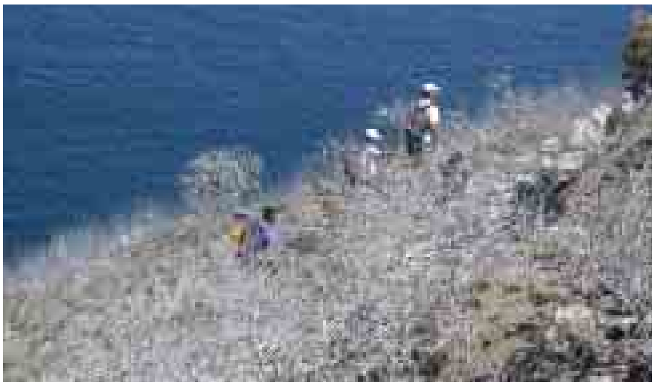
Expanding the exclosures has resulted in regeneration of the vegetation in previously degraded areas.

During the major El Niño event of 1997–8, when rainfall was high and goats dispersed over the normally arid lowlands, the vegetation grew more than usual, suggesting that many native species would quickly recover when goat grazing pressure is reduced. In October 2002, monitoring was carried out for the first time at one of three new exclosures that were built in 1998 to protect remnants of *Scalesia pedunculata* forest (see p. 27), and we noted that bird density was much higher in the fenced *Scalesia* stands than in the surrounding deforested areas (see photo above). This shows that the exclosures are important for protecting not just plants, but also the animal community that depends on them.

Rats and the Bainbridge islets

In August 2000 we made a baseline survey of the Bainbridge islets, eight cones and rocks off SE Santiago. This is the first time that a complete floristic inventory of all eight islets has been made, since some of the islets are very difficult to land on and climb, and it was done to establish a monitoring programme in conjunction with a project to eradicate the introduced Black Rat from these islets. Our aim is to evaluate the impact of rats on the native vegetation. Permanent transects were marked out on the islands, to be monitored over the coming years. In May 2001 and 2002, we assessed the rainy season state of the vegetation, permitting the identification of annual species. We now have the basis for evaluating changes in species composition and abundance after the rat eradication has been carried out.

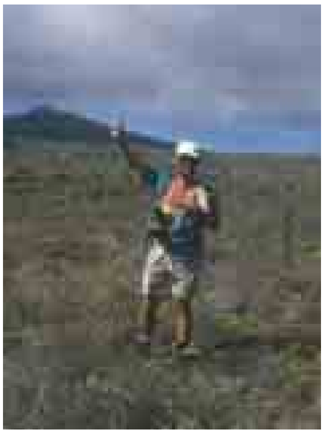
Some of the eight Bainbridge islets, taken from the summit of the largest, Bainbridge 3.



Heinke Jäger and the rat eradication team climbing to the summit of one of the Bainbridge islets.

Recovery after goat eradication, and declines due to invasive plants — long-term collaboration in monitoring with former members of the Department

Goats have already been eradicated from several islands in Galapagos, and we want to make sure that the native vegetation recovers properly, after removal of this threat. Permanent monitoring plots and transects have been established by a succession of botanists working at CDRS over the years since the 1970s, and we continue to monitor many of them, usually in association with the ex-members of the Department who still return as Visiting Scientists.



Henning Adsersen at new permanent plots in the arid and humid zones of Pinta island.

Scalesia helleri regenerating in one of Ole Hamann's permanent plots on the cliffs of Santa Fe, after eradication of the goats from the island.

In late 2000, a ten-day visit was made to Pinta along with former staff botanist Henning Adsersen, during which 15 new permanent plots were established along the line of a former monitoring transect. This was just after the eradication of the last goats from the island, and provides the baseline for studies of vegetation regeneration. Ole Hamann, another former staff botanist, has been monitoring permanent plots on Pinta since the 1970s, and the new plots will amplify his study. In 1999, 2001 and 2003, we accompanied Ole to monitor the permanent plots on Santa Fe and Santa Cruz that were established in the 1970s by him and Tjitte de Vries. The goats were eradicated from Santa Fe in 1971, and the plots have measured the return of threatened species such as *Scalesia helleri*. On Santa Cruz, the plots show a steady loss of *Scalesia pedunculata* forest, which is being replaced by invasive trees such as Cuban Cedar *Cedrela odorata* and Guava *Psidium guajava*.

The population dynamics of *Opuntia echios barringtonensis* on Santa Fe have been studied by Ole Hamann since the 1970s.

Prioritisation

The entire endemic flora mapped and red-listed

In 1997, we began a project to revise the threat status of all of the endemic plants of Galapagos. Our assessments effectively red-list these species on a global scale, because their entire distribution lies within Galapagos. The endemic species are especially important, because their future depends entirely on their conservation and continued existence in the islands.

Until this project, the most recent complete revision of the threat status of the Galapagos flora had been made in the mid-1980s, when each taxon (species or subspecies) was assigned a threat category based on the old Red Data Book criteria of IUCN. Our new revision uses the more objective and quantitative criteria that were published by IUCN in 1994 and revised in 2001.
The project mapped the known distribution of the endemics, using published and unpublished information and especially the records in the CDRS Herbarium. Every species and subspecies had been mapped and then evaluated by 2001. Of the 175 endemic species and 236 endemic taxa, eight species and 16 infraspecific taxa could not be evaluated satisfactorily, owing to lack of information on population status, or taxonomic uncertainties regarding the limits of the taxon. These were categorized as Data Deficient (DD) or Not Evaluated (NE).

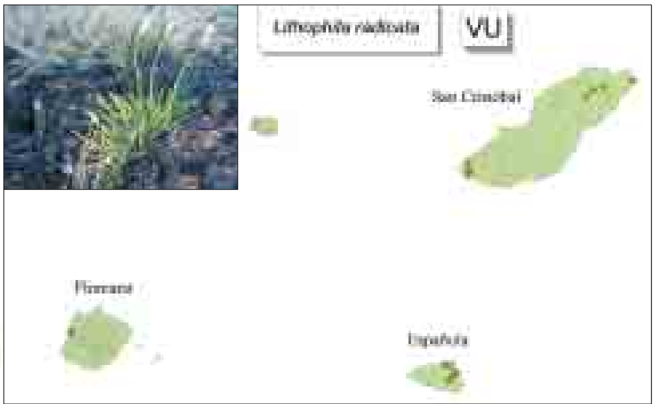
The major IUCN red-list categories mentioned in this report are:

EX = Extinct — no reasonable doubt that the last individual has died; exhaustive searches have failed to record any individual.

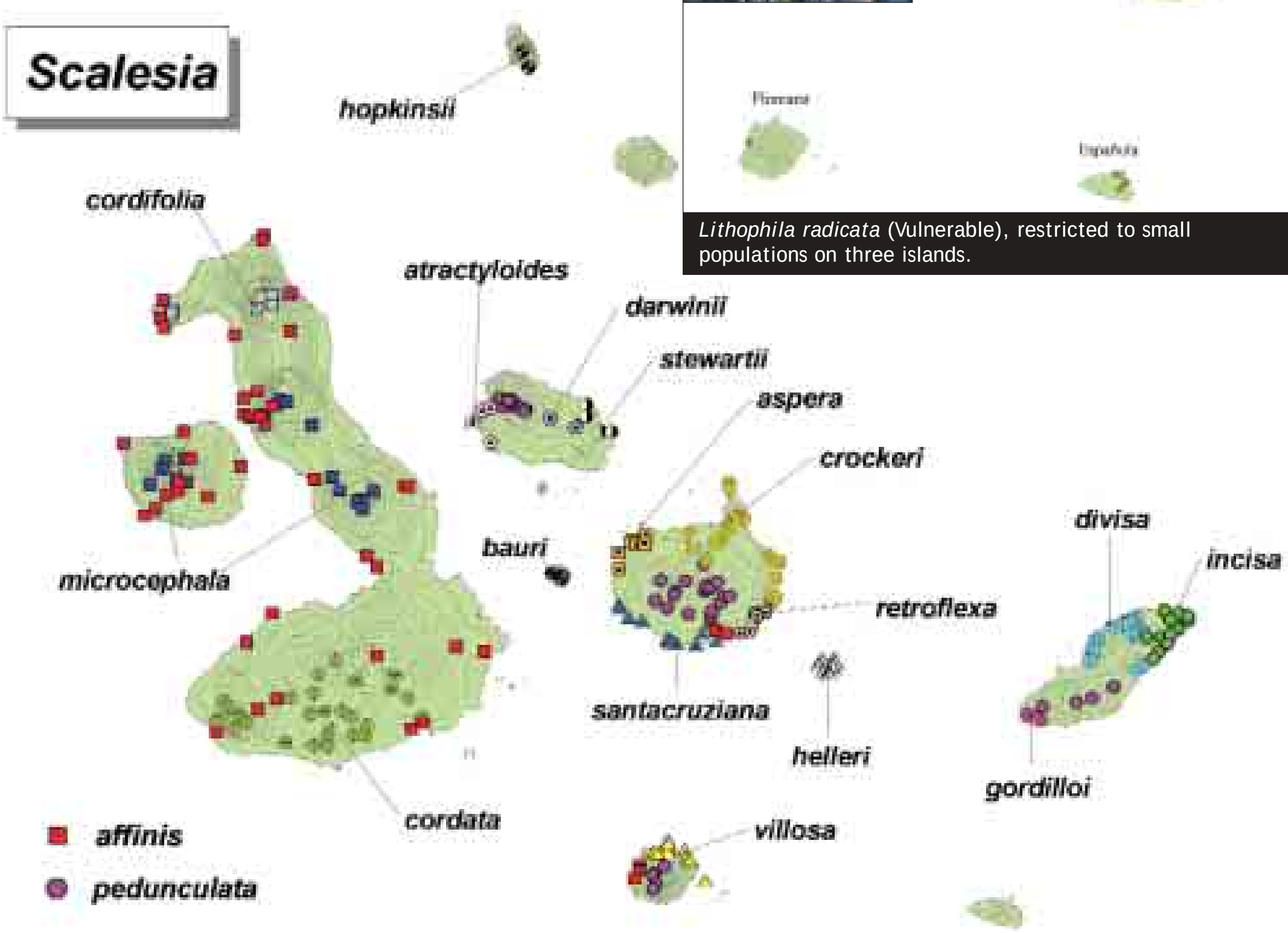
CR = Critically Endangered — faces an extremely high risk of extinction, having suffered severe decline or still declining, and with a very small population or restricted range (according to quantitative criteria defined by IUCN).

EN = Endangered — faces a high risk of extinction, having suffered decline or still declining, and with a small population or restricted range (according to quantitative criteria defined by IUCN).

VU = Vulnerable — in the case of Galapagos plants, most Vulnerable species are those with very small ranges or population sizes, but they have not yet suffered major declines. They are however naturally vulnerable to new threats.



Lithophila radicata (Vulnerable), restricted to small populations on three islands.



Simplified map of the distribution of the endemic genus *Scalesia*; working maps in GIS show all known records on all islands and islets.

For the evaluated taxa, three were classed as Extinct, and 95 of the remaining 164 species (58%), and 138 of the 217 taxa (64%) are threatened. "Threatened" in IUCN terminology includes the three categories Critically Endangered, Endangered and Vulnerable. These include 20 that are classed as Critically Endangered, or in grave danger of imminent extinction, and which require immediate action to ensure their survival. Galapagos has seen only three endemic plant species go extinct in historical time but this project revealed that many more species are on the brink of extinction. We must concentrate our efforts and resources to deal with the threats that they face. Almost 40% of Galapagos endemics are classed as Vulnerable. These have not necessarily declined, but many island taxa automatically fall into this category because of their naturally small ranges. Classifying them as Vulnerable is valid, since they are naturally susceptible to rapid environmental changes, such as the introduction of a new disease or insect pest which could affect them. The Vulnerable classification draws attention to the fact that we need to monitor them to make sure that they do not begin a decline that could quickly cause their extinction.

Two single-island endemic species that automatically classify as Vulnerable due to their small ranges: *Scalesia villosa*, endemic to Floreana island, and *S. gordilloi* endemic to the southern tip of San Cristóbal.

An Ecuadorian national red data book for plants. During 2000, this project also contributed to a collaborative effort on the endemic plants of the whole of Ecuador, which published a Red Book of the threatened plants of the country.

International recognition of our red-listing efforts. A further achievement during 2002 was the establishment of a new IUCN Specialist Group for Galapagos plants. This means that the red-list categories assigned by the project become the official evaluations of IUCN.

Our work is helping to provide the information necessary for the prioritisation of conservation action for the most threatened native plants and vegetation communities. The project will continue, with periodic revisions of the threat classifications according to new information revealed by our research.

An adult plant of the Floreana Flax, *Linum cratericola*, growing high on a cliff ledge, out of the reach of goats. This endemic species is Critically Endangered, being known from only a single, small site.

Biological studies

Galapagos Rock Purslane *Calandrinia galapagosa*

This species was chosen as one of our first threatened species studies, because it is a single-island endemic (only found on one island), known to be Critically Endangered (see p. 23), and the causes of its decline (apart from goats) were not well understood. A complete survey of its distribution began in early 2002, with Eliana Ramírez selected as a research student to do part of this work for her undergraduate thesis, with the support of the Galapagos National Park Service in San Cristóbal. Eliana and other Department members have surveyed the known populations of this plant and found new ones, including rediscovering the species at the site on the north coast of the island where it was first discovered, almost 100 years ago, and from where it was thought to have disappeared. Every one of the populations showed evidence of damage by goats or insects, including a stem-boring fly larva, which seems to be a species new to science. We have also assessed fencing requirements to protect against the goats. The largest known population is already fenced (see p. 27), and another will be fenced in 2003.

The beautiful but Critically Endangered Galapagos Rock Purslane *Calandrinia galapagosa*.

Research student Eliana Ramírez with a *Calandrinia* plant on the summit of its main site.

We are also collecting leaf and seed samples from some of the plants for genetic analysis, to investigate inter-population variability and the morphological variation seen in the species. There are at least two varieties, one with white flowers and green leaves, the other with pink flowers and purple leaves. In conjunction with colleagues at the Universities of Kansas, Florida International and New Mexico, we will examine genetic differences between these forms, as well as between isolated populations, to determine their distinctiveness and conservation priorities.

Scalesia atractyloides and *S. stewartii* — two threatened species on Santiago

When our surveys on Santiago revealed that the endemic tree *Scalesia atractyloides* still survived in several parts of the island (p. 15-16), we determined to investigate its biology as a first step in planning its conservation. In December 1999, we began a study of its ecology and phenology, in which we also included the commoner and closely related *S. stewartii* (see cover photograph). We once again established this as a student thesis project, and Walter Simbaña was selected to carry it out. Walter monitored monthly each known population of *S. atractyloides* and a sample within the large population of *S. stewartii*, and obtained more than one year's data on phenology, recruitment and mortality of both species, along with information on threats.

Walter completed the study in March 2002, and his thesis was approved by the Universidad Central in Quito in June that year. The study revealed serious effects of introduced goats, scale insects and aphids on the plants. For example the scale insects appear to kill the seedlings, weakening them by sucking the sap.

This information was used to select sites for release of *Rodolia* ladybird beetles to control the scale insects, as part of the first biological control project in Galapagos.

Research student Walter Simbaña with the fence protecting the population of *Linum cratericola*.

The Floreana Flax *Linum cratericola*

In April 1997, two scientists from the Botany Department rediscovered a tiny population of eight plants of the Floreana Flax *Linum cratericola*, after 16 years with no recorded observation of it. More plants were spotted in the same area by Galapagos National Park staff. The species was only discovered as recently as December 1966, in two small craters on Floreana island. Uno Eliasson, its discoverer, found it again in one of the sites in 1981, but it was not seen thereafter despite repeated searches during the 1990s. It has never been found anywhere else on Floreana, nor on any other island. Some considered, given the effort that had been spent searching for it, that it must have gone extinct. The two areas where it occurred were badly damaged by feral donkeys and goats, and the introduced pest bush, Curse of India *Lantana camara,* had heavily invaded one site. It seems truly extinct at that site, but the discovery of a few remaining plants at the other site was exciting. The plants were protected by fencing in November 1997, and Walter Simbaña, the student who studied the *Scalesia* on Santiago, has monitored flower and seed production, and factors that could affect its recovery, such as attacks by insects or grazing animals. The species remains extremely rare, but has increased from about 30 plants in late 1999 to about 200 adults and seedlings.

The first tiny plants of *Linum cratericola* found in 1997.

Threatened highland plants on Santa Cruz

In 2001, we began studies of the Vulnerable *Pernettya howellii* and the Critically Endangered *Acalypha wigginsii*. The *Acalypha* is a small plant whose entire world range comprises the peak of Cerro Crocker, the highest peak on Santa Cruz Island. This work includes initial surveys and longer-term monitoring of life-cycle and population dynamics. Threats to these plants, especially the *Acalypha*, increased dramatically with the construction of telecommunications antennae on Cerro Crocker, within the Galapagos National Park. Despite our warnings about the presence of these species at the site proposed for construction, one antenna was built on top of the largest population of *Acalypha*. This caused concern about our ability to get conservation concerns taken into account in planning decisions, even within the National Park. Our continued monitoring reveals that *Acalypha* can regenerate in moderately disturbed areas, although it suffers from heavy disturbance, including trampling and cutting during the maintenance work. The proposed construction of more antennae, and even wind-farms, on Cerro Crocker, could still conceivably cause the first recorded extinction of a Galapagos species due to construction, and ultimately due to demands for TV, mobile phones and (ironically) "green" energy. We provide data on such rare species to the National Park Service to aid them in formulating planning permission for such activities. Suitable alternative sites exist which have no special biological value, so we could easily afford to maintain both endemic species and technological development.

Acalypha wigginsii, Critically Endangered as a result of construction works and maintenance at its single known locality.

CDRS botanists Iván Aldaz and Anne Guézou monitoring the remains of the population of *Acalypha wigginsii* on top of which an antenna was built.

Management and Restoration

Fences

Fences are one of the most obvious ways of protecting native plants in Galapagos against one of the most obvious and serious threats to them: feral goats and other introduced ungulates. We have been building fences to protect samples of threatened vegetation almost since CDRS was established.

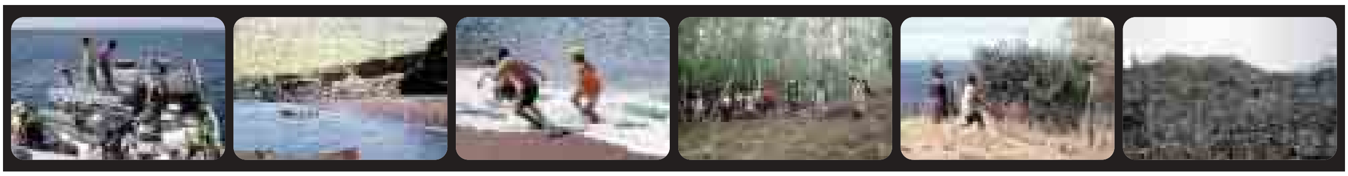
Protecting threatened plant communities on Santiago. The first fences to protect plants in Galapagos were built on Santiago island in the 1970s, when it became obvious that the highland forests were on their way to complete destruction by a burgeoning population of goats. Samples of key highland plant communities were fenced at that time, and more exclosures were built in the early 1990s.

One of the first exclosures built on Santiago, to protect a remnant of *Scalesia* forest.

We have been monitoring these exclosures since 1996 (see p. monitoring section) and, in September 1998, we carried out a survey to assess the state of the existing fences, plan repairs and expansion, and identify additional critical sites for new fences. Many of the older fences needed repair, some urgently, as goats had been able to enter. In December 1998, cost estimates were prepared and the work planned. We decided to repair all the existing exclosures, expand four of them, and construct three new ones to protect remnant patches of *Scalesia pedunculata* woodland. *Scalesia pedunculata* is the tree that was formerly dominant in the highlands of Santiago but is now reduced to tiny remnants, and whose regeneration is prevented by goats stripping the bark of saplings, which kills them. In addition, a fence was built around the hill carrying the newly rediscovered population of *Scalesia atractyloides* (see p. 15-16). Two groups of contractors were employed, each of 21 men, and the work was all completed during the month of December 1998. The logistical arrangements required for such a large task on an uninhabited island were complex, involving many people and the transport of large amounts of equipment and materials, including food, drinking water, wire mesh, metal poles, cement, sand, and more water for mixing concrete. This work would not have been possible without logistical support, including most of the boat transport, provided by the Galapagos National Park Service.

Construction of fence to protect *Scalesia retroflexa* on Santa Cruz island. In July 1999, a small fence was constructed to protect a tiny remnant population of *Scalesia retroflexa* on the SE coast of Santa Cruz. This is an outlier population of a species whose only other locality is further east, and is evolutionarily important as an example of one of the extremely high variety (five species and several intermediates) of *Scalesia* forms that occur around the coast of Santa Cruz. These genetically isolated populations are of great importance for study of the dispersal, isolation and evolution of the genus, and we are trying to preserve each one. The fenced population comprised only 12 adults and juveniles, and 5 seedlings, and was severely threatened with extinction by goats and donkeys. It has since increased to 25 adults and juveniles, with another 25 seedlings.

A tiny group of *Scalesia retroflexa* shrubs, protected by a fence in SE Santa Cruz.



Building a fence in Galapagos is not a straightforward matter. After measuring to estimate materials, these have to be imported from th mainland then taken to the island by boat, in the case the National Park's Guadalupe River. Everything has to be unloaded, often in heavy surf — on this occasion both dinghies in use were flipped by waves. We even have to take water, as most islands are waterless, and water is required for mixing cement, as well as drinking. Then all the materials must be hand-carried to the site — sometimes over 1000 m altitude and several km from the coast. But as can be seen from some of these shots, it's worth it, with the vegetation inside the fences clearly in better state than outside.

A fence to protect *Calandrinia galapagosa* on San Cristóbal island. The largest known population of the Galapagos Rock Purslane *Calandrinia galapagosa* had been protected for many years by an inadequate fence of barbed wire strands. The fence had deteriorated to such an extent that it had become virtually useless in preventing the entry of goats, which had caused much damage to the plants. To protect this population better, the fence was replaced in October 1999 by goat-proof chain-link mesh. At the same time, the area protected was increased, to include outlying plants and permit expansion of the population. The Galapagos National Park Service again helped with the fencing operation. Our current study of this species (see p. 25) includes planning for more fences around additional populations of this Critically Endangered species.

The new fence for *Calandrinia* at Cerro Colorado, San Cristóbal.

This old individual of *Calandrinia*, cropped back to the trunk by goats, is part of another group of this species which we plan to protect by a fence in 2003.

Experimental restoration of *Opuntia* on Española island — a new direction in Galapagos plant conservation

Photographs taken by the California Academy of Sciences expedition to Galapagos in 1905–6 show that the tree cactus found on Española, *Opuntia megasperma orientalis*, formerly occurred in areas where it is now locally extinct. In addition, we suspected from preliminary observations of its population age structure, that the species has not been recovering properly following the eradication of goats from the island in 1978. The goats had been responsible for reducing its population. Therefore, in 1999, we started a project that represents a new direction in Galapagos plant conservation: the experimental restoration of a threatened plant. We wanted to discover the reasons for lack of recruitment, and try to initiate or speed up the recovery of the species, especially in parts of the island where it is no longer found.

Goats under an *Opuntia* cactus in 1906.

Research student Vanessa Coronel measuring a young *Opuntia*.

To begin, fruits were collected on Española in May 1999 and taken back to the botanical laboratory at CDRS on Santa Cruz Island. Our initial hypothesis was that seed viability was low, perhaps due to a genetic bottleneck in the reduced population, so the first objectives were to test viability and determine germination rates. The germination experiments would also produce seedlings for repatriation of the species at Punta Cevallos, the eastern tip of Española, where Opuntia was locally extinct but formerly common. One treatment was to feed the fruit to giant tortoises and recover the seeds from the faeces, because tortois-

Seedling *Opuntia* cacti in pots at the CDRS Botany Dept, before repatriation to Española island.

es are known to be natural dispersers of *Opuntia* seed, and passage through their gut promotes germination. 40% germinated even with no special treatment, but the best treatment found was indeed to feed to tortoises, where we achieved 80% germination. Seed viability was obviously not the cause of failure of the species to regenerate. The seedlings that grew were cultivated in sterile vermiculite rather than soil, in order to reduce the chance of accidental introduction of micro-organisms to Española.

Vanessa Coronel, initially employed as a work-experience student to manage the germination experiments, was accepted as a research student at CDRS and continued the Española work for her undergraduate thesis. In February 2000, she took some of the seedlings to Española and replanted them in pots using soil from the island, as a stage in their adaptation to their future environment. We selected repatriation sites to include all major habitat types at Punta Cevallos. After a month, the seedlings were planted out, some in the open and others protected from bird attacks by small cages, some receiving water and others not. Vanessa spent a month on the island to monitor their progress and adapt conditions as found necessary. During 2000, Vanessa produced more seedlings in the laboratory and took them back to Española in November. Some pads were also taken from adult cacti and planted after different treatments, and a method was developed which much improved their eventual survival.

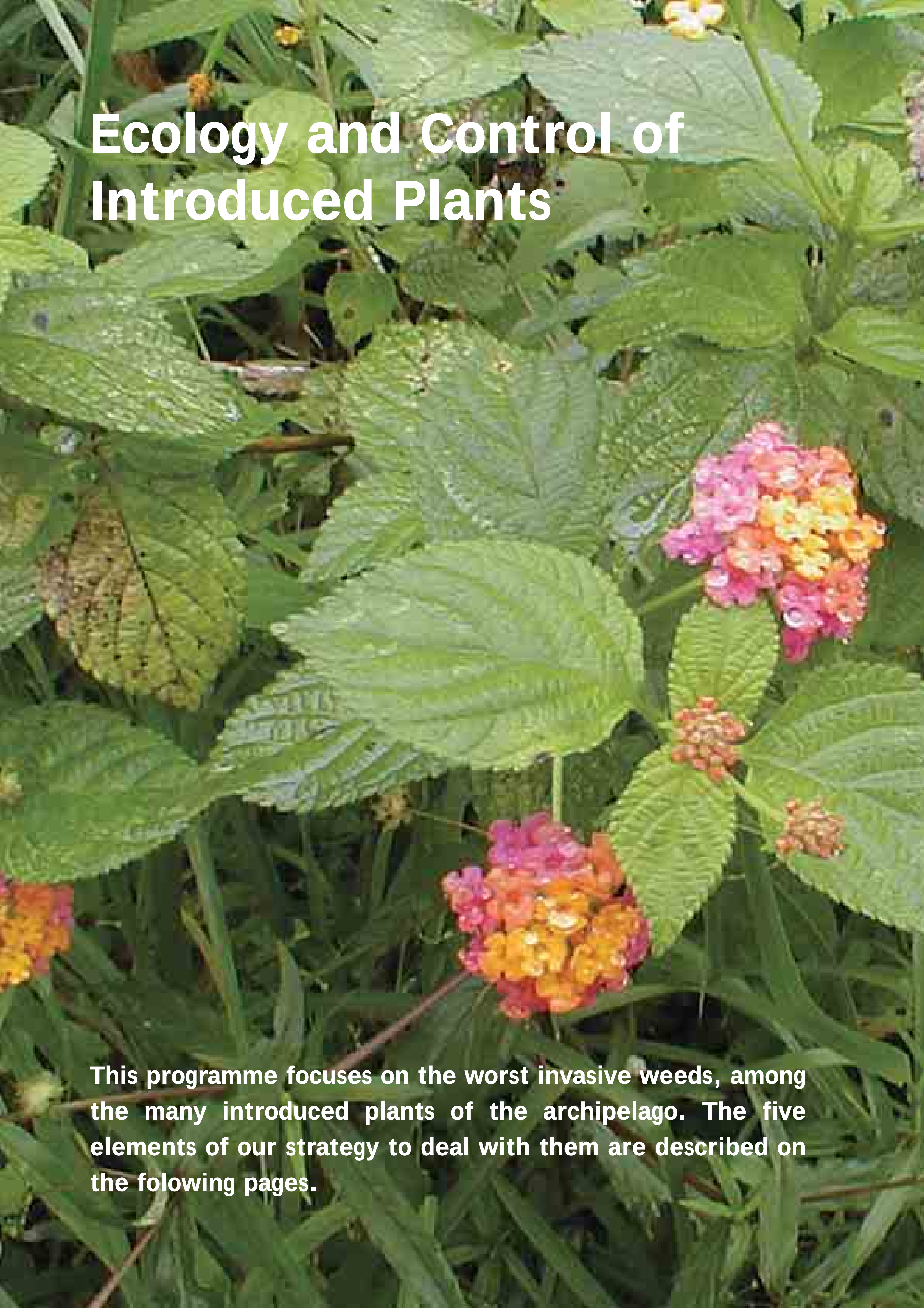
The cactus repatriation area at Punta Cevallos

Most of the seedlings survived until 2002, although some were destroyed by mockingbirds and lizards attacking them, and by albatrosses trampling them. Protection against such damage by cages, rather than watering, seemed to be the key factor in determining survival. Most seedlings and pads grew well during the first half (rainy season) of the year, but not much growth occurred during the dry season.

Repatriated *Opuntia* seedlings are vulnerable to damage by mockingbirds and other animals.

Vanessa finished her research on the island and successfully defended her thesis in 2002. Her results indicate that the critical stage in the life cycle may be the young seedling, when most are eaten or trampled, unless they are protected. This stage seems especially vulnerable to damage by finches, mockingbirds, albatrosses, lizards and giant tortoises, so we hope to investigate the interactions between the cacti and these animals in more detail, in order to plan an effective restoration programme.

Ecology and Control of Introduced Plants



This programme focuses on the worst invasive weeds, among the many introduced plants of the archipelago. The five elements of our strategy to deal with them are described on the folowing pages.

Baseline inventories

Inventory of introduced species in the Agricultural Zone of Santa Cruz.

Javier Robayo, a research student, carried out a complete introduced plant survey of the agricultural zone of Santa Cruz island during 2000, and discovered some 40 previously unrecorded species, increasing the total number of introduced plant species known from Galapagos to more than 500. Many of the new species are known to be invasive in other parts of the world, and have been included as candidates for the project to eradicate 30 introduced plant species from Galapagos during the next 6 years (see p 38).

The El Carmen sector of the agricultural zone on Santa Cruz island.

Introduced plant inventory of Floreana.

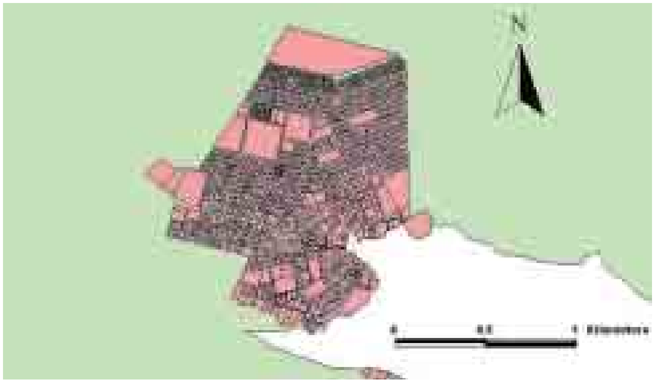
The findings of the Santa Cruz survey suggested that surveys of the other inhabited islands should be a priority. Javier was therefore commissioned to survey the urban and agricultural zones of Floreana during June–July 2001. He visited every property on the island, as well as an area of the National Park that adjoins the agricultural area and is heavily invaded with introduced plants. This time, only four species new for Galapagos were found, but several other introduced species, known from other islands, were also found for the first time on Floreana. This work also contributed to plans for eradication of some of the potentially invasive species that are still present in only small populations.

The agricultural zone of Floreana.

The farms surveyed on Floreana.

Inventory of Puerto Ayora, the largest town in Galapagos

In 2002, we consolidated the inventory work by contracting Ana Mireya Guerrero and Paola Pozo to work on this project over the coming years. They began with the biggest part of the task, the town of Puerto Ayora. There are 2000 properties in the town, and we plan to visit them all and record all plant species in the gardens, houses, vacant plots and roadsides. Mireya and Paola find new species for Galapagos every week, and we cannot yet predict the size of the eventual total list of introduced species for the archipelago. This list will be an essential baseline against which we will be able to detect new introductions, as well as enabling us to prioritise work on the species that have already been introduced (see p. 33).



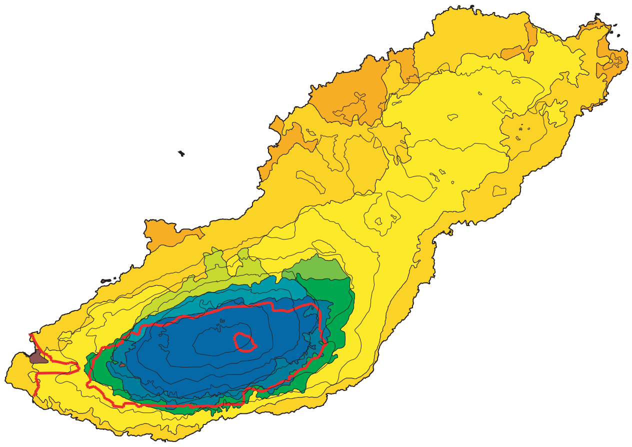
Street plan of Puerto Ayora.

Tradescantia spathacea and *Jatropha podagrica*, two introduced ornamentals new to the Galapagos list, found in Puerto Ayora by the inventory team.

Monitoring

Control of introduced plants and restoration of El Junco Lagoon

El Junco is close to the highest point on San Cristóbal Island, and is unique in being the only permanent fresh water lake in Galapagos. Although San Cristóbal has lost over 95% of its humid highland vegetation to agriculture and invasive plants, this site is still relatively intact. The endemic tree fern *Cyathea weatherbyana* and the endemic shrub *Miconia robinsoniana* still grow there, and the greatest threat to these species is posed by aggressive introduced plants, especially the Hill Blackberry *Rubus niveus* and Guava *Psidium guajava*. Our experiments are studying how weed control operations can best be carried out to promote recovery of the native vegetation.



The agricultural zone of San Cristóbal (red line) occupies most of the humid highlands. The El Junco reserve is an enclave within the agricultural area.

El Junco lagoon in the highlands of San Cristobal, now fenced and undergoing restoration.

The National Park Service fenced the area in October 2000 to keep out grazing animals, especially domestic cattle and feral horses. The 124 ha exclosure was mapped, and some 32 ha found to be dominated by invasive plants. The guava and blackberry were controlled, and seedlings of the natural dominant shrub *Miconia robinsoniana* planted, to speed up recovery of the native vegetation. Permanent plots were established, to monitor the community succession following weed eradication, and a management plan of the reserve was developed in conjunction with the National Park. Weed control and monitoring of the permanent plots continue, and the results are encouraging, with good recovery of *Miconia* and other native species in the controlled areas.

Excellent regeneration of the endemic shrub *Miconia robinsoniana* on the slopes above El Junco lagoon.

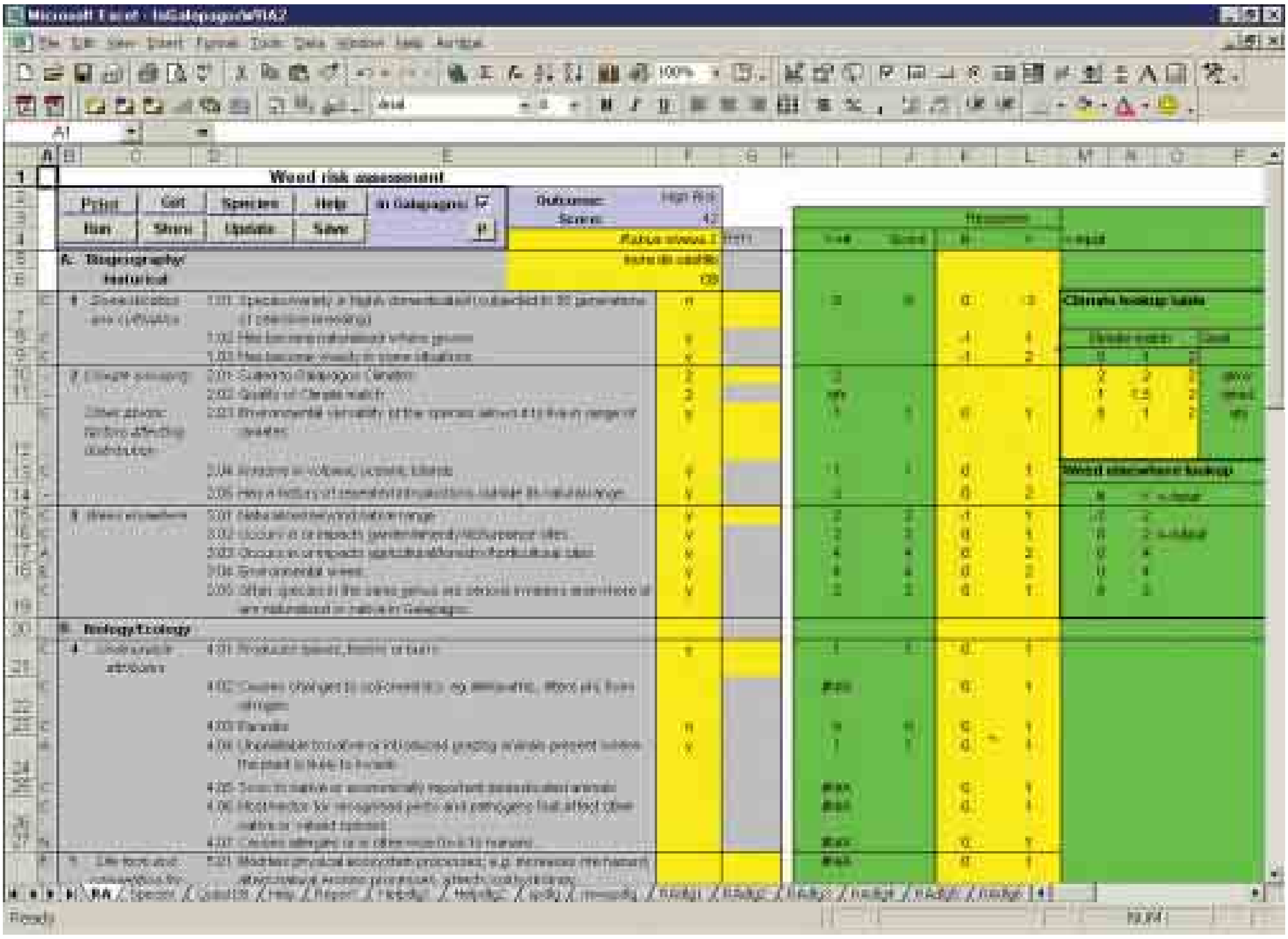
Monitoring the growth of *Miconia robinsoniana* seedlings at El Junco.

Miconia robinsoniana

Prioritisation

In the case of introduced species, we face several, related, prioritisation-evaluation problems. One is to evaluate potential new introductions, to judge whether they are likely to become invasive in Galapagos. This is important for assessing proposals by local residents to introduce new crop species and varieties. A second requirement is to assess the (potential) invasiveness of plant species that have already been introduced to Galapagos, as well as estimate the feasibility of their control. This is important to enable us to allocate scarce financial resources to the species that are, or are likely to become, serious problems but where we have a good chance of achieving successful control. Complete eradication is the procedure of choice, wherever possible, because although the cost may initially be high, it is finite and ceases once the species has been eradicated. Finally, for species that we cannot conceivably eradicate, we need a system to prioritise sites based on their biodiversity value, to allow us to choose the most important places to keep free of invasive plants. Together, these systems will provide a strong basis for strategic planning of action against weeds. In 2003, we are developing systems for each of these steps, taking advantage of models developed elsewhere, especially in Australia and New Zealand. Volunteer Paul Pheloung, who developed the weed risk assessment model used in Australia, has been helping us with this process.

Weed analysis expert Paul Pheloung developing our evaluation system.



The introductory screen of the introduced plant evaluation system.

Species studies

Biology and control of *Rubus niveus*

Hill Blackberry *Rubus niveus*, was introduced to Santa Cruz island as recently as the 1980s, but has since spread to become one of the worst weeds threatening the National Park. It is also a serious problem for farmers, invading their land and rendering it useless.

The introduced Hill Blackberry *Rubus niveus*, growing to more than 3 m high on what was formerly pastureland.

Distribution of *Rubus niveus* in Santa Cruz (about 3000 ha). It is invading the National Park, and threatening the humid zone vegetation.

Without knowledge of the biology of introduced plant species, their effective control is impossible. Research student Ondina Landázuri commenced experiments in 2000 to measure the impact of Hill Blackberry on the regeneration of native vegetation, develop manual and chemical control methods for the species, and investigate its biology, including flower and fruit production, seed production and dormancy, germination cues and seed bank longevity.

Ondina found that Hill Blackberry is most effectively pollinated by insects such as the Galapagos Carpenter Bee *Xylocopa galapagensis*, but it is also capable of self pollination. It can produce viable seeds very quickly, with flowering to seed-fall taking only 4–6 weeks, and it has an incredible reproductive potential. In the month of November 1999, an average 20,000 seeds per square meter were produced by a dense infestation. Many bird species feed on the fruit, and birds are most likely the main dis-

Ondina Landazuri at control site for Hill Blackberry.

persal agent. Its long distance dispersal ability was illustrated by its discovery in an area of high endemism on the peak of the island. If it becomes established there, several endemic plants, including *Pernettya howellii*, *Acalypha wigginsii* (see p. 26) and *Cyathea weatherbyana* will be endangered. The species was also found on Isabela Island and we are currently evaluating the possibility of its complete eradication there, before it spreads out of control (see p. 38).

Hill Blackberry *Rubus niveus* in fruit.

The biological study revealed one reason why it is so difficult to control Hill Blackberry. Fresh seeds are dormant and need to be buried in the soil for at least three months before they will germinate. The soil seed bank can have 1000–5000 seeds per square meter, which can remain viable for many years. Of seeds buried for 7 months, 46% were still viable. Some have survived for more than two years and maximum longevity is still unknown. Dormancy is broken by seed coat damage, during burial or by hydrochloric acid (as found in the stomachs of birds). Under the right conditions of light and water, germination is surprisingly high. In one experiment, a plot was cleared to increase light level and 3,800 seeds germinated per square meter in one month. These findings have important implications for management: we might be able to encourage the seeds to germinate in this way and then spray the resulting seedlings. All this information is included in the integrated management plan of this species, which is one of the products of this study.

Rubus niveus seedlings coming up after control.

Dispersal of seeds of introduced plants by birds.

From 2000–2002, Ana Mireya Guerrero studied the biology of the seed-dispersing and seed-predating birds in Galapagos, and their dispersal of native and introduced plant seeds. She demonstrated the importance of some species of bird in dispersing seeds of *Rubus* and other introduced species. The famous Darwin's finches turned out to be poor dispersers, as they are seed predators, which destroy and digest the seeds. The best dispersers are species that are often thought of as insectivores, but which actually eat a lot of fruit, such as the Galapagos Flycatcher and Mockingbird. Ana Mireya was subsequently employed on the introduced plant survey of Puerto Ayora (see p. 31).

Galapagos Mockingbird (omnivorous) and Galapagos Flycatcher (insectivore-frugivore), species which swallow fruit whole then regurgitate or defaecate the seeds later.

Darwin's finches in a Bursera tree — the finches digest most seed but disperse some.

Feasibility studies for the control of Quinine

The Red Quinine tree is perhaps the worst invasive plant (so far) on Santa Cruz island, thankfully the only island where it is yet known to occur. It has spread to occupy almost the entire highlands of the island, and we fear that either accidental transport, or its wind-dispersed seeds, may soon carry it to other islands.

Quinine flowers and fruit.

Photographs taken over the years show the rapid progression of the Quinine invasion and the way it completely changes the native habitat. Besides its dramatic effects on the highland scenery, Heinke Jäger's studies have shown that it drastically changes the species composition of the highland vegetation communities, causing reductions in many endemic species. It probably has more subtle effects on soil chemistry, which we have still to investigate.

These three photographs, taken in 1970, 1991 and 2001, show the progression of the invasion of the highlands of Santa Cruz by Quinine. The tree was absent from the area in 1970 and now covers it.

Because it is conspicuous (a tree), useless (low quinine content in the variety in Galapagos) and a problem for farmers as well as the National Park, it may, despite its wide distribution over more than 10,000 ha, still be a candidate for complete eradication (see p. 38). In any case, we need to know more about its biology in order to plan any kind of effective control. For this reason, during the past four years we have undertaken a series of studies of the biology and distribution of Quinine, which should help us to assess the feasibility and cost of an eradication attempt, or make the decision to take some other kind of action against it.

Quinine trees and shrubs overtop and shade out the native *Miconia* shrubs and ferns.

Studies so far have examined the effects of Quinine on the native vegetation, and aspects of its reproductive biology. Student Jorge-Luís Rentería found that Quinine seed is quite short-lived, giving grounds for optimism that, if adult seed-producing trees can be killed, the soil seed bank would soon be exhausted. We have also, after many years of trying, discovered an effective herbicide control technique for Quinine, which had proven resistant to the methods we previously had available. It is killed by application of Combo® into machete cuts made in the bark of the trees, a method which also kills the rootstock. This is important, because Quinine readily resprouts from fragments of root left alive in the soil by other methods.

We are currently estimating the costs of different methods of control of Quinine in different density populations, and also plan to investigate the eventual fate of the herbicide in the soil, an essential step if we are to undertake large-scale control by herbicide use.

One of our trials to develop an effiective method of controlling Quinine.

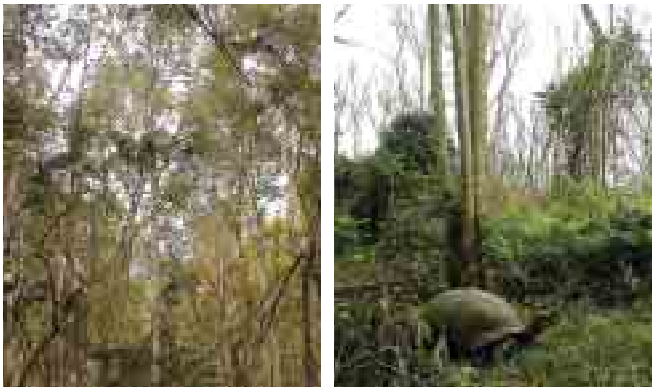
Shots taken in the dry season show the extent of the quinine invasion (green) among the brown fern-sedge highlands of Santa Cruz.

Management and control

Control trials

Experiments to find the most effective measures for controlling important weeds have been carried out on Santa Cruz, San Cristobal and Floreana islands, and new trials are planned, to discover appropriate ways to control more of Galapagos's worst weeds. Experiments on the following have been completed and effective methods identified: Quinine *Cinchona pubescens*, Guava *Psidium guajava*, five species of blackberry *Rubus* spp., Elephant Grass *Pennisetum purpureum*, Cuban Cedar *Cedrela odorata*, Sauco *Cestrum auriculatum*, Laurel *Cordia alliodora*, Mother-of-Thousands *Bryophyllum pinnatum*, Rose-apple *Syzygium jambos*, Tropical Kudzu *Pueraria phaseoloides* and Curse of India *Lantana camara*. Manual and chemical methods are both investigated. The most desirable methods are effective, fast and cheap, and result in minimal damage to the native vegetation. An example of this is the application of herbicides such as Roundup® and Combo® directly into cuts in the bark of invasive trees, resulting in minimal non-target damage. However, when infestations of shrubs such as blackberry are dense, spraying is necessary.

"Hack-and-squirt" is a preferred technique for trees, where herbicide is injected into machete cuts in the bark, thereby minimising non-target damage.



A control trial for the invasive timber tree *Cedrela odorata*, which dominated the native vegetation in an area important for Galapagos giant tortoises, until cleared by our trials.

A trial for control of the invasive shrub Curse of India *Lantana camara* using "basal bark" (spraying the base of the stems) application.

A trial for the control of the invasive ornamental herb Mother-of-Thousands *Bryophyllum pinnatum*.

In 2002, we published a manual for the identification and control of a selection of the worst weeds, for use by the local farming community and conservation land managers. We intend this to be the first of a series of publications for local use, on topics such as weed control, responsible gardening (avoiding the use of invasive ornamentals) etc.

Our weed identification and control manual, published in 2002.

Eradication

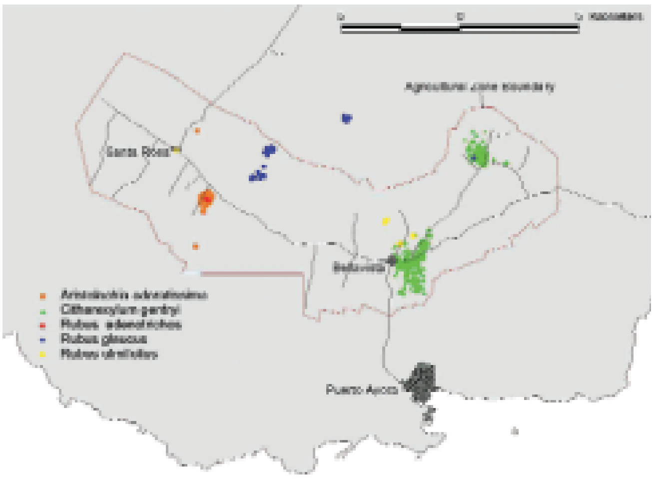
For the treatment of an invasive plant, the procedure of choice when possible is complete eradication, because although the cost may initially be high, it is finite and ceases once the species has been eradicated. The alternative is long-term control, which represents a never-ending investment. However, until recently, no invasive species had been completely eradicated from Galapagos and efforts had instead been directed at controlling some of the most obvious weeds in sites considered to be of high conservation value.

Tropical Kudzu — an introduction scare eradicated. The first successful eradication attempt began when Botany Department staff discovered that a farmer had imported and planted seeds of Tropical Kudzu *Pueraria phaseoloides* on his land. This plant is a close relative of the infamous Kudzu, perhaps the worst weed of the southeast USA, and is a fast-growing vine used in mainland Ecuador to smother other vegetation in orchards. That vigorous, smothering growth habit makes it a plant to be feared in Galapagos. Luckily, when we explained the potential danger, the farmer agreed to its eradication, and we immediately treated the 20 x 20 m plot where it had been sown, with Roundup® herbicide. Follow-up treatment, before we felt able to declare the plant completely eradicated, went on for more than three years, to ensure that no roots or ungerminated seed had survived. The plant had flowered but not produced seeds, so no new seeds had entered the soil seed bank. But even this relatively easy case took several years and was estimated to have cost in total almost US$ 4000, showing the importance of preventing the introduction of such species in the first place.

The last plant of Tropical Kudzu being sprayed with Roundup.

A herbarium sheet of Tropical Kudzu *Pueraria phaseoloides* as a permanent record of the species in Galapagos.

Eradication as a priority management tool. The Kudzu case represented a change of direction in weed control in Galapagos, and more emphasis is now beginning to be placed on eradication. In 2000, we began a new project to attempt to eradicate completely from Galapagos a number of introduced plant species that are known to be seriously invasive in other parts of the world but which currently have a limited distribution in our islands. Such plants could become serious invaders in the future, and should be treated now, while there remains a good chance of achieving eradication. The longer they are left, the greater the chance of them becoming widely dispersed and establishing seed banks in the soil. Once this happens, it may then be impossible to eradicate them, necessitating long-term and eventually much more



The distribution of some of our eradication target species on Santa Cruz island.

Rubus adenotrichos, one of the five species of blackberry targeted for eradication.

A potential future problem, the agro-forestry tree *Leucaena leucocephala* is one of many introduced species known to be terrible invaders in other parts of the world, which have not yet spread widely in Galapagos but are expected to do so unless they can be eradicated soon.

expensive continuous control. This new approach aims to reduce for the first time the number of invasive plant species in the archipelago. There is also a second objective, which is to improve our understanding of plant characteristics, such as biology, number of populations and range, which influence the cost of eradication and ultimately our ability to do so. Accordingly, we have chosen species with different characteristics, so we will be able to measure costs and evaluate success, and relate them to these factors.

An experimental approach to eradication. The project began with five species: the tree *Citharexylum gentryi* and four species of blackberry *Rubus*. A fifth blackberry species was added to the project as soon as it was discovered. All adults of *Citharexylum* were mapped and killed, and follow-up concentrates on finding and treating young plants and regrowth. Three species of *Rubus* on Santa Cruz have been treated in all known populations, and monitoring will similarly ensure that all regrowth is found and treated. Two species of *Rubus* on Isabela have been mapped, and treatment commenced. Monitoring and follow-up will have to continue for several more years in order to be sure of complete eradication.

Eradication of *Rubus adenotrichos* in progress.

Searching for and treating seedlings of *Citharexylum gentryi* in an attempt to eradicate it from Santa Cruz island.

Herbarium, Resources, Training and Development

This programme comprises all of the support functions of the Department, including institutional reporting, contributions to planning processes, personnel management, and maintenance of key resources including buildings and equipment and the reference collections.

The Herbarium CDS and Flora Database

An herbarium reference collection is an indispensable tool for all botanical research, because plant studies depend on reliable identifications and many plant groups are difficult to identify in the field. Herbarium specimens also provide material for traditional (morphological) and modern (genetic) research in plant systematics, evolution, and ecology. Until 1994, herbarium maintenance at CDRS was often not up to international standards, resulting in many specimens being taken by their collectors to other institutions outside Galapagos. In 1994, the collections were moved to a new dehumidified and air-conditioned room with custom-built storage cabinets. The collection data were entered into a computerized database that now forms the core of the CDRS Database of the Galapagos Flora.

Working with herbarium specimens.

Part of the seed and fluid-preserved collections.

The pollen collection comprises microscope slide mounts and electron micrographs.

The botanical collections have more than doubled in recent years, from 7000 specimens in 1996 to over 14000 in 2003, a growth of 1000 specimens per year. The collections currently represent approximately 85% of vascular plant taxa known from the islands, 70% of algae, 40% of lichens, and a collection of bryophytes which is not yet fully catalogued. The collections include isotype specimens (from the plant originally used to describe the taxon) of three endemic taxa. The principal collection is of pressed and dried specimens mounted on card sheets, but auxiliary collections include oversize specimens of fruit, wood, bark, roots and tubers, delicate structures preserved in fluid preservative, a seed collection and a pollen collection including electron micrographs.

A part of the auxiliary collection of timber samples.

Recent activities have included cataloguing the algae and lichens (1998–2000), initiation of the pollen collection (2001), and checking the identification of specimens of difficult groups. Revision of all endemic vascular taxa and all ferns and grasses has recently been completed. Visiting grass expert Simon Lægaard from Denmark checked all of the grass and sedge collections, and found more than 10 new introduced species for Galapagos, which had previously been overlooked in the collection. Work in the near future will focus on introduced species.

Simon Lægaard revising the identifications of the grass collections.

Training

During the period covered by this report, the Botany Department has trained more than twenty Ecuadorian work-experience students. These are undergraduates or recent graduates, who come to us for 6 months' on-the-job training in aspects of conservation biology. Since 1998 we have also supervised nine Ecuadorian students who have carried out their thesis research on projects forming part of our programmes. Their theses are listed in the publications section (p. 48). This represents an average of more than six Ecuadorian students accepted per year. Several of our ex-students now occupy staff positions at CDRS or other Ecuadorian biological or conservation institutions, or have gone on to postgraduate training overseas. We also support our staff and students to attend courses of relevance to their studies. Since 1998, we have sent Department members to specialist courses at Kew Gardens (UK), Spain, Colombia and Chile.

In addition to our stated mission to train Ecuadorian students, we also accept students from other countries who wish to carry out research related to our programmes. Studies by international students include investigations of the molecular phylogeny of the endemic Galapagos tomato and the endemic genus *Darwiniothamnus* (Darwin's asters), by Sarah Darwin of the Natural History Museum in London and Nicole Andrus of Florida International University, and a study of the ecology of invasion by grass into brackish lagoons, by Tania Siemens of Cornell University. Nicole's research led to the surprise finding that *Darwiniothamnus* is actually made up of two different plant groups, one originating from ancestors in the Caribbean region and the other from Chile. Tania's work should help in the design of a control programme for the introduced frog *Scinax quinquefasciatus*, which has established in the same lagoons.

Nicole Andrus collecting *Darwiniothemnus* leaves for DNA analysis.

The Galapagos endemic tomato *Solanum cheesmaniae* has yellow-orange fruit and can grow on bare lava.

Our work-experience students each carry out a research mini-project. Here, Katy Villacis investigates *Scalesia* germination.

Production of publicity materials and presentation of results

In addition to scientific and educational publications (see p. 48), Department staff and students have presented their results at many conferences both in Ecuador and internationally, including since 1998:

February 1999, Adelaide, Australia. 1st International Workshop on Weed Risk Assessment. Alan Tye presented requirements for weed risk assessment in Galapagos.

1999, Devonport, Australia. 12th Australian Weeds Conference. Mark Gardener presented results of control trials on several weed species.

October 1999, Sardinia. 5th International Conference on the Ecology of Invasive Plants. Heinke Jäger presented work on quinine in Galapagos.

July 2000, Gomera, Canary Islands. Workshop on the Conservation and Ecology of the Plants of Oceanic Archipelagos. Alan Tye presented analyses of the Galapagos flora and work for its conservation.

September 2000, Toronto, Canada. Conference of the Weed Science Society of America. Mark Gardener and Sarah Wilkinson presented aspects of planning for weed control in Galapagos.

October 2000, Quito, Ecuador. 3rd Ecuadorian Botanical Congress. Most of the department attended and presented results on a variety of projects. Patricia Jaramillo and Vanessa Coronel, both of the Department, won prizes for best presentations.

February 2001, Wellington, New Zealand. International Conference on the Ecology of Insular Biotas. Heinke Jäger presented a paper on the quinine invasion.

February 2001, Auckland, New Zealand. International Conference on Eradication of Island Invasives. Mark Gardener, Monica Soria and Alan Tye presented two talks on eradication projects and weed control planning.

September 2001, Loughborough, UK. 6th International Conference on the Ecology and Management of Alien Plant Invasions. Heinke Jäger presented her studies of the impact of the invasive quinine on the native flora.

June 2001, Guam. 10th Pacific Science Intercongress. Alan Tye and Syuzo Itow presented work on threatened species and plant community studies.

July 2002, Canterbury, UK. Joint conference of Society for Conservation Biology and British Ecological Society. Alan Tye presented an analysis of the rate of plant introductions to Galapagos.

October 2002, Cartagena, Colombia. 8th Latin-American Botanical Congress. Patricio Yánez presented an analysis of changes in vegetative cover on Alcedo Volcano, in relation to the presence of goats, and Ondina Landázuri talked about her work on the ecology of the invasive Hill Blackberry.

A leaflet illustrating the work supported by sponsors KNCF, Darwin Initiative and Frankfurt Zoological Society was produced in late 1999, in both Spanish (primarily for use among the local community) and English (primarily for use with visitors, including scientists and tourists). In 2000 a video illustrating this work was produced, primarily for local use and for showing to tourist visitors at the CDRS Interpretation Centre. The document you are reading now was produced as an account of the Department's work, to be used as information for our sponsors, for raising more funds, and for visitors and other interested parties.

Leaflet describing our work with threatened plants.

The Future: New Strategies, Challenges, and Projects Awaiting Funding

One of our major projects of the past five years has been to develop a strategic plan for botanical research in Galapagos, aimed at improving plant conservation here. We have taken two main approaches to this problem, one being the red-listing of the endemic flora, and the other the development of prioritisation methods for introduced species. These new strategies clearly identify the most pressing problems facing the native biota of the islands and enable us to focus our research on them.

Research priorities

Having developed our strategic approach to the conservation of Galapagos plants, we now have a clear idea of research priorities for the coming years. For native plants, we need baseline surveys, monitoring of threatened species and communities, biological studies of the most endangered species, and management and restoration. We also need to continue to revise priorities according to new information gathered. For introduced plants, we need more baseline inventories to complete our species list, monitoring of priority invasives, biological studies of these species and their impacts, and management and control. We need to complete our designs for prioritisation systems and, as for native species, revise priorities periodically.

Two critical areas where we need support

1. A challenge: find secure funding to save our endangered plants

We can now identify the most threatened native species and populations and plan their conservation. The next step is to obtain funding for the large amount of applied field research and practical conservation action that will be required in the coming years in order to save these most threatened species from extinction. This is perhaps our biggest challenge, since funds for threatened plants are scarce, and this programme has always been one of the most difficult areas of the work of the Charles Darwin Research Station to fund.

As of 2003, we have not been able to implement even a token endangered species monitoring programme, nor begin studies of the most endangered plant species of the archipelago. This is doubly disappointing, given that we now have an excellent basis for identifying the problems, but are unable to do much to counter them. This situation must change if we are to prevent the extinction of some of these species. Ideally, we must identify a long-term source of adequate funding, especially for monitoring, biological studies and restoration. In the short term, we are unable even to complete the programme of surveys for threatened and lost species, owing to shortage of funds, and additional resources are required to complete these baseline surveys of the archipelago.

Our native plants programme has always been run on a shoestring, despite which we have made some remarkable discoveries and achievements. With secure and adequate support, we could halt and reverse the declines in abundance that many of the endemic species have suffered.

2. Expand research on the worst weeds

In recent years, we have managed to build up a strong programme of research for the control of invasive introduced plants, from almost nothing in 1996. Invasive introduced species have become increasingly recognised internationally as a conservation challenge, resulting in an increase in the availability of funding. Along with our development of prioritisation tools, this has enabled us to undertake several new ventures, especially the experimental eradication of selected species from the archipelago. However, the size of the problem is enormous, with close to 600 introduced plant species registered to date. Some of these species are now so widespread that major funding is required to tackle them.

Two examples illustrate the range of challenges. Some tree species, such as Quinine, are serious problems but perhaps still eradicable. Our feasibility studies suggest that there may be a chance, but the necessary project would cost several million dollars over 15–20 years. Other serious problem species, such as Hill Blackberry, are already beyond any possibility of eradication, having a long-lived seed bank, rapid reproduction, long-distance dispersal and being quite inconspicuous when reduced to isolated and small individuals. For them, the only long-term chance of overall control is by biological control. We propose to undertake studies to determine whether we could safely control plants such as Hill Blackberry, Curse of India, and perhaps even Quinine, using biological control. To be safe, we need much research on natural enemies of these plants and their potential effects on non-target native species. Funding for these projects has yet to be identified.

Priority Projects Where We Urgently Need Support

Endangered plants:

- To support a basic but functioning programme of research and monitoring for the conservation of endangered plants: **US$ 250,000 per year.**
- To support a three-year study of one endangered plant species (and we have 20 Critically Endangered species): **US$ 60,000**
- To cerry out baseline surveys of one large island: **US$ 40,000**
- To carry out a restoration project for one endangered species: **US$ 50,000**
- To fence one medium size population of an endangered species: **US$ 10,000**

Introduced weeds:

- To carry out research for the biological control of one invasive species: **US$ 200,000**
- To support a two-year study of the biology of one invasive species, for planning its control: **US$ 40,000**
- To eradicate one invasive plant species completely from Galapagos over five-years: **US$ 25,000**

Essential resources and training:

- To finance or endow one key staff position in the Department: **US$ 30,000 per year.**
- To support the Herbarium CDS for one year (personnel and materials): **US$ 35,000**
- To support Departmental GIS and database management for one year: **US$ 15,000**
- To support one Ecuadorian student thesis project: **US$ 20,000**
- To support one Ecuadorian work-experience student for 6 months: **US$ 5000**

(All figures are estimates based on 2003 costs)

Optimism For The Future?

Over the past four centuries, Galapagos has seen a steady decline in its biological diversity, degradation of its natural habitats and scenery, and the introduction of a phenomenal number of organisms that threaten the native species. Our work is aimed at halting and, if possible, reversing this deterioration in the natural environment of the islands. So far we have been losing the battle, but promising developments, such as the introduction in 1998 of a quarantine system for Galapagos, which should slow the rate of arrival of new species, may enable us with a little effort to turn the tide. We need to work with the endangered species to discover the threats facing them and tackle them, and with the worst invaders to get rid of them completely, if possible, from the archipelago. We know what we need to do to save Galapagos, still the least altered large tropical archipelago in the world, and possibly the only place in the world where these ambitious goals might be achievable. With adequate support, we can achieve them.

Publications from the Botany Department, 1997-2003

Check our web site **www.darwinfoundation.org** where many of these publications are posted. CDRS Botany Department staff, students and volunteers are named in **bold** type.

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Who Are "We" Now?

(at the date of finalizing this report, April 2003)

Alan Tye, Head of Department since 1996.

Heinke Jäger, threatened species surveys and ecology of the invasive Quinine tree.

Chris Buddenhagen, manages introduced plants projects.

Patricio Yánez, coordinates introduced plant work with the Galapagos National Park Service.

Iván Aldaz, long-term vegetation monitoring.

Patricia Jaramillo, manages the Herbarium CDS.

Ana Mireya Guerrero, inventories of introduced plants, and departmental administration.

Paola Pozo, introduced plant inventories.

Scientific and Field Staff

José-Luís Escandón, manages the weed eradication field team, and **Mónica Soria,** site prioritisation.

The field team, left to right: **Manuel Orellana, Felix Burgos, Kléver Román, Manuel Montalván** and **Gilberth Valle.**

Research student **Ana Lucía Dávalos** and volunteer **Cristabel Durán.**

Volunteers and work-experience students, left to right: **Simon Lægaard, Susy Chamorro, Vanessa Coronel** and **Miguel Cueva.** Student **Eliana Ramírez** can be found on p. 25.

Anne Guézou, introduced plant inventories.

Scott Henderson, research student, Guava invasion ecology

Research student **Tania Siemens,** in one of her lagoon field sites**.**

Students and volunteers

During the period covered by this report we have seen between 40 and 50 students and volunteers come and go, but the only scientific staff to have joined and left the Department during this time were Sarah Wilkinson and Mark Gardener, who worked on introduced plants from 1997 to 2000. Sarah first came as a volunteer, then was contracted to work on control trials. She also compiled all information available on previous trials, began work on a weed control manual for farmers, and then, as a research student, carried out a study of the control of elephant grass with experimental promotion of *Scalesia* forest regeneration. Mark then considerably amplified the control trials programme and initiated biological studies of some of the worst invaders.

Sarah Wilkinson and friend on Floreana.

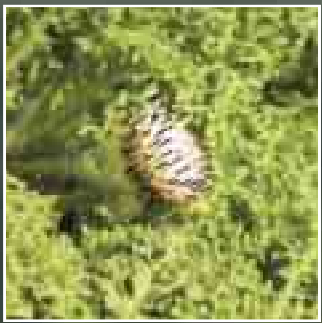
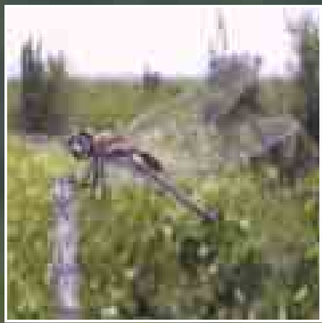
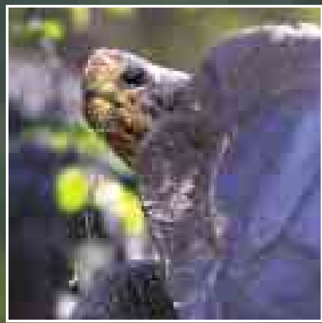
Mark Gardener with a dead Quinine tree.

www.darwinfoundation.org

The Charles Darwin Foundation and the

Charles Darwin Research Station



The Charles Darwin Foundation (CDF) is an international, non-governmental, non-profit organization, founded in 1959 under the auspices of UNESCO and the World Conservation Union. Its aim is to conserve the unique biodiversity of Galapagos through scientific research and related conservation action. CDF is based in the Galapagos Islands, where it operates the Charles Darwin Research Station (CDRS), in Puerto Ayora on Santa Cruz Island. The station's personnel includes scientists, educators, volunteers, research students and support staff from around the world, who work together to study and protect this precious and unique place.

CDF's programmes focus on research for the long-term conservation of the marine and terrestrial environments of Galapagos, and on providing environmental education. To conserve the unique biodiversity of Galapagos, CDF works in partnership with the Galapagos National Park Service (GNPS), which manages the Galapagos National Park and Galapagos Marine Reserve. CDF, which played a major role in establishing the GNPS, provides the core scientific research and technical support to strengthen and guide the park's management and conservation strategies.

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